



An analysis of multiple ecosystem services under future oil palm expansion scenarios in Central and West Kalimantan, Indonesia

Sunil K Sharma
Himlal Baral
Yves Laumonier
Beni Okarda

Heru Komarudin
Herry Purnomo
Pablo Pacheco

An analysis of multiple ecosystem services under future oil palm expansion scenarios in Central and West Kalimantan, Indonesia

Sunil K Sharma

CIFOR
Prime Ecoservices, Australia

Himlal Baral

CIFOR

Yves Laumonier

CIFOR

Beni Okarda

CIFOR

Heru Komarudin

CIFOR

Herry Purnomo

CIFOR

Pablo Pacheco

CIFOR

Occasional Paper 187

© 2018 Center for International Forestry Research



Content in this publication is licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0), <http://creativecommons.org/licenses/by/4.0/>

ISBN 978-602-387-077-6

DOI: 10.17528/cifor/006953

Sharma SK, Baral H, Laumonier Y, Okarda B, Komarudin H, Purnomo H and Pacheco P. 2018. *An analysis of multiple ecosystem services under future oil palm expansion scenarios in Central and West Kalimantan, Indonesia.*

Occasional Paper 187. Bogor, Indonesia: CIFOR.

Photo by Lucy McHugh/CIFOR.

Oil palm harvester.

CIFOR
Jl. CIFOR, Situ Gede
Bogor Barat 16115
Indonesia

T +62 (251) 8622-622

F +62 (251) 8622-100

E cifor@cgiar.org

cifor.org

We would like to thank all funding partners who supported this research through their contributions to the CGIAR Fund. For a full list of the 'CGIAR Fund' funding partners please see: <http://www.cgiar.org/our-funders/>

Any views expressed in this publication are those of the authors. They do not necessarily represent the views of CIFOR, the editors, the authors' institutions, the financial sponsors or the reviewers.

Contents

Acknowledgments	vi
Executive summary	vii
1 Introduction	1
2 Materials and methods	4
2.1 Study area	4
2.2 Research framework	4
2.3 Analysis of oil palm expansion and mapping of future land use under oil palm expansion scenarios	5
2.4 Identifying and mapping of future oil palm expansion scenarios	6
2.5 Mapping, quantifying and valuating of ecosystem services under future land-use and land-cover scenarios	9
3 Results	16
3.1 Current land use in the study areas	16
3.2 Oil palm expansion between 2000 and 2016	16
3.3 Future land use under the selected oil palm expansion scenarios	17
3.4 Land use transitions in future land-use	19
3.5 Mapping, quantifying and economic valuation of ecosystem services	22
3.6 Trade-offs or synergy between ecosystem services under future land-use scenarios	36
4 Discussion	37
4.1 Assessing ecosystem services on oil palm landscapes	37
4.2 Trade-offs or synergies and economic valuation of ecosystem services	38
5 Conclusion	39
References	40

List of figures and tables

Figures

1	Central Kalimantan and West Kalimantan, study area within Indonesian Borneo.	5
2	The framework of the methods and tools used in this study.	6
3	Land-use map of Central Kalimantan in 2016. Between 2000 and 2016, IOPPs extensively increased in the southwest region in regencies Kotawaringin Barat, Seruyan and Kotawaringin Timur in Central Kalimantan.	17
4	Land-use map of West Kalimantan in 2016. In West Kalimantan, IOPPs mainly expanded in the central part in regencies Landak, Sanggau, Sekadau, Sintang and in the south in Kab Ketapang regency.	17
5	Comparison of land-use categories converted to IOPPs in Central Kalimantan, West Kalimantan and Indonesian Kalimantan between 2000 and 2016.	18
6	Land-use categories converted to IOPPs in Central Kalimantan between 2000 and 2016.	18
7	Land-use categories converted to IOPPs in West Kalimantan between 2000 and 2016.	18
8	Central Kalimantan land-use maps for the three future oil palm expansion scenarios in 2035.	20
9	West Kalimantan land-use maps for the three future oil palm expansion scenarios in 2035.	21
10	Land-use categories transitioned to oil palm plantation in Central Kalimantan under the three future scenarios: business as usual, conservation and sustainable intensification scenarios between 2017 and 2035.	23
11	Land-use categories transitioned to oil palm plantations in West Kalimantan under the three future scenarios: business as usual, conservation and sustainable intensification scenarios between 2017 and 2035.	23
12	Carbon stock map in Central Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.	25
13	Carbon stock map in West Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.	26
14	Carbon stock map in Central Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.	27
15	Habitat quality maps in West Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.	28
16	Carbon stock map: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.	30
17	Water yield maps in West Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.	31

18	Area of oil palm plantations and palm oil production under the current land use and three future land-use scenarios in Central Kalimantan.	32
19	Area under the oil palm plantations and palm oil production under the current land use and three future land-use scenarios in West Kalimantan.	32
20	Timber production under the current land use and the three future land-use scenarios in Central Kalimantan and West Kalimantan.	33
21	TEV of ecosystem services under the current land use and the three future land-use scenarios in Central Kalimantan and West Kalimantan.	34

Tables

1	A summary of land-use and land-cover datasets used in this study.	7
2	Definition of forest cover and land-use classes in the 2016 land-use map.	7
3	Key features of the future oil palm expansion scenarios	8
4	Carbon stock for various carbon pools in the land-use classes in the study areas	11
5	Land-use classes, the equivalent biome, value range and the economic values for four major ecosystem services.	14
6	Land-use classes and their areas in Central and West Kalimantan in 2016.	16
7	Major features of the three oil palm expansion scenarios in Central and West Kalimantan by 2035.	22
8	Carbon stock in the current and future land-use scenarios in Central Kalimantan.	24
9	Carbon stock in the current and future land-use scenarios in West Kalimantan.	24
10	Transition of land-use classes under the future land-use scenarios in Central Kalimantan and West Kalimantan.	34
11	NPV of TEV of ecosystem services under current and future land-use scenarios.	35
12	Relative availability of four major ecosystem services and the TEV of the land-use classes relative to intact forest.	36

Acknowledgments

This research was conducted with financial assistance from the United States Agency for International Development (USAID) under the Governing Oil Palm Landscapes for Sustainability (GOLS) Project. This work is part of the CGIAR Research Program on Forests, Trees and Agroforestry (FTA). This research is supported by CGIAR Fund Donors. For a list of Fund donors, please see: www.cgiar.org/about-us/our-funders/. We would like to express our sincere thanks to the workshop participants for their valuable contribution to this research and also to two reviewers of the manuscript of this report.

Executive summary

This study provides an analysis and evaluation of ecosystem services and their trade-offs under the future scenarios of oil palm expansions in two provinces, Central Kalimantan and West Kalimantan, of Indonesia. The future land-use scenarios for oil palm expansions are based on the historical rates, current land-use policies (such as the forest moratorium), spatial planning and the existing suitability maps for oil palm plantations in both provinces. An extensive review of the literature and published documents and reports were used to understand past and future land-use changes, impacts on ecosystem services and socioeconomic conditions. National and provincial land-use policies and factors relevant to oil palm development were explored and analyzed. Further, relevant experts and stakeholders were consulted to consolidate knowledge for future land-use changes and oil palm development scenarios in the study area. The spatial analysis tool in ArcGIS and the Integrated Valuation of Ecosystem Services and Trade-offs Tool (InVEST) were used to analyze historical and future land-use changes, and to evaluate and analyze trade-offs with ecosystem services. This study focused on mapping, quantifying and evaluating the following five most relevant and vital ecosystem services: (i) carbon storage, (ii) habitat quality, (iii) water yield, (iv) palm oil production, and (v) timber production.

Based on the current land-use policy, spatial planning and maps of oil palm expansion in Indonesia, this study identified three plausible future scenarios; namely business as usual, conservation and sustainable intensification for future development of oil palm plantations in the study area. The business-as-usual scenario assumes that oil palm concession license holders will expand their plantations to all concession areas to access the economic opportunities of the high demand for palm oil for domestic as well as international demands. The conservation scenario considers that stringent criteria will ensure environmental integrity and sustainability. The forest moratorium on primary

forest and peatland will be supported by strict enforcement and monitoring to avoid the clearing of intact forest and peatland for oil palm and timber plantations. The sustainable intensification scenario considers that future expansions will occur within land suitable for oil palm plantations by applying yield enhancement technology.

Trade-offs and synergies with these ecosystem services were found to depend on the extent and types of land-use transition to oil palm plantations under the selected future land-use scenarios. Except for timber production, there are trade-offs in the four other ecosystem services under the business-as-usual scenario, primarily due to expansions of oil palm plantations on old-growth and regrowth forests. However, the model results showed synergy between increased palm oil yield (due to an extensive expansion of oil palm plantations) and water yield (reducing). This synergy occurred under all future land-use scenarios due to the conversion of agricultural land, scrublands and other land uses into oil palm plantations.

This study concludes that ecosystem services are negatively impacted in the business-as-usual scenario due to expansions of oil palm plantations on old-growth forest and regrowth forest. Assuming the lowest intensity of oil palm expansion, the conservation scenario enhances carbon stock and maintains a stable habitat quality relative to the current land use (2016). The sustainable intensification scenario with oil palm expansions only on suitable areas and enhancement of yield generates a positive impact on carbon stock and water yield, whereas habitat quality slightly deteriorates in the study areas. A detailed study at a local level (household or village) that evaluates the economic value of crucial ecosystem services and their trade-offs or synergies is recommended for accurate evaluation to better understand the impacts of oil palm expansion on the local community and the environment.

1 Introduction

Indonesia is the principal producer and exporter of palm oil to global markets (FAOSTAT 2017). Its palm oil production doubled between 2007 and 2017 from 18 million tons (Mt) to 36 Mt and met about 54% of the total global production (IndexMundi 2017). Primary drivers for this increase are considered to be: (i) highest yields (up to 12 tons per hectare per year) among all oilseed crops (Woittiez et al. 2017; Yan 2017); (ii) low production costs (Corley 2009) and high profit margins (Koh and Wilcove 2007); and (iii) growing domestic consumption of vegetable oil (Gaskell 2015) and biofuels (Kharina et al. 2016). The domestic consumption of palm oil is rapidly increasing in Indonesia, reaching 8.6 Mt in 2015 (Pacheco et al. 2017) from 5 Mt in 2010 (Gaskell 2015). If this trend continues, the predicted domestic demand of 10 Mt by 2035 (Gaskell 2015) will be reached much earlier. Further, based on population projections and per capita consumption, the demand for edible oilseed is predicted to double to 240 Mt by 2050, which would require an additional 12 million hectares (Mha) of oil palm plantations (Corley 2009).

The increased production of palm oil has resulted in significant land-use change in Indonesia. In 2015, oil palm plantations accounted for over 11 Mha (Kharina et al. 2016), or 6% of Indonesia's total area. Recent spatial data analysis showed a rapid and extensive expansion of oil palm plantations since the 1990s (Gunarso et al. 2013; Gaveau et al. 2014, 2016). Between 1990 and 2015, industrial plantations¹ expanded to about 5.5 Mha in Kalimantan, a greater than nine-fold increase in area since 1990 (Gaveau et al. 2016). Between 2005 and 2015, the same study

observed an expansion of industrial plantations in Kalimantan by almost three times the average annual expansion (357,000 ha per year) on the previous decade (127,000 ha per year), i.e. between 1995 and 2005.

The unprecedented expansion of oil palm plantation has significantly changed the landscape of Indonesia in the past few decades (Gunarso et al. 2013; Busch et al. 2015; Eldeeb et al. 2015). In addition to oil palm plantation on already cleared land or degraded land, industrial scale plantations were established on old-growth forests in Indonesia. A recent study estimated that out of 14.4 Mha of old-growth forest cleared between 1973 and 2015, oil palm plantations were established on more than half of that area, i.e. 7.8 Mha, and an additional 1.3 Mha area was used for pulpwood plantations (Gaveau et al. 2016). However, the analysis of time series data for land-use change showed that illegal logging and forest fires were the primary drivers of deforestation of old-growth forest before oil palm plantations were established (Gaveau et al. 2016).

The impacts of land-use change have been used to understand the gain or loss of ecosystem services in Indonesia. Many researchers have assessed and reviewed the impacts of oil palm plantations on the availability of multiple ecosystem services (e.g. Sumarga and Hein 2014; Dislich et al. 2016; Petrenko et al. 2016; Sumarga and Hein 2016; Vijay et al. 2016). They reported a significant loss of ecosystem services in landscapes modified by oil palm plantations compared with previous land uses, such as primary forests and peatlands. Sumarga and Hein (2014) observed the loss of timber production, destruction of orangutan habitat and increased carbon emissions resulting from the conversion of peatlands to oil palm plantations in Central Kalimantan, Indonesia. A

¹ According to a study by Gaveau et al. (2016) in Borneo, industrial plantations are predominantly oil palm plantations, accounting for almost 86% of the total area; the remaining 14% are pulpwood plantations.

review of studies confirms that the biodiversity loss is more evident in oil palm plantations than in forest and other tree covers (Fitzherbert et al. 2008). A global study highlighted that the potential expansion of oil palm into vulnerable forests posed the threat of extinction of mammal and bird species (Vijay et al. 2016). Further, Dislich et al. (2016) found that conversion of forest into oil palm plantation results in a reduction of 11 out of 14 ecosystem functions (or services) available from the forest, with the exception of food and raw materials.

However, the change in ecosystem services depends on the previous land use prior to establishing an oil palm plantation. Dislich et al. (2016) also reported that oil palm plantations on already cleared or deforested land can enhance the land's capacity by producing a high-value commodity (i.e. palm oil), as well as offering some positive impacts on multiple ecosystem services such as climate regulation, water regulation and erosion control relative to the deforested land. It is evident that oil palm plantation offers an additional sequestration of carbon on above- and belowground biomass. Oil palm plantation enhances carbon stocks by an average of 50.5 tC per hectare (Sumarga and Hein 2014) relative to the deforested land.

Despite the reported negative impacts on the delivery of ecosystem services, oil palm plantations have become an important contributor to Indonesia's national economy and support the livelihoods of rural people. Indonesia's export revenue from palm oil increased by over fivefold from US\$3.4 billion in 2004 to US\$17.5 billion in 2014 (Pacheco et al. 2017) and will continue to rise with the growth in palm oil production. A study in Riau Province found that industrial oil palm plantations enhanced local economic growth with positive impacts on livelihoods through increasing access to basic needs (e.g. school, health) and other development opportunities (e.g. roads, electricity, banks) (Budidarsono et al. 2013). Conversion of about 93,000 ha of peatlands to smallholder oil palm plantation in Siak generated over 37,000 jobs and increased the average household income by US\$4556 per year (Agustira et al. 2016). The net economic benefit was estimated to be US\$1036 million per year to the community after accounting for the environmental cost of US\$1116 million per year due to conversion of peatlands to oil palm plantation.

However, the expansion of oil palm plantation depends on permits issued by government authorities and is guided by existing land-use policies and plans. The forest moratorium initially adopted in May 2010 applies to all new oil palm concessions and restricts further clearing of primary forests and peatlands for oil palm development (Murdiyarto et al. 2011; Austin et al. 2014). In 2011, the indicative moratorium map delineated a total of 22.5 Mha, which includes 7.2 Mha of primary forests, 11.2 Mha of peatlands and an additional 4.1 Mha of other land across Indonesia (Murdiyarto et al. 2011). Although the moratorium is criticized for its narrow scope in applying only to primary forests and peatlands (Busch et al. 2015), this policy can be effectively used to restrict oil palm expansion to outside these areas and also to support Indonesia's voluntary commitment to abolish deforestation from palm oil production and supply chains by 2020 (UN Climate Summit 2014).

The recent history and driving forces for oil palm expansion imply that future expansion of plantations is inevitable in Indonesia for the following reasons: (i) ever-growing demand for palm oil in both domestic and global markets (e.g. Abdullah 2011; Kharina et al. 2016); (ii) contribution to national and local economic growth (e.g. Agustira et al. 2016; Pacheco et al. 2017); and (iii) expansion of oil palm in smallholder farms, which accounted for about 40% of the total oil palm plantation area in 2013 (Daemeter Consulting 2015). Understandably, many factors, including regulatory, social, economic and environmental, interact to determine the actual expansion of oil palm plantation on the ground. However, there have been attempts to delineate the areas for future expansion of oil palm plantation based on land use and characteristics. The available maps showing potential areas for future oil palm expansion in Indonesia include: (i) the provincial spatial land-use planning maps developed by Central Kalimantan and West Kalimantan provincial government, which identify lands based on their functions and delineate the land available for other uses including agricultural land and oil palm expansion (CIFOR 2014); (ii) the World Resource Institute's (WRI) oil palm concession maps, which show all oil palm plantation areas where the palm industries have already secured rights to develop oil palm as of 2010 - these companies have permits

from relevant government authorities to clear forest, plant and manage oil palm plantations; and (iii) the suitability maps that identify potential areas for oil palm expansion using various suitability criteria for sustainable palm oil production by avoiding clearing of forests, peatland and threats to loss of biodiversity (e.g. Mantel et al. 2007; Gingold et al. 2012).

This study is designed to examine the change in ecosystem services and their trade-offs for the period between 2017 and 2035. It focuses on oil palm expansion in two provinces, Central Kalimantan and West Kalimantan, of Indonesia. The future land-use scenarios for oil palm expansion are based on the historical rates, current land-use policies, such as the forest moratorium, spatial planning and the existing suitability maps for oil palm plantations in both provinces. The specific objectives of this study are to:

- identify plausible future land-use scenarios associated with oil palm expansion in Central Kalimantan and West Kalimantan
- quantify, evaluate and map key ecosystem services using ecosystem services mapping and modeling tools such as InVEST

- analyze trade-offs or synergies among multiple ecosystem services under different future land-use scenarios
- estimate and compare the total economic valuation of the ecosystem services under contrasted future oil palm expansion scenarios.

The economic valuation of ecosystem services enables a comparison of the gain or loss of the associated values of the ecosystem services due to land-use change under the future land-use scenarios. The research outcomes will inform management decisions at local, regional and national levels and assist stakeholders, such as government and nongovernment officials, the private sector and communities, to visualize the future expansion of oil palm in the study areas and to understand their impacts on the key ecosystem services. The economic valuation of the ecosystem services illustrates their value in monetary terms and provides evidence and justification for future sustainable land-use planning. However, this study is a desktop analysis only and is restricted to examining the impacts of future oil palm expansion on ecosystem services in the study areas examined.

2 Materials and methods

2.1 Study area

The study areas comprised two provinces in Kalimantan, the Indonesian part of Borneo, i.e. Central Kalimantan and West Kalimantan (Figure 1). This region has been identified as a part of one of the 25 biodiversity hotspots for conservation priorities in the world because of its high number of endemic species and the threat of habitat loss (Myers et al. 2000). Both provinces encompass some parts of the 'Heart of Borneo', the central, mountainous region of Borneo with intact natural rainforests and biodiversity, which supports the livelihoods of millions of people, including forest-dwelling indigenous Dayaks (WWF 2013).

Central Kalimantan (*Kalimantan Tengah*) is the second largest province in Indonesia, with a total territorial area of 153,564 km². Geographically, it is located at latitude 0°45'N–3°30'S and longitude 110°45'–115°50'E. This province comprises 13 regencies with a total population of over 2.2 million in the last census 2010 (BPS 2017). More than the half of the province has been assessed as high conservation value (HCV) areas. However, about two-thirds of the HCV areas are considered at high risk due to planned development activities (Ibie et al. 2016). Sabangau National Park has been established in this province to protect the natural habitat of orangutans.

West Kalimantan (*Kalimantan Barat*) is the third largest province in Indonesia occupying 147,307 km². It is located to the northwest of Central Kalimantan at latitude 2°08'N–3°05'S and longitude 108°0'–114°10'E. About 4.4 million people, twice the population of Central Kalimantan, inhabit this province. Kapuas Hulu regency on the northeast frontier is mountainous with a peak elevation of 2059 m. The regencies on the western part have low-lying plain areas.

2.2 Research framework

Figure 2 shows the framework outlining the research methods and tools used in this study to accomplish the objectives. An extensive review of the literature and published documents/reports helped explain past and future land-use change, impacts on ecosystem services and socioeconomic conditions. National and provincial land-use policies and factors relevant to oil palm development were explored and analyzed. Further, relevant experts and stakeholders were consulted to consolidate knowledge and understanding for future land-use change and oil palm development scenarios in the study area. A total of 35 stakeholders, representing government, nongovernment, industry and smallholder farmers, participated in a field-level consultation workshop held in Palankaraya, Central Kalimantan on 21 November 2016. Three potential future oil palm expansion scenarios were identified based on the existing land-use policies, suitability maps for oil palm in the study areas and the stakeholders' perspectives on the future of oil palm. The spatial analysis tools in ArcGIS version 10.2 were used to derive future land-use maps under the selected oil palm expansion scenarios.

The Integrated Valuation of Ecosystem Services and Trade-offs Tool (InVEST) was chosen to evaluate ecosystem services and analyze trade-offs. The key reasons for the selection of this particular tool were: (i) freely available computer software; (ii) widely used in terrestrial ecosystems and tested globally; (iii) capacity for generating spatially explicit maps; (iv) enables analysis of trade-offs between different land-use scenarios; and (v) provides specific models for various ecosystem services. The InVEST modules for the selected key ecosystem services were run for each scenario and the outputs were analyzed for spatial and temporal



Figure 1. Central Kalimantan and West Kalimantan, study area within Indonesian Borneo. Inset shows study area on map of Indonesia.

distribution of the ecosystem services and their trade-offs resulting from land-use change under these scenarios.

2.3 Analysis of oil palm expansion and mapping of future land use under oil palm expansion scenarios

To analyze the expansion of oil palm plantations between 2000 and 2016, this study used a recent spatial dataset from Borneo developed by Gaveau et al. (2016). The dataset represents a comprehensive methodology involving digitization of LANDSAT time series imagery followed by map refinement through ground verification, expert review and cross-checking with other datasets. Table 1 lists the land-use and land-cover datasets, their

sources and a brief description of each dataset used in this study.

The land-use map (2016) was used to investigate future land use under various oil palm expansion scenarios. The forest cover map and the industrial plantation map of 2016 developed by Gaveau et al. (2016) were integrated. The following six land-use classes were identified in the forest cover map: (i) intact forest, (ii) logged forest, (iii) regrowth forest, (iv) oil palm plantation, (v) timber plantation and (vi) non-forest. The industrial plantation map in 2016 was extracted from a time series mapping of industrial oil palm plantations (IOPPs) and industrial timber plantations (ITPs) in Borneo since 1973.² In addition to industrial-scale oil

² <https://data.cifor.org/file.xhtml?fileId=1627&version=2.0>

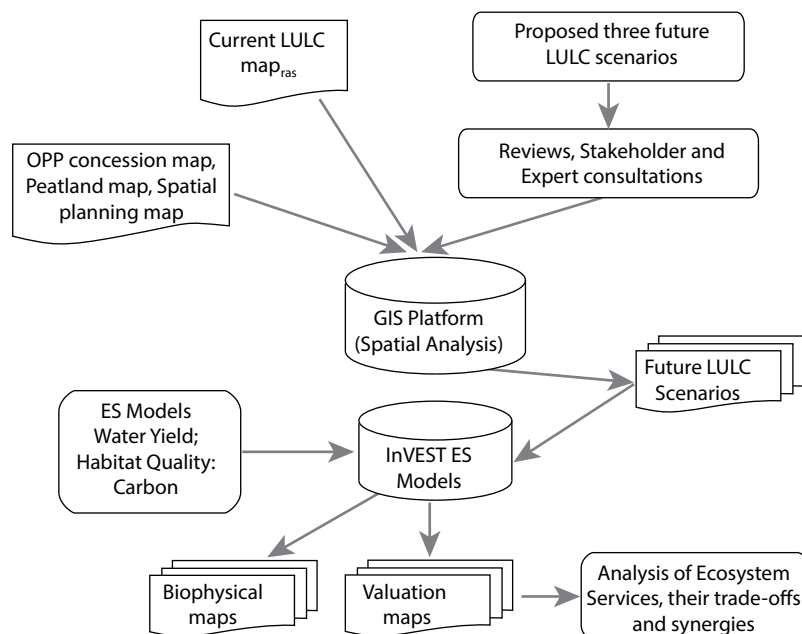


Figure 2. The framework of the methods and tools used in this study.

palm plantations, oil palm on smallholder farms has significantly increased in Indonesia (Jelsma et al. 2009; Sheil et al. 2009). In 2013, smallholder oil palm plantations represented about 16% and 35% of total oil palm plantations in Central Kalimantan and West Kalimantan, respectively (Daemeter Consulting 2015). The spatial mapping of the smallholder oil palm is currently being undertaken by CIFOR but a complete map is not yet ready for the study area.

About 90% of non-forests in the derived map correspond to the non-forest areas of the Ministry of Forest's land cover of 2015³ (MOF 2015) for the study areas. The MOF 2015 land-cover map categorized the non-forest areas into scrubland, agricultural land, other land and water bodies. The other land included housing, transmigration, mining and an airport on the MOF 2015 map. Hence, the derived land-use map and MOF 2015 map were merged to reclassify non-forest areas on the former map to corresponding non-forest land-use classes on the MOF 2015 map. Table 2 defines the land-use classes in the 2016 land-use map for the study areas. Section 3 provides further detail on

these land-use classes and also presents maps of the study areas.

2.4 Identifying and mapping of future oil palm expansion scenarios

Based on the current land-use policy, spatial planning and existing maps of oil palm expansion in Indonesia, three future plausible scenarios, namely, business as usual, conservation and sustainable intensification were identified in the study areas. Table 3 summarizes the key features of these scenarios.

These future land-use scenarios and mapping procedures are provided below.

2.4.1 Business-as-usual scenario

The business-as-usual scenario assumes that oil palm concession license holders will expand their plantations to all concession areas to access economic opportunities created by the high demand for palm oil for domestic as well as international use. In addition, the demand for wood is also growing for biofuel energy (UN Energy 2007) and timber supply (Hetsch 2009; Penna 2010). The WRI-compiled timber

³ <http://www.greenpeace.org/seasia/id/Global/seasia/Indonesia/Code/Forest-Map/en/data.html>

Table 1. A summary of land-use and land-cover datasets used in this study.

Dataset name	Source	Description
Planted industrial oil palm plantation in 2016	Gaveau et al. (2016), accessed from https://www.cifor.org/map/atlas/	Maps the previous land-use classes as intact forest, logged forest, regrowth forest or non-forest, before establishment of oil palm and pulp wood plantations in Borneo
Ministry of Forestry's land cover 2015	Accessed from http://www.greenpeace.org/seasia/id/Global/seasia/Indonesia/Code/Forest-Map/en/data.html	Classifies Indonesia's land use and land cover into 21 classes: forest cover (6), plantation (2), agricultural land (3), non-forest cover (3) and other land uses (7)
Land-use map for West and Central Kalimantan	Derived from Gaveau et al. (2016) and Ministry of Forestry land cover	This map distinguishes nine land-use and land-cover classes in the study area: intact forest, logged forest, regrowth forest, scrublands, agricultural land, other land, oil palm plantation, timber plantation and water
2014 Peatland map	Wahyunto et al. (2014)	The peatland map classifies the peatland depth into four classes: 50–100 cm, 101–200 cm, 201–400 cm and above 400 cm.

Table 2. Definition of forest cover and land-use classes on the 2016 land-use map.

Forest cover or land use	Definition
Intact forest	Pristine, old-growth forest with a closed canopy (over 90%) growing on mineral or peat soils
Logged forest	Old-growth forest, which has been selectively mechanically logged after 1973
Regrowth forest	Various old successional stages following swidden agriculture
Scrublands	Degraded and previously forest areas (old-growth and selectively logged forests) converted into scrublands due to deforestation, drought and recurrent fires. This includes scrublands and bare land on the MOF's land-cover map
Agricultural land	Rice land, dry rice land, and dry rice land mixed with scrublands
Other land	The areas under housing, transmigration, mining and airport in MOF (2015)
Oil palm plantation	IOPPs as mapped by Gaveau et al. (2016); does not show smallholder oil palm plantation areas
Timber plantation	Pulpwood plantations as mapped by Gaveau et al. (2016)
Water bodies	Rivers, lakes or any forms of water in the study area

concession map depicting the potential areas of timber plantation expansion in both provinces allowed timber plantation expansion to be considered in this scenario. Hence, favorable market conditions (i.e. increasing demand) and a profitable investment return drive a rapid expansion of both oil palm and timber plantations to all concession areas not planted before 2016 by 2035 in this scenario.

The concession maps for oil palm and timber were extracted for the study areas from the concession maps of Kalimantan compiled by the WRI based on data from the Ministry of Forestry prior to 2010 (Gingold et al. 2012). Overlaying the concession maps of oil palm and timber onto the study area land-use maps in 2016 shows the areas for future expansions of oil palm and timber plantations under this scenario.

Table 3. Key features of the future oil palm expansion scenarios.

Scenarios	Key features
Business as usual	<ul style="list-style-type: none"> • This scenario assumes that oil palm and timber plantation expansions occur on the respective concession areas as depicted on the concession area maps for 2035. • The high demand for palm oil for domestic use as well as from international markets is a main driver for oil palm expansion. • The growing demand for wood for biofuel energy and timber supply leads to expansion of timber plantations on concession areas.
Conservation	<ul style="list-style-type: none"> • No oil palm expansion occurs on forest cover (intact forest, logged forest and regrowth forest) and peatlands to conform to the forest moratorium and zero deforestation commitment. • Oil palm expansions are confined to the non-forest estate (APL: Areal Penggunaan Lain). • Oil palm expansions mainly occur on agricultural areas, regrowth forest, scrubland and other land. • High conservation value (HCV) and high carbon stock (HCS) areas are protected.
Sustainable intensification	<ul style="list-style-type: none"> • This scenario considers oil palm expansion on limited areas of the potential suitable land as mapped by WRI and SEKALA Project (Gingold et al. 2012). • Oil palm plantations are established by using improved varieties of cultivars and intensively managed to enhance palm oil productivity to 5.1 tons crude palm oil per hectare per year. • The expansion of timber plantations is not taken into account in this scenario because a suitability map for timber plantations was not available.

2.4.2 Conservation scenario

The conservation scenario considers stringent criteria to ensure environmental integrity and sustainability. Strict reinforcement and monitoring to avoid the clearing of intact forest and peatland for oil palm and timber plantations ensures conformation to the forest moratorium on primary forest and peatland. Further, logged forest and regrowth forest are also excluded from clearing, abolishing the deforestation of logged forest, which conforms to the 'zero deforestation' criterion set out to ensure sustainable palm oil production. In addition, this scenario also adheres to provincial spatial planning by restricting future expansion of oil palm and timber in the non-forest estate, i.e. the Areal Penggunaan Lain (APL) land class. The APL land class delineates the non-forest land and is legally available for other uses including agricultural land and settlement (Rosenbarger et al. 2013). The exclusion of all land classes except APL guarantees that future expansions of oil palm and

timber only occur in the non-forest estate. This scenario will protect HCV and high carbon stock (HCS) areas due to the protection of the intact forest, logged forest, regrowth forest, peatland and restricts future expansion only on the APL land class.

The exclusion areas (intact forest, logged forest, regrowth forest, peatland and land classes other than APL) on the spatial planning map were combined to delineate the areas of exclusion for oil palm and timber expansions under this scenario. The exclusion or constraint map was generated by integrating areas for: (i) intact forest, logged forest and regrowth forest on the 2016 land-use map; (ii) peatland; and (iii) the non-APL areas on the spatial planning map. The 2014 peatland map was developed and validated by Wahyunto et al. (2014). The peatland map classifies the peatland depth into four classes: 50–100 cm, 101–200 cm, 201–400 cm and above 400 cm. Before integrating the peatland map into the constraint map, all peat

depth classes were merged to exclude plantation on all peatland with a depth of more than 50 cm. The non-APL areas were extracted from the spatial planning maps for Central Kalimantan and West Kalimantan obtained from CIFOR. To incorporate a conservation perspective into this scenario, the plantation intensity is assumed to be one-quarter of the plantation rate between 2000 and 2016 in the respective province.

2.4.3 Sustainable intensification scenario

The sustainable intensification scenario considers that future expansions will occur within the land suitable for oil palm plantations and applies yield enhancement tools and technology. It uses the existing suitability map to allocate the future expansion of oil palm in the study areas. The expansion of oil palm plantations is only considered on non-forest lands including scrubland, agricultural land and other land, which are characterized by low carbon stock, i.e. with less than 35 tons of carbon per hectare and low biodiversity value (Gingold et al. 2012). However, the expansion of timber plantations is not taken into account in this scenario because a suitability map for timber plantations was not available.

The suitability maps for oil palm are based on various criteria for IOPP for Indonesian Kalimantan. Mantel et al. (2007) used relevant biophysical criteria, constraints and management needs to determine suitability ratings for oil palm plantation in Kalimantan. The suitability map developed by WRI and SEKALA uses 21 indicators of sustainable palm oil production set out by the Roundtable on Sustainable Palm (RSPO) standard (Gingold et al. 2012). Since the latter oil palm suitability map is more comprehensive and complies with the criteria for sustainable oil palm production, it was used to predict future oil palm expansion. All natural forests, including primary forests, secondary forests and peatland, are protected in the study area.

The suitability map classifies approximately 3.2 Mha or about 21% of the total area in Central Kalimantan and 5.2 Mha or about 35.3% of total land in West Kalimantan as potentially suitable for sustainable oil palm plantations. However, some suitable areas are located on the forest cover and peatland areas. This intersection of suitable land

with forest and peatland can be attributed to the difference in forest cover and peatland datasets used in the suitability mapping. To avoid losing these areas, a constraint map encompassing forest cover and peatland was combined with the land-use map to generate a scenario map that avoided clearing forest cover and peatland.

This scenario conservatively assumes that future oil palm plantations (2017–2035) increase at similar historical expansion rates between 2000 and 2016. Hence, an average annual expansion of 76,000 ha and 71,000 ha was applied to Central and West Kalimantan, respectively. Since oil palm plantations are established on suitable lands by using improved varieties of cultivars and are intensively managed to significantly enhance the oil palm productivity, this scenario assumes an average yield of 5.1 tCPO ha⁻¹ yr⁻¹ on par with the average yield under the RSPO-certified plantation (WWF 2012).

The suitability map for oil palm represents the potential areas for oil palm expansion in future. The proximity to existing road networks and mills may have a role in determining the locations of future expansion of oil palm plantations. With a massive road network and high density of mills across the study areas, all suitable areas have an equal chance of being used for oil palm plantation. Hence, the subset feature in Geostatistical Analyst of ArcGIS 10.2 was used to randomly identify an equivalent area for expansion between 2017 and 2035 based on a similar annual rate of oil palm expansion between 2000 and 2016.

2.5 Mapping, quantifying and valuating of ecosystem services under future land-use and land-cover scenarios

2.5.1 Key ecosystem services

This study focused on the five most relevant and important ecosystem services from the oil palm landscape based on stakeholder consultation, literature reviews (Bhagabati et al. 2014; Sumarga and Hein 2014; Vijay et al. 2016) and expert knowledge. These ecosystem services

include: i) Climate regulation service: Carbon storage; ii) Habitat quality; iii) Water yield; iv) Provisioning Service: Palm oil production; and v) Provisioning Service: Timber production.

Climate regulation service: Carbon storage

The land-use and land-cover changes (LULC) can represent a significant source of greenhouse gas (GHG) emissions in Indonesia. In 2005, about 63% of Indonesia's emissions were attributed to deforestation, particularly through peatland and forest fires (Government of Indonesia 2015). The expansion of oil palm plantations is considered a major driver of forest conversion and the resulting significant emissions. Oil palm development is predicted to contribute over a quarter (i.e. 26%) of net carbon emissions in West Kalimantan under the business-as-usual scenario by 2010 (Kimberly et al. 2012). Hence, carbon storage was selected as a key ecosystem service for this study. The change in carbon stock was analyzed to assess the impacts on climate regulation and understand trade-offs or synergies with other key ecosystem services under a different trajectory of future land-use scenarios. The InVEST Carbon Storage and Sequestration model was used for mapping, quantifying and evaluating carbon stored and sequestered under a LULC scenario. It applied carbon stock in the above- and belowground biomass, soil and dead organic matter to the current and future LULC maps (Equation 1). The model estimates the economic value of this ecosystem service to society by applying the carbon price and the discount rate, i.e. annual rate of devaluation of money. The model outputs include biophysical model outputs, comprising the carbon stock maps for the current and future LULC scenarios, and the valuation model output, comprising an economic valuation map and a sequestration map for future LULC (Sharp et al. 2016).

$$C_t = \sum_{(t=0,i)}^{(t=T)} (C_{AGB_i} + C_{BGB_i} + C_{SOM_i} + C_{DW_i}) \times Area_i$$

...Equation 1

where C_t : is total carbon in tC at time t ($t = 0, 1, 2, 3, \dots, T$ years); C_{AGB_i} is carbon in above ground biomass (AGB) in land-use class, i ($i = 1, 2, 3, \dots, I$ land-use class); C_{BGB_i} is carbon in belowground biomass (BGB) in land-use class, i ($i = 1, 2, 3, \dots, I$ land-use class); C_{SOM_i} is carbon in soil organic matter (SOM) in land-use class, i ($i = 1, 2, 3, \dots, I$ land-use class); C_{DW_i} is carbon in

dead wood in land-use class, i ($i = 1, 2, 3, \dots, I$ land-use class); and $Area_i$ is the area of i ($i = 1, 2, 3, \dots, I$ land-use class).

Carbon stock data were mainly sourced from Sumarga and Hein (2014), who compiled the carbon stock data from various sources and applied it to Central Kalimantan (Table 4). The carbon stock in peatland was obtained from Suwarna et al. (2012). They estimated carbon stock in the soil and vegetation of tropical peat forest in Indonesia. A global average carbon price of US\$18.7 per tC was applied an average price of US\$5.1 per tCO₂-eq for the carbon from forestry and land-use sectors in the voluntary markets in 2017 (Hamrick and Gallant 2017). A default value of 7% was used to estimate net present value (NPV).

Habitat quality

The direct measurement of biodiversity (in terms of genes, species or ecosystems and their abundance and frequency) is beyond the scope of this study because measurements are complex (e.g. Baral et al. 2014), and require significant resources and time to collect. Instead, habitat quality is used as a proxy measure for biodiversity and assessed in a landscape by employing threats of different land-use classes and their relative vulnerability, accessibility and proximity to the identified threats (Arunyawat and Shreatha 2016; Sharp et al. 2016). This habitat-based approach is relatively simple and requires minimal data inputs for mapping biodiversity conservation status in a landscape. Hence, the InVEST Habitat Quality Model was used by applying threats from agricultural development and road networks. The data inputs require current and future LULC maps, sources of threat, accessibility to threat, sensitivity of LULC classes to each threat and a half-saturation value. The half-saturation constant represents a landscape degradation value. This parameter was set to the default value of 0.5 (Sharp et al. 2016). Equation 2 calculates the habitat quality of a grid cell x in land-use class j .

$$Q_{xj} = H_j \left\{ 1 - \left(\frac{D_{xj}^z}{D_{xj}^z + K^z} \right) \right\} \quad \dots \text{Equation 2}$$

where Q_{xj} is the habitat quality in the grid cell x in land-use class j . H_j implies the habitat suitability of land-use class j . D_{xj}^z represents the total threat level in the grid cell x in land-use class j . K is the user-defined value for the half-saturation constant.

Table 4. Carbon stock for various carbon pools in the land-use classes in the study areas.

Land-use class	Carbon in Aboveground biomass, tC	Carbon in Belowground biomass, tC	Carbon in Soil organic matter, tC	Carbon in Dead wood, tC	Total Carbon, tC
Intact forest	234.8	43.2	37.2	29.8	345
Logged forest	161.76	39.2	43	26.7	270.66
Regrowth forest	139.05	39.2	43	26.7	247.95
Scrubland	19.4	3.9	43.1	2.4	68.8
Agricultural land	4.8	1	43.1	0	48.9
Other land	0	0	0	0	0
Oil palm plantation	42.5	8	37.2	0	87.7
Timber plantation	91.2	18.2	37.2	2.9	149.5
Water bodies	0.1	0	0	0	0.1
Peatland–scrubland	19.4	0	1205.59	2.4	1227.39
Peatland–intact forest	189.45	0	1537.37	29.8	1756.62
Peatland–logged forest	161.76	0	1713.77	26.7	1902.23
Peatland–regrowth forest	139.05	0	1486.39	0	1625.44

Water yield

Several studies have acknowledged the significance of water-related ecosystem services and investigated the impacts on water yield and water quality due to land-use change (e.g. Schmalz et al. 2015; Ardaban et al. 2016, 2017; Arunyawat and Shrestha 2016). During our field trip, many local people highlighted the change in water yield following land-use change and expressed their interest in better understanding the impact of oil palm plantations on water yield. Water yield is considered to be equal to net water run-off in given environmental and climatic conditions. Given the simplicity of the model and its low data requirement, InVEST Water Yield Model was chosen to assess the impact on water yield under future land-use scenarios. This model applies the Budyko curve and annual average precipitation to estimate water yield for a defined LULC class as given by Equation 3 (Sharp et al. 2016).

$$Y_x = \left(1 - \frac{AET_x}{P_x}\right) XP_x \quad \dots \text{Equation 3}$$

where Y_x is the annual water yield for the grid cell x in a landscape. AET_x represents the annual actual evapotranspiration for the grid cell x and P_x is the annual precipitation on the grid cell x .

The following input datasets were obtained from various sources:

- Root restricting layer depth: A GIS raster dataset for root restricting layer depth was derived from WRI's soil depth map for Kalimantan.
- Precipitation map: This map was extracted from WRI's average annual precipitation data set for Kalimantan.
- Plant available water content: A GIS raster dataset for this input was developed by using the soil profile in FAO's soil map (Fischer et al. 2008) and the corresponding value for the available water fraction was obtained from Soil-Plant-Atmosphere-Water (SPAW) at <https://hrsl.ba.ars.usda.gov/SPAW/Index.htm>.
- Average annual reference evapotranspiration: This was obtained by multiplying Pan Evapotranspiration data by 0.7 based on Allen et al. (1998). The Pan Evapotranspiration data set was sourced from <http://www.cgiar-csi.org/data/global-aridity-and-pet-database>.
- Evapotranspiration coefficient (KC): This is a factor for potential evapotranspiration for each plant type and was derived based on the sample evapotranspiration coefficient for different vegetation types in Sharp et al. (2016).

- Z parameter: The model default value of 0.5 was applied.

Provisioning Service: Palm oil production

An assessment of palm oil yield under future land-use scenarios, in conjunction with impacts on other ecosystem services, provides a holistic understanding of trade-offs or synergies between the ecosystem services. Despite the focus of this study being on a spatially explicit assessment of ecosystem services, the lack of discrete spatial data on oil palm plantations (for example, plantation location, age, typologies (industrial or smallholder), management regime and productivity) prevented any spatial analysis of palm oil production. Instead, a simple quantitative approach was applied using average palm oil productivity in oil palm plantations and plantation area to estimate total palm oil production under these scenarios as described by Equation 4.

$$PO_t = \sum_{(t=1)}^{(t=T)} (Y_t \times EOA_t) + (Y_t \times \sum_{(s=5)}^{(s=18)} NOA_s) \times P_t$$

... Equation 4

where PO_t is total value of palm oil production in year t ($t = 1, 2, 3, \dots, T$) in US\$. Y_t represents the palm oil yield in tCPO ha⁻¹ yr⁻¹. EOA_t represents the area of existing oil palm plantation in hectares and NOA_s is the new oil palm plantation at 5 years and over s ($s = 5, 6, 8, \dots, 18$ years). The plantations reach 18 years in 2035. P_t is the price of palm oil per tCPO in US\$.

Many studies reported great variability in palm oil productivity across regions and typologies (industrial or smallholder) (Shiel et al. 2009; Sumarga and Hein 2014; Fargeon 2015; Woittiez et al. 2017). With uncertainty and variation in the yield data, this study applied an average yield of 3.8 tCPO ha⁻¹ yr⁻¹ (Woittiez et al. 2017). However, the sustainable intensification scenario uses an average yield of 5 tCPO ha⁻¹ yr⁻¹ due to the productivity enhancement.

A recent price of US\$665 per tCPO from the Malaysian Palm Oil Council (MPOC)⁴ was used to evaluate the oil palm asset price. New

plantations are assumed to expand at the annual rate determined for the respective future land-use scenario and are considered to produce palm oil after 5 years as suggested by Sumarga and Hein (2014).

Provisioning Service: Timber production

Timber plantation is also a driver for land-use change in the study areas and is likely to grow in the concession areas under the business-as-usual and conservation scenarios. Hence, timber production is a provisioning ecosystem service from the timber plantation landscape. The total value of timber production is estimated by multiplying the area of timber plantation, the allowable cut per hectare and the timber price as given by Equation 5.

$$TP_t = \sum_{(t=1)}^{(t=T)} (AC_t \times TPA_t) \times P_t$$

... Equation 5

where TP_t is total value of timber in year t ($t = 1, 2, 3, \dots, T$) in US\$. AC_t represents the annual allowable cut per hectare in m³ha⁻¹yr⁻¹. TPA_t implies the area of timber plantation in hectares. P_t is the price of timber per cubic meter in US\$.

This study applied an average annual allowable cut of 0.86 m³ha⁻¹yr⁻¹ based on Sumarga and Hein's (2014) estimate for Central Kalimantan. The timber price of US\$205 m⁻³ (Suwarno et al. 2016) was used for both provinces.

2.5.2 Total economic valuation of ecosystem services

The economic valuation of ecosystem services has been popularized to appreciate the significance of the natural ecosystem by expressing the values in monetary terms or a dollar value (Costanza et al. 1997; de Groot et al. 2012; Kubiszewski et al. 2013; Anderson et al. 2017). The monetary values of ecosystem services are considered highly useful in decision making, emphasizing the protection and conservation of ecosystems that provide an array of ecosystem services to society (Tallis and Polasky 2009). Assigning a monetary value to ecosystem services is very subjective and challenging, particularly for sociocultural values, or loss or gain of biodiversity. However, different value aggregation methods have been developed

4 http://www.mpoc.org.my/Daily_Palm_Oil_Prices.aspx

and used for economic valuation of ecosystem services (Kubiszewski et al. 2013; Costanza et al. 2014). The benefit transfer method is the most widely used in the emerging field of ecosystem services valuation and is recommended for applying the economic values measured in one location to a similar location (Costanza et al. 1997) from social, economic and environmental perspectives (de Groot et al. 2012). However, this has not restricted the application of global economic values compiled in the ESV Database by The Economics of Ecosystem and Biodiversity (TEEB)⁵, Costanza et al. (1997), Costanza et al. (2014) and de Groot et al. (2012) to similar biomes. Since the first global valuation of ecosystem services in 1997 by Costanza et al., subsequently updated by de Groot et al. (2012) and Costanza et al. (2014), many studies have used biome-level values to demonstrate the significance of natural ecosystems to human well-being and to inform decision making on natural resource management and investment (e.g. Kubiszewski et al. 2013; Kundu et al. 2016; Anderson et al. 2017; Tolessa et al. 2017). These studies justified the application of biome-level data through the lack of country-level, regional or local data and did not account for geographical variability and uncertainty in valuation. Although these values are not the market value or a price for ecosystem services, the economic values help all stakeholders to understand and appreciate the relative values of the ecosystem services. They also enable comparison of the change in these values over time and space in conjunction with the drivers of change.

There is little data available for the economic valuation of ecosystem services for Indonesia. Despite some data on economic valuation of ecosystem services from protected areas (van Beukering et al. 2003) and forest ecosystems (van Beukering et al. 2009), it is not enough to assess the total economic valuation (TEV) of ecosystem services in the study area. Hence, this study chose to use the benefit transfer method and apply the relevant biome-level global data for economic valuation of ecosystem services. One of the advantages of applying a global value to ecosystem services is that it generalizes ecosystem

service values and enables comparison in different geographic locations worldwide.

This study applied the global values for TEV of ecosystem services at biome level based on de Groot et al. (2012) to similar biomes in the study areas. These global values were derived from a comprehensive compilation of ecosystem services values at 665 data points across the world. They reported ecosystem services values ranges (minimum, maximum), mean and median for distinct subservices under the provisioning, regulating, habitat and cultural services from 10 broadly categorized biomes. The tropical forest biome was used for the valuation of ecosystem services from forest covers in the study areas. Based on the current vegetation structure and disturbances, the forest covers were categorized into intact forest, logged forest and regrowth forest. Applying the mean values for ecosystem services of the tropical forest biome to these forest covers ignores the difference in their capacity to provide ecosystem services. This valuation leads to overestimation or underestimation of ecosystem services depending upon the proportion of these forest covers. In highly disturbed areas, the mean value approach overestimates the total value, whereas in less disturbed areas, the total value is underestimated.

To differentiate the landscape's capacity to deliver ecosystem services, unique landscape indexes are increasingly used to value ecosystem services (Burkhard et al. 2009, 2015; Soheli et al. 2015). This approach could be used to identify and assign relative indexes for different conditions of a land-use class. By considering the valuation of ecosystem services in the original database, the minimum and maximum values encompass the differences in the biome conditions and their capacities in terms of delivery of ecosystem services. The maximum values of ecosystem services represent an excellent biome condition with high capacity, whereas the minimum values indicate a poor biome with low capacity for delivering ecosystem services. To ensure some confidence in the valuations and account for the variation in ecosystem services across different biome conditions, the minimum and maximum values from de Groot et al. (2012) were consecutively applied to the poor and the excellent biome conditions, whereas the mean value was used for the average

5 (<http://www.fsd.nl/esp/80763/5/0/50>)

biome condition. The intact forests are primary forests in excellent condition with minimum or no human interference. Hence, this forest was assigned maximum values for ecosystem services for the tropical forest biome. Logged forests and regrowth forests represent disturbed old-growth forests and were considered to be in an average state. Hence, these forests were assigned the mean value of the tropical forest biome. However, de Groot et al. (2012) presented a huge discrepancy on the economic values for habitat services between the tropical and woodland biomes. For a tropical biome, the maximum value of habitat services is unrealistically low at US\$110, whereas the woodland biome has a very high value with a minimum value of US\$1274. To provide a reasonable estimate of the economic value of the habitat services, the maximum (US\$1630), mean (US\$1328) and minimum (US\$279), derived from analysis of 30 studies on tropical forests, were used (Carrasco et al. 2014).

In the case of planted forests, ecosystem services are significantly reduced where these plantations were established following a clearing of natural old-growth forest. However, several studies have investigated and recognized the roles of planted forests in providing habitats for different species (e.g. Brockerhoff et al. 2013), climate change mitigation (e.g. Carle and Holmgren 2008; Peng

et al. 2014), water regulation (e.g. Jackson et al. 2005) and reducing pressure on natural forests (e.g. Warman 2014). To conform to these findings and to account for the ecosystem services from plantations, the minimum values for ecosystem services for the tropical forest biome were applied to oil palm and timber plantations. In addition, the market values of palm oil and timber yields from these plantations were added to the provisioning services for TEV.

Scrublands were previously forested areas (old-growth and selectively logged forests) and became degraded due to deforestation, drought and recurrent fires. To value ecosystem services from scrublands, these areas were considered equivalent to a woodland biome in a poor state and were assigned the minimum value for this biome. However, applying the minimum economic value of US\$1274 for the woodland-to-scrubland area remarkably overestimates the value. Scrublands are in a degraded state and experience high disturbance. In the absence of an economic valuation of habitat services from scrubland in the study area or the region, this study applied a minimum value of habitat services from tropical forest. Since agricultural land was not included in the de Groot et al. (2012) biome list, this study used the economic value of ecosystem services from the 'crop' category compiled by Costanza et al.

Table 5. Land-use classes, the equivalent biome, value range and the economic values for four major ecosystem services.

Land use in the study areas	Equivalent biome	Value used	Provisioning services (US\$)	Regulating services (US\$)	Habitat services (US\$)	Cultural services (US\$)	Total economic values of Ecosystem Services (US\$ per ha per year)
Intact forest	Tropical	Maximum	4,229	10,789	1,630	9,040	25,689
Logged forest	Tropical	Mean	6,106	2,934	1,328	1,006	11,373
Regrowth forest	Tropical	Mean	6,106	2,934	1,328	1,006	11,737
Scrublands	Woodland	Minimum	1,593	65	279	8	1,945
Agricultural land	Crop	Mean	2,949	2,205	279	95	5,567
Other land	-	-	-	-	-	-	-
Oil palm plantation	Tropical	Minimum	4,361 - 5,225	46	279	0	4,687 - 5,551
Industrial plantation	Tropical	Minimum	2,010	46	279	0	2,336
Water bodies	Water lakes	Mean	1,914	187	0	2,166	4,267

(2014). However, the economic value for habitat services from agriculture was adjusted to the minimum value of habitat services from tropical forest. These values were converted into 2016 US dollar values by applying the percentage increase in CPI for the relevant periods (Williamson 2017). In terms of TEV of ecosystem services, logged forests and regrowth forests accounted for about 42%, agricultural land 23%, oil palm plantation 20%, water bodies 18%, scrublands 13% and timber plantations 9% of the ecosystem services provided by the intact forests. Table 5 summarizes the land-use classes, the equivalent biome, value ranges, the economic values for four major ecosystem services and the percentage values relative to intact forests.

The NPV is often used to convert the future return or benefit in the current value by applying a desired

rate of depreciation or discounted rate. This value represents the TEV over the period in today's value. After estimation of the total economic values of ecosystem services for the current and future land-use scenarios, the TEV over time (between 2017 and 2035) was converted into the NPV by applying Equation 6:

$$NPV_s = \sum_{t=1}^{(t=T)} \frac{TEV_{st}}{(1+r)^t} \quad \dots \text{Equation 6}$$

where NPV_s is the NPV for the land-use scenario s . s represents current land use, business-as-usual, conservation and sustainable intensification scenarios. TEV_{st} is the TEV for scenario, s in year, t ($t = 1, 2, 3, 4 \dots T$). r is the discount rate.

3 Results

3.1 Current land use in the study areas

The land-use map (2016) represents the nine land-use classes in both provinces (Figures 3 and 4). Table 6 presents the spatial extent of each land-use class in both provinces. Oil palm plantation covers about one-tenth of the area of both provinces. Oil palm mainly dominates in the southwest region in regencies Kotawaringin Barat, Seruyan and Kotawaringin Timur in Central Kalimantan. In West Kalimantan, plantation mainly occurs in the central part in regencies Landak, Sanggau, Sekadau, Sintang and in the south in Kab Ketapang regency. ITP was mapped onto approximately 112,000 ha in Central Kalimantan and 67,000 ha in West Kalimantan.

3.2 Oil palm expansion between 2000 and 2016

Central Kalimantan and West Kalimantan share over 60% of the total IOPP (5.06 Mha) of Indonesian

Kalimantan. One-third of the IOPP has been developed on the forest cover, shrub and non-forest in Kalimantan. Figure 5 compares the land-use categories that have been converted to IOPPs in Central Kalimantan, West Kalimantan and Indonesian Kalimantan between 2000 and 2016.

In Central Kalimantan, the area of IOPPs increased considerably between 2000 and 2016, by about five fold from 0.3 Mha to 1.6 Mha. They expanded by about 81,180 ha per year in this period and accounted for about 11% of the provincial territory. Figure 6 summarizes the conversion of different land-use classes to oil palm plantation in Central Kalimantan between 2000 and 2016.

West Kalimantan has also experienced a similar area expansion of IOPP, i.e. about 11% of the province, in this same period. The plantations increased over four fold to approximately 1.57 Mha in 2016 from 0.4 Mha in 2000 with an

Table 6. Land-use classes and their areas in Central and West Kalimantan in 2016.

Land-use classes	Central Kalimantan, area (ha)	West Kalimantan area (ha)
Intact forest	3,668,508	3,804,271
Logged forest	3,389,895	1,901,026
Regrowth forest	2,720,392	243,842
Scrublands	1,610,658	1,914,060
Agricultural land	1,831,809	5,175,098
Other land	342,159	110,535
Oil palm plantation	1,607,635	1,579,123
Industrial plantation	113,598	66,973
Water bodies	107,761	30,479
Total area	15,392,415	14,825,407

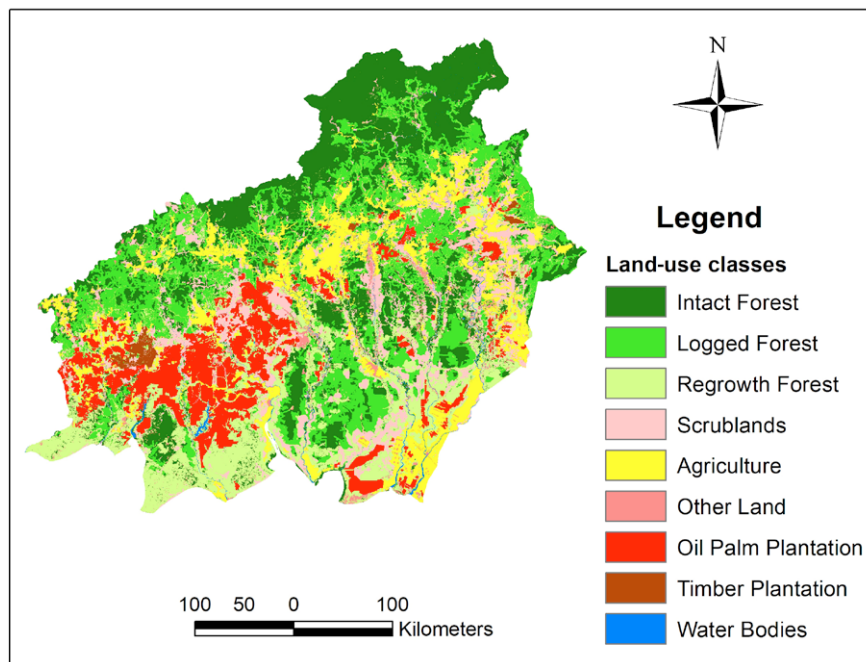


Figure 3. Land-use map of Central Kalimantan in 2016. Between 2000 and 2016, IOPPs extensively increased in the southwest region in regencies Kotawaringin Barat, Seruyan and Kotawaringin Timur in Central Kalimantan.

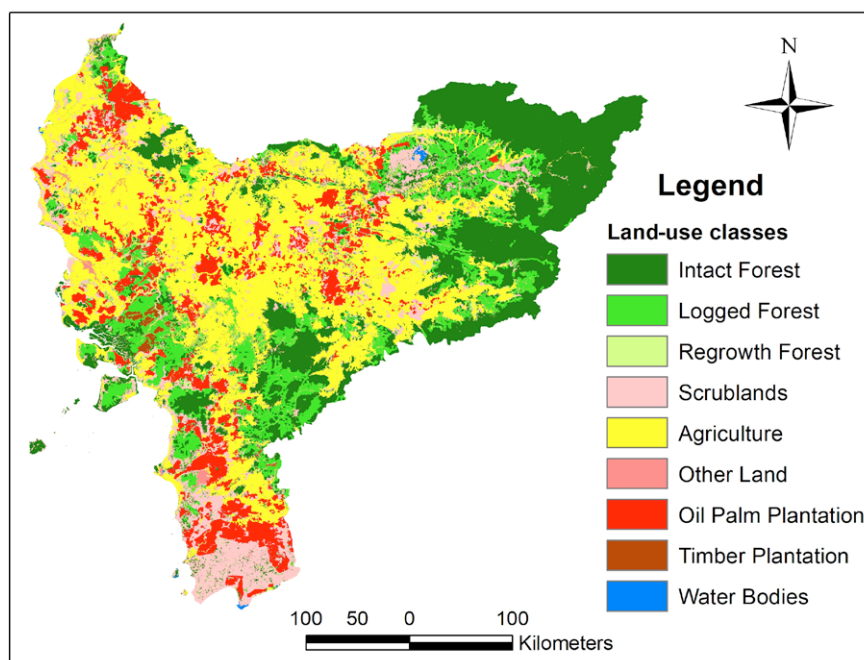


Figure 4. Land-use map of West Kalimantan in 2016. In West Kalimantan, IOPPs mainly expanded on the central part in regencies Landak, Sanggau, Sekadau, Sintang and on the south in Kab Ketapang regency.

annual expansion rate of 73,287 ha. Figure 7 summarizes the conversion of different land-use classes to oil palm plantation in West Kalimantan between 2000 and 2016.

3.3 Future land use under the selected oil palm expansion scenarios

Figures 8 and 9 show spatial maps of the study areas under three future oil palm expansion

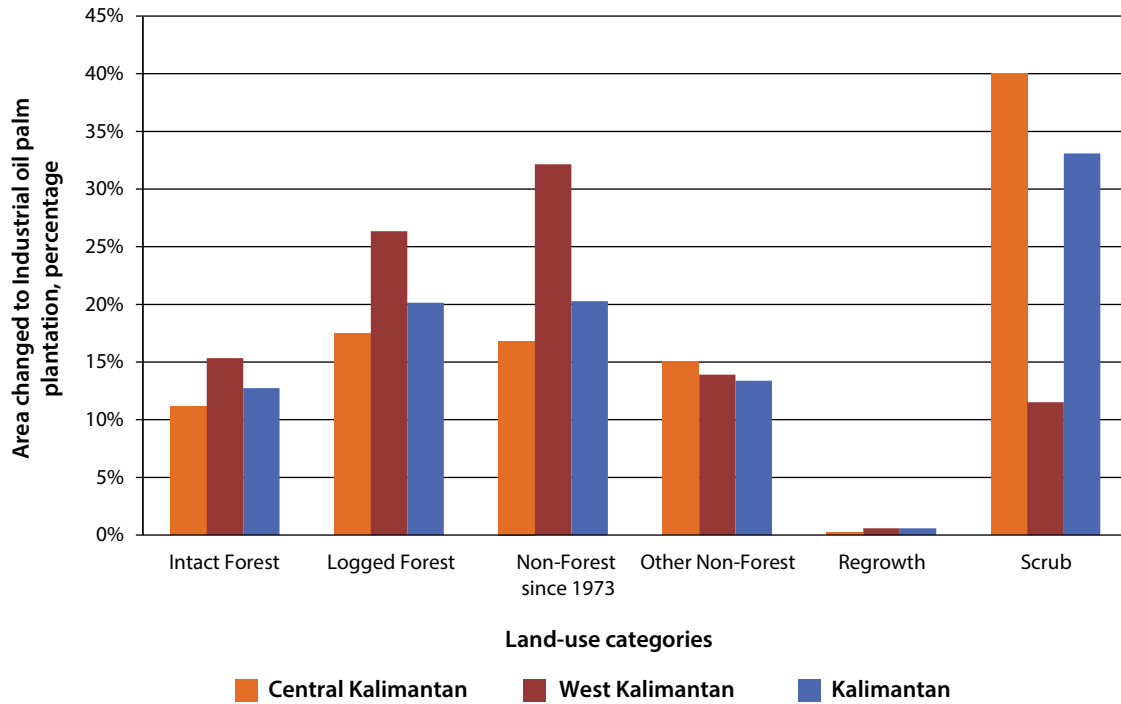


Figure 5. Comparison of land-use categories converted to IOPPs in Central Kalimantan, West Kalimantan and Indonesian Kalimantan between 2000 and 2016.

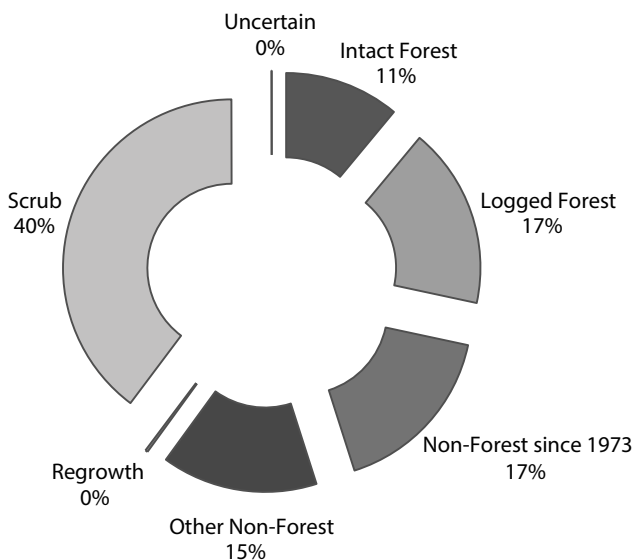


Figure 6. Land-use categories converted to IOPPs in Central Kalimantan between 2000 and 2016.

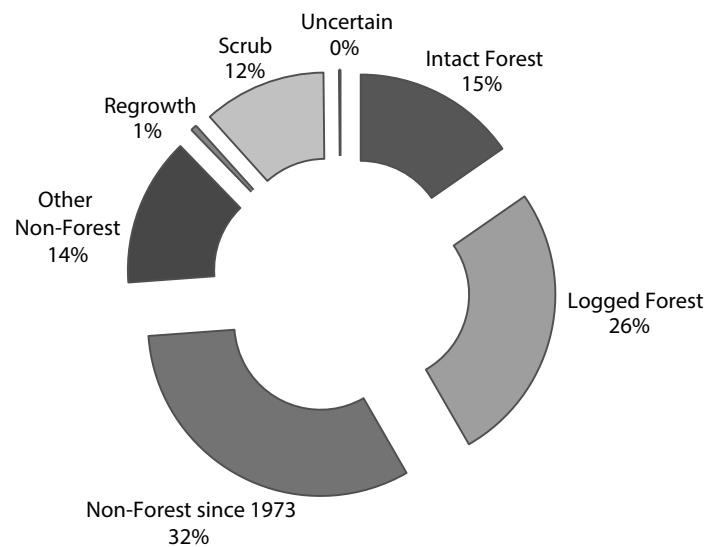


Figure 7. Land-use categories converted to IOPPs in West Kalimantan between 2000 and 2016.

scenarios by 2035. The major features of these scenarios are presented in Table 7 for Central and West Kalimantan.

3.3.1 Business-as-usual scenario

WRI’s oil palm concession map (2010) delineates 3.21 Mha or about one-fifth of the total area of

the province as oil palm concessions in Central Kalimantan. There is an overlap of about 186,000 ha between oil palm and timber concessions. However, oil palm plantation is the preferred option over timber plantation on the intersected areas for the high economic returns. Out of 1.6 Mha of oil palm plantation mapped in 2016, about 1.57 Mha of the existing oil palm plantation had

been developed on concession areas. Applying the assumption that oil palm expands across the entire concession area, the plantation area grows to the remaining 2.01 Mha under the business-as-usual scenario by 2035. Thus, total oil palm plantations exceed 3.58 Mha under this scenario (Figure 8a).

Excluding the overlapping areas between oil palm and timber concessions, timber plantations expand across additional areas of 401,763 ha based on the WRI's timber concession map by 2035. Of total timber plantations, 486,780 ha comprise 85,017 ha of the existing timber plantations established before 2017. Over half of the timber plantations develop on forest areas resulting in further loss of 80,744 ha of intact forest, 90,485 of logged forest and 55,377 ha of regrowth forest. The remaining expansions of timber plantations occur on scrublands (70,657 ha), agricultural land (60,882 ha) and other land (7250 ha).

Based on WRI's oil palm concession map (2010), 4.43 Mha of the province has legal permission for oil palm concessions in West Kalimantan. About 1.2 Mha of 1.58 Mha of the existing oil palm plantation was developed on the concession areas in West Kalimantan. Under the business-as-usual scenario, oil palm plantations grow across the remaining concession areas of 3.3 Mha by 2035. In West Kalimantan, oil palm plantations expand at the rate of 181,000 ha per year with a total area of 4.8 Mha of the province (Figure 9a).

In West Kalimantan, timber plantations increase to 1.88 Mha from about 67,000 ha on the WRI's timber concession map under this scenario by 2035. About 50% of timber plantations expand at the expense of agricultural land (about 0.9 Mha), whereas forest cover contributes over 30% or 0.55 Mha. The remaining expansions of timber plantations occur on scrublands (331,051 ha or 18%) and oil palm plantation (46,438 ha).

3.3.2 Conservation scenario (CON)

Applying the assumptions of the conservation scenario, oil palm plantations slightly increase by 216,000 ha, whereas timber plantation areas expand by about 17,000 ha by 2035 in Central Kalimantan. Altogether over 13.7 Mha are excluded from the future expansions of oil palm and timber plantations under this scenario, including forest cover (0.98 Mha), peatland (2.66 Mha) and areas other than APL land in the

spatial planning map (12.8 Mha). However, the existing oil palm plantations (1.6 Mha) and timber plantations (109,000 ha) in the constrained area before 2017 are continually used for palm oil and timber productions under this scenario (Figure 8b).

In West Kalimantan, excluding the forest cover and peatland, and restricting plantations to the designated land for agriculture and other uses (APL) on the spatial planning map, oil palm will expand by an additional 0.54 to 2.1 Mha. Timber plantations will also increase by about 74,000 ha to 141,022 ha (Figure 9b).

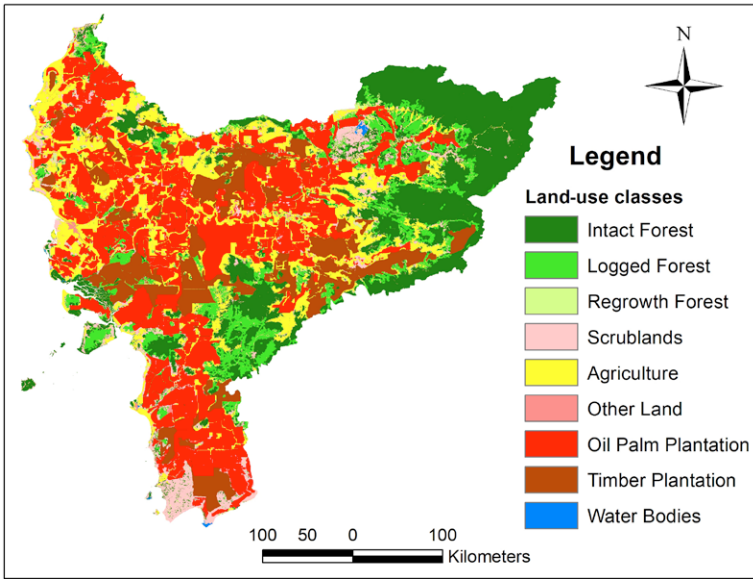
3.3.3 Sustainable intensification scenario (SUS-INT)

In Central Kalimantan, applying a similar historical annual rate of oil palm expansion between 2000 and 2016, oil palm plantations should expand by 1.59 Mha by 2035. The resulting scenario map shows an expansion of oil palm plantations by about 1.37 Mha to a total of 2.98 Mha. Central Kalimantan experiences an average expansion of 76,000 ha per year of oil palm between 2017 and 2035 (Figure 8c).

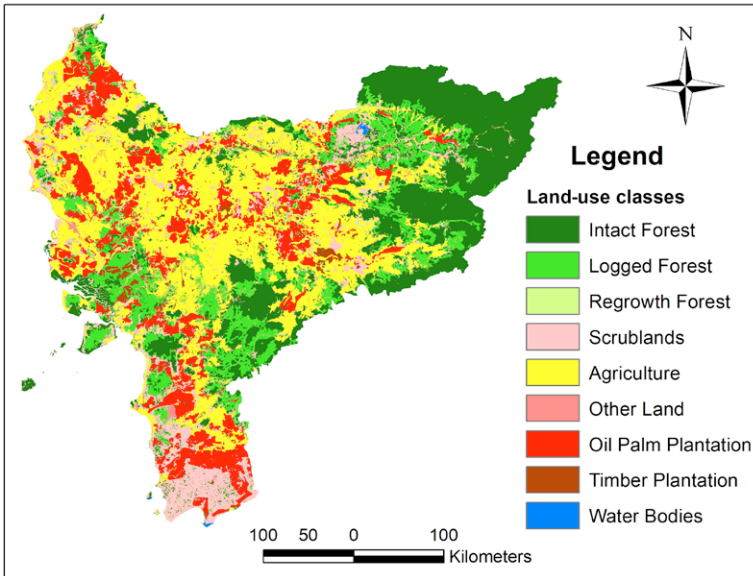
In West Kalimantan, the areas of oil palm plantations should expand by 1.32 Mha by 2035 with a similar annual rate to oil palm expansion between 2000 and 2016. With the exclusion of intersected forest cover and peatland on the suitability map, oil palm plantations increase by about 1.28 Mha on suitable land to a total of 2.86 Mha under the sustainable intensification scenario. Oil palm plantations will expand at an average rate of 71,000 ha per year between 2017 and 2035 (Figure 9c).

3.4 Land use transitions in future land-use

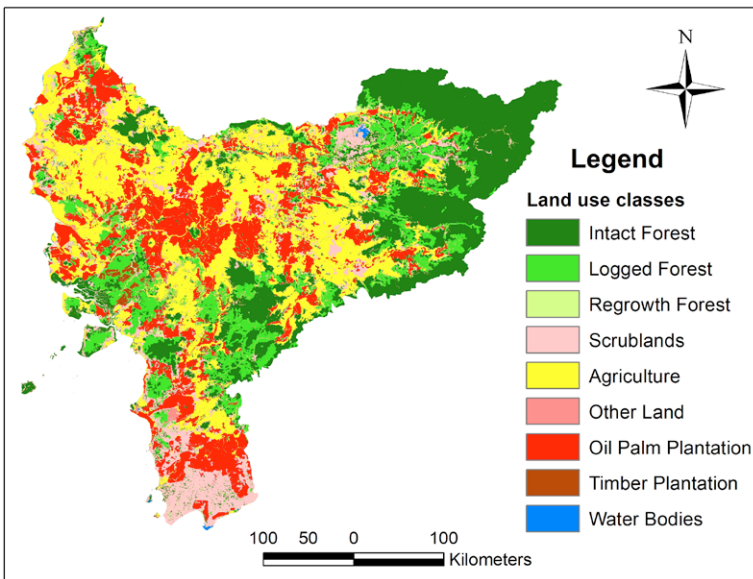
Figure 10 summarizes the land-use transition to oil palm plantation in Central Kalimantan. In the business-as-usual scenario, about two-thirds (1.2 Mha) of oil palm expansions occur on forest covers resulting in further loss of 215,158 ha of intact forest, 358,222 ha of logged forest and 586,244 ha of regrowth forest. Both scrublands and agricultural land contribute about one-fifth each. Oil palm plantations also replace about 28,581 ha of timber plantations under this scenario. Approximately 133,000 ha of agricultural land and 78,000 ha of



(a) Central Kalimantan land-use map for the business as usual scenario in 2035.

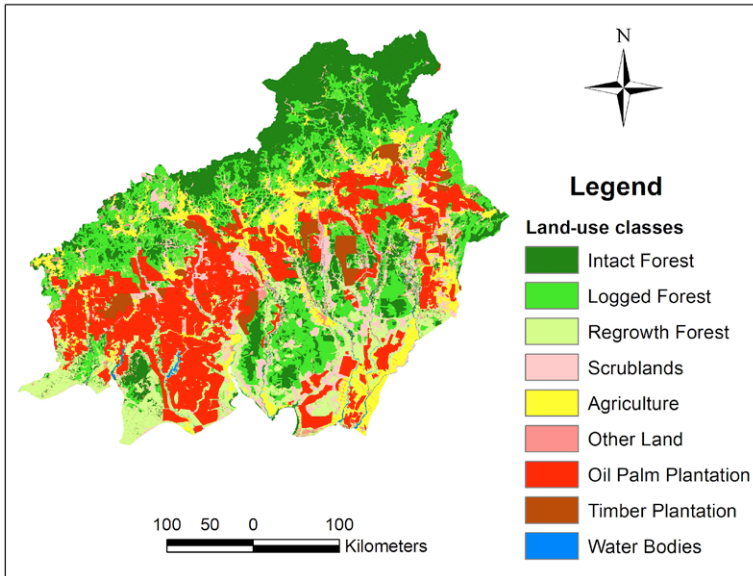


(b) Central Kalimantan land-use map for the conservation scenario in 2035.

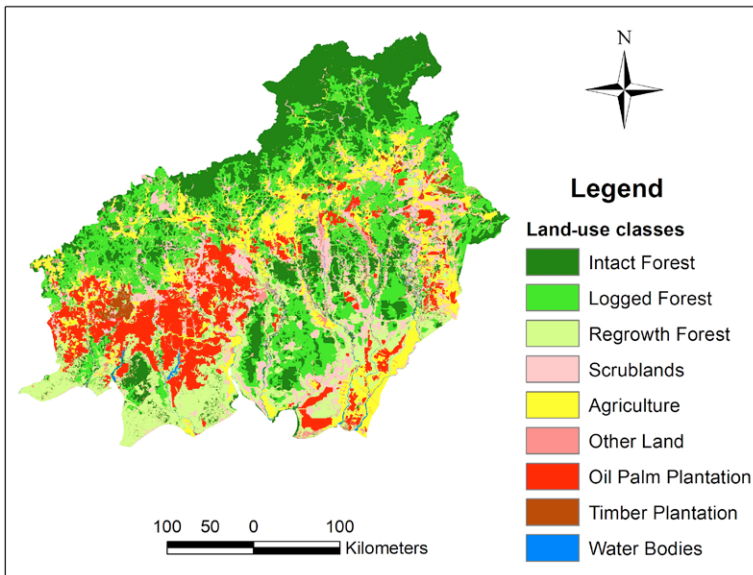


(c) Central Kalimantan land-use map for the sustainable intensification scenario in 2035.

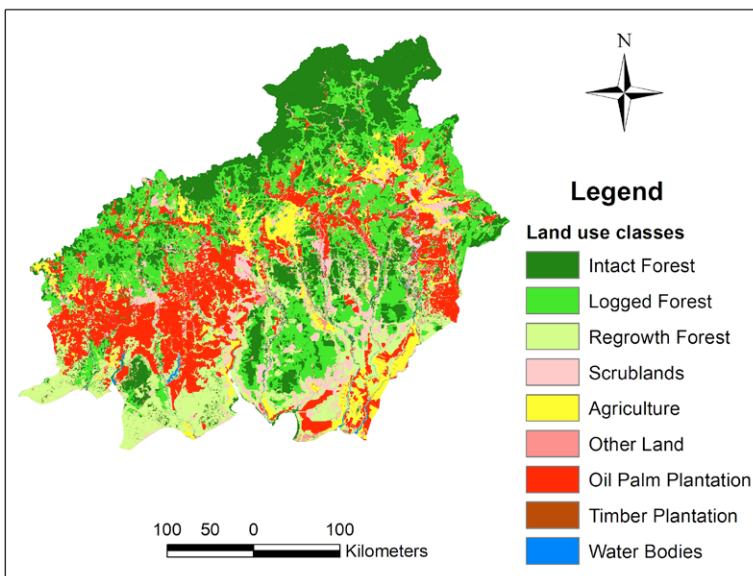
Figure 8. Central Kalimantan land-use maps for the three future oil palm expansion scenarios in 2035.



(a) West Kalimantan land-use map for the business as usual scenario in 2035.



(b) West Kalimantan land-use map for the conservation scenario in 2035.



(c) West Kalimantan land-use map for the sustainable intensification scenario in 2035.

Figure 9. West Kalimantan land-use maps for the three future oil palm expansion scenarios in 2035.

Table 7. Major features of the three oil palm expansion scenarios in Central and West Kalimantan by 2035.

Oil palm expansion scenarios	Central Kalimantan	West Kalimantan
Business as usual (BAU)	<ul style="list-style-type: none"> Oil palm plantations expand by 2.01 Mha to 3.58 Mha, enveloping over 23% of the province. About two-thirds (1.2 Mha) of oil palm expansion occurs across forest cover. Timber plantations increase by 373,000 ha to about 487,000 ha. About half of timber plantations occur across forest cover. 	<ul style="list-style-type: none"> Oil palm plantations grow at a rate of 181,000 ha per year and increase by 3.3 Mha to a total area of 4.8 Mha, covering over 32% of the province. About two-thirds or 2.0 Mha of oil palm expansion occurs across agriculture areas. Timber plantations increase by 1.82 Mha to 1.88 Mha.
Conservation (CON)	<ul style="list-style-type: none"> Oil palm plantations increase by about 218,000 ha to 1.82 Mha, whereas timber plantations expand by about 17,000 ha to about 114,000 ha. Over 13.7 Mha of land is excluded from the future expansion of oil palm and timber plantations. 	<ul style="list-style-type: none"> Oil palm plantations increase by about 534,000 ha to 2.11 Mha, whereas timber plantations expand by about 74,000 ha to about 141,000 ha. Over 9.63 Mha of land is excluded from the future expansion of oil palm and timber plantations.
Sustainable intensification (SUS-INT)	<ul style="list-style-type: none"> Oil palm plantations grow at an annual average rate of 76,000 ha and increase by about 1.37 Mha to a total of 2.98 Mha. Expansion primarily occurs on suitable non-forest lands (about 94%). Timber plantations reduce by over 82,000 ha due to transition to oil palm plantations. 	<ul style="list-style-type: none"> Oil palm plantations grow at an annual average rate of 71,000 ha and increase by about 1.28 Mha on suitable land to a total of 2.86 Mha. About 87% of oil palm expansion occurs on agricultural land and nearly 12% on scrubland. Timber plantation area remains the same.

scrubland transition to oil palm plantations in the conservation scenario. Under the sustainable intensification scenario, about 94% of the oil palm plantations develop on non-forest areas including agricultural land, scrubland and other land. The remaining 82,366 ha of timber plantations are converted into oil palm plantations.

In West Kalimantan, about two-thirds or 2.0 Mha of the oil palm expansions occur in agricultural areas, whereas about 0.6 Mha of forest cover transitions to oil palm plantations in the concession areas. Further, about 0.6 Mha of scrubland is also converted to oil palm plantation under this scenario. Since the forest cover and peatland are protected in the conservation scenario, the plantations only expand on the non-forest lands, primarily agricultural land (about 413,000 ha) and scrubland (about 114,000 ha). Under the sustainable intensification scenario, plantations

mainly replace agricultural land (about 1.2 Mha) and scrubland (over 145,080 ha) (Figure 11).

3.5 Mapping, quantifying and economic valuation of ecosystem services

3.5.1 Carbon storage and sequestration

By applying the secondary source of carbon stock data for land-use classes with and without peatland, the model estimates that 6516 million tons of carbon (million tC) are stored in the current land use in Central Kalimantan. Carbon storage is reduced by about 9% (591 million tC) under the business-as-usual scenario, whereas conservation and sustainable intensification scenarios result in an increase of the carbon stock by 10 million tC and 39 million tC, respectively (Table 8).

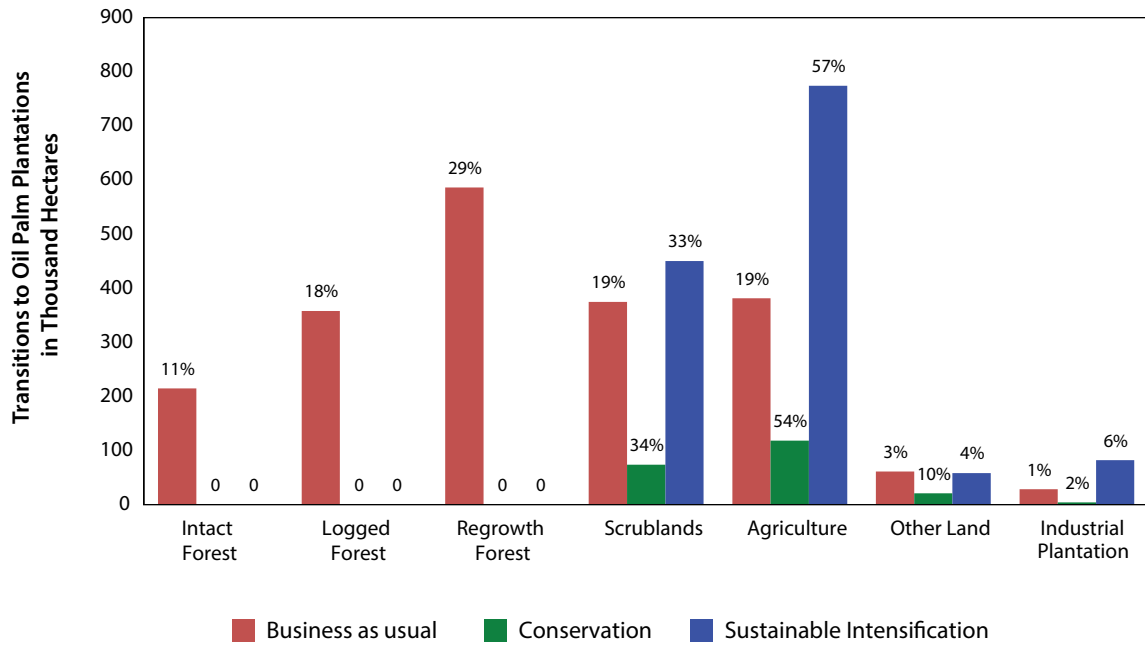


Figure 10. Land-use categories transitioned to oil palm plantation in Central Kalimantan under the three future scenarios: business as usual, conservation and sustainable intensification between 2017 and 2035.

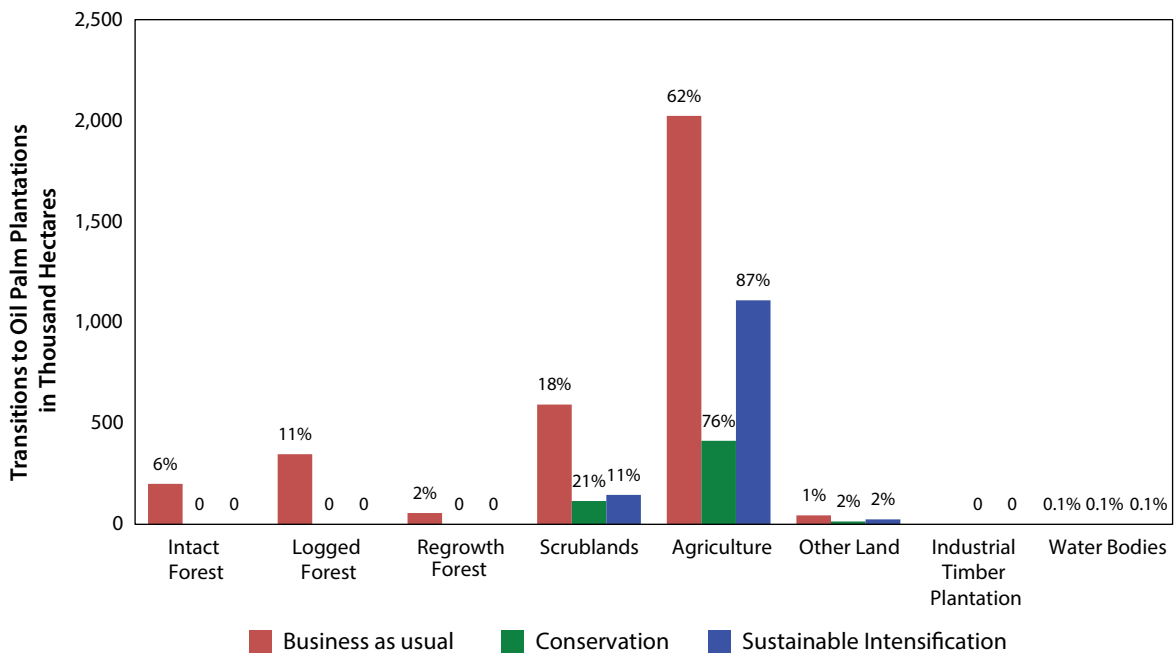


Figure 11. Land-use categories transitioned to oil palm plantations in West Kalimantan under the three future scenarios: business as usual, conservation and sustainable intensification between 2017 and 2035.

Obviously, the reduction of carbon stock is expected in business as usual due to the conversion of HCS areas, i.e. old-growth and regrowth forests. However, the carbon stock increases in

conservation and sustainable intensification due to avoiding clearance of the HCS areas, including forests and peatland, and most of the expansion occurring on agricultural land and scrubland.

Table 8. Carbon stock in the current and future land-use scenarios in Central Kalimantan.

Current and future LULC scenarios	Total carbon stock, million tC	Carbon stock change, million tC	Net Present Value from current to future LULC scenarios, US\$ million
Current LULC - 2016	6516		
BAU - 2035	5925	-591	-6442
CON - 2035	6526	10	105
SUS-INT - 2035	6555	39	424

Table 9. Carbon stock in the current and future land-use scenarios in West Kalimantan.

Current and future LULC Scenarios	Total Carbon Stock, million tC	Carbon Stock Change, million tC	Net Present Value from current to future LULC scenarios, US\$ million
Current LULC - 2016	3925		
BAU - 2035	3146	-779	-8489
CON - 2035	3951	26	282
SUS-INT - 2035	3964	39	429

In West Kalimantan, the current land use stores about 3925 million tC, which is approximately 60% of the carbon stock in Central Kalimantan. Aggressive expansion of oil palm and timber plantations into HCS areas results in about 20% loss of carbon stock (779 million tC) in the business-as-usual scenario. Carbon stock increases by 26 million tC in the conservation scenario to 3951 million tC, i.e. 1.6-times more than in Central Kalimantan due to the relatively high intensity of oil palm expansion on agricultural land and scrubland, i.e. low carbon stock areas in West Kalimantan. However, the carbon stock increases by the same amount, i.e. 39 million tC, as in Central Kalimantan under the sustainable intensification scenario to 3964 million tC in West Kalimantan (Table 9).

Regarding the NPV, the loss of carbon stock in the business-as-usual scenario results in a negative NPV of (-)US\$6.4 billion in Central Kalimantan and (-)US\$8.5 billion in West Kalimantan at a 7% discount rate without an increase in the carbon price of US\$18.72 per tC. The NPV is proportional to the amount of carbon stock loss or gain in the future scenarios. Due to the increase in carbon stock in conservation and sustainable intensification scenarios, the NPVs are positive with the highest return of US\$429 million in

sustainable intensification in West Kalimantan (Tables 8 and 9).

The spatial distribution of carbon stock under the current land use and future scenarios is visualized in Figure 12a–d for Central Kalimantan and Figure 13a–d for West Kalimantan. Since the change in carbon stock is not prominent on the provincial maps, a small area is highlighted to focus on carbon stock change as a result of plantation expansions in these scenarios.

3.5.2 Habitat quality

The model estimated relative habitat quality values between 0 and 1 across the province under the future land-use scenarios. Habitat quality is expected to decline in future land-use scenarios due to expansions of oil palm plantations at the expense of forest cover. However, the conservation scenario presents an exception with almost no change in habitat quality in both provinces. This is attributed to the protection of old-growth and regrowth forests under this scenario. Under the business-as-usual scenario, the habitat quality declines significantly with an almost 12% reduction in the average habitat quality value from 0.572 in current land use to 0.503, in Central Kalimantan. Similarly, the habitat quality decreases by over 14%

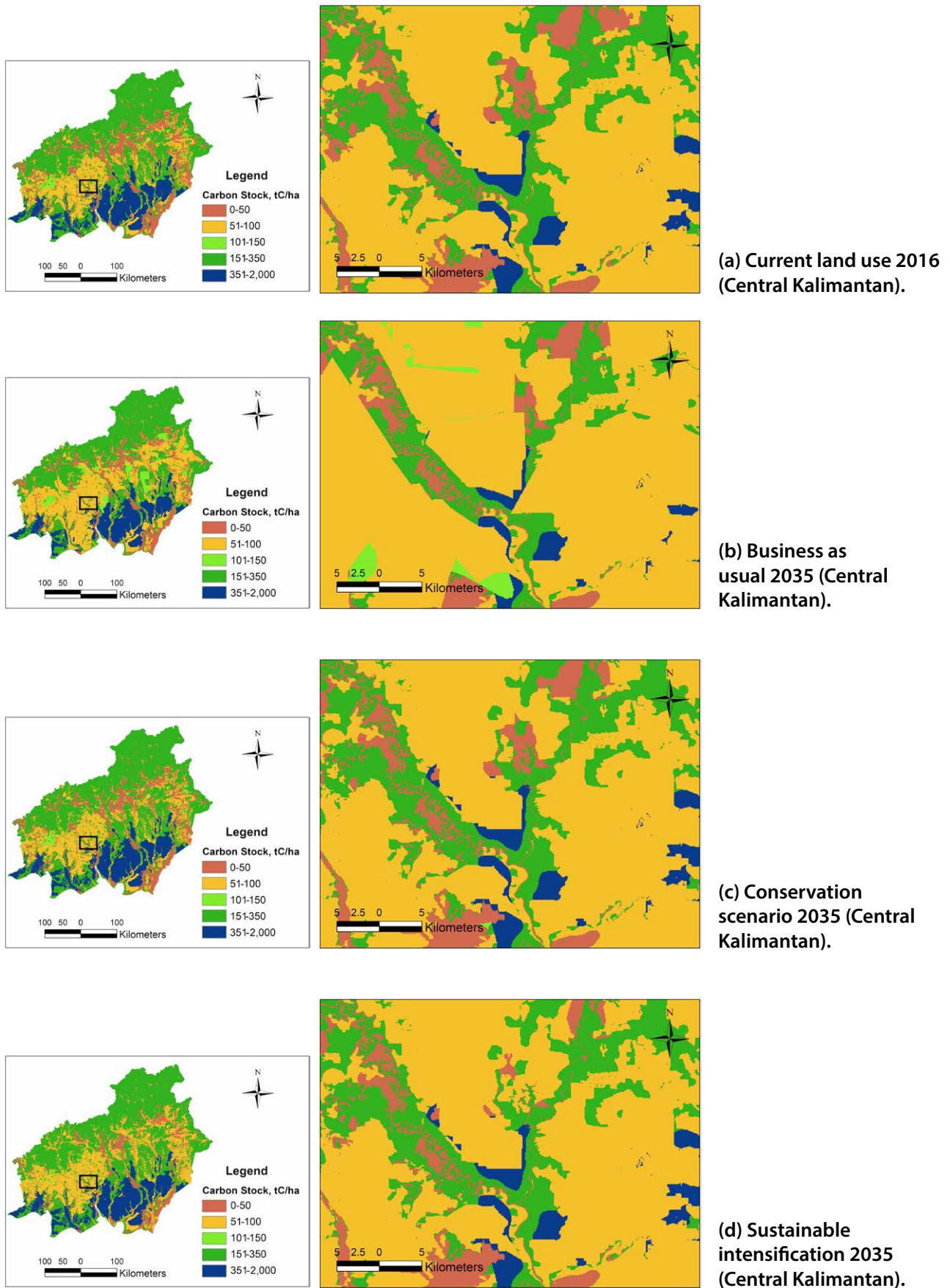


Figure 12. Carbon stock map in Central Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.

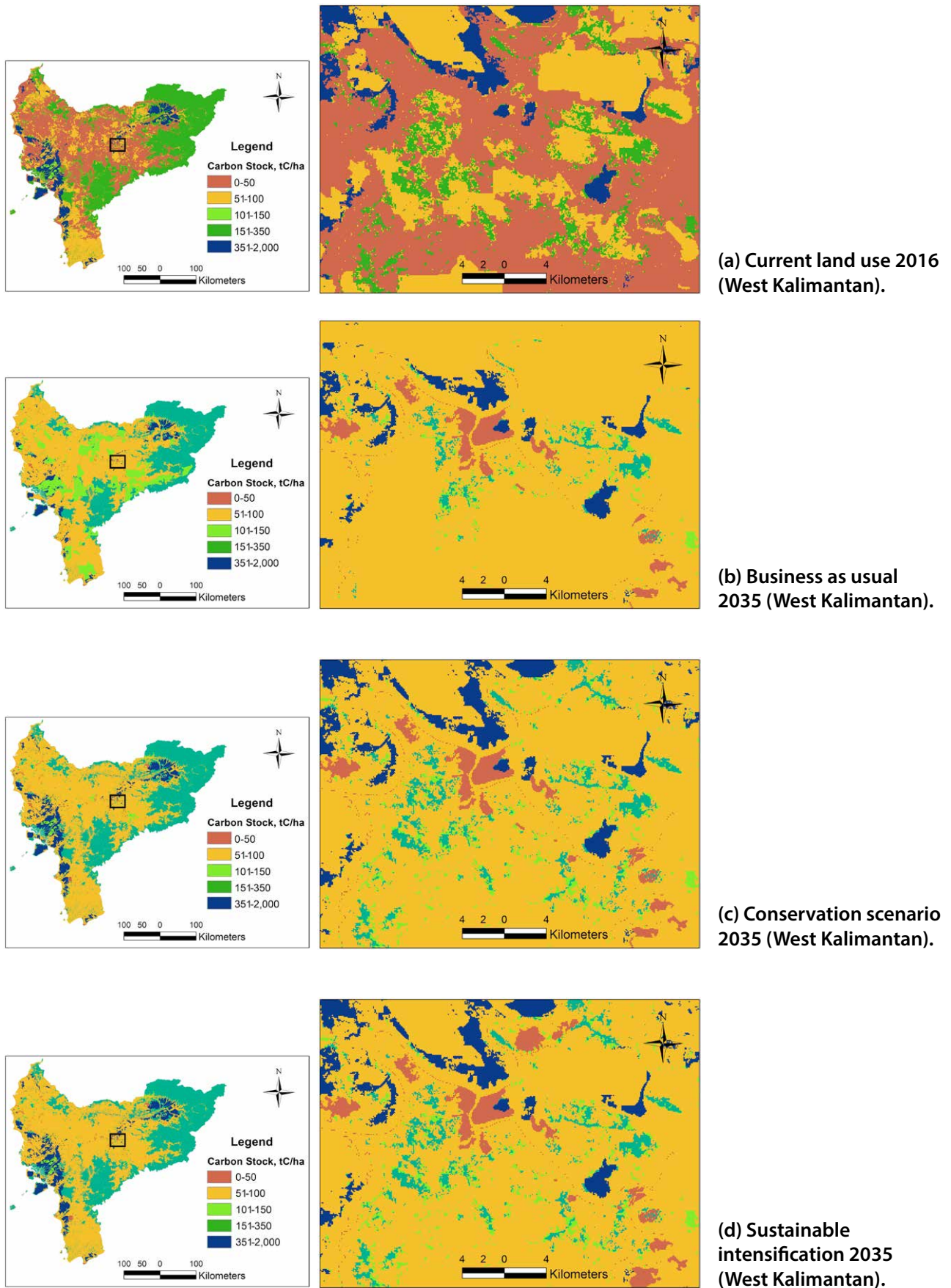


Figure 13. Carbon stock map in West Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.

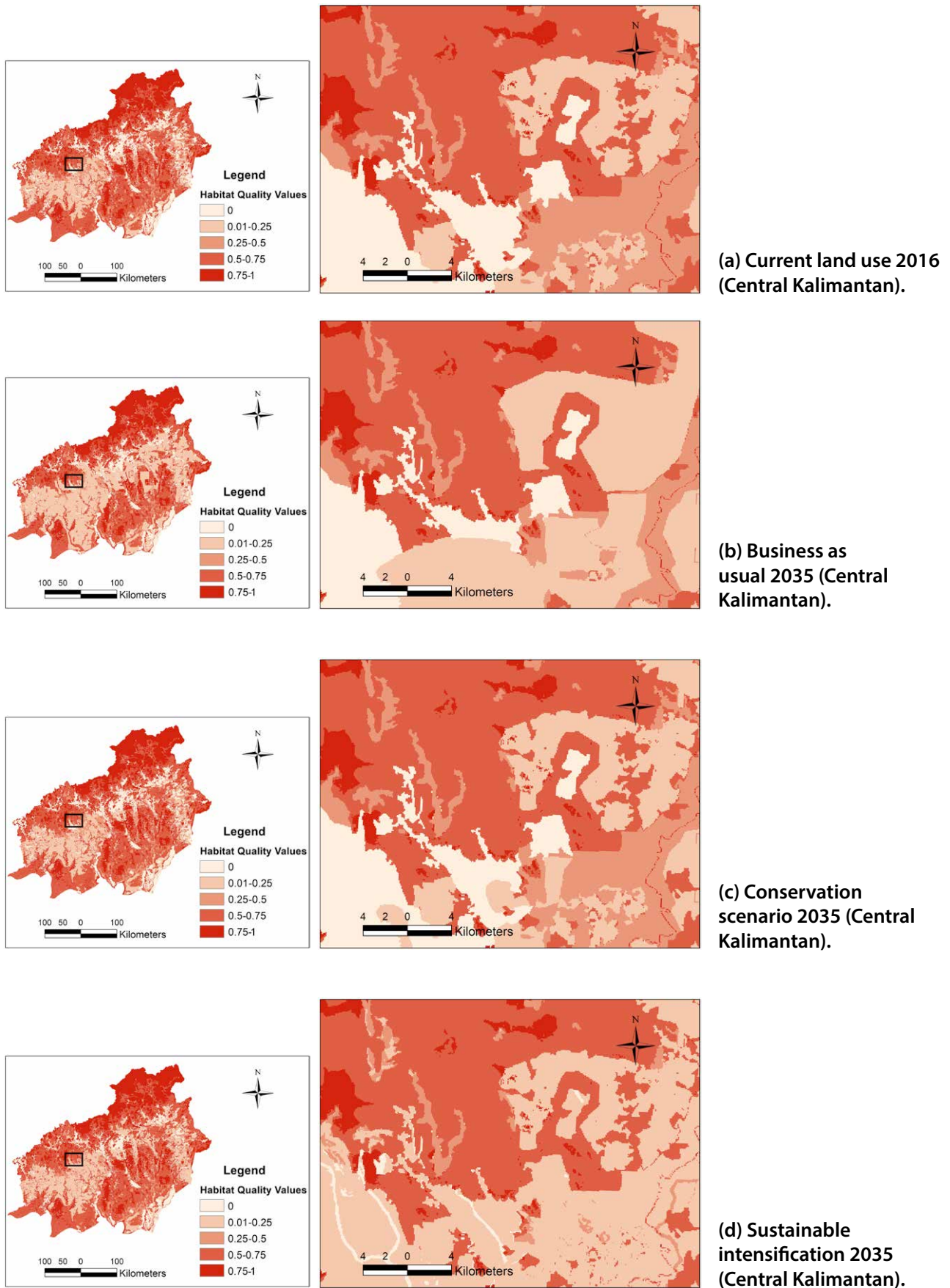


Figure 14. Carbon stock map in Central Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.

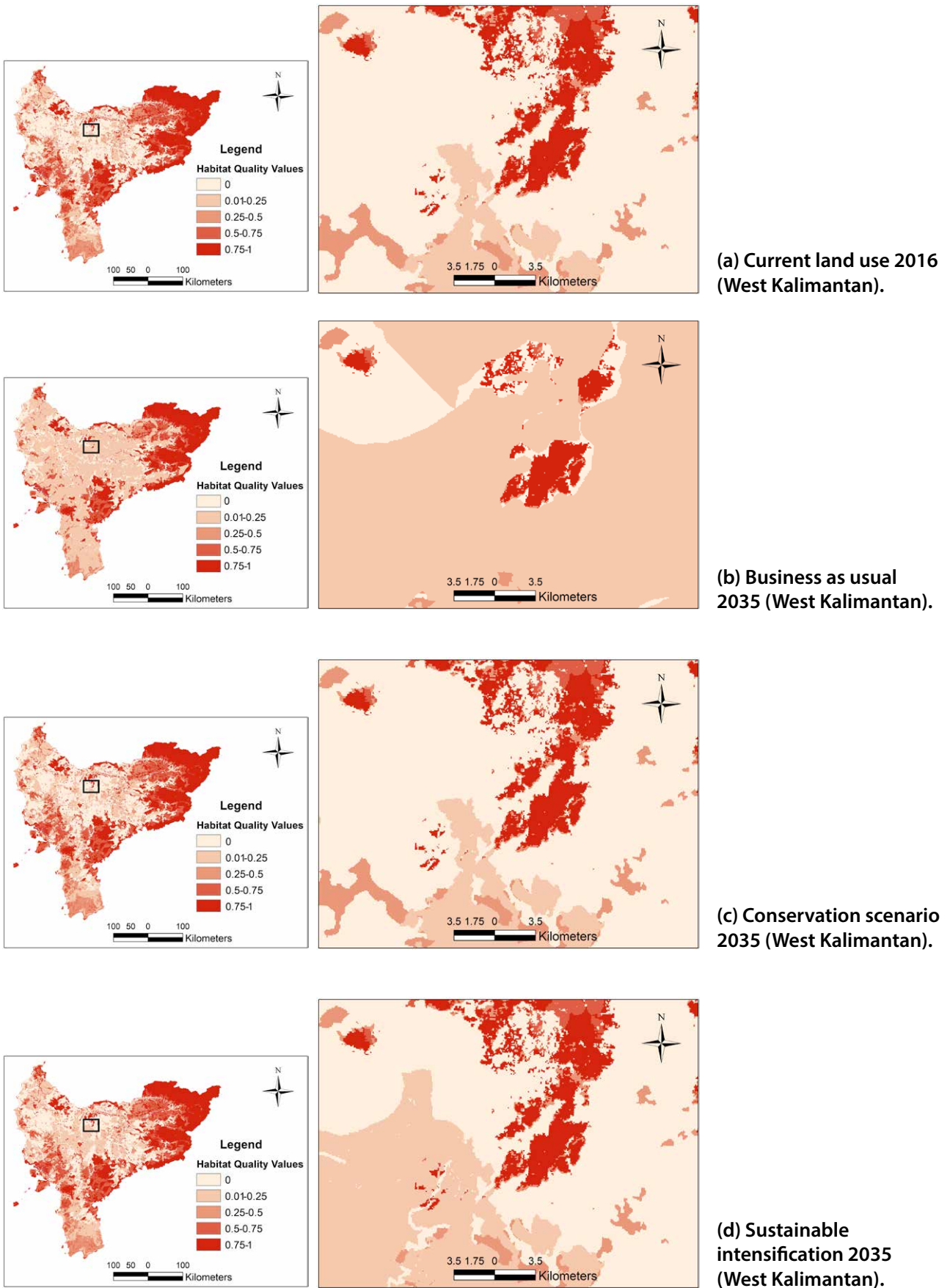


Figure 15. Habitat quality maps in West Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.

from 0.418 to 0.358 in West Kalimantan. The old-growth and regrowth forests in the concession areas are cleared for expansion of oil palm and timber plantations, which entails a remarkable loss of habitat quality in both provinces. Besides, these expansions also open up the habitat frontiers in the adjacent areas of old-growth and regrowth forest by increasing the level of threat due to proximity to these areas causing a decline in habitat quality. The model predicts a very nominal loss of habitat quality, i.e. less than 1% in both provinces from the oil palm expansions under the sustainable intensification scenario. The change in habitat quality is less distinct on the provincial maps. Hence, a small area is highlighted to demonstrate the impact on habitat quality as a result of oil palm expansion under three scenarios (Figures 14 and 15).

Under the conservation and sustainable intensification scenarios, the old-growth and regrowth forests are protected ensuring no loss of habitat quality. Hence, high habitat quality areas are located in the northeast regions of both provinces, which correspond to the areas of forest cover. Habitat quality tends to decline from a conversion of scrublands to plantation, while it slightly increases due to conversion of agricultural land to plantation. Habitat quality is considered to deteriorate on plantations (oil palm and timber) relative to scrubland. The conversion of scrubland to oil palm plantation evidently causes loss of habitats of native flora and fauna and may also negatively impact aquatic ecosystems due to water contamination. However, by employing some conservation strategies, the habitat quality might improve in plantations (oil palm). A small increase in the number of forest-dwelling species was reported in oil palm plantations after implementation of conservation efforts in these plantations (Koh 2008).

3.5.3 Water yield

The model predicts a decline in water yield under all future land-use scenarios relative to the current land use. In Central Kalimantan, the water yield will decrease by 0.62%, 0.14% and 0.13% under sustainable intensification, business-as-usual and conservation scenarios, respectively. In contrast, the business-as-usual scenario will experience the highest loss of water yield (1.7%), followed by the sustainable intensification scenario (0.54%) in West Kalimantan. The lowest decline in water

yield is predicted for the conservation scenario in both provinces. Although, these reductions in water yields do not show any significant loss at the provincial level, the changes in water yield are evident at the local level, as illustrated in Figures 16 and 17. With the same bioclimatic and biophysical variables, the reduction in water yield is solely attributed to a change in current land use to plantation (oil palm or timber) in the future scenarios at the provincial level. The expansion of oil palm and timber plantations on agricultural land, scrublands and other lands increases the transpiration from these areas. Thus, the water yield is negatively impacted due to a decrease in water available as run-off. In both provinces, the highest percentage loss of water yield is supported by increased conversion of these land uses to plantations. For instance, in the sustainable intensification scenario in Central Kalimantan, above 90% or over 1.0 Mha of oil palm expansions occur on agricultural land (57%), scrublands (33%) and other land (4%), which corresponds to the highest percentage loss in water yield. Similarly, about 2.7 Mha of these lands are converted to oil palm and timber plantations resulting in the highest loss in water yield in the business-as-usual scenario in West Kalimantan.

3.5.4 Palm oil production

In Central Kalimantan, the business-as-usual scenario produces 8.45 million tons of crude palm oil per year (Mt CPO yr⁻¹) from an average area of 2.22 Mha based on the average yield of 3.8 tCPO per ha per year between 2017 and 2035. Assuming an enhancement of productivity to 5.1 tCPO per ha per year equivalent to the average yield under the Roundtable for Sustainable Palm Oil (RSPO), the sustainable intensification scenario supplies almost the same amount of palm oil as the business-as-usual scenario, i.e. 8.37 Mt CPO yr⁻¹ from 2.05 Mha. In the conservation scenario, the existing oil palm plantation dominates the palm oil production with an annual yield of 6.49 Mt CPO from 1.71 Mha (Figure 18). Based on the current price of US\$665 per t CPO from the MPOC,⁶ the gross revenue is estimated to US\$5.61 billion for business-as-usual, US\$5.56 billion for sustainable intensification and US\$4.31 billion for the conservation scenarios.

6 http://www.mpoc.org.my/Daily_Palm_Oil_Prices.aspx

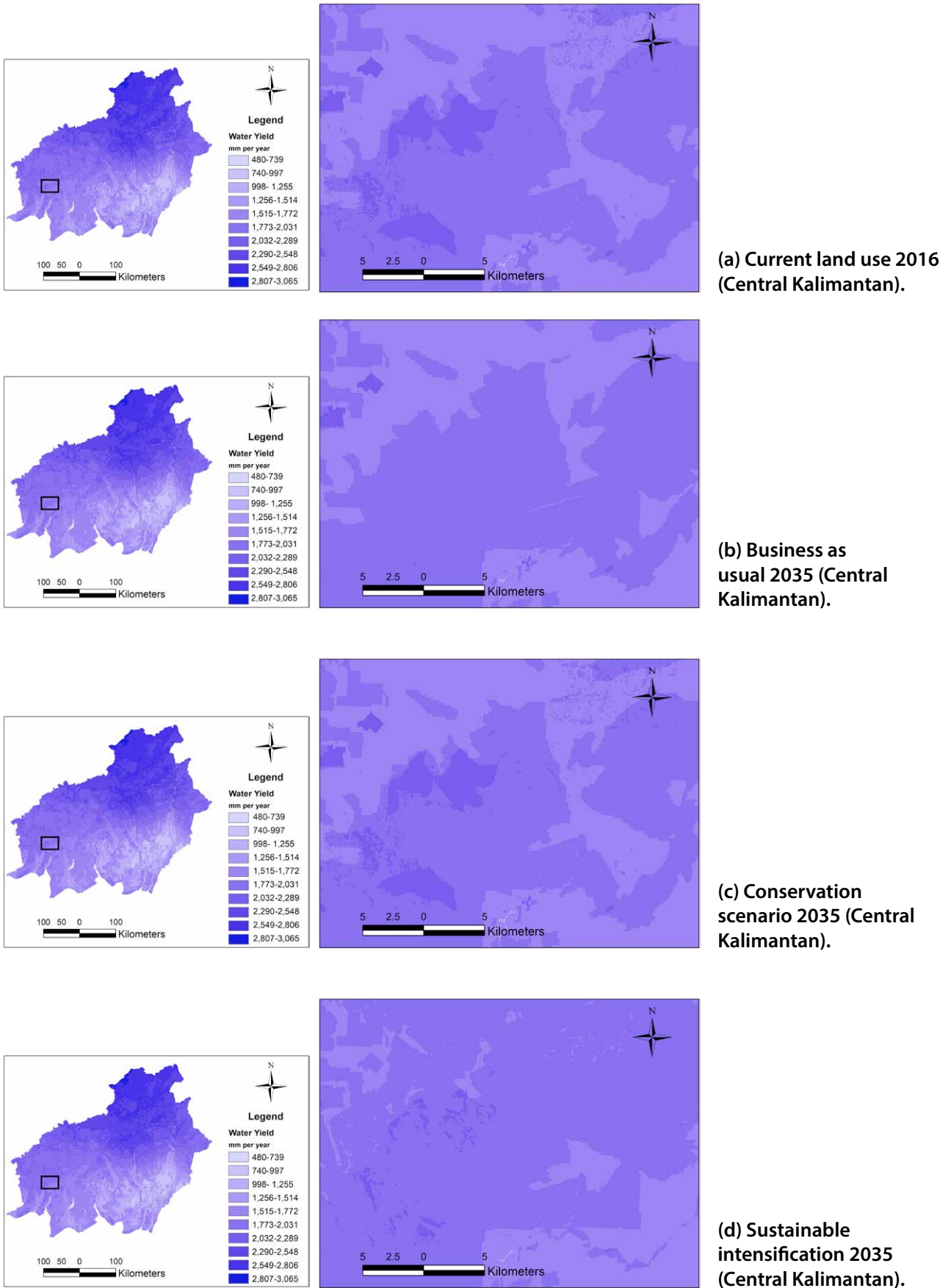


Figure 16. Water yield map: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.

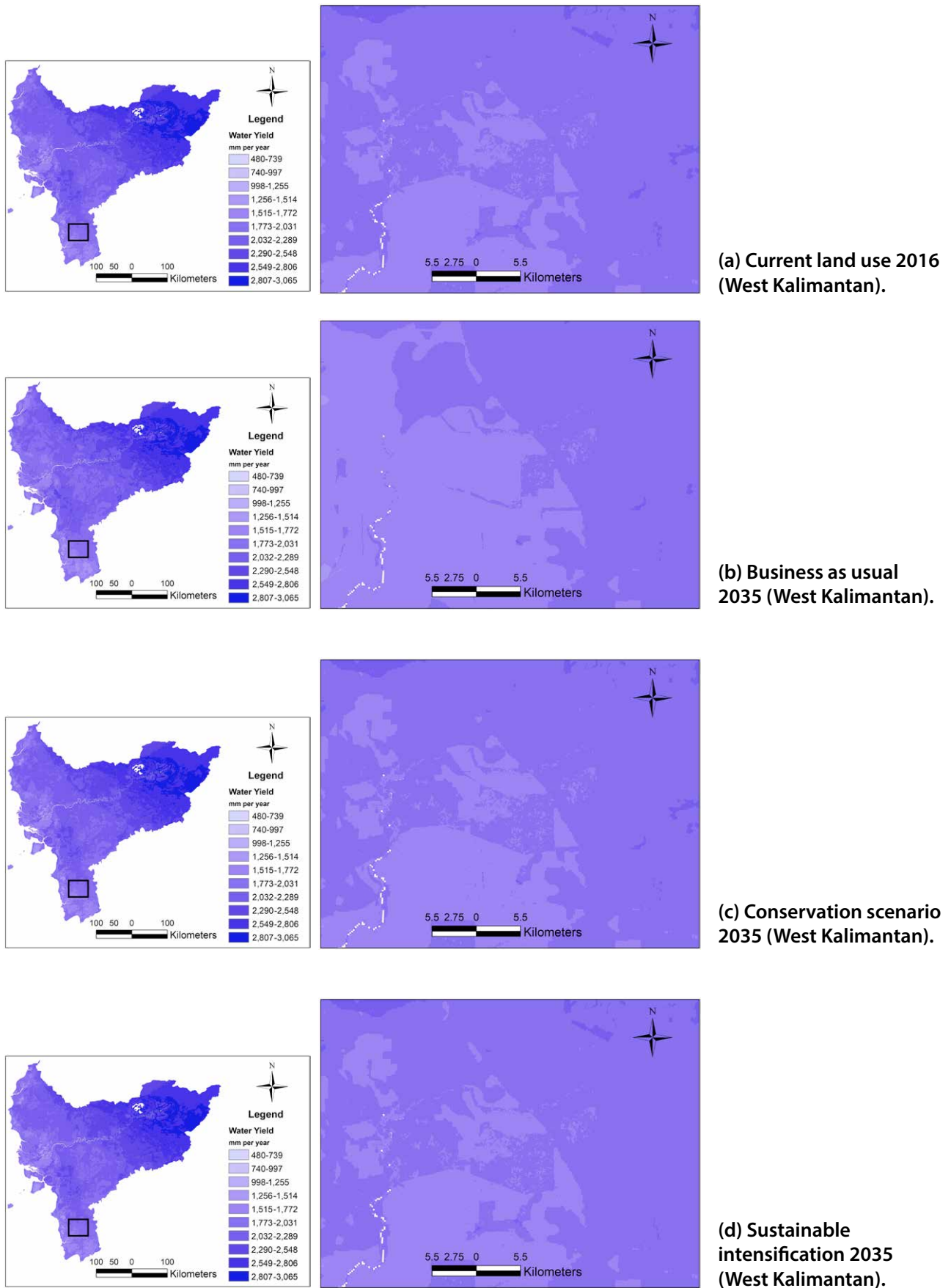


Figure 17. Water yield maps in West Kalimantan: (a) current land use (LULC 2016); (b) business as usual scenario 2035; (c) conservation scenario 2035; (d) sustainable intensification 2035.

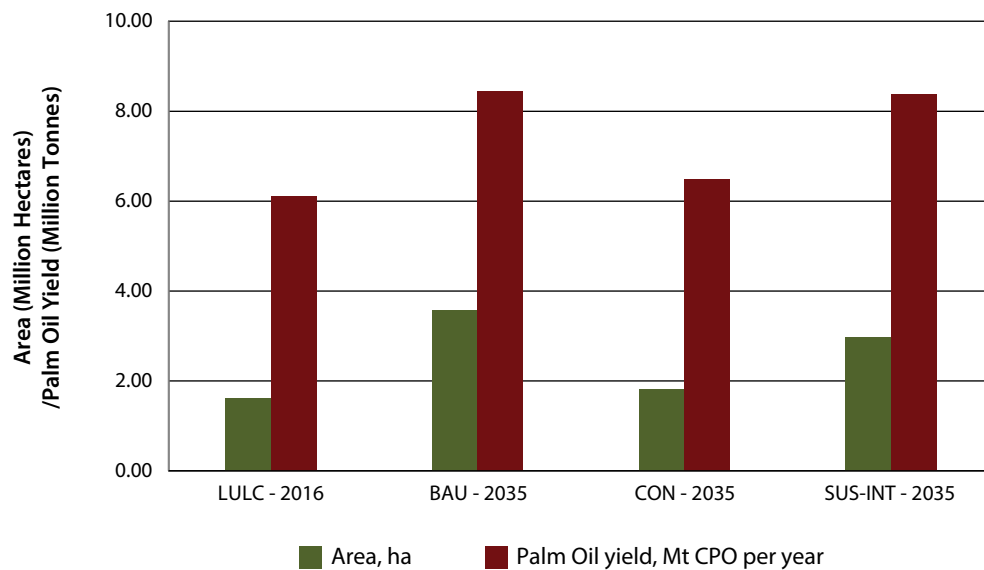


Figure 18. Area of oil palm plantations and palm oil production under the current land use and three future land-use scenarios in Central Kalimantan.

Note: LULC – land use, land cover; BAU – business as usual; CON – conservation; SUS-INT – sustainable intensification.

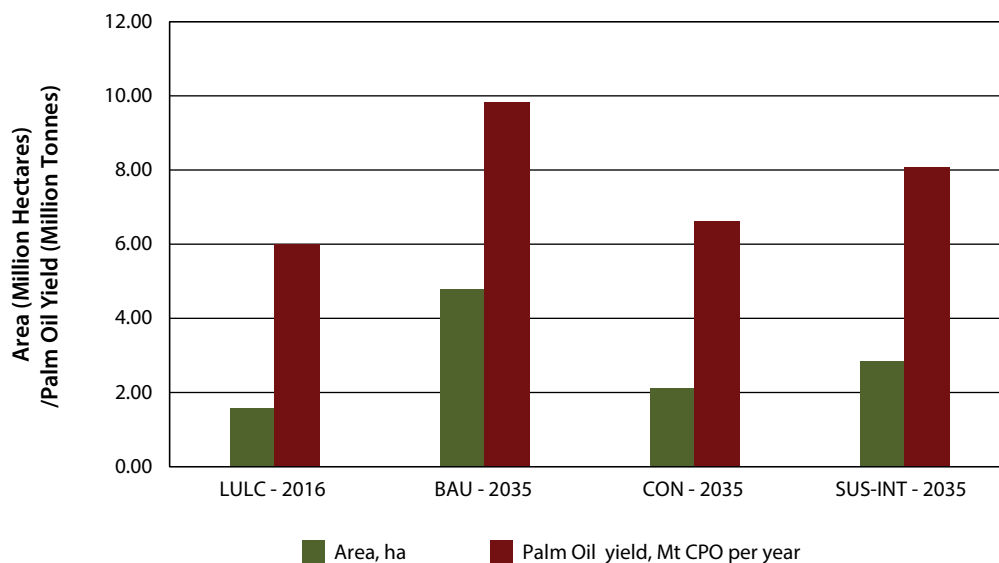


Figure 19. Area under the oil palm plantations and palm oil production under the current land use and three future land-use scenarios in West Kalimantan.

Note: LULC – land use, land cover; BAU – business as usual; CON – conservation; SUS-INT – sustainable intensification.)

In contrast to Central Kalimantan, the business-as-usual scenario produces 16% more palm oil, i.e. 9.85 Mt CPO yr⁻¹, in West Kalimantan due to an average oil palm area of 2.6 Mha between 2017 and 2035. This yield is about 20% more than in the sustainable intensification scenario (8.08 Mt CPO yr⁻¹). While the existing oil palm

plantation accounts for about 6.0 Mt CPO yr⁻¹, the conservation scenario yields a slightly higher annual yield of about 6.63 Mt CPO yr⁻¹ (Figure 19). Based on the current price of palm oil US\$665 per t CPO, the gross revenue per year is estimated to about US\$6.55 billion for business-as-usual, US\$5.37 billion for sustainable

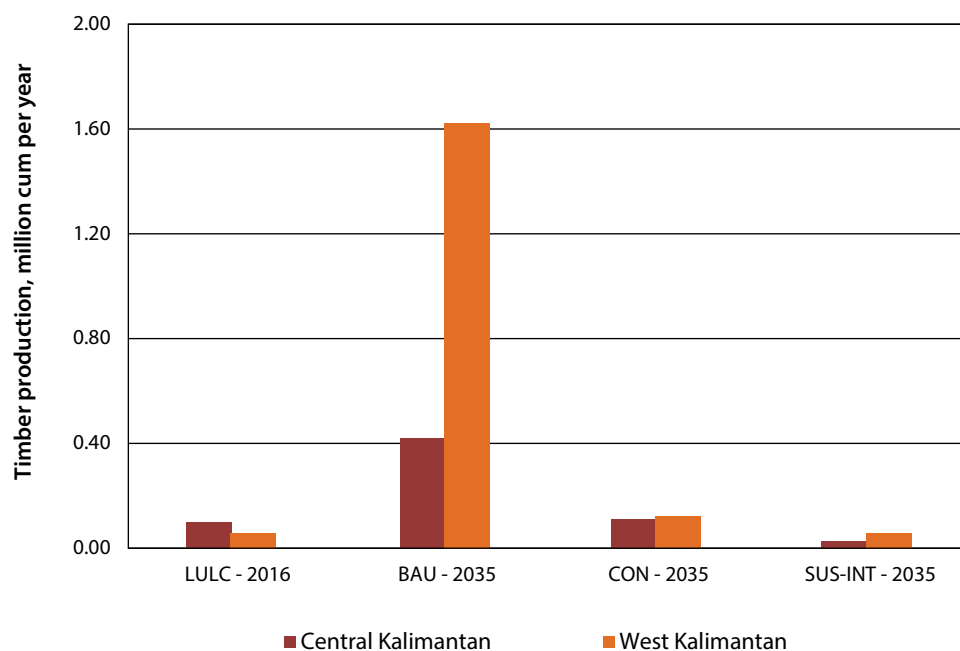


Figure 20. Timber production under the current land use and the three future land-use scenarios in Central Kalimantan and West Kalimantan.

Note: LULC – land use, land cover; BAU – business as usual; CON – conservation; SUS-INT – sustainable intensification.

intensification and US\$4.41 billion for the conservation scenarios.

3.5.5 Timber production

Based on the allowable cut of 0.86 m^3 per ha per year (Suwarno et al. 2016), the total timber production increases to about 0.42 million m^3 per year ($\text{m}^3 \text{ yr}^{-1}$) in the business-as-usual scenario from about 0.10 million $\text{m}^3 \text{ yr}^{-1}$ in the current land use in Central Kalimantan. Due to a restriction on expansion of timber plantation on forest cover, timber production decreases to about 0.11 million $\text{m}^3 \text{ yr}^{-1}$ and 0.03 million $\text{m}^3 \text{ yr}^{-1}$ in conservation and sustainable intensification scenarios, respectively. In West Kalimantan, timber production is projected to increase by many fold to 1.62 million $\text{m}^3 \text{ yr}^{-1}$ in business as usual from 0.06 million $\text{m}^3 \text{ yr}^{-1}$ in the current land use. In contrast to Central Kalimantan, timber plantation increases by 74,000 ha in the conservation scenario resulting in a rise in timber production to 0.12 million $\text{m}^3 \text{ yr}^{-1}$ in West Kalimantan. However, sustainable intensification produces the same quantity of timber, i.e. 0.06 million $\text{m}^3 \text{ yr}^{-1}$ as in the current land use because the timber plantation area does not change in this scenario relative to current land use (Figure 20).

3.5.6 Total economic valuation of ecosystem services

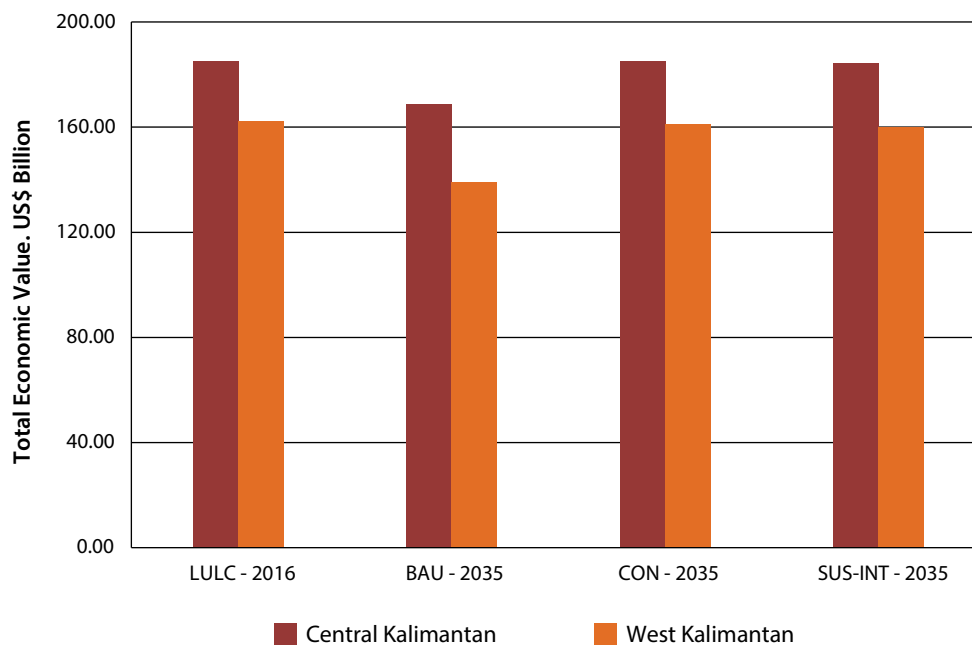
Table 10 summarizes the transitions in land-use classes relative to current land use in 2016 under the three scenarios: business as usual, conservation and sustainable intensification in Central Kalimantan and West Kalimantan. These land-use transitions have direct impacts upon the supply of various ecosystem services and determine the associated TEV of these services.

Based on the ecosystem services valuation of different biomes from de Groot et al. (2012) and Costanza et al. (2014), the total values of ecosystem services (TEV) decline under future land-use scenarios relative to values of current land use. The TEV of the current land use were US\$185.61 billion per year and US\$162.14 billion per year in Central Kalimantan and West Kalimantan, respectively. Among the three future scenarios, the conservation scenario has the highest value in both provinces, with a value of US\$185.12 billion per year in Central Kalimantan and US\$161.06 billion per year in West Kalimantan. Under the business-as-usual scenario, the value decreases by about 9% or US\$17 billion per year to US\$168.61 billion per

Table 10. Transition of land-use classes under the future land-use scenarios in Central Kalimantan and West Kalimantan.

SN	Land use classes in the study areas	Central Kalimantan			West Kalimantan		
		Business-as-usual Scenario	Conservation Scenario	Sustainable Intensification Scenario	Business-as-usual Scenario	Conservation Scenario	Sustainable Intensification Scenario
1	Intact Forest	↓	=	=	↓	=	=
2	Logged Forest	↓	=	=	↓↓↓	=	=
3	Regrowth Forest	↓↓↓	=	=	↓↓↓	=	=
4	Scrublands	↓↓↓	↓	↓↓↓	↓↓↓↓	↓	↓
5	Agriculture	↓↓↓	↓	↓↓↓↓	↓↓↓↓	↓	↓↓↓
6	Other Land						
7	Oil Palm Plantation	↑↑↑	↑	↑↑	↑↑↑	↑	↑↑
8	Industrial Plantation	↑↑↑	↑↑	↓↓↓	↑↑↑	↑↑↑	=
9	Water Bodies	↓	=	=	↓	=	=

Note: Where equals sign (=) represents less than 5% change, the upward or downward arrow (↑ or ↓) represents 5–19% change; ↑↑ or ↓↓ represents 20–40% change and ↑↑↑ or ↓↓↓ represents above 40% change in land use relative to land use in 2016.

**Figure 21. TEV of ecosystem services under the current land use and the three future land-use scenarios in Central Kalimantan and West Kalimantan.**

Note: LULC – land use, land cover; BAU – business as usual; CON – conservation; SUS-INT – sustainable intensification.

Table 11. Net Present Value (NPV) of Total Economic Value (TEV) of ecosystem services under current and future land-use scenarios.

Central Kalimantan				
Discount rate	Current (US\$)	Business as usual (US\$)	Conservation (US\$)	Sustainable intensification (US\$)
3.5%	2,540	2,312	2,538	2,527
		-228	-2	-12
5.0%	2,239	2,038	2,237	2,228
		-201	-2	-11
10.0%	1,550	1,410	1,549	1,542
		-139	-1	-8
15.0%	1,148	1,045	1,147	1,143
		-103	-1	-6
West Kalimantan				
Discount rate	Current (US\$)	Business as usual (US\$)	Conservation (US\$)	Sustainable intensification (US\$)
3.5%	2,223	1,906	2,208	2,192
		-317	-15	-31
5.0%	1,960	1,680	1,946	1,932
		-280	-13	-27
10.0%	1,356	1,163	1,347	1,337
		-194	-9	-19
15.0%	1,005	862	998	991
		-143	-7	-14

year in Central Kalimantan. In West Kalimantan, the value declines significantly by over 13% or US\$23 billion per year to US\$139.00 billion per year in the business as usual scenario. Under the sustainable intensification scenario, the value reduces by less than 2% to US\$184.35 billion per year in Central Kalimantan and US\$159.87 billion per year in West Kalimantan (Figure 21).

The NPVs of the TEV of the ecosystem services were estimated for the current land use and the three future land-use scenarios at the discount rates of 3.5%, 5%, 10% and 15% (Table 11). The negative sign (-) indicates a total loss of ecosystem services under the future land-use scenarios relative to current land use. The NPVs of the ecosystem services decrease with an increase in the discount

rate from 3.5% to 15%. At the lowest discount rate of 3.5%, business as usual results in an equivalent to (-)US\$228 billion in Central Kalimantan and (-)US\$317 billion in West Kalimantan. The NPV indicates the lowest loss of ecosystem services under the conservation scenario equivalent to (-)US\$2 billion in Central Kalimantan and (-)US\$15 billion in West Kalimantan at the 3.5% discount rate.

The reductions in these TEV are directly attributed to the loss of old-growth and regrowth forests in the business-as-usual scenario. The conservation scenario offers the highest TEV among the three scenarios because of the protection of all forest covers from the expansion of oil palm and timber plantations.

Table 12. Relative availability of four major ecosystem services and the Total Economic Valuation (TEV) of the land-use classes relative to intact forest.

SN	Land-use classes in the study areas	Provisional Services	Regulating Services	Habitat Services	Cultural Services	Relative total economic values of ES to Intact Forest
1	Intact Forest	+++	+++++	+++++	+++++	100%
2	Logged Forest	++++	++	++++	++	44%
3	Regrowth Forest	++++	++	++++	++	44%
4	Scrublands	++	+	+	+	8%
5	Agriculture	++	+++	+	+	22%
6	Other Land	–	–	–	–	–
7	Oil Palm Plantation	+++	+	+	–	20%
8	Timber Plantation	++	+	+	–	9%
9	Water Bodies	++	++	–	+++	17%

3.6 Trade-offs or synergy between ecosystem services under future land-use scenarios

The model results in Section 3 show a synergy between increased palm oil yield (due to an extensive expansion of oil palm plantations) and water yield (reducing). The reduction in water yield is considered a positive ecosystem service for reducing or avoiding the negative consequences of increased water flows, such as flooding, landslides and loss of property and lives (Arunyawat and Shrestha 2016). This synergy occurs under all future land-use scenarios due to the conversion of agricultural land, scrublands and other land uses into oil palm plantations. Water yield is significantly reduced through the increased rate of transpiration compared with land uses before conversion. The expansions of oil palm on old-growth or regrowth forests under the business-as-usual scenario result in trade-offs between palm oil yield and carbon stock as well as habitat quality. In the business-as-usual scenario, the increased palm oil yield results in a significant loss of the carbon stock and habitat quality due to the conversion of

HCS and habitat quality forest covers to oil palm plantation.

Table 12 summarizes the relative availability of four ecosystem services and the TEV of the land-use classes relative to intact forest. Trade-offs or synergies are evident due to the change in the ecosystem services attributed to the land-use change under a future scenario. Under the business-as-usual scenario, the expansion of oil palm plantations across intact forest results in trade-offs of all four ecosystem services. The TEV of ecosystem services show a reduction in value of 80% due to the conversion of intact forest to oil palm plantation. The development of oil palm plantation on logged forest or regrowth forest also results in trade-offs as the TEV of ecosystem services reduce by over 50%. Oil palm expansions onto agricultural land increases the value of provisioning ecosystem services by about 75% due to the revenue from palm oil production, whereas regulating and cultural services are significantly reduced. After clearing intact forest, timber plantations retain about 9% of the ecosystem services from the previous land use (Table 12).

4 Discussion

4.1 Assessing ecosystem services on oil palm landscapes

Ecosystem services are often mapped, valued and analyzed to assess the impacts of future land-use scenarios (Lawler et al. 2014; Sumarga and Hein 2014). This study assessed three key ecosystem services supplied by an oil palm landscape of local and global significance: carbon stock, habitat quality and water yield (e.g. Ardaban et al. 2016; Arunyawat and Shrestha 2016). In addition, palm oil yield and timber production were also assessed in conjunction with future land-use scenarios (e.g. Sumarga and Hein 2014) and their trade-offs or synergies with key ecosystem services analyzed.

The accuracy and reliability of data are critically important to assess and evaluate these ecosystem services with high confidence. In the absence of primary data on carbon stock and water yield variables from the study area, this study relied upon secondary data sources. Carbon density (tC per ha) data compiled from the previous studies in the area (e.g. Sumarga and Hein 2014) were applied to the land-use classes in the study areas. This meant that the accuracy of the data could not be ascertained. With peatland present in both study areas, carbon could be underestimated or overestimated if the carbon stock data and peatland maps do not represent reality.

In the absence of data on habitats for key species and their level of disturbance, this study employed the InVEST Habitat Quality Model to map habitat quality in both study areas. This approach is considered preferable to other biodiversity assessment methods based on vegetation condition without taking into account threat sources (Baral et al. 2014). The representation given by the Habitat Quality Model can be improved by incorporating

all typologies of habitats based on vegetation, conditions and disturbance levels. Nonetheless, the habitat quality approach is not a comprehensive method for assessing biodiversity. In the InVEST Habitat Quality Model, sensitivities of different habitats to threats are very subjective and user bias is likely to be present for different threats, resulting in a misleading interpretation of habitat quality.

Regarding water yield, several hydrological studies suggest that forest vegetation with high evapotranspiration rates reduces water yield, while agricultural crops or urbanization increases surface run-off or overland flow (Hamilton 2008; Suryatmojo et al. 2013). The InVEST Water Yield Model demonstrated a correlation between water yield (reducing) and expansion of oil palm plantation on agricultural land or scrublands in both study areas. Water yield increases with loss of vegetation cover, whereas it decreases with an increased vegetation cover. This result is consistent with water yield predictions for the agriculture-dominated sub-watershed in Northern Thailand using the InVEST Water Yield Model (Arunyawat and Shrestha 2016). Since this study did not validate the model outputs, the results are an indicative representation of water yield in the study area due to expansion of oil palm plantation. Further, the model might not have fully captured the impact on water yield due to the hydrology of peatland in the study area, which needs to be taken into account for an accurate understanding of the relationship between land-use change and water yield. To improve confidence and the reliability of outputs for its application in decision making (e.g. Guswa et al. 2014), water yield prediction needs to be performed at a district or sub-watershed level using accurate data and subsequent model calibration and sensitivity analysis (e.g. Sanchez-Canales et al. 2012; Hamel and Guswa 2016).

4.2 Trade-offs or synergies and economic valuation of ecosystem services

Several studies have explored the trade-offs or synergies between multiple ecosystem services under specific land-use and management regimes or land-use change scenarios (e.g. Power 2010; Klasen et al. 2016; Sumarga and Hein 2016). The management regime or land-use change can cause trade-offs or synergies due to either an enhancement or a reduction of multiple ecosystem services. Such knowledge is needed to understand the realities of whether the specific ecosystem service of interest is enhanced or lost from the land-use change or management intervention (e.g. Power 2010; Sumarga and Hein 2014; Klasen et al. 2016). There is a broad interest in the impacts of oil palm plantations on ecosystem services and their trade-offs (e.g. Obidizinski et al. 2012; Sumarga and Hein 2014; Dislich et al. 2016; Petrenko et al. 2016; Sumarga and Hein 2016; Vijay et al. 2016). For example, Obidizinski et al. (2012) studied the environmental and social impacts of existing oil palm plantations and highlighted the trade-offs of an inequitable distribution of economic benefits and the significant damage to the environment. A review of the ecosystem services (or functions) from oil palm plantations identified trade-offs for 11 out of 14 ecosystem services under forest cover (Dislich et al. 2016). This study highlighted that some of the trade-offs are irreversible with much broader impacts (e.g. climate regulation, habitat loss) and showed that the intensity of trade-offs increases if the oil palm plantation replaces forest cover or peatlands.

The trade-offs for oil palm plantations are evident between the provisioning service from palm oil production and losses of regulating, cultural and habitat functions. Trade-offs or synergies between ecosystem services are evaluated against the previous land-use or the land management regime or between the current and future land use. Oil palm can offer climate regulation services where the previous land use has a lower capacity for carbon sequestration and storage. For example, Germer and Sauerborn (2008) observed a synergy for climate regulation from the conversion of tropical grassland to oil palm plantation with net carbon sequestration in biomass and soil. This study confirmed the trade-offs or synergies observed in

the above studies by demonstrating (i) trade-offs in four ecosystem services due to oil palm expansion on old-growth forest and regrowth forest under the business-as-usual scenario and (ii) synergies for climate regulation from oil palm expansion on degraded or agricultural land by enhancing carbon sequestration and storage in green biomass and soil in all future land-use scenarios.

This study focused on the entire province level and generated spatial maps for five key ecosystem services. These spatial maps showed the change in ecosystem services and their trade-offs or synergies under three future land-use scenarios. Another study (Klasen et al. 2016) demonstrated that trade-offs tend to vary at different spatial scales, and that a study focusing on local (i.e. households or village) or regional (i.e. district) scales can be used to undertake a detailed analysis of trade-offs or synergies between ecosystem services due to oil palm expansion. Such a study can assist land-use planners or decision makers in making better-informed land-use decisions.

The global value of ecosystem services at the biome level might not provide accurate values for ecosystem services in the study area. However, global values have been used to understand the economic values of ecosystem services at the global level (e.g. Costanza et al. 1997, 2014; de Groot et al. 2012) and at landscape (Kundu et al. 2016; Tolessa et al. 2017) and country (Kubiszewski et al. 2013; Anderson et al. 2017) levels. By applying global ecosystem services values to the representative biome, a preliminary value of ecosystem services can be generated in any geographic location and thus help to develop an understanding of the contribution of these ecosystem services to humans. This approach enabled an assessment and evaluation of ecosystem services TEV in the study area under three future land-use scenarios and demonstrated a significant loss of ecosystem services under the business-as-usual scenario. This supports the perspective that intensive expansion of oil palm, as in the business-as-usual scenario, could seriously harm the province's capacity to supply ecosystem services. The high associated cost signifies the gravity of the loss of these services. However, valuation of these ecosystem services based on local- or provincial-level data would increase the accuracy and confidence in the valuation of ecosystem services in the study area.

5 Conclusion

The analyses of future land-use scenarios have shown significant impacts on the supply of ecosystem services based on the intensity of oil palm expansions under these scenarios. The business-as-usual scenario results show detrimental impacts on ecosystem services due to an intensive expansion of oil palm plantation including across areas of old-growth forest and regrowth forest. Assuming the lowest intensity of oil palm expansion, the conservation scenario enhances carbon stock and maintains a stable habitat quality relative to the current land use (2016). The sustainable intensification scenario with oil palm expansions only on suitable areas and enhancement of yield generates a positive impact on carbon stock and water yield, whereas habitat quality deteriorates slightly in the study areas.

Based on the TEV of ecosystem services, the conservation scenario generates the highest values of ecosystem services under the three future land-use scenarios in both study areas. However, the sustainable intensification scenario offers a compromise solution for future expansion of oil palm by ensuring a supply of ecosystem services comparable to the conservation scenario, and

without significantly affecting palm oil yield. This scenario would help meet the future demand for palm oil through area expansion of oil palm and yield enhancement. However, a potential issue of food security might emerge because of the extensive conversion of agricultural land to oil palm plantations under the sustainable intensification scenario. Therefore, future oil palm expansion should be approached cautiously to achieve sustainable land use and balance human and environmental needs.

The TEV of ecosystem services must not be taken as a market value or for payment of ecosystem services. These values should be understood in relative terms between these scenarios and used to enhance awareness regarding the impacts of future expansion of oil palm plantations on key ecosystem services. A detailed study at a local level (household or village) that evaluates the economic values of key ecosystem services and their trade-offs or synergies is recommended for an accurate valuation of ecosystem services to better understand the impacts of oil palm expansion on the local community and the environment.

References

- Abdullah R. 2011. World palm oil supply, demand, price and prospects: focus on Malaysian and Indonesian palm oil industries. *Oil Palm Industry Economic Journal* 11(2):13–25.
- Agustira MA, Rañola Jr R F, Sajise AJU and Florece LM. 2016. Economic impacts of smallholder oil palm (*Elaeis guineensis* Jacq.) plantations on peatlands in Indonesia. *Journal of Economics, Management and Agricultural Development*, 1(2):105–23.
- Allen RG, Pereira LS, Raes D and Smith M. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56. Rome, Italy: Food and Agriculture Organization of the United Nations.
- Anderson SJ, Ankor BL and Sutton PC. 2017. Ecosystem service valuations of South Africa using a variety of land cover data sources and resolutions. *Ecosystem Services* 27:173–78.
- Ardaban Z, Baral H, Stork NE, Ling MA, Yavari AR, Jafari HR and Amirnejad H. 2017. Modeling of ecosystem services informs spatial planning in lands adjacent to the Sarvelat and Javaherdasht protected area in northern Iran. *Land Use Policy* 61:487–500.
- Ardaban Z, Baral H, Yavari AR, Jafari HR, Stork NE, Ling MA and Amirnejad H. 2016. Anthropogenic decline of ecosystem services threatens the integrity of the unique Hyrcanian (Caspian) forests in Northern Iran. *Forests* 7(51):1–27.
- Arunyawat S and Shrestha R. 2016. Assessing land use change and its impact on ecosystem services in Northern Thailand. *Sustainability* 8:768. doi:10.3390/su8080768
- Austin K, Alisjahbana A, Darusman T, Boediono R, Budianto BE, Purba C, Indrarto GB, Pohnan E, Putraditama A and Stolle F. 2014. *Indonesia's forest moratorium: Impacts and next steps*. Working Paper. Washington, DC: World Resources Institute.
- [BPS] BPS-Statistics Indonesia. 2017. *Statistical Yearbook of Indonesia 2017*. Jakarta, Indonesia
- Baral H, Keenan RJ, Sharma SK, Stork NE and Kasel S. 2014. Spatial assessment and mapping of biodiversity and conservation priorities in a heavily modified and fragmented production landscape in North-Central Victoria. Australia. *Ecological Indicators* 36:552–62.
- Bhagabati NK, Ricketts T, Sulistyawan TBS, Conte M, Ennaanay D, Hadian O, McKenzie E, Olwero N, Rosenthal A, Tallis H, et al. 2014. Ecosystem services reinforce Sumatran tiger conservation in land use plans. *Biological Conservation* 169:147–56.
- Brockhoff EG, Jactel H, Parrotta JA and Ferraz SFB. 2013. Role of eucalypt and other planted forests in biodiversity conservation and the provision of biodiversity-related ecosystem services. *Forest Ecology and Management* 301:43–50.
- Budidarsono S, Susanti A and Zoomers A. 2013. Oil palm plantations in Indonesia: The implications for migration, settlement / resettlement and local economic development. In Fang Z, ed. *Biofuels: Economy, Environment and Sustainability*, Rijeka, Croatia: InTech. 173–93.
- Burkhard B, Kroll F, Müller F and Windhorst W. 2009. Landscapes' capacities to provide ecosystem services: A concept for land-cover based assessments. *Landscape Online* 15:1–22.
- Burkhard B, Müller A, Müller F, Grescho V, Anh Q, Arida G, Bustamante JV, Chien HV, Escalada HM, Marquez L, et al. 2015. Land cover-based ecosystem service assessment of irrigated rice cropping systems in southeast Asia—An explorative study. *Ecosystem Services* 14:76–87.
- Busch J, Ferretti-Gallon K, Engelmann J, Wright M, Austin KG, Stolle F, Turubanova S, Potapov PV, Margono B, Hanse MC, et al. 2015. Reductions in emissions from

- deforestation from Indonesia's moratorium on new oil palm, timber, and logging concessions. *Proceedings of the National Academy of Sciences of the United States of America* 112(5):1328–33.
- Carle BJ, and Holmgren P. 2008. Wood from planted forests: A global outlook 2005-2030. *Forest Products Journal* 58(12):6–18.
- Carrasco LR, Nghiem TPL, Sunderland, T and Koh LP. 2014. Economic valuation of ecosystem services fails to capture biodiversity value of tropical forests, *Biological Conservation*, 178:163–70.
- [CIFOR] Center for International Forestry Research. 2014. *Land use in Central Kalimantan: Combining development and sustainability goals for land optimization*. Bogor, Indonesia: Centre for International Forestry Research.
- Corley RHV. 2009. How much palm oil do we need? *Environmental Science and Policy* 12(2):134–39.
- Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson SJ, Kubiszewski I, Farber SR and Turner K. 2014. Changes in the global value of ecosystem services. *Global Environmental Change* 26:152–58.
- Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, et al. 1997. The value of the world's ecosystem service and natural capital. *Nature* 387:253–60.
- Daemeter Consulting. 2015. *Indonesian Oil Palm Smallholder Farmers: A Typology of Organizational Models, Needs, and Investment Opportunities*. Bogor, Indonesia: Daemeter Consulting.
- de Groot R, Brander L, van der Ploeg S, Bernard R, Braat L, Christie M, Crossman N, Ghermandi A, Hein L, Hussain S, et al. 2012. Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services* 1:50–61.
- Dislich C, Keyel AC, Salecker J, Kisel Y, Meyer KM, Auliya M, Barnes AD, Corre MD, Darras K, Faust H, et al. 2017. A review of the ecosystem functions in oil palm plantations, using forests as a reference system. *Biological Reviews* 92:1539–69. doi:10.1111/brv.12295
- Eldeeb O, Prochazka P and Maitah M. 2015. Causes for deforestation in Indonesia: Corruption and palm tree plantation. *Asian Social Science* 11(27):120–24.
- [FAOSTAT] Food and Agriculture Organization Corporate Statistical Database. 2017. *Palm oil, food and agriculture data*. Rome: Food and Agriculture Organization of the United Nations. Accessed 16 Dec 2017. <http://www.fao.org/faostat/en/#data/QD>
- Fargeon H. 2015. *Modeling of ecosystem services and land-use scenarios in the upper Kapuas Hulu River basin, Indonesia*. Paris: Agro Paristech, Universite Paris-Saclay.
- Fischer G, Nachtergaele F, Prieler S, van Velthuisen HT, Verelst L and Wiberg D. 2008. *Global Agro-ecological Zones Assessment for Agriculture*. Rome: IIASA and Food and Agriculture Organization of the United Nations.
- Fitzherbert EB, Struebig MJ, Morel A, Danielsen F, Bruehl CA, Donald F and Phalan B. 2008. How will oil palm expansion affect biodiversity? *Trends in Ecology and Evolution* 23(10): 538–45.
- Gaskell JC. 2015. The role of markets, technology, and policy in generating palm-oil demand in Indonesia. *Bulletin of Indonesian Economic Studies* 51(1): 29–45.
- Gaveau DLA, Sheil D, Husnayaen MAS, Sanjiwana A, Ancrenaz M, Pacheco P and Meijaard E. 2016. Rapid conversions and avoided deforestation: Examining four decades of industrial plantation expansion in Borneo. *Scientific Report* 6:32017. doi: 10.1038/srep32017
- Gaveau DLA, Sloan S, Molidena E, Yaen H, Sheil D and Abram NK. 2014. Four decades of forest persistence, clearance and logging on Borneo. *PLoS ONE* 9(7):e101654. doi:10.1371/journal.pone.0101654
- Germer J and Sauerborn J. 2008. Estimation of the impact of oil palm plantation establishment on greenhouse gas balance. *Environment, Development and Sustainability* 10(6):697–716.
- Gingold B, Rosenbarger A, Ketut YI, Muliastra D, Stolle F, Sudana IM, Manessa MDM, Murdimanto A, Tiangga SB, Madusari CC, et al. 2012. *How to identify degraded land for sustainable palm oil in Indonesia*. Working Paper. Washington, DC: World Resources Institute/SEKALA.
- Government of Indonesia. 2015. Intended Nationally Determined Contribution Republic of Indonesia. Submitted to UNFCCC. Jakarta: Government of Indonesia. Accessed 23 June 2017. <http://www4.unfccc.int/Submissions/INDC/Published%20Documents/>

- Indonesia/1/INDC_REPUBLIC%20OF%20INDONESIA.pdf
- Gunarso P, Hartoyo ME, Agus F and Killeen TJ. 2013. *Oil palm and land use change in Indonesia, Malaysia and Papua New Guinea*. Reports from the Technical Panels of the 2nd Greenhouse Gas Working Group of the Roundtable on Sustainable Palm Oil (RSPO). Jakarta, Indonesia: RSPO.
- Guswa A, Brauman KA, Brown C, Hamel P, Keeler BL and Sayre SS. 2014. Ecosystem services: Challenges and opportunities for hydrologic modeling to support decision making. *Water Resource Research* 50:4535–44.
- Hamel P and Guswa AJ. 2015. Uncertainty analysis of a spatially explicit annual water-balance model: case study of the Cape Fear basin, North Carolina. *Hydrology and Earth System Science* 9:839–53.
- Hamilton LS. 2008. *Forest and water: A thematic study prepared in the frame- work of the Global Forest Resources Assessment 2005*. FAO Forestry Paper 155. Rome: Food and Agriculture Organization of the United Nations.
- Hamrick K and Gallant M. 2017. *Unlocking potential state of the voluntary carbon markets*. Washington, DC: Forest Trends' Ecosystem Marketplace.
- Hetsch S. 2009. *Potential sustainable wood supply in Europe*. Geneva Timber and Forest Discussion Paper 52. Geneva: United Nations.
- Ibie BF, Yulianti N, Rumbang N and Ibie E. 2016. *Central Kalimantan high conservation value provincial assessment*. Central Kalimantan, Indonesia: Palangkaraya Institute for Land Use and Agriculture Research, Climate Policy Initiative.
- IndexMundi. 2017. Agriculture. Accessed 6 February 2018. <https://www.indexmundi.com/agriculture/?country=id&commodity=palm-kernel-oil&graph=production>
- Jackson RB, Jobbágy EG, Avissar R, Roy SB, Barrett DJ, Cook CW and Farley KA. 2005. Trading water for carbon with biological carbon sequestration. *Science* 310(5756):1944–47.
- Jelsma I, Giller K and Fairhurst T. 2009. Smallholder palm oil production systems in Indonesia: Lessons from the NESP Ophir Project. Wageningen: Wageningen University.
- Kharina A, Malins C and Searle S. 2016. *Biofuels policy in Indonesia: Overview and status report*. White Paper. Washington, DC: International Council on Clean Transportation.
- Kimberly MC, Curran LM, Ratnasari D, Pittman AM, Soares-Filho BS, Asner GP, Trigg SN, Gaveau DA, Lawrence D and Rodrigues H. 2012. Committed carbon emissions, deforestation, and community land conversion from oil palm plantation expansion in West Kalimantan, Indonesia. *Proceedings of the National Academy of Sciences of the United States of America* 109(19):7559–64
- Klasen S, Meyer KM, Dislich C, Euler M, Faust H, Gatto M, Hettig E, Melati DN, Jaya INS, Otten F, et al. 2016. Economic and ecological trade-offs of agricultural specialization at different spatial scales. *Ecological Economics*. 122:111–20.
- Koh LP. 2008. Can oil palm plantations be made more hospitable for forest butterflies and birds? *Journal of Applied Ecology* 45:1002–09.
- Koh LP and Wilcove DS. 2007. Cashing in palm oil for conservation. *Nature* 448:993–994.
- Kubiszewski I., Costanza R., Dorji L., Thoennes P. and Tshering K. 2013. An initial estimate of the value of ecosystem services in Bhutan. *Ecosystem Services* 3:11–21.
- Kundu M, Schneider T, Teketay D and Knoke T. 2016. Changes of ecosystem service values in response to land use/land cover dynamics in Munessa–Shashemene landscape of the Ethiopian highlands. *Science of the Total Environment* 547:137–47.
- Lawler JJ, Lewis DJ, Nelson E, Plantinga AJ, Polasky S, Withey JC, Helmers DP, Martinuzzi S, Pennington D and Radeloff VC. 2014. Projected land-use change impacts on ecosystem services in the United States. *Proceedings of the National Academy of Sciences of the United States of America* 111(20):7492–97.
- Mantel S, Wösten H and Verhagen J. 2007. *Biophysical land suitability for oil palm in Kalimantan, Indonesia*. Report 2007/01, Wageningen, The Netherlands: ISRIC –World Soil Information, Alterra, Plant Research International, Wageningen UR.
- Murdiyarso D, Dewi S, Lawrence D and Seymour F. 2011. *Indonesia's forest moratorium: a stepping stone to better forest governance?* Working Paper No. 76. Bogor, Indonesia: Center for International Forestry Research.
- Myers N, Mittermerier RA, Mittermeier CG, da Fonseca GAB and Kent J. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403:853–58.

- Obidzinski K, Andriani R, Komarudin H and Andrianto A. 2012. Environmental and social impacts of oil palm plantations and their implications for biofuel production in Indonesia. *Ecology and Society* 17(1):25.
- Pacheco P, Gnych S, Dermawan A, Komarudin H and Okarda B. 2017. *The palm oil global value chain: Implications for economic growth and social and environmental sustainability*. Working Paper 220. Bogor, Indonesia: CIFOR.
- Peng SS, Piao S, Zeng Z, Ciais P, Zhou L, Li LZ, Myneni RB, Yin Y and Zeng H. 2014. Afforestation in China cools local land surface temperature. *Proceedings of the National Academy of Sciences of the United States of America* 111(8):2915–19.
- Penna I. 2010. *Understanding the FAO's 'Wood supply from planted forests' projections*. University of Ballarat Centre for Environmental Management Monograph Series No. 2010/01. Victoria, Australia: University of Ballarat.
- Petrenko C, Paltseva J and Searle S. 2016. *Ecological impacts of palm oil expansion in Indonesia*. Washington, DC: The International Council on Clean Transportation (ICCT).
- Power AG. 2010. Ecosystem services and agriculture: Tradeoffs and synergies. *Philosophical Transactions of the Royal Society* 365:2959–71.
- Rosenbarger A, Gingold B, Prasodjo R, Alisjahbana A, Putraditama A and Tresya D. 2013. *How to change legal land use classifications to support more sustainable palm oil in Indonesia*. Issue Brief. Washington, DC: World Resource Institute.
- Sánchez-Canales M, López Benito A, Passuello A, Terrado M, Ziv G, Acuña V, Schuhmacher M and Elorza FJ. 2012. Sensitivity analysis of ecosystem service valuation in a Mediterranean watershed. *Science of The Total Environment* 440:140–53.
- Schmalz B, Kandziora M, Chetverikova N, Müller F and Fohrer N. 2015. Water-related ecosystem services: The case study of regulating ecosystem services in the Kielstau Basin, Germany. In Chicharo L, Müller F and Fohrer N., eds, *Ecosystem Services and River Basin Ecohydrology*. Dordrecht, The Netherlands: Springer. 215–32.
- Sharp R, Tallis HT, Ricketts T, Guerry AD, Wood SA, Chaplin-Kramer R, Nelson E, Ennaanay D, Wolny S, Olwero N, et al. 2016. *InVEST Version User's Guide*. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.
- Sheil D, Casson A, Meijaard E, van Noordwijk M, Gaskell J, Sunderland- Groves J, Wertz K and Kanninen M. 2009. *The impacts and opportunities of oil palm in Southeast Asia: What do we know and what do we need to know?* Occasional Paper No. 51, Bogor, Indonesia: CIFOR.
- Sohel MSI, Mukul SA and Burkhard B. 2015. Landscape's capacities to supply ecosystem services in Bangladesh: A mapping assessment for Lawachara National Park. *Ecosystem Services* 12:128–35.
- Sumarga E and Hein L. 2016. Benefits and costs of oil palm expansion in Central Kalimantan, Indonesia, under different policy scenarios. *Regional Environmental Change* 16:1011–21.
- Sumarga E and Hein L. 2014. Mapping ecosystem services for land use planning, the case of Central Kalimantan. *Environmental Management* 54:84–97.
- Suryatmojo H, Fujimoto M, Yamakawa Y, Kosugi K and Mizuyama T. 2013. Water balance changes in the tropical rainforest with intensive management system. *International Journal of Sustainable Future for Human Security* 1:56–62.
- Suwarna U, Darusman E and Istomo D. 2012. Estimation of total carbon stocks in soil and vegetation of tropical peat forest in Indonesia. *Journal of Tropical Forest Management* 18(2):118–28. (in Indonesian).
- Suwarno S, Hein L and Sumarga E. 2016. Who benefits from ecosystem services? A Case study for Central Kalimantan, Indonesia. *Environmental Management* 57:331–44.
- Tallis H and Polasky S. 2009. Mapping and valuing ecosystem services as an approach for conservation and natural-resource management. *Annals of the New York Academy of Sciences* 1162:265–83.
- Tolessa T, Senbeta F and Kidane M. 2017. The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. *Ecosystem Services* 23:47–54.
- UN Climate Summit. 2014. Forests: Action statements and action plans. New York: UN Headquarters. Accessed 23 June 2017.

- York-Declaration-on-Forest-%E2%80%93-Action-Statement-and-Action-Plan.pdf
 UN Energy. 2007. *Sustainable Bioenergy: A Framework for Decision Makers*. New York: United Nations.
- van Beukering PJH, Cesar HSJ and Jansen MA. 2003. Economic valuation of the Leuser National Park on Sumatra, Indonesia. *Ecological Economics* 44(1):43–62.
- van Beukering PJH, Gorgan K, Hansfort SF and Seager D. 2009. *An economic valuation of Aceh's forests: The road towards sustainable development*. Report number R-09/14. Cambridge, UK: Fauna and Flora International.
- Vijay V, Pimm SL, Jenkins CN and Smith SJ. 2016. The impacts of oil palm on recent deforestation and biodiversity loss. *PLoS ONE* 11(7):e0159668. doi:10.1371/journal.pone.0159668
- Wahyunto W, Nugroho K, Ritung S and Sulaeman Y. 2014. *Indonesian peatland map: Method, certainty and uses*. Bogor, Indonesia: Indonesian Center for Agricultural Land Research and Development.
- Williamson SH. 2017. Seven Ways to Compute the Relative Value of a U.S. Dollar Amount, 1774 to present, Measuring Worth. Accessed 23 November 2017. <https://www.measuringworth.com/>
- Warman RD. 2014. Global wood production from natural forests has peaked. *Biodiversity and Conservation* 23:1063–78. doi:10.1007/s10531-014-0633-6
- Woittiez LS, van Wijk MT, Slingerland M and van Noordwijk M. 2017. Yield gaps in oil palm: A quantitative review of contributing factors. *European Journal of Agronomy* 83:57–77.
- [WWF] World Wildlife Fund. 2013. *The human heart of Borneo*. Indonesia: World Wildlife Fund.
- [WWF] World Wildlife Fund. 2012. Profitability and sustainability in palm oil production: Analysis of incremental financial costs and benefits of RSPO compliance. Gland, Switzerland: World Wildlife Fund, CDC and FMO.
- Yan W. 2017. A makeover for the world's most hated crop. *Nature* 543:306–08. doi:10.1038/543306a

CIFOR Occasional Papers contain research results that are significant to tropical forest issues. This content has been peer reviewed internally and externally.

Based on the current land-use policy, spatial planning and maps of oil palm expansion in Indonesia, this study identified three plausible future scenarios; namely business as usual, conservation and sustainable intensification for future development of oil palm plantations in the study area.

This study concludes that ecosystem services are negatively impacted in the business-as-usual scenario due to expansions of oil palm plantations on old-growth forest and regrowth forest. Assuming the lowest intensity of oil palm expansion, the conservation scenario enhances carbon stock and maintains a stable habitat quality relative to the current land use. The sustainable intensification scenario with oil palm expansions only on suitable areas and enhancement of yield generates a positive impact on carbon stock and water yield, whereas habitat quality slightly deteriorates in the study areas. A detailed study at a local level (household or village) that evaluates the economic value of crucial ecosystem services and their trade-offs or synergies is recommended for accurate evaluation to better understand the impacts of oil palm expansion on the local community and the environment.



RESEARCH
PROGRAM ON
Forests, Trees and
Agroforestry

The CGIAR Research Program on Forests, Trees and Agroforestry (FTA) is the world's largest research for development program to enhance the role of forests, trees and agroforestry in sustainable development and food security and to address climate change. CIFOR leads FTA in partnership with Bioversity International, CATIE, CIRAD, ICRAF, INBAR and TBI.

cifor.org

forestsnews.cifor.org



Center for International Forestry Research (CIFOR)

CIFOR advances human well-being, equity and environmental integrity by conducting innovative research, developing partners' capacity, and actively engaging in dialogue with all stakeholders to inform policies and practices that affect forests and people. CIFOR is a CGIAR Research Center, and leads the CGIAR Research Program on Forests, Trees and Agroforestry (FTA). Our headquarters are in Bogor, Indonesia, with offices in Nairobi, Kenya, Yaounde, Cameroon, and Lima, Peru.

