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Abstract

Forest ecosystems provide benefits to people locally and globally. Sustainable management of forest resources is required to ensure continued supply of these benefits, but complex social-ecological processes are often a constraint to the design of such forest management strategies. In this study we develop a model of adaptive forest zonation to facilitate forest ecosystem management. We employ the ecosystem services concept and a land-use change model to identify potential areas for conservation and for economic use in the Kapuas Protected Forest Management Unit in Indonesia. Local people actively participated in a process to jointly define management zones and stakeholders' associated rights and responsibilities. Our results show that a stakeholder agreement has facilitated the reduction of threats to forest ecosystems and increased local awareness of the need for forest ecosystem conservation. Compared to current forest zonation, we show that the availability of an economic development zone in adaptive forest zonation could potentially increase ecosystem benefits for local communities by about 40% through rattan and jelutong collection and agroforestry rubber and jelutong production. Although our results are specific for the Kapuas District, the methodology of adaptive forest zonation can be applied more generally. We recommend to include our methods in guidelines for zonation and management plans to help improve sustainable forest management practices of all forest management units in Indonesia.

Keywords: Ecosystem services, land-use, ecosystem management, peat forest ecosystems, forest management units, Central Kalimantan

1. Introduction

The Ecosystem Services (ES) concept has been used for framing the relationship between human well-being and ecosystems in the context of ecosystem management since the last few decades (Turner et al., 2003; Millenium Ecosystem Assessment, 2005; Balmford et al., 2010; UN et al., 2014). Integrating ecosystem services into ecosystem management requires consideration of the broader economic, social and political context. In this context, stakeholder participation is important in order to understand local and regional perceptions and interests in ecosystem management (Stringer et al., 2006; Reed, 2008; Seppelt et al., 2011; Luyet et al., 2012).

In order to effectively conserve forest ecosystems, sustainable forest management must secure local livelihoods for forest-dependent communities (Pagiola et al., 2002; Kroeger & Casey, 2007; LaRocco & Deal, 2011; Deal et al., 2012). The integration of the ES concept in sustainable forest management can thus be used to understand the benefits forest communities and other stakeholders receive under different forest management regimes (Deal et al. 2012; Quine et al. 2013). However, forest ecosystems generally provide a broad range of ES involving multiple stakeholders from local to global. The application of the ES concept for ecosystem management is challenging due to a lack of quantitative information on flows of ES and the value different stakeholders place on them (Hein et al., 2006, Deal et al. 2012; Quine et al. 2013b).

The evolution of sustainable forest management practices in Indonesia has seen the introduction of Forest Management Units (FMUs) through Government Regulation No 6/2007. The concept of FMUs has its origins in the Forestry Law of 1967 but earlier attempts at achieving sustainable forest management through forest utilisation and conservation programmes failed (FORCLIME Forest and Climate Change Programme 2011; Setyarso et al. 2014). The FMUs' task is to ensure that economic, environmental and social functions are sustainably implemented in forest management.[1] However, to date, FMUs have not explicitly considered ES in the formulation of forest management plans.

The objective of this study is to test how the ES framework in combination with land use modelling can be used to enhance forest management in an FMU, and to develop a replicable method for doing so. In particular, we developed and analysed adaptive forest zonation, as the foundation of the forest management plan for the Kapuas Protection FMU, in Kapuas District, Central Kalimantan. The FMU is for the largest part located in a peatland area. Reconciling local use and conservation is a challenge in peat forests where drainage-dependent land uses increase fire risk (Taufik et al. 2017). Adaptive forest zonation is a novel approach which involves the identification of specific zones for different forest uses to meet the interests of different stakeholders. In our case study, these zones have been identified on the basis of a quantitative analysis of ES flows under different types of management in combination with extensive stakeholder workshops with local forest users. We employed the LUCES model described in Suwarno and Suyamto (2014), Suwarno (2016) and Suwarno et al. (2016b) to identify potential future land-use change resulting from the current forest governance system.

[1] This is stipulated in Law No. 41/1999 on forestry and Government Regulation No. 44/2004 on forest planning.

Next, potential areas to be allocated to conservation and economic development zones were identified and delineated based on a combination of potential land-use change and biophysical criteria of sustainable forest management. Subsequently, a participatory process was conducted to discuss the zonation draft with the local communities, which was revised to meet the agreement between the communities and the management of Kapuas Protected FMU. Finally, to assess ES delivery of two management plans (scenarios) for this particular area, we calculated and analysed the potential benefits from ES that the communities and management of Kapuas Protected FMU would receive based on recent and adaptive forest zonation.

In this paper, we also discuss the option of a financial mechanism to govern the potential benefits received by the Kapuas Protected FMU and the option of applying integrated peat management based on hydrological landscape (rather than forest) boundaries. Given the importance of Indonesian peat forest ecosystems for providing benefits to humans (Olbrei and Howes 2012; Galudra et al. 2014; Matthews et al. 2014; Tachibana 2016), the results of this study can provide valuable input to support and improve the implementation of sustainable forest management practices in FMUs in general and in the Kapuas Protected FMU specifically.

2. Methods

2.1. Case study area

2.1.1. Biophysics and local livelihoods

The Kapuas Protection FMU covers an area of 105,372 ha of which about 95% is peat and swamp forest. Forests in the Kapuas Protected FMU were logged between 1994 and 1998 (Euroconsult Mott MacDonald 2009; Suyanto et al. 2009; Tachibana 2016; Yamamoto and Takeuchi 2016). These logging activities were conducted under the Mega Rice Project that aimed to develop 1 million ha of agricultural land, especially for paddy fields. The project cut through two peat domes in this area and a main canal that linked three rivers was built with the aim of draining the peatland. The draining process damaged the peat's hydrological system and reduced the capacity of the peat ecosystem to control the water balance. As a result, the area south of the main canal has become degraded in terms of both hydrology and vegetation. The area is now very dry during the dry season of about 2 to 3 month, with average temperature about 35^oC to 40^oC causing a high risk of forest and land fires (Euroconsult Mott MacDonald 2009; Kapuas 2012). In the wet season the area is regularly flooded (Euroconsult Mott MacDonald 2009; Kapuas 2012). In contrast, the secondary peat forest to the north of the main canal is still intact and has a unique diversity of typical flora and fauna. It now hosts the largest remaining unprotected wild orangutan population in the world (Suyanto et al., 2009; BOSF, 2010).

The seven neighbouring villages in the Kapuas Protection FMU area have a total population of about 5,500 (BPS, 2014) (see Figure 1). The livelihoods of these local people are mainly related to agriculture, logging and collecting Non-Timber Forest Products (NTFPs). Prior to 1970, NTFPs, such as rattan (*Calamus spp*.), damar (*Shorea sp*.), jelutong (*Dyera costulata*), eaglewood (*Aquilaria malaccensis*), katiau (*Ganua motleyana*), kalanis (a tree root), ehang, nyatu (*Palaquium javense*) and animals (snakes, birds and deer), swidden upland rice and fishing were the main sources of local livelihoods (Suyanto et al. 2009). These livelihoods then changed due to the establishment of the Mega Rice Project (Suyanto et al., 2009). During the Mega Rice Project (1995-1998), agriculture was the main livelihood for most of the people to the south of the main canal, while to the north it remained to be NTFP collection and shifting cultivation. In 1999, with the failure of the Mega Rice Project, many local people to the south either left or planted oil palm (Suyanto et al., 2009; Galudra et al., 2011). The use of slash and burn to prepare the peatland for oil palm has increased the risk of land and forest fires in this area. Together with encroachment, forest fires are now considered the main threat to the area. Reports from Global Forest Watch show that 155 fire alerts occurred in this area between 1 September and 15 October 2015 (http://fires.globalforestwatch.org). Most of the fires (92%) occurred on degraded peat land to the south of the main canal, which has open access for some villages.

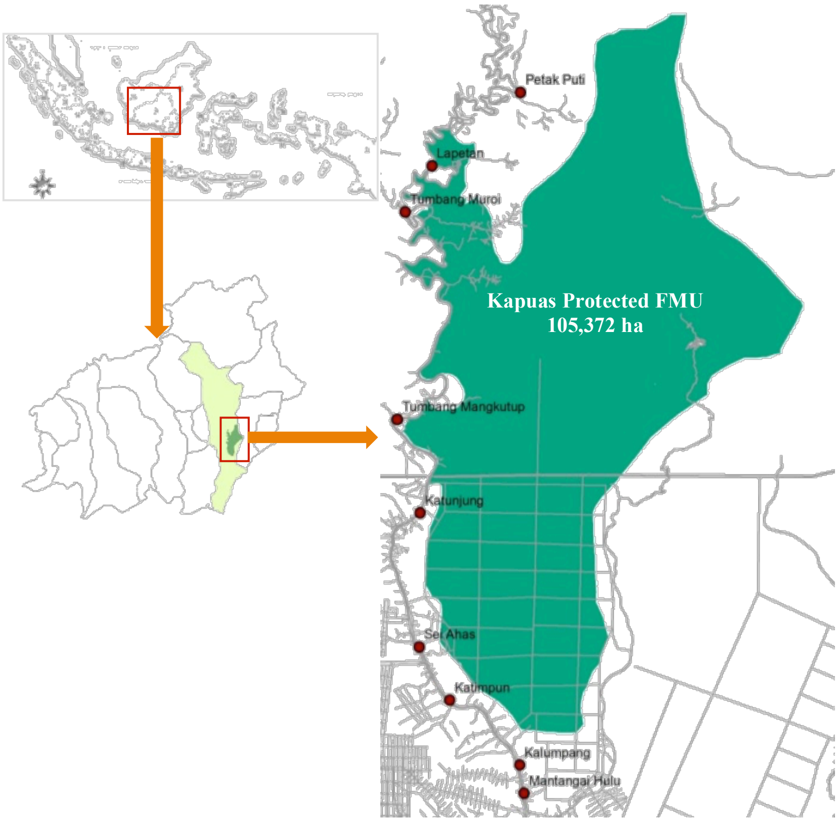


Figure 1. The Kapuas Protected FMU area and neighbouring villages (Source: Kapuas Protected FMU)

2.1.2. Institutional aspects

The Kapuas Protected FMU was established on 2 May 2011, based on the Ministry of Forestry Decree No: SK.247/Menhut-II/2011, covering 105,372 ha. Much of the FMU's area is part of the former Mega Rice Project area. The Kapuas Protected FMU's main task is to address the ecological and economic issues resulting from the former Mega Rice Project. These issues include reducing carbon emissions and fires from degraded peatland and rehabilitating the degraded peatland area. Moreover, the Kapuas Protected FMU is also required to work for sustainable local livelihoods which were not sufficiently addressed by previous international projects implemented in this area (Olbrei & Howes, 2012; Atmadja et al., 2014; Medrilzam et al., 2014). The Kapuas Protected FMU's long-term vision is to develop a "Protected FMU business for the sustainable use of peat swamp forests, contributing to sustainable livelihoods and prosperous communities through equal sharing of benefits" (Kapuas Protected FMU, 2012). The aims of Kapuas Protected FMU are defined as follows: (1) to develop sustainable livelihoods for local communities with minimal greenhouse gas emissions and fires, and (2) to increase the capacity and participation of stakeholders (public, private and local communities) in managing and utilizing peat swamp forests (Kapuas Protected FMU, 2012).

2.2. Forest zonation development and analysis

In this study, we developed an adaptive forest zonation to enhance the effectiveness of the current forest zonation of Kapuas Protected FMU in conserving forest ecosystems and sustaining local livelihoods. The term 'adaptive' is used here to refer to adaptive management which includes structured and iterative decision-making processes to improve long-term management outcomes and reduce uncertainty (Holling, 1978). This decision-making simultaneously meets one or more management objectives and accrues information needed to improve future management. We designed a procedure for the development of adaptive forest zonation in three steps (Figure 2). These steps include learning processes in the outcomes of current management. The details of each step are explained in sections 2.2.1 to 2.2.5.

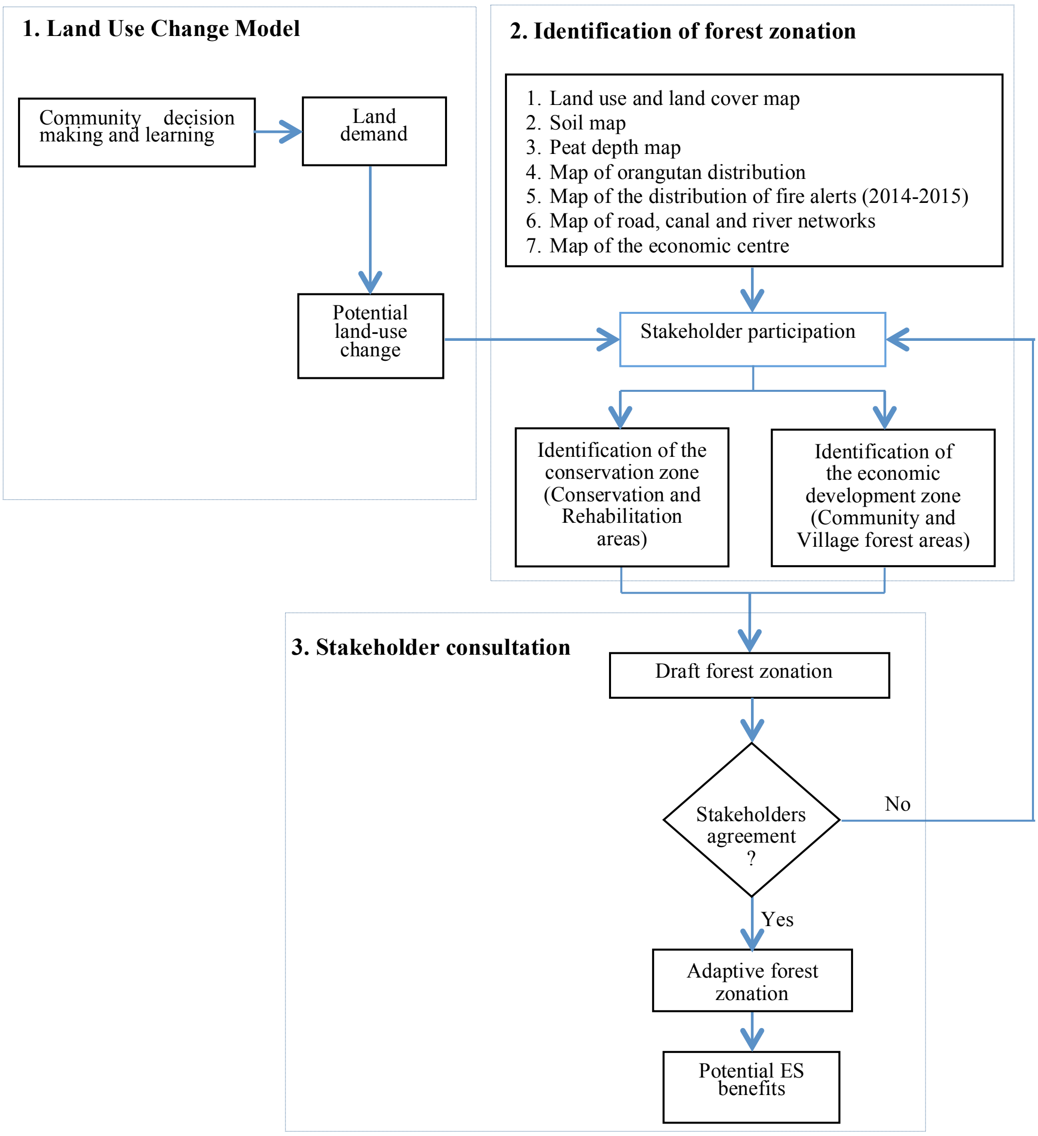


Figure 2. Three steps in developing adaptive forest zonation

2.2.1. Land-use change model

The land-use change model was developed in this study to understand land-use patterns and to predict land-use change based on the stakeholders' interests. This model was based on the Land-Use Change and Ecosystem Services model (LUCES)[2]. The LUCES model is a hybrid agent-based land-use model that captures the interactions of stakeholders in the decision-making process. The LUCES model was designed to consider the interests of local people and private companies in shaping their opportunities for further socio-economic change and the impact of these interests on land-use decisions (Suwarno and Suyamto 2014; Suwarno 2016; Suwarno et al. 2016b). The LUCES model can produce a spatially explicit representation of a land area (represented as a raster) with the potential for land cover change in each pixel governed by a combination of formally planned and unplanned change, with the latter decided by local agents. Planned land-use change is driven by private companies, which have obtained

[2] Details of the LUCES model can be obtained from the corresponding author.

government permits to maximise their profits. Meanwhile, land use by local community members is mainly driven by available labour and continues outside of formal planning. One assumption built into the LUCES model is that a community will only expand the area used if more labour becomes available. Accordingly, the recent version of the LUCES model only includes incumbent labour and has yet to include potential migrant labour.

Simulation of the land-use change in the LUCES model is based on Unified Modelling Language (UML) and implemented using the ABM software NetLogo 5.0.5. The simulations of the potential land-use change in the LUCES model were conducted based on 3 scenarios, with details as follows:

(1) Business As Usual (BAU) reflects the current trend, including the Forest Conversion Moratorium, which initially ran from 2011 to 2014. The Moratorium applies only to new or extended permits for companies converting peat forest to other land use; it does not apply to local communities.
(2) The Extended Moratorium (EM) scenario extends the period of the Forest Conversion Moratorium to 25 years starting from 2011. The Forest Conversion Moratorium applies to new or extended permits for companies converting peat forest to other land use; it does not apply to local communities.
(3) The Moratorium Plus Livelihoods (MPL) scenario adds to the Extended Moratorium an improved livelihood programme with enhanced markets for NTFPs, agroforestry products and community timber as well as an improved monitoring programme to avoid community logging.

These three scenarios were parameterized based on the data of economic value of the selected ES (rattan and jelutong resin collection and the production of timber, agroforestry rubber, oil palm, paddy and carbon emissions) provided by different types of ecosystems in combination with information regarding the community perspective on their income expectation and potential land-use changes. The data on economic value of these ES was obtained from the previous studies that were conducted in the period of 2008-2012 (Setiawan et al. 2011; Iwan, 2008; Martoniady, 2009; Sapiudin, 2009; Budiningsih and Effendi, 2013; Herman et al, 2009; Suyanto et al. 2009; Nugroho, 2008; Yandi, 2008; Iksan and Abdussamad, 2010; Ismail, 2010; Boer et al. 2012; Sanchez, 2000; Agus et al. 2009; Hooijer et al. 2010; Lim et al. 2012; Carlson et al. 2012a; Carlson et al. 2012b; and the reports from two logging companies in 2012 and two oil palm companies in 2012) and fieldwork in 2012, 2013 and 2014. The secondary economic data include potential production of each service per year (yields) and macroeconomic parameters in 2010 and 2011. Meanwhile, the fieldworks in 2012, 2013 and 2014 were conducted to gather the data on the cost of harvesting jelutong resin and its price at the farm gate and information on the perspective of the communities regarding their income expectation and potential land-use change. This information gathered through personal interviews and focus group discussions.

Table 1. Key features of the three Forest Conversion Moratorium scenarios using the LUCES model to determine current and future landscapes as well as ecosystem services supply (source: Suwarno and Suyamto 2014; Suwarno 2016; Suwarno et al. 2016b)

No	Scenario	Description	Remarks
1	Business as usual (BAU)	- Protection of peat forest from conversion activities on a company scale (2011-2014) - Illegal conversion of peat forest on a community scale	- No change in road network and market prices during the 15 years simulation - Settlement distribution changes are based on the change in land demand and centre of economic activities
2	Extended moratorium (EM)	Similar to BAU, but: - Extension of the period for protection of peat forest from conversion activities on a company scale (2011-2036) - New oil palm and timber plantations on a company scale can only be established on mineral soil	- Same as BAU
3	Moratorium plus livelihoods (MPL)	Similar to EM but: - Higher market prices for NTFP, agroforestry products and community timber by about 15 % - Local demand for timber can only be supplied from community timber plantations	- Support of the NTFP market chain, agroforestry products and community timber products - Increase illegal logging litigation - Other conditions are the same as BAU

In this study, we improved the LUCES model by using SARVision land cover maps of 2010. These maps were derived from FBS and FBD ALOS PALSAR strip data provided by JAXA EORC, with a resolution of 50 m (Hoekman et al., 2010). We also increased the resolution of the model from 0.5 km^2 to 0.2 km^2 per pixel by maximising the number of cells in NetLogo 5.0.5 to provide more detail. Considering the position of the villages and hydrological units as important factors in sustainable forest management, we first used the ecological boundaries (rivers in the west and east) of the Kapuas Protected FMU area and present the results only for this area. The numbers presented represent best estimates. As parameter and model uncertainty prevails, we conducted a sensitivity analysis (see Section 3.4).

2.2.2. Identification of areas for adaptive forest zonation

The purpose of adaptive forest zonation is to balance conservation and economic interests. Based on the adaptive management concept, we divided the area of Kapuas Protected FMU into (1) conservation and (2) economic development zones to meet the main aim of Kapuas Protected FMU in conserving forest ecosystems and sustaining local livelihoods. The conservation zone includes conservation and rehabilitation areas, while the economic development zone includes community and village forests. The community forest (Hutan Kemasyarakatan – HKm) is the forest area that can be legally managed by the group of communities with the aim to empower the communities who live inside and around the forest (Ministry of Forestry Regulation No. P.88/Menhut-II/2014, about community forest). The village forest (Hutan Desa) is the forest area that can be legally managed by the village with the aim to increase and sustain the livelihood of the people in the village (Ministry of Forestry Regulation No. P.89/Menhut-II/2014 concerning village forests). Both community forest and village forest must comply with two conditions: (1) the area has no other forest concession, and (2) the area is the main source of the communities' livelihood. Permits for community forest and village forest are for 35 years (released by national government and monitored by the district and province government) with an evaluation period of 5 years. The difference between community forest and village forest concerns the management: community forest requires the group of communities to apply and manage this forest, while for village forest is managed by villages as institutions.

The potential area allocated for conservation and economic zones was identified using biophysical criteria that include hydrological units (rivers) as the ecological instead of administrative boundaries; see Table 2. It was important to consider hydrological units in this study, as Kapuas Protected FMU is located in a peat forest ecosystem influenced by its hydrology. Hence, we used the ecological boundaries (rivers in the west and east) of the Kapuas Protected FMU area and present the results for this area. We considered the location of the villages as an important factor in defining the potential area to be defined as economic development zones. Moreover, we also considered the communities' capacities to manage the forest as an important factor in designing the area for community forest and village forest. We conducted a series of focus group discussions with communities and representatives from Kapuas Protected FMU, District Forest Agency and District Planning Agency to discuss the possible areas to be allocated to community and village forests. The results were then used as additional determinants for zoning.

Table 2. Biophysical criteria used to delineate conservation and community development zones

Zone	Area	Criteria
Conservation zone	Conservation	- Peat land with a minimum depth of 2m - Good forest cover (old and young secondary peat forest with the percentage forest cover between 50-100%) - Area for orangutan habitat
	Rehabilitation	- Peat land with a minimum depth of 2m - Degraded forest cover (pioneer secondary peat forest) - Area(s) prone to forest fire (based on history of fire alerts)
Economic development zone	Community forest	- Mineral soil or peat land with a maximum depth of 1m - Exclude the orangutan habitat

		- Exclude areas of good forest cover (old secondary peat forest) - A maximum distance of 6km from the centre of the village, river or road (community preference)
	Village forest	- Mineral soil and/or peat land with a maximum depth of 2m - Exclude the orangutan habitat - A maximum distance of 10km from the centre of the village, river or road (community preference)

2.2.3. Stakeholder participation and consultation

Stakeholder participation and consultation are crucial for forest zonation development (see Figure 2). We conducted a series of focus group discussions (FGDs) (2 to 5 FGDs per village) in the period 2014 to 2015 to capture the local communities' preferences for defining the area to be allocated for economic development and conservation zones (see section 2.2.2). These FGDs were initiated by Kapuas Protected FMU and involved 10 to 15 village representatives. Most of the village representatives have been engaged with the Kapuas Protected FMU through some community development projects.

In these FGDs, we discussed the communities' preferences concerning the management of the economic development zone. The option of community forest and village forest, as suggested by the management of Kapuas Protected FMU, were discussed in these FGDs. Concerning conservation zones, these FGDs also considered the possibility of conducting participatory conservation activities. These FGDs resulted in a first draft of the conservation and economic development zone, and the first draft of an agreement determining rights and responsibilities pertaining to the two zones.

Further, several other focus group discussions were conducted in the period June to September 2015 to assess and communicate the first draft of the forest zonation with stakeholders in the villages, the sub districts and the districts. We also discussed and finalised the agreement on rights and responsibilities relating to the economic development zones in these FGDs.

2.2.4. Calculating potential benefits for local communities

The calculation of potential benefits for local communities was conducted in this study to understand potential gains and losses from implementing adaptive forest zonation. The calculation of potential ecosystem benefits for local communities was based on the economic value of seven ES (rattan and jelutong resin collection and the production of timber, agroforestry rubber, oil palm, and paddy and carbon emissions) resulted from previous studies that were conducted in the period of 2008 to 2012 (Sanchez 2000; Iwan 2008; Nugroho 2008; Yandi 2008; Agus et al. 2009; Herman et al. 2009; Martoniady 2009; Sapiudin 2009; Hooijer et al. 2010; Iksan and Abdussamad 2010; Ismail 2010; Setiawan et al. 2011; Boer et al. 2012; Carlson et al. 2012a; Lim et al. 2012; Carlson et al. 2012b; Budiningsih and Effendi 2013a; and the report from two logging companies and two oil palm companies in 2012). In order to support the calculation of the potential benefits for local communities, this study also elaborates the information on the potential monetary benefits of seven ES explained above provided by Sumarga et al. (2015); Suwarno et al. (2016a).

The studies by Sumarga et al. (2015); Suwarno et al. (2016a) employed ecosystem accounting to assess the contribution of ecosystems to economic and other human activities in a way that is consistent with national accounts (UN et al., 2014; Edens and Hein, 2013). The net benefits in ecosystem accounting are expressed as an annual resource rent (RR) and valued by analysing the market price and deducting the total costs (intermediate, employment and user production costs) (Edens and Hein, 2013). Suwarno et al., (2016a) also include Government Regulation No. 55/ 2005, concerning the procedure for governing timber and NTFPs, to support the calculation. These regulations determine taxes, including taxes on timber and land, and fees for extracting timber and NTFPs from both natural and plantation forests. Further, we included the potential cost of carbon emissions resulting from forest conversion to other land-use and vice versa. We describe the potential carbon emissions resulting from forest fire, frequent in this area, and its negative impact on local communities. The results of this analysis were then discussed with the stakeholders in the district, particularly the District Forest Agency and District Planning Agency, during a focus group discussion that was organised by the management of Kapuas Protected FMU in September 2015.

3. Results

3.1. Potential land-use change

Our analysis shows the potential land-use and land cover change in the study area in the period 2010 to 2040, based on the business as usual scenario (current management).

These changes mostly relate to the conversion of forest to oil palm and agriculture (paddy fields). Simulations of the LUCES model show that the rate of land-use change for oil palm and paddy could increase from about 2% to 3% and 0.2% to 1% per year, respectively. The rate of decline of old secondary, young secondary and pioneer peat forest and of permanent agroforestry could increase from about 0% to 0.1%, 0.03% to 1.69%, 0.09% to 1.17% and 0.02% to 0.14% per year, respectively (Table 3).

Table 3. Potential land-use change in Kapuas Protected FMU area based on the result of the LUCES model (BAU scenario)

Class	Initial 2010 (ha)	2020 (ha)	2030 (ha)	2040 (ha)
Old secondary peat forest (> 50 yrs)	67,390	67,301	67,199	67,177
Young secondary peat forest (25 – 50 yrs)	2,831	2,619	2,611	2,169
Pioneer peat forest	24,912	24,619	24,212	23,996
Agroforestry	7,021	6,922	6,832	6,912
Oil palm	1,946	2,602	3,075	3,598
Agriculture	1,272	1,309	1,443	1,520
Total	105,372	105,372	105,372	105,372

In addition to land-use and land-cover changes in this area, there is also a high risk of forest encroachment. This risk is related to local interest to meet economic expectations by converting the forest area to other uses. Our interviews with local communities and experts in Kapuas Protected FMU show that local communities have already occupied large areas of forest, particularly close to their villages.

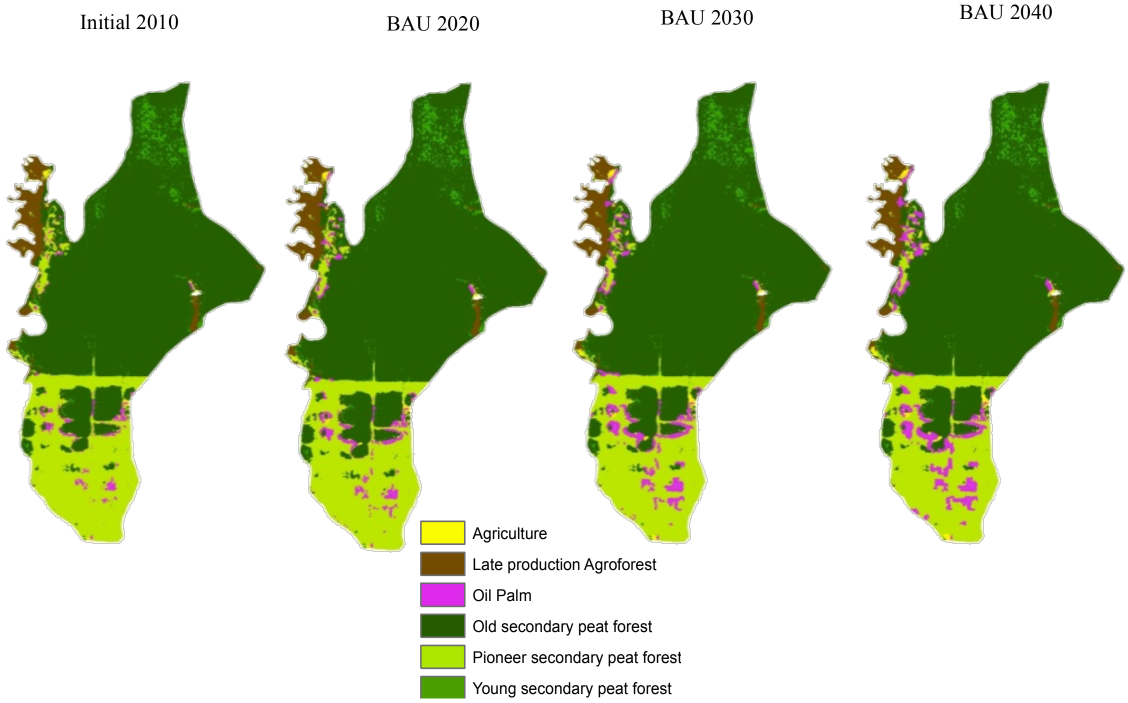
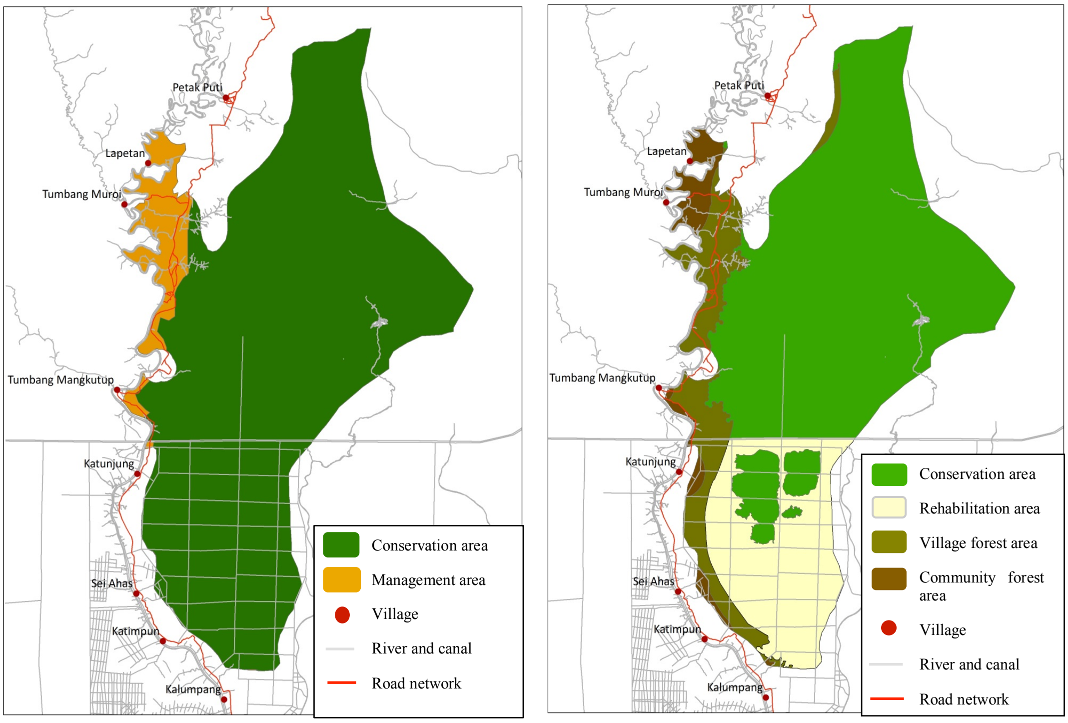


Figure 3. Potential land-use change using the LUCES model. The area of pioneer secondary peat forest south of the canal is subject to a high risk of fire prohibiting the succession process. The area of young secondary forest in the north is used by local communities for their home gardens prohibiting the succession process of this forest to old secondary forest

3.2. Adaptive forest zonation for Kapuas Protected FMU

Adaptive forest zonation for the Kapuas Protection FMU includes conservation and rehabilitation areas in the conservation zones, and village and community forests in the community development zone (Figure 4).



A B

Figure 4. Forest zonation for Kapuas Protected FMU current (A) and adaptive (B) and neighbouring villages

The conservation area under the adaptive forest zonation includes old secondary forest to the north and south of the main canal, delineated based on the condition of the forest cover, peat depth and its importance for orangutan habitat. The rehabilitation area was delineated at the edge of the degraded peat forest (pioneer peat forest) to the south of the main canal. This rehabilitation area is the main aspect for adaptive conservation due to potential problems of forest fire, encroachment and flooding. The community development zone was divided into community forest and village forest with stakeholder participation in order to secure sustainable local livelihoods in the area of the Kapuas Protected FMU (Table 4). Further, the rights and responsibilities of local communities and the management of Kapuas Protected FMU were defined in the stakeholders' agreement as explained in Table 4.

Table 4. Details of the areas in the current and the adaptive forest zonation

Forest zonation	Zone	Programmes	Area (ha)
Current forest zonation	Conservation	Not defined	65,785
	Rehabilitation	Not defined	25,198
	Management	Not defined	14,389
Adaptive forest zonation	Conservation	Conservation	70,296
		Rehabilitation	19,379
	Community development	Community forest	3,711
		Village forest	11,986

Table 5. Rights and responsibilities granted to local communities and the management of Kapuas Protected FMU based on the negotiated stakeholder agreement

Zone	Area	Local communities		The management of Kapuas Protected FMU	
		Responsibilities	Rights	Responsibilities	Rights
Conservation zone	Conservation	Prevent: - Illegal logging - Forest encroachment - Forest fire	- Communities may collect NTFPs with tax reduction	- Monitor and prevent illegal logging - Forest fire prevention and suppression	- Tax from NTFP collection and limited timber production
	Rehabilitation	- Participate in rehabilitation programme under coordination of Kapuas Protected FMU	- Communities share in benefits from carbon trading	- Conduct and monitor rehabilitation programme	- Possibility to enter carbon market
Adaptive economic development	Community forest	- Same as conservation area	- Communities may convert this area to (1) agroforestry rubber or (2) agroforestry rubber and jelutong	- Provide local communities with assistance in developing Agroforestry - Monitor the development of agroforestry - Establish a premium market for NTFPs and agroforestry products	- Benefit sharing from NTFP collection and agroforestry production - Extend or stop the permit for community forest based on the performance of local communities
	Village forest	- Same as conservation area	- Local communities may be granted a permit to collect NTFPs tax free	- Establish a premium market for NTFPs - Monitor and evaluate the sustainability of the village forest	- Benefit sharing from NTFP collection and agroforestry production - Extend or stop the permit for a local community forest based on the performance of the local community

3.3. Potential benefits from ecosystem services for local people

Our results show that adaptive forest zonation can provide more sustainable options for local livelihoods through the availability of community and village forests under an economic development zone. Communities may increase the annual benefits they receive from NTFP collection by about 12% (from € 1.9 million to € 2.2 million). The NTFPs could be collected in the conservation area and the village forest, with the assumption that due to limited access NTFPs are collected from 10% of the conservation area and 25% of the village forest area. The communities could also potentially receive annual benefits from timber production of about € 534 from the village forest. This is due to government regulations that only allow limited timber production in village forests that have protected status (maximum 50 m^3 per year per village forest) (Ministry of Forestry Regulation No. P.89/Menhut-II/2014 concerning village forests). The availability of community forest would also increase the potential benefits communities receive from rubber and jelutong agroforestry. Our results show that the communities could potentially receive € 190,997 per year from agroforestry rubber or € 483,714 per year from agroforestry jelutong. Moreover, they could also potentially receive € 3.8 million per year from jelutong agroforestry in rehabilitation areas (see Table 6). Since the rehabilitation may require a long process, the calculation of potential benefits from this area are not included in the total potential benefits that communities may receive from adaptive forest zonation. In general, adaptive forest zonation could potentially increase ES benefits of local communities by about 40% compared to the current forest zonation (see Table 6).

Table 6. Comparison of the potential ecosystem service benefits local people and the management of Kapuas Protected FMU receive under the current and adaptive forest zonation

Forest zonation		Current forest zonation			Adaptive forest zonation			
Zones		Conser-vation	Rehabili-tation	Manage-ment	Conservation		Community development	
Programmes		Not defined	Not defined	Not defined	Conser-vation	Rehabili-tation	Community forest	Village forest
Potential area (ha) for:	Timber production	0		0	0	0	0	58[5]
	Agroforestry	0			0	6,783[3]	732[4]	0
	NTFPs collection	6,579[1]		5,247	7,030[2]	0	2,439	2,996[2]
	Paddy production	0		1,272		0	1,272	0
Benefits per ha per yr[6] (€)	Timber production							9
	Rubber agroforest						261	
	Jelutong agroforest					560	661	
	Rattan collection	99		74	99		99	95
	Jelutong collection	90		68	90		90	90
	Padi production			316			316	
Benefit per yr (€)	Timber production						0	534
	Rubber agroforest						190,997	0
	Jelutong agroforest					3.798.263	483,714	0
	Rattan collection	651,272		389,575	695,933		241,491	284.657

	Jelutung collection	592,065		354,159	632,666		114,480	269.675
	Padi production			401,952			401,952	
Total benefits		2,389,022			3,316,099[7]			

[1] We assumed that NTFPs were collected at a maximum distance of 10 km from villages, rivers or road (assuming it would take about 10% of the conservation zone in the current forest zonation)

[2] We assumed that NTFPs were collected at a maximum distance of 10 km from villages, rivers or road (assuming it would take about 10% of the conservation area in the conservation zone and 25% of the village forest and 100% of the community forest area in adapted forest zonation)

[3] We assumed that rehabilitation covers about 35% of the total rehabilitation area

[4] We assumed that agroforestry would be initiated in about 30% of the total community forest area

[5] According to Ministry of Forestry Regulation No. P.89/Menhut-II/2014 concerning village forests, timber production is allowed for domestic consumption with a maximum of 50 m^3 from the whole village forest per year (with the assumption that potential timber production is 0.86 m^3 per ha per year, 50m^3 per year is then equal to 58 ha per year -- Sumarga et al., 2015 and Suwarno et al., 2015)

[6] Calculations of benefits per ha are based on Sumarga et al., 2015 and Suwarno et al., 2015

[7] Potential benefits from rehabilitation is excluded due to high uncertainty

3.4. Uncertainty and sensitivity of the model

Adaptive forest zonation involves uncertainty in terms of the exact benefits people receive from agroforestry systems in community forests and rehabilitation areas. Local people could potentially receive substantial benefits per hectare from jelutong and rubber agroforestry 10 years after planting: € 770 per year for agroforestry jelutong and rubber (Budiningsih and Effendi 2013b), € 261 per year for agroforestry rubber (Suwarno et al. 2016a) and € 820 per year for agroforestry jelutong (monoculture) (Budiningsih and Effendi 2013b). Thus, the options for alternative livelihoods should be provided in the first 10 years. Here we propose to include NTFP collection (i.e. rattan, jelutong, gemor (*Alseodaphne* sp), illipe nut (*Shorea* sp), fruits and fish) in livelihood options as far as areas in the conservation and village forests are reachable.

In order to support our analysis, we also conducted a sensitivity analysis for the main parameters in the LUCES model for the land use-change in the area. We found that any changes of farm-gate prices for agricultural products and the reference wage rate for household labour have a significant role in changing land-use in communities. An increase farm-gate prices (in this case for fresh fruit bunches of oil palm) of 5% has increased the potential land-use change in the communities by about 3%, i.e. the land area converted for agricultural use is 3% larger compared to our base case. A decrease of farm gate prices of 5% has no significant on the reduction of land-use change. For household labour, an increase of availability household labour of 5% increases the potential land-use change in the communities by about 6%. A reduction of the availability household labour of 5% leads to a decrease of land-use change by about 3%. These results show that effects of income expectations of communities, influenced by the farm-gate prices, on land use change are dominated by effects of the availability of household labour.

4. Discussion

4.1. Can consideration of the Ecosystem Services (ES) concept support the implementation of sustainable forest management in Forest Management Units (FMUs)

The ES concept provides a framework to anticipate a wide range of social and ecological consequences that may result from different decisions and tools to identify, negotiate, avoid and manage negative trade-offs (DeClerck et al., 2006; Ingram et al., 2012). This holistic concept is important to improve sustainable forest management practices in Indonesia to promote environmentally, socially and economically sustainable conservation management and to maintain the ecosystem benefits for present and future generations. Moreover, the ES concept will ensure that local livelihoods and the conservation programme funds are included in ecosystem management to balance conservation and development programmes and achieve positive outcomes (Sunderland et al., 2008; Kettunen et al, 2009; Mulia et al., 2013; Alvarado-Quesada et al., 2014).

The integration of the ES concept to support a better ecosystem management has been discussed in a number of studies (de Groot et al., 2010; Deal et al., 2012). The valuation of ES benefits can assist in elucidating interests of different stakeholders in ecosystem management (Farber et al. 2002; Liu et al. 2010), while the trade-off analysis on how they will change based on various scenarios could provide essential information for forest managers to adapt their management programmes. For example, information on how the monetary values of ES from forest ecosystems will change due to land-use change, could provide essential information for forest managers to work with stakeholders in conserving a forest area rather than convert it to other uses (Ruckelshaus et al. 2015).

In this study, the information from the ES valuation and trade-off analysis was used as a foundation to develop adaptive forest zonation. ES valuation in this study is biased towards the provisioning services, relative to regulating and cultural services. This selection was based on stakeholders' perspectives on what the most important ES are for them, as well as data availability. However, since the adaptive management that we propose would lead to a better protection of forest cover compared to the business as usual we postulate that our approach is advantageous, at least in this specific case, for globally relevant ES such as carbon sequestration and storage and biodiversity conservation.

Our research shows that, from an economic perspective, adaptive forest zonation could potentially increase the ecosystem service benefits local beneficiaries receive. Providing more rights to and authority over community and village forests can increase the possibility of local beneficiaries meeting their livelihood expectations and reducing their interest in converting their forests to other uses. These benefits would be generated mostly from NTFP collection and limited timber production from agroforestry in the village forest and rubber and jelutong production in the community forest. From a conservation perspective, we show how the rules, rights and responsibilities in the stakeholder agreement can increase local community awareness of the need to conserve and protect the peat forest.

The stakeholder agreement details the shared responsibility for conservation (preventing forest fire, illegal logging and forest encroachment), which could reduce the risk of forest fire, a major problem in this area especially during El Nino events. The agreement discusses how enrichment planting of fruit and jelutong trees, in the buffer zone of the village forest, will improve the quality of the orangutan habitat and reduce potential conflict between the orangutan and humans. It likewise outlines the benefits of the rehabilitation programme using jelutong trees, which could also speed up the improvement of forest ecosystems and potentially generate benefits from jelutong resin collection over the following ten years. These results confirm the advantages of integrating the ES concept in sustainable, efficient and inclusive forest management that not only considers biodiversity conservation but also local livelihoods. These results also support other studies that indicate the positive impacts of the ES concept in sustaining local livelihoods, (Deal et al., 2012; Quine et al., 2013; Spangenberg et al., 2015) biodiversity conservation (Kettunen et al., 2009; Persha, 2011; Corbera & Pascual, 2012), and preventing land-use change and carbon emissions (Lin et al., 2011; Viglizzo et al., 2012; Sumarga et al., 2015). New opportunities to benefit from planted gaharu trees as part of agroforests have not yet been factored in (Soeharto et al., 2016).

4.2. Ecosystem management and landscape integrity

A tropical peat forest is a unique ecosystem with an accumulation of partially decayed organic matter from plant debris under waterlogged conditions (Andriesse 1988). The organic matter accumulates at different rates in time and space resulting in different depths of peat with the highest and thickest points, peat dome summits, being close to riverbanks and mineral soil, forming the ecological boundaries of the peat ecosystem. A tropical peat ecosystem, usually located in lowlands between rivers with extensive floodplains, is a unique hydrological unit that can maintain balance, stability and productivity (Page et al. 2009).

The area of Kapuas Protected FMU is part of a peat forest ecosystem in Central Kalimantan Province. The peat ecosystem in this area consists of three domes, distributed along two big rivers. The boundaries of the Kapuas Protected FMU are designated based on the forest function. In order to capture the complexity of forest ecosystems, the management of Kapuas Protected FMU should integrate ecological and socio-economic systems within specific ecological boundaries rather than political or administrative boundaries (Minang et al., 2015; Mitchell et al., 2013). However, the current boundaries of this FMU do not include ecological boundaries.

Considering the importance of the hydrological unit as well as the dynamics of the socio-ecological processes in tropical peat forest ecosystems, the adaptive forest zonation in this study was developed using two rivers as ecological boundaries. The balance between conservation and economic development zones described in this study aims to increase and sustain the livelihoods of local people and their awareness of the need to conserve peat forest ecosystems. The allocated area for community forest along the riverbanks and villages will provide an opportunity for villagers to increase their income and encourage them not to convert the peat forest to oil palm anywhere between peat domes and rivers, which covers most of the drainage system. Long-term agreements between local communities and the management of Kapuas Protected FMU (community and village forests) will increase local participation in the rehabilitation of degraded peatlands. In turn, the peat forest ecosystems will gradually regain balance and capacity to provide benefits.

A limitation of this study is that it could not do justice to the concept of adaptive management as a long-term learning process (Holling, 1978). It focussed on identification of specific zones for different forest uses to meet the interests of different stakeholders as currently interpreted. Once space has been carved up between the primary stakeholders (FMU and local communities), further adjustments will be contentious. Conventional elements of the bundles of property rights (Schlager and Ostrom, 1992) are not clear on the ‘rights to alter’ (Galik and Jagger, 2015) while modifying water tables is a key determinant of peat landscapes. Further shifts may be expected to be one-way (more *de facto* rights for local communities), unless the benefits of intact ecosystems are understood in similar ways by all stakeholders, and actualized in terms of financial transfers. This is especially challenging for the ES beyond 'provisioning', as these are hard to quantify for all involved stakeholders, especially in a changing landscape. Overall, natural resource management in a landscape like the one studied has few opportunities for "win, win" solutions that directly benefit all, but many for "lose-less, lose-less" negotiated trade-offs replacing current conflict (van Noordwijk, 2017). In local articulations of a "common but differentiated responsibility" for restoration and avoided degradation of commons the question who pays for basic rights of clean air and water remains crucially important (Namirembe et al., 2017).

4.3. Policy implementation

Forest degradation and deforestation have become the main issue in the Indonesian forestry sector. Forest degradation has reduced the capacity of forest ecosystems to provide and sustain benefits for forest dependent people and other beneficiaries globally (Achard et al. 2002; Sunderland et al. 2008; Suwarno et al. 2015). In order to restore and sustain forest ecosystems, each FMU should develop a forest management plan that incorporates the concept of ES. However, the technical guidelines on the use of the ES concept in developing management plans, is not included in any regulation that govern FMU. Technical guidelines on forest zonation development that embrace the ES concept could significantly improve forest management practices in FMUs. These guidelines should contain detailed step-by-step instructions on conducting: (1) ES valuation; (2) land-use change simulation; (3) trade-off analysis; (4) delineation of forest zones; and (5) stakeholder consultations. Considering our experience in utilising the ES concept and SFM framework in developing adaptive forest zonation in Kapuas Protected FMU, guidelines could be based on our diagram for forest zonation development.

The institution of FMUs is categorised as a public institution under the Ministry of Internal Affairs Regulation No. P.61/2010. Meanwhile, FMUs have also received a mandate from the national government to generate management and business partnerships with other parties (under sustainable forest management) and to act as a private institution (Setyarso et al. 2014). However, the FMUs' current financial arrangements do not support this mandate. The FMU as an institution was established under district or provincial government, and should adopt the financial mechanisms under decentralised forest government. Efforts to improve the management of FMUs in providing public services have been made by the national government (Ministry of Forestry) through the introduction of quasi-public agencies (Setyarso et al. 2014). A quasi-public agency is an institution formed, controlled and appointed by a specific government body, with the aim of providing public services while generating its own income (Cummings et al., 2010; Kosar, 2011). The establishment of quasi-public agencies in FMUs will provide them with more financial independence, while the government will be able to maintain some form of control over FMUs.

Experience in establishing quasi-public agencies as financial mechanisms under the Public Service Agency (Badan Layanan Umum Daerah) has been achieved in three FMUs (Lakitan Production FMU in South Sumatra, Yogyakarta Production FMU in Yogyakarta and Gularaya

Production FMUs in South East Sulawesi). These three Production FMUs initiated the establishment of District Public Service Agency as a quasi-public agency to support the implementation of the economic development and conservation programme (Setyarso et al. 2014). The experiences of these three Production FMUs show that a District Public Service Agency, as a quasi-public agency, can help FMUs to achieve their objectives in sustaining local livelihoods and conservation funding. Considering the importance of District Public Service Agencies and the different characteristics of Production FMUs and Protected FMUs, we recommend to develop and to test a quasi-governmental agency in Kapuas Protected FMU.

5. Conclusion

The importance of ES in generating sustainable benefits from well-managed forest ecosystems has been recognised in the FMUs as a promising mechanism to balance conservation and economic development programmes. However, how the ES concept could be used in the formulation of management strategies for Indonesian forest management units has, to date, not been explicitly considered. Our study aimed to test the applicability of the ES concept in comparing land-use scenarios in a specific FMU through the development of adaptive forest zonation. The adaptive forest zonation was developed in this study to accommodate local community interest in sustaining ES benefits they could receive and FMU interest in conserving forest ecosystems. The results from our study show that adaptive forest management has the potential to benefit both conservation and local livelihoods. Adaptive forest zonation could potentially increase ES benefits received by local communities by about 40%, through rattan and wild jelutong collection and production of agroforestry rubber and jelutong, compared to the current forest zonation. It could also potentially decrease the risk of forest fire, carbon emissions and forest encroachment resulting from stakeholder agreements as part of the process in developing adaptive forest zonation. Hence, it is recommended that the adaptive forest zonation development steps taken in this study be included in the national guidelines for forest zonation development for FMUs. Moreover, we also recommend creating a Public Service Agency, as a quasi-governmental institution in order to support FMUs in generating direct benefits to finance their conservation and development programmes. One of the FMUs' mandates is to generate business partnerships with other parties. FMUs are registered as a district or provincial agency and are required to follow the financial mechanisms of decentralised governance that does not allow them to receive direct income from a third party. The establishment of a Public Service Agency could facilitate this financial arrangement between FMUs as the institution under district or provincial government and a private institution.

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Land-use trade-offs in the Kapuas peat forest, Central Kalimantan, Indonesia

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Abstract

Forest ecosystems provide benefits to people locally and globally. Sustainable management of forest resources is required to ensure continued supply of these benefits, but complex social-ecological processes are often a constraint to the design of such forest management strategies. In this study we develop a model of adaptive forest zonation to facilitate forest ecosystem management. We employ the ecosystem services concept and a land-use change model to identify potential areas for conservation and for economic use in the Kapuas Protected Forest Management Unit in Indonesia. Local people actively participated in a process to jointly define management zones and stakeholders' associated rights and responsibilities. Our results show that a stakeholder agreement has facilitated the reduction of threats to forest ecosystems and increased local awareness of the need for forest ecosystem conservation. Compared to current forest zonation, we show that the availability of an economic development zone in adaptive forest zonation could potentially increase ecosystem benefits for local communities by about 40% through rattan and jelutong collection and agroforestry rubber and jelutong production. Although our results are specific for the Kapuas District, the methodology of adaptive forest zonation can be applied more generally. We recommend to include our methods in guidelines for zonation and management plans to help improve sustainable forest management practices of all forest management units in Indonesia.

Keywords: Ecosystem services, land-use, ecosystem management, peat forest ecosystems, forest management units, Central Kalimantan

1. Introduction

The Ecosystem Services (ES) concept has been used for framing the relationship between human well-being and ecosystems in the context of ecosystem management since the last few decades (Turner et al., 2003; Millenium Ecosystem Assessment, 2005; Balmford et al., 2010; UN et al., 2014). Integrating ecosystem services into ecosystem management requires consideration of the broader economic, social and political context. In this context, stakeholder participation is important in order to understand local and regional perceptions and interests in ecosystem management (Stringer et al., 2006; Reed, 2008; Seppelt et al., 2011; Luyet et al., 2012).

In order to effectively conserve forest ecosystems, sustainable forest management must secure local livelihoods for forest-dependent communities (Pagiola et al., 2002; Kroeger & Casey, 2007; LaRocco & Deal, 2011; Deal et al., 2012). The integration of the ES concept in sustainable forest management can thus be used to understand the benefits forest communities and other stakeholders receive under different forest management regimes (Deal et al. 2012; Quine et al. 2013). However, forest ecosystems generally provide a broad range of ES involving multiple stakeholders from local to global. The application of the ES concept for ecosystem management is challenging due to a lack of quantitative information on flows of ES and the value different stakeholders place on them (Hein et al., 2006, Deal et al. 2012; Quine et al. 2013b).

The evolution of sustainable forest management practices in Indonesia has seen the introduction of Forest Management Units (FMUs) through Government Regulation No 6/2007. The concept of FMUs has its origins in the Forestry Law of 1967 but earlier attempts at achieving sustainable forest management through forest utilisation and conservation programmes failed (FORCLIME Forest and Climate Change Programme 2011; Setyarso et al. 2014). The FMUs' task is to ensure that economic, environmental and social functions are sustainably implemented in forest management.[1] However, to date, FMUs have not explicitly considered ES in the formulation of forest management plans.

The objective of this study is to test how the ES framework in combination with land use modelling can be used to enhance forest management in an FMU, and to develop a replicable method for doing so. In particular, we developed and analysed adaptive forest zonation, as the foundation of the forest management plan for the Kapuas Protection FMU, in Kapuas District, Central Kalimantan. The FMU is for the largest part located in a peatland area. Reconciling local use and conservation is a challenge in peat forests where drainage-dependent land uses increase fire risk (Taufik et al. 2017). Adaptive forest zonation is a novel approach which involves the identification of specific zones for different forest uses to meet the interests of different stakeholders. In our case study, these zones have been identified on the basis of a quantitative analysis of ES flows under different types of management in combination with extensive stakeholder workshops with local forest users. We employed the LUCES model described in Suwarno and Suyamto (2014), Suwarno (2016) and Suwarno et al. (2016b) to identify potential future land-use change resulting from the current forest governance system.

[1] This is stipulated in Law No. 41/1999 on forestry and Government Regulation No. 44/2004 on forest planning.

Next, potential areas to be allocated to conservation and economic development zones were identified and delineated based on a combination of potential land-use change and biophysical criteria of sustainable forest management. Subsequently, a participatory process was conducted to discuss the zonation draft with the local communities, which was revised to meet the agreement between the communities and the management of Kapuas Protected FMU. Finally, to assess ES delivery of two management plans (scenarios) for this particular area, we calculated and analysed the potential benefits from ES that the communities and management of Kapuas Protected FMU would receive based on recent and adaptive forest zonation.

In this paper, we also discuss the option of a financial mechanism to govern the potential benefits received by the Kapuas Protected FMU and the option of applying integrated peat management based on hydrological landscape (rather than forest) boundaries. Given the importance of Indonesian peat forest ecosystems for providing benefits to humans (Olbrei and Howes 2012; Galudra et al. 2014; Matthews et al. 2014; Tachibana 2016), the results of this study can provide valuable input to support and improve the implementation of sustainable forest management practices in FMUs in general and in the Kapuas Protected FMU specifically.

2. Methods

2.1. Case study area

2.1.1. Biophysics and local livelihoods

The Kapuas Protection FMU covers an area of 105,372 ha of which about 95% is peat and swamp forest. Forests in the Kapuas Protected FMU were logged between 1994 and 1998 (Euroconsult Mott MacDonald 2009; Suyanto et al. 2009; Tachibana 2016; Yamamoto and Takeuchi 2016). These logging activities were conducted under the Mega Rice Project that aimed to develop 1 million ha of agricultural land, especially for paddy fields. The project cut through two peat domes in this area and a main canal that linked three rivers was built with the aim of draining the peatland. The draining process damaged the peat's hydrological system and reduced the capacity of the peat ecosystem to control the water balance. As a result, the area south of the main canal has become degraded in terms of both hydrology and vegetation. The area is now very dry during the dry season of about 2 to 3 month, with average temperature about 35^{o}C to 40^{o}C causing a high risk of forest and land fires (Euroconsult Mott MacDonald 2009; Kapuas 2012). In the wet season the area is regularly flooded (Euroconsult Mott MacDonald 2009; Kapuas 2012). In contrast, the secondary peat forest to the north of the main canal is still intact and has a unique diversity of typical flora and fauna. It now hosts the largest remaining unprotected wild orangutan population in the world (Suyanto et al., 2009; BOSF, 2010).

The seven neighbouring villages in the Kapuas Protection FMU area have a total population of about 5,500 (BPS, 2014) (see Figure 1). The livelihoods of these local people are mainly related to agriculture, logging and collecting Non-Timber Forest Products (NTFPs). Prior to 1970, NTFPs, such as rattan (*Calamus spp*.), damar (*Shorea sp*.), jelutong (*Dyera costulata*), eaglewood (*Aquilaria malaccensis*), katiau (*Ganua motleyana*), kalanis (a tree root), ehang, nyatu (*Palaquium javense*) and animals (snakes, birds and deer), swidden upland rice and fishing were the main sources of local livelihoods (Suyanto et al. 2009). These livelihoods then changed due to the establishment of the Mega Rice Project (Suyanto et al., 2009). During the Mega Rice Project (1995-1998), agriculture was the main livelihood for most of the people to the south of the main canal, while to the north it remained to be NTFP collection and shifting cultivation. In 1999, with the failure of the Mega Rice Project, many local people to the south either left or planted oil palm (Suyanto et al., 2009; Galudra et al., 2011). The use of slash and burn to prepare the peatland for oil palm has increased the risk of land and forest fires in this area. Together with encroachment, forest fires are now considered the main threat to the area. Reports from Global Forest Watch show that 155 fire alerts occurred in this area between 1 September and 15 October 2015 (http://fires.globalforestwatch.org). Most of the fires (92%) occurred on degraded peat land to the south of the main canal, which has open access for some villages.

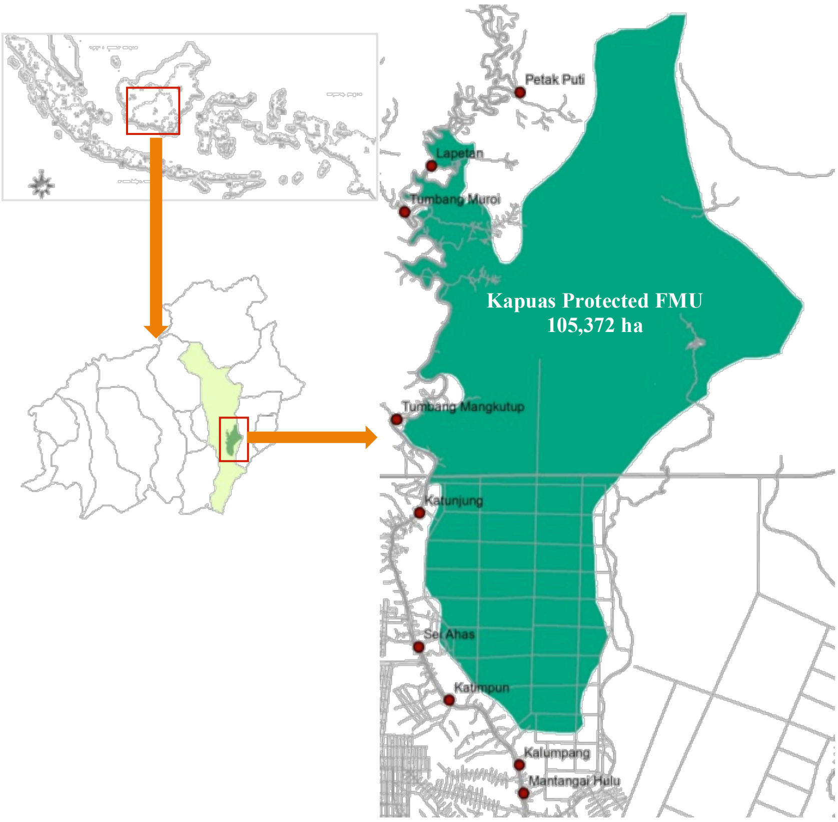

Figure 1. The Kapuas Protected FMU area and neighbouring villages (Source: Kapuas Protected FMU)

2.1.2. Institutional aspects

The Kapuas Protected FMU was established on 2 May 2011, based on the Ministry of Forestry Decree No: SK.247/Menhut-II/2011, covering 105,372 ha. Much of the FMU's area is part of the former Mega Rice Project area. The Kapuas Protected FMU's main task is to address the ecological and economic issues resulting from the former Mega Rice Project. These issues include reducing carbon emissions and fires from degraded peatland and rehabilitating the degraded peatland area. Moreover, the Kapuas Protected FMU is also required to work for sustainable local livelihoods which were not sufficiently addressed by previous international projects implemented in this area (Olbrei & Howes, 2012; Atmadja et al., 2014; Medrilzam et al., 2014). The Kapuas Protected FMU's long-term vision is to develop a "Protected FMU business for the sustainable use of peat swamp forests, contributing to sustainable livelihoods and prosperous communities through equal sharing of benefits" (Kapuas Protected FMU, 2012). The aims of Kapuas Protected FMU are defined as follows: (1) to develop sustainable livelihoods for local communities with minimal greenhouse gas emissions and fires, and (2) to increase the capacity and participation of stakeholders (public, private and local communities) in managing and utilizing peat swamp forests (Kapuas Protected FMU, 2012).

2.2. Forest zonation development and analysis

In this study, we developed an adaptive forest zonation to enhance the effectiveness of the current forest zonation of Kapuas Protected FMU in conserving forest ecosystems and sustaining local livelihoods. The term 'adaptive' is used here to refer to adaptive management which includes structured and iterative decision-making processes to improve long-term management outcomes and reduce uncertainty (Holling, 1978). This decision-making simultaneously meets one or more management objectives and accrues information needed to improve future management. We designed a procedure for the development of adaptive forest zonation in three steps (Figure 2). These steps include learning processes in the outcomes of current management. The details of each step are explained in sections 2.2.1 to 2.2.5.

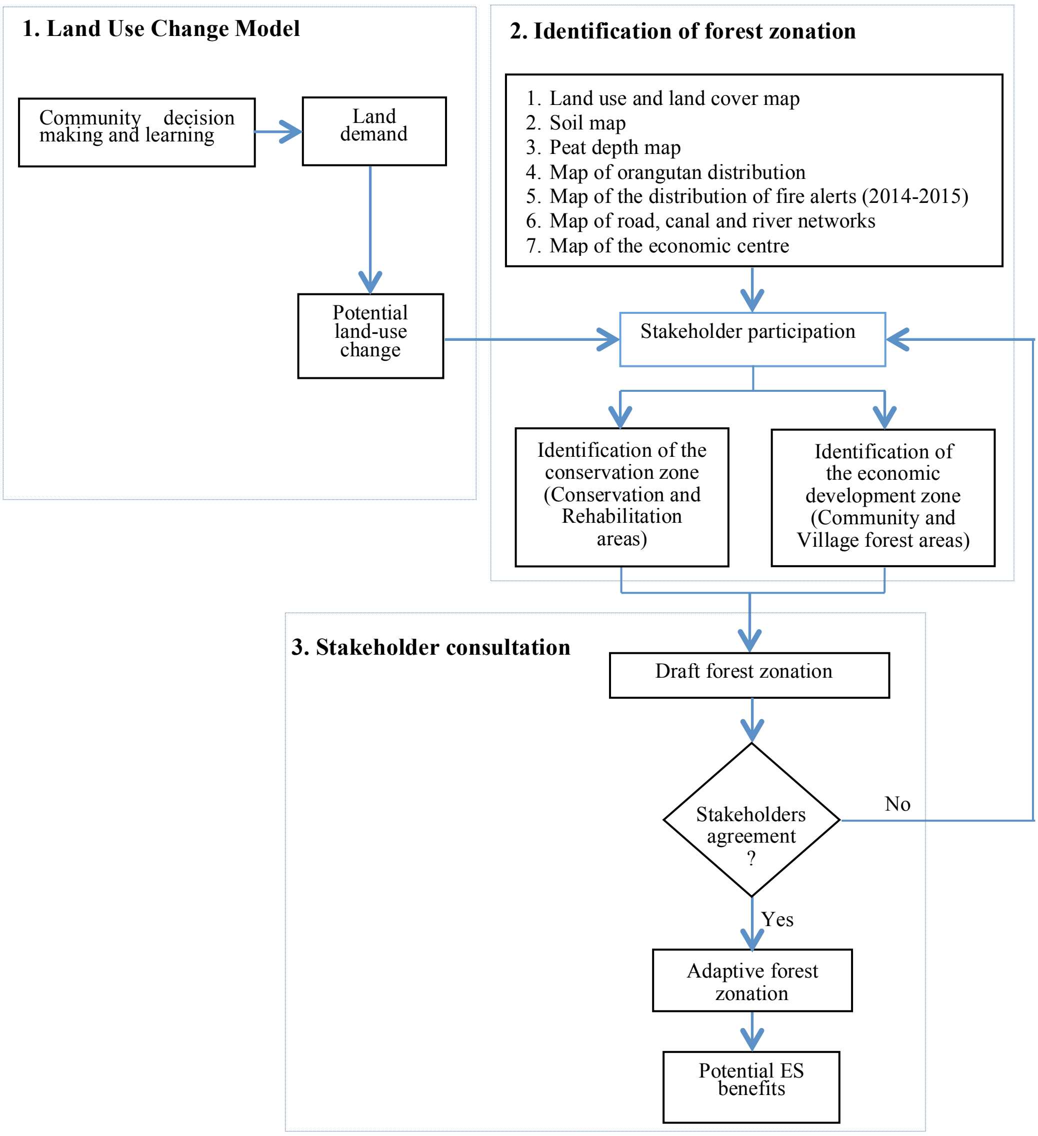

Figure 2. Three steps in developing adaptive forest zonation

2.2.1. Land-use change model

The land-use change model was developed in this study to understand land-use patterns and to predict land-use change based on the stakeholders' interests. This model was based on the Land-Use Change and Ecosystem Services model (LUCES)[2]. The LUCES model is a hybrid agent-based land-use model that captures the interactions of stakeholders in the decision-making process. The LUCES model was designed to consider the interests of local people and private companies in shaping their opportunities for further socio-economic change and the impact of these interests on land-use decisions (Suwarno and Suyamto 2014; Suwarno 2016; Suwarno et al. 2016b). The LUCES model can produce a spatially explicit representation of a land area (represented as a raster) with the potential for land cover change in each pixel governed by a combination of formally planned and unplanned change, with the latter decided by local agents. Planned land-use change is driven by private companies, which have obtained

[2] Details of the LUCES model can be obtained from the corresponding author.

government permits to maximise their profits. Meanwhile, land use by local community members is mainly driven by available labour and continues outside of formal planning. One assumption built into the LUCES model is that a community will only expand the area used if more labour becomes available. Accordingly, the recent version of the LUCES model only includes incumbent labour and has yet to include potential migrant labour.

Simulation of the land-use change in the LUCES model is based on Unified Modelling Language (UML) and implemented using the ABM software NetLogo 5.0.5. The simulations of the potential land-use change in the LUCES model were conducted based on 3 scenarios, with details as follows:

(1) Business As Usual (BAU) reflects the current trend, including the Forest Conversion Moratorium, which initially ran from 2011 to 2014. The Moratorium applies only to new or extended permits for companies converting peat forest to other land use; it does not apply to local communities.
(2) The Extended Moratorium (EM) scenario extends the period of the Forest Conversion Moratorium to 25 years starting from 2011. The Forest Conversion Moratorium applies to new or extended permits for companies converting peat forest to other land use; it does not apply to local communities.
(3) The Moratorium Plus Livelihoods (MPL) scenario adds to the Extended Moratorium an improved livelihood programme with enhanced markets for NTFPs, agroforestry products and community timber as well as an improved monitoring programme to avoid community logging.

These three scenarios were parameterized based on the data of economic value of the selected ES (rattan and jelutong resin collection and the production of timber, agroforestry rubber, oil palm, paddy and carbon emissions) provided by different types of ecosystems in combination with information regarding the community perspective on their income expectation and potential land-use changes. The data on economic value of these ES was obtained from the previous studies that were conducted in the period of 2008-2012 (Setiawan et al. 2011; Iwan, 2008; Martoniady, 2009; Sapiudin, 2009; Budiningsih and Effendi, 2013; Herman et al, 2009; Suyanto et al. 2009; Nugroho, 2008; Yandi, 2008; Iksan and Abdussamad, 2010; Ismail, 2010; Boer et al. 2012; Sanchez, 2000; Agus et al. 2009; Hooijer et al. 2010; Lim et al. 2012; Carlson et al. 2012a; Carlson et al. 2012b; and the reports from two logging companies in 2012 and two oil palm companies in 2012) and fieldwork in 2012, 2013 and 2014. The secondary economic data include potential production of each service per year (yields) and macroeconomic parameters in 2010 and 2011. Meanwhile, the fieldworks in 2012, 2013 and 2014 were conducted to gather the data on the cost of harvesting jelutong resin and its price at the farm gate and information on the perspective of the communities regarding their income expectation and potential land-use change. This information gathered through personal interviews and focus group discussions.

Table 1. Key features of the three Forest Conversion Moratorium scenarios using the LUCES model to determine current and future landscapes as well as ecosystem services supply (source: Suwarno and Suyamto 2014; Suwarno 2016; Suwarno et al. 2016b)

No	Scenario	Description	Remarks
1	Business as usual (BAU)	- Protection of peat forest from conversion activities on a company scale (2011-2014) - Illegal conversion of peat forest on a community scale	- No change in road network and market prices during the 15 years simulation - Settlement distribution changes are based on the change in land demand and centre of economic activities
2	Extended moratorium (EM)	Similar to BAU, but: - Extension of the period for protection of peat forest from conversion activities on a company scale (2011-2036) - New oil palm and timber plantations on a company scale can only be established on mineral soil	- Same as BAU
3	Moratorium plus livelihoods (MPL)	Similar to EM but: - Higher market prices for NTFP, agroforestry products and community timber by about 15 % - Local demand for timber can only be supplied from community timber plantations	- Support of the NTFP market chain, agroforestry products and community timber products - Increase illegal logging litigation - Other conditions are the same as BAU

In this study, we improved the LUCES model by using SARVision land cover maps of 2010. These maps were derived from FBS and FBD ALOS PALSAR strip data provided by JAXA EORC, with a resolution of 50 m (Hoekman et al., 2010). We also increased the resolution of the model from 0.5 km^2 to 0.2 km^2 per pixel by maximising the number of cells in NetLogo 5.0.5 to provide more detail. Considering the position of the villages and hydrological units as important factors in sustainable forest management, we first used the ecological boundaries (rivers in the west and east) of the Kapuas Protected FMU area and present the results only for this area. The numbers presented represent best estimates. As parameter and model uncertainty prevails, we conducted a sensitivity analysis (see Section 3.4).

2.2.2. Identification of areas for adaptive forest zonation

The purpose of adaptive forest zonation is to balance conservation and economic interests. Based on the adaptive management concept, we divided the area of Kapuas Protected FMU into (1) conservation and (2) economic development zones to meet the main aim of Kapuas Protected FMU in conserving forest ecosystems and sustaining local livelihoods. The conservation zone includes conservation and rehabilitation areas, while the economic development zone includes community and village forests. The community forest (Hutan Kemasyarakatan – HKm) is the forest area that can be legally managed by the group of communities with the aim to empower the communities who live inside and around the forest (Ministry of Forestry Regulation No. P.88/Menhut-II/2014, about community forest). The village forest (Hutan Desa) is the forest area that can be legally managed by the village with the aim to increase and sustain the livelihood of the people in the village (Ministry of Forestry Regulation No. P.89/Menhut-II/2014 concerning village forests). Both community forest and village forest must comply with two conditions: (1) the area has no other forest concession, and (2) the area is the main source of the communities' livelihood. Permits for community forest and village forest are for 35 years (released by national government and monitored by the district and province government) with an evaluation period of 5 years. The difference between community forest and village forest concerns the management: community forest requires the group of communities to apply and manage this forest, while for village forest is managed by villages as institutions.

The potential area allocated for conservation and economic zones was identified using biophysical criteria that include hydrological units (rivers) as the ecological instead of administrative boundaries; see Table 2. It was important to consider hydrological units in this study, as Kapuas Protected FMU is located in a peat forest ecosystem influenced by its hydrology. Hence, we used the ecological boundaries (rivers in the west and east) of the Kapuas Protected FMU area and present the results for this area. We considered the location of the villages as an important factor in defining the potential area to be defined as economic development zones. Moreover, we also considered the communities' capacities to manage the forest as an important factor in designing the area for community forest and village forest. We conducted a series of focus group discussions with communities and representatives from Kapuas Protected FMU, District Forest Agency and District Planning Agency to discuss the possible areas to be allocated to community and village forests. The results were then used as additional determinants for zoning.

Table 2. Biophysical criteria used to delineate conservation and community development zones

Zone	Area	Criteria
Conservation zone	Conservation	- Peat land with a minimum depth of 2m - Good forest cover (old and young secondary peat forest with the percentage forest cover between 50-100%) - Area for orangutan habitat
	Rehabilitation	- Peat land with a minimum depth of 2m - Degraded forest cover (pioneer secondary peat forest) - Area(s) prone to forest fire (based on history of fire alerts)
Economic development zone	Community forest	- Mineral soil or peat land with a maximum depth of 1m - Exclude the orangutan habitat

		- Exclude areas of good forest cover (old secondary peat forest) - A maximum distance of 6km from the centre of the village, river or road (community preference)
	Village forest	- Mineral soil and/or peat land with a maximum depth of 2m - Exclude the orangutan habitat - A maximum distance of 10km from the centre of the village, river or road (community preference)

2.2.3. Stakeholder participation and consultation

Stakeholder participation and consultation are crucial for forest zonation development (see Figure 2). We conducted a series of focus group discussions (FGDs) (2 to 5 FGDs per village) in the period 2014 to 2015 to capture the local communities' preferences for defining the area to be allocated for economic development and conservation zones (see section 2.2.2). These FGDs were initiated by Kapuas Protected FMU and involved 10 to 15 village representatives. Most of the village representatives have been engaged with the Kapuas Protected FMU through some community development projects.

In these FGDs, we discussed the communities' preferences concerning the management of the economic development zone. The option of community forest and village forest, as suggested by the management of Kapuas Protected FMU, were discussed in these FGDs. Concerning conservation zones, these FGDs also considered the possibility of conducting participatory conservation activities. These FGDs resulted in a first draft of the conservation and economic development zone, and the first draft of an agreement determining rights and responsibilities pertaining to the two zones.

Further, several other focus group discussions were conducted in the period June to September 2015 to assess and communicate the first draft of the forest zonation with stakeholders in the villages, the sub districts and the districts. We also discussed and finalised the agreement on rights and responsibilities relating to the economic development zones in these FGDs.

2.2.4. Calculating potential benefits for local communities

The calculation of potential benefits for local communities was conducted in this study to understand potential gains and losses from implementing adaptive forest zonation. The calculation of potential ecosystem benefits for local communities was based on the economic value of seven ES (rattan and jelutong resin collection and the production of timber, agroforestry rubber, oil palm, and paddy and carbon emissions) resulted from previous studies that were conducted in the period of 2008 to 2012 (Sanchez 2000; Iwan 2008; Nugroho 2008; Yandi 2008; Agus et al. 2009; Herman et al. 2009; Martoniady 2009; Sapiudin 2009; Hooijer et al. 2010; Iksan and Abdussamad 2010; Ismail 2010; Setiawan et al. 2011; Boer et al. 2012; Carlson et al. 2012a; Lim et al. 2012; Carlson et al. 2012b; Budiningsih and Effendi 2013a; and the report from two logging companies and two oil palm companies in 2012). In order to support the calculation of the potential benefits for local communities, this study also elaborates the information on the potential monetary benefits of seven ES explained above provided by Sumarga et al. (2015); Suwarno et al. (2016a).

The studies by Sumarga et al. (2015); Suwarno et al. (2016a) employed ecosystem accounting to assess the contribution of ecosystems to economic and other human activities in a way that is consistent with national accounts (UN et al., 2014; Edens and Hein, 2013). The net benefits in ecosystem accounting are expressed as an annual resource rent (RR) and valued by analysing the market price and deducting the total costs (intermediate, employment and user production costs) (Edens and Hein, 2013). Suwarno et al., (2016a) also include Government Regulation No. 55/ 2005, concerning the procedure for governing timber and NTFPs, to support the calculation. These regulations determine taxes, including taxes on timber and land, and fees for extracting timber and NTFPs from both natural and plantation forests. Further, we included the potential cost of carbon emissions resulting from forest conversion to other land-use and vice versa. We describe the potential carbon emissions resulting from forest fire, frequent in this area, and its negative impact on local communities. The results of this analysis were then discussed with the stakeholders in the district, particularly the District Forest Agency and District Planning Agency, during a focus group discussion that was organised by the management of Kapuas Protected FMU in September 2015.

3. Results

3.1. Potential land-use change

Our analysis shows the potential land-use and land cover change in the study area in the period 2010 to 2040, based on the business as usual scenario (current management).

These changes mostly relate to the conversion of forest to oil palm and agriculture (paddy fields). Simulations of the LUCES model show that the rate of land-use change for oil palm and paddy could increase from about 2% to 3% and 0.2% to 1% per year, respectively. The rate of decline of old secondary, young secondary and pioneer peat forest and of permanent agroforestry could increase from about 0% to 0.1%, 0.03% to 1.69%, 0.09% to 1.17% and 0.02% to 0.14% per year, respectively (Table 3).

Table 3. Potential land-use change in Kapuas Protected FMU area based on the result of the LUCES model (BAU scenario)

Class	Initial 2010 (ha)	2020 (ha)	2030 (ha)	2040 (ha)
Old secondary peat forest (> 50 yrs)	67,390	67,301	67,199	67,177
Young secondary peat forest (25 – 50 yrs)	2,831	2,619	2,611	2,169
Pioneer peat forest	24,912	24,619	24,212	23,996
Agroforestry	7,021	6,922	6,832	6,912
Oil palm	1,946	2,602	3,075	3,598
Agriculture	1,272	1,309	1,443	1,520
Total	105,372	105,372	105,372	105,372

In addition to land-use and land-cover changes in this area, there is also a high risk of forest encroachment. This risk is related to local interest to meet economic expectations by converting the forest area to other uses. Our interviews with local communities and experts in Kapuas Protected FMU show that local communities have already occupied large areas of forest, particularly close to their villages.

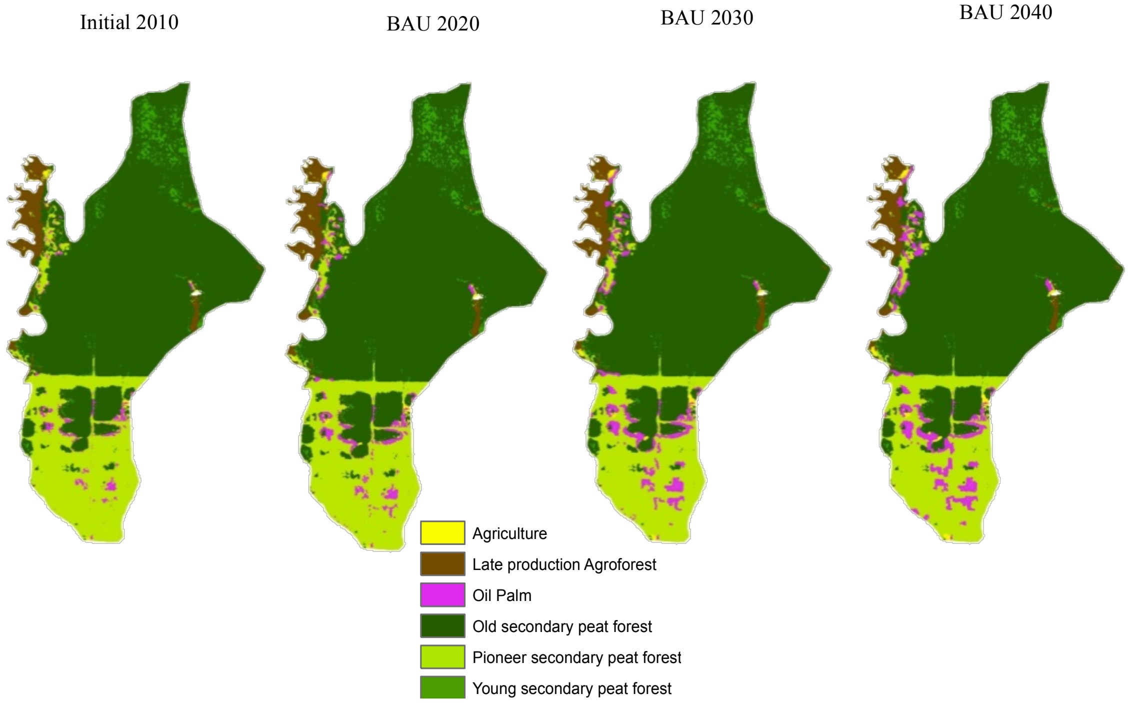

Figure 3. Potential land-use change using the LUCES model. The area of pioneer secondary peat forest south of the canal is subject to a high risk of fire prohibiting the succession process. The area of young secondary forest in the north is used by local communities for their home gardens prohibiting the succession process of this forest to old secondary forest

3.2. Adaptive forest zonation for Kapuas Protected FMU

Adaptive forest zonation for the Kapuas Protection FMU includes conservation and rehabilitation areas in the conservation zones, and village and community forests in the community development zone (Figure 4).

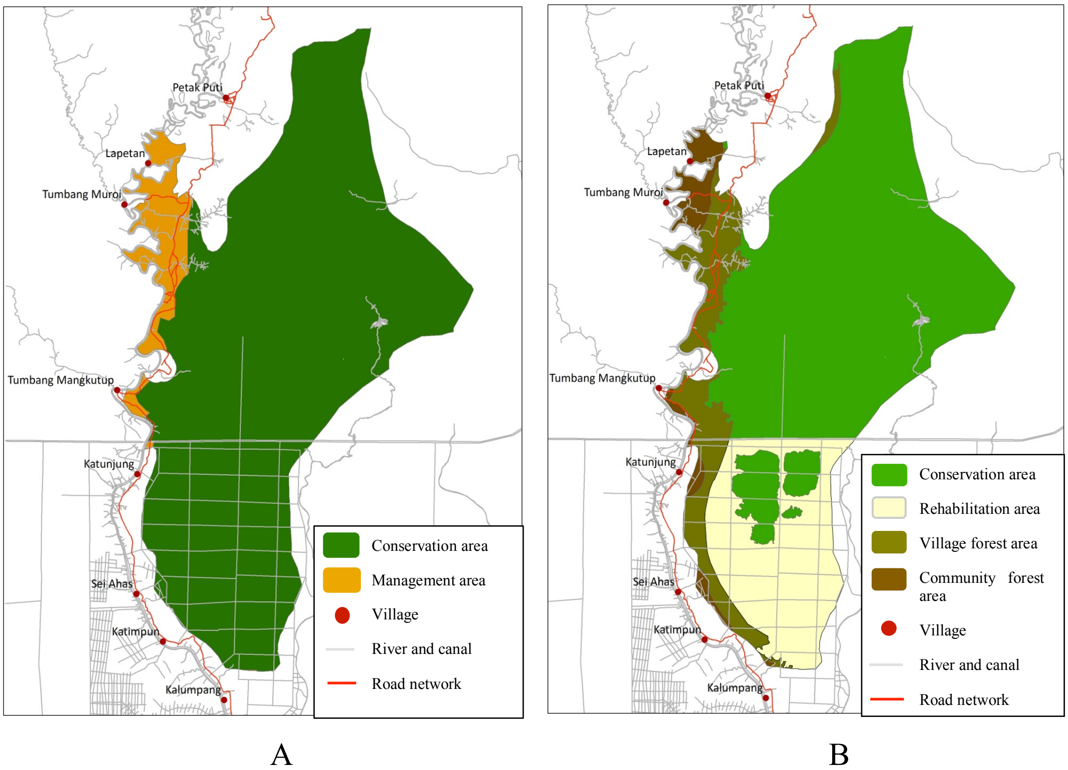

Figure 4. Forest zonation for Kapuas Protected FMU current (A) and adaptive (B) and neighbouring villages

The conservation area under the adaptive forest zonation includes old secondary forest to the north and south of the main canal, delineated based on the condition of the forest cover, peat depth and its importance for orangutan habitat. The rehabilitation area was delineated at the edge of the degraded peat forest (pioneer peat forest) to the south of the main canal. This rehabilitation area is the main aspect for adaptive conservation due to potential problems of forest fire, encroachment and flooding. The community development zone was divided into community forest and village forest with stakeholder participation in order to secure sustainable local livelihoods in the area of the Kapuas Protected FMU (Table 4). Further, the rights and responsibilities of local communities and the management of Kapuas Protected FMU were defined in the stakeholders' agreement as explained in Table 4.

Table 4. Details of the areas in the current and the adaptive forest zonation

Forest zonation	Zone	Programmes	Area (ha)
Current forest zonation	Conservation	Not defined	65,785
	Rehabilitation	Not defined	25,198
	Management	Not defined	14,389
Adaptive forest zonation	Conservation	Conservation	70,296
		Rehabilitation	19,379
	Community development	Community forest	3,711
		Village forest	11,986

Table 5. Rights and responsibilities granted to local communities and the management of Kapuas Protected FMU based on the negotiated stakeholder agreement

Zone	Area	Local communities		The management of Kapuas Protected FMU	
		Responsibilities	Rights	Responsibilities	Rights
Conservation zone	Conservation	Prevent: - Illegal logging - Forest encroachment - Forest fire	- Communities may collect NTFPs with tax reduction	- Monitor and prevent illegal logging - Forest fire prevention and suppression	- Tax from NTFP collection and limited timber production
	Rehabilitation	- Participate in rehabilitation programme under coordination of Kapuas Protected FMU	- Communities share in benefits from carbon trading	- Conduct and monitor rehabilitation programme	- Possibility to enter carbon market
Adaptive economic development	Community forest	- Same as conservation area	- Communities may convert this area to (1) agroforestry rubber or (2) agroforestry rubber and jelutong	- Provide local communities with assistance in developing Agroforestry - Monitor the development of agroforestry - Establish a premium market for NTFPs and agroforestry products	- Benefit sharing from NTFP collection and agroforestry production - Extend or stop the permit for community forest based on the performance of local communities
	Village forest	- Same as conservation area	- Local communities may be granted a permit to collect NTFPs tax free	- Establish a premium market for NTFPs - Monitor and evaluate the sustainability of the village forest	- Benefit sharing from NTFP collection and agroforestry production - Extend or stop the permit for a local community forest based on the performance of the local community

3.3. Potential benefits from ecosystem services for local people

Our results show that adaptive forest zonation can provide more sustainable options for local livelihoods through the availability of community and village forests under an economic development zone. Communities may increase the annual benefits they receive from NTFP collection by about 12% (from € 1.9 million to € 2.2 million). The NTFPs could be collected in the conservation area and the village forest, with the assumption that due to limited access NTFPs are collected from 10% of the conservation area and 25% of the village forest area. The communities could also potentially receive annual benefits from timber production of about € 534 from the village forest. This is due to government regulations that only allow limited timber production in village forests that have protected status (maximum 50 m^3 per year per village forest) (Ministry of Forestry Regulation No. P.89/Menhut-II/2014 concerning village forests). The availability of community forest would also increase the potential benefits communities receive from rubber and jelutong agroforestry. Our results show that the communities could potentially receive € 190,997 per year from agroforestry rubber or € 483,714 per year from agroforestry jelutong. Moreover, they could also potentially receive € 3.8 million per year from jelutong agroforestry in rehabilitation areas (see Table 6). Since the rehabilitation may require a long process, the calculation of potential benefits from this area are not included in the total potential benefits that communities may receive from adaptive forest zonation. In general, adaptive forest zonation could potentially increase ES benefits of local communities by about 40% compared to the current forest zonation (see Table 6).

Table 6. Comparison of the potential ecosystem service benefits local people and the management of Kapuas Protected FMU receive under the current and adaptive forest zonation

Forest zonation		Current forest zonation			Adaptive forest zonation			
Zones		Conser-vation	Rehabili-tation	Manage-ment	Conservation		Community development	
Programmes		Not defined	Not defined	Not defined	Conser-vation	Rehabili-tation	Community forest	Village forest
Potential area (ha) for:	Timber production	0		0	0	0	0	58[5]
	Agroforestry	0			0	6,783[3]	732[4]	0
	NTFPs collection	6,579[1]		5,247	7,030[2]	0	2,439	2,996[2]
	Paddy production	0		1,272		0	1,272	0
Benefits per ha per yr[6] (€)	Timber production							9
	Rubber agroforest						261	
	Jelutung agroforest					560	661	
	Rattan collection	99		74	99		99	95
	Jelutung collection	90		68	90		90	90
	Padi production			316			316	
Benefit per yr (€)	Timber production						0	534
	Rubber agroforest						190,997	0
	Jelutung agroforest					3.798.263	483,714	0
	Rattan collection	651,272		389,575	695,933		241,491	284.657

	Jelutung collection	592,065		354,159	632,666		114,480	269.675
	Padi production			401,952			401,952	
Total benefits		2,389,022			3,316,099[7]			

1 We assumed that NTFPs were collected at a maximum distance of 10 km from villages, rivers or road (assuming it would take about 10% of the conservation zone in the current forest zonation)
2 We assumed that NTFPs were collected at a maximum distance of 10 km from villages, rivers or road (assuming it would take about 10% of the conservation area in the conservation zone and 25% of the village forest and 100% of the community forest area in adapted forest zonation)
3 We assumed that rehabilitation covers about 35% of the total rehabilitation area
4 We assumed that agroforestry would be initiated in about 30% of the total community forest area
5 According to Ministry of Forestry Regulation No. P.89/Menhut-II/2014 concerning village forests, timber production is allowed for domestic consumption with a maximum of 50 m^3 from the whole village forest per year (with the assumption that potential timber production is 0.86 m^3 per ha per year, 50m^3 per year is then equal to 58 ha per year -- Sumarga et al., 2015 and Suwarno et al., 2015)
6 Calculations of benefits per ha are based on Sumarga et al., 2015 and Suwarno et al., 2015
7 Potential benefits from rehabilitation is excluded due to high uncertainty

3.4. Uncertainty and sensitivity of the model

Adaptive forest zonation involves uncertainty in terms of the exact benefits people receive from agroforestry systems in community forests and rehabilitation areas. Local people could potentially receive substantial benefits per hectare from jelutong and rubber agroforestry 10 years after planting: € 770 per year for agroforestry jelutong and rubber (Budiningsih and Effendi 2013b), € 261 per year for agroforestry rubber (Suwarno et al. 2016a) and € 820 per year for agroforestry jelutong (monoculture) (Budiningsih and Effendi 2013b). Thus, the options for alternative livelihoods should be provided in the first 10 years. Here we propose to include NTFP collection (i.e. rattan, jelutong, gemor (*Alseodaphne* sp), illipe nut (*Shorea* sp), fruits and fish) in livelihood options as far as areas in the conservation and village forests are reachable.

In order to support our analysis, we also conducted a sensitivity analysis for the main parameters in the LUCES model for the land use-change in the area. We found that any changes of farm-gate prices for agricultural products and the reference wage rate for household labour have a significant role in changing land-use in communities. An increase farm-gate prices (in this case for fresh fruit bunches of oil palm) of 5% has increased the potential land-use change in the communities by about 3%, i.e. the land area converted for agricultural use is 3% larger compared to our base case. A decrease of farm gate prices of 5% has no significant on the reduction of land-use change. For household labour, an increase of availability household labour of 5% increases the potential land-use change in the communities by about 6%. A reduction of the availability household labour of 5% leads to a decrease of land-use change by about 3%. These results show that effects of income expectations of communities, influenced by the farm-gate prices, on land use change are dominated by effects of the availability of household labour.

4. Discussion

4.1. Can consideration of the Ecosystem Services (ES) concept support the implementation of sustainable forest management in Forest Management Units (FMUs)

The ES concept provides a framework to anticipate a wide range of social and ecological consequences that may result from different decisions and tools to identify, negotiate, avoid and manage negative trade-offs (DeClerck et al., 2006; Ingram et al., 2012). This holistic concept is important to improve sustainable forest management practices in Indonesia to promote environmentally, socially and economically sustainable conservation management and to maintain the ecosystem benefits for present and future generations. Moreover, the ES concept will ensure that local livelihoods and the conservation programme funds are included in ecosystem management to balance conservation and development programmes and achieve positive outcomes (Sunderland et al., 2008; Kettunen et al, 2009; Mulia et al., 2013; Alvarado-Quesada et al., 2014).

The integration of the ES concept to support a better ecosystem management has been discussed in a number of studies (de Groot et al., 2010; Deal et al., 2012). The valuation of ES benefits can assist in elucidating interests of different stakeholders in ecosystem management (Farber et al. 2002; Liu et al. 2010), while the trade-off analysis on how they will change based on various scenarios could provide essential information for forest managers to adapt their management programmes. For example, information on how the monetary values of ES from forest ecosystems will change due to land-use change, could provide essential information for forest managers to work with stakeholders in conserving a forest area rather than convert it to other uses (Ruckelshaus et al. 2015).

In this study, the information from the ES valuation and trade-off analysis was used as a foundation to develop adaptive forest zonation. ES valuation in this study is biased towards the provisioning services, relative to regulating and cultural services. This selection was based on stakeholders' perspectives on what the most important ES are for them, as well as data availability. However, since the adaptive management that we propose would lead to a better protection of forest cover compared to the business as usual we postulate that our approach is advantageous, at least in this specific case, for globally relevant ES such as carbon sequestration and storage and biodiversity conservation.

Our research shows that, from an economic perspective, adaptive forest zonation could potentially increase the ecosystem service benefits local beneficiaries receive. Providing more rights to and authority over community and village forests can increase the possibility of local beneficiaries meeting their livelihood expectations and reducing their interest in converting their forests to other uses. These benefits would be generated mostly from NTFP collection and limited timber production from agroforestry in the village forest and rubber and jelutong production in the community forest. From a conservation perspective, we show how the rules, rights and responsibilities in the stakeholder agreement can increase local community awareness of the need to conserve and protect the peat forest.

The stakeholder agreement details the shared responsibility for conservation (preventing forest fire, illegal logging and forest encroachment), which could reduce the risk of forest fire, a major problem in this area especially during El Nino events. The agreement discusses how enrichment planting of fruit and jelutong trees, in the buffer zone of the village forest, will improve the quality of the orangutan habitat and reduce potential conflict between the orangutan and humans. It likewise outlines the benefits of the rehabilitation programme using jelutong trees, which could also speed up the improvement of forest ecosystems and potentially generate benefits from jelutong resin collection over the following ten years. These results confirm the advantages of integrating the ES concept in sustainable, efficient and inclusive forest management that not only considers biodiversity conservation but also local livelihoods. These results also support other studies that indicate the positive impacts of the ES concept in sustaining local livelihoods, (Deal et al., 2012; Quine et al., 2013; Spangenberg et al., 2015) biodiversity conservation (Kettunen et al., 2009; Persha, 2011; Corbera & Pascual, 2012), and preventing land-use change and carbon emissions (Lin et al., 2011; Viglizzo et al., 2012; Sumarga et al., 2015). New opportunities to benefit from planted gaharu trees as part of agroforests have not yet been factored in (Soeharto et al., 2016).

4.2. Ecosystem management and landscape integrity

A tropical peat forest is a unique ecosystem with an accumulation of partially decayed organic matter from plant debris under waterlogged conditions (Andriesse 1988). The organic matter accumulates at different rates in time and space resulting in different depths of peat with the highest and thickest points, peat dome summits, being close to riverbanks and mineral soil, forming the ecological boundaries of the peat ecosystem. A tropical peat ecosystem, usually located in lowlands between rivers with extensive floodplains, is a unique hydrological unit that can maintain balance, stability and productivity (Page et al. 2009).

The area of Kapuas Protected FMU is part of a peat forest ecosystem in Central Kalimantan Province. The peat ecosystem in this area consists of three domes, distributed along two big rivers. The boundaries of the Kapuas Protected FMU are designated based on the forest function. In order to capture the complexity of forest ecosystems, the management of Kapuas Protected FMU should integrate ecological and socio-economic systems within specific ecological boundaries rather than political or administrative boundaries (Minang et al., 2015; Mitchell et al., 2013). However, the current boundaries of this FMU do not include ecological boundaries.

Considering the importance of the hydrological unit as well as the dynamics of the socio-ecological processes in tropical peat forest ecosystems, the adaptive forest zonation in this study was developed using two rivers as ecological boundaries. The balance between conservation and economic development zones described in this study aims to increase and sustain the livelihoods of local people and their awareness of the need to conserve peat forest ecosystems. The allocated area for community forest along the riverbanks and villages will provide an opportunity for villagers to increase their income and encourage them not to convert the peat forest to oil palm anywhere between peat domes and rivers, which covers most of the drainage system. Long-term agreements between local communities and the management of Kapuas Protected FMU (community and village forests) will increase local participation in the rehabilitation of degraded peatlands. In turn, the peat forest ecosystems will gradually regain balance and capacity to provide benefits.

A limitation of this study is that it could not do justice to the concept of adaptive management as a long-term learning process (Holling, 1978). It focussed on identification of specific zones for different forest uses to meet the interests of different stakeholders as currently interpreted. Once space has been carved up between the primary stakeholders (FMU and local communities), further adjustments will be contentious. Conventional elements of the bundles of property rights (Schlager and Ostrom, 1992) are not clear on the ‘rights to alter’ (Galik and Jagger, 2015) while modifying water tables is a key determinant of peat landscapes. Further shifts may be expected to be one-way (more *de facto* rights for local communities), unless the benefits of intact ecosystems are understood in similar ways by all stakeholders, and actualized in terms of financial transfers. This is especially challenging for the ES beyond 'provisioning', as these are hard to quantify for all involved stakeholders, especially in a changing landscape. Overall, natural resource management in a landscape like the one studied has few opportunities for "win, win" solutions that directly benefit all, but many for "lose-less, lose-less" negotiated trade-offs replacing current conflict (van Noordwijk, 2017). In local articulations of a "common but differentiated responsibility" for restoration and avoided degradation of commons the question who pays for basic rights of clean air and water remains crucially important (Namirembe et al., 2017).

4.3. Policy implementation

Forest degradation and deforestation have become the main issue in the Indonesian forestry sector. Forest degradation has reduced the capacity of forest ecosystems to provide and sustain benefits for forest dependent people and other beneficiaries globally (Achard et al. 2002; Sunderland et al. 2008; Suwarno et al. 2015). In order to restore and sustain forest ecosystems, each FMU should develop a forest management plan that incorporates the concept of ES. However, the technical guidelines on the use of the ES concept in developing management plans, is not included in any regulation that govern FMU. Technical guidelines on forest zonation development that embrace the ES concept could significantly improve forest management practices in FMUs. These guidelines should contain detailed step-by-step instructions on conducting: (1) ES valuation; (2) land-use change simulation; (3) trade-off analysis; (4) delineation of forest zones; and (5) stakeholder consultations. Considering our experience in utilising the ES concept and SFM framework in developing adaptive forest zonation in Kapuas Protected FMU, guidelines could be based on our diagram for forest zonation development.

The institution of FMUs is categorised as a public institution under the Ministry of Internal Affairs Regulation No. P.61/2010. Meanwhile, FMUs have also received a mandate from the national government to generate management and business partnerships with other parties (under sustainable forest management) and to act as a private institution (Setyarso et al. 2014). However, the FMUs' current financial arrangements do not support this mandate. The FMU as an institution was established under district or provincial government, and should adopt the financial mechanisms under decentralised forest government. Efforts to improve the management of FMUs in providing public services have been made by the national government (Ministry of Forestry) through the introduction of quasi-public agencies (Setyarso et al. 2014). A quasi-public agency is an institution formed, controlled and appointed by a specific government body, with the aim of providing public services while generating its own income (Cummings et al., 2010; Kosar, 2011). The establishment of quasi-public agencies in FMUs will provide them with more financial independence, while the government will be able to maintain some form of control over FMUs.

Experience in establishing quasi-public agencies as financial mechanisms under the Public Service Agency (Badan Layanan Umum Daerah) has been achieved in three FMUs (Lakitan Production FMU in South Sumatra, Yogyakarta Production FMU in Yogyakarta and Gularaya

Production FMUs in South East Sulawesi). These three Production FMUs initiated the establishment of District Public Service Agency as a quasi-public agency to support the implementation of the economic development and conservation programme (Setyarso et al. 2014). The experiences of these three Production FMUs show that a District Public Service Agency, as a quasi-public agency, can help FMUs to achieve their objectives in sustaining local livelihoods and conservation funding. Considering the importance of District Public Service Agencies and the different characteristics of Production FMUs and Protected FMUs, we recommend to develop and to test a quasi-governmental agency in Kapuas Protected FMU.

5. Conclusion

The importance of ES in generating sustainable benefits from well-managed forest ecosystems has been recognised in the FMUs as a promising mechanism to balance conservation and economic development programmes. However, how the ES concept could be used in the formulation of management strategies for Indonesian forest management units has, to date, not been explicitly considered. Our study aimed to test the applicability of the ES concept in comparing land-use scenarios in a specific FMU through the development of adaptive forest zonation. The adaptive forest zonation was developed in this study to accommodate local community interest in sustaining ES benefits they could receive and FMU interest in conserving forest ecosystems. The results from our study show that adaptive forest management has the potential to benefit both conservation and local livelihoods. Adaptive forest zonation could potentially increase ES benefits received by local communities by about 40%, through rattan and wild jelutong collection and production of agroforestry rubber and jelutong, compared to the current forest zonation. It could also potentially decrease the risk of forest fire, carbon emissions and forest encroachment resulting from stakeholder agreements as part of the process in developing adaptive forest zonation. Hence, it is recommended that the adaptive forest zonation development steps taken in this study be included in the national guidelines for forest zonation development for FMUs. Moreover, we also recommend creating a Public Service Agency, as a quasi-governmental institution in order to support FMUs in generating direct benefits to finance their conservation and development programmes. One of the FMUs' mandates is to generate business partnerships with other parties. FMUs are registered as a district or provincial agency and are required to follow the financial mechanisms of decentralised governance that does not allow them to receive direct income from a third party. The establishment of a Public Service Agency could facilitate this financial arrangement between FMUs as the institution under district or provincial government and a private institution.

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