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Ecosystem services under future oil palm expansion scenarios in West Kalimantan, Indonesia

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ABSTRACT

This study analyzes the five primary ecosystem services and their trade-offs and synergies associated with future scenarios of oil palm plantations in West Kalimantan, Indonesia. Three plausible future scenarios were assessed: 1) business as usual, 2) conservation and, 3) sustainable intensification, based on current land-use policy and spatial planning and projected oil palm expansion. The spatial analysis tool in ArcGIS and the Integrated Valuation of Ecosystem Services and Trade-offs Tool (InVEST Tool) were used to analyze historical and future land-use change, valuation and trade-offs of ecosystem services. The sustainable intensification scenario generates a positive impact on carbon storages and water yield, although habitat quality nominally declines. In terms of total economic value of ecosystem services, the conservation scenario generates the highest value of ecosystem services, while the sustainable intensification scenario offers a compromise solution for future expansion of oil palm by ensuring the supply of ecosystem services comparable to conservation scenario but without significantly affecting palm oil yield in comparison to the business-as-usual scenario. A detailed study with better information on the economic values of ecosystem services can provide a better understanding of the social and environmental impacts of oil palm expansion.

1. Introduction

Many studies review the impacts of oil palm plantations on multiple ecosystem services (e.g., Sumarga and Hein, 2014, 2016; Dislich et al., 2017; Petrenko et al., 2016; Vijay et al., 2016; Guillaume et al., 2018). They report 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. Fitzherbert et al. (2008) confirm that the biodiversity loss is more evident in oil palm plantations than in forest and other tree crops such as, rubber plantation. A global study highlights that the potential expansion of oil palm plantations to vulnerable forests threatens mammal and bird species with extinction (Vijay et al., 2016). Further, Dislich et al. (2017) 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, except for pollination, biological control and food and raw materials.

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 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 by Budidarsono et al. (2013) 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). Smallholder oil palm growers accounted for approximately 40% of Indonesia's oil palm plantation area in 2013 (Daemeter Consulting, 2015).

The recent history and driving forces for oil palm expansion suggest that future expansion of plantations is inevitable, because: (i) there is growing demand for palm oil in both domestic and global markets (e.g.,

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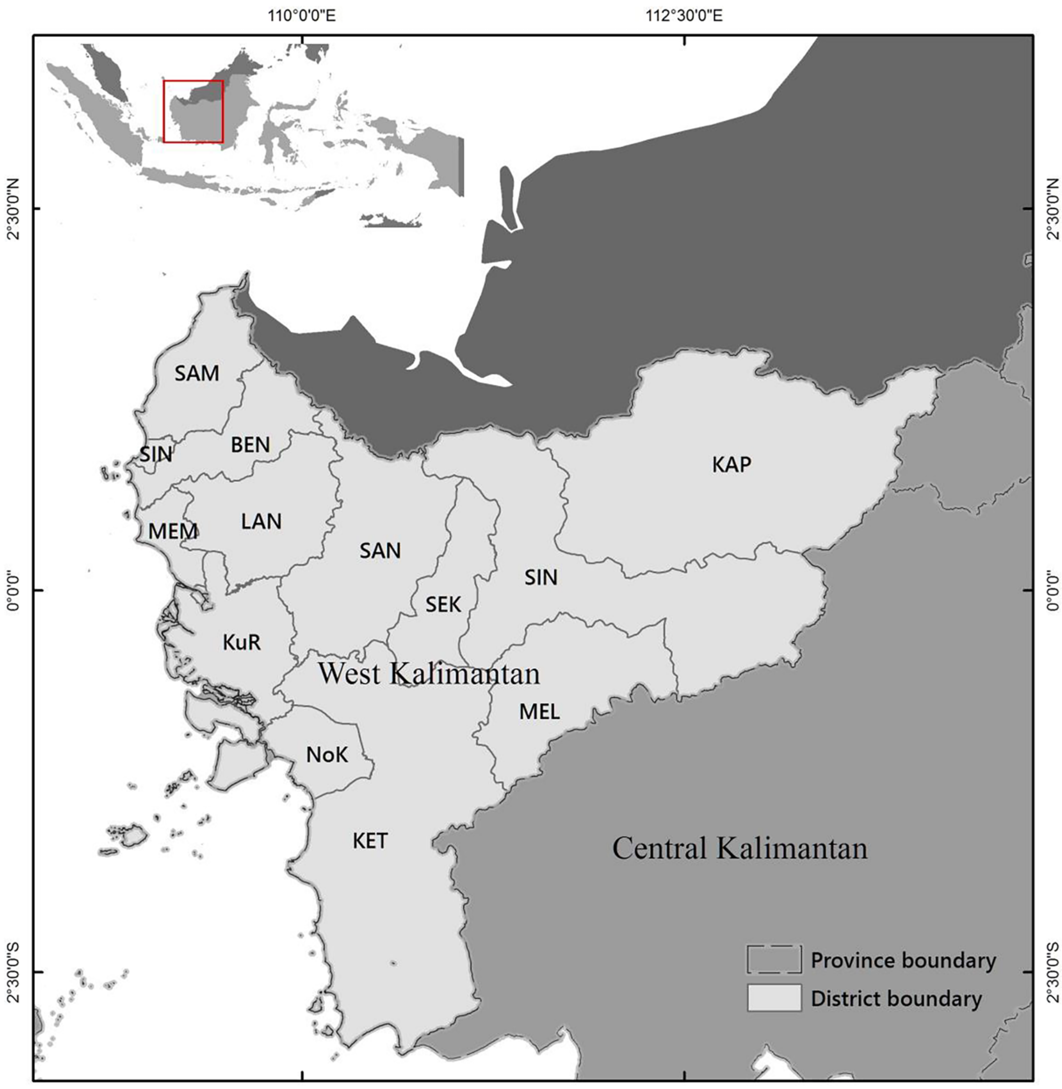

Fig. 1. Indonesia country map and the location of the study area, West Kalimantan in the Indonesian Borneo. Indonesia is shown in light grey while dark grey represents other neighboring countries. Regencies or districts names are abbreviated as, BEN = Bengkayang; KAP = Kapuas Hulu; KET = Ketapang; KuR = Kubu Raya; LAN = Landak; MEL = Melawi; MEM = Mempawah; NoK = North Kayong; SAM = Sambas; SAN = Sanggau; SEK = Sekadau and SIN = Sintang.

Abdullah, 2011; Kharina et al., 2016). (ii) palm oil contributes to the national and local economic growth (e.g., Agustira et al., 2016; Pacheco et al., 2017), and (iii) there is a growing dependence of smallholder farms on income streams from oil palm production. This study aims to analyze and evaluate the impacts on key ecosystem services and their trade-offs under three plausible future oil palm expansion scenarios between 2017 and 2035 in West Kalimantan, Indonesia (Fig. 1).

This study area is located within the Oceania and the research outcomes highlight key sustainability issues in this region and beyond. The study (i) clarifies and raises awareness of the relative importance of different land use and land cover (LULC) types in the landscape; (ii) assesses the impacts on ecosystem services under the projected future LULC changes and their consequences for sustainability; (iii) evaluates the trade-off of ecosystem services among current and future LULC scenarios; and (iv) supports evidence-based decision-making, policy development and management for enhancing ecosystem services.

2. Methods

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

Three future land-use scenarios for oil palm expansions were identified based on historical rates, current land-use policies (such as forest moratorium policy banning forest and peatland clearing), spatial planning and existing suitability maps for oil palm plantations in the province.

This study applies spatial analyses to map, quantify and value ecosystem services to visualize the change in space and over time. The land-use and land-cover datasets used in this study are listed in Annex A. To analyze the expansion of oil palm plantations between 2000 and 2016, this study uses a recent spatial dataset from Borneo developed by Gaveau and colleagues (Gaveau et al. 2016). A 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 and six land-use classes were identified: (i) intact forest, (ii) logged forest, (iii) regrowth forest, (iv) oil palm plantation, (v) timber plantation and (vi) non-forest. The industrial plantation map for 2016 was extracted from time-series mapping, recorded since 1973, of industrial oil palm plantations (IOPP) and industrial timber plantations (ITP) in Borneo (https://data.cifor.org/file.xhtml?fileId=1627&version=2.0). In 2013, smallholder oil palm plantations represented approximately 35% of total oil palm plantations in West Kalimantan (Daemeter Consulting, 2015). Spatial mapping of smallholder oil palm is currently undertaken by CIFOR, but a complete map was not available for the study area.

Approximately 90% of non-forests in the derived map correspond to the non-forest areas of the Ministry of Environment and Forestry's land-cover data for 2015 (MOEF 2015) (http://www.greenpeace.org/seasia/id/Global/seasia/Indonesia/Code/Forest-Map/en/data.html). The MOEF 2015 land-cover map categorized the non-forest areas into scrublands, agriculture, other land and water bodies. The other-land category included housing, mining and an airport. The derived land-use map and MOEF 2015 map were therefore merged to reclassify non-forest areas in the former map to corresponding non-forest land-use classes on the MOEF 2015 map. Thus, the 2016 land-use map represents nine forest-cover or land-use classes in the study area (Annex B). Section 3 provides further detail on these land-use classes and also presents map of the study area.

2.2. 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 were identified in the study area: 1) business as usual, 2) conservation and, 3) sustainable intensification. Table 1 summarizes the key features of these scenarios.

These scenarios did not consider restoration of existing oil palm areas to natural forest.

2.3. Mapping, quantification and valuation of ecosystem services under future LULC scenarios

2.3.1. 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 considered were: (i) carbon storage, (ii) habitat quality, (iii) water yield, (iv) palm oil production and (v) timber production. The specific models in InVEST Tool (InVEST 3.3.3 x86; https://naturalcapitalproject.stanford.edu/invest/) with spatial resolution of 100 m × 100 m were used while a non-spatial quantitative method was used for palm oil production and timber production. A brief description of these ecosystem services, the InVEST models and methods used for mapping, quantification and valuation are included in the Supplementary material in Annex C.

2.3.2. Total economic value of ecosystem services

The TEV of ecosystem services has been used to value natural ecosystems in monetary terms (Costanza et al., 1997; de Groot et al., 2012; Kubiszewski et al., 2013; Anderson et al., 2017). Assigning a monetary value to ecosystem services is subjective and challenging, particularly for socio-cultural values and loss or gain of biodiversity. However, different value aggregation methods have been developed (Kubiszewski et al., 2013; Costanza et al., 2014). Due to a lack of data, many studies have used biome-level values to demonstrate the importance 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).

Data for Indonesia are not adequate for the economic valuation of ecosystem services in the study area. Hence, in this study, the benefit-transfer method was used, applying global values for TEV of ecosystem services at biome level to the study areas. To differentiate the capacities of different land-uses to deliver ecosystem services, the minimum and maximum values from de Groot et al. (2012) were consecutively applied for poor and the excellent biome conditions; the mean value was used to average biome condition (Table 2).

The net present value (NPV) is often used to convert the future return or benefit to the current value by applying a desired rate of depreciation. This value represents the TEV over the period at today's value. After estimation of the total economic values of ecosystem services for current and future land-use scenarios, the TEV between 2017 and 2035 was converted to the NPV by applying the equation below:

$$\boldsymbol{NPV_s} = \sum_{t=1}^{t=T} \frac{\boldsymbol{TEV_{st}}}{(1+\boldsymbol{r})^t}$$

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

3. Results

3.1. Current land-use in the study area

The current land-use (in 2016) included nine categories of land use: three classes of forest cover (intact forest, logged forest and regrowth forest), industrial oil palm plantation, timber plantation, agriculture, scrubland, other land and water bodies (Fig. 2 (a) and Table 3). Oil palm plantation covers about one-tenth of the area. Oil palm dominates on the central part in the regencies of Landak, Sanggau, Sekadau and Sintang and the south in Kab Ketapang regency. ITP was mapped on about 67,000 ha of West Kalimantan.

In West Kalimantan, the IOPPs were mainly expanding in the central regencies of Landak, Sanggau, Sekadau and Sintang and in the south in

Table 1
Key features of the future oil palm expansion scenarios.

Scenarios	Key features
Business as usual	• Assumes oil palm and timber plantation expansions occur on the respective concession areas as depicted in the concession area maps for 2035. • The high demand for palm oil from domestic and international markets is a main driver for oil palm expansion. • The forest moratorium on forest and peatland is not enforced. • The growing demand for wood for biofuel energy and timber leads to expansion of timber plantations on concession areas.
Conservation	• No oil palm expansion occurs on forests (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 allocated for non-forestry use (APL: Areal Penggunaan Lain) (Rosenbarger et al., 2013). • Oil palm expansions mainly occur on agricultural areas, scrubland and other land. • High conservation value and high carbon storage (HCS) areas are protected.
Sustainable intensification	• Oil palm expansion occurs on limited areas of potentially suitable land, as mapped by the World Resources Institute (WRI) and PT Serasi Kelola Alam (SEKALA) Project (Gingold et al., 2012). • Oil palm plantations are established by using improved varieties of cultivars and are intensively managed to enhance palm oil productivity from an average 3.8 tons crude palm oil (CPO) per hectare per year (tCPO ha^{-1} yr^{-1}) to 5.1 tCPO ha^{-1} yr^{-1}. Note: The expansion of timber plantations is not taken into account in this scenario because a suitability map for timber plantations was not available.

Table 2
Land-use classes, the equivalent biome, value range and the economic values for four major ecosystem services.

Land use classes in th study areas	Equivalent Biome	Value used	Provisioning Services (US$)	Regulating Services (US$)	Habitat Services (US$)	Cultural Services (US$)	Total economic value system services (US$ per ha per year
Intact Forest	Tropical	Maximum	4,229.36	10,789.16	1,630.33	9,039.88	25,68833
Logged Forest	Tropical	Mean	6,106.24	2,999.64	1,327.74	1,005.72	11,979,34
Regrowth Forest	Tropical	Mean	6,106.24	2,999.64	1,327:74	1,005.72	11,979,34
Scrublands	Woodland	Minimum	1,592.68	64.96	279.31	8.12	1945.07
Agriculture	Crop	Mean	2948.72	2,205.16	279.31	95.12	5,567.00
Other Land	–	–	–	–	–	–	–
Oil Palm Plantation	Tropical	Minimum	4,361–5.225	46.40	279.91	0.00	4,687–5,551
Industrial Plantation	Tropical	Minimum	2,010.26	46.40	279.31	0.00	2,335.97
Water Bodies	Water Lakes	Mean	1,914.00	187.00	0.00	2,166.00	4,267.00

Kab Ketapang regency.

3.2. Oil palm expansion between 2000 and 2016

West Kalimantan has about one-third of the total IOPP area (5.06 Mha) of Indonesian Kalimantan. Fig. 3 compares the land-use categories that have transitioned to IOPPs in West Kalimantan and Indonesian Kalimantan between 2000 and 2016.

The area of IOPPs increased considerably between 2000 and 2016, from 0.4 Mha to 1.57 Mha, expanding by about 73,282 ha yr^{-1} and accounting for around 11% of the provincial territory. Expansion over forest cover accounted for over 42% of the total expansion, with 15% expansion on intact forest, 26% on logged forest and 1% on regrowth. The plantation on non-forest areas since 1973 almost doubled to 32%.

3.3. Future land-use under the selected oil palm expansion scenarios

Fig. 2 (b-d) shows the maps of the study area under the three future oil palm expansion scenarios in 2035. Table 4 presents the major features of these scenarios in West Kalimantan.

3.4. Land-use transitions in future land use

Under the business-as-usual scenario, about two-thirds or 2.0 million ha of the oil palm expansions occur in agriculture areas whereas about 0.6 million ha of forest cover and about the same extent of

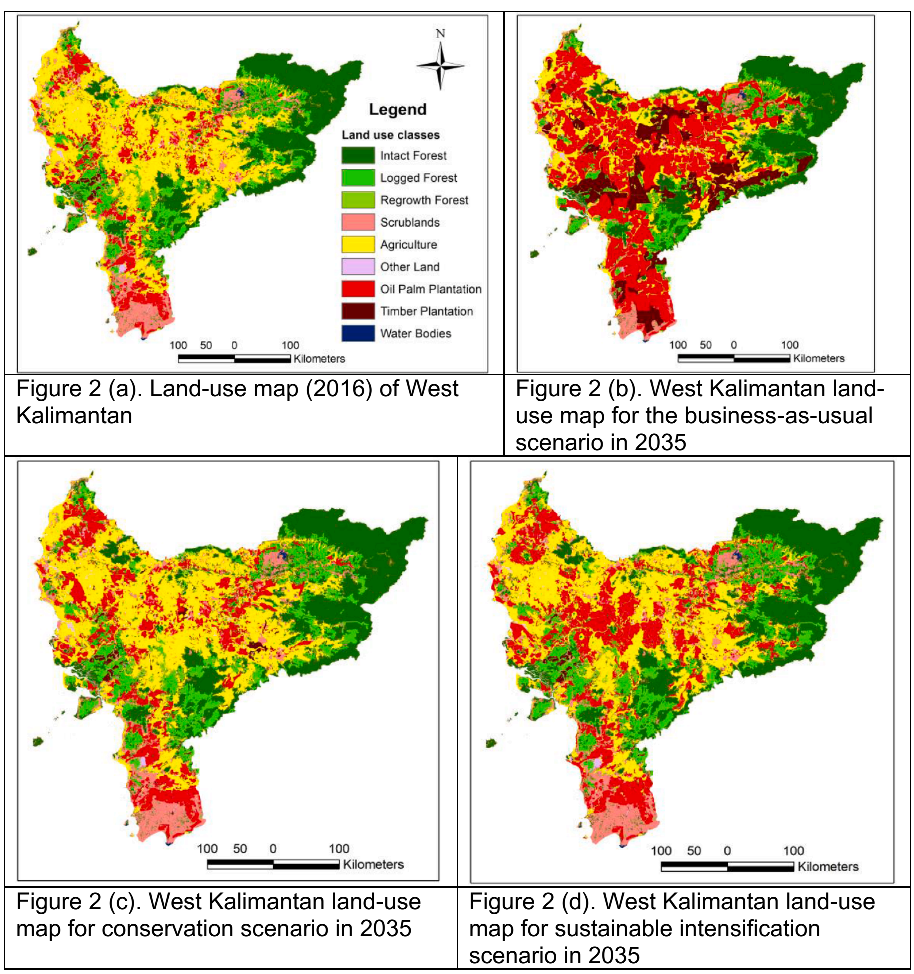

Fig. 2. (a). Land-use map (2016) of West Kalimantan. (b). West Kalimantan land-use map for the business-as-usual scenario in 2035. (c). West Kalimantan land-use map for conservation scenario in 2035. (d). West Kalimantan land-use map for sustainable intensification scenario in 2035.

Table 3
Land-use classes and their areas in West Kalimantan in 2016.

Land-use classes	Area (ha)
Intact forest	3,804,271
Logged forest	1,901,026
Regrowth forest	243,842
Scrublands	1,914,060
Agriculture	5,175,098
Other land	110,535
Oil palm plantation	1,579,123
Industrial plantation	66,973
Water bodies	30,479
Total area	14,825,407

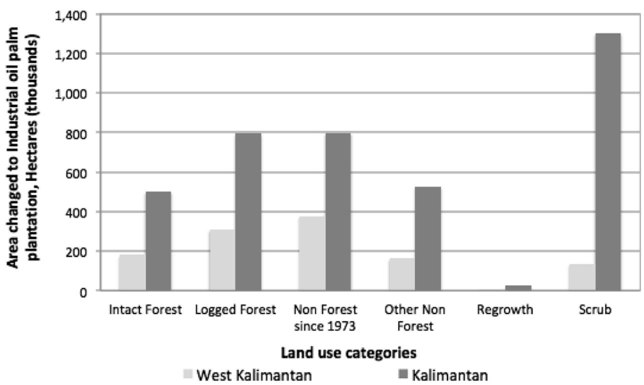

Fig. 3. Comparison of land-use categories transitioned to IOPPs in West Kalimantan and Indonesian Kalimantan between 2000 and 2016.

shrubland transition to oil palm plantations. Since the forest cover and peatland are protected in conservation scenario, the plantations only expand on the non-forest lands, primarily on agriculture (about 413,000 ha) and scrublands (about 114,000 ha). Under the sustainable intensification scenario, the plantations mainly replace agriculture (about 1.2 million ha) and scrublands (over 145,080 ha).

3.5. Mapping, quantifying and valuing ecosystem services

3.5.1. Carbon storage

The model estimates 3925 million ton of carbon storage (million tC) in the current land-use in West Kalimantan. Aggressive expansions of oil palm and timber plantations on HCS areas result in approximately 20% loss of carbon storage (-779 million tC) in the business-as-usual scenario by 2035. Carbon storage increases by 26 million tC and 39 million tC in the conservation and sustainable intensification scenarios, respectively, due to the relatively high intensity of oil palm expansion on agriculture and scrublands, i.e., currently low carbon storage areas, in West Kalimantan (Table 5).

In terms of NPV, the loss of carbon storage in the business-as-usual scenario results in a NPV decrease of US$8.5 billion at a 7% discount rate without an increase in the carbon price of US$18.72 per tC. Due to the increase in carbon storage in conservation and sustainable intensification scenarios, the NPVs are positive with the highest return of US$429 million in sustainable intensification.

The spatial distribution of carbon storage under the future scenarios is shown in Fig. 4. Carbon storage changes in the inset map illustrate differences between plantation expansions in these scenarios.

3.5.2. Habitat quality

Under the business-as-usual scenario, habitat quality declines substantially by over 14% in West Kalimantan. The old-growth and regrowth forests in the concession areas are cleared for expansion of oil palm and timber plantations, which results in a remarkable loss of habitat quality. The conservation scenario shows almost the same average habitat quality as current land use. This is attributed to the protection of old-growth and regrowth forests in this scenario. The model predicts a nominal loss of habitat quality, i.e., less than 1% under sustainable intensification scenario. The change in habitat quality is less distinct on the provincial map. Hence, a small area is highlighted to demonstrate the impact on habitat quality as a result of oil palm expansions under three scenarios (Fig. 5).

3.5.3. Water yield

relative to the The model predicts a decline in water yield under all future land-use scenarios current land use. The business-as-usual scenario results in the highest loss of water yield (−1.7%), followed by the sustainable intensification scenario (−0.54%). The lowest decline in water yield is predicted for the conservation scenario. Although, these reductions in water yields do not show any significant loss at the provincial level, the changes in water yield area are evident at the local level, as illustrated in Fig. 6. With the same eco-climatic and biophysical variables, the reduction in water yield is solely attributable to a change in current land use to the plantations (oil palm or timber) in the future scenarios. The expansion of oil palm and timber plantations onto agriculture, scrublands and other land-use increases stand transpiration. Thus, the water yield is negatively impacted due to a reduction in water available for a run-off. The highest percentage loss of water yield is supported by increased conversion to plantations.

3.5.4. Palm oil production

The business-as-usual scenario produces 9.85 Mt CPO yr^{-1} in West Kalimantan from an oil palm area of 2.6 million ha based on an average yield of 3.8 tCPO $ha^{-1} yr^{-1}$ between 2017 and 2035. Assuming productivity is enhanced to 5.1 tCPO $ha^{-1} yr^{-1}$, equivalent to the average yield in accordance with the Roundtable for Sustainable Palm Oil, the yield is about 20% more than in the sustainable intensification scenario (8.04 Mt CPO yr^{-1}). While the existing oil palm plantation yields approximately 6.0 Mt CPO yr^{-1}, the conservation scenario yields a slightly higher annual yield of about 6.63 Mt CPO yr^{-1} (Table 6; Fig. 7). Based on the current price of palm oil, US$665 per ton according to the Malaysian Palm Oil Council (MPOC) (http://www.mpoc.org.my/Daily_Palm_Oil_Prices.aspx accessed on 23 July 2017), the gross revenue per year is estimated to be approximately US$6.55 billion for business-as-usual, US$5.34 billion for sustainable intensification and US$4.41 billion for the conservation scenario.

Table 4
Major features of the three oil palm expansion scenarios in West Kalimantan by 2035.

Business as usual	Conservation	Sustainable intensification
• Oil palm plantations grow at the rate of 179,000 ha yr^{-1} 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 expansions occur on agriculture areas. • Timber plantations increase by 1.82 Mha to 1.88 Mha.	• Oil palm plantations grow at the rate of 30,000 ha yr^{-1} and increase by 0.53 Mha to a total area of 2.1 Mha, covering over 14% of the province. • Over 9.63 Mha of land are excluded from the future expansion of oil palm and timber plantations.	• Oil palm plantations grow at an annual average rate of 71,000 ha yr^{-1} and increase by about 2.8 Mha covering over 19% of the province. • About 87% of oil palm expansions occur on agriculture and nearly 12% on shrubland. • Timber plantations area remains the same as 2016.

Table 5
Carbon storage in the current and future land-use scenarios in West Kalimantan.

Current and LULC scenarios	Total carbon storage, million tC	Carbon storage change, million tC	NPV from current to future LULC scenarios, US$ million
Current LULC (2016)	3,925		
Business as usual (2035)	3,146	−779	−$8,489
Conservation (2035)	3,951	26	$282
Sustainable intensification (2035)	3,964	39	$429

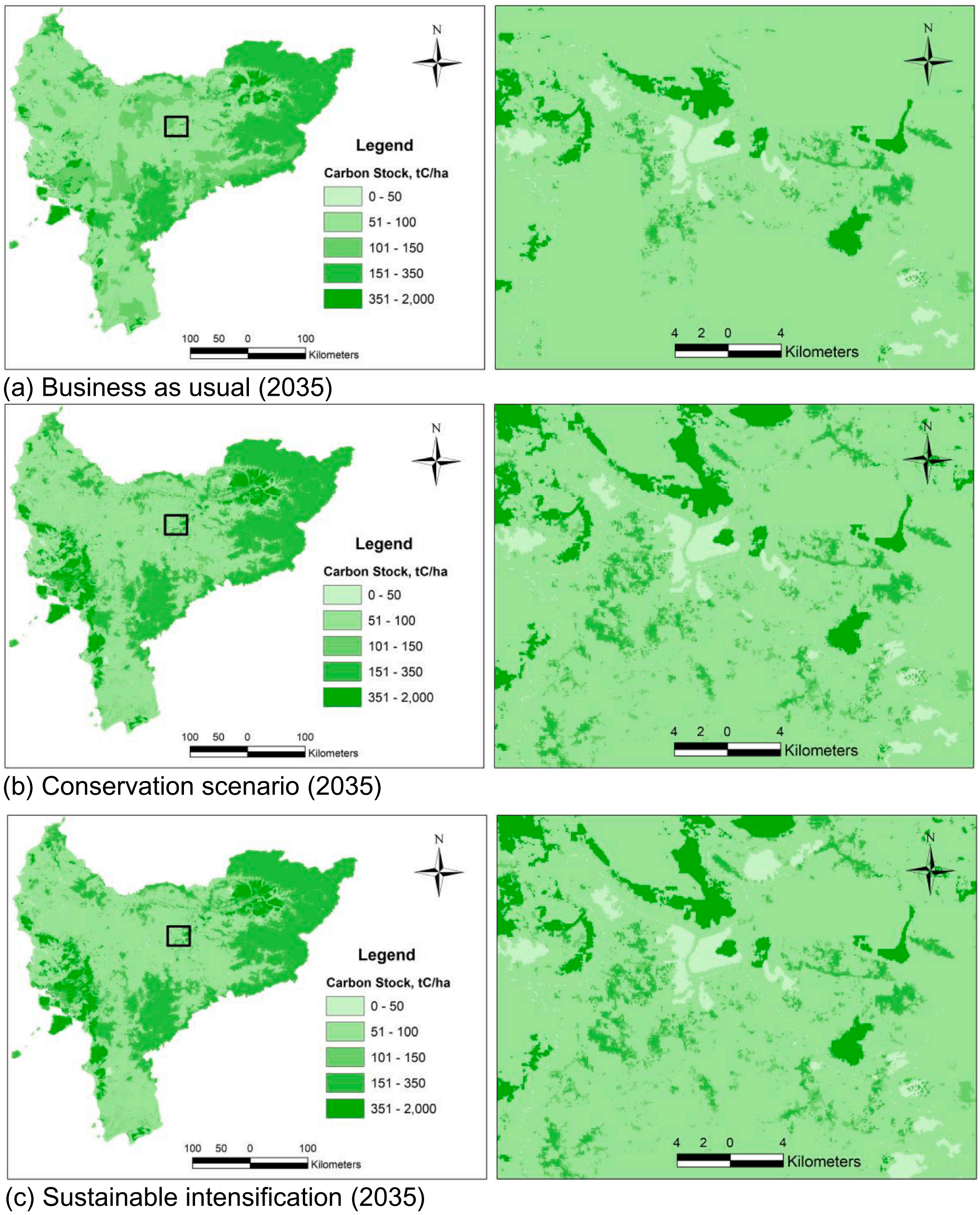

Fig. 4. Carbon storage maps under alternative scenarios in West Kalimantan.

3.5.5. *Timber production*

Timber production is projected to increase to 1.62 million $m^3\ yr^{-1}$ under business-as-usual. Timber plantation increases by 74,000 ha under the conservation scenario resulting in a rise in timber production to 0.12 million $m^3\ yr^{-1}$. However, sustainable intensification scenario produces the same quantity of timber i.e., 0.06 million $m^3\ yr^{-1}$ as under current land use because the timber plantation area does not change in this scenario relative to the current land use (Fig. 8).

3.5.6. *Total economic value of ecosystem services*

Among the three future scenarios, the conservation scenario has the highest economic value of ecosystem services equivalent to US$154

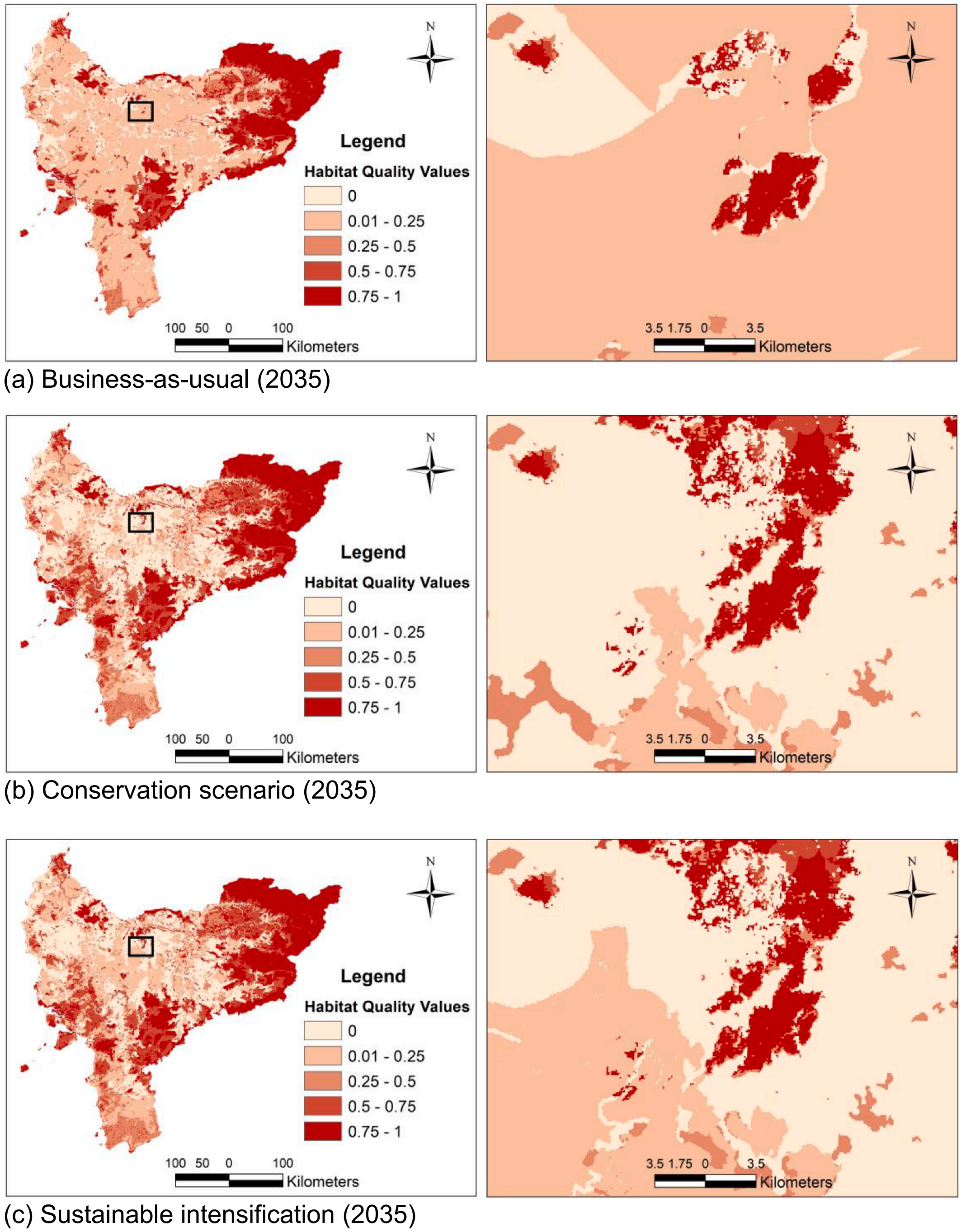

Fig. 5. Habitat quality maps under alternative scenarios for West Kalimantan.

billion yr^{-1}. Under the business-as-usual scenario, the value declines significantly by over US$24 billion yr^{-1} to US$ 132 billion yr^{-1}. Under the sustainable intensification scenario, the value reduces by about 2% to US$ 153 billion yr^{-1} in West Kalimantan (Fig. 9).

The NPVs of the TEV of the ecosystem services were estimated for the current land use and the three future land-use scenarios at discount rates of 3.5%, 5%, 10% and 15% (Table 7). The values with minus (−) indicate an overall loss of ecosystem services under the future land-use scenarios relative to the current land-use. The NPVs of the ecosystem services reduce 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 a loss equivalent to US$317 billion, whereas results the lowest loss equivalent to US$15 billion is under the conservation scenario.

3.5.7. Overall impacts and trade-off or synergy of ecosystem services under future LULC scenarios

The expansion of oil palm and timber plantations under the LULC scenarios result trade-offs or synergies in the ecosystem services. Under the business as usual scenario, the palm oil and timber production trade-offs with the carbon storage and habitat quality primarily due to the expansion of plantations on high carbon storage and conservation areas including intact, logged and regrowth forest. The expansion of oil palm plantations on low carbon storage area i.e., agriculture, scrubland and other land uses compromised the palm oil production under the conservation and sustainable intensification scenarios. However, the current carbon storage increased by 26 million tC and 39 million tC under these scenarios, respectively.

Conservation scenario produces the lowest water yield and is

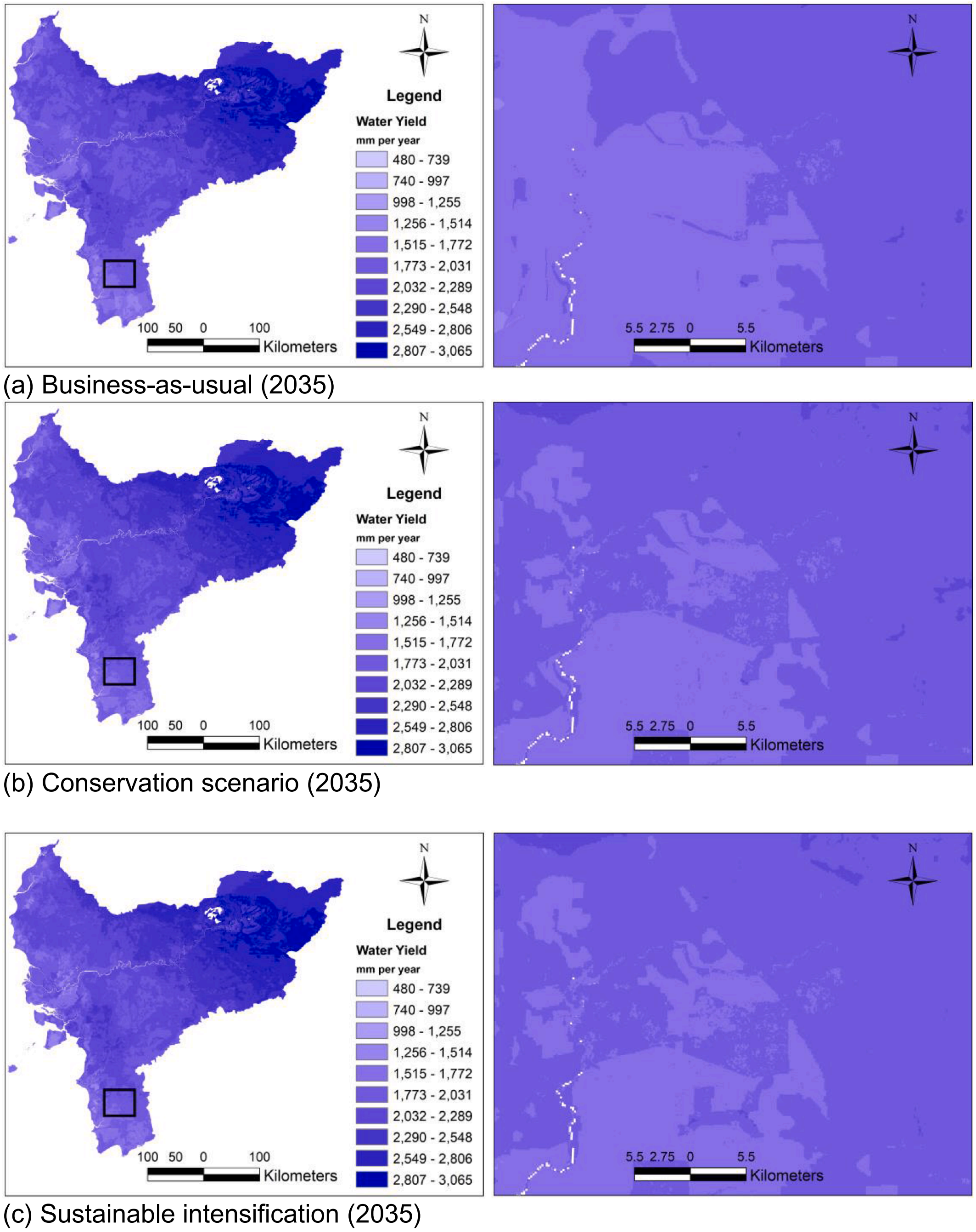

Fig. 6. Water yield maps under alternative scenarios for West Kalimantan.

Table 6
Oil palm plantation area, palm oil production and gross revenues under three future land-use scenarios in West Kalimantan.

Descriptions	LULC Scenarios		
	BAU – 2035	CON – 2035	SUS-INT – 2035
Plantation Area (Million hectares)	4.80	2.11	2.86
Palm Oil yield (Mt CPO per year)	9.85	6.63	8.08
Gross Revenues (Millions US$)	6.55	4.41	5.37

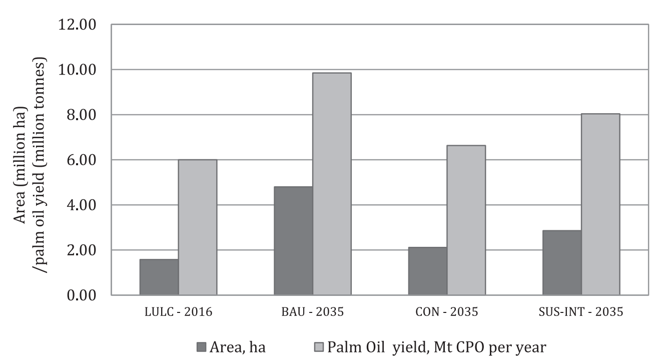

Fig. 7. Area under oil palm plantation and palm oil production under current land use and three future land-use scenarios in West Kalimantan.

considered as desirable for maintaining more forest cover. By accounting oil palm together with timber plantation, these LULC classes are considered to have higher evapotranspiration rate than agriculture

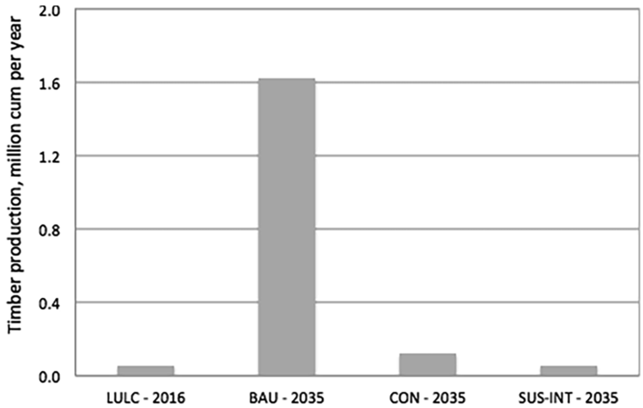

Fig. 8. Timber production under the current land use and the three future land-use scenarios in West Kalimantan.

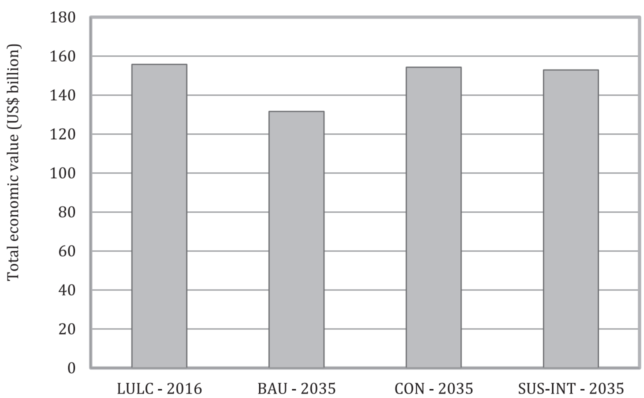

Fig. 9. TEV of ecosystem services under the current land use and the three future land-use scenarios in West Kalimantan.

Table 7
NPV of TEV of ecosystem services under current and future scenarios.

Discount rate	Current land use (US$ billion)	Business as usual (US$ billion)	Conservation (US$ billion)	Sustainable intensification (US $ billion)
3.5%	2,223	1,906 −317	2,208 −15	2,192 −31
5.0%	1,960	1,680 −280	1,946 −13	1,932 −27
10.0%	1,356	1,163 −194	1,347 −9	1,337 −19
15.0%	1,005	862 −143	998 −7	991 −14

or grassland. With no conversion of primary, secondary and peatlands for oil palm expansion increases evapotranspiration of the area. Eventually, the conversion of agriculture and scrubland to oil palm plantation can be stipulated for reducing water yield from the watershed or landscape. This implies a synergy between carbon benefit and (reducing) water yield as the positive impact on carbon and water at the same.

4. Discussion

4.1. Assessing ecosystem services on oil palm landscape

Ecosystem services are often mapped, valued and analyzed according to their trade-offs to assess the impacts of future land-use scenarios (Lawler et al., 2014; Sumarga and Hein, 2014). This study assessed three key ecosystem services, carbon storage, habitat quality and water yield, supplied from a oil palm landscape, according to their local and global significance (e.g., Arunyawat and Shrestha, 2016; Ardaban et al., 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 analyzed for trade-offs or synergies with key ecosystem services.

The accuracy and reliability of data is critically important for an accurate assessment and valuation of these ecosystem services. In the absence of primary data on carbon storage and water yield variables from the study area, this study relied upon secondary data sources. Carbon density (tC ha^{-1}) data compiled from previous studies in the area (e.g., Sumarga and Hein, 2014) were applied to the land-use classes in the study area. Since carbon density data were compiled from secondary sources with an unknown degree of certainty, the accuracy of the data could not be ascertained. With peatland present in the study area, carbon could be underestimated or overestimated if the carbon storage 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. This approach is considered appropriate for biodiversity assessment by taking into account of habitat types, their condition, threats sources and sensitivity of the habitat types to threat sources (Baral et al., 2014). The Habitat Quality Model can improve representation of habitat quality by incorporating all typologies of habitats based on vegetation, conditions and disturbance levels. Nonetheless, this approach is not a comprehensive method for assessing biodiversity. Sensitivities of different habitats to threats are very subjective; user bias is likely to be present for different threats and may result in a misleading interpretation of habitat quality. However, expert knowledge, relevant literature and the ground information on habitat types, threats and their interaction can minimize biases.

Several hydrological studies suggest that forest vegetation, with its high evapotranspiration rate, 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 agriculture or scrublands. Water yield increases with loss of vegetation cover. This result is consistent with InVEST Water Yield Model predictions for an agriculture-dominated subwatershed in Northern Thailand (Arunyawat and Shrestha, 2016). Since this study did not validate the model outputs, the results indicate 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; this 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 decision-making (e.g., Guswa et al., 2014), the water yield prediction needs to be performed at a district or subwatershed level using accurate data, with subsequent model calibration and sensitivity analysis (e.g., Sánchez-Canales et al., 2012; Hamel and Guswa, 2015).

4.2. Trade-offs or synergies 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 whether the specific ecosystem services 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). In particular, there is broad interest in the impacts of oil palm plantations on ecosystem services and their trade-offs (e.g., Obidzinski et al., 2012; Sumarga and Hein, 2014, 2016; Dislich et al., 2017; Petrenko et al., 2016; Vijay et al., 2016). For example, Obidzinski et al. (2012) studied the environmental and social impacts of existing oil palm plantations and highlighted the trade-offs of 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., 2017). 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 covers on 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 land use and the future land use. Oil palm can offer climate regulation services where the previous land use has a lower capacity for carbon storage. For example, Germer and Sauerborn (2008) observed a synergy for climate regulation from the conversion of tropical grassland to oil palm plantation with a net increase in carbon storage in biomass and soil. This study confirmed the trade-offs or synergies observed in the above studies by demonstrating (i) trade-offs of the 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 expansions on degraded or agriculture land by enhancing carbon storage in green biomass and soil in all future land-use scenarios.

5. Conclusion

These analyses of future land-use scenarios highlighted sustainability impacts on multiple ecosystem services under possible future land-use scenarios. The business-as-usual scenario results in detrimental impacts on ecosystem services due to intensive expansion of oil palm plantations, particularly on areas of old-growth forest and regrowth forest. Assuming the lowest intensity of oil palm expansion, the conservation scenario enhances carbon storage and maintains a stable habitat quality relative to 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 storage and water yield, whereas habitat quality is slightly reduced in the study area.

This study concludes that 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, without significantly affecting palm oil yield compared to the business-as-usual scenario. Smallholder farmers and industrial plantation can adopt sustainable intensification for oil palm by overcoming technological, social and economic barriers. However, food security can become a potential issue because of the extensive conversion of agricultural areas to oil palm plantations under this scenario. Therefore, future oil palm expansion should be considered cautiously to achieve a balance between 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 among these scenarios and used to enhance awareness regarding the impacts of the future expansion oil palm plantations on key ecosystem services. A detailed study at a local level (household or village) with better info on the economic values of ecosystem services can provide a better understanding of the impacts of oil palm expansion on the local community and the environment.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2019.100978.

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