

Mapping Ecosystem Services for Land Use Planning, the Case of Central Kalimantan

Elham Sumarga · Lars Hein

Received: 15 October 2013 / Accepted: 15 April 2014 / Published online: 3 May 2014
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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.

Keywords Spatial modeling · Land use planning · Central Kalimantan · Peatland

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 CO₂ 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 its 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 2 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

Electronic supplementary material The online version of this article (doi:10.1007/s00267-014-0282-2) contains supplementary material, which is available to authorized users.

E. Sumarga (✉) · L. Hein
Environmental Systems Analysis Group, Wageningen
University, P.O. Box 47, 6700 AA Wageningen,
The Netherlands
e-mail: elham.sumarga@wur.nl

E. Sumarga
School of Life Sciences and Technology, Institut Teknologi
Bandung (ITB), Jl Ganesa 10, Bandung 40132, Indonesia

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 services concept has been postulated as having an important potential to support land use planning (Daily et al. 2009). Ecosystem services 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 ecosystem services at the scale of the landscape (e.g., Willemsen et al. 2008), biome (e.g., O'Farrell et al. 2010), country (e.g., Egoh et al. 2008) 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 ecosystem services, 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 ecosystem services 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 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 land use planning. We analyze the following ecosystem services at the provincial scale: timber production, rattan production, palm oil production, paddy rice production, carbon storage, carbon sequestration, and wildlife habitat. We analyze which mapping method is suitable for each of these services, given the complexity of the landscape and data availability, and we examine how ecosystem services maps can be used in spatial planning. Specifically, we analyze which areas would be available for future oil palm expansion in Central Kalimantan with minimal impacts on ecosystem services supply.

Central Kalimantan (153,564 km²) was selected as a case study because of the diversity of ecosystem services 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 reducing emissions from deforestation and degradation (REDD+), 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 ecosystem services at an aggregated scale, selecting suitable mapping method for individual ecosystem services, and showing how ecosystem services 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 analyzed and modeled a comprehensive set of ecosystem services at the aggregated scale of a province. Data scarcity required us to test a number of approaches to map ecosystem services 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.

Materials and Methods

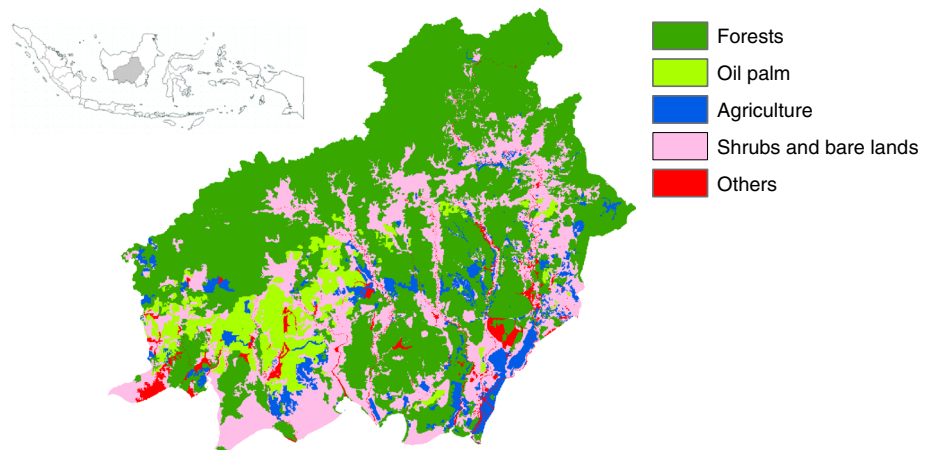
Study Area

Central Kalimantan is the third largest province in Indonesia, located at latitude 0°45' North–3°30' South and longitude 110°45'–115°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/km² and a total population of around 2.2 million people. Figure 1 presents the location and land cover of the study area. The map was generated by reclassifying land cover map 2010 (Tropenbos Indonesia, unpublished).

Mapping Approach

In order to identify the most relevant ecosystem services 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),

Fig. 1 Land cover map of Central Kalimantan



Watershed Management Agency (BP DAS), Provincial Environmental Management Agency (BPLHD), and researchers from Palangkaraya University. The stakeholders identified seven key ecosystem services, 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 ecosystem services. 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 “[Discussion](#)” section of our paper.

Mapping the seven selected ecosystem services required a specific dataset for each service, see [Table 1](#). The data were collected from a variety of sources. These data were combined with land cover maps (Tropenbos International Indonesia, unpublished), soil map (Wetlands International—Indonesia Programme 2004) and a Digital Elevation Model (90 m 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 100 m 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 ecosystem services 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.

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 ecosystem services 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 lookup 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 lookup tables, specifying the amount of carbon in specific land cover type, since our dataset was

Table 1 Summary of data for mapping ecosystem services

Type of ES	Indicators	Data available	Sources
Timber production	Annual timber harvested (m ³ /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 bunch (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 Appendix A of Electronic Supplementary Material
Carbon sequestration	Annual net ecosystem productivity (NEP) (ton/ha/year)	Research findings on NEP in 15 land cover types	References listed in Appendix A of Electronic Supplementary Material
Wildlife habitat	Suitability for orangutan habitat (%)	Estimated population of orangutan in 8 protected areas (about 20,000 individuals)	Provincial conservation agency (2011, unpublished)

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 ecosystem services supply (Phillips et al. 2006). Ecosystem services supply is expressed as probability of occurrence or suitability of an area for specific activities or specific ecosystem services 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 ecosystem services and we come back to this in “Discussion” section. For all services except carbon storage and sequestration (that were modeled with lookup 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 analyzed using variogram analysis. A gstat library of “R” (Pebesma 2004) was used for variogram analysis. The best variogram model was selected for each ecosystem service. 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 analyze 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.

Lookup Tables Based on Land Cover and Soil Types

Lookup 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. (1998), Chairns et al. (1997), Khalid et al. (1999a, b), Masripatin

et al. (2010), Murdiyarto et al. (2009), Rahayu et al. (2003), Syahrudin (2005), and Verwer and van der Meer (2010), see Table A1 in Appendix A of Electronic Supplementary Material. Soil carbon data are derived from van der Kamp et al. (2009), Murdiyarto et al. (2009), and Wetlands International—Indonesia Programme (2004), see Table A2 in Appendix A of Electronic Supplementary Material. 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: Germer and Sauerborn (2008), Hirano et al. (2007), Hirata et al. (2008), Hooijer et al. (2006), Komiyama (2006), Luysaert et al. (2007), Saigusa et al. (2008), Saner et al. (2012), Sanchez (2000), and Suzuki et al. (1999), see Table A3 in Appendix A of Electronic Supplementary Material. 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 analyzed 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.

Incorporating ES Maps in Spatial Planning

Spatial planning requires the analysis and balancing of economic, social, sustainability, and legal criteria in the

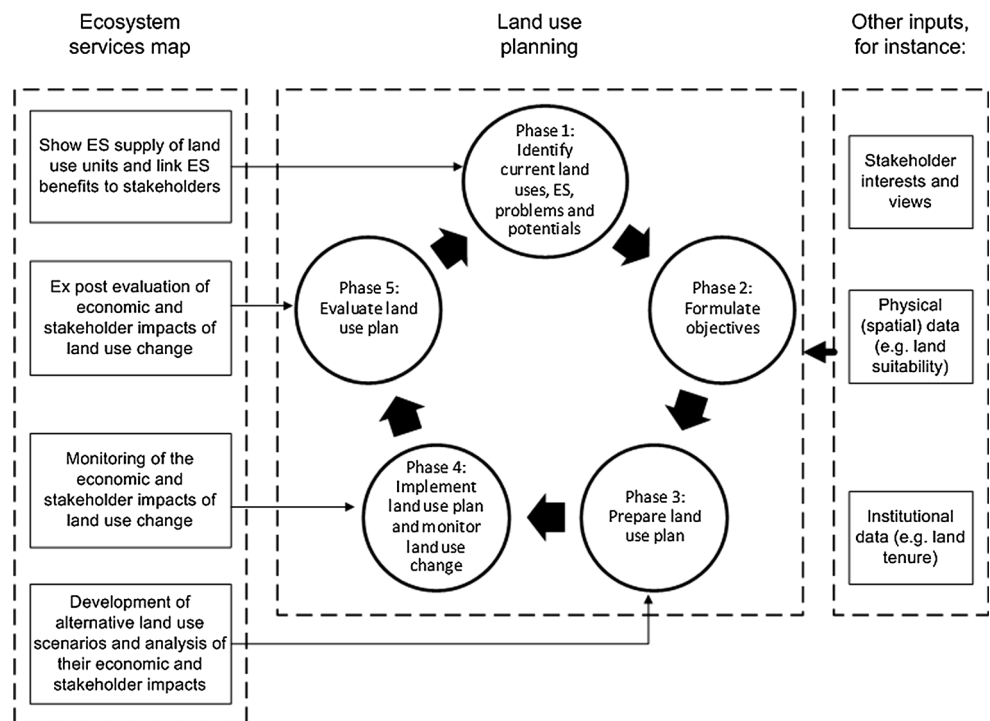
context of the current land use and the potential suitability of ecosystems for other land use (Cao et al. 2012). Usually, if not always, spatial planning involves considering trade-offs, because land conversion or changing land use within specific land cover units will normally change the overall output of ecosystem services from a landscape. Figure 2 presents a framework that depicts how ecosystem services can contribute to spatial planning. Some recent examples of how ecosystem services 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 ecosystem services 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.

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 ecosystem services 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.

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 ecosystem services 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 ecosystem services 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

Fig. 2 Framework for integrated analysis of ES and land use planning



sufficient accuracy to provide meaningful support to spatial planning, in particular at the scale of Central Kalimantan province.

Results

Ecosystem Services Maps

Timber Production

Figure 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 m³/ha/year with a standard deviation of 0.17 m³/ha/year. This value is higher than the annual allowable cut (AAC) at the level of Central Kalimantan (an average of 0.52 m³/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 Fig. 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 bunch (FFB), is presented in Fig. 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 (Bureau of Statistics 2011). By taking this proportion into account, i.e.,

Table 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 constraints 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)	Maintaining all protected areas and all land with high suitability for orangutan habitat (i.e., no loss of land with suitability > 50 %)
Excluding peatlands. Current Indonesian regulation specifies that land conversion is allowed in peatlands with a depth of less than 3 m (Ministry of Agriculture, 2009). However, even conversion of areas where the peat depth is less than 3 m 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	No conversion of peatland (of any depth)
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	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 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 paddy land in view of its importance for local food supply

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 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 analyzed 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 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 Fig. 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 to 7,882 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 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

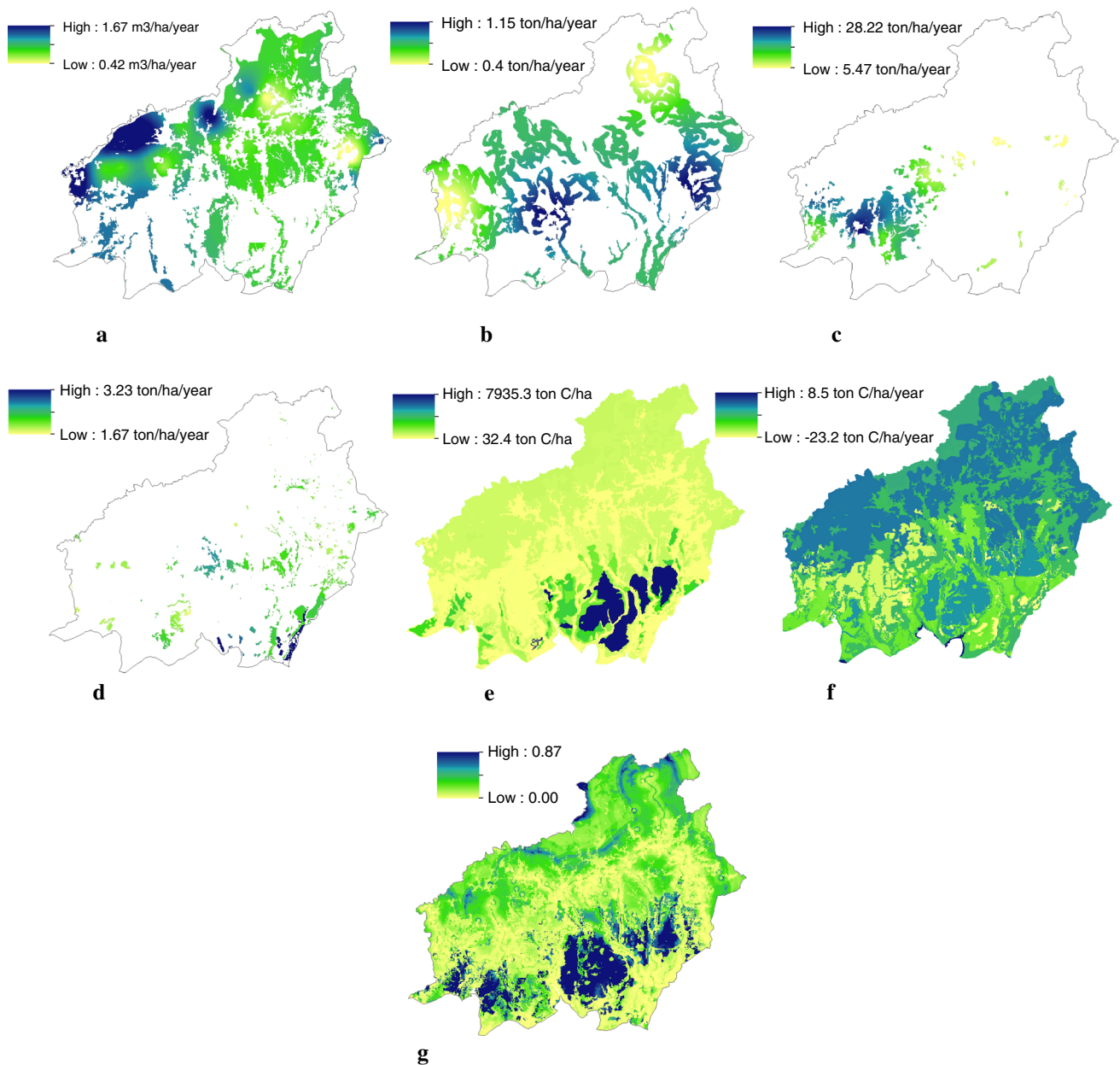


Fig. 3 Ecosystem services maps of Central Kalimantan. **a** Timber production, **b** rattan production, **c** oil palm production, **d** paddy rice production, **e** carbon storage, **f** carbon sequestration, and **g** orangutan habitat suitability

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; 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 ecosystem service flows as a function of the 2010 land use. For this reason, our provincial estimate is an underestimate of actual CO₂ 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

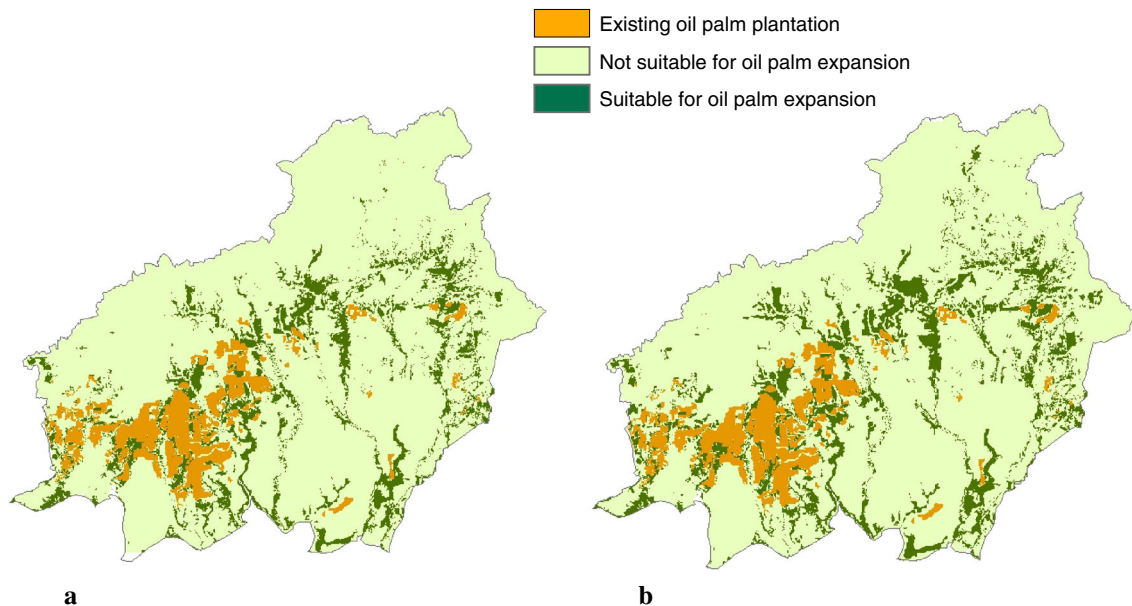


Fig. 4 Maps of planning for oil palm expansion based on **a** environmentally sustainable scenario and **b** mixed sustainable-rapid development scenario

2010, current emission levels are therefore likely to be considerably higher than the 2010 levels that we calculate.

Habitat for Orangutan

Figure 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).

Spatial Planning for Oil Palm Expansion

We applied two scenarios to produce maps of where oil palm expansion would lead to minimal damage of other

ecosystem services, on the basis of criteria developed by the relevant stakeholders. Figure 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 (analyzed 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 (Fig. 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.

Discussion

Implications for ES Mapping

Now that there is an increasing experience with mapping ecosystem services (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 ecosystem services at aggregated scales. Our study shows that mapping ecosystem services at aggregated scales is possible, even in a data poor developing country context, but that further research is needed to analyze 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 ecosystem services at aggregated scales are described below.

Lookup 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 ecosystem services mapping, mainly for ecosystem services distributed in a single land cover type. Some ecosystem services, 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 ecosystem services mapping, geostatistics has been used for example for carbon mapping (in more data-rich environments than Central Kalimantan) (e.g., Beilman et al. 2008). Our study shows the applicability of geostatistics for mapping other ecosystem services. 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 ecosystem services 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., Phillips 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 ecosystem services 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).

Integrating Ecosystem Services in Spatial Planning

In the context of land use planning, we believe that an ecosystem services 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 ecosystem services maps to identify the “hot spots” of ecosystem services which is useful for instance in determining co-benefits of REDD+ project. An ecosystem services 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 ecosystem services 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 ecosystem services supply and stakeholders. Finally, the spatial approach to modeling ecosystem services flows developed in this paper can support the emerging thinking on Ecosystem Accounting, which requires spatial analysis of ecosystem services flows, and ecosystems' capacities to generate ecosystem services (UNSD 2013; Edens and Hein 2013). This paper demonstrates several approaches that can be used to analyze ecosystem services at aggregated scales in a data poor context that are relevant to Ecosystem Accounting, which requires a “wall-to-wall” mapping of ecosystem services supply in specific administrative units.

A critical constraint of using an ecosystem services approach to land use planning is that ecosystem services supply may not be sustainable. In case of overharvesting of ecosystem services, 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 ecosystem services 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).

Policy Implications for Ecosystem Management in Central Kalimantan

The ecosystem services maps (Fig. 3a–i) show where ecosystem services are generated and thereby indicate the potential consequences of land use change. Table 3 illustrates multiple ecosystem services 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 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

Table 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

also affects a number of other services (in particular orangutan habitat and timber production). Monetary analysis of the changes in ecosystem services supply as a function of land use change is required to further substantiate the effects of land use change in peat lands.

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 5 cm/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 (analyzed from land cover and soil maps), and recommend no further peat conversion also on shallow peat (<3 m 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 ecosystem services 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 ecosystem services. The resulting map (Fig. 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 ecosystem services (as we did not model all ecosystem services), stakeholder interests, legislation, land suitability, infrastructure, etc. In the context of land use planning process (Fig. 2), our study stands at phase 1 (ecosystem services mapping) and phase 3 (spatial planning). Given a general lack of capacity at the district level, rather than promoting mapping ecosystem services in every district, we recommend producing ecosystem services 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).

Conclusion

We examined three different approaches (interpolation with the use of geostatistics, lookup tables, and Maxent) to map ecosystem services at the aggregated scale (153,000 km²) 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 ecosystem services 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 ecosystem services. 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 ecosystem services 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 ecosystem services approach can assist in identifying areas suitable for oil palm expansion.

Acknowledgments We would like to thank Tropenbos Indonesia, the Indonesian Ministry of Forestry, Stephan Mantel, and Frans Rip for spatial data of Central Kalimantan; the Borneo Orangutan

Survival Foundation for expert advice; Matthias Schroter, Roy Remme, Aritta Suwarno, and Peter van der Meer for discussion and comments on this manuscript; and two anonymous reviewers for their valuable suggestions for improving this manuscript. We would also like to thank all participants in the workshop, in particular Bihokda Handen from Central Kalimantan Provincial Forestry Agency. The financial support of the European Research Council (Grant Agreement No. 263027) is also thankfully acknowledged.

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