Spatial modelling and ecosystem accounting for land use planning

Addressing deforestation and oil palm expansion in Central Kalimantan, Indonesia

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1. GENERAL INTRODUCTION

1.1. Background

Quantification, monetary valuation and spatial modelling of ecosystem services

The concept of ecosystem services (ES), defined as contributions of ecosystem to benefit human well-being (TEEB, 2010; UN et al., 2014), has been widely applied to analyse the interactions between ecosystems and people (Turner and Daily, 2008; Sutton-Grier et al., 2014). A wide range of ES studies have addressed critical environmental issues such as deforestation, greenhouse gasses (GHG) emissions, and biodiversity conservation (Abram et al., 2014; Hurteau et al., 2014; Scolozzi et al., 2014). ES studies range from basic exploration and identification of ES types (Maass et al., 2005; Beaumont et al., 2007) to applications such as the formulation of ES based land management options (Egoh et al., 2008; Barbier et al., 2008).

Identification, quantification and monetary valuation of ESs are the crucial initial steps in exploring a comprehensive set of ESs of a land-use type (Porter et al., 2009) or a region with multiple land uses (Nelson et al., 2009; Lavorel et al., 2011). Identification of the key ESs is required to ensure that those services are maintained under current practices of land management (Zedler and Kercher, 2005). ES quantification can reveal ES supply and use (Schirpke et al., 2014; Bagstad et al., 2014) and the capacity of an ecosystem to provide services (Schröter et al., 2014); both are crucial to analyse the sustainability of ES utilisation (Edens and Hein, 2013). Monetary valuation of ESs, which has a narrower spectrum given that not all ES types can be appropriately valued (Collar, 2003), is an important tool to communicate ES values to society, particularly to policy makers (Viglizzo et al., 2011; Ghaley et al., 2014). In turn, identification, quantification and monetary valuation of ES can facilitate a more in-depth analysis of the implications of land-use policy, usually invloving land-use conversion and trade-offs in ES supply (Polasky et al., 2010; Kragt and Robertson, 2014).

The ‘Ecosystem Accounting’ approach has been developed in the context of the Syetm of Environmental Economic Accounting (SEEA) (Mäler et al., 2008; Li and Fang, 2014; UN et al., 2014). Ecosystem accounting intends to integrate ESs and their economic values into a national accounts setting, with the eventual aim of developing ecosystem accounts as a satellite to the national accounts. Ecosystem accounting values ESs in a way that is in line with the valuation principles of the national accounts (Edens and Hein, 2013). The key principles include restricting monetary valuation to the contribution of the ecosystem (e.g. standing wood) to the generated benefits (e.g. harvested timber), and the exclusion of consumer surplus (Edens and Hein, 2013; Obst and Vardon, 2014). Compared to the System of National Accounts (SNA), ecosystem accounting includes a broader set of ES, including also regulating services and cultural services (UN et al., 2014; Bartelmus, 2014). Currently, efforts to standardize the ecosystem accounting approach are still ongoing.

Spatial analysis is a key element in ecosystem accounting (UN et al., 2014). Spatial variation in ecosystem properties such as climate, elevation, soil types, plant and animal communities, as well as the different types of land management, leads to spatial variability in ES distribution (Naidoo et al., 2008; Fang et al., 2014). The availability of spatial information of ESs creates opportunities for a broad range of applications required for land-use planning and management (Tallis and Polasky, 2009; Maes et al., 2012). These include identification of areas with high number of ES supplied, often called as ES hotspots (Gimona and van der Horst, 2007; Wu et al., 2013), analysis of ES supply and ES demand interactions (Schulp et al., 2014; Stürck et al., 2014) and analysing the impacts of land-use change on ES trade-offs (Camacho-Valdez, 2014; Nahuelhual et al., 2014). Importantly, spatial information of a comprehensive set of ES also allows land-use planners to analyse the costs and benefits of land management options (Lawler et al., 2014).

Different mapping techniques have been applied to provide spatial information of ES (Martínez-Harms and Balvanera, 2012; Egoh et al. 2012). Those techniques range from very intensive ground survey based mapping to a qualitative look-up table approach, i.e. assigning a qualitative or quantitative value to a specific mapping unit such as land-cover type (Burkhard et al., 2009). Higher accuracy of ES mapping can typically be reached at the expense of higher costs (Schröter et al., 2014). Spatial modelling techniques allow dealing with the complexities in mapping the spatial distribution of ESs (as explored in this thesis). The selection of spatial modelling techniques for ES mapping therefore depends on the availability of ES data, the availability of spatial data potentially used as predictors or proxies, budgets, and desired accuracy level.

Deforestation and oil palm expansion in Indonesia

Deforestation, in particular in tropical countries, is one of the world's prominent environmental issues. The worst global deforestation took place during the period 1990 - 2000 with an annual net deforestation rate of about 8.3 million ha. This is equivalent to a loss of 0.2 percent of the remaining forest area each year during this period (FAO, 2010). The decade 2000 – 2010 shows a lower net deforestation rate (about 5.2 million ha/year), but there is still no indication of deforestation rates approaching zero (FAO, 2010). The highest rate of deforestation took place in tropical forests, with Indonesia in the top three countries affected by deforestation (FAO, 2010).

During 1990 - 2010, about 24 million ha of Indonesian forests have been converted for other uses (FAO, 2010). This land-use change led to several serious environmental problems, prominent among them GHG emissions (van der Werf et al., 2009; Baccini et al., 2012), flooding (Bradshaw et al., 2007) and loss of habitat for biodiversity (Sodhi et al., 2010; Normile, 2010). Converting a hectare of peat swamp forest, for example, leads in the first year to carbon emissions of about 177 ton C per ha from forest clearing, depending on forest cover (Germer and Sauerborn, 2008), and followed by annual carbon emissions up to 27 ton C per ha from peat decomposition, depending on land uses and peat drainage practices after land clearance (Page et al., 2011). Increases in flood intensity in many places in Indonesia are directly related to the loss of forests and their hydrological services (Mawardi, 2010). Indonesian deforestation is also responsible for the loss of biodiversity, including strong declines in key species such as Sumatran tiger (*Panthera tigris*), Sumatran elephant (*Elephas maximus*), Sumatran rhinoceros (*Dicerorhinus sumatrensis*) and orangutan (*Pongo spp*.) in recent years. These and other species are now under thread of extinction (Kinnaird et al., 2003; Gaveau et al., 2009).

Deforestation in Indonesia is driven by complex direct and indirect causes. The direct drivers include illegal logging (Casson and Obidzinski, 2007), forest fires (Tosca et al., 2011) and agricultural expansion (Koh et al., 2011; Wicke et al., 2011). Those drivers are a function of among others the increasing national and global demands for food, fiber and biofuel products including palm oil (Koh and Wilcove, 2008; Sheil et al., 2009; Sayer et al., 2012), the weakness of law enforcement in Indonesia (Smith et al., 2007) and a lack of effective land-use policy (Brockhaus et al., 2012). This has led to a lack of consideration of environmental externalities and social impacts of the rapid, insufficiently regulated expansion of, in particular, oil palm plantations in the country.

Oil palm expanded rapidly in Indonesia in the last decades (Statistics Indonesia, 2014a). The highest annual expansion rate took place during 2005-2010 (514,000 ha), and in 2010 the plantations covered 7.7 million ha (Gunarso et al. 2013). Indonesia is now the world's biggest producer of palm oil, accounting for around half of the global production (Green Palm Sustainability, 2015). Despite its significant support to local and national development, unfortunately, oil palm expansion has also significantly contributed to Indonesian deforestation. At least 56% of the oil palm expansion in Indonesia during the period 1990 – 2005 has involved the conversion of primary, secondary and plantation forests (Koh and Wilcove 2008).

Problem statement

There are considerable challenges in facilitating oil palm development while discontinuing deforestation and forest degradation. This is not simple in the context of Indonesia, considering the complexity of poverty, unemployment, economic development, governance and land-use policy issues. The big question is always from which point should we start? This study addresses this issue and uses the improvement of land-use planning as a critical starting point, with a case study in Central Kalimantan Indonesia.

Central Kalimantan has been experiencing a high rate of deforestation and oil palm expansion in recent decades (Broich et al., 2011; Ministry of Agriculture, 2014). There is uncertainty on provincial land-use planning due to disagreements between provincial and central government's land-use plans (Galudra et al., 2011). Deforestation, oil palm expansion and environmental degradation in Central Kalimantan have also become global issues, in view of the vast extent of peatlands in this province, the globally significant greenhouse gas emissions from peat and forest degradation, and the province's biodiversity including orangutan habitat. Opening peat forests, and drainage for oil palm cultivation, causes high carbon emissions, also when compared to the emissions from other land conversions (Germer and Sauerborn, 2008). Central Kalimantan's forests are the habitat for about 33,000 orangutan, which is around half of the global population of orangutan remaining in nature (Wich et al., 2008).

Developing an ES-based approach to land-use planning in Central Kalimantan requires addressing several scientific challenges. The multiple types of land cover and the multi-functionality of the landscape in Central Kalimantan generate a high diversity of ESs. On the other hand, however, data on ES, particularly spatial data, are scarce. This points to the need for an initial study on mapping the key ESs, by selecting spatial modelling techniques which are appropriate for a data poor environment. In addition, there are scientific challenges related to a lack of experience with ecosystem accounting, particularly with the spatial modelling of ES for ecosystem accounting, and a lack of experience with valuating ESs for ecosystem accounting. Final challenges pertain to a lack of experience in modelling palm oil expansion scenarios in a data-poor environment, such as Central Kalimantan, and on the inclusion of hydrological aspects and in particular soil-subsidence in trade-off analyses.

Coping with these challenges requires a comprehensive study that integrates ES mapping, ecosystem accounting, land-use change modelling, hydrological modelling and analysis of the trade-offs in ES supply as a function of management options. This study therefore intends to both further the development of ecosystem accounting approaches, in particular related to the application of spatial models and, to a more limited degree, valuation, and to provide a scientific basis for better management of oil palm expansion in Central Kalimantan.

1.2. Objectives and research questions

Considering the ongoing deforestation and oil palm expansion problems and the related current research gaps, this study aims to examine how spatial models for ES can be applied in support of ecosystem accounting and land-use planning, with a specific case study on deforestation and oil palm expansion in Central Kalimantan, Indonesia.

In order to achieve this objective, four research questions (RQ) have been formulated.

RQ1: How can ESs be mapped at the provincial scale and how can the ES maps be integrated in an ES-based approach to land-use planning?

Mapping ESs is a key element of ecosystem accounting and land-use planning. Mapping a comprehensive set of ESs, in the context of Central Kalimantan, needs to deal with the challenge that relatively little data are available on ESs at this scale. This study therefore selects seven ESs, which represents three main classes of ES (MA, 2003): provisioning services, regulating services, and cultural services. The critical point is how to achieve a reasonable accuracy with limited ES data (Eigenbrod et al., 2010). Accuracy is an important issue given the potential error propagation in integrating ES maps in land-use planning. This study selects land allocation for oil palm expansion as an example of an ES based land-use planning. Not all aspects of land-use planning, such as stakeholder interests, land suitability and institutional aspects, can be included here. This study focuses on a spatial analysis of ESs in order to identify sites that are potentially suitable for oil palm expansion, and examines how spatial information on ESs can be used to support land-use planning.

RQ2: How can ESs be valued in a way that is aligned with national accounts, and how can the spatial information of ES values be used to analyse the trade-offs in ES supply resulting from land use conversion?

This RQ directly links to RQ1 by putting monetary values on ESs which are previously mapped in physical terms. This part of the study focuses on the application of valuation methods which are consistent with the principles of ecosystem accounting (UN et al., 2014). This study also explores how regulating and cultural services can be valued, and it presents the first ecosystem accounting - valuation study in Indonesia. The retrieved monetary values of selected ESs are used, subsequently, to analyse the trade-offs from land-use conversion.

RQ3: How can ongoing oil palm expansion be spatially and temporally modelled, and what are the implications of this expansion on ES supply?

Understanding implications of different options of land management is a key input for land-use planners. This study develops a land-use change model to model oil palm expansion in three different policy scenarios. These include a business-as-usual scenario, a scenario involving continuation of the current moratorium on deforestation, and an alternative, sustainable production scenario. All three scenarios are developed on the basis of stakeholder inputs, and reflect current Indonesian legislation. This part of the thesis builds upon the research conducted to address RQs 1 and 2, by using the detailed spatial information on ES supply to analyse the implications of each scenario for ES, in both physical and monetary terms. This allows for a comprehensive comparison of social costs and benefits of oil pam expansion in these different policy scenarios.

RQ4: How can the long term hydrological and economic impacts of oil palm development on peatlands be modelled?

The previous RQs did not yet deal with the ecosystem dynamics of the study area. In particular, hydrological changes are crucial in understanding the long-term development of the area, and its capacity to supply ESs. A particular concern in this regard is soil subsidence in the peatlands following drainage. Palm oil expansion is increasingly focussing on peatlands in Indonesia including Central Kalimantan, and requires drainage for the plants to grow and be productive. Peatlands cover about one-third of Central Kalimantan and, following draining, are subject to irreversible soil subsidence. This study models different types of flood risk on drained peatlands for oil palm plantation, considering soil subsidence rates and drainage limits. This study also analyses the economic impacts of peat subsidence by linking the different types of flood risks to values of expected flows of ES under two land-use scenarios: a rapid oil palm expansion scenario and a mixed land-use scenario integrating oil palm plantation, natural forest preservation and jelutung (*Dyera* spp.) forest development. This kind of analysis provides understanding on the long term consequences of draining peatlands for oil palm including the increase of flooding, and informs present-day decision making by analyzing the hydrological and economic implications of these decisions.

1.3. Methodology

The general methodology for the four RQs is summarized below. The methodology is described in more detail in the next chapters of this thesis.

Mapping ESs (RQ1)

There is a wide range of methods for ES mapping. Three mapping methods are selected after considering the availability of input data and the required accuracy: geostatistical interpolation, lookup table and Maximum Entropy (Maxent) model. Geostatistics (spatial statistics) is a spatial modelling technique that considers spatial autocorrelation among values in sampled locations. Spatial autocorrelation is correlation between values in certain separation distance (Isaak & Srivastava, 1989). Modelling spatial autocorrelation allows for predicting values in un-sampled location through kriging interpolation. The model accuracy is analysed by cross validation (leave-one-out method) based on calculating the coefficient of variation (CV) of root mean square error (RMSE). The interpolation technique is applied to map four provisioning services: timber production, rattan production, oil palm production and paddy rice production.

A lookup table approach is applied for mapping carbon storage and carbon sequestration. Using Lookup tables is a simple mapping technique which is suitable for mapping ESs which are distributed across the landscape with relative homogeneity within land-cover types or soil types (Lautenbach et al., 2011), such as carbon storage and carbon sequestration. In principle, this mapping technique converts input map, e.g. a land cover map or soil map, into ES maps by assigning ES data to each class of the input maps (assuming equal importance of every hectare in each class). The accuracy of this mapping technique depends on the accuracy of both input map and ES data.

Maxent is applied for mapping habitat suitability for the endangered orangutan (*Pongo pygmaeus*). Orangutan was selected because it is a flagship conservation species for Central Kalimantan, and because it has relatively high requirements on its habitat (dense forest cover, low disturbance) which also indicates the potential suitability of the habitat to other species that depend upon a well-preserved forest cover (such as the leopard). Maxent is a model for predicting species distribution, representing habitat suitability of the species. Maxent requires presence data as training point, and environmental variables as predictors. The Maximum Entropy (Maxent) Species Distribution Modeling version 3.3.3 (Phillips 2010) is applied. Model accuracy is analysed using the area under receiver operating characteristic (ROC) curve (AUC).

Valuing ES and mapping ES values (RQ2)

Valuation in the context of accounting requires a clear distinction between services and benefits, with services representing the contribution made by ecosystems to benefits used by people (UN et al., 2014). Some of these benefits are already captured in the SNA (e.g. crop harvesting), but other benefits (e.g. carbon sequestration) are not recognized in the SNA, which is why the production boundary is extended in ecosystem accounting. For valuation of four provisioning services (timber, oil palm, rattan, paddy rice) and one cultural service (nature recreation), this study calculates the resource rent (UN et al. 2014) to reveal the contribution of the ecosystem to the market outputs. The resource rent equals the revenues minus the value of intermediate consumption, labour and the user costs of fixed assets (UN et al., 2014). The user costs of fixed assets consist of consumption of fixed capital (depreciation) and the cost of capital. A cost based approach is applied to value carbon sequestration and wildlife habitat. Carbon sequestration is valued based on the marginal social damage costs (Tol, 2008), in which the sequestration of a ton of carbon is valued using the social cost of emitting a ton of carbon. A defensive expenditure method is tested for valuing the orangutan habitat service, through analysis of the costs related to the reintroduction of orangutan in the forests.

Two mapping techniques are applied to map ES values. First, physical ES maps (RQ1) are converted into monetary ES maps by multiplying the resource rents or social costs with the quantity of ESs supplied. This applies to mapping monetary values of timber, rattan, paddy rice, and carbon sequestration. Second, the lookup table technique is used, i.e. assigning a value to a mapping unit, for mapping the monetary values of oil palm production, nature recreation and orangutan habitat. The seven maps of ES values are then combined to extract the aggregate value of specifics land uses, on the basis of which the trade-offs from land-use change are analysed for the specific case of oil palm expansion in peat areas.

Modelling oil palm expansion (RQ3)

An integrated model combining inductive and deductive approaches is developed and applied to model oil palm expansion up to 2025. The inductive approach includes analysis of the empirical pattern of oil palm expansion. Considering the binary response variable (that is the presence and absence of oil palm expansion), a logistic regression is selected to model spatial patterns of oil palm expansion in the past (2005-2010), and used to predict oil palm expansion in 2015, 2020 and 2025. The logistic regression is a Generalized Linear Model (GLM) with a binary response variable, using explanatory variables to linearly model the logit of probability, after which the presence probability can be generated using logit transformation. The approach is applied to model three policy scenarios involving different types of land allocation. The scenarios include a business-as-usual scenario, the moratorium scenario, and the sustainable production scenario.

Trade-offs in ES supply in each scenario are analysed, involving the following six ESs: oil palm production, timber production, rattan production, paddy rice production, carbon sequestration, and orangutan habitat. The trade-offs are analysed in term of physical quantities and monetary values, based on the physical quantities and the monetary values derived from the two previous studies (RQ1 and RQ2).

Modelling hydrological and economic impacts of oil palm development (RQ4)

A deductive approach is applied to model flood risks on drained peatlands for oil palm. The model is developed based on soil subsidence rates, drainage limits and surface elevation. A high resolution LiDAR digital elevation model (DEM) was available to indicate current surface elevation (as modelled by DELTARES with whom I worked together for this part of the research). Three different types of flood risks are modelled: impaired drainability, prolonged flooding, and near permanent inundations, with a time frame up to 100 years. To facilitate an integrative hydrological and economic analysis, two land-use scenarios are developed: (i) the oil palm scenario, which assumes that the entire study area, including all peatlands, is fully developed for oil palm plantations by the year of 2011 (for which elevation and land cover data are available), and (ii) a mixed land-use scenario, which combines preservation of currently remaining natural peat forest, oil palm on mineral land and in areas that are currently intensively drained, and jelutung plantation forest on the rest of peatlands.

The economic impacts of peat subsidence under the two land-use scenarios are analysed through assessment of four ESs: oil palm production, jelutung production (latex and timber), carbon sequestration, and orangutan habitat. The ESs are valued both in terms of physical quantity and monetary values, except for orangutan habitat which is assessed only in term of physical quantity due to methodological difficulties in valuing this service. The expected flows of ES are analysed by calculating the net present value (NPV), i.e. a sum of discounted values for a valuation period (21 years for oil palm production and carbon sequestration and 30 years for jelutung production).

1.4. Thesis outline

This thesis consists of six chapters, including this introduction (Chapter 1). Chapters 2, 3, 4 and 5 address RQs 1, 2, 3 and 4 respectively (see Figure 1.1 for the linkages between RQs). The structure of this thesis is as follows.

Chapter 2 presents the spatial modelling of seven different types of ES at a provincial scale (RQ1). This chapter demonstrates the application of three mapping techniques for ES mapping: geostatistical interpolation, lookup table and Maxent model. Subsequently, the integration of ES maps in provincial land-use planning is also demonstrated in this chapter, with a specific example on the selection of sites for oil palm expansion.

Chapter 3 tests ecosystem accounting-conform valuation methods for seven ESs, and results in maps of ES values in Central Kalimantan (RQ2). The valuations are approached by resource rent assessment for provisioning services and nature recreation, social damage costs for carbon sequestration, and reintroduction costs for orangutan habitat. This chapter also demonstrates how the ES values can be mapped and the aggregate values of multiple ES in different land uses can subsequently be extracted.

Chapter 4 examines the physical and monetary impacts of oil palm expansion in Central Kalimantan up to 2025 under different policy scenarios (RQ3). Oil palm expansion is modelled based on an integrative deductive – inductive approach combining logistic regression modelling and land-use scenario analysis. This chapter uses ESs mapped and valued in Chapters 2 and 3 to analyse the physical and economic impacts of the modelled oil palm expansions.

Chapter 5 provides an analysis of the hydrological and economic impacts of oil palm development on peatlands (RQ4). This chapter models three types of flood risks following peat drainage for oil palm cultivation under two land-use scenarios: the Oil Palm scenario assuming conversion of all peatlands in the study area into oil palm plantation, and the Mix scenario combining three different land uses (oil palm, natural forest and jelutung forest). This chapter then links the modelled flood risks to the provision of four ESs: oil palm production, jelutung production, carbon sequestration and orangutan habitat, analysed in a time frame of 125 years.

Finally, a discussion and the main conclusions of this thesis are presented in Chapter 6. This chapter evaluates the implications of the outcomes of the research for all four RQs. This includes the general applicability of spatial modelling developed in this study with regards to ES mapping, ES valuation, land-use change modelling, and flood risk modelling. This chapter also provides recommendations for further research and analyses the implications for land and resource management in Central Kalimantan.

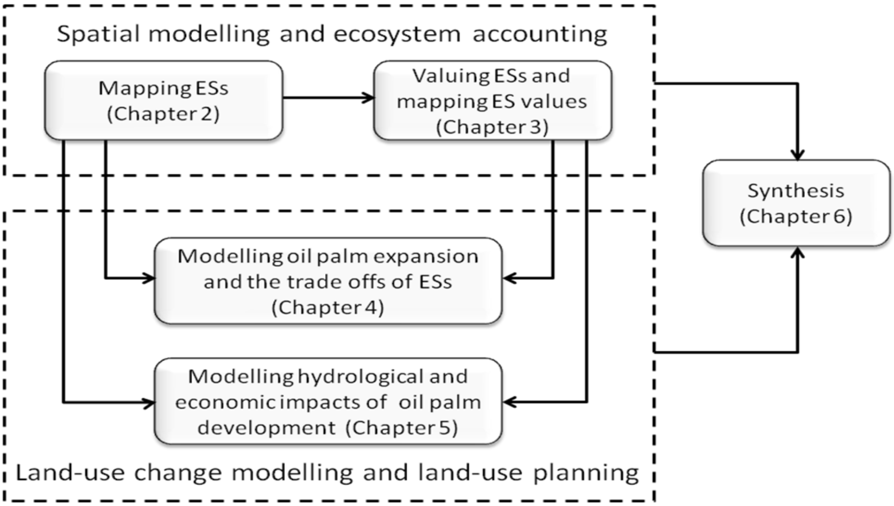


Figure 1.1. Overview of the structure of this thesis

2. MAPPING ECOSYSTEM SERVICES FOR LAND USE PLANNING, THE CASE OF CENTRAL KALIMANTAN INDONESIA

ABSTRACT

Indonesia is subject to rapid land use change. One of the main causes for the conversion of land is the rapid expansion of the oil palm sector. Land use change involves a progressive loss of forest cover, with major impacts on biodiversity and global CO2 emissions. Ecosystem services have been proposed as a concept that would facilitate the identification of sustainable land management options, however the scale of land conversion and its spatial diversity pose particular challenges in Indonesia. The objective of this paper is to analyze how ecosystem services can be mapped at the provincial scale, focusing on Central Kalimantan, and to examine how ecosystem services maps can be used for a land use planning. Central Kalimantan is subject to rapid deforestation including the loss of peatland forests and the provincial still lacks a comprehensive land use plan. We examine how seven key ecosystem services can be mapped and modeled at the provincial scale, using a variety of models, and how large scale ecosystem services maps can support the identification of options for sustainable expansion of palm oil production.

Modified from:

Sumarga, E. and Hein, L., 2014. Mapping ecosystem services for land use planning, the case of Central Kalimantan Indonesia. Environmental Management 54: 84-97.

2.1. Introduction

The rapid loss of Indonesian forest cover is of global concern. Indonesian forests contain high biodiversity and a wide variety of endemic species such as the orangutan (Johnson et al., 2005). In addition, deforestation, and in particular the conversion and subsequent drainage of peatland forests, is leading to high greenhouse gas emissions; due to land-use change Indonesia is currently one of the world's largest emitter of greenhouse gasses (WRI, 2013). Deforestation rates vary considerably between the various Indonesian islands. Kalimantan has been subject to rapid deforestation in the past two decades (Hansen et al., 2009; Broich et al., 2011). Deforestation is caused by a variety of factors, prominent among them are fires (Page et al., 2002; Dennis et al., 2005), logging (Currant et al., 2004), and the conversion of land, including peatland, to oil palm plantations (Hunt, 2010; Koh and Ghazoul, 2010). In addition to severely affecting biodiversity and causing substantial CO_2 emissions, land-use conversion is affecting local communities by restricting access to land (Carlson et al., 2012) and affecting local hydrology and water quality (Wösten et al., 2008). Land-use conversion in Indonesia and it's environmental effects have received ample attention in the last years, and, among many other national and international initiatives, a moratorium on forest conversion was enacted in 2011(Indonesian President Instruction no 10, 2011), and extended for another two years in May 2013 (Indonesian President Instruction no 6, 2013).

Population growth and further economic development mean that land in Indonesia will remain under considerable pressure in the decades ahead. Oil palm presents a major development opportunity to Indonesia (Rifin, 2013), but because of the environmental impacts there is a need to carefully plan and monitor the conversion of land. The ecosystem service (ES) concept has been postulated as having an important potential to support land-use planning (Daily et al., 2009). ESs mapping and analysis facilitates trade-off analysis (Haines-Young et al., 2012) and can also be used to optimize the allocation of land to specific uses (Goldstein et al., 2012). There is increasing experience with the application of various mapping methods to ESs at the scale of the landscape (e.g. Willemen et al., 2008), biome (e.g. O'Farrel et al., 2010), country (e.g. Egoh et al., 2008), continent (e.g. Kienast et al., 2009) up to the global scale (e.g. Naidoo et al., 2008). However, there is still a lack of experience with mapping a comprehensive set of ESs, in a data poor developing country context, at the scale of a large province. Since land-use plans in Indonesia are made at the scale of the province, policy makers would need information at this particular scale. In addition, there is a need to further clarify how ESs maps can be used in support of land-use planning (Bolliger et al., 2011; Martínez-Harms and Balvanera, 2012), in particular in countries that are subject to rapid land-use change such as Indonesia (Wang et al., 2012).

The objective of this article is to analyse how ESs can be mapped at the provincial scale, focusing on Central Kalimantan, and to examine how ESs maps can be used for land-use planning. We analyse the following ESs at the provincial scale: timber production, rattan production, palm oil production, paddy rice production, carbon storage, carbon sequestration, and wildlife habitat. We analyse which mapping method is suitable for each of these services, given the complexity of the landscape and data availability, and we examine how ESs maps can be used in spatial planning. Specifically, we analyse which areas would be available for future oil palm expansion in Central Kalimantan with minimal impacts on ESs supply.

Central Kalimantan (153,564 km^2) was selected as a case study because of the diversity of ESs provided and the rapid land-use change taking place in this province (Broich et al., 2011), mostly conversion of forest to oil palm plantation. Moreover, to date Central Kalimantan is one of few Indonesian provinces in which the provincial land-use plan (Indonesian acronym: RTRWP) has not yet been finalized, in which the existence of conflicting interest in land use may play a role. RTRWP is a general plan of land allocation and land utilization at a provincial scale. Central Kalimantan has also been selected by the Indonesian government as the pilot province for testing the implementation of REDD+ (Reducing Emissions from Deforestation and Degradation), making it particularly urgent to have information on carbon stocks and carbon sequestration in this province.

The innovations of this article pertain to the comprehensive mapping of multiple ESs at an aggregated scale, selecting suitable mapping method for individual ESs, and showing how ES maps can be used in support of land-use planning. Land-use planning has been identified as one of prerequisites of sustainable environmental management in Indonesia (Smit et al., 2013), as well as a range of other countries experiencing land-use change, however to date very few studies have analysed and modeled a comprehensive set of ES at the aggregated scale of a province. Data scarcity required us to test a number of approaches to map ESs that will also be relevant for other studies in developing countries. We also propose a pro-active approach to deal with land-use change, identifying areas environmentally suitable for expansion of oil palm rather than focusing on restricting such activities. Such approach is complementary to the current national policy on the moratorium on the allocation of new concessions in primary forests and peatlands.

2.2. Materials and Method

2.2.1. Study area

Central Kalimantan is the third largest province in Indonesia, located at latitude 0^{o}45’ North – 3^{o}30’ South and longitude 110^{o}45’– 115^{o}50’ East. Most of the area (65%) has a low altitude (<100 m above sea level), especially the southern part of the province. About 58% of the province area is covered by forests (land-cover map 2010), including plantation forest. Between 2000 and 2010, about 1.3 million ha has been deforested. The province has a low population density with an average of 14 people/km^2 and a total population of around 2.2 million people. Figure 2.1 presents the location and land cover of the study area. The map was generated by reclassifying land-cover map 2010 (Tropenbos Indonesia, unpublished).

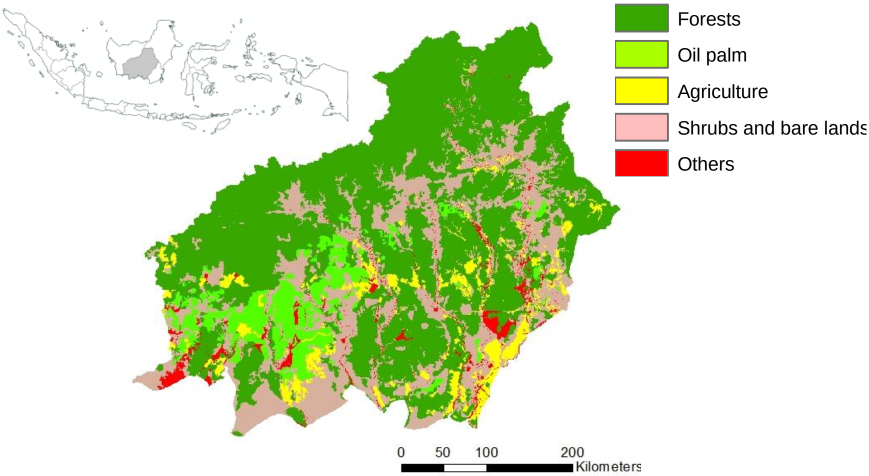


Figure 2.1. Land cover map of Central Kalimantan

2.2.2. Mapping approach

In order to identify the most relevant ESs in Central Kalimantan, we held a four hour workshop at the Provincial Forestry Authorities in Palangkaraya, the provincial capital of Central Kalimantan in May 2012. The workshop was attended by representatives of Provincial Forestry Agency (Dishut), Provincial Planning Agency (Bappeda), Biodiversity Conservation Agency (BKSDA), Watershed Management Agency (BP DAS), Provincial Environmental Management Agency (BPLHD), and researchers from Palangkaraya University. The stakeholders identified seven key ESs, in three different categories: provisioning services (timber production, rattan production, palm oil production, paddy rice production), regulating services (carbon storage, carbon sequestration), and cultural services (wildlife habitat). Because Central Kalimantan is the national pilot province for REDD+, the stakeholders indicated an interest in separating carbon sequestration and carbon storage. The workshop did not involve oil palm companies and farmers; this may influence to the selection of the key ESs. However, as most of the participants are from provincial government agencies which are responsible for natural resource management in Central Kalimantan, we consider their opinions to be sufficiently representative for this study. The most important industrial crop (oil palm) and the most important crop for local farmers (rice) have been included. Nevertheless, our case presents a comprehensive but not a complete overview; we did not consider other agricultural crops (such as vegetables), other industrial crops (for example rubber), water regulation, aquaculture, and tourism. We discuss the implications of the scope of our study in the Discussion Section of our paper.

Mapping the seven selected ESs required a specific dataset for each service, see Table 2.1. The data were collected from a variety of sources. These data were combined with land-cover maps (Tropenbos International Indonesia, unpublished), soil map (Wetland International, 2004) and a Digital Elevation Model (90m resolution) and topographic and hydrological map (Wageningen University, unpublished). Tropenbos International is an NGO working on promoting sustainable tropical forest management, with a national office in Indonesia, including a GIS department. The land-cover map, topographic map, and hydrological map are available in vector format. All spatial input data were converted to raster format with a pixel size of 100m for further spatial analysis. To validate our analyses with regards to the provisioning services (rice, timber and palm oil production), we calculate the total provincial production based on our maps and we compare these with the provincial statistics. The baseline year for our study was 2010. Our land-cover map depicts land cover in 2010, and as much as possible we have used ESs data from 2010. However for some services only data from 2009 or 2011 were available. In these cases we have used this as a proxy.

Table 2.1. Summary of data for mapping ESs

Type of ES	Indicators	Data available	Sources
Timber production	Annual timber harvested (m3/ha/year)	Average timber production in 2011 from 38 logging concessions	The Indonesian Ministry of Forestry (2011, unpublished)
Rattan production	Annual rattan harvested (ton/ha/year)	Average rattan production in 2011 from 6 districts (out of a total of 14 districts)	The Indonesian Ministry of Forestry (2011, unpublished)
Oil palm production	Annual fresh fruit brunch (FFB) of oil palm harvested (ton/ha/year)	Average FFB production in 2010 from 21 districts/sub districts	Bureau of Statistics (2011)
Paddy rice production	Annual paddy rice (un-milled) harvested (ton/ha/year)	Average irrigated paddy rice production in 2010 from 13 districts, and average upland paddy rice production in 2010 from 39 districts/sub districts	Bureau of Statistics (2011)
Carbon storage	Total carbon storage in vegetation and soil (ton/ha)	Research findings on carbon storage in 16 land cover types and 16 soil types	References listed in Appendices 2.1 and 2.2
Carbon sequestration	Annual net ecosystem productivity (NEP) (ton/ha/year)	Research findings on NEP in 15 land cover types	References listed in Appendix 2.3
Wildlife habitat	Suitability for orangutan habitat (%)	Estimated population of orangutan in 8 protected areas (about 20,000 individuals)	Provincial conservation agency (2011, unpublished)

There are several techniques available to map provisioning services (timber, rattan, oil palm, and paddy rice production), and wildlife habitat. These include lookup tables, interpolation, regression modeling and probabilistic models such as Maxent. For the provisioning services, we first tested the use of modeling the supply of the provisioning services based on ecosystem properties, using regression analysis to relate ES supply to a set of ecosystem properties (including soil, rainfall, slope, soil and vegetation biomass).

However, the correlation we obtained was too poor to be applicable in the context of Central Kalimantan (typically $R^2 < 0.2$ for all provisioning services). The explanation for this may be that there is no strong correlation between ecosystem properties and extraction rates of provisioning services, the latter being an overriding factor determining flows of provisioning services. We observed that provisioning services are commonly supplied in only one land-cover class, but that within these land-cover classes there is substantial variation. We therefore mapped the provisioning services with spatial interpolation instead of using look-up tables (which results in a specific value for a given land-use class, see Troy and Wilson, 2006; Burkhard et al., 2009). Interpolation was carried out in ArcGIS using ordinary kriging, see below.

For carbon sequestration and carbon storage, we applied an approach based on look-up tables, specifying the amount of carbon in specific land-cover type, since our dataset was not sufficiently accurate to allow spatial interpolation. We calculated stored soil carbon based on soil type and the depth of the peat layers. All carbon data were obtained from the literature, considering carbon measurements carried out in Indonesia or Southeast Asia.

Wildlife habitat is not strongly linked to specific land-cover types, and is spatially very heterogeneous. We therefore applied Maxent to model this service. The two key advantages of Maxent are that Maxent only requires presence data and that it is capable of capturing both linear and nonlinear relationships between environmental variables and ES supply (Philips et al., 2006). ES supply is expressed as probability of occurrence or suitability of an area for specific activities or specific ESs based on a set of relevant biophysical parameters. Hence our maps indicate the probability of ecosystems to support orangutan populations. This deviates somewhat from our approach used to model the other ESs and we come back to this in the Discussion section. For all services except carbon storage and sequestration (that were modelled with look-up tables) we examine significance levels, and details on the modeling approaches are provided below.

Interpolation

We applied ordinary kriging for interpolation, based on geostatistical analysis of point data. We applied this technique for the following services: production of timber, rattan, oil palm and paddy rice. For timber and oil palm production, we used the average annual production, i.e. total annual production divided by a concession area, even though in reality there is a rotation period of 35 years within a logging concession and a production cycle of 25 years for oil palm cultivation. We followed the following steps. First, the production data were modified into point data by digitizing the data at the center of the represented area, i.e. concession area for timber production, sub-district and district for rattan, palm oil and rice production. Second, the spatial structure of the production data was analysed using variogram analysis. A gstat library of "R" (Pebesma, 2004) was used for variogram analysis. The best variogram model was selected for each ES. Third, the parameters of the best variogram models (partial sill, range, and nugget) were used in an ordinary kriging interpolation using the spatial analyst tool of Arc Map 10 (ESRI). Finally, a cross validation (leave-one-out method) was applied to analyse model accuracy by calculating coefficient of variation (CV) of root mean square error (RMSE). This value represents the deviation of the prediction error from the mean of input data, whose value ranges from 0 to 1. A CV of RMSE of 0 indicates a perfect accuracy.

Look-up tables based on land cover and soil types

Look-up tables were applied for mapping carbon storage and carbon sequestration. Carbon storage was mapped based on the sum of carbon stored in vegetation (above ground, root, dead wood, and litter carbon) and carbon stored in the soil. In total, we identified 16 land-cover units and 16 soil types with their specific carbon contents. Vegetation carbon data are from Amthor et al. (2008); Chairns et al. (1997); Khalid et al. (1999a); Khalid et al. (1999b); Masripatin et al. (2010); Murdiyarso et al. (2009); Rahayu et al. (2003); Syahrinudin (2005); Verwer and van der Meer (2010), see Appendix 2.1. Soil carbon data are derived from van der Kamp et al. (2009); Murdiyarso et al. (2009); Wetland International-Indonesia Programme (2004), see Appendix 2.2. The carbon data were assigned to the land cover and soil maps to generate carbon storage map using spatial analyst tool of Arc Map 10. The vegetation and soil carbon were mapped separately, after which they were combined for the carbon storage map. Carbon sequestration was represented by net ecosystem productivity (NEP), i.e. the difference between net primary productivity (NPP) and soil respiration (Goulden et al., 2011). In production forest, the carbon loss due to wood harvest was also subtracted from the NPP. In total, we identified 15 land-cover types and their NEP. The NEP data are from: Hirano et al. (2007); Hirata et al. (2008); Hooijer et al. (2006); Komiyama (2006); Luyssaert et al. (2007); Saigusa et al. (2008); Saner et al. (2012); Sanchez (2000); Suzuki et al. (1999), see Appendix 2.3.The carbon sequestration map was generated by assigning the NEP data to the land-cover map.

Maximum Entropy (Maxent)

We applied the Maxent model (Phillips et al., 2006) for mapping the habitat suitability of orangutan (*Pongo pygmaeus*). Orangutan was selected as key indicator for wildlife habitat because of its status as a prime conservation flagship species, its endangered status, and because it is an indicator for overall ecological quality (orangutan require large contiguous stretches of forest with sufficient forage trees and sufficient high trees with overlapping canopies). Maxent is a model for predicting species distribution, which also represents habitat suitability of the species. Maximum Entropy (Maxent) Species Distribution Modeling version 3.3.3 (Phillips, 2010) was applied. Maxent requires presence data as training point, and environmental variables as predictors. We generated 650 presence points of orangutan (from about 20,000 individuals) within the 8 protected areas where orangutan reportedly occurs. We used land-cover types, elevation, distance from road/river, and distance from settlement as environmental variables. Model accuracy was analysed using the area under receiver operating characteristic (ROC) curve (AUC), whose value ranges from 0.5 to 1. An AUC of 1 indicates a perfect accuracy.

2.2.3. Incorporating ES maps in spatial planning

Spatial planning requires the analysis and balancing of economic, social, sustainability and legal criteria in the context of the current land use and the potential suitability of ecosystems for other land use (Cao et al., 2012). Usually, if not always, spatial planning involves considering trade-offs, because land conversion or changing land use within specific land-cover units will normally change the overall output of ESs from a landscape. Figure 2.2 presents a framework that depicts how ESs can contribute to spatial planning. Some recent examples of how ESs have been considered in spatial planning are provided by Niemelä et al. (2010), Barral and Oscar (2012), and Breure et al. (2012). There is still limited experience with the inclusion of ES maps in spatial planning (Goldstein et al., 2012), but see Raymond et al.(2009), Klain and Chan (2012), and Maes et al. (2012) for examples of studies focusing on either a limited set of services or a smaller scale.

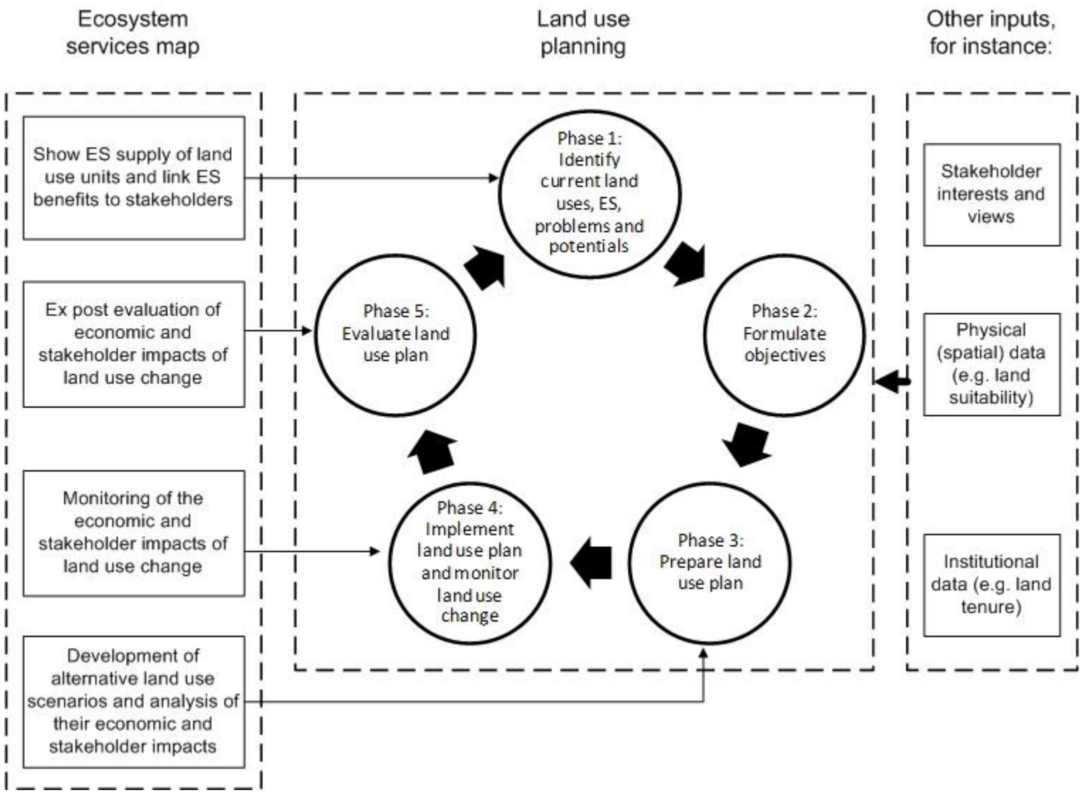


Figure 2.2. Framework for integrated analysis of ES and land use planning

During the stakeholder workshop in May 2012, the participants of the workshop were also asked to identify two scenarios in which oil palm expansion could be combined with maintaining the supply of ESs in the province: an ‘environmentally sustainable’ scenario and a ‘mixed sustainable-rapid development’ scenario. The scenarios defined by the participants are presented below. Note that the basic criteria of the scenarios were identified by the participants, however following the development of our maps we needed to make a number of assumptions for some of the criteria (in particular for avoiding orangutan habitat destruction), as explained below.

In the environmentally sustainable scenario, strict criteria were developed for identifying land on which oil palm expansion could be permitted. The mixed sustainable-rapid development scenario relaxes some of the strict environmental constraints of the first scenario. In particular, the scenario allows for the conversion of land supplying provisioning services (except paddy rice which was considered vital by the participants in view of its importance for local food production), but not for the loss of regulating services. The specific criteria for the two scenarios are listed in Table 2.2.

The first scenario is aligned with the notion that only degraded land should be used for oil palm expansion (Fairhurst and McLaughlin, 2009; Gingold et al., 2012). The term “degraded land” is not easy to define, and we specify the criteria for land conversion on degraded land based on the ES approach. The second scenario is based on the assumption that oil palm development is an important source of economic growth for the province, but that there is a need to ensure that crucial ESs are not affected by this expansion. Note that a trade-off analysis in monetary terms can provide more robust information on optimal land use (Johnson et al. 2012) but to date the data are lacking for an economic valuation of sufficient accuracy to provide meaningful support to spatial planning, in particular at the scale of Central Kalimantan province.

Table 2.2. Criteria for two scenarios of oil palm expansion

Environmentally sustainable scenario	Mixed sustainable-rapid development scenario
• Exclusion of orangutan habitat. Following our mapping of ecosystem services, we have defined this as excluding protected areas and non-protected areas that are important orangutan habitat (suitability > 50%). These constrains on land development have also been voiced by several studies looking at the impacts of land use change on biodiversity (Wich et al. 2008; Nantha and Tisdell 2009). • Excluding peatlands. Current Indonesian regulation specifies that land conversion is allowed in peatlands with a depth of less than three meters (Regulation of Minister of Agriculture number 14, 2009). However, even conversion of areas where the peat depth is less than three meters leads to substantial CO_2 emissions due to peat oxidation (Hooijer et al. 2010; Germer and Sauerborn 2008; Page et al. 2011), and all peat areas are excluded in this scenario. • Maintaining carbon stocks. Based on the feedback obtained from the participants in the workshop, we have interpreted this as excluding areas where the current carbon storage in the vegetation exceeds the carbon storage in a mature oil palm plantation. • Maintaining the supply of areas important for timber, rattan and paddy rice production. Rice and rattan are important products for local communities and the participants indicated that the conversion of these land uses should be avoided. In addition, the stakeholders from the forestry sector indicated that land actively used for timber logging and production should be avoided in this scenario.	• Maintaining all protected areas and all land with high suitability for orangutan habitat (i.e., no loss of land with suitability > 50%). • No conversion of peatland (of any depth). • Conversion of forest land is allowed for those cases where the carbon stored in the vegetation is lower than the carbon stored in palm oil plantations (carbon storage < carbon storage in oil palm). • Maintaining all paddy land in view of its importance for local food supply.

2.3. Results

2.3.1. Ecosystem service maps

Timber production

Figure 2.3a presents the timber production map resulting from the ordinary kriging interpolation. Only the timber production in production forest was mapped. Cross validation of the model gave a CV of RMSE of 0.33. The mean of timber production derived from the map is 0.86 m^3/ha/year with a standard deviation of 0.17 m^3/ha/year. This value is higher than the annual allowable cut (AAC) at the level of Central Kalimantan (an average of 0.52 m^3/ha/year) listed in the forestry statistics 2012 (Ministry of Forestry, 2012). Note that timber production from illegal logging is not included in our analysis (or in the statistics), hence actual off take may exceed AAC even more. Our model also excludes fuelwood and timber harvesting by local communities.

Rattan production

The rattan production map resulting from the ordinary kriging interpolation is presented in Figure 2.3b. Rattan usually grows in mineral soil, and farmers mainly cultivate rattan around rivers (which provide the main route for transport of rattan), with a typical maximum distance of 25 km from settlement and 4 km from rivers (Godoy and Feaw, 1991). Hence, the rattan production was only mapped in areas with those characteristics. A CV of RMSE of 0.44 was obtained from cross validation of the model. The estimated mean of rattan production (derived from the map) is 0.79 ton/ha/year with a standard deviation of 0.15 ton/ha/year in areas where rattan cultivation takes place.

Oil palm production

The plantation area in Central Kalimantan is dominated (about 98%) by oil palm (Provincial statistical data 2011). The oil palm plantations have been developed both at a large scale (by private companies) and at a small scale (by smallholders). Based on the land-cover map 2010, oil palm plantation has been established in about 1.2 million ha area. The oil palm production map, expressed in fresh fruit brunch (FFB), is presented in Figure 2.3c. Cross validation of the best fit variogram model gave a CV of RMSE of 0.34. The estimated mean of FFB production (derived from the map) is 16.7 ton/ha/year with a standard deviation of 4.8 ton/ha/year. A significant part of the oil palm in Central Kalimantan is recently planted and not yet productive, oil palm starts bearing fruit after some 5 or 6 years. In 2011, around 34% of the plants are not yet productive (Provincial Statistical Bureau, 2011). By taking this proportion into account, i.e. only 66% of the oil palm is productive, the estimated provincial FFB production is 13.1 million ton/year. This estimate is comparable to the production data recorded in the provincial statistics, which is 13.6 million ton FFB.

Paddy production

Paddy rice is the main crop in Central Kalimantan. Figure 2.3d presents the paddy rice production map which was generated by combining the production maps of the irrigated paddy rice and upland paddy rice. We analysed the spatial structure (variogram) of paddy rice production in irrigated and upland area separately. Cross validation to the two best variogram models gave good accuracy, i.e. a CV of RMSE of 0.18 for irrigated rice and 0.14 for upland rice. The mean paddy rice production in irrigated and upland areas is 3.2 ton/ha/year and 2.1 ton/ha/year respectively. The estimate of total paddy rice production in the province is 1.7 million ton, much higher than the production recorded in the provincial statistics, i.e. 610,000 ton. In provincial statistics, production is recorded on 247,600 ha area, which is much lower than the area dedicated to paddy identified from the land-cover map, i.e. 771,900 ha. In addition, about 90% of paddy fields are in upland areas where farmers cultivate paddy rice mostly for self-consumption, which appears to be underrepresented in provincial statistics.

Carbon storage

The carbon storage map is presented in Figure 2.3e. High carbon storage is identified in the southern part of study area which is dominated by peat swamp forest, including both primary and drained secondary forests. An important factor for carbon storage is the depth of the peat layer. The peat thickness created a high variation of carbon storage with values ranging from 32 ton C/ha to 7882 ton C/ha. The estimate of the total carbon storage in all ecosystems in Central Kalimantan is 9.3 Gton C. In particular for above ground carbon, our estimate (an average of 116 ton C/ha) has close agreement with a global estimate by Baccini et al. (2012) (an average of 119 ton C/ha for tropical Asia).

Carbon sequestration

Figure 2.3f presents the carbon sequestration map which was generated from NEP data for 15 land-cover types. There is no NEP data for some land covers, displayed in white in the map. Negative values, indicating that carbon emissions (from soil respiration) are higher than uptake of carbon in the ecosystem, are found in the southern part of study area which comprise a mix of peat lands and areas with mineral soils. Drained secondary peat swamp forest and oil palm plantations developed in peat contribute most to the emission. We identify 8.2 million ha that contribute to sequestration, with a total sequestration of 23.3 million ton C/year; and 6.7 million ha with a ‘negative sequestration’ (i.e., emission), with a total emission of 24.2 million ton C/year. At the scale of the province, there is therefore a net emission in 2010 of 0.9 million ton C/year. Nevertheless, given the difficulty of measuring carbon fluxes (Page et al., 2011), and also because there are different estimates on the precise emission rates that follow peat drainage (compare for instance Fargione et al., 2008; Wicke et al., 2008; and Murdiyarso et al., 2010), we expect that there is considerable uncertainty in our estimate, even though we are not able to pinpoint the exact level of the uncertainty. Note that our estimate excludes the carbon emission resulting from land-use change. These emissions vary per year, mainly as a function of the carbon stock of burned and cleared vegetation (Page et al., 2002; Kronseder et al., 2012). Their inclusion would require comparing land cover in 2011 and 2010 and is outside the scope of the current article, which aims to present ES flows as a function of the 2010 land use. For this reason, our provincial estimate is an underestimate of actual CO_2 emissions in Central Kalimantan. Note also that land-use change, and in particular the expansion of oil palm plantations including on peat, has expanded strongly since 2010, current emission levels are therefore likely to be considerably higher than the 2010 levels that we calculate.

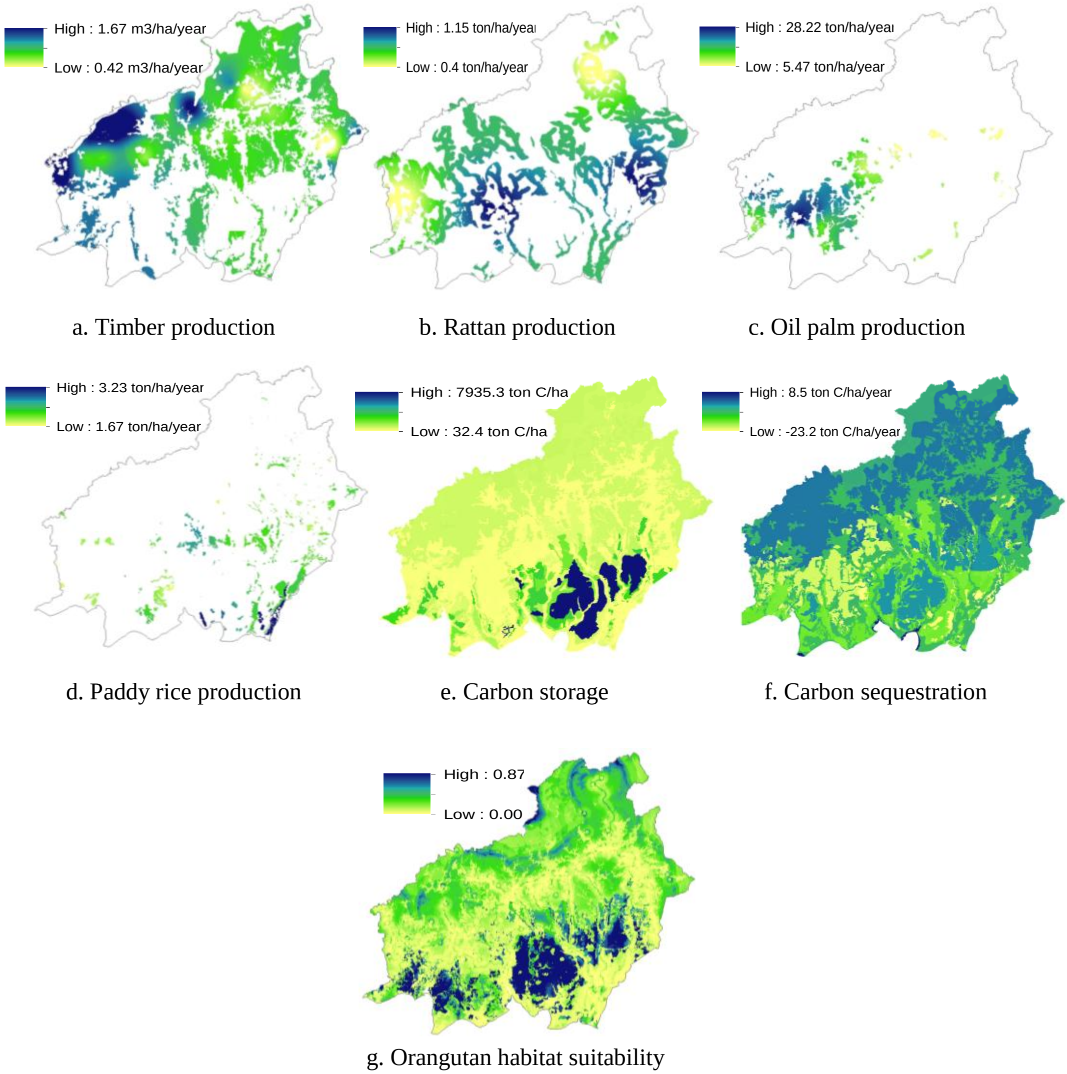


Figure 2.3. Ecosystem service maps of Central Kalimantan

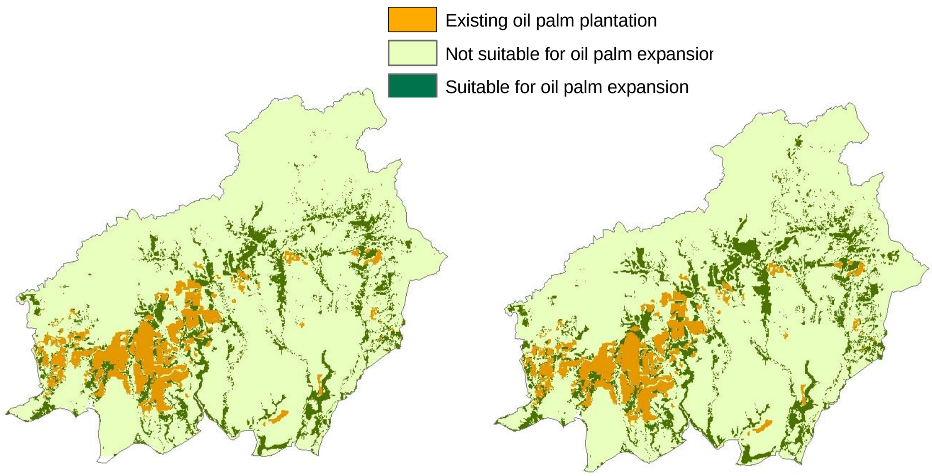
Habitat for orangutan

Figure 2.3g presents the habitat suitability map for orangutan resulting from Maxent modeling. The model's accuracy (expressed in AUC) is 0.88. The relative contribution of environmental variables to the model is: land cover (75.1%), distance from road (12.8%), elevation (6.2%), and distance from settlement (5.8%). The map shows high orangutan habitat suitability in peat swamp forest, where about 56 % of the forest has a suitability probability of more than 0.5. We used a threshold of 0.5, which represents the probability of a random prediction, to determine areas suitable and unsuitable for orangutan habitat in 2010. This reflects the fast deforestation in Central Kalimantan, in particular in the last two decades (Hansen et al., 2009). By using this threshold, only 1.4 million ha area (9.2% of the total land area) is predicted to be suitable as orangutan habitat. We identify about 60% of the suitable area is inside protected areas. This is comparable to the estimate of orangutan distribution provided by Wich et al. (2008), in which 61% of orangutan population in Central Kalimantan is distributed in protected areas, see also Broich et al. (2011).

2.3.2. Spatial planning for oil palm expansion

We applied two scenarios to produce maps of where oil palm expansion would lead to minimal damage of otherESs, on the basis of criteria developed by the relevant stakeholders. Figure 2.4 presents maps of the potential area for oil palm expansion, one for each scenario. Existing oil palm plantations are also presented in the map. In the environmental sustainability scenario, it is estimated that there is a potentially suitable area for oil palm expansion of 1.79 million ha. For the mixed sustainable-rapid development scenario, the potential expansion area is about 2.12 million ha. At the current rate of expansion of 110,000 ha per year (analysed from the land-cover map 2005 and 2010), this would be sufficient to accommodate oil palm expansion in the coming 16 years in case of the first scenario and 19 years in the second scenario.

However, there are a range of other criteria that also determine the suitability of land for oil palm (Figure 2.2). In particular, in the case of Central Kalimantan, other key criteria are land ownership, local community interests, legislation, productivity, and access. Applying these criteria will reduce the possible area for oil palm expansion. A particularly relevant aspect in this regard is that oil palm companies require large contiguous tracks of land for plantation development, and that land held by multiple smallholders is difficult and expensive to obtain. This and other institutional factors are not reflected in the map. Our maps identify a ‘search area’, in which plantation companies can focus either the conversion of land which they already own a license for, or for acquiring new licenses. In addition, our maps demonstrate priority areas for provincial governments and other stakeholders for engagement with plantation companies for the renegotiation of existing licenses in areas that are unsuitable for land conversion to plantations.



a. environmentally sustainable scenario b. mixed sustainable-rapid development scenario

Figure 2.4. Maps of planning for oil palm expansion based on: (a) environmentally sustainable scenario and (b) mixed sustainable-rapid development scenario

2.4. Discussion

2.4.1. Implications for ES mapping

Now that there is an increasing experience with mapping ESs(Nemec and Raudsepp-Hearne, 2013), it is critical that there is not only a scaling up of existing approaches, but also that more attention is paid to testing the applicability and reliability of various mapping methods. In our study, we tested different mapping techniques for ESs at aggregated scales. Our study shows that mapping ESs at aggregated scales is possible, even in a data poor developing country context, but that further research is needed to analyse the uncertainty levels in the outputs. Better input data, such as more measurements, higher resolution remote sensing data, and more detail land cover map, are also highly required for improvements. Some general implications for mapping ESs at aggregated scales are described below.

Look up tables

In the case of a scarcity of site specific data, proxy based and lookup tables approaches are widely applied, using land cover (Troy and Wilson, 2006; Burkhard et al., 2009), or even administrative boundary (Raudsepp-Hearne et al., 2010) as the mapping units. This approach is susceptible to a generalization error (Plummer, 2009) which is associated with transferring values and/or ignoring the variation within a mapping unit. An additional disadvantage of the use of lookup tables is that the method does not allow calculating the spatial error of the simplification involved. The accuracy of lookup tables depends upon the detail (diversity) of mapping units (e.g., land-cover classes); and the reliability of data within each class. For carbon storage mapping, for example, we had a combination of vegetation carbon data in 16 land-cover types and soil carbon in 16 soil types. The carbon data were also mostly obtained from studies in Kalimantan or Indonesia. This enhances the accuracy compared to an approach with fewer classes with data from other parts of the world.

Geostatistics

Interpolation with the use of geostatistics is an adequate technique for ES mapping, mainly for ESs distributed in a single land-cover type. Some ESs, such as timber production, rice production and palm oil production, are distributed in single or very few land-cover types that have spatial variability in terms of their capacity to provide the service. In ES mapping, geostatistics has been used for example for carbon mapping (in more data-rich environments than Central Kalimantan) (e.g. McGrath and Zhang, 2003; Beilman et al., 2008). Our study shows the applicability of geostatistics for mapping other ESs. We applied a stratified interpolation technique for paddy rice production mapping. Geostatistical analysis and interpolation were run in different types of paddy rice field (irrigated and upland paddy rice), after which the maps were combined. This was due to the distinct production patterns in the two fields. A direct interpolation will produce a higher bias. In general, this technique is applicable if ES values depend on land cover and are spatially heterogeneous.

Maxent

Maxent performed well in our modeling, indicated by high AUCs (0.88). Maxent is commonly applied for habitat suitability modeling (e.g. Philips et al., 2006; Loiselle et al., 2008; Ward, 2007). Maxent has also been applied, for example, to map land suitability for agriculture (Heumann et al., 2011), to predict wildfire probability (Parisien et al., 2012), and to predict alien species invasion (Poulos et al., 2012). In terms of ES mapping, however, Maxent does not deliver the actual performance of the services. Maxent generates a suitability, which represents only a relative provision of the services. The actual presence of the service supply still needs to be confirmed by field measurements. In the case of orangutan habitat we expect the error made in this way to be small. The reason for this is that the past decade has seen a progressive decrease in area available for orangutan, leading to the species occupying the large majority of potentially suitable habitats available to them (Johnson et al., 2005).

2.4.2. Integrating ESs in spatial planning

In the context of land-use planning, we believe that an ES approach to land-use planning offers a number of advantages compared to an approach based on land suitability. First, it allows for a more comprehensive insight in the benefits provided by land-use units under current management (and therefore the trade-offs involved in land conversion). It also allows stacking multiple ES maps to identify the “hot spots” of ESs which is useful for instance in determining co-benefits of REDD+ project. An ES approach also shows benefits from regulating and cultural services that are not always sufficiently considered in land-use planning (Klain and Chan, 2012). Second, it presents an indication of how land-use change will affect different stakeholders. Local communities may benefit from paddy production, collection of NTFPs such as rattan, and perhaps some degree of forest logging – but not from carbon sequestration or storage and only to a limited degree from oil palm establishment (Hein and van der Meer, 2012). These two aspects allow for a more accurate identification of zones where land-use conversion will have minimal impacts in term of ES supply and impacts on stakeholders. In addition, they allow for a more comprehensive monitoring of the effects of land-use change, in terms of overall effects on ES supply and stakeholders. Finally, the spatial approach to modelling ES flows developed in this paper can support the emerging thinking on Ecosystem Accounting, which requires spatial analysis of ES flows, and ecosystems’ capacities to generate ESs (Edens and Hein, 2013). This paper demonstrates several approaches that can be used to analyse ESs at aggregated scales in a data poor context that are relevant to Ecosystem Accounting, which requires a ‘wall-to-wall’ mapping of ES supply in specific administrative units.

A critical constraint of using an ES approach to land-use planning is that ES supply may not be sustainable. In case of overharvesting of ESs, the long-term value of land units exposed to unsustainable extraction may be lower than estimated based on current flows. In addition, there may be land-use units that are ‘under-utilized’ compared to their long-term capacity to generate services. Hence, a further refinement of the ES approach to land-use planning could be to include both flows of services and stocks of ecological capital (which represents the capacity of ecosystem to generate services over time).

2.4.3. Policy implications for ecosystem management in Central Kalimantan

The ES maps (Figure 2.3a-2.3g) show where ESs are generated and thereby indicate the potential consequences of land-use change. Table 2.3 illustrates multiple ESs provided by a peat swamp forest and by an oil palm plantation on a peatland. Several studies emphasized the negative impacts resulting from peat swamp forest conversion to oil palm and the need to stop more conversion (Hooijer et al., 2010; Wicke et al., 2008). Our study confirms the environmental impacts associated with peat forest conversion to oil palm plantation. Table 2.3 shows that the highest carbon stocks are located in the peatlands, that their conversion causes very significant carbon emissions and that conversion of peat also affects a number of other services (in particular orangutan habitat and timber production). Monetary analysis of the changes in ES supply as a function of land-use change is required to further substantiate the effects of land-use change in peat lands.

Table 2.3. Average ES provided by peat swamp forest and oil palm on peatland

	Peat swamp forest	Oil palm on peatland
Timber production	On average 0.83 m^3/ha/year	n.a.
Oil palm production	n.a.	On average 14.8 ton/ha/year
Carbon sequestration	From + 5 (non-drained) to - 4 (drained) ton C/ha/year	emissions of up to 23 ton C/ha/year
Habitat for orangutan	Mostly suitable, depending on forest cover	not suitable

Our paper did not consider an additional concern related to oil palm expansion. Much of the peatlands in Central Kalimantan are located only few meters above high tide sea and river water levels. Peat drainage, for oil palm or other agricultural activities, causes soil subsidence with subsidence rates of up to five centimeter per year (Hooijer et al., 2006; Verhoeven and Setter, 2009; Miettinen and Liew, 2010). This will affect the local hydrology, and could lead to severe flood risks in the lowest parts of the drained peatlands in a time frame of decades. We identified about 267,000 ha area of oil palm plantation established in peatland in Central Kalimantan (analysed from land cover and soil maps), and recommend no further peat conversion also on shallow peat (<3 meter deep, based on the threshold used in Indonesian land-use regulations). We have considered this aspect in mapping the possible area for oil palm expansion; in both scenarios we exclude peat (regardless of peat depth) from land available for oil palm expansion.

In Indonesia, land-use planning is strongly influenced by the recent institutional decentralization, where responsibility for natural resource management has been shifted from the national and provincial levels to the district levels (Firman, 2009). Decentralization has brought several challenges to effective land-use planning, including a lack of synchronization of planning efforts between the national, provincial and district levels, and a lack of capacity and information at the district level (Setiawan and Hadi, 2007). Furthermore, the degree of transparency in managing land and natural resources (for instance with regards to granting licenses for land conversion) varies between individual districts (Firman, 2009). An ES approach would be instrumental to support province and district levels with land-use planning. Our study illustrates where oil palm expansion could potentially be allowed in view of the need to limit the loss of ESs. The resulting map (Figure 2.4) can be considered as a basic input for the spatial planning process for oil palm expansion. This map should however not be used in isolation, but be combined with information on other ESs (as we did not model all ESs), stakeholder interests, legislation, land suitability, infrastructure, etc. In the context of land-use planning process (Figure 2.2), our study stands at phase 1 (ES mapping) and phase 3 (spatial planning). Given a general lack of capacity at the district level, rather than promoting mapping ESs in every district, we recommend producing ES maps at higher scales (province or island) in a participatory manner with district staff where appropriate, and disseminating these maps to the districts.

Producing and disseminating regular updates of these maps would also provide an additional tool for monitoring land-use change and promote transparency (Fuller, 2006).

2.5. Conclusion

We examined three different approaches (interpolation with the use of geostatistics, lookup tables, and Maxent) to map ESs at the aggregated scale (153,000 km^2) required for land-use planning, in a data-scarce developing country setting. We found that geostatistics led to acceptable levels of accuracy for mapping timber, rattan, oil palm, and paddy rice production; so did Maxent for mapping orangutan habitat. The accuracy of mapping using lookup tables could not be derived; it depends on the accuracy of both the lookup information (which varied considerably for different land-cover types in our study) and the accuracy and level of detail of the land-cover maps. Our study also shows how ES mapping can support land-use planning, in the case of Central Kalimantan by identifying areas where land-use conversion to oil palm has minimal impacts on the supply of other ESs. At present, it has been stated that 'waste land' should be used for oil palm plantation establishment in Kalimantan (and elsewhere), in order to reduce its environmental impacts. However in reality most land is not laid idle but used, albeit with a varying degree of intensity. With an ES approach the concept of 'idle land' can be specified and more informed land-use planning can be undertaken. Our approach offers a constructive approach to inform local, provincial and national governments of trade-offs involved in land-use planning. Our example shows how an ES approach can assist in identifying areas suitable for oil palm expansion.

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3. MAPPING MONETARY VALUES OF ECOSYSTEM SERVICES IN SUPPORT OF DEVELOPING ECOSYSTEM ACCOUNTS

ABSTRACT

Ecosystem accounting has been proposed as a comprehensive, innovative approach to natural capital accounting, and basically involves the biophysical and monetary analysis of ecosystem services in a national accounting framework. Characteristic for ecosystem accounting is the spatial approach taken to analyzing ecosystem services. This study examines how ecosystem services can be valued and mapped, and presents a case study for Central Kalimantan, Indonesia. Four provisioning services (timber, palm oil, rattan, and paddy rice), one regulating service (carbon sequestration), and two cultural services (nature recreation, and wildlife habitat) are valued and mapped in a way that allows integration with national accounts. Two valuation approaches consistent with accounting are applied: the resource rent and cost-based approaches. This study also shows how spatial analysis of ecosystem accounting can support land use planning through a comprehensive analysis of value trade-offs from land conversion.

Modified from:
Sumarga, E., Hein, L., Edens, B., Suwarno, A., 2015. Mapping monetary values of ecosystem services in support of developing ecosystem accounts. Ecosystem Services 12: 71-83.

3.1. Introduction

Ecosystem accounting (EA) is a new area of environmental economic accounting that aims to measure ecosystem services (ESs) in a way that is aligned with national accounts (Boyd and Banzhaf, 2007; European Commission (EC) et al., 2013, Edens and Hein, 2013). The System of National Accounts (SNA) (EC et al., 2009) provides the global standard for national accounting, and the Central Framework of the System for Environmental Economic Accounts (SEEA-CF) was designed as a satellite account of the SNA (UN, 1993, UN et al., 2003), with a global standard for the SEEA-CF adopted in 2012 (UN et al., 2014). EA involves an extension of the production boundary of the System of National Accounts (EC et al., 2013). This allows the inclusion of a broader set of ESs types such as regulating services and cultural services as well as the natural growth of biological assets such as timber in measures of economic activity. In turn, this allows a more comprehensive recording of changes in ecosystem capital, i.e. the stock of ecosystems that provides a foundation for future well-being, and provides a more complete dataset for environmental policy making (Campbell and Tilley, 2014).

EA involves approaches to measuring ecosystem capital and comprises the monitoring of ES flows, the capacity of ecosystems to generate these services, and the condition of ecosystems (EC et al., 2013). Ecosystem condition determines the capacity to generate services, as in the case of standing timber stock, species composition, soil fertility, rainfall, etc. determining the capacity to supply timber at present as well as over time. There remain considerable challenges in implementing EA (Edens and Hein 2013). One of the main issues is if, how and to what degree ecosystem capital can be valued in monetary terms. In particular, it is still being discussed if ES flows and the capacity of ecosystems to generate services can be valued in monetary terms in a way that is both consistent with accounting, and that is sufficiently robust for the purpose of accounting (UN et al., 2014). Note that ecosystem condition is not directly connected to human benefits and can therefore not be valued in monetary terms.

Spatial explicitness is a distinguishing property of EA (all with the exception of the land account that provides indications of acreages of land in specific classes potentially combined with ownership information of the land). Both ES flow, ecosystem capacity and ecosystem condition are spatially heterogeneous (Schröter et al., 2014). There is a wide range of experience with mapping the values of ES (Plieninger et al., 2013; van Berkel and Verburg, 2014; Palomo et al., 2014), and very limited experience with mapping the values of the capacity of ecosystems to supply ES (Chen et al., 2009; Ericksen et al., 2012). Values have been mapped among others in support of land-use planning (Fisher et al., 2011; Ruiz-Frau et al., 2012; Scolozzi et al., 2012) and to monitor the impacts of land-use change (Kreuter et al., 2001; Li et al., 2010; Mendoza-González et al., 2012). However, at present, there have been few if any analyses involving the mapping of ES values in the context of, and aligned with environmental-economic accounting.

The objective of this paper is to examine how ES can be valued and mapped in a manner aligned with national accounts. In particular, we analyse and map the monetary value of a comprehensive set of ES in Central Kalimantan province, Indonesia. The novelty of our paper is in the application of a valuation approach consistent with accounting, and in the application of valuation approach to a relatively large area (around 150,000 km^2). In addition, we explore an experimental valuation approach for one specific element of biodiversity: the conservation of orangutan habitat. We selected Central Kalimantan in view of our interest in testing the EA approach in a developing country context, and because Central Kalimantan has been subject to rapid land-use change including deforestation in the past decades (Broich et al., 2011; Miettinen et al., 2012), requiring better information on costs and benefits of different land management approaches, and on possible value trade-offs following land conversions. This study includes a specific analysis on the conversion of forests into oil palm in terms of the trade-offs that occur between ES values.

We value and map seven ESs, following the classifications of MEA (2003) and TEEB (2010), in a way that permits integration with national accounts. In particular, we distinguish the following services: timber production, rattan production, oil palm production, paddy rice production, carbon sequestration, wildlife habitat, and nature recreation. Although this is not a complete set of ESs generated in the study area, our set is sufficiently large and diverse to explore if and how ESs valuation and mapping can be applied in the context of EA. We explore in our paper if valuation data and analytical approaches are sufficiently robust for integration in accounts, if not, what further steps need to be taken, and what potential other policy applications may exist for spatial maps of monetary values aligned with the system of national accounts.

The outline of the paper is as follows. In the Methods Section, we describe the valuation methods selected for valuing the seven ESs and how the values are then mapped. In the Results Section, we present the monetary value maps and the summary of multiple ES values in the main land-cover classes. In the Discussion Section, we discuss three main issues: monetary valuation and mapping of ESs in support of accounting, challenges in valuation and integrating ES values in an accounting framework, and value trade-offs and their policy implications.

3.2. Methods

3.2.1. Study Area

We selected Central Kalimantan province, Indonesia for this study, in view of our interest in testing accounting methods in a developing country context and for a large area. Central Kalimantan is one of the largest provinces in Indonesia, and has been appointed as pilot province for a REDD+ project enhancing data availability of some ESs, in particular those related to carbon. The province covers an area of 153,500 km^2, and is located at latitude

0^o45’ North – 3^o30’ South and longitude 110^o45’– 115^o50’ East. Most of the area (57%) is covered by forest (Figure 2.1). This province has experienced rapid land-cover change, mostly conversion of forest to other uses, such as oil palm plantations. Based on a comparison of land-cover maps of 2000 and 2010 (Tropenbos Indonesia, unpublished), about 14,000 km^2 areas (12.7%) have been deforested during that period. The province has a low population density with an average of 14 people/km^2 and a total population of 2,149,896.

3.2.2. Spatial modeling and mapping of ESs

This papers builds upon previously developed ES models (Sumarga and Hein, 2014), in which physical models for a range of ESs were developed and applied to Central Kalimantan. A range of methods were applied to model and map these services in physical terms including Geostatistics, Maxent, and lookup tables. For this paper, we extend the previous paper with an additional ES, recreation. We exclude from our paper the service carbon storage since this does not constitute a flow and therefore cannot be included as an ES in an ecosystem account (even though it is highly relevant for land-use planning).

3.2.3. Valuation methods

In this paper, we examine how the seven ESs can be valued, and subsequently mapped, in a way that is aligned with national accounting. Valuation in the context of accounting requires a clear distinction between services and benefits, with services representing the contribution made by ecosystems to benefits used by people (EC et al., 2013). Some of these benefits are already captured in the SNA (e.g. crop harvesting), but other benefits (e.g. carbon sequestration) are not recognized in the SNA, which is why the production boundary is extended in EA. In the SNA, goods and services are valued at exchange values, based on representative market prices where these are available (EC et al., 2009). The SNA provides a standard on how products and assets can be valued in the context of the national accounts, including valuation approaches for valuing public goods (such as health care), for agricultural commodities and assets (both produced asset such as machines or non-produced assets such as land).

The SNA valuation approach has not yet been comprehensively applied to non-market ESs (e.g. Edens and Hein, 2013), but the SNA does provide a number of insights in how this can be done. For instance, public goods are valued ‘at-cost’ (EC et al., 2009), which implies that an avoided-damage cost method may be appropriate for non-market ESs, if it is reasonable to expect that a government, households, or firm would invest in order to mitigate the damages resulting from environmental degradation. The production factor approach, i.e. valuing an ES as a supporting factor of production, is another valuation approach that is potentially consistent with the SNA (EC et al., 2013), but this method is difficult to apply when an ES (such as flood control) is providing an input to a whole range of activities at the same time. This would require disentangling the contribution of flood control to a myriad of economic activities, even though in reality in some cases a loss of a flood control service would be mitigated by the construction of physical flood control infrastructure.

In this study, we apply two main valuation approaches. We analyse provisioning services and recreation based on a resource rent approach. For carbon sequestration and orangutan habitat we apply a cost based approach, as explained in more detail below.

Provisioning services

The four provisioning services we analyse (timber, oil palm, rattan, paddy rice) were chosen because they constitute the main products traded in Central Kalimantan. We calculate the resource rent (EC et al. 2013) to reveal the contribution of the ecosystem to the market outputs. The resource rent equals the revenues minus the value of intermediate consumption, and labor and the user costs of fixed assets (UN et al., 2014). The user costs of fixed assets consist of consumption of fixed capital (depreciation) and the cost of capital. The latter measures an opportunity cost for the money tied up in fixed assets. The costs of capital can be estimated as the interbank lending rate plus a risk premium (Veldhuizen et al., 2009). We consider the costs of capital only for oil palm cultivation and ecotourism that require significant investments (in the case of ecotourism for instance for means of transport). Since both the lending rate and the inflation rate vary considerably between years we took an average of both for the 3 years period. For the period 2009-2011, the average interbank lending rate is 13.0% (Statistics Indonesia, 2014b), the average inflation rate is 4.5% (Statistics Indonesia, 2014c), and we assume a risk premium of 1.5% (Veldhuizen et al., 2009), resulting in a real discount rate of 10%. We use the following equation to calculate the resource rent:

$$RR = TR - (IC + LC + UCF)$$

where

RR = resource rent
TR = total revenue
IC = intermediate consumption
LC = wages (labour costs)
UCF = user costs of fixed assets

We collected data from several sources to calculate the resource rent. For timber production, we analysed data from the financial reports of two logging companies that are based in Central Kalimantan (data were given on the condition that the name of the companies would not be published). There are various taxes applied to timber production such as forest product tax and reforestation tax. In line with the SNA (EC et al., 2009), we excluded product based taxes from the calculation in order to obtain the output at basic prices to estimate the total revenue. For the other provisioning services, we used data (production, price, costs, and revenue) from a range of sources (Table 3.1). As data are obtained from diverse sources and different years, the resource rent values are standardized into 2010 values on the basis of an inflation rate of 11.1 % (2008) and 2.8 % (2009) (Statistics Indonesia, 2014c). The values are in Indonesian Rupiah (IDR), and then converted into Euro (€) with an exchange rate of IDR 12,000 for € 1 (average for 2010). We have chosen not to use PPP adjusted rates as some of the services, in particular oil palm, timber and rattan, are produced predominantly for international markets.

Table 3.1. Costs and revenue of provisioning services production (in euros)

Ecosystem service	Total revenue	Intermediate costs	Labor costs	User costs of fixed assets	Resource rent	Sources of data
Timber[a]	€ 118/m3	€ 71.6/m3	€ 11/m3	€ 0.4/m3	€ 35/m3	Financial report of two logging companies (unpublished)
Oil palm on mineral soil (0 – 4 years)	€ 368/ha/ year	€ 644/ha/ year	€ 378/ha/ year	€ 65/ha/ year	€ -719/ha/ year	Fairhurst and McLaughlin (2009); Ismail (2010)
Oil palm on mineral soil (5 – 9 years)	€ 2,744/ha/ year	€ 626/ha/ year	€ 368/ha/ year	€ 132/ha/ year	€ 1,618/ ha/ year	
Oil palm on mineral soil (10 – 20 years)	€ 3,135/ha/ year	€ 641/ha/ year	€ 377/ha/ year	€ 56/ha/ year	€ 2,060/ ha/ year	
Oil palm on peat soil (0 – 4 years)	€ 368/ha/ year	€ 778/ha/ year	€ 457/ha/ year	€ 130/ha/ year	€ -997/ha/ year	
Oil palm on peat soil (5 – 9 years)	€ 2,744/ha/ year	€ 685/ha/ year	€ 403/ha/ year	€ 264/ha/ year	€ 1,392/ ha/ year	
Oil palm on peat soil (10 – 20 years)	€ 3,135/ha/ year	€ 701/ha/ year	€ 412/ha/ year	€ 113/ha/ year	€ 1,910/ ha/ year	
Rattan	€ 145/ton	€ 20/ton	€ 21/ton	€ 0.2/ton	€ 104/ton	Iwan (2008); Martoniady (2009); involving 60 farmers
Paddy rice	€ 238/ton	€ 39/ton	€ 66/ton	€ 3/ton	€ 130/ton	Nugroho (2008); Evaristy (2008); Yandi (2008); involving 88 farmers

[a] Costs are mostly allocated for intermediate costs as companies hire other parties for several main activities such as road construction and log transportation

Regulating services

In view of the fragmented nature of the various carbon markets (Lovell, 2010), and the high impact of the institutional setting of the market on the carbon prices (Michaelowa and Jotzo, 2005), we value carbon sequestration services based on the marginal social damage costs (Tol, 2008). That is, the sequestration of a ton of carbon is valued using the social cost of emitting a ton of carbon. The social cost of carbon (SCC), is "an estimate of the monetized damages associated with the increment increase in carbon emissions in a given year" (Interagency Working Group on Social Cost of Carbon, United States Government, 2013). Since these marginal damage costs indicate a present value of future damage cost estimates, the discount rate plays an important role in determining the marginal damage costs. In view of the public good character of carbon damages we apply a social discount rate of 3% (Interagency Working Group on Social Cost of Carbon, United States Government, 2013). The appropriate discount rate to use for non-market ESs is not yet mainstreamed in EA (EC et al., 2013).

Consequently, we used an SCC value for 2010 at USD 32/ton CO_2 that is equivalent to € 24 /ton CO_2 (€ 88/ton C) with an exchange rate of $ 1.33 for € 1 (average in 2010). The monetary values for carbon sequestration service are negative in areas where carbon emissions are higher than carbon sequestration levels. This occurs, in particular, in drained peatlands (Sumarga and Hein, 2014). There are two ways of interpreting such negative values. One way is to conceive this as an ecosystem disservice (Zhang et al., 2007; Swain et al., 2013). However, from an accounting perspective, which does not have a notion of ´negative production´, it is preferable to separate the sequestration service (that is always positive), from the emissions, which can be presented as a degradation cost. Hence, we produce two maps, one depicting the value of carbon sequestration, and one map depicting the costs of carbon emissions. The latter can be integrated in a full EA in the form of ecosystem degradation.

Cultural services

Nature recreation

We estimate the monetary value of the nature recreation service based on both the entrance fees paid to the parks and on the revenue generated in the local ecotourism sector. We elicited the revenue from entrance fees of three national parks (Tanjung Puting, Sebangau, and Bukit Baka Bukit Raya) and two recreation parks (Bukit Tangkiling and Tanjung Keluang). We obtained this information from the statistics of National Parks and Conservation and Tourism offices. We also calculate the revenue from ecotourism. By far the most visited park in Central Kalimantan is Tanjung Puting National Park, which has a large orangutan population and a rehabilitation centre where orangutans can easily be spotted, in addition to a variety of other species such as the proboscis monkey. We focus on tourism revenues that can be directly attributed to the presence of the park and its biodiversity, in particular revenue from a lodge inside the park, and revenue generated from tourists booking a boat to visit the park (that can only be reached by boat). In 2010, around 50 boats were owned and operated by people from a nearby town and nearby villages, and they offer tours of one day up to a week or more in the park, including a guide, meals, operation of the boat etc. To estimate the resource rent generated by the lodge and the boats we conducted a survey in July 2012 and in March 2013 to collect data on the cost and benefit of the tour organization and the hotel business, covering the hotel manager and 30 boat owners. In particular, we asked for data on guests, revenues and costs (intermediate consumptions, labor costs, costs of fixed assets), that was willingly shared with us.

Subsequently, the resource rent equation 1 is applied to calculate the resource rent for recreation. We then used the resource rent of tour organization in Tanjung Puting national park (€/visitor/year) to estimate the value in the other two national parks, using a proportional (per visitor) benefit transfer. In these other parks, visitors also have to enter by boat, but the number of visitors is much smaller, see Table 3.2.

Table 3.2. Costs and revenue of tour organization and hotel inside Tanjung Puting National Park[a]

	Total revenue (€)	Intermediate costs (€)	Costs of employment (€)	User costs of fixed assets (€)	Resource rent (€)
Tour organization	€ 1,300,000	€ 401,250	€ 373,750	€ 75,000	€ 450,000
Hotel	€ 129,000	€ 35,580	€ 35,000		€ 58,420

[a] Analyzed from primary interviews

Orangutan habitat

Biodiversity is one of the most difficult aspects to analyse in an EA context, and it is questionable if it is feasible at all to value biodiversity, or aspects thereof, in a meaningful way using monetary indicators (Ehrenfeld, 1998; Nunes and van den Bergh, 2001). In order to explore and test what a potential approach to monetize biodiversity could look like, we applied the following valuation method, for one specific aspect of biodiversity: orangutan habitat. We select this as an indicator in view of the importance of the orangutan as a flagship conservation species (Alfred et al., 2010), because of its endangered status, and because Central Kalimantan is likely to have the world's largest population of orangutan at the provincial level (Wich et al., 2008). Consistent with accounting principles, we tested a defensive expenditure method for valuing the orangutan habitat service. We apply this method by analysing the costs related to the reintroduction of orangutan in the forests of Central Kalimantan from an orangutan rescue center, operated by the NGO Borneo Orangutan Survival Foundation (BOSF). The reintroduction costs include pre-release cost, release cost and post-release monitoring cost. We assume, therefore, that the exchange value of the orangutan population can be approximated by analysing the costs spent on the reintroduction of (marginal) orangutans. Once released, the orangutan will stay in the forest throughout his lifetime and the value of the orangutan habitat service needs to be converted to an annual value. This is done by considering that the average age an orangutan reaches in the wild is 50 years (Wich et al., 2004) and that orangutan are on average 10 years when they are released by BOSF (data from BOSF). We therefore divide the reintroduction costs by 40 years in order to obtain a monetary value for the presence of an orangutan in a forest habitat during one year. We acknowledge that orangutan habitat harbors many more species than orangutan alone, and that our value is a gross underestimation of the overall value of wildlife habitat. Note also that a willingness to pay (WTP) survey, a more frequently applied method for valuing conservation of wildlife, could not be applied in this study. This method elicits consumer surplus, hence it is incompatible with accounting principles.

3.2.4. Mapping monetary value of ESs

Our monetary analysis builds upon the mapping of ES supply in biophysical terms published in Sumarga and Hein (2014). We calculated the resource rent of the production of timber, rattan and paddy rice in €/production unit/year, and multiply the values with the productivity of the provisioning services (production/ha/year). In this way, we convert the ES maps in terms of physical quantity into maps in terms of monetary value. We applied the same procedure for carbon sequestration by assigning the SCC (in ton of C) into the carbon sequestration map. To ensure consistence with accounting procedures, we separately mapped the monetary value of the carbon sequestration service (in areas with a positive net carbon flux) and the degradation costs of carbon emissions (in areas with a negative net carbon flux).

We applied the lookup tables technique, i.e. assigning a value to a mapping unit (assuming equal importance of every hectare in the mapping unit), for mapping the monetary values of oil palm production, nature recreation and orangutan habitat. First we created mapping units, followed by assigning the monetary value of those services to the related mapping units. For oil palm production, we created age classes as the mapping unit, since costs and revenue from oil palm production are highly dependent on plantation ages. Limited availability of land-cover maps allowed us to create six classes only, a combination of three productivity classes: unproductive ages (0-4 years), early production ages (5-9 years) and mature production ages (> 9 years) and two soil types: mineral soil and peat soil. For nature recreation, we used the five-park map as the mapping unit. For orangutan habitat, we created the habitat unit as the mapping unit. We considered the protected area map, the orangutan habitat suitability map from Maxent (Sumarga and Hein, 2014), and orangutan distribution area identified by Wich et al. (2008) to indicate the habitat unit. All of our maps are in raster format with a pixel size of 100 m x 100 m.

3.3. Results

3.3.1. Monetary value maps

Timber production

We analysed data from two timber logging companies. The average resource rent obtained by logging companies from timber production is € 35/m3. The costs and revenue of timber production is summarized in Table 3.1. The monetary value map of timber production generated based on the resource rent is presented in Figure 3.1a. The estimated total value for Central Kalimantan in 2010 is € 183 million with an average of € 30 per ha and a standard deviation of € 6 per ha.

Oil palm

We analysed the resource rent of oil palm production in terms of fresh fruit brunch (FFB) production. The average resource rent for six classes of plantations is summarized in Table 3.1, and the resulting map is presented in Figure 3.1b. The average resource rents are negative in the first four years as there is no FFB production. The highest production level is achieved after year 10, corresponding to a resource rent of on average € 2,060/ha/year for plantations in mineral soils and € 1,910/ha/year for plantations in peat soils. Plantations in peat soil generate lower resource rents due to higher costs of land management, particularly for constructing and maintaining drainage systems.

Rattan production

Due to the policy of the Indonesian Ministry of Trading in opening or closing raw rattan export, the rattan price in Indonesia is highly volatile. In 2012 for example, raw rattan export was stopped in order to promote production of processed rattan. Due to the un-readiness of the domestic market in absorbing the rattan supply, this policy led to a sharp decline in the rattan price. We analyse the resource rent of rattan for 2010, when no export limitations were in place, and base our analysis on studies conducted in periods without a ban on rattan export. The average resource rent of rattan production is €104/ton, with the cost and revenue summarized in Table 3.1. The monetary value map of rattan production is presented in Figure 3.1c. The total resource rent of rattan in 2010 is about € 390 million with an average of € 82 per ha and a standard deviation of € 15 per ha.

Paddy rice production

The average resource rent of paddy rice production is € 130/ton with the cost and revenue summarized in Table 3.1. The monetary value map of paddy rice production is presented in Figure 3.1d. The total monetary value of paddy rice production in the province in 2010 is € 222 million with an average of € 289 per ha and a standard deviation of € 47 per ha.

Carbon sequestration

The monetary value map of carbon sequestration is presented in Figure 3.1e, and the map of the degradation costs of carbon emissions is presented in Figure 3.1f. We identify 8.2 million ha contributing to sequestration, with a total monetary value of € 1,990 million in 2010; and 6.7 million ha with a 'negative sequestration' (i.e. emission), with a total social costs of € 2,113 million in 2010. At the scale of the province, there is therefore a net cost in 2010 of € 123 million, based on the factors that we considered in our analysis. We did not consider, however, carbon emissions due to land-use change (since we value sequestration and emissions for the average situation in 2010), hence we are likely to underestimate carbon emissions given the rate of land degradation in Indonesia (Gunarso et al., 2013).

Also note that because of rapid land-use change (and associated ongoing drainage (Hooijer et al., 2012)), the values retrieved for 2010 may not be representative for other years.

Nature recreation

Table 3.3 provides data on revenues obtained by five parks from the visitors' entrance fees in 2010, as well as the resource rent from tour organizations and the hotel business inside Tanjung Puting National Park. We assume that the revenues from entrance fees are fully considered as resource rent as the costs of recreation provision can be neglected because of the minimum availability of infrastructure and facilities inside the national parks. There were around 50 boats operated by local people for tours in Tanjung Puting National Park in 2010. The peak season for the tour is from June to August. On average, a boat is rented 156 days/year. Our survey showed that the aggregated resource rent of the tour organizations is in total € 450,000 for 50 boats in 2010. The costs and revenues of the tour organizations are summarized in Table 3.2. We consider this value as an additional resource rent obtained from nature recreation in Tanjung Puting National Park. The resource rent per visitor (€ 42) is used to estimate the benefits in the other two national parks that experience a similar type of tourism. There is a hotel (Rimba Lodge) inside Tanjung Puting National Park. The hotel had on average 1032 guests/year in the period 2011-2012, and they stayed on average for 1.5 nights. The resource rent of the hotel business is € 58,417/year with the cost items summarized in Table 3.2. The monetary value map of nature recreation in the five parks is presented in Figure 3.1h with a total estimate of resource rent of around € 644,000/year.

Orangutan habitat

BOSF released a total of 64 orangutans during 2012 and 2013. The reintroduction costs vary depending on the distance between the rehabilitation center and the release area. The average cost for orangutan reintroduction is € 7,300/orangutan, which, based on an orangutan's average lifespan following release, is equivalent to € 183/orangutan/year. We use this value to estimate the avoided costs of orangutan habitat in areas where the occurrence of wild orangutan were identified. The population size of wild orangutan in Central Kalimantan is about 33,000 individuals, 61% of which live in protected areas (Wich et al., 2008). The orangutan population and the estimate of avoided costs in each location (habitat unit) are summarized in Appendix 3.1. The monetary value map of orangutan habitat services is presented in Figure 3.1g. Estimated in this way, the monetary value for the 33,000 wild orangutan is € 6,336,000/year. Note that, as with all other value estimates that we provide, this does not represent the total economic value, since we exclude consumer surplus in our estimations in order to be consistent with accounting principles. In particular, the willingness to pay of the general public for remaining orangutan in the wild, in particular for the last populations, may far exceed the avoided release costs. Zander et al. (2014) investigated the visitors' willingness to pay to support orangutan conservation in Sarawak and found a value of € 2,200/orangutan/year, which would be almost 12 times the value we estimated.

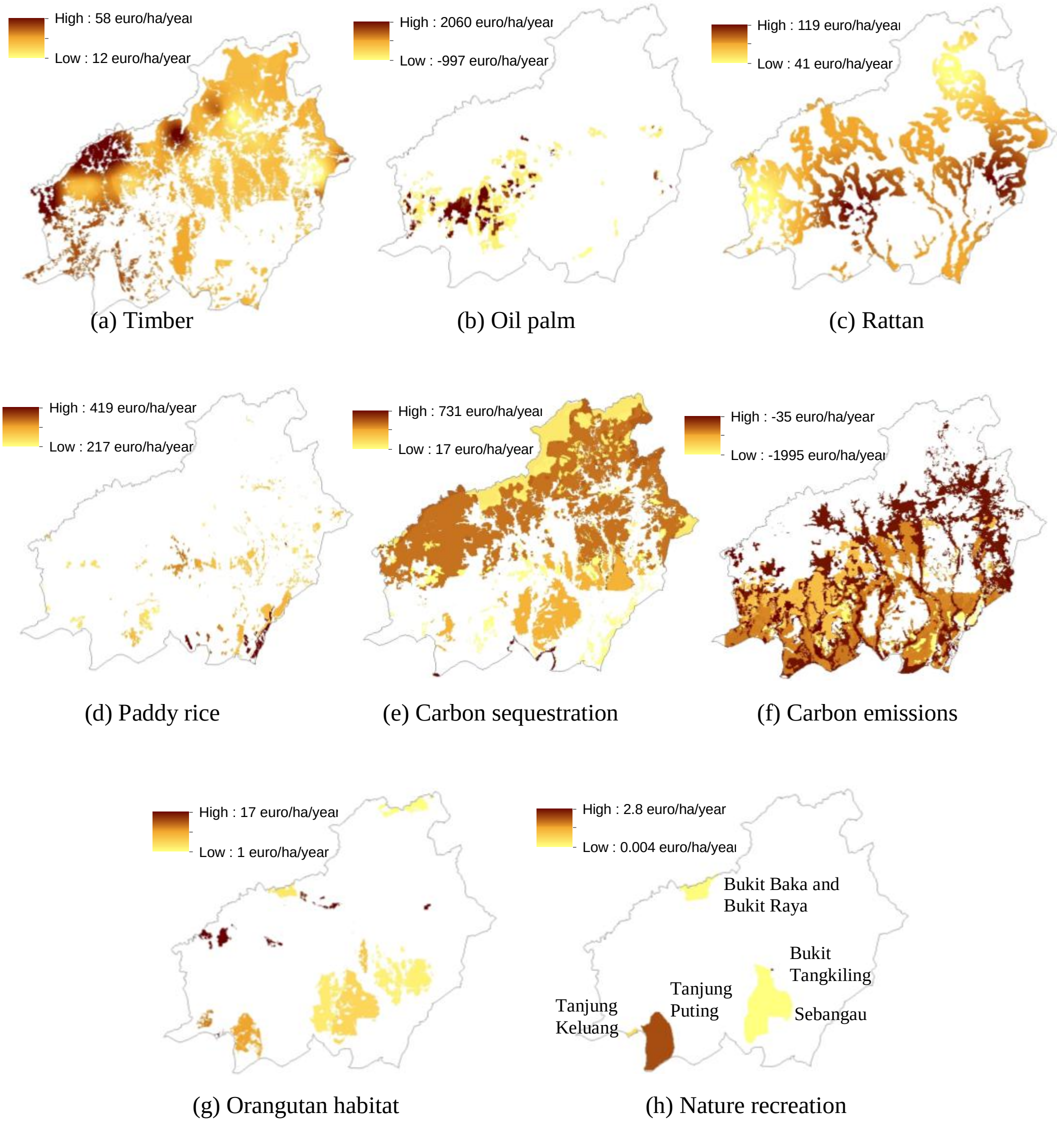

Figure 3.1. Monetary value maps of ecosystem services

Table 3.3. Monetary benefit from nature recreation in five parks

Conservation parks	Number of visitors[a]		Revenue from entrance fees (€)	Revenue for tour organization (€)	Revenue for hotel (€)	Total revenue (€)
	Domestic	Foreigner				
Tanjung Puting National Park	2,300	8,400	122,630	450,000	58,420	631,050
Bukit Baka & Bukit Raya National Park	10	80	320	3,860		4,180
Sebangau National Park	30	20	70	1,890		1,960
Tanjung Keluang Recreation Park	57,500	0	4,790			4,790
Bukit Tangkiling Recreation Park	33,000	0	2,750			2,750

[a] Classified into domestic and foreigner due to the difference of entrance fee

3.3.2. Monetary values of ES in different land-cover units

Table 3.4 summarizes the monetary value of ESs in the main land-cover classes in Central Kalimantan. We distinguish between peat and mineral soils given the different implications of land use in these two soil types for ES supply, in particular with regards to carbon emissions.

Note that our study is not complete, for instance we did not model hydrological services, other plantation crops (such as rubber) and other non-timber forest products. Also, there is substantial spatial variability in the trade-offs involved with land-use conversion, in Table 3.4 we provide a provincial average value only. Note also that the resource rents of oil palm production are not extracted directly from Figure 3.2b. In order to make them comparable with the other values, the values for oil palm production are the average resource rents of oil palm production during one cycle of production (20 years), with the annual values not discounted.

Table 3.4. The mean and, in brackets, standard deviation of the monetary value of ES in different land cover classes. Mean and standard deviations represent the average and the spatial variability of the values.

ES	Natural forest		Oil palm plantation		Rattan field	Paddy field	
	Dry land	Peat land	Dry land	Peat land		Dry land	Peat land
Timber (€/ha/year) [a]	28 (6)	27 (3)					
FFB of oil palm (€/ha/year)			1,293	1,094			
Rattan (€/ha/year)					82 (15)		
Paddy rice (€/ha/year)						290 (50)	283 (36)
Carbon sequestration in areas with net sequestration (€/ha/year)	269 (103)	214 (8)[d]	170[f]			176	
Carbon emissions in areas with net emissions (€/ha/year)		-392 (38)[e]	-20[g]	-2,042			-1,144
Orangutan habitat (€/ha/year) [b]	4 (3)						
Nature recreation (€/ha/year) [c]	0.6 (0.8)						

[a] in production forest / [b] in areas suitable for orangutan habitat, mostly in protected areas /[c] in protected areas / [d] in primary forests / [e] in drained forests / [f] established on degraded grassland / [g]established on forests, excluding carbon emission from land clearing

3.4. Discussion

3.4.1. Monetary valuation and mapping of ESs in support of accounting

In this paper we present a crucial part in the development of an ecosystem account: an analysis of the monetary values of ESs, both in spatial terms and in terms of an overview of the overall flow of ESs generated in Central Kalimantan. In spite of Central Kalimantan being a generally data-poor environment, we managed to model seven ESs both in physical terms (Sumarga and Hein, 2014) and in monetary terms (this paper).

Critical in applying an accounting approach to ES mapping and valuation are: (i) distinguishing flows and assets; (ii) the use of appropriate physical and monetary assessment techniques; and (iii) sufficient accuracy and awareness of the limitations of the approach (EC et al., 2013). We will discuss these aspects below, focusing on the monetary aspects.

Distinguishing flows and assets. This paper focuses on the valuation of flows of ESs. Analysing ecosystems in terms of assets requires an additional analytical step. The ecosystem asset comprises two main components: the capacity of land-cover units to generate ESs and the condition of the ecosystem. The capacity reflects the maximum quantity of services an ecosystem can provide under current management (EC et al., 2013, Schröter et al., 2014), akin to the concept of theoretical ES flow as defined by Bagstad et al. (2014). For provisioning services, capacity depends upon the stock of ecosystem assets (e.g. standing stock of timber) and the regrowth of the ecosystem stock (e.g. mean annual increment of timber volume). For regulating and cultural services, capacity depends upon ecosystem processes and properties (e.g. riparian vegetation reducing flood risks), and the service materializes as soon as people are benefitting from the service (e.g. by having properties in the flood zone), cf. Bagstad et al. (2014). In the case of Central Kalimantan, the future flow of some services can be expected to differ substantially from the present flow. For instance, in the case of oil palm cultivation on peatlands, peat drainage leads to soil subsidence (Wosten et al., 2008; Hooijer et al., 2012), and – in the lowland environment of Central Kalimantan – to an increase in flood risks in the medium to long term (several decades) depending upon drainage depth and local hydrological conditions.

Physical and monetary assessment techniques. In a national accounting context, resource rent is an appropriate indicator for the monetary value of provisioning services (Campbell and Haynes, 1990; EC et al., 2013). We also applied it to the tourism service, calculating the resource rent approach to analyse the net revenue generated by the ES, which is providing opportunities for recreation. The resource rent approach deducts from the gross revenue in the sector all human and capital costs. By using a market interest rate to calculate the user costs of capital, the risks associated with economic activities are also accounted for. However, an element that is not included is the entrepreneurial reward (Carter, 2011), i.e. the reward for creating a business opportunity. This reward is in practice very difficult to calculate and it is also not explicit in the SNA (2008). By assuming it is zero there may be an overestimate of the resource rent attributed to ecosystems. The entrepreneurial risk and reward may be highest in innovative, immature business sectors, which do not include most of the sectors that we analysed in our paper (rice production, rattan production, oil palm production), with the potential exception of nature tourism that is still a relatively new sector in Central Kalimantan.

A range of valuation approaches have been proposed for ESs that have no market prices (Boyer and Polasky, 2004; Bateman et al., 2011). Our study shows the applicability of damage costs and defensive expenditures approaches in support of EA (see also Brouwer et al., 2009). In line with the SNA (2008), orangutan habitat is valued ‘at cost’, which is the general approach prescribed in the SNA for valuing public services. Valuation of the carbon sequestration service remains prone to considerable uncertainty given the high uncertainties related to estimating the social damage costs of carbon (Anthoff and Tol, 2013). In recent papers, efforts are being made to include the effects of low-probability, high-impact effects (such as surpassing thresholds in the climate system) in the social costs of carbon (e.g. Dietz, 2011). In addition, there is an issue of the discount rate to use, which has a major effect on the SCC given the long time frame of the impacts of climate change

(Guo et al., 2006). Based on the National accounting guidelines a case could be made for the use of market discount rates, however we argue that for the analysis of public services in the context of EA a social discount rate is more appropriate (we use an SCC based on a discount rate of 3% in our paper). This aspect needs further discussion in the context of the statistical community (see also EC et al., 2013).

Accuracy. This study notes that the effectiveness of EA (in a spatial context) is driven by a combination of the availability of data and the applied mapping methods. Lack of data will potentially lead to poor estimates through, among others, generalization. We have ample valuation data for rattan, paddy rice, and nature recreation using a variety of sources. In case of orangutan habitat, only three estimates of reintroduction costs are available (reintroductions happened only 3 times in the last couple of years). In addition, we experienced a lack of valuation data for timber and oil palm production, since financial information is typically confidential for private timber and oil palm companies. We expect that a better understanding of accuracy levels can be obtained in more data rich environment, through a better understanding of standard deviations in the factors determining the resource rent and other ES values.

In the spatial analysis of ES values, a key issue in mapping ecosystem values is the generalization error, in particular when a benefit transfer approach is used (Plummer, 2009: Liu et al., 2010). This method assumes the similarity of values in a specific land-cover type, regardless of the difference in locations and the spatial variability within the mapping unit. This study shows how our mapping approaches are capable of reducing generalization error in three ways. First, by using empirical data from surveys and studies within Central Kalimantan, both in mapping ESs in term of physical quantity (Sumarga and Hein, 2014) and in monetary valuation. In this way the potential error from transferring values can be minimized. Second, exhibiting the spatial variation of ESs inside a land-cover type (for timber, rattan, and paddy rice) by applying interpolation. We applied this approach in mapping ESs in term of physical quantity; hence this variation was maintained in the monetary value maps. We did not have sufficient data to also deal with the spatial variability in the monetary values, even though this is relevant for EA. For instance, the labor costs of rattan harvest increase with the distance from the river (since rattan has to be manually carried to the river side where it is loaded onto boats). Such enhanced details are highly relevant for the next steps in developing monetary ecosystem accounts. Third, by detailing the mapping units, through breaking down land-cover types into sub land-cover types (for carbon sequestration) and modelling habitat suitability (for orangutan habitat).

3.4.2. Challenges in valuation and integrating ES values in an accounting framework

Our study indicates a number of issues that require further research before a standardized approach to the mapping of ES values for the purpose of accounting can be developed:

Valuing perennial crops. The production of perennial crops such as oil palm depends on the age of the crop. The costs are high in the first years, and there is no revenue due to zero production. Building upon the SNA (2008), EC et al. (2009) suggest that the value of immature crops is attributed to the closeness to harvest, and considered to be work-in-progress (EC et al., 2009). The value of harvested crop is actually the accumulated value of the work-in-progress. This approach requires a comprehensive, multiyear analysis of crop production, which is in many cases based on estimates of how data can be broken down for individual years of the production cycle. In our approach, we analysed the value of oil palm production in 6 classes, but the overall approach to value perennial crops still needs to be further discussed and agreed upon in the EA community.

Valuing wildlife habitat. We explored an innovative approach in order to test if this is feasible for the valuation of habitat and to obtain an idea of the order of magnitude of the values resulting from this approach. We focus only on the value of wildlife habitat for one species, orangutan. Orangutan is an endangered species (IUCN, 2013), and is the only remaining Asian great ape that is distributed only in Borneo and Sumatera (Nelleman et al., 2007). Its status attracts global attention for preservation; this allows us to value orangutan habitat through the costs of the release program. However, there is a large variety of wildlife in Central Kalimantan, including many IUCN Red List species such as Malayan sun bear (*Helarctos malayanus*), gibbons (Hylobates sp), maroon leaf monkey (*Presbytis rubicunda*), Sunda pangolin (Manis javanica), Sunda slow loris (*Nycticebus coucang*), Horsfield's tarsier (*Tarsius bancanus*), and Great argus (*Argusianus argus*). Hence, our valuation – even though in principle aligned with the SNA valuation principles - grossly underestimates the value of wildlife habitat by not considering all these other species as well as the value of the ecosystems as a whole. No reintroduction programs exist for these other species in Kalimantan and it seems unlikely that there are ecosystems on the planet for which there are reintroduction programs for all or most species. Hence it appears as if our species-based approach would not be suitable for scaling up. A question is if the same valuation principle, valuing biodiversity through the costs of rehabilitation, could be deployed at the ecosystem scale, in other words if the costs of ecosystem rehabilitation programs could be used as an indication of the SNA-conform value of the biodiversity (including ecosystem, species and genetic diversity) contained in that ecosystem. This is certainly not correct from a welfare economics perspective (Jobstvogt et al., 2014; Zander et al., 2014), but the consistency of this approach with accounting principles deserves further attention (Turner et al., 2010; UN et al., 2014). For the time being, however, biodiversity accounts may need to be developed in physical units only, and suitable indicators for biodiversity such as species status, richness and abundance indices (Keeping, 2014; Shtilerman et al., 2014; Taft et al., 2014) need to be presented alongside monetary data from ecosystem accounts.

Integrating ESs values in an accounting framework. It is relatively straightforward to integrate values from timber, oil palm, rattan, rice, and recreation in an aggregate measure such as GDP as the benefits to which they contribute are already within scope of the SNA production boundary. EA allows us to separately identify these values and make the contribution of the ecosystem to economic activity visible. In case of carbon sequestration, the benefit lies outside the SNA production boundary and its valuation would lead to an adjustment of GDP (that is sometimes called a green(ed) GDP (Boyd and Banzhaf, 2007)). There is an ongoing development of green GDP in Indonesia as an indicator of sustainable development; this adjusted GDP involves the values of resource depletion, degradation and pollution (Gustami, 2012). Revealing resource depletion and degradation has always been an important motivation of EA development, particularly for resource-dependent countries (Repetto et al., 1989; Howarth and Faber, 2002). Implementing adjusted measures would be highly relevant for Central Kalimantan, where an adjustment could consist of both additions (e.g. carbon sequestration or habitat services) and deductions (due to either resource depletion or environmental degradation) in order to provide a more comprehensive insight in the costs and benefits of land-use change including the rapid spread of oil plantations in different soil types.

Environmental assets valuation. In national accounting as in micro-economics, environmental assets are valued on the basis of present and future returns generated by the assets (EC et al., 2009). Besides estimating a path of future returns, other key inputs required for calculating the net present value (NPV) are an estimation of asset life, and the selection of a discount rate (EC et al., 2009). Analysing the value of the environmental assets represented by different land-cover units on the basis of the expected flow of ESs (EC et al., 2013) is a next step in developing ecosystem accounts (Edens and Hein, 2013). Because we analysed the production of palm oil over the production cycle of the oil palm, we are able to provide the NPV of the asset 'oil palm plantation' following accounting conventions. We calculate the NPV for oil palm on mineral and peatland (Appendix 3.2). We used a production cycle of 20 years with a discount rate of 10% (equal to the interest rate we applied to calculate the user costs of fixed capital). Our analysis yields an environmental asset value of € 6,596 per hectare on mineral soil and € 4,393 on peat soil, resulting from the resource rent generated by the production of FFB. Our average NPV for Central Kalimantan falls within the range reported by Budidarsono et al. (2012), which is € 3,667 - € 24,583 at a discount rate of 8%, and by Butler et al. (2009), who report the NPV to vary between € 3,196 - € 8,025 at a discount rate of 10%. We carried out a sensitivity analysis for the discount rate used to analyse the value of palm oil production, using the discount rates of 8% and 12%. For mineral land, we find an NPV of € 8,792 per ha for a discount rate of 8%, and € 4,894 for a discount rate of 12% using the data in our model. For peat soil, these values are € 6,349 per ha for a discount rate of 8% and € 2,889 per ha for a discount rate of 12% respectively (see Appendix 3.2). These values demonstrate the sensitivity of the NPV to the discount rate.

Completing the ecosystem accounts. This study analyses how different ESs generated in Central Kalimantan province can be valued and mapped in a way that is in line with national accounts. There are a range of ESs in Central Kalimantan that this study does not cover, such as other crop production services (e.g. hevea rubber, vegetables), other non-timber forest products such as jelutung (*Dyera costulata*), aquaculture and fisheries, flood control, erosion control, cultural practices, and habitat for other species. This study provides an important basis for accounting for a broader set of ESs by exploring spatial patterns and valuation approaches. Nevertheless, further studies are required to develop an ecosystem account covering a more comprehensive suite of ESs, and to analyse the capacity of the ecosystem to generate services in both physical and monetary terms (EC et al., 2013), building upon this paper as well as Sumarga and Hein (2014). Key challenges include the development of suitable accounting methods for hydrological services, and other significant cultural services in Central Kalimantan such as cultural heritage, landscape beauty, and scientific and educational information, where the existing valuation approaches tend to focus on measuring consumer surplus (e.g. van Berkel and Verburg, 2014), hence they are not consistent with national accounting valuation principles.

3.4.3. Value trade-offs and policy implications

Central Kalimantan is one of few provinces in Indonesia that has not yet finalized its provincial land-use planning. The discussion on land-use planning in this province has been ongoing for about 11 years and started when the provincial spatial planning act (Provincial Legislation no 08, 2003) was first submitted to the central government for approval. The delay in approval is related to the conflicts of interests among the sectors depending on land, including the forestry sector, the agricultural and mining industries, and the district, provincial and central government (Galudra et al., 2011). A key issue pertains to the area designated as forests, in which any land conversion, including for oil palm plantations and mining, will be prohibited (Brockhaus et al., 2012).

Provided that valuation outcomes are robust and developed using a consistent approach, valuation allows analysis of value trade-offs related to land management. In the context of Central Kalimantan, the main land management issue is deforestation, particularly in relation to oil palm expansion. In the last decade, the deforestation and oil palm expansion rate in Central Kalimantan have been among the highest in Indonesia (Broich et al., 2011; Koh et al., 2011). In the period 2000-2010, about 933,000 ha of new oil palm plantation has been established, mostly by converting forests (514,000 ha) (analysed from changes in the land-cover map between 2000 and 2010, see Sumarga and Hein, 2014). The ES trade-offs as an implication of the conversion of forests into oil palm plantation are shown in Table 3.4.

Table 3.4 shows that conversion of peat forests into oil palm plantations results in a decrease in the overall value of the ES generated. Oil palm plantations require drainage of peatlands to a water table depth of 80 to 90 cm, resulting in carbon emissions of on average around 86 ton CO_2/ha/per year (Hooijer et al. 2010). This leads, for Central Kalimantan, to average annual societal costs of around € 2,042/ha/year. The costs of carbon emissions can be compared with the benefits of palm oil production in two ways. First, they can be compared in terms of the annual costs of the carbon emissions versus the as average resource rent over the lifetime of the palm oil plantation, which is € 1,094/ha/year (based on Appendix 3.2a). Second, they can be compared in terms of the NPV of the carbon emissions versus the NPV of the resource rent of the oil palm plantations. At a 10% private discount rate, the NPV of the oil palm on peat soil is € 4,393 per ha (for a 20 years discounting period). For an 8% discount rate the NPV is € 6,349, and for a 12% discount rate, it decreases to € 2,889 per ha. This NPV can be compared to the social costs of carbon emissions, recognizing the uncertainties in the marginal damage cost estimates of carbon emissions. Key sources of uncertainty in the social costs of carbon are the assumed damage costs resulting from climate change, the occurrence of low probability, high impact events, and the selected social discount rate (Guo et al., 2006; Tol, 2008; Nordhaus, 2011; Ackerman and Stanton, 2012). The SCC used in this study (€ 88/ton C; equivalent to € 24/ton CO_2) is an average value derived from three integrated assessment models: DICE, PAGE, and FUND based on a discount rate of 3% (Interagency Working Group on Social Cost of Carbon, United States Government, 2013). If the social discount rate is increased to 5%, the models indicate an average SCC of € 30/ton C (Interagency Working Group on Social Cost of Carbon, United States Government, 2013), which reduces the costs of carbon emission from oil palm on peatland to € 702/ha/year. At a 3% social discount rate, the NPV of the carbon emissions for one production cycle of the oil palm plantations (20 years) is € 32,422 per ha, and at a 5% social discount rate it is € 11,146 per ha.

Hence, for commonly used private discount rates (8 to 12%) and social discount rates (3 to 5%) we find that the social costs of carbon emissions of oil palm plantation on peat far exceed the private benefits of palm oil cultivation, even without considering the impacts of plantation establishment on other ESs (such as timber, NTFP and biodiversity). Our study confirms the recommendations of, among others, Wicke et al. (2008) and Hooijer et al. (2010) to stop further conversion of peat lands into oil palm plantations.

Note also that our study does not address long-term hydrological effects of peat drainage that include increased flood risks because much of the drained land will irreversibly subside in the coming decades (Hooijer et al., 2012) to a level where it is prone to frequent flooding making it impossible to continue growing oil palm. This may decrease the value of environmental assets in the coming decades. It is noteworthy that such long-term environmental trends, although very relevant for environmental management, are not sufficiently included in an ecosystem account. Follow up studies are required to further analyse asset value of oil palm development on peatland, particularly in relation to flood risk due to continuous soil subsidence. This points to the need to supplement ecosystem accounts with other types of information in order to have a sufficiently comprehensive basis for decision making on ecosystem use.

3.5. Conclusions

We valued and mapped seven ESs in Central Kalimantan aligned with the principles of national accounting, using resource rents and costs approaches as principal valuation methods. Our value maps show the substantial spatial variation in the values of ES even at the level of a province, clearly indicating that any approach aimed to scale up ES values needs to consider the spatial heterogeneity of ES. For the seven services that we selected, valuation following an accounting approach proved feasible, and we recommend further testing of the monetary valuation of ES in a range of different contexts in order to develop an EA approach to measuring and monitoring ecosystem capital. In terms of valuing biodiversity/habitat services, we show that there are potential approaches that can be applied to analyse the value of this service in a manner that is in principle consistent with accounting, but that data limitations will restrict valuation possibilities. Our case study demonstrates a major policy application of monetary value maps, i.e. supporting land use planning. We show that the conversion of Indonesian peat land to oil palm plantations is highly inefficient from a societal perspective: the societal costs, in particular those related to greenhouse gas emissions following peat drainage, far exceed the private benefits. We conclude that EA including monetary valuation of ES flows and ecosystem assets – once fully developed and standardized - is a highly promising approach to support more sustainable and efficient ecosystem management.

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4. BENEFITS AND COSTS OF OIL PALM EXPANSION IN CENTRAL KALIMANTAN, INDONESIA, UNDER DIFFERENT POLICY SCENARIOS

ABSTRACT

Deforestation and oil palm expansion in Central Kalimantan province are among the highest in Indonesia. This study examines the physical and monetary impacts of oil palm expansion in Central Kalimantan up to 2025 under three policy scenarios. Our modelling approach combines a spatial logistic regression model with a set of rules governing land use change as a function of the policy scenario. Our physical and monetary analyses include palm oil expansion and five other ecosystem services: timber, rattan, paddy rice, carbon sequestration, and orangutan habitat (the last service is analysed in physical units only). In monetary terms our analysis comprises the contribution of land and ecosystems to economic production, as measured according to the valuation approach of the System of National Accounts. We focus our analysis on government-owned land which covers around 97% of the province, and where the main policy issues are. We show that, in the business as usual scenario, the societal costs of carbon emissions and the loss of other ecosystem services far exceed the benefits from increased oil palm production. This is, in particular, related to the conversion of peatlands. We also show that, for Central Kalimantan, the moratorium scenario, which is modelled based on the moratorium currently in place in Indonesia, generates important economic benefits compared to the business as usual scenario. In the moratorium scenario, however, there is still conversion of forest to plantation and associated loss of ecosystem services. We developed an alternative, sustainable production scenario based on an ecosystem services approach, and show that this policy scenario leads to higher net social benefits including some more space for oil palm expansion.

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4.1. Introduction

Oil palm is the most rapidly expanding perennial crop in tropical countries (Phalan et al., 2013). Indonesia and Malaysia supply about 85 % of the world's palm oil production (RSPO, 2013). Oil palm development in Indonesia started in 1911 (Corley and Tinker, 2003) with a particularly rapid expansion in recent decades. In the period 2005-2010, oil palm plantations expanded at a rate of 514,000 ha per year and in 2010 the plantations covered 7.7 million ha (Gunarso et al., 2013).

Oil palm development in Indonesia has led to a number of environmental and social concerns (Sheil et al., 2009; Carlson et al., 2012; Hein and van der Meer, 2012). At least 56 % of oil palm expansion in Indonesia during the period 1990 – 2005 has involved the conversion of forests (Koh and Wilcove, 2008). Forest conversion, and in particular peat conversion, has led to high carbon (C) emissions, with emissions from land-use change making Indonesia the third largest greenhouse gas emitter on the planet (Germer and Sauerborn, 2008; Carlson et al., 2013). The conversion of forests has also initiated social problems (Rist et al., 2010; Obidzinski et al., 2012). This includes conflicts related to land ownership (Feintrenie et al. 2010) and restricted access to land resources, particularly for local people who traditionally utilize forest products for their daily life. Finally, forest conversion also leads to a loss of biodiversity (Wilcove and Koh, 2010). For example, in Indonesia the population of the orangutan (*Pongo spp*.) has declined substantially, in particular due to habitat loss (Nantha and Tisdell, 2008).

There have been various responses aimed at reducing the environmental and social issues associated with palm oil expansion. The Round-Table on Sustainable Palm Oil (RSPO) is an international response supported by a consortium of companies, NGOs and government agencies, and is resulting in increasing numbers of RSPO-certified plantations and mills that produce palm oil in a more responsible manner. In Indonesia, national instruments include regulations on the maximum peat depth that can be converted to oil palm cultivation (Ministry of Agriculture, 2009) and a temporary moratorium on the conversion of peatlands and primary forests (Indonesian President Instruction no. 10, 2011; Indonesian President Instruction no. 6, 2013). However, at the same time, continued oil palm expansion is promoted by the Ministry of Agriculture which targets an annual expansion rate of oil palm plantation of 2.55 % (Ministry of Agriculture, 2011). In view of the high global demand for palm oil products and the profitability of the crop, further expansion of oil palm plantations can be expected in the coming decades (Sheil et al., 2009; Miettinen et al., 2012; Sayer et al., 2012). In Indonesia, the government has also supported the Indonesian Sustainable Palm Oil (ISPO) that was established in 2011. A key factor in the Indonesian policy environment is the current moratorium on the conversion of certain types of forest land (in particular production forests) to other land uses such as oil palm plantations. The moratorium was first applied in 2011 and has been extended in 2013 (each time for two years). The discussion on extension of this moratorium is ongoing and has major repercussions for Indonesia's and even the planet's greenhouse gas emissions and biodiversity.

This study aims to model oil palm expansion in Central Kalimantan, Indonesia, and analyse its impact on the trade-offs of ecosystem services (ES). In addition to oil palm production, five other (ESs) are analysed: timber production, rattan production, paddy rice production, C sequestration, and habitat for orangutan, building upon earlier work that we conducted in this area (Sumarga and Hein, 2014). Central Kalimantan is selected for several reasons. First, deforestation and oil palm expansion rates in this province are one of the highest in Indonesia (Broich et al., 2011; Ministry of Agriculture, 2014). Comparison of land cover between 2000 and 2010 indicates that about 933,000 ha of new oil palms have been established during this period, 474,000 ha of which resulted from converting forests. Second, Central Kalimantan has extensive peatlands (about 3 million ha), with the deepest peat layer reaching 12 m (Wahyunanto et al., 2004). Draining peatlands for oil palm plantation significantly contributes to global C emissions. Third, Central Kalimantan provides a habitat to a little over half of the world's remaining wild orangutan, counting around 33,000 individuals distributed over 15 main populations (Wich et al., 2008). Deforestation in Kalimantan leads to an annual decline of 1.5% to 2 % in this population (Ministry of Forestry, 2007).

We apply a novel modelling approach by integrating inductive and deductive approaches which in most studies are applied separately (Kolb et al., 2013; Widener et al., 2013; Hu et al., 2014; Mas et al., 2014). An inductive approach to land-use modelling uses observed trends in land-use change to model land-use change (Aspinall, 2004; Mas et al., 2014). A deductive approach specifies social, economic or policy scenarios or defining rules of behaviour and interaction among agents of land-use change (Le et al., 2010; Ralha et al., 2013). We model the effects of three scenarios on ES supply: (i) a business as usual scenario; (ii) a moratorium scenario; and (iii) a sustainable production scenario, developed on the basis of an ES approach and two stakeholder workshops conducted in Central Kalimantan. Subsequently, we link land-use change to ESs, analysing the trade-off between oil palm expansion and other ESs. under different scenarios. Building upon previous work (Sumarga et al., 2015), we analyse the trade-offs in ES supply in monetary terms, using an ecosystem accounting approach (European Commission et al., 2013; Edens and Hein, 2013).

Our study contributes to reaching a better understanding of the environmental, social and economic impacts of palm oil expansion resulting from land-use change. In particular, our study provides a number of new insights in the costs and benefits of different environmental policy options, at the scale of Central Kalimantan province, with potential implications for the overall debate on the moratorium policy in Indonesia. Our work is also relevant for the sustainability discussions conducted in the context of the RSPO and ISPO, where impacts resulting from land-use change have been proven relatively difficult to tackle (Sheil et al., 2009).

4.2. Methods

4.2.1. Study area

Central Kalimantan is the third largest province in Indonesia covering 15,356,400 ha. The province has a moist tropical climate, and is located at latitude $0^o45'$ North – $3^o30'$ South and longitude $110^o45'$– $115^o50'$ East. The province has a total population of 2,1459,000 with an employment rate of 68 % in 2013. GDP per capita is about € 1,940 (Statistics Indonesia, 2014d) and agriculture is the main economic sector, with rice, oil palm and rubber as the main crops. In addition, mining (coal, gold) and tourism are increasingly important. A land-cover map of Central Kalimantan is presented in Figure 2.1.

4.2.2. Spatial modelling of oil palm expansion and its impacts on ESs

This study integrates three modelling parts: regression of the spatial pattern of oil palm expansion, land-use scenarios, and impacts of oil palm expansion on the trade-offs of ESs (Figure 4.1).

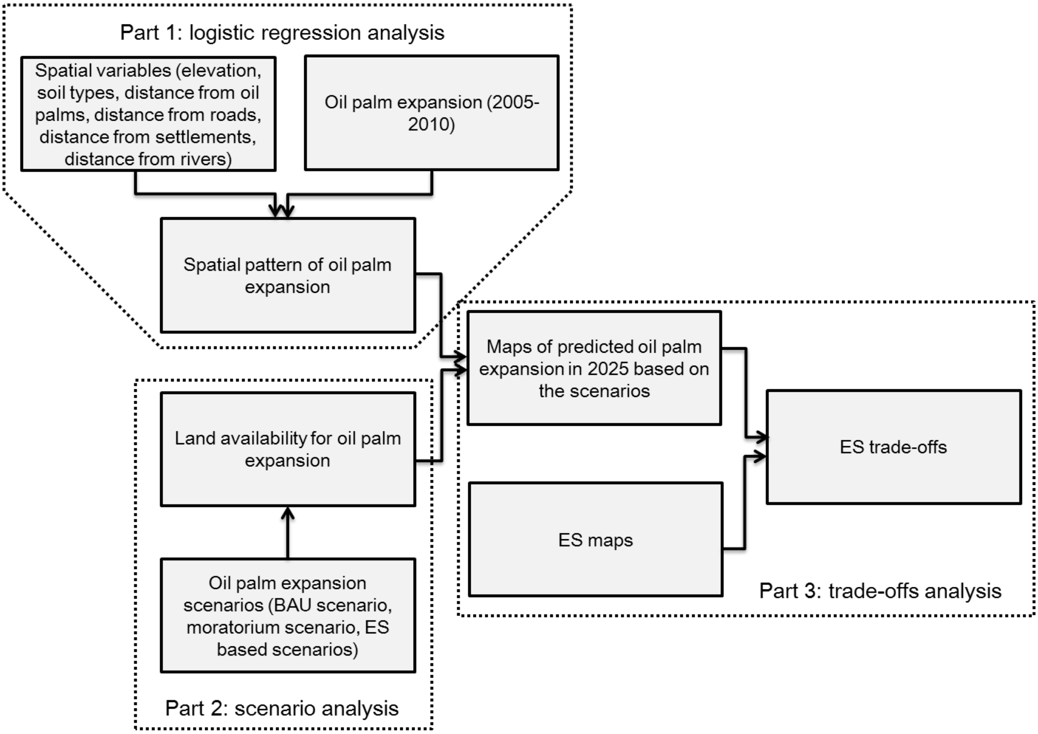


Figure 4.1. Framework for modelling oil palm expansion and its impact to ecosystem services

Spatial pattern of oil palm expansion

Considering the binary response variable (the presence and absence of oil palm expansion), we applied a logistic regression to model spatial patterns of oil palm expansion in the past (2005-2010), and used the model to predict oil palm expansion in 2015, 2020 and 2025. The general model for the logistic regression is given by Formula 4.1.

$$p = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots + \beta_i x_i)}} \qquad \text{(Formula 4.1)}$$

where:
p = presence probability (indicating conversion to oil palm)
$\beta_0, \beta_1, \ldots \beta_i$ = coefficients
$x_1, x_2, \ldots x_i$ = values of predictors

We first overlaid the land-cover map of 2005 with the map of 2010 to identify the oil palm expansion areas during that period. The land-cover map of 2010 is the most recent land-cover map that contains detailed information on oil palm distribution. Next, we randomly generated 1000 presence points within the expansion areas, and 1000 absence points outside the existing oil palm and the expansion areas. Random sampling is an unbiased sampling technique that ensures that each point has the same probability of being selected (see also Aspinall,, 2004 and van Gils et al., 2008 for random point generation). We related oil palm expansion to six predictors: elevation, soil types, distance to the existing oil palm areas (and thereby to oil palm mills), distance to roads, distance to rivers, and distance to settlements. We recognized the potential change of roads and settlements during 2010-2020, however, considering the difficulty of projecting new roads and settlements, we treated roads and settlements as static. All maps of the predictors are in raster format with a spatial resolution of 100 by 100 m. The predictors were selected to represent the physical factors that are often considered in the selection of new locations for oil palm plantations. We extracted the values of the six predictors in the selected presence and absence points, and ran the logistic regression. The logistic regression was run using the GLM method “R” with the binomial link family (Hastie and Pregibon, 1992). The model accuracy was approached by measuring the sensitivity, specificity, and Area Under ROC (Receiver Operating Characteristic) Curve (AUC), see Appendix 4.1b.

Land-use scenarios

We developed three land-use scenarios for the use of government land. Government land covers 97 % of Central Kalimantan and it is here where the main policy issues are. All forest land is government-owned in Central Kalimantan (as in Indonesia as a whole) and the government also owns the large majority of the peatlands (Central Kalimantan Forestry Service, 2013). Hence our study does not cover the conversion of privately-owned land, including agricultural land owned by smallholders, to oil palm. Since this type of land conversion in most cases does not lead to deforestation or drainage of peat, and since it does not lead to a loss of access of land to local stakeholders, the social costs of this kind of land-use change are usually small (and the economic benefits may be substantial, in particular if unproductive land is converted to oil palm) (e.g. Colchester et al., 2006). Note that, in Central Kalimantan (as well as in other parts of Indonesia), there are widespread agricultural settlements and encroachments on land that is officially classified as forests. These lands are included in our analysis, as they are government-owned.

Our first scenario is a **business as usual scenario (BAU)**. It is assumed that the moratorium is lifted per mid-2015, and oil palm expansion is allowed in all areas currently proposed by oil palm companies and located in "*Areal Penggunaan Lain*" (APL: 'other forest land'), including in primary forests and peatlands. APL is state land allocated to any use other than conservation forests, protected forests and production forests. Note that APL land may include good quality secondary or primary forests. The conversion of land classified as "production forests" is not allowed in this scenario, in line with government regulations (Indonesian Republic Law no 41, 1999).

In the second scenario, the **moratorium scenario (M),** we assume that the current forest conversion moratorium is extended to 2025. In this scenario, oil palm expansion in primary forests and peatlands is prohibited. The boundaries of primary forest are indicated in the 2010 land cover map of the Ministry of Forestry (Ministry of Forestry 2011 unpublished) and the boundaries of the peatlands are from Wahyunanto et al. (2004). Note that, in line with current practices, land that can be converted under the moratorium includes good quality secondary forest, as long as it is classified as APL land. Production forests cannot be converted in this scenario.

The third scenario is an alternative **'sustainable production' scenario (SP)**. This scenario was developed using an ES approach, building on inputs received during two stakeholder workshops conducted one each in two districts (West Kotawaringin and Kapuas) in February and March 2014. These stakeholder workshops were attended by 48 participants from both government agencies (Forestry, Agriculture, Environment, Planning, Development Economic, National Park) and non-government organizations (Orangutan Foundation International, Friends of National Parks Foundation, local community, journalist). These stakeholders indicated that the moratorium was not sufficient to arrest forest degradation, and that at the same time there is a need to better regulate oil palm expansion. They proposed to examine an approach where ESs would be integrated in the policy framework. In this scenario, both production and APL forest can be converted to oil palm plantations provided that: no primary forest or peatland is converted and no key ESs are lost. The latter has been interpreted by the researchers as prohibiting the conversion of (i) land used for timber production; (ii) rattan fields; (iii) croplands (illegally) established in forest land; (iv) forest land with a C content at least as high as in a mature palm oil plantation (i.e. 51 ton C/ha); and (v) orangutan habitat (as mapped in Sumarga and Hein 2014).

Impact of oil palm expansion on ES supply

The implications of the three scenarios for ES supply were analysed for the period 2015 – 2025. Given that there is no map indicating oil palm expansion in Central Kalimantan that is more recent than 2010, we mapped oil palm expansion during the period 2010 – 2015 using the logistic regression model under the moratorium policy that has been in place in the past years. We used the raster calculator of ArcMap 10.1 to apply the logistic regression model with the six layers of predictors as inputs. For the distance to existing oil palms predictor, we used oil palm distribution in 2010 as a reference. We overlaid this map with the map of land availability for oil palm expansion from the M scenario, resulting in the predicted areas of oil palm expansion during 2010 – 2015. We combined this map with the oil palm map of 2010 to generate the oil palm extension map of 2015, which was then used as a reference for predicting oil palm expansion in the period 2015-2020. To model the expansion up to 2020, we created the map with the distance to oil palm in 2015, and used it as one of the six predictors. We then overlaid the predicted expansion from the logistic regression model with the land availability from the three scenarios to generate the three corresponding maps indicating oil palm expansion up to 2020. We applied the same procedures to analyse oil palm expansion in the period 2020-2025 and map oil palm extent in 2025, for the three scenarios.

The trade-offs of ESs were analysed in terms of physical quantities and monetary values. We used the physical quantities and the monetary values derived from maps of ESs prepared by two previous studies (Sumarga and Hein, 2014; Sumarga et al., 2015) (see Table 4.1). Our monetary analysis uses the valuation approach of the national accounts (European Commission et al., 2009), in line with these previous studies. This valuation approach is based on exchange values and excludes consumer surplus (Edens and Hein, 2013; European Commission et al., 2013). We come back to the implications of our valuation approach in the Discussion section. As indicator for monetary value of timber, palm oil, rattan and rice we used the resource rent generated by the crop, reflecting the contribution of the ecosystem to the production of this crop, expressed on a per ha basis. The resource rent requires subtracting the costs of intermediate inputs and labour, and the user costs of fixed capital from the gross farm-gate revenues (see e.g. Edens and Hein, 2013). For the costs of C sequestration, we used the social costs of C from the US EPA (Interagency Working Group on Social Cost of Carbon, United States Government, 2013), with an exchange rate of $ 1.33 for € 1 (average in 2010). Orangutan habitat was not expressed in a monetary value in view of the difficulties in assigning a monetary value to biodiversity habitat (e.g. Sumarga et al., 2015). Note that the widely applied contingent valuation method (Loureiro and Ojea, 2008; Jacobsen et al., 2012) is incompatible with ecosystem accounting principles. Note that costs of land (and land concessions) are not included in the resource rent and the monetary assessment is net of taxes and subsidies. Hence, our valuation study provides an analysis of costs and benefits at the level of society, which includes state, companies and smallholders. Net benefits of land-use options for individual companies or smallholders may be lower (due to the costs of obtaining land, or taxes) or higher (in case of subsidies).

Table 4.1. Provincial averages of values for ecosystem services, values are presented in terms of physical quantities and monetary values

Ecosystem services	Provincial average	
	Physical quantity	Monetary value
Newly planted oil palm (0-4 years)	3.6 ton/ha/year[c]	Resource rent of € -646/ha/year (on mineral soil) and € -924/ha/year (on peat soil) reflecting costs for establishing the plantations[c]
FFB production of young oil palm (0-9 years)	15.2 ton/ha/year[c]	Resource rent of € 761/ha/year (on mineral soil) and € 509/ha/year (on peat soil)[c]
FFB production of mature oil palm (0-20 years)	24 ton/ha/year[c]	Resource rent of € 1,770/ha/year (on mineral soil) and € 1,571/ha/year (on peat soil)[c]
Timber production	0.86 m^3/ha/year[a]	Resource rent of € 35/m^3[b]
Rattan production	0.79 ton/ha/year[a, e]	Resource rent of €104/ton[b]
Paddy rice production	2.2 ton/ha/year[a]	Resource rent of € 130/ton[b]
Carbon sequestration	Detailed information in Appendix 4.3	a Social cost of C of € 88/ton C[b]
Orangutan habitat	Habitat suitability map of orangutan[a]	Not assessed[d]

[a] Sumarga and Hein (2014) / [b] Sumarga et al. (2015)/[c] Sumarga et al. (2015) with an assumed increase of productivity of 20%, the negative resource rent reflect the costs of establishing the oil palm plantations including costs for land preparation, planting and plantation maintenance / [d] not assessed due to methodological difficulties, see explanation in the text / [e] rattans, dominated by *Calamus manan* and *Calamus caesius*, are planted in secondary forest with a typical maximum distance of 25 km from settlements and 4 km from rivers.

We assumed a constant productivity for timber, rattan and paddy rice in all years of the analysis. For oil palm, we assumed that new varieties of oil palm with a higher productivity will gradually be introduced, reaching an average productivity of 24 ton fresh fruit brunch (FFB)/ha/year (Indonesian Oil Palm Research Institute, 2015) in mature oil plants for newly planted oil palms in 2025. This productivity is about 20 % higher than the current average productivity. Finally, we assume constant prices for crop inputs (labour, equipment, intermediate inputs) and crop prices. This, of course, is a major simplification that causes some uncertainty in our results. However, meaningful forecasts of price changes in these factors are not available.

4.3. Results

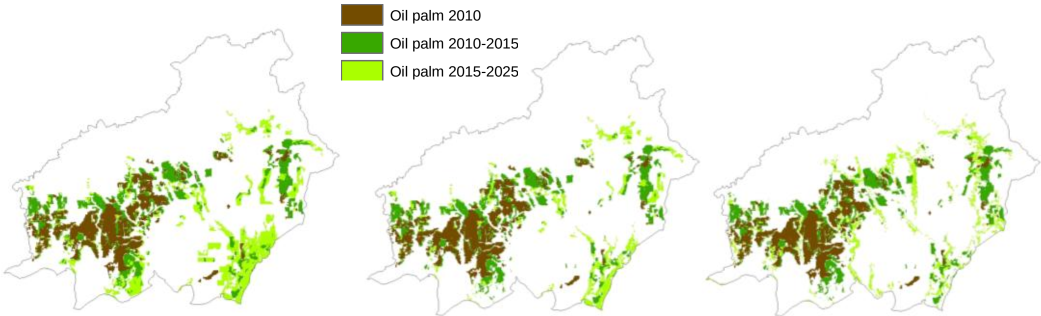
4.3.1. Logistic regression model

The coefficients of the logistic regression model are: intercept (2.76), elevation (-1.685e-02), distance to roads (-9.477e-06), distance to rivers (1.048e-04), distance to settlements (-

6.139e-05), distance to existing oil palm (-3.572e-05) and peat soil (-6.432e-01), see Appendix 4.1a for detailed information. With the full model (all variables are included), the coefficients indicate that the areas with a low elevation, close to roads, close to settlements, close to existing oil palm plantations, and mineral soil are preferred for the expansion. The model provides a high spatial accuracy with a sensitivity of 0.89, a specificity of 0.79, and an AUC of 0.9 (see Appendix 4.1b for the explanations).

4.3.2. Areas planted with oil palm in 2025

Maps of oil palm expansion up to 2025 are presented in Figure 4.2. In the BAU scenario, the predicted new oil palm area during the period 2015 – 2025 is 1,233,900 ha. In the SP scenario, about 698,700 ha of new oil palm areas will be planted in that period. The M scenario provides the lowest estimate, i.e. 637,800 ha newly planted oil palm. The M scenario gives a lower estimate of expansion areas than the SP scenario since state land with status as “Production forest”, even if it is degraded, cannot be converted in the M scenario, but this type of land can be converted in the SP scenario.



a. the BAU scenario b. the M scenario c. the SP scenario

Figure 4.2. Oil palm expansion according to three scenarios: the BAU, M, SP scenarios (see section 4.2.2 for descriptions of the scenarios).

There has been an exponential growth of oil palm areas in Central Kalimantan from 257,000 ha in 2000 to 394,000 ha in 2005 and 1,200,000 ha in 2010. Our model forecasts strong oil palm expansion continuing in the period 2015 – 2020, in particular in case of the BAU scenario. This growth would, in all three scenarios, level off in the period 2020 – 2025 (see Appendix 4.2). The main reason for this is that only limited land remains available for oil palm expansion in this period, depending upon the regulations (and enforcement of these regulations) that drive land-use change.

4.3.3. Impact of oil palm expansion on ES supply

Trade-offs in ES supply from oil palm expansion are influenced by three main factors: the rate of land-use change, the land cover of the converted areas, and the soil types of the converted areas (mineral or peat). Acreage converted, and land-cover and soil types of the converted areas determine the types, quantities, and values of ESs that will be lost due to land-use change. The C balance is influenced, in particular, by the amount of forests and peatlands converted to oil palm (see Appendix 4.3). The results of our analysis, for the three scenarios, are summarized in Table 4.2, with detailed calculations presented in Appendices 4.4a – 4.4c.

Table 2. Trade-offs in ecosystem services supply from oil palm expansion in different scenarios for the period 2015 - 2025, negative values indicate depletions of ecosystem services both in terms of physical quantities and monetary values, values are rounded. Mton indicates million metric ton.

Ecosystem services	BAU scenario		Moratorium scenario		SP scenario	
	Physical quantity	Monetary value	Physical quantity	Monetary value	Physical quantity	Monetary value
FFB production of oil palm	17.3 Mton/ year	€ 627.4 million/year	8.8 Mton/ year	€ 377.5 million/year	10 Mton/ year	€ 463.7 million/year
Timber production	- 0.31 mega m^3/year	- € 10.9 million/year	- 0.18 mega m^3/year	- € 6.3 million/year	No change	No change
Rattan production	- 0.34 Mton/ year	- € 35.2 million/year	- 0.3 Mton/ year	- € 32.0 million/year	No change	No change
Paddy rice production	- 0.49 Mton/ year	- € 63.8 million/year	- 0.27 Mton/year	- € 35.2 million/year	No change	No change
Carbon sequestration	- 16.7 Mton C/year	- € 1,466 million/year	- 0.9 Mton C/year	- € 80.0 million/year	1 Mton C/ year	€ 92.2 million/year
Orangutan habitat	- 102,000 ha		- 10,000 ha		No change	

In the BAU scenario, 450,000 ha of forests, 428,000 ha of rattan field (mostly in forests), and 223,000 ha of paddy rice areas are estimated to be converted to new oil palm plantations in the period 2015 – 2025. The model forecasts that oil palm expansion will take place in about 541,000 ha of peatlands, covering 215,000 ha of forests and 326,000 ha of non-forest areas, and replace about 102,000 ha of orangutan habitat. This can be classified as a substantial impact, considering that this would lead to a loss of close to 10% of the current habitat in this province, and that Central Kalimantan contains over half of the global orangutan population. The effects on ES supply are summarized in Table 4.2. This scenario provides the highest increase of monetary value from oil palm production, but on the other hand leads to the highest social costs, in particular, from C emission (and orangutan habitat). Overall, in this scenario the societal costs (an aggregate value of € 1.5 billion/year from carbon emissions and the loss of production of timber, rattan, and paddy rice) far exceed the societal benefits (a value of € 627 million/year from the increase of oil palm production).

In the M scenario, 212,000 ha of forests, 390,000 ha of rattan field, and 123,000 ha of paddy rice areas will be converted to oil palm plantations. The expansion will replace about 10,000 ha of orangutan habitat. This scenario leads to the lowest increase of oil palm production. Since oil palm expansion on peatlands is not allowed in this scenario, the net C emissions from this scenario are much lower than the emissions in the BAU scenario. This scenario has an overall net societal benefit; the benefits from expansion of palm oil production (€ 377 million/year) exceed the costs related to a loss of other ES (€ 153 million/year).

In the SP scenario, oil palm expansion will only take place in degraded lands with mineral soils. Hence there will be no change in forested areas, rattan field, paddy rice areas, and orangutan habitat. This scenario provides a positive net C balance, because C storage in oil palm plantations exceeds C storage in degraded lands and no peatland is allowed to be converted. Compared to other scenarios, the SP scenario provides the highest net monetary value, which is € 556 million with no degradation of the areas currently suitable for orangutan habitat.

4.4. Discussion

4.4.1. Modelling approach

There are a wide range of approaches to model land-use change (Overmars et al., 2007; Pontius Jr. et al., 2008; Gutzler et al., 2015). Selection of the appropriate modelling approach needs to be based on the specific research objectives, the physical characteristics of the landscape and the ESs it supplies, the scale of the analysis, the key drivers for land-use change and (spatial) data availability. Our approach integrates deductive and inductive modelling elements and integrates both spatial predictors and policy scenarios in the model. In the case of oil palm expansion in Indonesia, both aspects need to be considered because the expansion is driven by a combination of physical, social, and political factors (McCarthy and Cramb, 2009).

Our model examines only the conversion of land to oil palm (contrary to more generally applicable land-use models such as for instance CLUE-S, see Verburg and Overmars, 2007). Instead of analysing demand for different land uses, and the relative suitability of each pixel to fulfil that demand, our model only predicts the probability of an area (pixel) to be converted into oil palm, with time steps of five years. For modelling a specific type of land-use conversion (in our case conversion to oil palm), we believe our model is a suitable alternative to other modelling approaches, because it allows using both scenarios and a comprehensive set of variables to predict land-use change and because the significance of each variable can be retrieved. In addition, our model does not require the prior definition of land demand (i.e. the demand for specific types of land use) as a driver for land-use change. In the case of oil palm expansion, such land demand would be very difficult to estimate, given the global market for oil palm and the wide range of potential areas that can be used for oil palm across the globe.

In spite of the wide attention that land-use change from oil palm expansion received, there are few other studies with which we can compare our results. Carlson et al. (2013) provide estimates of oil palm expansion in the whole of Kalimantan in 2020 based on three scenarios: a BAU scenario, a peatland protection scenario, and a forest protection scenario. By using the extent of oil palm plantations in 2010 as a baseline, they estimated that oil palm areas in 2020 will increase with about a factor 3.7 in the BAU scenario, a factor 3.1 in the peatland protection scenario, and a factor 1.9 in the forest protection scenario. Their BAU forecast is somewhat higher than the estimate of the BAU scenario in our study (in our BAU scenario, the area covered by oil palm in 2020 is about a factor 2.9 higher than in 2010). Our other scenarios (M, SP) result in an expansion of oil palm plantations (between 2010 and 2020) within the range specified by the two environmental protection scenarios of Carlson et al. (2013): an increase with a factor of 2.4 and 2.5 for respectively the M and the SP scenarios. Note that the difference between the amount of ha converted in both the M and SP scenario is small, but there is a difference in the specific areas that are converted (see Figure 4.1).

4.4.2. Scenario comparison and policy implications

Oil palm development brings both significant societal benefits and costs. For example, oil palm production can be a major driver for local and national economic development and the crop generates substantial export value (Koh and Wilcove, 2007; Obidzinsky et al., 2012). It can also increase local employment opportunities and allow local smallholder farmers to benefit from improved infrastructure (such as the presence of oil palm mills) (Sandker et al., 2007). On the other hand, the rapid and often uncontrolled expansion of oil palm plantations in Indonesia is causing costs to society related to a loss of access to land for local people, pressure on infrastructure (in particular from trucks transporting CPO) and environmental impacts. This study only examines societal costs of the environmental impacts related to land-use change, including C emissions, loss of timber and non-timber forest production, loss of cropland, and biodiversity habitat loss.

A main challenge for Indonesian policy makers and government officials is to facilitate the expansion of oil palm while minimising the social and environmental costs, as also discussed in the context of the RSPO and ISPO. The RSPO criteria are relatively effective in enhancing social and environmental management in plantations (e.g. regulate pesticide use), and also include several simple criteria to discourage negative effects from land-use change, in particular a ban on establishing plantations in primary forest. However, from a land management perspective the criteria are not yet adequate, since (i) very little primary forests remain, and the conversion of good quality secondary forests also brings significant environmental costs such as biodiversity loss, habitat destruction, and C emissions; (ii) the conversion of shallow or deep peat is not restricted by the RSPO criteria; and (iii) the effects of land-use change are determined by the aggregate effect of individual land conversions (and the spatial pattern of such conversions) and are therefore difficult to assess or mitigate at the level of individual plantations. Hence, government intervention remains essential for an effective regulation of palm oil expansion. Moving towards better regulation requires a significant effort from the side of the Indonesian government including enhanced land-use planning, continuous development and improvement of regulations for land management and land conversion, monitoring of land-use change, and enforcement of the regulations (Wicke et al., 2011; Smit et al., 2013; Lee et al., 2014).

Our scenario analysis may provide useful information for land-use planning, since it compares the potential societal benefits (from palm oil expansion) and the societal costs (due to selected environmental impacts) in different policy scenarios. We show that, in the case of Central Kalimantan, the moratorium has important economic benefits for society at large. The benefits of the moratorium, in particular from reduced CO_2 emissions, far outweigh costs of foregone oil palm expansion. We also show that the most important environmental issue with regards to land conversion to oil palm plantations is the conversion of peat, where the impacts of CO_2 emissions are largest and also many other ESs including biodiversity habitat are located. Note, however, that our comparison is incomplete: we do not assess social costs (loss of access to land, social changes in society, etc.) and benefits (local employment opportunities) and associated economic costs (impacts on infrastructure from CPO trucking) and benefits (multiplier effects resulting from local economic development). In addition, we only analyse selected ESs. Our analysis does not include for instance the growth of other (agroforestry) crops on mineral or peat soil (e.g. jelutung, *Dyera costulata*), tourism and recreation, fisheries and aquaculture (which is an important economic activity in Central Kalimantan including in lakes and rivers in peatlands, see van Beukering et al. (2008) and Suyanto et al. (2009)), biodiversity other than orangutan habitat, or the impacts of oil palm plantations or mills on water pollution. We also do not consider price changes in ESs. A continuing rapid expansion of oil palm, at the rates experienced in the past years in Indonesia, as well as increasing production in other countries such as Colombia could lead to lower prices for palm oil in the future, whereas prices of other ecosystem products such as timber and rattan may increase over time due to increasing scarcity. In this case, the relative benefits from other services, and the societal costs in the BAU scenario, would be underestimated in our study.

In addition, our study does not consider the effects of the drainage of peatlands. Drainage (of at least 80 to 90 cm) is required to grow oil palm in peat soils which leads to soil subsidence in the order of 3 to 5 cm per year (substantially more in the first year following drainage) (Wösten et al., 2008; Hooijer et al., 2012). Over time, this will affect water flows and flood risks, and it may well render the peatland unsuitable for oil palm in the course of one to several decades because rain or river water accumulates in the drained peatlands which have become the lowest-lying areas in the landscapes. This omission also means that we are very likely to overestimate the net benefits of oil palm plantations and to underestimate the benefits from other land uses, in particular in the peatlands.

We compared trade-offs in ES supply between the three policy scenarios (Table 4.2) using an accounting approach to value ESs (European Commission et al., 2013). In particular, this approach measures the value of the contributions of ecosystems to economic activity (including consumption and production) in an approach that is applicable at aggregated scales such as the whole of Central Kalimantan province (Edens and Hein, 2013; Obst and Vardon, 2014). However, since this approach excludes consumer surplus, we underestimate the total economic value generated by ecosystems in the province, such as the value accruing to consumers of palm oil or rice because of a lower price compared to a situation with less oil palm production in Central Kalimantan (which provides 11 % of the national oil palm production and 1.2 % of the national rice production). Our study indicates that the costs of C emissions alone substantially exceed the benefits of oil palm expansion in the BAU scenario. The other ESs (and the aspects not monetised such as habitat loss and other ESs that we did not consider in our study) point to this scenario being the least preferred from the perspective of society at large. A critical point is, however, that the costs of C emission are not directly paid by the emitter. Costs are born over the longer term, by all countries that will face the impacts of climate change (including Indonesia which has a high population density in its low-lying coastal zones). This, again, points to the need to establish markets for C, as well as to the need to prioritise the protection of peatlands from drainage (Agrawal et al., 2011; Hooijer et al., 2012).

The moratorium, in our analysis, is not able to arrest the conversion of well-preserved secondary forest to other land uses such as oil palm. This explains the CO_2 emissions that still take place in the M scenario, which includes the conversion of 212,000 ha of forest land to oil palm. The converted forest in this scenario has a C storage more than 100 ton C/ha and represents well preserved secondary forest with potentially the capacity to return to full forest cover. Still, the M scenario is a lot better than the BAU scenario with a positive economic impact for society at large. From a social planner perspective, SP is the preferred scenario. This scenario leads to minimal impacts on ESs, an important expansion of oil palm, and a net increase of C storage. An important consideration, however, is that enforcement of policies is critical, and that further work is needed to examine how an SP scenario could be enforced given that there are few maps of ES supply in the province and that enforcement has often proven to be complex in the Indonesian policy context (Sayer et al. 2012). It is also important to consider that such a policy scenario may lead to the perverse incentive of degrading forest so as to reduce ES supply and facilitate obtaining a license for land-use conversion.

4.5. Conclusion

We modelled oil palm expansion in Central Kalimantan and analysed its effects on the supply of ESs in three scenarios: a business as usual , moratorium, and sustainable production scenario. We analysed the effects of land-use change on six ESs: oil palm, timber, rattan, paddy rice, C sequestration, and orangutan habitat, and we analysed these effects in both physical quantities and monetary values. We modelled land-use change based on an integrated inductive and deductive approach that combines a spatial logistic regression model with a set of rules governing land-use change as a function of the policy scenario. Our study shows that in all scenarios there will be a continued rapid increase in oil palm production in Central Kalimantan. In the case of the BAU scenario, however, this expansion would lead to substantial net costs to society resulting from a loss of ESs and in particular C emissions. Continuation of the moratorium leads to a positive net benefit for society. However, there is still a conversion of forest, even with this moratorium in place. A sustainable production scenario, that was developed using inputs from two stakeholder workshops, provides for an alternative – although difficult to enforce – policy scenario. In this scenario, land-use change is restricted to areas where impacts on ESs would be minimal, and this would have the highest net societal benefits.

Acknowledgements

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5. HYDROLOGICAL AND ECONOMIC IMPACTS OF OIL PALM CULTIVATION IN INDONESIAN PEATLANDS

ABSTRACT

Oil palm has increasingly been established on peatlands throughout Indonesia. One of the concerns is that the drainage required for cultivating oil palm in peatlands leads to soil subsidence potentially increasing future flood risks. This study analyses the hydrological and economic impacts of oil palm production in a peat landscape in Central Kalimantan. We examine two land use scenarios, one involving conversion of the complete landscape including a large peat area to oil palm plantations, and another involving mixed land use including oil palm plantations, Jelutung (jungle rubber) plantations, and natural forest. The hydrological impact is analyzed through flood risk modeling using a high resolution DEM. For the economic analysis, we analyze four ecosystem services: oil palm production, Jelutung production, carbon sequestration, and orangutan habitat. This study shows that after 100 years, in the oil palm scenario, about 67% of peat in the study area will be subject to regular flooding. The flood-prone area will be unsuitable for oil palm and other crops requiring drained soils. The oil palm scenario is the most profitable only in the short term and when the externalities of oil palm production (i.e. the costs of CO_2 emissions) are not considered. The social costs of carbon emissions exceed the private benefits from oil palm plantations in peat. Depending upon the local hydrology, income from Jelutung (that can sustainably be grown in un-drained conditions and does not lead to soil subsidence) outweighs that from oil palm after several decades. These findings illustrate the trade-offs faced at present in Indonesian peatland management, and point to economic advantages of an approach that involves expansion of oil palm on mineral lands while conserving natural peat forests and using degraded peat for crops that do not require drainage.

Modified from:

Sumarga, E., Hein, L., Hooijer, A., Vernimmen, R. Hydrological and economic impacts of oil palm cultivation in Indonesian peatlands (submitted to Ecology and Society).

5.1. Introduction

Indonesian peatlands are subject to rapid land-cover change with significant national and global implications. Indonesia counts around 20 million ha of peatlands (Wahyunto et al., 2004; Page and Banks, 2007) and over half of this area has been converted or degraded (Miettinen et al., 2012). Conversion of peatlands to, in particular, oil palm and *Acacia* plantations is still ongoing (Gunarso et al., 2013). The environmental impacts of peat degradation and conversion have been published in a range of studies (Hooijer et al., 2012; Schrier-Uijl, 2013; Varkkey 2013). One of the concerns is that most plantation crops including oil palm and *Acacia* require drainage, affecting water levels not only in converted areas but also in surrounding peatlands (DID Sarawak, 2001, Hooijer et al., 2012). Drainage of peat leads to high CO_2 emissions; in degraded peatland that was drained but not converted to agriculture, carbon losses up to 463 t C/ha in the first 15 years following drainage have been reported by Hooijer et al. (2014); emissions are higher in agricultural areas that have lower water tables. In addition, drained and degraded peatlands burn on a regular basis, causing air pollution and smog at distances of 100s of kilometers (He et al., 2010). The degradation of peatlands also has important consequences for biodiversity, with most of the last refugia for, for instance, orangutan found in the remaining peat forests (Yule, 2010; Posa et al,. 2011). Finally, a range of social issues have been reported in relation to the large scale conversion of peat areas to plantations (Obidzinski et al., 2012, Schrier-Uijl, 2013).

An aspect of peat conversion that has received less attention to date, at least in an Indonesian context, is that peat drainage leads to soil subsidence. Peat consists of some 90% water and drainage leads to compaction of peat, causing a subsidence of typically between 1 and 1.5 meter in the first years after drainage. Subsequently, drained peat will oxidize, causing subsidence due to a loss of organic matter by 3 to 5 cm per year (Wösten et al., 1997; Hooijer et al., 2012; Couwenberg and Hooijer, 2013). These processes occur world-wide in peat and have been described in a range of publications (Gambolati et al., 2006, Leifeld et al., 2011, Pronger et al., 2014). Tropical countries experience higher oxidation rates than temperate countries since the oxidation rate increases with temperature (Andriesse, 1988, Couwenberg et al., 2010, Hooijer et al., 2014). Drained peatlands are, over time, likely to become subject to flooding, either by inflow of river or sea water, or from rainwater that cannot be easily discharged from the area by gravity because gradients are too low. As soon as peat is prone to floods, it becomes less suitable or, depending upon drainage levels, unsuitable for growing either oil palm or *Acacia*. Technically, it is possible to pump excess water out of the plantations once surface gradients have become too low for gravity drainage but this involves very high costs compared to the revenues from agricultural land uses (Roggeri, 1995, Lim et al., 2012).

The last years have seen an increasing conversion of peatlands to plantations, in particular oil palm. There is currently a discussion in Indonesia on promoting biofuel production using palm oil, which could further increase land-use change in peatlands. The hydrological and long-term economic impacts of current peat management practices appear to be insufficiently considered in this debate. The effects of peat soil subsidence are going to be very large for Indonesia, potentially rendering millions of ha of land unproductive in the country. However, studies of the issue are scarce, which may be related to a lack of reliable data, for instance on peat surface elevation and thickness and land use in peat areas. Moreover, the most severe impacts of peat subsidence will occur in a time frame of several decades up to a century, perhaps leading to the perception that this is not an urgent issue. However, peat subsidence is irreversible and decisions on land use made today will have consequences for many decades.

The objective of this paper is to examine the effects of peat subsidence on the potential of land to sustain ecosystem services (ESs) including palm oil production. We study part of the Ex-Mega Rice Project (EMRP) area: a large, failed agricultural development project in Central Kalimantan, for which detailed elevation, peat and economic data are available. We analyze peat elevation, subsidence and flood risks at present and in the future as a function of land management taking a long-term (up to 100 years) perspective. We develop two scenarios to compare different management options: (i) conversion of the whole area to oil palm plantations involving drainage of all the peatlands in the area; (ii) a mixed land-use scenario involving protection of currently remaining peat forests, oil palm on mineral land and in areas that are currently intensively drained, and Jelutung (*Dyera* spp.) plantation forest on the rest of peatlands. We select the first scenario to elicit the potential impacts of the main type of land-use change ongoing in Kalimantan's peatlands at present, the conversion of peatlands to estate crops requiring drainage, in particular oil palm. Oil palm represents one of the most profitable land uses on peat (Sheil et al., 2009) and applications for new licenses to grow oil palm cover an extensive part of Indonesia including many peat areas (Murdiyarso et al., 2011). We base our second scenario on a detailed land-use planning study that was undertaken in the case study area in the period 2007 to 2008, using Jelutung as one of the most profitable species that can be grown on un-drained peat (Poesie et al., 2011; Budiningsih and Effendi, 2013). We include both private (crop production) and social benefits (orangutan habitat and reduced carbon emissions) in the cost benefit comparison and specifically study the long-term effects of peat subsidence following drainage and how this will affect the costs and benefits of land use in the two scenarios. We acknowledge that we only include part of the overall costs and benefits of land-use change in our analysis, and we come back on the simplifications of our valuation approach in the Discussion section.

This work complements previous work where we looked at impacts of land-use change in peatlands on ecosystem services supply but did not yet examine the effects of soil subsidence (Sumarga and Hein, 2014; Sumarga et al., 2015; Sumarga and Hein, 2015). Our results are innovative in their integration of a flooding model for tropical peatlands with an economic analysis, focusing on an important but insufficiently studied type of land-use change. The paper elicits the difficulties of maintaining production over the long-term in drained peat areas and has important consequences for today's choices on land use in peatlands.

5.2. Methods

5.2.1. Study area

Our case study area covers 'Block A' and 'Block B' of the EMRP area in Central Kalimantan, in total about 490,000 ha, of which 62% is peatland. The Mega Rice Project was initiated in 1995 to convert about one million ha of peat and lowland swamp forest into paddy rice cultivation. The project was formally terminated in 1999 in recognition of the difficulties associated with promoting rice production in the infertile and difficult to manage soils in the area. The area has been mostly deforested now, and most of the peat is drained by canals, and subject to frequent fires (van der Meer and Ibie, 2009). Figure 5.1 presents the location and forest coverage of Block A and Block B of the EMRP.

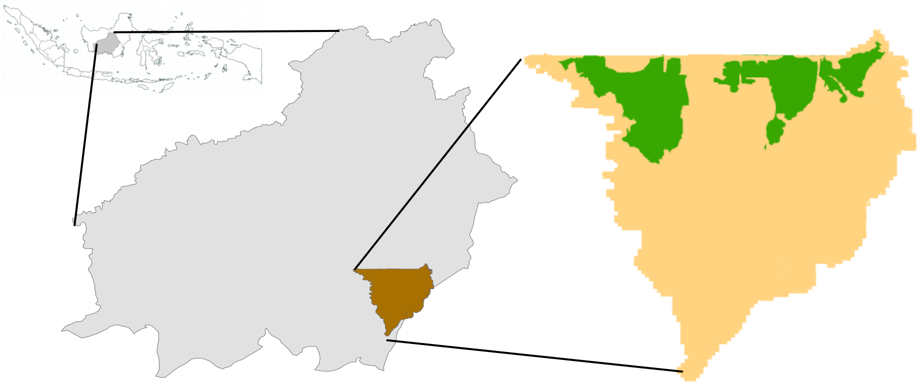

Figure 5.1. Block A and Block B of the EMRP and their forests coverage (green). The forest area was derived from the 2010 land-cover map of the Indonesian Ministry of Forestry.

5.2.2. Scenarios

We compare two scenarios to assess different management options: (i) conversion of the whole area to oil palm plantations involving drainage of all the peatlands in the area; (ii) a mixed land-use scenario involving protection of currently remaining peat forests, oil palm on mineral land and in areas that are currently intensively drained, and Jelutung plantation forest on the remaining peat area. There are at present no forests left on mineral soil in the study area. The two scenarios are described in more detail below. Given the availability of detailed hydrological and land-cover baseline data for 2011, we use 2011 as the base year of our study, even though in 2011 only a relatively small area, i.e. about 10,000 ha (2%) in the case study area was converted to oil palm. We also use 2011 prices throughout the paper.

Oil palm ('OP') scenario

This scenario assumes that all peatlands, including the remaining natural peat forests, will be converted to oil palm plantation. All peat areas that are not yet drained will be drained to facilitate oil palm cultivation. All peat areas will be subject to subsidence, as explained in the next section, and over time production of oil palm fruits will decrease with increasing flood risks in the plantations on peat. On mineral lands, we assume oil palm production can continue without being affected by an increase in floods. There are two potential causes of floods: floods caused by high water levels in rivers outside the plantation, and inundation caused by heavy rainfall inside the plantation. Both types of flood are amplified by land subsidence: the former because the area is progressively subsiding below high river water level, and the latter because the natural discharge of the rainfall is reduced as canal gradients decrease. We assume that flood control to mitigate flood risks is not economically feasible when drainage by gravity alone no longer suffices. We come back on this assumption in the Discussion section.

Mixed land-use scenario ('MIX' scenario)

This scenario assumes that the remaining natural peat forests will be maintained, and oil palm will only be established in mineral soils and in currently heavily drained areas. The remaining peat area is developed into Jelutung plantation forest, producing timber and latex. We base this scenario on a detailed land-use planning study that was undertaken in the case study area in the period 2007 to 2008, involving an elaborate analysis of land suitability and land-use options to balance production and sustainability concerns in the land use of the EMRP area (Euroconsult Mott MacDonald and Deltares, 2008). A range of paludiculture crops can be grown in the peat, but for reasons of simplicity we select Jelutung for our scenario analysis. Jelutung is one of the most profitable species that can be grown on un-drained peat (Poesie et al., 2011), and it is locally grown and marketed in the case study area (Budiningsih and Effendi, 2013). We assume that Jelutung can be grown in un-drained conditions, which may require making small ridges or mounds for the plants when planted in the wettest areas (van Wijk, 1950). However, under conditions of near-permanent inundation (more than 6 months per year), Jelutung cultivation would in the long term no longer be possible because seedlings cannot survive anymore. In recognition of Central Kalimantan's importance for the orangutan (around 50% of the remaining global population of wild orangutan occurs in this province) and the presence of an orangutan release area managed by the NGO Borneo Orangutan Survival Foundation in this area we also consider orangutan habitat as an ES provided by the remaining forests in the area. In the second scenario we assume, based on the aforementioned land-use plan, that outside of the peat areas that are now intensively drained and would be converted to palm oil, no further peat subsidence or increase in flood risks takes place. The land-use map of this scenario, derived from the 2010 land-cover map of the Indonesian Ministry of Forestry and the master plan for the rehabilitation of the EMRP, is presented in Figure 5.2.

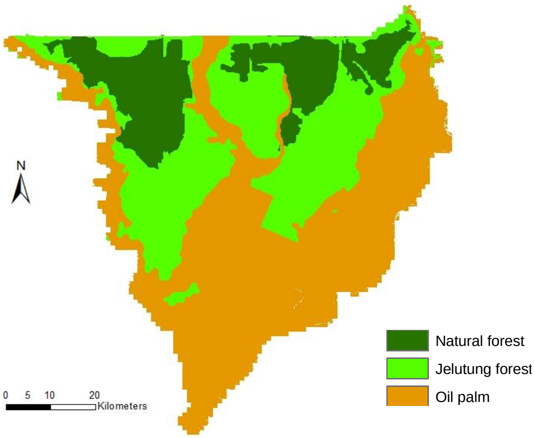

Figure 5.2. Land-use map of the 'MIX' scenario, derived from the spatial zoning of master plan for the rehabilitation and revitalization of the EMRP area (Euroconsult Mott MacDonald and Deltares, 2008).

5.2.3. Flood risk modeling

A Digital Elevation Model (DEM) was created using airborne LiDAR data collected in Central Kalimantan in 2011 from which the minimum value in a 25 m window was selected as representing the peat surface (Figure 5.3). The peat extent was derived from the Puslitanak map of 2004 (Wahyunto et al., 2004). The availability of this data makes it possible to create subsidence/flood risk models for the area by applying subsidence rates known from literature.

We developed a flood-risk model for the Block A and B peatland in EMRP area, which includes (parts of) three separate peat domes, assuming that the area is fully developed into oil palm plantations and drained, by the year of 2011 (for which we have elevation and land-cover data). Flood risks were modeled annually for 125 years (six production cycles of oil palm production; Fairhurst and McLaughlin 2009) by taking into account three different drainage limits. Around 60 to 70% of the area has been drained already by 2015, as a consequence of the construction of canals in the area in the 1990s (Figure 5.4). These canals were dug originally to assist with water management for agricultural purposes. The MRP aimed to grow over a million ha of rice, but this failed due to a combination of peat soil not being suitable, fires, and flooding.

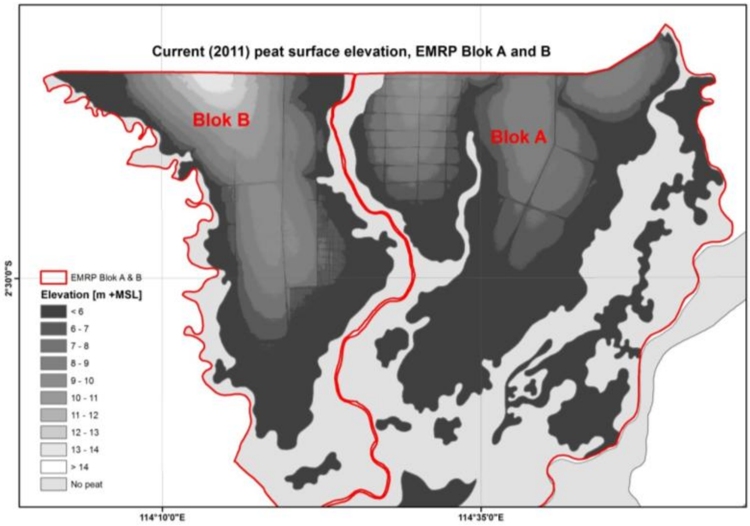

Figure 5.3. Peat surface elevation map for EMRP Blok A and B derived from LiDAR flown in 2011 (processed by Deltares in 2012). Non-peat areas are masked out using the Puslitanak peat extent map (Wahyunto et al., 2004).

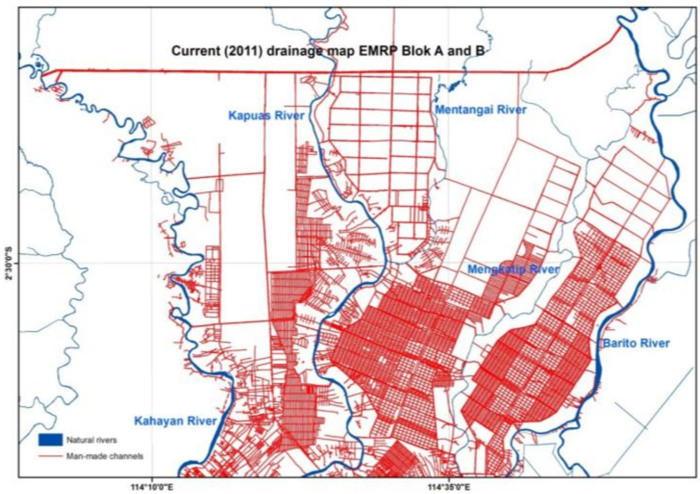

Figure 5.4. Canal outline in the EMRP Blok A and B peatland areas

Peatland drainage is mostly controlled by water levels in local rivers, which are usually around 1–2 m and 2–4 m above mean sea level (MSL) in the dry and wet periods respectively, depending on river discharge rates and distance from the sea. To predict when peatland drainage would be inhibited by subsidence, and to what extent this would affect land-use options, we used the following three drainability thresholds (Deltares, 2015):

1. Impaired drainability – When the peat surface approaches the local Free Drainage Limit (FDL), defined by adding a conveyance gradient (DID Sarawak 2001) of 0.2 m km^{-1} to high water level (HWL) with distance from the river, drainage will be impaired and cultivation will require increased water management efforts. A soil depth of 0.5 m above the water table is added to FDL levels, which is the minimum required to grow crops on peatland.
2. Annual prolonged flooding – This will become inevitable when the peat surface subsides to the high water level (HWL) that occurs throughout much of the tropical wet season, the minimum value of which we determined from the elevation of river levees.
3. Near-permanent inundation – Once subsidence lowers the peat surface to the low water level (LWL) that occurs in rivers during the tropical dry season, the peat surface will be inundated almost permanently (more than 6 months per year). Subsidence rates will be reduced at this stage because of water-logging and it is uncertain if the peat surface will drop further to MSL.

For LWL and HWL we used 1.5 m and 3.5 m respectively, based on field observations. To estimate how long it would take for peat surface levels to subside below the drainability thresholds, subsidence rates known from literature (3.5 cm/year; Deltares 2015) were applied to the data on peat surface elevation and peat thickness. For those areas that were still forested in 2010 (Figure 5.1) a higher initial subsidence of 1.4 m over the first 5 years was applied (Andriesse, 1988; DID Sarawak, 2001; Hooijer et al., 2012; Wösten et al., 1997). This initial subsidence was however only applied to those forested areas more than 2.5 km from a canal, as around existing canals some of this initial subsidence will already have taken place. Whenever the forest was closer to a canal a linear relationship was used, being 0 m in 5 years at 0 m from the canal and 1.4 m in 5 years at 2.5 km from the canal. The canal outline is shown in Figure 5.4.

5.2.4. Ecosystem services supply in the two scenarios

We examined three ESs (fresh fruit brunches/FFB production of oil palm, latex and timber production of Jelutung, and orangutan habitat) and one ecosystem disservice (carbon emissions), for the two scenarios specified above and for the four plantation cycles covered by the hydrological model (2011, after 25 years, after 50 years, and after 100 years). These services are described below. We realize that there are more ESs generated in the study area (e.g. rattan and wood production) but for reasons of simplicity restrict ourselves to the most economically important ones in the study area (Sumarga and Hein, 2014, Sumarga et al., 2015). We come back on this assumption in the Discussion section.

Oil palm (fresh fruit bunches) production

We calculated the annual revenues from producing FFB of oil palm, and the Net Present Value (NPV) of the expected income flow, both for oil palm in mineral soil and on peat with different flood levels. For the NPV calculation, we used a plantation cycle of 21 years with an average yield of 19 ton FFB/ha/year (based on Fairhurst and McLaughlin, 2009) and a discount rate of 10% (based on the average interbank lending rate and inflation rate 2009-2011, see Sumarga et al. 2015). We assume an FFB price of €130 per ton FFB (average 2010-2012, derived from Kalimantan-news 2011 and Central Kalimantan Estate Agency 2012). Given the strong fluctuations in FFB prices we have taken the average over a three years period to reduce the effects of these fluctuations. We included in our calculations land lease costs of 342 euro/ha reflecting the costs for acquiring land and various fees for permits and licenses, based on Boer et al. (2012). For reasons of simplicity, we assume constant prices for production costs and FFB. We also assume a constant yield for the first three plantation cycles, and a 20% yield increase for the next three plantation cycles due to the use of enhanced varieties (based on Fairhurst and McLaughlin 2009). We come back to our assumptions in the Discussion section.

We also analyze how oil palm FFB production will decline with increasing flood risks. The impact of flooding on oil palm productivity is considerable. Prolonged floods (weeks to months) can cause mortality of mature trees (Abram et al., 2014). Physiologically, in soil waterlogged conditions, soil pores become water-filled, leading to several major problems inside the plant body such as oxygen and nutrient deficits (Colmer and Voesenek, 2009). Seedlings and young plants are especially vulnerable (Hai et al., 2001; Dewi, 2009; Holidi et al., 2014). Ahamad et al. (2009) found in Malaysian oil palm plantations that a flood of 7 days at 25 cm already leads to a productivity loss of 20%. An FFB production drop of about 30% is reported by Sabari et al. (2014) due to flood events in a Malaysian plantation in 2008. Prolonged floods may also cause physical damage to trees (‘toppling over’) causing permanent production losses from affected trees. Based on these estimates, we conservatively assume a production loss of 25% in the case of impaired drainability, of 50% in the case of annual prolonged flooding, and of 100% in the case of near-permanent inundation. We acknowledge the uncertainty in these assumptions and carry out a sensitivity analysis, as reported in the Discussion section. We assume that production of FFB will stop as soon as the NPV turns negative.

Jelutung production

We calculated the annual yields and the NPV of Jelutung production based on Husin (2011). We used a production cycle of 30 years and a discount rate of 10%. The production includes latex production during years 10 to 30 and timber production at the end of year 30. We also included land lease costs of € 342 as used for oil palm. We assume that Jelutung is developed in a monoculture system. In line with the NPV calculation for FFB production, we also used constant (2011) prices for latex and production costs.

Carbon emissions

For carbon sequestration and emissions, we calculated the flow of carbon, expressed on a per hectare, per year basis, and the NPV of these flows in four land-use types: oil palm on peat, oil palm on mineral soil, natural peat forest, and Jelutung forest. Oil palm development on peat requires continuous peat drainage, resulting in high carbon emissions. We used an estimate of carbon emissions of 15 ton C/ha/year for oil palm on peat with a water table depth of 50 cm (derived from Hooijer et al., 2012). The 50 cm drainage on oil palm is best environmental practice, and is the drainage depth promoted by sustainability initiatives in the sector (Ministry of Agriculture 2011; Lim et al. 2012), however in practice drainage depths in plantations in peat often exceed 50 cm (Couwenberg and Hooijer, 2013). Hence, our assessment in this regard is conservative. For oil palm on mineral soil, the carbon balance depends on the previous land-cover types converted to oil palm. We used an average carbon sequestration of 1.9 ton C/ha/year (based on an average estimate of Germer and Sauerborn (2008), assuming that the plantation was established in a not-forested area and excluding carbon emissions from land clearing).

There is no specific data on carbon sequestration or emissions in Jelutung plantations, and we assume that these are equal to the rates in secondary forest, given that the Jelutung trees become quite large and resemble natural forest trees in the study area (their latex is tapped in the lower parts of the stem). For un-drained conditions we assume, based on the estimates of Suzuki et al. (1999) for carbon sequestration in protected, un-drained peat swamp forest that the sequestration amounts to 5.3 ton C/ha/year. For lightly to moderately drained secondary forest in peat, carbon emissions of 7.9 ton C/ha/year have been estimated by Hooijer et al. (2014). We assume that these emissions also occur in the drained Jelutung plantations and drained forests in our study area.

The monetary value of carbon sequestration and the costs of carbon emissions were based on the Social Costs of Carbon (SCC) estimated by the United States Environmental Protection Agency (2013). The used value is USD 39/ton CO_2 that is equivalent to € 28 /ton CO_2 (€ 103/ton C) with an average 2011 exchange rate of $ 1.39 for € 1. Acknowledging that the SSC is calculated using a social discount rate (in the case of the value we used 3%), we nevertheless used a discount rate of 10% and a 21 years discounting period, to analyse the NPV of the benefits of carbon sequestration and the costs of emissions, in order to be aligned with the NPV calculations for our other ESs. If we would have used a lower discount rate and a longer discounting period to calculate the NPV, both the social costs of the carbon emissions and the social benefits from carbon sequestration would have been markedly higher. Because of high carbon emissions in the oil palm scenario, this would have favoured the mixed land-use scenario.

Orangutan habitat

Finally, we also assessed orangutan (*Pongo pygmaeus*) habitat maintained in this scenario based on an orangutan habitat suitability map (Sumarga and Hein, 2014). Orangutan is an endangered species, and Central Kalimantan has the world’s largest population of orangutan at the provincial level (Wich et al. 2008). We analysed this service only in term of physical quantity given the difficulties with monetary valuation of aspects of biodiversity (cf. Sumarga et al., 2015). We use hectare (ha) of orangutan habitat as the indicator for his service, with orangutan habitat comprising, in general terms, forests with a well preserved crown cover with overlapping branches to allow the animals to migrate within the forest, and not heavily influenced by disturbances from villages or roads. We analysed the suitability for orangutan habitat in the study area based on data from Sumarga and Hein (2014). In general, orangutan habitat translates to orangutan numbers in the sense that the density of the species is, on average, one individual per 100 ha. However, numbers can be higher or lower depending upon food availability and/or on the presence of orangutan fled from other areas, or released in the area.

5.3. Results

5.3.1. Flood risk maps

Figure 5.5 shows the four flood risk maps that present the modeled flood conditions in 2011, and after 25, 50 and 100 years of subsidence in case of the ‘OP’ scenario. For our analysis, we calculated flood maps for every year (until 125 years after drainage) since we have related palm oil production to flood conditions occurring in each year for which the net present value of palm oil production was calculated. Figure 5.5 shows that under current (2011) conditions already considerable areas are subject to drainage problems under the FDL drainability threshold (impaired drainability), whereas currently no flooding problems exist at the LWL drainage limits (near-permanent inundation). Near-permanent drainage problems (LWL threshold) start for small areas in 25 years, whereas in 100 years’ time some 46% of the peat area will be subject to near-permanent inundation. Details of flooded areas in each year are presented in Table 5.1.

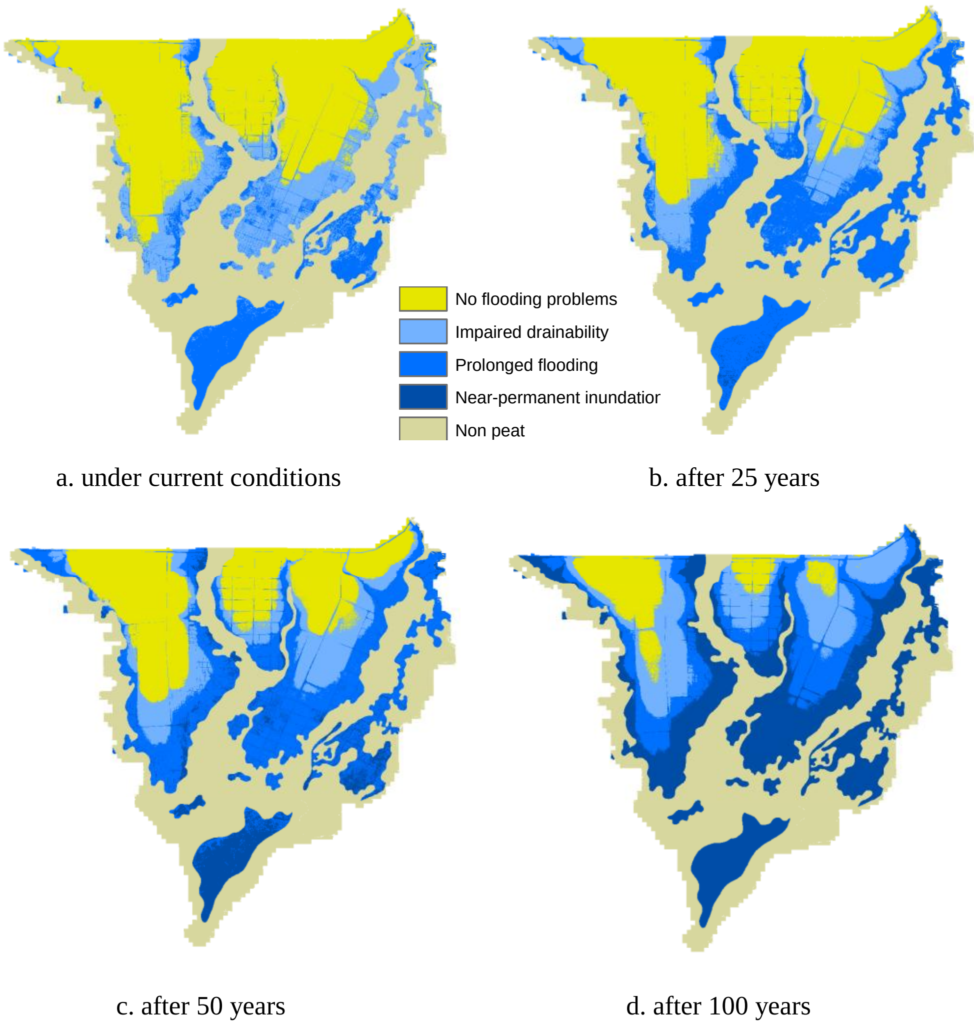

Figure 5.5. Flood risk maps for the EMRP Block A and B peatland areas under (a) current (2011) conditions and after (b) 25, (c) 50 and (d) 100 years of subsidence applying the FDL, HWL and LWL drainage limits for the ‘OP’ scenario.

Table 5.1. Flooded areas (ha) for each drainage limit under current (2011) condition and after 25, 50, and 100 years under two land-use scenarios ('OP' and 'MIX'), areas are rounded to thousand ha.

a. The OP scenario					
Land use	Flood level	2011	After 25 years	After 50 years	After 100 years
Oil palm on mineral soil	No flooding	193,000	193,000	193,000	193,000
Oil palm on peat	No flooding	168,000	134,000	103,000	36,000
	Impaired drainability	80,000	53,000	52,000	63,000
	Frequent flooding	53,000	113,000	110,000	64,000
	Near-permanent inundation	0	1,000	36,000	138,000
b. The Mix scenario (based on Euroconsult MacDonald and Deltares, 2008)					
Land use	Flood level	2011	After 25 years	After 50 years	After 100 years
Natural forest	No flooding[1]	84,000	84,000	84,000	84,000
Jelutung forest	No flooding[1]	156,000	156,000	156,000	156,000
Oil palm on mineral soil	No flooding	193,000	193,000	193,000	193,000
Oil palm on peat	No flooding	1,000	0	0	0
	Impaired drainability	23,000	1,000	0	0
	Frequent flooding	37,000	58,000	34,000	0
	Near-permanent inundation	0	2,000	27,000	61,000

[1]Assuming that there is no further peat subsidence in jelutung and natural forests. This may require, for some currently drained areas, some degree of hydrological restoration. Costs of restoration are not included in the analysis. Note also that a minor part of the Jelutung forest is subject to impaired drainability and prolonged flooding but since Jelutung is assumed to tolerate such levels of flooding these are classified as having no flooding problems in Table 5.1.

5.3.2. Ecosystem services production

Oil palm production

A cash flow analysis in line with the assumptions specified above, and including costs of land lease, costs of intermediate consumption, labor and the user costs of produced assets (depreciation and capital use costs) shows that, for one plantation cycle in the first three plantation cycles, the NPV of FFB production is € 7,295 for oil palm on mineral soil (Appendix 5.1a) and € 5,104/ha for oil palm on peat (under no-flooding conditions for the entire period of a plantation cycle, see Appendix 5.1b). After 100 years, with the assumed yield increase described in the Methods section, the NPV for a 21 years plantation cycle is € 10,903 for oil palm production on mineral soil and € 8,712 for production on peat. Based on the assumptions on production loss described in the Methods section, the NPV of FFB production under impaired drainability is drastically reduced, to only € 593 per hectare, and the NPV is 0 for areas under near-permanent inundation and under prolonged flooding conditions. Hence, in our model, oil palm plantations will be abandoned by the time floods reach near permanent inundation and profits are very low under impaired drainability condition. In practice, companies may start abandoning plantations already under impaired drainability condition given that the low NPV per hectare leads to a very low return on capital invested for the companies involved. Appendix 5.1c provides the NPV of FFB production when flood risks change within a plantation cycle.

Jelutung production

We used the costs and revenue of a monoculture Jelutung production provided by Harun (2011), and modified the NPV calculation with a discount rate of 10%, resulting in an NPV of € 3,887/ha. This NPV includes the revenue from timber harvest in the last year of the production cycle (30 years). The average Jelutung production is 4.7 ton/ha/year for latex production and 10.7 m^3/ha/year for timber production. Detailed calculations of the NPV of Jelutung production are presented in Appendix 5.1d. This analysis shows that Jelutung generates somewhat lower net revenues than oil palm grown on peat in no-flooding conditions. However, once the oil palm area subsides below FDL and drainage becomes impaired, the value of oil palm production becomes only about one sixth of Jelutung production.

Carbon sequestration

Based on the carbon sequestration and carbon emissions data specified in the Methods section, we derived the NPV of carbon sequestration as follows: € 1,862/ha for oil palm on mineral soil, - € 14,698/ha for oil palm on peat, and on average € 5,193/ha for natural peat forest and Jelutung forest (see Appendix 5.1e for detailed calculations). The positive value represents sequestration and the negative value represents emissions.

Orangutan habitat

We identified about 34,000 ha of peat forest in the study area (40% of the remaining forest) as suitable area for orangutan habitat (based on the habitat suitability map for orangutan from Sumarga and Hein 2014). In the 'MIX' scenario, in line with the forest protection and rehabilitation program, we assumed that because of natural re-growth all forest area (about 84,000 ha) will become suitable for orangutan habitat. In the 'OP' scenario, conversion of forest into oil palm plantation will remove the capacity of the area to support orangutan preservation, hence the overall area will be unsuitable for orangutan habitat.

5.3.3. Scenario analysis of ecosystem productivity

Table 5.2 shows the benefits from different land uses in the two scenarios, analyzed for four plantation cycles of oil palm production. In scenario 1, the social costs of carbon emissions considerably outweigh the benefits of oil palm production, confirming that growing oil palm in peat is not recommendable from an economic perspective. However private profits, in the first approximately four decades of oil palm outweigh the profits from Jelutung plantations. In the second period of our scenario analysis, the mixed land use generates a higher return for the growers of plantation crops. After two plantation cycles, oil palm production is no longer feasible due to flooding in a large part of the study area, whereas Jelutung production continues without a decline in production. Timber and rattan harvesting, in the mixed land-use scenario, provide additional revenue throughout the modeling period that are not included in our calculations.

We are overestimating the benefits of the oil palm scenario by omitting two factors. First, the oil palm scenario requires important investments in – currently lacking – infrastructure, in particular roads, to reach the plantations. At least in part these roads would have to be constructed in peat, making them relatively expensive to construct and maintain. In the second scenario, the most inaccessible parts of the area would remain forested and much less infrastructure would be required. Second, there are several other products that can be harvested in the forest such as rattan and mushrooms, and there may also be opportunities for ecotourism, a growing business in Central Kalimantan. Moreover, fishing is a main activity in the area, and large scale oil plantations would, through loss of access to river and through pollution of rivers because of runoff from plantations reduce fishing opportunities in the area.

In addition, the study area contains an orangutan release area and is bordering the Mawas forest comprising around 2,500-3,000 orangutan or around 5% of the global total of the remaining specimens in the wild. We are not able to put a meaningful monetary value on this service, but believe that it should be an important point of consideration in deciding on land-use options. Our study clearly shows the trade-off in development that Indonesia is facing regarding the use of peatlands, between short term profits from oil palm cultivation (1 or at most 2 plantation cycles) and long-term profits from more sustainable land use. If all peat land in the case study site would have been converted to oil palm in 2011, only around 12% of the peat area would still be suitable (no flooding problems) for oil palm by 2111 (Table 5.1).

Table 5.2. Economic implications of two land-use scenarios ('OP' and 'MIX') on ESs, in terms of physical units and NPV

a. The OP scenario								
Period	Oil palm production[1]		Jelutung production		Carbon sequestration[2]		Orangutan habitat	Total NPV (€ million)
	Physical flow (Mton FFB/year)	NPV (€ million)	Physical flow (Mton latex/year)	NPV (€ million)	Physical flow (Mton C/year)	NPV (€ million)	Thousand ha	
2011	4.5 (mineral) 3.8 (peat)	1,863 (mineral) 811 (peat)	0	0	0.37 (mineral) -4.52 (peat)	359 (mineral) -4,424 (peat)	0	-1,391
After 25 years	4.5 (mineral) 3.0 (peat)	1,863 (mineral) 669 (peat)	0	0	0.37 (mineral) -4.52 (peat)	359 (mineral) -4,424 (peat)	0	-1,533
After 50 years	4.5 (mineral) 2.6 (peat)	1,863 (mineral) 536 (peat)	0	0	0.37 (mineral) -4.52 (peat)	359 (mineral) -4,424 (peat)	0	-1,666
After 100 years	4.5 (mineral) 1.5 (peat)	1,863 (mineral) 276 (peat)	0	0	0.37 (mineral) -4.52 (peat)	359 (mineral) -4,424 (peat)	0	-1,926
b. The Mix scenario								
Period	Oil palm production[1]		Jelutung production		Carbon sequestration[2]		Orangutan habitat	Total NPV (€ million)
	Physical flow (Mton FFB/year)	NPV (€ million)	Physical flow (Mton latex/year)	NPV (€ million)	Physical flow (Mton C/year)	NPV (€ million)	Thousand ha	
2011	4.5 (mineral) 0.1 (peat)	1,863 (mineral) 6.4 (peat)	0.4	606	0.37 (mineral) 0.36 (peat)	359 (mineral) 349 (peat)	84	3,183
After 25 years	4.5 (mineral) 0.007 (peat)	1,863 (mineral) 1.1 (peat)	0.4	606	0.37 (mineral) 0.36 (peat)	359 (mineral) 349 (peat)	84	3,178
After 50 years	4.5 (mineral) 0 (peat)	1,863 (mineral) 0 (peat)	0.4	606	0.37 (mineral) 0.36 (peat)	359 (mineral) 349 (peat)	84	3,177
After 100 years	4.5 (mineral) 0 (peat)	1,863 (mineral) 0 (peat)	0.4	606	0.37 (mineral) 0.36 (peat)	359 (mineral) 349 (peat)	84	3,177

[1] See Appendix 5.2 for an example of detailed calculation of the total NPV of FFB production on peat under increasing flood risks in rotation 1 of the 'OP' scenario.

[2] + indicates sequestration, - indicates emissions. Carbon emissions are expected to slow down in near-inundated conditions but this is not accounted for in the current calculations since the slow down rate is unknown.

5.4. Discussion

5.4.1. Uncertainties

Our study benefited from the availability of a high-resolution LiDAR DEM for the study area. LiDAR can be used to producing an accurate, high resolution DEM due to its capability of canopy penetration (Liu, 2008). The accuracy of a LiDAR DEM depends on the land-cover types with typical vertical uncertainty less than 30 cm in evergreen and deciduous forests (Hodgson and Bresnahan 2006) and we believe our DEM to be relatively robust, compared to other sources of uncertainty. A second potential source of uncertainty is the assumptions used for subsidence rates. Subsidence rates are based on empirical studies in Indonesia and Malaysia, with comparable peat conditions to our study area, and have been confirmed in a range of studies (Couwenberg and Hooijer, 2013; Farmer et al., 2014). We are therefore confident about our assumptions in this regard. A third source of uncertainty pertains to the CO_2 emission from drainage. We acknowledge the uncertainties involved, and in response have selected a relatively conservative scenario, assuming that oil palm in the area will be grown under the best environmental practices promoted by the RSPO and ISPO (50 cm drainage). This, however, is not likely to occur in reality in the whole study area given the difficulties in managing water levels in Indonesian peatlands and the tendency of plantation holders in peat to drain more (to over 1m depth) in order to reduce risks of water-logging during the wet season (Couwenberg and Hooijer, 2013). Hence we underestimate the amount of CO_2 emissions, and accordingly also the subsidence rate, in particular in the 'OP' scenario. Our model also does not account for the potential increase of sea or river level due to climate change, making this assessment even more conservative.

Our land-use scenario is also a main source of uncertainty. It is clear that in 2011 not all land in the study area was converted to oil palm plantations. As shown in Figure 5.4, around 70% of the study area was drained by 2011, which means that in the 'OP' scenario, we assume an additional drained area of around 30%. Also, identified from the 2010 land-cover map, only about 2% of peatland in the area was converted to oil palm in 2010, and there were no other large plantations in this year. Hence, our model strongly overestimates the total NPV generated in the study area by oil palm plantations in 2011. This also applies for the 'MIX' scenario, where we assume about 20% of the peat area developed for oil palm. We recall that the purpose of our paper is to elicit the hydrological and economic implications of potential land-use decisions, by comparing a scenario involving full land-use change to oil palm with a more balanced mixed land-use scenario.

We are aware of the limitations in our valuation approach. For instance we do not include any multiplier effects from oil palm or Jelutung production, and we do not analyze potential changes in consumer surplus due to changes in market supply of palm oil or Jelutung, based on our assumption that the overall effect of either scenario on global market production for both crops is very small. We also assume that an increase in Jelutung production would not lead to lower prices for producers (based on the assumption that it is produced for a global market where it competes with other rubber crops). As mentioned earlier, we included only four ESs in our analysis, albeit based on our earlier work the most important ones (Sumarga et al. 2014). This means that we underestimate the total benefits of, in particular, the mixed land-use scenario. For instance, some of the forested area (close to rivers) in the mixed land use scenario is suitable for rattan, which would yield net benefits of around € 30/ha/year (Sumarga et al., 2015). Forest timber production could lead to benefits of around € 28/ha/year (Sumarga et al., 2015), but care needs to be taken that this would not negatively affect orangutan habitat. We are not able to quantify benefits from other services such as fish production in blocked canals or other non-timber forest products.

Other potential sources of uncertainty are the assumptions on the loss of oil palm FFB production due to different levels of flooding, the discount rates, and the prices of oil palm FFB and Jelutung in the future. We assumed constant prices for both FFB and Jelutung. In reality these prices will change, and changes over a period of 100 years may be considerable. For instance, we assumed an FFB price of € 130/ton FFB, (average 2010-2012) whereas the oil palm price fluctuated between 2011 and July 2015 between around € 110 and € 150. The effect of the uncertainties can be identified by a sensitivity analysis. We analyzed the sensitivity of the NPV of oil palm FFB production to the assumed production losses due to different types of flooding. We find a high sensitivity of the NPV of FFB production to the assumed production loss both under prolonged flooding and impaired drainability conditions. For instance, by assuming production losses in prolonged flooding areas to be 40% (instead of 50%), the NPV of FFB production increases from - € 3,917 to - € 2,113. The NPV of oil palm grown under impaired drainability and frequent flooding would also be higher when lower production losses are assumed but this would also not significantly affect the overall benefits produced in the two scenarios.

5.4.2. Is sustainable oil palm on drained peatland possible?

Oil palm has increasingly been established on peatland in Central Kalimantan, increasing from about 4,000 ha (1.4% of the total area of oil palm) in 2000 to 97,000 ha (8.2% of the total area of oil palm) in 2010 (Sumarga and Hein, 2014). Two reasons may contribute to the increase of oil palm expansion on peatland. First, the availability of land with mineral soil for oil palm expansions is increasingly limited. Mineral soil areas in the lowlands are preferable for oil palm cultivation due to the lower production costs (Fairhurst and McLaughlin, 2009). However, due to the high competition for land, most of those areas have already been occupied by oil palm and other land uses, or are unavailable due to land ownership disputes, or are too fragmented for industrial use. Second, there are relatively few people living on peat land which reduces the chance of social conflicts in case of the conversion of peat (Casson et al., 2007).

Efforts have been made to promote sustainable management of oil palm on peatland (Agus and Subiksa, 2008; Nurida et al., 2011; Lim et al., 2012). The efforts address three main issues: yield improvement, environmental management, and local community empowerment. An aspect getting a lot of attention is how to maintain the optimum FFB production while minimizing greenhouse gas (GHG) emissions. This mainly focuses on water management practices, principally by keeping water level at 50-70 cm below peat surface. This water level is still conducive to oil palm growth and production, and leads to lower fire risks and carbon emissions compared to deeper drainage levels. Our study, however, shows that even with such relatively shallow drainage (compared to current practices), CO_2 emissions are still considerable (their social costs being larger than the net benefits from oil palm) and even in this case oil palm areas will subside, in an irreversible manner, to be eventually taken out of production.

We assumed that flood control through pumping water out of peatlands to maintain oil palm production in the study area is not possible. Maintaining production under increased flood risks requires flood control involving an integrated system of drainage canals, dykes, pumping stations, and retention basins. Design of these elements requires considering safety levels, costs, and subsequently the optimal safety level, pump capacity and retention capacity as a function of land use, acceptable risk levels and local topography and hydrology (Morita, 2008; Mondeel and Budinetro, 2010). Applying flood control measures in tropical peat for individual blocks/plantations is very expensive because extensive stretches of dykes would be required, and because these dykes, if constructed on peat, will sink into the peat. They may also crack during periods of drought, and therefore require continuous, and expensive, maintenance. Developing a ‘polder’ system with dykes on mineral land around the peat to manage water and flood levels in the peat is also not likely to be feasible in the study area. The individual peat domes in the area are very large (several 10,000 ha) and construction of dykes, pumping stations, canals and water level monitoring systems would be very expensive. With an average annual rainfall of about 2,900 mm (Ichsan et al., 2013) and high rainfall intensity during extreme events, the pumping capacity required would be large and expensive. It would also require developing the institutions required for large-scale water management, which would be a major challenge in the remote study area (Loucks et al., 2005).

Based on the impacts of flooding on crop production options, the irreversible nature of peat subsidence, the lack of options to mitigate flood risks, and the additional risks that climate change and sea level rise pose to Indonesian lowlands, we conclude that sustainable oil palm cultivation in Indonesian peatlands is not possible. Through careful land-use planning expansion of the oil palm sector should be accommodated in mineral lands, whereas peatlands should be restored to natural conditions where needed or used for the production of crops that do not require drainage, in combination with sustainable forest management and wildlife conservation where appropriate.

5.4.3. Policy implications

The Indonesian government has issued three regulations directly related to oil palm development on peatland. The latest regulation is Presidential Instruction No. 6 (2013) that forbids both local and central governments to issue new concessions (including for oil palm) in peatland and primary forests in all kind of state lands (conservation forests, protected forests, production forests, and lands for other purposes). This moratorium is temporary and valid for two years (May 2013 – May 2015), and may be extended. This regulation is an extension of Presidential Instruction No. 10 (2011), which regulates the same moratorium issue. The new extension of the moratorium for 2015 – 2017 has been proposed by the Ministry of Environment and Forestry, but the regulation has not been legislated yet. Another regulation is the Ministry of Agriculture Decree No. 14, 2009 guiding the use of peatland for oil palm cultivation. This regulation allows oil palm cultivation on peatland, but restricts the cultivation to land with a peat depth less than 3 meter.

The challenge to facilitate oil palm expansion while minimizing environmental degradation is also responded to by two certification schemes: the Roundtable on Sustainable Palm Oil (RSPO) and the Indonesian Sustainable Palm Oil (ISPO) initiative. Both RSPO and ISPO require compliance with national laws and regulations, including the Indonesian forest conversion moratorium policy. Several principles and criteria have been adopted by both RSPO and ISPO to promote sustainable oil palm on peatland, including minimizing soil subsidence, maintaining water quality and availability and reducing GHG emissions. This requires a water management program that maintains the water table within a range of 50 - 75 cm below ground surface through a network of appropriate water control structures. As we analyzed, however, these recommendations are not sufficient to ensure sustainability of oil palm cultivation.

Hence, policies should be aimed at finding cost-effective ways to minimize peat degradation. Potential options to consider are:

- Permanent moratorium on converting peatlands. The moratorium of issuing new oil palm concession on peatland is a temporary policy which is valid only for two years; hence it creates uncertainty in the context of peatland preservation. We recommend to permanently install and enforce this policy to stop further degradation of the remaining peatlands. In a Central Kalimantan context, applying a moratorium on converting peatland up to 2025 is expected to generate considerable social benefits from reduced carbon emission (about € 1,400 million/year) compared to maintaining business as usual (Sumarga and Hein, 2015).
- Peatland restoration. Considering that many unproductive peat areas have been partly or fully drained, peat restoration programs should be initiated by rewetting actions such as canal blocking to reduce ongoing subsidence, GHG emissions and fire risk. This can be combined with assisted natural regeneration, using species such as Jelutung (*Dyera spp.*), *Shorea balangeran*, *Palaquium* sp., and *Gonystylus bancanus* in Kalimantan (van der Meer and Ibie, 2009). Pilot projects should be started in order to test how to most

cost-efficiently restore degraded peatlands, building among others upon the technical designs for canal blocking developed by the Kalimantan Forest Climate Partnership project (Australia Indonesia Partnership, 2009). Given the major reductions in CO_2 emissions that can be achieved with peat restoration, it should be examined if and how REDD+ funding could be used to fund this.

- Facilitating the use of "degraded land" on mineral soil for oil palm expansion. Sumarga and Hein (2014) formulate an ES approach to identify areas where palm oil expansion would not compromise the supply of key ESs and identify 1.8 million ha of land available in Central Kalimantan (see also Smit et al., 2013). Given that land holdings are much more scattered in these mineral lands, the promotion of palm oil production in mineral lands may be well combined with an approach enabling smallholders to produce palm oil by providing them with technical advice, loans, high quality seedlings, etc. (Barlow et al., 2003; Feintrenie et al., 2010).

5.5. Conclusions

We analyzed the hydrological and economic impacts of two scenarios for peatland management: a scenario involving conversion of the whole case study area of around half a million ha (of which around 60% peatland) to oil palm ('OP'), and a scenario involving mixed land use with oil palm on mineral land and heavily degraded peat, combined with Jelutung and forests in other peatlands ('MIX'). We assume best water management practices in oil palm plantations on peat as currently promoted by RSPO and IPSO, and analyze the effects of drainage on soil subsidence and, consequently, flood risks. Three types of flood risks were modeled: impaired drainability, frequent flooding, and near-permanent inundation. We estimated the economic value generated by two ESs, palm oil production and Jelutung production, and the costs associated with CO_2 emissions in drained peatlands. We also estimated orangutan habitat (in physical terms only) as an indicator for biodiversity.

In the 'OP' scenario, soil subsidence progressively affects the possibility to use the peat for oil palm production. In 100 years' time, around 46% of the peat in the study area will be subject to near-permanent inundation and only 12% of the peat is not affected by floods and therefore still suitable for oil palm. In the 'OP' scenario, the social costs of carbon emissions from oil palm on peat exceed the private benefits from oil palm, confirming the magnitude of the externalities resulting from oil palm cultivation on peat. In the 'MIX' scenario, production of oil palm is concentrated on mineral lands and Jelutung production on peat can continue sustainably. We show that, when the costs of CO_2 emissions are not considered, oil palm cultivation on peat is profitable in the short term, but that after around one plantation cycle the profits from mixed land use in the case study area are higher. Our findings point to the importance of a permanent moratorium on peat conversion and to the need to restore degraded peatlands, in combination with policies that facilitate expansion of oil palm on mineral lands.

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6. DISCUSSION AND CONCLUSIONS

6.1. Introduction

This thesis examined how spatial models for ES can be applied in support of ecosystem accounting and land-use planning, with a specific case study on deforestation and oil palm expansion in Central Kalimantan, Indonesia. Specifically, this thesis analysed the ecological, hydrological and economic impacts of oil palm expansion in Central Kalimantan, and identified options to reduce the environmental impacts and negative externalities of oil palm expansion. To structure the research, four research questions were formulated (Chapter 1). These are:

1. How can ESs be mapped at the provincial scale, and how can the ES maps be integrated in an ES-based approach to land-use planning?
2. How can ESs be valued in a way that is aligned with national accounts, and how can the spatial information of ES values be used to analyse the trade-offs in ES supply resulting from land-use conversion?
3. How can ongoing oil palm expansion be spatially and temporally modelled, and what are the implications of this expansion on land-use management and ES supply?
4. How can the long term hydrological and economic impacts of oil palm development on peatlands be modelled?

Sections 6.1 to 6.4 present the main conclusions of the thesis with regards to these four research questions. Each conclusion is followed by a brief discussion on whether the research question is answered, what is still missing and what are the potential scientific implications and/or is the relevance for ecosystem management. In Sections 6.5 and 6.6, the general recommendations for further research and land-use management are presented.

6.2. Mapping ecosystem services for land-use planning

ESs have become a widely used concept in environmental management (Daily et al., 2009; Potschin and Haines-Young, 2011). Integrating ESs in environmental management, particularly in land-use planning, requires the spatial analysis and mapping of ESs (Bolliger et al., 2011; Martínez-Harms and Balvanera, 2012). There is increasing experience with various methods to map ESs (Nelson et al., 2009; O'Farrel et al., 2010). This thesis mapped seven ESs (i.e. timber production, rattan production, oil palm production, paddy rice production, carbon storage, carbon sequestration and wildlife habitat) at the provincial scale and analysed how ESs can be incorporated in provincial land-use planning.

This thesis analysed how three spatial techniques can be applied to map ESs, i.e. geostatistics for mapping timber production, rattan production, oil palm production and paddy rice production, lookup tables for mapping carbon storage and carbon sequestration, and Maxent, a species distribution model, for mapping wildlife habitat. When the different techniques are compared, their applicability clearly depends on the nature of the services, the properties of the land-cover units in which the service is supplied, and the availability of data. A main advantage of geostatistics and Maxent is that they present an indication of the spatial accuracy of the resulting maps. Using geostatistics allows for a helpful cross validation when enough field data to validate a model are lacking. Maxent also provides the ‘AUC’ indicator as an accuracy measure. Some methodological implications observed from ES mapping in this thesis are described below.

Geostatistics is an adequate technique for ES mapping, mainly for ESs distributed in a single or in very few land-cover types that are spatially variable within the land-cover type in terms of ES supply. This spatial variability is generally not reflected in lookup tables and the use of lookup tables therefore leads to a generalization and loss of spatial accuracy. Depending upon the representativeness of the information contained in the lookup table, the error may also lead to an error in the overall average estimate at the provincial level. Lookup tables are applicable when dealing with ESs that are distributed in different land-cover types with distinctive values in each land-cover type, and when site specific data of ES are lacking. Besides the generalization error, the main limitations of lookup tables are the absence of quantitative accuracy measures and the potential incompleteness of the resulting ES map in case ES data for some mapping units (e.g. land-cover types) are unavailable. The qualitative accuracy of lookup tables can be improved by providing a more detailed mapping unit (e.g. land-cover classes) and using more reliable ES data for each class.

Maxent is a powefull model for habitat suitability modelling. The advantages of applying Maxent are that (i) its algorithms determine the contribution of explanatory variables to the probability of a species’ presence; (ii) the model’s accuracy is calculated; (iii) it requires a relatively small minimum number of presence points; and (iv) it is less sensitive to spatial uncertainty of species records (Baldwin 2009). However, Maxent expresses the suitability of an area to supply a specific ES. This does not always fully match with the actual supply of the service. This limitation needs to be considered when Maxent is used as a basis for the physical and/or monetary analysis of ESs. Note that in our case study, Central Kalimantan, we have used Maxent in particular to map orangutan habitat, in line with the most common application of MAxent, i.e. to model potential species distributions. The specific context of this province with its high degree of deforestation leading to orangutan seeking refuge in remaining forest areas, means that most, if not all, areas potentially suitable for orangutan are likely to be inhabited by the species. This was also confirmed by statements from the NGO BOSF, which mentioned during fieldwork that very few areas remain to release rehabilitated orangutan in the province, since most areas already have too many orangutans. Hence, our use of Maxent likely also indicates the actual supply of the service ‘orangutan habitat’.

This thesis also shows various applications of ES maps in support of land-use planning. In the context of spatial planning, ES maps provide information on the current set of benefits provided by the ecosystems in a specific area. By linking these benefits to specific stakeholders, insight can be obtained in the social and equity aspects of ES supply; often different stakeholders benefit from different types of ES (Hein et al., 2006). Chapter 2 demonstrates how ES maps can be used in support of spatial planning, in particular, by examining where oil palm expansion could possibly be allowed in view of the need to limit the loss of ES. The resulting map is a basic input for the spatial planning process for oil palm expansion (Chapter 4). However, the map should not be used in isolation, but be combined with information on stakeholder interests, legislation, land suitability, infrastructure etc. This is important, as we also indicate in our published article, because in addition to land suitability and minimizing environment impacts there are always more considerations guiding land-use policies. A major advantage of the combined physical and monetary approach, as developed in the Chapters 2 and 3, is that the consequences of different land-use options can also be expressed in monetary terms, as illustrated in Chapter 4.

Land-use dynamics are driven and affected by a set of complex interactions among socio-economic and ecological processes (Rounsevell et al., 2012). In this context, a critical constraint of using an ES approach to land-use planning is that ES supply may not be sustainable. In case of overharvesting of ESs, the actual long-term value of land units exposed to unsustainable extraction may be lower compared to estimates based on current flows. In addition, some land-use units are ‘under-utilized’ compared to their long-term capacity to generate services. Hence, a refinement of the ES approach to land-use planning could be to include both flows of services and stocks of ecological capital (which represents the capacity of ecosystem to generate services over time). This approach is aligned with the emerging thinking on ecosystem accounting (Edens and Hein, 2013; UN et al., 2014). In this context, this thesis shows that mapping ESs at aggregated scales is possible, even in a data poor developing country context, but that further research is needed to analyse the uncertainty levels in the outputs and to deal with ecosystem degradation, c.q. changes in the long-term potential of land to generate ESs. We examined this in detail in Chapter 5, where we show that soil subsidence following peat drainage substantially increases flood risks over time leading to strong reductions in the capacity of the land to support oil palm cultivation and in the overall value of the ecosystem assets in the case study area.

6.3. Mapping monetary values of ESs in support of ecosystem accounting

Different approaches have been developed for monetary valuation of ESs (Bateman et al., 2011). In an ecosystem accounting approach, the contribution of ecosystems to providing benefits for society is valued in a manner that is consistent with the principles of national accounting (UN et al., 2014). This thesis applied the ecosystem accounting approach to value the seven studied ESs, demonstrates how the ES values can be mapped at the provincial scale, and analysed impacts of land-use conversion to the trade-offs of ES.

This thesis shows the applicability of two different valuation techniques: resource rent assessment for valuing timber production, rattan production, oil palm production, paddy rice production and nature recreation, and costs-based valuation for valuing carbon sequestration and wildlife habitat. The existence of markets for ESs is a key aspect considered in the selection of valuation techniques. The exclusion of consumer surplus in ecosystem accounting limits choices of valuation techniques. Contingent valuation and associated methods, which are often applied to explore the consumer surplus obtained from regulating and cultural services (Lindhjem and Tuan, 2012; Zander et al., 2014), are not compatible with accounting principles. Some methodological implications observed from ES valuation in this thesis are described below.

Assessing the resource rent is an appropriate way to value ESs in an accounting context for those services that can be related to products that are traded in a market. This technique deducts the monetary value of all other contributions (e.g. intermediate inputs, labour, consumption costs of fixed capital, costs of capital) to reveal the contribution of the ESs to the marketed benefits. This thesis shows that assessing resource rents of provisioning services is straightforward. This usually deals with single primary product, such as timber, rattan, paddy, and fresh fruit brunch of oil palm. An important condition for this (which was met in this research) is that no strong market distortions, such as government subsidies, occur and that no open-access situation exists in terms of using this product (Obst et al., 2015). The resource rent assessment for nature tourism in this thesis includes the revenues from entrance fees, lodges inside national parks and revenue of tour organizations. In this case, care needs to be taken that the various elements that contribute to the resource rent (entrance fees, different types of tourist expenditures) are reflected in the calculations. This thesis also shows the major limitations of a reintroduction costs method for biodiversity habitat valuation. The reintroduction costs are because of data scarcity usually only available for very few species, in case of this thesis only for orangutan. This underestimates the value of this ES since the ecosystem also provides a habitat to many other species. Our experience confirms that at present appropriate methods to value biodiversity habitat in an ecosystem accounting context are still lacking (cf. ONS and Defra, 2014).

Chapter 3 demonstrates how monetary ES maps can be generated on the basis of physical ES maps. The accuracy of monetary value maps depends on both the accuracy of the physical flow maps, the accuracy of the valuation data (prices, inputs used, etc.), and on the spatial representativeness of the relation between the physical and monetary aspects of the ES. For instance, the RR generated by rattan cultivation is likely to decrease with increasing distance from the river, since transporting rattan to the river requires additional labour. In principle, such spatial relations can be included in the valuation maps, but this has not yet been done in our publications.

Monetary valuation of ESs that is consistent with accounting principles, as demonstrated in this thesis, is relevant for natural resource management policies in two ways. First, the value of ecosystem contributions to the economic activities lying within the

System of National Accounts scope can be identified and visualized. Second, for the benefits that are outside the SNA boundary (e.g. carbon sequestration), the value can be integrated in an adjusted aggregate value, such as green GDP. Eliciting these values provides useful information for the design of sustainable resource management strategies, in particular if these information sets are included in the national accounting framework and therefore regularly updated by the statistical agencies of the countries that prepare the accounts. Standardizing ecosystem accounting approaches and linking them to the national accounts, however, requires further research (Edens and Hein, 2013, Obst et al., 2015), for instance in terms of specifying use and supply tables, increasing the number of ESs for which physical and monetary data are available and testing accounting-conform valuation methods for a larger number of ESs.

6.4. Analysing social costs and benefits of oil palm expansion

Few studies model spatial and temporal oil palm expansion in Indonesia (see for an example e.g. Miettinen et al., 2012). The increase in global demand for palm oil and Indonesia's role as the world's main palm oil producer mean that oil palm expansion in Indonesia likely continues in the coming decades (Sheil et al., 2009; Sayer et al., 2012). Modelling spatial and temporal expansion of oil palm facilitates a comprehensive analysis of the consequences of today's choices on oil palm expansion. This thesis applied an integrated inductive and deductive approach to model oil palm expansion in Central Kalimantan up to 2025 and analysed the social costs and benefits of three expansion scenarios.

This thesis shows the applicability of the integrated inductive and deductive approaches to model oil palm expansion. In the inductive approach, logistic regression is selected to map oil palm expansion based on the empirical pattern of oil palm expansion in relation to selected physical variables. The deductive modelling approach is applied through development of three expansion scenarios: a business-as-usual scenario, a moratorium scenario, and a sustainable production scenario. The combination of logistic regression and scenario-based modelling allows combining the advantages of the two techniques. Supported by the availability of data on ES values modelled in Chapters 2 and 3, the impacts of different scenarios of oil palm expansion on the trade-offs of ESs have been analysed. Some methodological implications observed from oil palm expansion modelling and the economic implications analysis in this thesis are described below.

The main advantage of the application of logistic regression techniques is the inclusion of the key physical land properties often considered in the selection of new land for expanding oil palm plantations. This thesis uses six physical variables as predictors: elevation, soil types and distance to roads, settlements, the existing oil palms and rivers. Involving physical variables is crucial in case of modelling oil palm expansion in Indonesia, where, although a license has been granted to convert an area, in many cases often only part of the licensed area is finally converted to oil palm, among others due to the specific physical properties of the land. Another advantage of the logistic regression technique is the availability of accuracy measures to evaluate the performance of the model. Recognizing a model's accuracy helps to understand the model's quality and, in terms of mapping, this determines whether the model is appropriate (or not) for the mapping application. The use of this technique also benefits from the availability of multi-year remote sensing data, such as land-cover maps. This allows derivation of both presence and absence points of oil palm expansion without ground sampling, which is usually very costly for a large area such as Central Kalimantan.

Involving land-use policies in the scenario analysis is essential for modelling oil palm expansion in Indonesia. Land available for the expansion is largely owned by the Indonesian government, hence the expansion is mainly driven by government policies to allocate land, and their enforcement. This thesis analysed two scenarios based on the past and current land-use policy (the business-as-usual scenario and the moratorium scenario) and one alternative scenario based on the ES production (the sustainable production scenario). This thesis shows that providing an alternative land-use scenario has higher net societal benefits resulting from combining expansion of the oil palm sector and maintaining key ESs. Under the sustainable production scenario, the net carbon balance is positive, orangutan habitat can be maintained and the net social benefits are much higher than in the other two scenarios. However, this scenario is much more difficult to enforce, hence posing another type of trade-off in land management. Finding more efficient land-use options, in combination with stricter planning and enforcement of land-use plans, can change the direction of future oil palm expansion in Indonesia and ensure that economic benefits from natural resources can be reaped by the current as well as future generations. This thesis also shows that linking oil palm expansion under different scenarios to the trade-offs in ESs supply provides clear messages about the costs and benefits of oil palm expansion, which is important to inform policy makers of the present and future consequences of their decisions.

6.5. Analysing hydrological and economic impacts of oil palm development on peat

Peatland is, in its natural condition, too wet for oil palm. Cultivating oil palm on peatland requires extra water and soil management. This leads to higher production costs. However, the limited availability of land with mineral soils for oil palm expansion, the high global demand for palm oil and the financial attractiveness of oil palm production compared to other agricultural land uses on peatland, push an increasing part of oil palm development to peatland in Indonesia, including Central Kalimantan. Chapter 5 models the hydrological impacts of draining peatland for oil palm in a period up to a century and analyses the economic impacts of two land-use scenarios. Involving hydrological processes in this chapter enriches the coverage of ES analysed in this thesis, since hydrology was not considered in Chapters 2, 3 and 4.

This thesis demonstrated how the hydrological impacts of oil palm production on peatland can be analysed with flood risk modelling that integrates a high resolution digital elevation model (DEM) with current knowledge on soil subsidence rates and drainage limits. Although recently major efforts have started to collect high-resolution altitude data for the country's peatlands, limited availability of a high resolution DEM limits the spatial cover of this study, which covers only small part of Central Kalimantan (about 3%; i.e. Block A and Block B of the Ex Mega Rice Project area). This thesis developed two land-use scenarios: the oil palm scenario assuming the conversion of the entire study area into oil palm, and the mixed scenario combining oil palm development with natural forest preservation and jelutung forest development. Based on the modelled flood risks as framed in the two land-use scenarios, this thesis further analysed the economic impacts of the two scenarios through assessment of four ESs: oil palm production, jelutung production, carbon sequestration and biodiversity habitat. Some methodological implications observed from the applied hydrological-economic modelling are described below.

This thesis shows how, in the absence of quantitative accuracy measures, the quality of a deductive model can be analysed based on three aspects: the logic of modelling framework, the reliability of assumptions used and the correctness of the model's input. This thesis considered these aspects through (i) development of a logical modelling framework integrating surface elevation, peat subsidence rates, and drainage levels; (ii) use of data and assumptions on subsidence rates, drainage levels and temporal river water levels based on empirical research and observation; and (iii) use of a high quality surface elevation data derived from a high resolution LiDAR DEM with a typical vertical uncertainty of less than 30 cm. The modelling framework developed in this thesis can be readily adopted for application in other places provided data are available.

The hydrological and economic impacts of oil palm production on peatland analysed in this chapter are likely to be representative for many areas in Indonesia, given that basic peat properties, subsidence rates and oil palm production systems are not strongly different in other parts of the country.

6.6. Recommendations for further research

This thesis provides several innovations. These include spatial modelling of ESs in a data poor environment, experimental ecosystem accounting, developing a land-use change model for oil palm expansion, and modelling hydrological-economic interactions for oil palm production on peatland. However, this thesis only presents one further step in the development of spatial modelling of ES and ecosystem accounting in support of land-use planning. This section presents a number of recommendations for further research in the field of ES mapping, ecosystem accounting, land use change modelling, hydrological modelling and land-use planning, as summarized below.

(i) Complete ecosystem accounting. Chapters 2 and 3 map and value eight types of ESs. Expanding the valuation and mapping to other types of ES is urgently required to strengthen the support to provincial land-use planning. The heterogeneity of land-cover types of Central Kalimantan means that a wider range of ESs is supplied than analysed in this thesis. Other important ESs in Central Kalimantan that need to be further mapped and valued include jelutung production, hevea rubber production, fish provision and soil erosion control. Wildlife habitat should be mapped for other species than orangutan. In terms of valuation, further testing is needed on how to value regulating and cultural services, for instance by considering how benefits for visitors to national parks could be included in the accounts. Monetary valuation of biodiversity for accounting may not be possible with sufficient credibility any time soon, and therefore it is suggested to develop instead a non-monetary set of metrics for including biodiversity in an accounting approach (e.g. Remme et al., submitted).

(ii) Apply spatial modelling and ecosystem accounting at the country level. This thesis demonstrates the significant contribution ecosystem accounting can make to land-use planning and resource management. Scaling up to the national level is required in order to extend this approach to other provinces and to allow linking with the national accounts, which are also produced at the country level. This is in line with the current efforts on aimed at implementing Ecosystem Accounting in the context of the System of Environmental-Economic Accounting in Indonesia, as started by the Statistical Bureau of Indonesia (BPS) with support of the World Bank and UN DESA. Given the extent and spatial diversity of Indonesia, it would be recommendable to start with a small initial set of services (including for example carbon sequestration, flood protection, water regulation and eco-tourism).

(iii) Improve hydrological modelling by incorporating the impacts of climate change. Chapter 5 prepared together with DELTARES, develops a flood risk model in drained peatland for oil palm plantation by integrating a high resolution DEM with current knowledge on peat subsidence rates and drainage levels. The model requires improvement in term of involving more aspects influencing the potential flooding occurrence and the flooding levels. A key aspect need to be investigated is the inclusion of the predicted rainfall. Climate change will potentially increase rainfall intensity and change the length of rainy season in the future, which subsequently will influence the river water level and the amount of excess water in the area.

(iv) Analyse costs and benefits of pumping on flooded oil palm on peatland. There is no empirical experience with pumping as a flood control system in a flooded oil palm on peatland. Chapter 5 assumes that such an application is very expensive because an integrated construction of dykes, drainage canals, retention ponds and pumping station are required. These structures need to deal with high-rainfall events typical for Indonesia's climate. However, further research is needed to more robustly confirm this assumption, specifically on the costs and benefits of pumping applications to mitigate flood risks in oil palm plantation on peatland.

6.7. Recommendations for ecosystem management

Based upon the results of the research conducted for this thesis, five main recommendations for ecosystem management in Central Kalimantan and more generally in Indonesia are summarized below.

(i) A permanent moratorium should be implemented on converting primary and good quality secondary forests and peatland of all depth, including for oil palm expansion. Chapters 2, 3, 4 and 5 of this thesis all reveal the significant environmental degradation related to conversion of peatland and/or primary forests into oil palm. The most crucial types of environmental degradation shown in this thesis include the considerable amount of carbon emissions, loss of wildlife habitat and irreversible soil subsidence and its further impact on flooding. The moratorium on converting peatland and primary forests currently taking place in Indonesia (since 2011) is strongly recommended to be made permanent. Specifically in Chapter 4, this thesis shows that under the moratorium scenario, oil palm expansion in the coming decade can be combined with considerable social benefits from reduced carbon emissions. Considering the difficulty to enforce the 3m limit of conversion of peatland into oil palm (i.e. Regulation of Ministry of Agriculture no 14, 2009) and the long period during which peatlands of less than 3 meter deep will still continue to lead to carbon emissions following drainage, the moratorium on converting peatland should apply to all peatland, of all depths. There is also a need to produce an up-to-date map of peat land cover for use by the Indonesian government, given the major differences in peat maps for the country that exist to date. Moreover, this map should not only be produced but also be made available to government bodies and other agencies including NGOs working at the local level (e.g. district, forest management units, etc.).

(ii) Allocate degraded land on mineral soil to oil palm expansion. In view of the high global demand for palm oil products and the profitability of the crop, further expansion of oil palm plantations in Indonesia is inevitable in the coming decades. Chapter 2 develops ES-based criteria to identify degraded land for oil palm expansion. The criteria include exclusion of peatland, areas suitable for wildlife habitat, areas with high carbon storage and areas important for ES production. Application of these criteria is financially examined in Chapter 4, in comparison with two other scenarios of oil palm expansion: the business-as-usual scenario and the moratorium scenario. This thesis shows that the ES-based scenario provides the highest net social benefits from oil palm expansion. Hence, it is strongly recommended to prioritize degraded land with mineral soil for the selection of areas for further oil palm expansion. This may involve a stronger role of smallholders that are owners of many of the degraded lands and that when supported (by credit, seedlings or access to oil palm mills) could play a larger role in the expansion of the oil palm sector in the future.

(**iii) Promote integration of ESs in provincial land-use planning**. Chapter 2 shows the application of an ES-based approach to land-use planning, with a specific case on identification of sites for oil palm expansion in a way that allows minimal impacts on ES. Chapters 4 and 5 also demonstrate how the environmental and economic impacts of different land-use scenarios can be analysed based on the spatial information of ES modelled and valued in Chapters 2 and 3. These experiences suggest that ESs are valuable inputs for land-use planning, in particular in order to support environmentally sustainable land management. As mentioned also earlier in this thesis, of course, the use of ESs in land-use planning shoud be combined with considering other critical inputs, such as stakeholders interests, land-use regulations and physical land properties.

(iv) Promote integration of ESs into national accounts. In the context of Indonesia, efforts on implementing ecosystem accounting are still in an early phase. For example, the World Bank through its WAVES project is developing a pilot project on ecosystem accounting, but its pilot area has not been selected yet. However, whether integration of ES values into national accounts can finally be standardized and implemented is still uncertain, both at national and provincial levels. The integration is not easy given the potential uncertainty in valuation methods of regulating and cultural services, and the potential debates on the acceptability of the application of the new adjusted measure, such as green GDP, for example to indicate the national or regional economic growth rate. Further testing and piloting ecosystem accounting approaches is therefore required. Chapters 2 and 3 demonstrate that, in principle, data are available to produce comprehensive (though not complete) ecosystem accounts also in Indonesia.

(v) Restore peatlands. Given that peat subsidence is irreversible and that it has major implications for greenhouse gas emissions, fire risks and thereby people's health, biodiversity and future crop production opportunities, there is an urgent need to restore drained peat lands in Indonesia. Restoration of degraded peatlands will usually involve both repairing the hydrological integrity of the peat domes, and restoring the vegetation to either forestry of agroforestry purposes, the latter based on paludiculture (i.e. species adapted to peat) crops. For degraded peatland inside national parks and other protected areas, reforestation with natural species is the best option, among others by assisted natural regeneration. For economic production, developing jelutung plantations is so far the best option since jelutung potentially produces two commercial products, latex and timber, has a ready market, and is well adapted to an un-drained condition.

6.8. Overall conclusions

This thesis shows that even in a large, data-poor environment an evidence-based approach to analyse the costs and benefits of land-use options can provide relevant and detailed information in support of policy making. Ecosystem accounting is highly useful in this regard; it provides spatially explicit and monetary information that can easily be used to evaluate land-management options, also in monetary terms. Ecosystem accounting can also be used to monitor changes in ecosystem capital over time and assess the effectiveness of past policies by looking at how they affected ecosystems, at different locations and in different periods (Suwarno et al., 2015).

Another major advantage of developing ecosystem accounts is that it integrates data that are otherwise scattered over many different institutions. For any given environmental analysis that requires such data (including by government agencies), getting access to these data is highly time consuming and this affects the moment at which the results of the analysis can be presented to policy makers. Developing ecosystem accounts, and making them easily available to a wide range of users including at the local level and including non-government agencies would provide a major support to environmental policy design and enforcement in the country.

This thesis demonstrates the applicability of the Ecosystem Accounting approach and develops several new insights on how to best map, value and account for ESs, and how to subsequently analyse land-use options on the basis of this information. Given the urgency and the importance of improving land-management practices in Central Kalimantan and Indonesia at large, it is hoped that the outcomes of this thesis can help in moving towards a more sustainable ecosystem management where also future generations will be able to earn an income from natural resources.

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APPENDICES

Appendix 2.1. Carbon data (ton C/ha) used in vegetation carbon mapping

Land cover	Above ground	Root	Dead wood	Litter	Total
Primary dryland forest	234.8[a]	43.2[b]	22.3[c]	7.5[d]	307.8
Secondary dryland forest	210.5[e]	39.2[b]	20.0[c]	6.7[d]	276.4
Primary peatland forest	141.0[f]	33.8[g]	25.5[h]	4.5[d]	204.8
Secondary peatland forest	126.0[i]	30.2[g]	22.8[h]	4.0[d]	183.0
Primary mangrove forest	124.3[j]	18.1[j]	18.6[j]	n.a.	161
Secondary mangrove forest	118.3[k]	17.2[l]	17.7[m]	n.a.	153.2
Plantation forest	91.2[n]	18.2[g]	n.a.	2.9[d]	112.3
Savannah	10[o]	2[g]	n.a.	n.a.	12
Oil palm	42.5[p]	8[t]	n.a.	n.a.	50.5
Crop /rice	4.8[q]	1.0[g]	n.a.	n.a.	5.8
Settlement	5[r]	1[g]	n.a.	n.a.	6
River/lake	0.1 [r]	n.a.	n.a.	n.a.	0.1
Bare/Imperata	3.6 [u]	4[u]	n.a.	n.a.	7.6
Jakaw (vegetation after shifting cultivation)	38.7 [q]	7.7[g]	3.7[c]	1.2[d]	51.3
Shrub	19.4[s]	3.9[g]	1.8 [c]	0.6 [d]	25.7
Agroforestry	55.1 [q]	11.0[g]	5.2 [c]	1.8 [d]	73.1

Notes: All values have been rounded
[a] Darmawan and Siregar (2009) as reviewed by Masripatin et al. (2010). [b] Estimated from above ground carbon based on the allometric equation from Chairns et al. (2007). [c] Estimated from above ground carbon based on the ratio from Yoneda et al. (1990) as reviewed by Verwer and van der Meer (2010). [d] Estimated from above ground carbon based on the average ratio from Delaney et al. (1997) and Brown et al., (1995) as reviewed by Verwer and van der Meer (2010). [e] Darmawan et al (2010) as reviewed by Masripatin et al. (2010). [f] The average from Waldes and Page (2002); Murdiyarso et al. (2009); MoFor (2008); Istomo et al. (2006); and Petrova et al. (2008) as reviewed by Verwer and van der Meer (2010). [g] Estimated from above ground carbon based on the ratio from GOFC-Gold (2009) as reviewed by Verwer and van der Meer (2010). [h] Estimated from above ground carbon based on the average ratio from Clark et al., 2002; Yoneda et al., 1990; Chambers et al., 2004; Brown et al., 1995; Pyle et al., 2008; Rice et al., 2004; Keller et al., 2004; and Palace et al., 2008 as reviewed by Verwer and van der Meer (2010). [i] Rochmayanto (2009) as reviewed by Masripatin et al. (2010). [J] Murdiyarso et al. (2009). [k] The average from Darmawan and Siregar (2009), Darmawan and Siregar (2008), reviewed by Masripatin et al., (2010). [l] Estimated from above ground carbon based on the ratio from Murdiyarso (2009). [m] Estimated from above ground carbon based on the ratio from Murdiyarso (2009). [n] Gintings (1997) as reviewed by Masripatin et al. (2010). [o] Peace, 2007 reviewed by Masripatin et al. (2010). [p] Khalid et al. (1999a). [q] Rahayu et al. (2003). [r] Amthor et al. (1998). [s] Lusiana (2005) as reviewed by Masripatin et al. (2010). [t] Khalid et al. (1999b). [u] Syahrinudin (2005).

Appendix 2.2. Carbon data used in soil carbon mapping

Dryland/Peatland	Depth	Soil types	Carbon (ton C/ha)
Dryland	n.a.	Soil under primary forest	37.2[a]
	n.a.	Soil under secondary forest	43.0[a]
	n.a.	Soil under grass/imperata	43.1[a]
	n.a.	others	43.1[b]
Mangrove	n.a.	Soil under mangrove	1059.2[c]
Peatland	< 50	hemist/mineral	26.6[d]
	50-100	hemist/fibrist	295.3[d]
		hemist/fibrist/mineral	231.8[d]
		hemist/mineral	166.0[d]
		hemist/saprist/mineral	349.0[d]
		saprist/mineral	105.3[d]
	100-200	hemist/fibrist	656.1[d]
		hemist/fibrist/saprist	990.8[d]
	200-400	hemist/fibrist	1158.3[d]
	400-800	hemist/fibrist	4638.3[d]
	800-1200	hemist/fibrist	7730.5[d]

Notes: All values have been rounded
[a] Van der Kamp et al. (2009). [b] Referred to grass. [c] Murdiyarso et al. (2009). [d] Wetland International (2004)

Appendix 2.3. Carbon data used in carbon sequestration mapping

Land cover	Net carbon flux; + indicates sequestration, - is emission (ton C/ha/year)	Sources
Mangrove	8.5[a]	Komiyama (2006)
Primary dipterocarps forest (protected forest)	0.8 [a]	Hirata et al. (2008)
Primary dipterocarps forest (production forest)	0.6 [a b]	Hirata et al. (2008)
Secondary dipterocarps forest/tropical rain forest (protected forest)	4.0 [a]	Luyssaert et al. (2007); Hirata et al. (2008); Saigusa et al. (2008)
Secondary dipterocarps forest/tropical rain forest (production forest)	3.7 [a b]	Luyssaert et al. (2007); Hirata et al. (2008); Saigusa et al. (2008)
Drained peat swamp forest (protected forest)	-4.3[c]	Hirano et al.(2007)
Drained peat swamp forest (production forest)	-4.6[b c]	Hirano et al. (2007)
Primary peat swamp forest (protected forest)	5.3 [a]	Suzuki et al. (1999)
Oil palm on mineral soil	-7.2[d]	Germer and Sauerborn (2008)
Oil palm on peat soil	-23.2[e]	Hooijer et al. (2006); Hooijer et al. (2010)
Grassland (imperata)	-0.4 [a]	Sanchez (2000)
Complex agroforest	2 [a]	Sanchez (2000) [f]
Crops on mineral soil	2 [a]	Sanchez (2000) [f]
Crops on drained peatland	-13 [a]	Hooijer et al., 2010
Shrubs on drained peatland	-4.1 [a]	Hooijer et al. (2006)

Notes: All values have been rounded
[a] based on Net Ecosystem Productivity (NEP) estimates; [b] wood harvest is considered using a wood density of 0.6 g/cm3 (Saner et al., 2012); [c] net emissions depend on the drainage depth that varies strongly for the individual peat land areas. The figure of -4.33 conservatively assumes a modest drainage of less than 10 cm; [d] from conversion of forest with burning, considering the carbon emission from forest clearing; [e] assuming a drainage of 90 cm in oil palm plantations in line with observed, general practices in Kalimantan. [f] conservative, low estimate in view of frequent occurrence of fires in Central Kalimantan.

Appendix 3.1. The avoided costs of orangutan habitat

Location*	Estimated population*	Estimated avoided costs (€)	Suitable area** (ha)	Estimated value (€/ha)
Bukit Baka and Bukit Raya NP	675	123,525	58,545	2.1
Tanjung Puting NP	6,000	1,098,000	188,679	5.8
Lamandau NR	1,200	219,600	32,273	6.8
Mawas NR	3,500	640,500	355,897	1.8
Sebangau NP (incl. Sebangau Kahayan)	7,600	1,390,800	454,937	3.1
Ketingan	3,000	549,000	274,030	2.0
Rungan Kahayan	1,000	183,000	46,093	4.0
Arut Belantikan	6,000	1,098,000	66,664	16.5
Seruyan	1,000	183,000	13,308	13.8
Kahayan and Sambah	1,000	183,000	16,571	11.0
Sambah and Katingan	500	91,500	9,730	9.4
Kahayan Kapuas	300	54,900	33,548	1.6
Tanjung Keluang NR	200	36,600	2,385	15.3
Pararawen NR	500	91,500	6,617	13.8
Sapat Hawung NR	500	91,500	92,072	1.0

*Based on Wich et al. (2008)

**Generated from Maxent modeling with an optimum threshold of 0.24

Appendix 3.2a. NPV of FFB production on peat soil, modified from Fairhurst and McLaughlin (2009) with a discount rate of 8%, 10%, and12%, values are rounded.

Year		0	1	2	3	4	5	6	7	8	9	10
FFB yield	ton/ha	0	0	0	5	10	15	20	24	26	27	27
FFB price	€/ton	123	123	123	123	123	123	123	123	123	123	123
Revenue	€/ha	0	0	0	613	1225	1838	2450	2940	3185	3308	3308
Planting and other farming costs	€/ha	949	1770	614	1092	639	639	639	639	639	639	639
Harvesting and transportation costs	€/ha	0	0	0	33	67	100	133	160	173	180	180
Depreciation cost	€/ha	0	0	0	83	165	165	165	165	165	165	165
Costs of fixed assets	€/ha	0	0	0	289	281	264	248	231	215	198	182
Total costs	€/ha	949	1770	614	1496	1151	1168	1185	1195	1192	1182	1166
Total costs 2010	€/ha	1083	2020	701	1707	1314	1333	1352	1364	1360	1349	1330
Resource rent	€/ha	-1083	-2020	-701	-1095	-89	505	1098	1576	1825	1959	1977
PV (discount rate 8 %)	€/ha	-1083	-1870	-601	-869	-65	343	692	920	986	980	916
PV (discount rate 10 %)	€/ha	-1083	-1836	-579	-823	-61	313	620	809	851	831	762
PV (discount rate 12 %)	€/ha	-1083	-1803	-559	-779	-56	286	556	713	737	706	637

Year		11	12	13	14	15	16	17	18	19	20	NPV
FFB yield	ton/ha	27	27	27	27	27	26	25	24	23	22	
FFB price	€/ton	123	123	123	123	123	123	123	123	123	123	
Revenue	€/ha	3308	3308	3308	3308	3246	3185	3063	2940	2818	2695	
Planting and other farming costs	€/ha	639	639	639	639	639	639	639	639	639	639	
Harvesting and transportation costs	€/ha	180	180	180	180	177	173	167	160	153	147	
Depreciation cost	€/ha	165	165	165	165	165	165	165	165	165	165	
Costs of fixed assets	€/ha	165	149	132	116	99	83	66	50	33	17	
Total costs	€/ha	1149	1133	1116	1100	1080	1060	1037	1014	991	967	
Total costs 2010	€/ha	1311	1292	1274	1255	1232	1210	1183	1157	1130	1104	
Resource rent	€/ha	1996	2015	2034	2053	2014	1975	1879	1783	1687	1591	
PV (discount rate 8 %)	€/ha	856	800	748	699	635	577	508	446	391	341	6349
PV (discount rate 10 %)	€/ha	700	642	589	541	482	430	372	321	276	237	4393
PV (discount rate 12 %)	€/ha	574	517	466	420	368	322	274	232	196	165	2889

Appendix 3.2b. NPV of FFB production on mineral soil, modified from Fairhurst and McLaughlin (2009) with a discount rate of 8%, 10%, and 12%, values are rounded.

Year		0	1	2	3	4	5	6	7	8	9	10
FFB yield	ton/ha	0	0	0	5	10	15	20	24	26	27	27
FFB price	€/ton	123	123	123	123	123	123	123	123	123	123	123
Revenue	€/ha	0	0	0	613	1225	1838	2450	2940	3185	3308	3308
Planting and other farming costs	€/ha	949	959	614	1092	639	639	639	639	639	639	639
Harvesting and transportation costs	€/ha	0	0	0	33	67	100	133	160	173	180	180
Depreciation cost	€/ha	0	0	0	41	83	83	83	83	83	83	83
Costs of fixed assets	€/ha	0	0	0	144	140	132	124	116	107	99	91
Total costs	€/ha	949	959	614	1311	929	954	979	997	1002	1001	992
Total costs 2010	€/ha	1083	1094	701	1496	1060	1088	1117	1138	1144	1142	1132
Resource rent	€/ha	-1083	-1094	-701	-883	165	749	1333	1802	2041	2166	2175
PV (discount rate 8 %)	€/ha	-1083	-1013	-601	-701	122	510	840	1052	1103	1083	1007
PV (discount rate 10 %)	€/ha	-1083	-995	-579	-663	113	465	753	925	952	918	839
PV (discount rate 12 %)	€/ha	-1083	-977	-559	-629	105	425	675	815	824	781	700

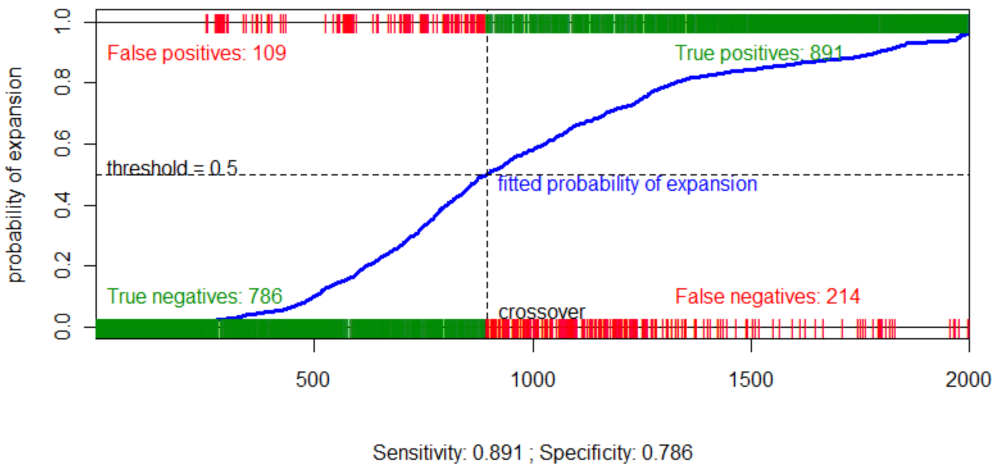
Year		11	12	13	14	15	16	17	18	19	20	NPV
FFB yield	ton/ha	27	27	27	27	27	26	25	24	23	22	
FFB price	€/ton	123	123	123	123	123	123	123	123	123	123	
Revenue	€/ha	3308	3308	3308	3308	3246	3185	3063	2940	2818	2695	
Planting and other farming costs	€/ha	639	639	639	639	639	639	639	639	639	639	
Harvesting and transportation costs	€/ha	180	180	180	180	177	173	167	160	153	147	
Depreciation cost	€/ha	83	83	83	83	83	83	83	83	83	83	
Costs of fixed assets	€/ha	83	74	66	58	50	41	33	25	17	8	
Total costs	€/ha	984	976	968	959	948	936	921	906	892	877	
Total costs 2010	€/ha	1123	1114	1104	1095	1082	1068	1051	1034	1017	1000	
Resource rent	€/ha	2184	2194	2203	2213	2165	2117	2011	1906	1800	1695	
PV (discount rate 8 %)	€/ha	937	871	810	753	682	618	544	477	417	364	8792
PV (discount rate 10 %)	€/ha	766	699	638	583	518	461	398	343	294	252	6596
PV (discount rate 12 %)	€/ha	628	563	505	453	395	345	293	248	209	176	4894

Appendix 4.1a. Coefficients and P values of predictors

Predictors	Coefficients	P values
Intercept	2.76e+00	< 2e16****
Elevation	-1.685e-02	< 2e-16****
distance to roads	-9.477e-06	0.193537
distance to rivers	1.048e-04	4.02e-07****
distance to settlements	-6.139e-05	< 2e16****
distance to existing oil palms	-3.572e-05	< 2e16****
soil type (peat)	-6.432e-01	0.000535****

Significant codes: ‘****’ 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

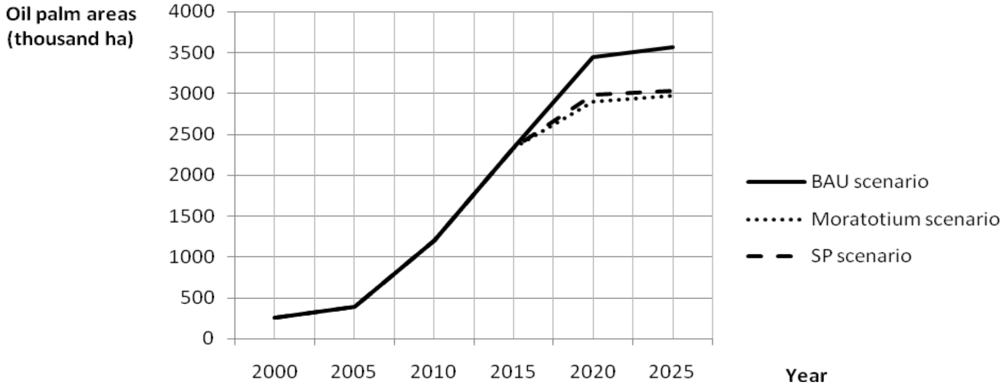
Appendix 4.1b. The success of logistic regression model



The accuracy of the model was analysed by measuring its sensitivity, specificity and AUC (Area under the ROC curve). The ROC is a graph of “sensitivity” versus (1- “specificity”) at different thresholds. The “sensitivity” denotes the ability of the model to correctly predict the presence of oil palm expansion at specific threshold, while the “specificity” does for the absence of the expansion. The maximum value of the AUC is 1 which represents a perfect accuracy. The accuracy assessment was analysed using an “R” script of Rossiter (2014).

The graph presents the success of the model with a sensitivity of 0.89 (891 out of 1000 presence points are correctly predicted) and a specificity of 0.79 (786 out of 1000 absence points are correctly predicted) at a threshold of 0.5. Overall, the AUC of the model is 0.9. This indicates the goodness of fit of the model, and the appropriateness of the model to be applied for predicting the oil palm expansion in the future.

Appendix 4.2. Oil palm expansion from 2000 to 2025 according to three scenarios.



Appendix 4.3. Carbon balances for oil palm establishment on different land cover and soil types, + indicates sequestration, - is emission. The estimates are for the first cycle (25 years) of oil palm plantation.

	Land clearing (ton C/ha)	Change in soil carbon or peat decomposition (ton C/ha/year)	Fixation in oil palm plantation (ton C/ha/year)	Carbon balances (ton C/ha)	
				for 25 years	Average per year
Oil palm on peat	-176.7 (forests conversion), -11.7 (non-forests conversion)[a]	-27.2[b]	1.4[a]	-821.5 (forests conversion), -656.5 (non-forests conversion)	-32.8 (forests conversion), -26.3 (non-forests conversion)
Oil palm on mineral soil	-176.7 (forests conversion), -11.7 (non-forests conversion)[a]	-1.6 (forest conversion), 0.5 (non-forests conversion)[a]	1.4[a]	-182.5 (forests conversion), 36.5 (non-forests conversion)	-7.3 (forests conversion), 1.5 (non-forests conversion)

[a] average estimates of Germer and Sauerborn (2008) / [b] Page et al. (2011)

Carbon balances of land conversion for oil palm depend on three aspects: land clearing, change in soil carbon, and carbon fixation by oil palm. Land clearing removes biomass (carbon) stored in former land covers (usually by burning), where conversion of forests produces higher carbon emissions. Change in soil carbon represents a balance between carbon emissions from decomposition of soil organic matter and carbon fixation from formation of soil organic matter. Oil palm establishment on peat soil, which is composed by accumulation of organic matter in a water-logged condition, requires drainage, which subsequently leads to very high carbon emissions from organic matter decomposition. The last aspect, i.e. carbon fixation by oil palm, refers to the net amount of carbon sequestered by oil palm during photosynthesis and respiration.

Appendix 4.4a. Value trade-offs of ecosystem services from oil palm expansion in the period 2015 – 2025 under the BAU scenario, negative value indicates reduction, values are rounded

Types of ecosystem services	Change of area (ha)	Productivity/ quantity	Monetary value	Change of value (€/year)
Oil palm on mineral soil (5 years old)	78,200	Productivity of 3.6 ton FFB/ha/year	Resource rent of € -646/ ha/year (during year 0 – 4)	-50,517,200
OP mineral soil (10 years old)	614,600	Productivity of 15.2 ton FFB/ha/year	Resource rent of € 761/ ha/year (during year 0 – 9)	467,710,600
Oil palm on peat soil (5 years old)	45,500	Productivity of 3.6 ton FFB/ha/year	Resource rent of € -924/ ha/year (during year 0 – 4)	-42,042,000
Oil palm on peat soil (10 years old)	495,600	Productivity of 15.2 ton FFB/ha/year	Resource rent of € 509/ ha/year (during year 0 – 9)	252,260,400
Oil palm total				627,411,800
Timber	-363,200	Productivity of 0.86 m^3/ha/year	Resource rent of € 35/m^3	-10,932,320
rattan	-428,000	Productivity of 0.79 ton/ha/year	Resource rent of €104/ton	-35,164,480
rice	-223,000	Productivity of 2.2 ton/ha/year	Resource rent of €130/ton	-63,778,000
Carbon balance (conversion of forest on mineral soil)	219,770	Net emissions of 7.3 ton C/ha/year	Social costs of € 88/ton C	-151,079,630
Carbon balance (conversion of non-forest on mineral soil)	440,830	Net sequestration of 1.5 ton C/ha/year	Avoided social costs of € 88/ton C	60,413,100
Carbon balance (conversion of forest in peat soil)	236,110	Net emissions of 32.8 ton C/ha/year	Social costs of € 88/ton C	-619,698,534
Carbon balance (conversion of non-forest on mineral soil)	367,650	Net emissions of 26.3 ton C/ha/year	Social costs of € 88/ton C	-755,253,523
Carbon balance total				-1,465,618,590

Appendix 4.4b. Value trade-offs of ecosystem services from oil palm expansion in the period 2015 – 2025 under the M scenario, negative value indicates reduction, values are rounded

Types of ecosystem services	Change of area (ha)	Productivity/ quantity	Monetary value	Change of value (€/year)
Oil palm on mineral soil (5 years old)	76,700	Productivity of 3.6 ton FFB/ha/year	Resource rent of € -646/ ha/year (during year 0 – 4)	-49,548,200
Oil palm on mineral soil (10 years old)	561,100	Productivity of 15.2 ton FFB/ha/year	Resource rent of € 761/ ha/year (during year 0 – 9)	426,997,100
Oil palm on peat soil (5 years old)	0	Productivity of 3.6 ton FFB/ha/year	Resource rent of € -924/ ha/year (during year 0 – 4)	0
Oil palm on peat soil (10 years old)	0	Productivity of 15.2 ton FFB/ha/year	Resource rent of € 509/ ha/year (during year 0 – 9)	0
Oil palm total				377,448,900
Timber	-209,100	Productivity of 0.86 m^3/ha/year	Resource rent of € 35/m^3	-6,293,910
rattan	-390,000	Productivity of 0.79 ton/ha/year	Resource rent of €104/ton	-32,042,400
rice	-123,000	Productivity of 2.2 ton/ha/year	Resource rent of €130/ton	-35,178,000
Carbon balance (conversion of forest on mineral soil)	212,000	Net emissions of 7.3 ton C/ha/year	Social costs of € 88/ton C	-136,188,800
Carbon balance (conversion of non-forest on mineral soil)	425,800	Net sequestration of 1.5 ton C/ha/year	Avoided social costs of € 88/ton C	56,205,600
Carbon balance (conversion of forest in peat soil)	0	Net emissions of 32.8 ton C/ha/year	Social costs of € 88/ton C	0
Carbon balance (conversion of non-forest on mineral soil)	0	Net emissions of 26.3 ton C/ha/year	Social costs of € 88/ton C	0
Carbon balance total				-79,983,200

Appendix 4.4c. Value trade-offs of ecosystem services from oil palm expansion in the period 2015 – 2025 under the SP scenario, negative value indicates reduction, values are rounded

Types of ecosystem services	Change of area (ha)	Productivity/quantity	Monetary value	Change of value (€/year)
Oil palm on mineral soil (5 years old)	48,300	Productivity of 3.6 ton FFB/ha/year	Resource rent of € -646/ ha/year (during year 0 – 4)	-31,201,800
Oil palm on mineral soil (10 years old)	650,300	Productivity of 15.2 ton FFB/ha/year	Resource rent of € 761/ ha/year (during year 0 – 9)	494,878,300
Oil palm on peat soil (5 years old)	0	Productivity of 3.6 ton FFB/ha/year	Resource rent of € -924/ ha/year (during year 0 – 4)	0
Oil palm on peat soil (10 years old)	0	Productivity of 15.2 ton FFB/ha/year	Resource rent of € 509/ ha/year (during year 0 – 9)	0
Oil palm total				463,676,500
Timber	0	Productivity of 0.86 m^3/ha/year	Resource rent of € 35/m^3	0
rattan	0	Productivity of 0.79 ton/ha/year	Resource rent of €104/ton	0
rice	0	Productivity of 2.2 ton/ha/year	Resource rent of €130/ton	0
Carbon balance (conversion of forest on mineral soil)	0	Net emissions of 7.3 ton C/ha/year	Social costs of € 88/ton C	0
Carbon balance (conversion of non-forest on mineral soil)	698,600	Net sequestration of 1.5 ton C/ha/year	Avoided social costs of € 88/ton C	92,215,200
Carbon balance (conversion of forest in peat soil)	0	Net emissions of 32.8 ton C/ha/year	Social costs of € 88/ton C	0
Carbon balance (conversion of non-forest on mineral soil)	0	Net emissions of 26.3 ton C/ha/year	Social costs of € 88/ton C	0
Carbon balance total				92,215,200

Appendix 5.1a. NPV of FFB production in mineral soil, modified from Fairhurst and McLaughlin (2009) with a discount rate of 10% and FFB price of € 130/ton, values are rounded.

Year		0	1	2	3	4	5	6	7	8	9	10
FFB yield	ton/ha	0	0	0	5	10	15	20	24	26	27	27
FFB price	€/ton	130	130	130	130	130	130	130	130	130	130	130
Gross revenue	€/ha	0	0	0	650	1300	1950	2600	3120	3380	3510	3510
Planting and other farming costs	€/ha	1083	1094	701	1246	729	729	729	729	729	729	729
Land lease costs	€/ha	342	0	0	0	0	0	0	0	0	0	0
Harvesting costs	€/ha	0	0	0	38	76	114	152	183	198	205	205
Depreciation cost	€/ha	0	0	0	47	94	94	94	94	94	94	94
Costs of fixed assets	€/ha	0	0	0	165	160	151	141	132	122	113	104
Total costs	€/ha	1425	1094	701	1496	1060	1088	1117	1138	1144	1142	1132
Net benefit	€/ha	-1425	-1094	-701	-846	240	862	1483	1982	2236	2368	2378
PV	€/ha	-1425	-995	-579	-635	164	535	837	1017	1043	1004	917

Year		11	12	13	14	15	16	17	18	19	20	NPV
FFB yield	ton/ha	27	27	27	27	27	26	25	24	23	22	
FFB price	€/ton	130	130	130	130	130	130	130	130	130	130	
Gross revenue	€/ha	3510	3510	3510	3510	3445	3380	3250	3120	2990	2860	
Planting and other farming costs	€/ha	729	729	729	729	729	729	729	729	729	729	
Land lease costs	€/ha	0	0	0	0	0	0	0	0	0	0	
Harvesting costs	€/ha	205	205	205	205	202	198	190	183	175	167	
Depreciation cost	€/ha	94	94	94	94	94	94	94	94	94	94	
Costs of fixed assets	€/ha	94	85	75	66	56	47	38	28	19	9	
Total costs	€/ha	1123	1114	1104	1095	1082	1068	1051	1034	1017	1000	
Net benefit	€/ha	2387	2396	2406	2415	2363	2312	2199	2086	1973	1860	
PV	€/ha	837	764	697	636	566	503	435	375	323	276	7294

Note: This NPV applies for oil palm production in the period of 2011, after 25 years and after 50 years

Appendix 5.1b. NPV of FFB production on peat soil with no flooding problems, modified from Fairhurst and McLaughlin (2009) and FFB price of € 130/ton with a discount rate of 10%, values are rounded.

Year		0	1	2	3	4	5	6	7	8	9	10
FFB yield	ton/ha	0	0	0	5	10	15	20	24	26	27	27
FFB price	€/ton	130	130	130	130	130	130	130	130	130	130	130
Revenue	€/ha	0	0	0	650	1300	1950	2600	3120	3380	3510	3510
Planting, drainage and other farming costs	€/ha	1082	2018	700	1245	729	729	729	729	729	729	729
Land lease costs	€/ha	342	0	0	0	0	0	0	0	0	0	0
Harvesting and transportation costs	€/ha	0	0	0	38	76	114	152	182	198	205	205
Depreciation cost	€/ha	0	0	0	94	188	188	188	188	188	188	188
Costs of fixed assets	€/ha	0	0	0	329	320	301	282	263	245	226	207
Total costs	€/ha	1424	2018	700	1706	1313	1332	1351	1362	1359	1348	1329
Net benefit	€/ha	-1424	-2018	-700	-1056	-13	618	1249	1758	2021	2162	2181
PV	€/ha	-1424	-1834	-579	-793	-9	384	705	902	943	917	841

Year		11	12	13	14	15	16	17	18	19	20	NPV
FFB yield	ton/ha	27	27	27	27	27	26	25	24	23	22	
FFB price	€/ton	130	130	130	130	130	130	130	130	130	130	
Revenue	€/ha	3510	3510	3510	3510	3445	3380	3250	3120	2990	2860	
Planting, drainage and other farming costs	€/ha	729	729	729	729	729	729	729	729	729	729	
Land lease costs	€/ha	0	0	0	0	0	0	0	0	0	0	
Harvesting and transportation costs	€/ha	205	205	205	205	201	198	190	182	175	167	
Depreciation cost	€/ha	188	188	188	188	188	188	188	188	188	188	
Costs of fixed assets	€/ha	188	169	150	132	113	94	75	56	38	19	
Total costs	€/ha	1310	1291	1272	1254	1231	1208	1182	1156	1129	1103	
Net benefit	€/ha	2200	2219	2238	2256	2214	2172	2068	1964	1861	1757	
PV	€/ha	771	707	648	594	530	473	409	353	304	261	5104

Note: This NPV applies for oil palm production in the period of 2011, after 25 years and after 50 years

Appendix 5.1c. NPVs of FFB production under increasing flood risks within a plantation cycle in the period of 2011, after 25 years and after 50 years

Number of years (no flooding – impaired drainability)	21-0	20-1	19-2	18-3	17-4	16-5	15-6	14-7	13-8	12-9	11-10
NPV (€/ha)	5104	4998	4875	4735	4574	4390	4184	3953	3699	3419	3112
Number of years (impaired drainability – prolonged flooding)	21-0	20-1	19-2	18-3	17-4	16-5	15-6	14-7	13-8	12-9	11-10
NPV (€/ha)	593	487	365	224	64	0	0	0	0	0	0
Number of years (prolonged flooding – near-permanent inundation)	21-0	20-1	19-2	18-3	17-4	16-5	15-6	14-7	13-8	12-9	11-10
NPV (€/ha)	0	0	0	0	0	0	0	0	0	0	0

Number of years (no flooding – impaired drainability)	10-11	9-12	8-13	7-14	6-15	5-16	4-17	3-18	2-19	1-20
NPV (€/ha)	2773	2401	2007	1607	1240	937	715	593	593	593
Number of years (impaired drainability – prolonged flooding)	10-11	9-12	8-13	7-14	6-15	5-16	4-17	3-18	2-19	1-20
NPV (€/ha)	0	0	0	0	0	0	0	0	0	0
Number of years (prolonged flooding – near-permanent inundation)	10-11	9-12	8-13	7-14	6-15	5-16	4-17	3-18	2-19	1-20
NPV (€/ha)	0	0	0	0	0	0	0	0	0	0

Note: Given the assumptions on subsidence rate and drainage levels used in this study, the maximum peat subsidence in a plantation cycle is about 70 cm, hence an area will experience maximum two flood risks (no flooding - impaired drainability, impaired drainability - prolonged flooding, or prolonged flooding – near-permanent inundation).

Appendix 5.1d. NPV of Jelutung production (€/ha), modified from Harun (2011) with a discount rate of 10%, values are rounded.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Revenue	0	0	0	0	0	0	0	0	0	0	56	56	101	101	182	182
Equipments and inputs	0	102	125	163	142	131	125	125	135	125	190	128	167	128	157	128
Land lease costs	342	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Land preparation costs	127	364	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Planting	0	50	10	0	0	0	0	0	0	0	0	0	0	0	0	0
Plant maintenance	0	18	18	18	18	18	68	309	18	18	18	13	63	304	13	13
Total costs	469	534	153	180	159	149	193	434	153	143	207	140	230	432	169	140
Net value	-469	-534	-153	-180	-159	-149	-193	-434	-153	-143	-151	-84	-128	-330	13	42
PV	-469	-485	-126	-135	-109	-92	-109	-223	-71	-60	-58	-29	-41	-96	3	10

	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	NPV
Revenue	328	328	590	590	1063	1063	1913	1913	3444	3444	6199	6199	11158	11158	35834	
Equipments and inputs	167	128	157	128	196	128	157	128	167	128	157	128	167	128	159	
Land lease costs	342	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Land preparation costs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Planting	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Plant maintenance	13	13	63	13	13	13	13	13	13	13	13	13	13	13	13	
Total costs	180	140	219	140	209	140	169	140	180	140	169	140	180	140	172	
Net value	148	188	371	450	854	923	1744	1773	3264	3304	6030	6059	10978	11018	35662	
PV	32	37	67	74	127	125	214	198	331	305	506	462	761	695	2044	3887

Appendix 5.1e. NPVs of carbon sequestration (€/ha), values are rounded.

Year	0	1	2	3	4	5	6	7	8	9	10
C sequestration of oil palm in mineral soil (ton C/ha/year)	2	2	2	2	2	2	2	2	2	2	2
SCC (€/ton C)	103	103	103	103	103	103	103	103	103	103	103
Value of C sequestration (€/ha/year)	196	196	196	196	196	196	196	196	196	196	196
PV (€/ha)	196	178	162	147	134	122	110	100	91	83	75
C sequestration of oil palm on peat (ton C/ha/year)	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
SCC (€/ton C)	103	103	103	103	103	103	103	103	103	103	103
Value of C sequestration (€/ha/year)	-1545	-1545	-1545	-1545	-1545	-1545	-1545	-1545	-1545	-1545	-1545
PV (€/ha)	-1545	-1405	-1277	-1161	-1055	-959	-872	-793	-721	-655	-596
C sequestration of peat and Jelutung forest (ton C/ha/year)	5	5	5	5	5	5	5	5	5	5	5
SCC (€/ton C)	103	103	103	103	103	103	103	103	103	103	103
Value of C sequestration (€/ha/year)	546	546	546	546	546	546	546	546	546	546	546
PV (€/ha)	546	496	451	410	373	339	308	280	255	232	210

Year	11	12	13	14	15	16	17	18	19	20	NPV
C sequestration of oil palm in mineral soil (ton C/ha/year)	2	2	2	2	2	2	2	2	2	2	
SCC (€/ton C)	103	103	103	103	103	103	103	103	103	103	
Value of C sequestration (€/ha/year)	196	196	196	196	196	196	196	196	196	196	
PV (€/ha)	69	62	57	52	47	43	39	35	32	29	1862
C sequestration of oil palm on peat (ton C/ha/year)	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	
SCC (€/ton C)	103	103	103	103	103	103	103	103	103	103	
Value of C sequestration (€/ha/year)	-1545	-1545	-1545	-1545	-1545	-1545	-1545	-1545	-1545	-1545	
PV (€/ha)	-542	-492	-448	-407	-370	-336	-306	-278	-253	-230	-14698
C sequestration of peat and Jelutung forest (ton C/ha/year)	5	5	5	5	5	5	5	5	5	5	
SCC (€/ton C)	103	103	103	103	103	103	103	103	103	103	
Value of C sequestration (€/ha/year)	546	546	546	546	546	546	546	546	546	546	
PV (€/ha)	191	174	158	144	131	119	108	98	89	81	5193

Appendix 5.2. Total NPV of FFB production under increasing flood risks in the first plantation cycle of the ‘OP’ scenario.

Number of years (no flooding – impaired drainability)	21-0	20-1	19-2	18-3	17-4	16-5	15-6	14-7	13-8	12-9	11-10
Area (ha)	140,600	1,200	1,200	1,300	1,200	1,300	1,200	1,300	1,300	1,300	1,300
NPV (€/ha)	4063	3963	3848	3715	3563	3390	3196	2979	2739	2476	2186
NPV (€ million)	717.6	6.1	6.1	6.0	5.7	5.5	5.2	5.0	4.7	4.5	4.1
Number of years (impaired drainability – prolonged flooding)	21-0	20-1	19-2	18-3	17-4	16-5	15-6	14-7	13-8	12-9	11-10
Area (ha)	30,000	2,700	2,100	2,900	2,200	5,400	0	3,100	2,300	3,000	2,200
NPV (€/ha)	593	487	365	224	64	0	0	0	0	0	0
NPV (€ million)	18	1.3	0.8	0.6	0.1	0	0	0	0	0	0
Total NPV (€ million)											

Number of years (no flooding – impaired drainability)	10-11	9-12	8-13	7-14	6-15	5-16	4-17	3-18	2-19	1-20	
Area (ha)	1,300	1,300	1,400	1,400	1,400	1,500	1,500	1,500	1,600	1,600	
NPV (€/ha)	1867	1516	1145	768	421	136	0	0	0	0	
NPV (€ million)	3.7	3.2	2.8	2.3	1.8	1.4	1.1	1.0	0.9	0.9	790
Number of years (impaired drainability – prolonged flooding)	10-11	9-12	8-13	7-14	6-15	5-16	4-17	3-18	2-19	1-20	
Area (ha)	2,900	2,100	2,700	2,000	2,600	2,000	2,800	2,100	2,900	2,200	
NPV (€/ha)	0	0	0	0	0	0	0	0	0	0	
NPV (€ million)	0	0	0	0	0	0	0	0	0	0	21
Total NPV (€ million)											811

SUMMARY

Ecosystem accounting is a new area of environmental economic accounting that aims to measure ecosystem services in a way that is in line with national accounts. The key characteristics of ecosystem accounting include the extension of the valuation boundary of the System of National Accounts, allowing the inclusion of a broader set of ecosystem services types such regulating services and cultural services. Consistent with the principles of national account, ecosystem accounting focuses on assessment of the contribution of ecosystem in generating benefits for human well-being. Those valuation characteristics allow ecosystem accounting to explicitly visualize the comprehensive values of ecosystem contribution, and integrate them in a standardized national account.

There is a wide range of potential application of ecosystem accounting in natural resource management and environmental preservation. This includes the provision of basic data on the values of multiple ecosystem services (both in terms of physical quantities and monetary values), monitoring ecosystem services dynamics, analyzing impacts of land-use change and land management on the trade-offs of ecosystem services, and development of ecosystem services based land-use planning. Ecosystem accounting approach has also been widely involved in addressing critical environmental issues such as deforestation, GHG emissions, and biodiversity conservation.

Considering the spatial heterogeneity of ecosystem services distribution, spatial analysis is a key element in ecosystem accounting. The availability of spatial information of the values of ecosystem services creates opportunity for a broad range of applications required for land-use planning and management, such as identification of areas with high variability of ecosystem services (often called as ecosystem services hotspots) and areas with high aggregate values of ecosystem services, identification of ecosystem services supply and ecosystem services demand interaction, and analysing the impacts of land-use change on the trade-offs of ecosystem services. Most importantly, spatial information of a comprehensive set of ecosystem services values allows land-use planners to analyse the relationship between any options of land management and the existence of a combination of ecosystem services, hence the best management type which optimize the provision of ecosystem services can be formulated.

The objective of this thesis is to develop an ecosystem services approach to land-use planning through integration of ecosystem accounting and spatial modelling, with a specific case study on deforestation and oil palm expansion in Central Kalimantan Indonesia. The main motivations of this study includes the high rate of deforestation and oil palm expansion in Central Kalimantan, the environmental degradation related to the deforestation such as greenhouse gas emissions and biodiversity loss, the uncertainty of provincial land-use planning, and the lack of experiences on the integration of ecosystem accounting in land-use planning.

In chapter 2 of this thesis, seven key ecosystem services (timber production, rattan production, oil palm production, paddy rice production, carbon storage, carbon

sequestration, and wildlife habitat) are assessed and mapped at a provincial scale. The ecosystem services are assessed in term of physical quantities. Three mapping techniques are applied: spatial interpolation, lookup tables, and Maximum Entropy (Maxent) modelling. An ecosystem services based land-use planning is tested using the seven ecosystem services maps to identify areas for oil palm expansion. This study shows that selection of the best spatial modelling technique for ecosystem services mapping highly depends on the availability of input data and the characteristics of spatial distribution of ecosystem services. This study also demonstrates the significant support of spatial information of ecosystem services in provincial land-use planning.

In chapter 3, six ecosystem services mapped in chapter 2 (timber production, rattan production, oil palm production, paddy rice production, carbon sequestration, and wildlife habitat) are valued in monetary terms. The valuation also includes additional cultural service, i.e. nature recreation. Two valuation methods consistent with the principles of ecosystem accounts are applied: resource rent valuation and costs based approach. The monetary values of ecosystem services are then mapped, allowing analysis on the aggregate values of the seven ecosystem services in different land-use types. This study shows the capability of resource rent valuation in filtering and visualizing the value of ecosystem contribution in providing benefits that have market values, and the applicability of a costs based approach for carbon sequestration valuation. However, application of the cost based approach is considered inappropriate in monetary valuation of biodiversity habitat, and further improvement is required. This study also shows how the trade-offs of ecosystem services from the past and the potential land-use change can be analyzed based on the spatial information of monetary values of ecosystem services.

Chapter 4 of this thesis presents land-use change modelling, with a specific case of modelling oil palm expansion in Central Kalimantan. An integrated deductive inductive modelling is developed, using logistic regression and scenario based modelling. The scenarios used in the modelling consist of two scenarios reflecting the past and the current policies on oil palm expansion, i.e. a business as usual scenario and a moratorium scenario, and one alternative scenario, i.e. the sustainable production scenario, developed based on stakeholder workshop and ecosystem services approach studied in chapter 2. Based on the monetary values of ecosystem services valued and mapped in chapter 3, the societal costs and benefits of oil palm expansion based on the three policy scenarios are then analyzed. The model forecasts the continuation of strong oil palm expansion in the period 2015 – 2020, in particular in case of the business as usual scenario, and forecasts that oil palm expansion would level off in the period 2020 – 2025 in all three scenarios. In the business as usual scenario, this expansion would lead to substantial net costs to society resulting from a loss of ecosystem services, particularly from carbon emission emissions. The sustainable production scenario provides the highest net benefits to society, however, implementation of this scenario requires fundamental change of current land-use policy.

Chapter 5 presents hydrological and economic impacts of oil palm development on peat, with a case study in the ex mega rice project area, Central Kalimantan.

Hydrological aspect of oil palm development have not been studied in the previous chapters, and this chapter addresses this aspect through modelling three types of flooding on drained peatland for oil palm: impaired drainability, frequent flooding, and near permanent inundation. The model integrates current knowledge on subsidence rates and drinage limits, and uses a high resolution LiDAR DEM. The results of the model are presented up to 2136. The economic impacts are analysed through two land-use scenarios: the oil palm scenario assuming all peatlands in the study area will be converted into oil palm, and the mix scenario combining natural forest preservation, jelutung forest development and oil palm plantation. This study shows that in 100 years' time only around 10% of the area would still be suitable for oil palm. This study also shows that under the first scenario, the social costs of carbon emissions considerably outweigh the benefits of oil palm production. In term of private benefits, the mixed land-use option scores better even at the first plantation cycle. The mix land-use scenario also potentially preserve about 84,000 ha habitat for orangutan. This study provides useful inputs for a comprehensive analysis on the sustainability of oil palm development on peatland.

In general this thesis demonstrates the significant contribution of ecosystem accounting and spatial modelling for land-use planning. Valuation methods and spatial modelling techniques developed in this study provide basis for completing ecosystem accounting in Central Kalimantan, with potential applicability in other regions. By addressing the critical environmental issues in Central Kalimantan, i.e. deforestation and oil palm expansion and their environmental and economic impacts, this study contributes to formulate a better land-use management, which facilitates the need for oil palm development while maintaining the provision of important ecosystem services.

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I am not a true 'Wageningener' in doing this PhD. Only about half of the PhD period I spent in Wageningen, in six times visits. I thank all members of ESA for the great working atmosphere at ESA, which made my Wageningen time as the time to be more productictive, but always enjoyable.Thanks to Matthias, Roy, Maryna and Mengru for organizing lunch presentation, from which I was benefited, particularly from the critical responses to my presentations and all papers I prepared. In particular, I thank Ria Cuperus and Mathilde Witteveen for taking care of the crucial administrative things for my visits: flight ticket, housing and residence permit. Mathilde's helps in printing my thesis draft for reading committee and delivering this thesis to promotion secretariat crucially ensured that I defend this thesis as scheduled.

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Curriculum Vitae

Elham Sumarga was born on the 29th of December 1970 in Madiun, Indonesia. He spent 12 years of his primary and secondary schools in Magetan, Indonesia. In 1989, Elham took a BSc at Bogor Agricultural University (IPB), Indonesia with a specialization on Forest Resource Conservation. After his graduation in 1995, he worked at Winaya Mukti University, Bandung, Indonesia as a junior lecturer and researcher. During 1997-2000, Elham took an MSc in Biology at Institut Teknologi Bandung, Indonesia. He did a research on population dynamics and sustainable use of rattans in Bukit Tigapuluh National Park. Elham was awarded a StuNed sholarship in 2006 to participate in a Master study at the International Institute for Geoinformation and Earth Observation (ITC), Enschede, the Netherlands, with a specialization on Forestry for Sustatinable Development. He did a one month fieldwork at Ruvu North Forest Reserve, Tanzania for his Master thesis, in which he analyzed forest cover change, mapped forest carbon, and modelled wood extraction risks at the forest reserve. In 2009, Elham won a second StuNed scholarship to take an MSc at the University of Twente, the Netherlands. For his MSc thesis, Elham did a one month intensive survey in Pizzalto Mountain, Italy to compare three modelling techniques (logistic regression, Maxent and geostatistics) to map the distribution of an endemic *Acer*. After his graduation in 2011, Elham joined the School of Life Science and Technology, Institut Teknologi Bandung, Indonesia. At the same year, Elham started his PhD at the Environmental System Analysis, Wageningen University. His PhD research focused on spatial modelling and ecosystem accounting in support of land use planning, fully funded by the European Research Council (ERC) through the Ecospace project. His PhD research dealt with specific cases of deforestation and oil palm expansion in Central Kalimantan, with potential applications for resource management in other places in Indonesia and other countries.

Publications

Sumarga, E., Hein, L., 2015. Benefits and costs of oil palm expansion in Central Kalimantan, Indonesia, under different policy scenarios. Regional Environmental Change DOI 10.1007/s10113-015-0815-0.

Schröter, M., Remme, R.P., **Sumarga, E**., Barton, D.N., Hein, L., 2015. Lessons learned for spatial modelling of ecosystem services in support of ecosystem accounting. Ecosystem Services 13: 64-69.

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- Sixth ALTER-net summer school 'Biodiversity and ecosystem services: an interdisciplinary perspectives', ALTER-net, Peyresq, France (2011)

Oral Presentations

- *Mapping multiple ecosystem services: an approach for analysing deforestation impacts.* Indonesian Scholars International Convention (ISIC2012), 9-10 November 2012, London, United Kingdom
- *Land use change and ecosystem service dynamics in Central Kalimantan Indonesia*. Student Conference on Conservation Science (SCCS-NY), 8-11 October 2013, New York, United States
- *Modelling oil palm expansion in Central Kalimantan and its impacts on ecosystem services*. Asia Global Land Project Conference (GLP), 24-26 September 2014, Taipei, Taiwan

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