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Pilot ecosystem account for Indonesian peatlands

Sumatra and Kalimantan islands

BADAN PUSAT STATISTIK

WAVES

SarVision

Acknowledgements

This report is a first, preliminary pilot ecosystem account for Indonesian peatland. It is prepared in order to test and pilot the System of Environmental Economic Accounting – Experimental Ecosystem Accounting Approach (SEEA-EEA), for a specific, policy relevant ecosystem type, i.e. Indonesian peatlands. The report was supported by SarVision, Wageningen and Wageningen University, the Netherlands. The report was provided under auspices of Statistics Indonesia (Badan Pusat Statistik/BPS), with further technical support provided by the Ministry of Environment and Forestry (MoEFRI/KLHK), the Indonesian Ministry of National Development Planning (BAPPENAS), and the Ministry of Agriculture (MoARI/Kementan). The key technical advisors were Resti Salmayenti, MSc, Dr Elham Sumarga and prof. dr Lars Hein. The project has been facilitated and supported by the World Bank project 'Wealth Accounting and Valuation of Ecosystem Services project in Indonesia (WAVES Indonesia)'.

Disclaimer

This report is a pilot of an experimental methodology, i.e. the SEEA EEA. The report is not a statistical publication and is meant to examine how the methodology of the SEEA EEA can potentially be applied to a specific policy relevant ecosystem. The account is based on government data. Additional datasets were used for elements for which such data were not available. A major issue was data availability, in particular for the condition and ecosystem services supply and use accounts. Although it was found that all data required to prepare an accurate, detailed account are available, we could not get access to all data that we needed to develop the account. The single dataset that is most crucial for managing and monitoring peatlands is groundwater level. We had several datasets from various sources and used spatial interpolation to estimate groundwater depths in the peatlands of Sumatra and Kalimantan for the year 2013. This influences the accuracy of our results. Moreover, should better data be made available in the future a more accurate peat ecosystem account can be developed.

Summary

Peatlands cover around 7.8% of Indonesia and support an important agricultural sector. However, activities in peatlands lead to various environmental impacts in particular high carbon emissions as well as, in drained, degraded peatlands, fire and smog formation with associated health impacts. In addition, over time, agricultural activities cannot be maintained because of soil subsidence and subsequent flood risks. Therefore, it is very important that a science-based information system to support peat management is established.

The SEEA framework is a comprehensive statistical system for monitoring and analysing environmental information. In order to monitor the changes of peat ecosystems and economic activities concerning their physical and monetary values, this study applies the System of Environmental Economic Accounting – Experimental Ecosystem Accounting (SEEA EEA) framework to develop pilot ecosystem accounts of peatlands in Indonesia. The ecosystem accounting framework comprises a set of connected accounts, dealing with land and ecosystem use (the extent account), the state or health of the ecosystem (the condition account), the supply of ecosystem services including crops and forestry products as well as regulating and cultural services (the physical and monetary ecosystem services accounts) and the monetary ecosystem asset account (depicting the monetary value of the ecosystems). Thematic accounts part of the SEEA EEA include the carbon, biodiversity and water accounts. The SEEA EEA follows a similar approach to monetary analysis as the national accounts, i.e. focusing on measuring the value of ecosystems to economic production and household consumption. It is important that monetary values included in the SEEA EEA do not indicate 'total economic values' (in line with the valuation approach of the System of National Accounts on which SEEA is based). Also, externalities are not explicitly covered. Hence, although the peat ecosystem accounts provide useful information to support policy making, the current version of the accounts is not complete and cannot be the only basis for decision making.

The report presents an ecosystem account for peatlands in the Indonesian islands of Sumatra and Kalimantan. The study applies the SEEA EEA framework to develop and monitor the changes of peat ecosystems and economic activities concerning their physical and, to some degree, monetary values in Indonesia. The SEEA EEA is a comprehensive system to analyse and report environmental information. The ecosystem accounting framework comprises a set of connected accounts, dealing with land and ecosystem use (the extent account), the state or health of the ecosystem (the condition account), the supply of ecosystem services including crops and forestry products as well as regulating and cultural services (the physical and monetary ecosystem services accounts) and the monetary ecosystem asset account (depicting the monetary value of the ecosystems. It needs to be noted that the peat account is still incomplete. Several important ecosystem services are missing (e.g. flood occurrence, the control of fires in undrained peatlands, hydrological services, and the supply of non-timber forest products). Also there was a shortage of data (in particular for recent years) on drainage levels in the peat. Hence further work on the peat account is required before it can act as a comprehensive basis for decision making – at this point in time information from the account needs to be considered jointly with other datasets (such as the aforementioned ones on hydrology and fire impacts).

By integrating and reporting on various aspects of environment and human activities in peat ecosystem, the pilot ecosystem accounts can support a range of policies in Indonesia. First, the accounts can support the rehabilitation of peatland. Targets are set to restore approximately 2.5 Mha degraded peatland by 2020. Pilot ecosystem accounts for Indonesian peatland can, first, facilitate identifying areas that can be considered a priority for rehabilitation. Second, the pilot ecosystem accounts can support monitoring of the physical and monetary

impacts of peat rehabilitation. Third, the results of the carbon account can support the National Action Plan to Reduce Greenhouse Gas (GHG) Emissions, by monitoring carbon emissions from peatland. Another relevant application is to support the payment for ecosystem services (PES) in Indonesia by identifying areas of specific relevance for ecosystem services supply, as well as by providing information on co-benefits of payment schemes.

The peatland account is based on the Indonesian governments (MoEFRI or KLHK) land cover map. Based on the SEEA EEA, four individual ecosystem accounts are compiled for several years in the period 1990-2015. It should be noted that this is a pilot study, and the account is not yet complete. There is still a lack of data, such as drainage and production data (e.g. on non-timber forest products), and extrapolation was required to fill data gaps. Information is missing on the impacts of fires and smog on people's health. Nevertheless, the current account presents a first indication of how a peat account for Indonesia can be developed using various valuation techniques and approaches. There is room to improve the quality of data and to increase the number of services (including water) and monetary values (e.g. of health impacts).

Indonesian peatland cover approximately 8% of Indonesia's land surface and support an important agricultural sector. Peatland are important for the cultivation of oil palm, one of the main agricultural commodities currently produced in Indonesia. Other provisions important to Indonesia's economy include timber and paddy production, and biomass production for pulp. Yet given the increasing scarcity of unused land, the pressure to convert peatland to cropland or plantation forestry areas are still expanding.

It is found that 52% of peat forests in Kalimantan and Sumatra have been converted to other land covers from 1990 up to 2015 according to government data for this period. In both Sumatra and Kalimantan plantation areas and agricultural lands expanded drastically during 1990 to 2015. This led to increases in the production of plantation crops such as oil palm fruit, rubber and acacia. However, activities in peatland also lead to various environmental impacts such as high carbon emissions, degraded peatlands, fire and smog formation with associated health impacts. In addition, over time, agricultural activities cannot be maintained because of soil subsidence in drained peatlands and subsequent flood risks.

Oil palm plantation areas have expanded significantly and generated the highest monetary value in 2015, meanwhile timber production, CO2 sequestration, and protected land decreased over time. This was established through an ecosystem services account that tracked six main ecosystem services provided by Indonesian peatland, including the production of oil palm, biomass for pulp, paddy, timber, CO2 sequestration, and protected land as biodiversity habitat. However in economic analyses of land use options in peatlands also externalities (such as health effects of peat fires and CO2 emissions) and the long term forecasts of production need to be considered. The current and future increases in flood occurrence in peatlands due to soil subsidence are not yet included in the accounts, and this is a priority for further work so the peat accounts can more meaningfully be used to advice policy makers.

Forest conversion and other land use changes in peatland lead to the decrease of carbon stored in vegetation. This was determined through the carbon account, used to monitor the change in carbon stocks and emissions (based on net carbon flux and peat fires) from peatlands. Around 31% of above ground carbon stocks in 1990 was lost by 2015 in Indonesia. Meanwhile, the total emissions from net carbon (CO2) flux increased by 74% during the same period. Additionally, large parts of peatland were burned every year, resulting in more carbon emissions. It needs to be noted that there is a degree of uncertainty in these estimates. For example, the land use mapping conducted for the extent account shows that there is a possibility that the government of Indonesia underestimates the amount of land already converted to plantations and overestimates remaining forest cover. More accurate data on land use, fire and subsidence rates can lead to more accurate estimates of carbon flows.

This is a pilot study, and the account is not yet complete. There is still a lack of data, such as drainage and production data (e.g. on non-timber forest products), and extrapolation was required to fill data gaps. Information is missing on the impacts of fires and smog on people's health. Nevertheless, the current account presents a first indication of how a peat account for Indonesia can be developed using various valuation techniques and approaches. There is room to improve the quality of data and to increase the number of services (including water) and monetary values (e.g. of health impacts). The peat accounts present a useful partial (and incomplete) basis to support monitoring and policy making on Indonesian peatlands. It is noteworthy that this report only shows relatively coarse, aggregated maps, however all maps are available at a fine resolution so that scaling down to individual provinces or potentially districts is possible. The summary table below provides a synthesis of the accounts.

Summary table for peat ecosystems (all data are conform government data)

Peatland	**Indicator**	**Unit**	**Year**						
			1990	**1996**	**2000**	**2006**	**2009**	**2013**	**2014**
Ecosystem extent									
Sumatra	Undisturbed forest	1000ha	481	450	378	402	281		225
	Disturbed forest	1000ha	4159	3824	2659	2081	1642		1257
	Water	1000ha	5	5	5	4	4		4
	Degraded peatland[a]	1000ha	768	829	1447	1468	1720		1394
	Bare ground	1000ha	33	96	213	466	355		380
	Urban	1000ha	30	31	35	35	35		34
	Forest plantation	1000ha	7	32	48	262	420		864
	Perennial crops	1000ha	378	535	941	1007	1211		1398
	Dry agricultural land	1000ha	317	365	422	421	479		612
	Paddy field	1000ha	192	202	213	214	215		192
	Others	1000ha	7	7	16	17	15		15
Kalimantan	Undisturbed forest	1000ha	113	80	68	62	58		50
	Disturbed forest	1000ha	3790	3234	2978	2799	2565		2308
	Water	1000ha	6	5	5	5	5		6
	Degraded peatland[a]	1000ha	589	1083	1335	1432	1500		1532
	Bare ground	1000ha	27	44	44	62	94		203
	Urban	1000ha	59	73	83	131	256		336
	Forest plantation	1000ha	0	1	0	0	1		300
	Perennial crops	1000ha	59	73	83	131	256		336
	Dry agricultural land	1000ha	231	243	248	268	270		284
	Paddy field	1000ha	68	113	113	115	126		126
	Others	1000ha	1	1	1	1	2		3
Ecosystem condition									
Sumatra	Dry biomass[b]	Mt	1475	1409	1170	1079	991		965
	Water level[c]	cm						0-117	
	Hotspots[d]	Total pixel				4035	2448		5663
Kalimantan	Dry biomass[b]	Mt	1148	1015	959	928	887		835
	Water level[c]	cm						0-96	
	Hotspots[d]	Total pixel				3879	2619		2635
Ecosystem services (physical values)									
Sumatra	Timber production*	$1000m^3$			1893	1482	1094		777
	Oil palm production	1000t			10389	16837	20242		23635
	Biomass production for pulp*	1000t			1011	5503	8833		18161
	Paddy production*	1000t			620	625	627		561
	CO_2 sequestration*	$1000tCO_2$			7175	7629	5337		4282
	Protected habitat*	1000ha			442	451	423		416
Kalimantan	Timber production*	$1000m^3$			794	741	666		576
	Oil palm production	1000t			14	2185	4282		8022

	Biomass production for pulp*	1000t			0	2	24		624
	Paddy production*	1000t			192	196	214		214
	CO_2 sequestration*	1000tCO_2			1299	1182	1099		958
	Protected habitat*	1000ha			-	-	-		-
Ecosystem services (monetary values) (IDR billion/year)									
Sumatra	Timber production*				1278	1001	739		525
	Oil palm production				1764	2858	3436		4012
	Biomass production for pulp*				95	518	831		1709
	Paddy production*				1510	1522	1526		1365
	CO_2 sequestration*				2498	2656	1858		1491
	Protected habitat*				5238	5351	5015		4929
Kalimantan	Timber production*				536	500	450		389
	Oil palm production				1	88	173		324
	Biomass production for pulp*				0	0	2		59
	Paddy production*				338	344	375		376
	CO_2 sequestration*				452	412	383		334
	Protected habitat				-	-	-		-
Carbon									
Sumatra	Carbon stocks[b]	1000t	2707	2585	2148	1980	1819		1770
	CO_2 emissions (oxidation)[e]	1000tCO_2	131	146	178	195	225		272
	CO_2 emissions (fire)[f]	1000ha				318	183		286
Kalimantan	Carbon stocks[b]	1000m^3	2107	1862	1759	1702	1628		1533
	CO_2 emissions (oxidation)[e]	1000t	91	94	95	99	108		115
	CO_2 emissions (fire)[f]	1000t				386	325		324

*Note: *ES based on land cover data, oil palm production was estimated from several sources.*
[a] :land covers of wet shrub, dry shrub, savanna and grasses and open swamp, [b]: vegetation, [c]: the values are displayed in maps (see details in the chapter of results, [d]: 1-km fire pixel based on MODIS fire product, calculated for the minimum confidence value at 80%, [e]:net carbon flux (excluding from peat fires), [f]: from burned peat (33-cm depth of burned peat for all types of LC)

Abbreviations

AGB	Above-Ground Biomass
BGB	Below-Ground Biomass
CO_2	Carbon dioxide
ES	Ecosystem Services
FFB	Fresh Fruit Bunches (of oil palm)
Ha	Hectare
LC	Land Cover
MoARI	Ministry of Agriculture Republic of Indonesia
MODIS	Moderate Resolution Imaging Spectroradiometer
MoEFRI	Ministry of Environment and Forestry Republic of Indonesia
NCA	National Capital Accounting
SCC	Social Cost of Carbon
SEEA	System of Environmental-Economic Accounting
SEEA CF	SEEA Central Framework
SEEA EEA	SEEA Experimental Ecosystem Accounting

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Chapter 1. Introduction

1.1 Background

Peatlands in Indonesia support several economic activities, in particular agriculture and plantation forestry. Peatlands are important for the cultivation of oil palm, one of the main agricultural commodities produced in Indonesia. Given increasing scarcity of unused mineral land, the pressure to convert peatlands to cropland or plantation forestry areas is still increasing. This has also been facilitated by the decentralisation policies applied as of 1999, that shifted responsibilities for land conversion to lower administrative levels [2-5].

However, unsustainable peatland uses are cause of environmental concern[6]. The tropical peatlands of Indonesia are one of the world's largest carbon pools, storing around 30–700 tC/ha carbon per every meter of peat soil depth[7]. Burning peat forest, peat drainage, and fertilisation in plantation and agricultural lands lead to substantial emissions of carbon dioxide (CO_2)[8-10]. Cultivation on peatlands requires drainage, which, in turn, leads to irreversible soil subsidence [11, 12]. Over time, this will lead to flooding of these areas, and consequently soil subsidence will severely hamper crop production in peatlands. In particular, subsidence will lead to peatlands becoming relatively low-lying areas in the landscape, where rain and potentially river and or sea water will collect during the rainy season. Many plantation crops including oil palm, and forestry crops such as acacia are highly sensitive to flooding and production cannot be maintained in these areas in the near to medium future. Furthermore, peat drainage and cultivation also have major social/environmental impacts on biodiversity and health issues.

The environmental problems in peat ecosystem have drawn the attention of the government. Better management plans to move towards sustainable development including in peatlands are required. In 2011, a Norway-Indonesia partnership focusing on the reduction of GHG emissions was followed by a Presidential Instruction (inpres) No.10/2011 about a two-year suspension of new licences for primary natural forest and peatland clearing. This instruction has succeeded in protection of carbon and biodiversity in 71% or 11.2 Mha of Indonesian highly threatened peatlands [13]. In 2014, a Government Regulation (PP) No.71/2014 about peatland protection and ecosystem management was issued to protect 30% of Indonesian hydrological unitary peatlands [14]. As a further step, a peat restoration agency (BRG) has been formed by the president of Indonesia with a target to restore approximately 2.5 Mha of degraded peatlands by 2020 (SK.05/BRG/Kpts/2016). This was followed by a Presidential Decree (Perpres) No.1/2016 about restoration priority in seven provinces (12.9 Mha of peatlands in Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan and Papua provinces). These priority areas also include most severely burned parts in 2015, shallow peat areas with canals (3 Mha), as well as peat domes with canals and without canals (2.8 Mha and 6.2 Mha) [15].

A range of studies on Indonesian peatlands have been conducted. Peatland maps for Indonesia, for example, have been published by several research institutions including the governmental agency, the Ministry of Agriculture (MoARI) and BRG. The Ministry of Environment and Forestry (MoEFRI) also continuously publishes Indonesian land cover maps, in which peatlands are included. Furthermore, several research activities have been implemented to analyse the environmental impacts and economic benefits from activities in peatlands, for instance regarding carbon emissions [9, 10], and ecosystem services [6]. However, this information needs to be integrated and disseminated in order to effective monitor and report on the changes of environmental and economic conditions in the peat ecosystem and support policy making on peat management.

The United Nations System of Environmental-Economic Accounting - Experimental Ecosystem Accounting (SEEA EEA) is a framework for monitoring the interaction between ecosystems and economic activities. The SEEA framework is comprehensive (covering ecosystem extent, condition, services and assets), coherent (aligned with the System of National Accounts) and flexible (can be implemented at different institutional scales or for different ecosystem types). This peat account is based upon the SEEA EEA. It is the world's first pilot ecosystem account following the SEEA EEA developed for peatlands.

The Indonesian government has been applying national capital accounting to support analysing the relation between natural resources and economic development in the last two decades. This is supported by regulation (UU) No.32/2009 about environmental protection and management, and regulation (PP) No.46/2017 about economic instruments for the environment. In line with these regulations Statistics Indonesia (BPS) has developed an integrated environmental and economic balance system, called SISNERLING, to account the timber, mineral and energy at national level. SISNERLING is based upon the SEEA Central Framework (CF). The SEEA CF and the SEEA EEA are complementary information systems, covering different ecosystem-environment dependencies. In addition, the SEEA (EEA) is, contrary to the SNA and the SEEA CF, a spatial account, where maps as well as accounting tables are presented for each account.

1.2 Objective of the report

The objective of this study is to develop pilot ecosystem accounts for Indonesian peatlands, following the framework of SEEA EEA. Based on the technical recommendations of SEEA EEA, there are four pilot accounts (ecosystem extent account, ecosystem condition account, ecosystem services account and carbon account) included in this study. Specific indicators for each account are selected in this report, based on technical consistency with the SEEA EEA framework, data availability and policy relevance. The accounts identify the ecosystem in physical (applied for all accounts) and monetary (only applied to ecosystem services) terms.

This study establishes pilot ecosystem accounts for Indonesian peatlands based on data mainly from governmental institutions. The accounts integrate different statistics and thereby provide new insights. They can also guide the monitoring process in the future as new data are collected continually. Several types of missing data were collected from literature reviews. The description of data sources and methods used are explained in the methodology. The results are displayed in tables and maps that allow tracking the temporal and spatial changes of the selected indicators.

1.3 Scope of work

The scope of this study is the peat area of Indonesia, specifically in Sumatra and Kalimantan, based on peatland map from MoARI (2011). The scope is a soil type of characterization which is fixed in time. There is no additional or reductional size of peatlands. It is noted that there are still uncertainties about peatland area and cover [16-19]. Where government data are available, this account exclusively uses government data. For indicators for which there were no government data available other sources have been used. The peat ecosystem accounts are established for following years: 1990, 1996, 2000, 2006, 2009, and 2014. The most recent data for 2016 are not presented in this report due to a lack of access to land cover data. In addition, several indicators are limited to certain years due to data limitations. In particular, there are relatively few data on peat drainage and production rate of agricultural products. Since the account is incomplete (not all services, values and externalities are considered), it needs to be kept in mind that the accounts only provide a partial insight in natural capital provided by peat under different uses.

Chapter 2. Theoretical framework and indicators

2.1 SEEA-EEA framework

Pilot ecosystem accounts for Indonesian peatlands are developed based on SEEA EEA framework. This framework is based on the System of National Accounts (SNA) with a focus on environmental resources and their interactions with economic (human) activities[20]. The framework consists of several individual accounts: ecosystem extent, ecosystem condition, ecosystem services, ecosystem asset and thematic (land, water, carbon and biodiversity) accounts. Technical recommendations for SEEA EEA have been published, and these have been applied in developing the peat ecosystem account. Figure 1 illustrates the relationship between the accounts and the terms of valuation. Physical terms are applied to all accounts, and monetary terms are applied only to ecosystem services, ecosystem asset and thematic accounts[20].

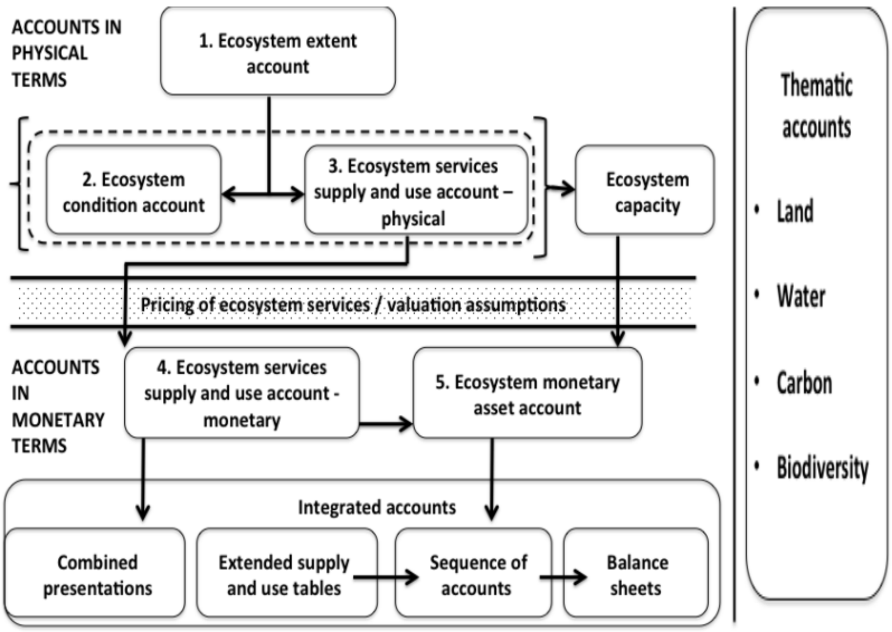

Figure 1. Connections between ecosystem and related accounts (Source:[20])

Referring to SEEA EEA framework, this study develops four specific pilot peatland ecosystem accounts, covering the ecosystem extent account that explains states and changes of land cover (LCs), the ecosystem condition account that monitors the state of peat ecosystems, the ecosystem service (ES) account which estimates the physical and monetary values of main ecosystem services provided by Indonesian peatlands, and lastly carbon account that tracks the stocks, emissions and sequestration of carbon in peat. For reasons of data availability, only the peatlands in Kalimantan and Sumatra are included in the peat account.

2.2 Accounts and indicators

2.2.1 Ecosystem extent account

Ecosystem extent accounting is an initial step that explains the distribution of environmental characteristics and human activities in the ecosystem. In this account, land cover (LC), land use (LU) or ecosystem use are classified. This information facilitates monitoring and reporting the changes in LC over time. This information is also essential to analyse ecosystem services provided by peat, since these services are closely linked to land cover [21, 22]. The indicator of this account follows the same LC categories as the land account of Indonesia published recently (see details in the methodology chapter).

2.2.2 Ecosystem condition account

The ecosystem condition account focusses on the physical state or condition of the ecosystem. For this account, three indicators (vegetation biomass, water level and hotspots) were selected based on the characteristics of Indonesian peatlands, policy relevance and data availability.

Vegetation biomass

In addition to carbon in the soil, peatlands also store noteworthy amounts of carbon in the vegetation. The reduction of vegetation density in peat forests by fires, deforestation and land conversion, decreases the carbon content due to biomass loss and peat decomposition [23]. This indicator is included in the condition account to track the changes of vegetation biomass in peat ecosystem.

Water level

Drainage is required to convert peatland into a plantation or agricultural land. For example, a drainage depth of around 50-70 cm is typically needed for oil palm plantation [24], even though drainage can be shallower or deeper in the case of poor water management. The groundwater level varies within a year, and this account includes the annual average groundwater depth. Drainage depth is closely related to CO_2 emissions and subsidence and also increases the risk of fire [25-28]. Therefore, water level is included in this account.

Fire hotspot

Forest fires have negative impacts on people's health, and lead to ecosystem damages and a reduction of agricultural production [29, 30]. It was estimated that forest fires in Indonesia, including peatlands, also become a large source of CO_2 emissions [10, 23, 31]. This study uses the number of fire (hotspots) as an indicator in order to track the temporal and spatial distribution of fire accidents in peatlands using satellite product.

2.2.3 Ecosystem service account

The ecosystem service account provides information about the main ecosystem services (ES) generated in peatlands. This account encompasses the values both in physical and monetary terms. The values of ES can be estimated using several valuation techniques, depending on the characteristic of selected indicators and data availability[20, 32, 33]. Importantly, these indicators should be consistent with the valuation principles of the System of National Accounts, as explained in the SEEA EEA Technical Recommendations. The detailed description of methods used for this account is presented in the methodology chapter.

ES (based on MoEFRI land cover data)

The estimation of the main ES (physical value) provided by Indonesian peatlands at national level has been conducted using several data sources [6]. To maintain the consistency of data collected by the government, firstly this study focuses on ES estimated based on MoEFRI land cover data (published continuously). From diverse ecosystem services provided by Indonesian peatlands, there are five ES that can be identified. These ES are divided into three provisioning services (biomass (acacia) production for pulp, timber production, and paddy production) measured in terms of annual product harvested, carbon sequestration (a regulating service) measured in terms of total carbon (CO_2) sequestration in undisturbed forests, and a cultural service measured in terms of total area of protected peatlands (peat swamp forest). The protected area network consists of protected forests and conservation areas (national park, recreation park, nature reserve and wildlife sanctuary) in 2000 which have not been changed to non-forest areas[6]. Comparing to the previous study [6], this report only selects the CO_2 sequestrations instead the CO_2 emissions. The carbon emissions are categorised as an ecosystem disservice and explained independently in the carbon account, which is more aligned with the SEEA EEA Technical recommendations.

ES: oil palm production

Plantation areas in Indonesian peatlands have been expanded to support the economics of this country. However, LC maps used in this study are not able to distinguish the variations of plantation. Diverse types of the plantation that have been widened in Indonesian peatlands such as oil palm, rubber and coconut plantations [6, 34-37]. Therefore, this study tries to identify more types of ES using other data sources, which might have inconsistency with data from the LC map. However, this report only presents one additional ecosystem service, oil palm production, due to limitation of data sources.

2.2.4 Carbon account

Carbon account is presented to monitor the trend of carbon stocks and emissions in peatland ecosystem. This account is divided into several indicators, including carbon stocks (vegetation), carbon emissions from peat fires as well as oxidation of soils, and a net carbon flux is assessed.

2.3 Study area

In this section, the boundaries of the study area are defined. The territory analysed in this research comprises all peatlands of Sumatra and Kalimantan as identified in government publications, which together account for around 75% of Indonesian peatlands. The area is distributed between 6^0 08' north latitude and 11^0 15'south latitude, and between 95^0 45' and 141^0 05' of east longitude. Located in the equatorial zone makes Indonesia experiences tropical climate with an average temperature around 24-28^{0}C and precipitation ranging from 906-4627 mm/year with three seasonal patterns distributed spatially [39, 40]. The population of Indonesia is still increasing, from around 87.8 million in 1960 to 257.6 million in 2015 [38].

The ecosystem account of this study is the tropical peatland with peatlands in Sumatra and Kalimantan as the specific ecosystem type (ET). According to peatland map from the Centre for Research and Development of Agricultural Land Resources (BBSDLP), the MoARI, Indonesia has 14.9 Mha peatlands (approximately 7.8% of Indonesian land surface) that are mainly spread in seventeen provinces (of thirty-three provinces) in the three biggest islands (Sumatra, Kalimantan and Papua) [16]. As seen in Figure 2, Indonesian peatlands are scattered, 43% in Sumatra, 32% in Kalimantan, and 25% in Papua [16].

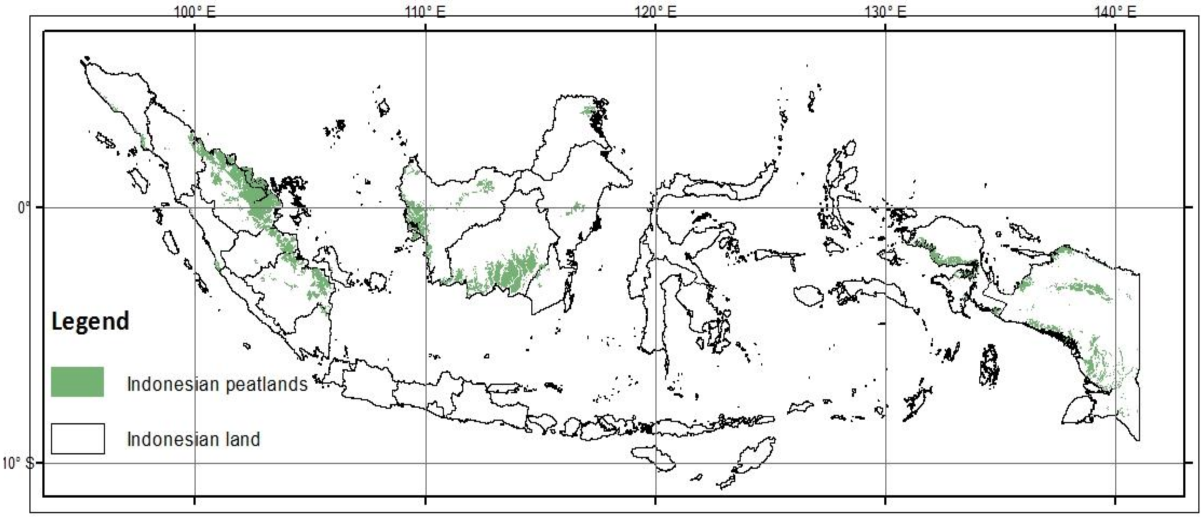

Figure 2. Distribution map of Indonesian peatlands (Source: [41])

2.4 Limitations in the approach

The peat account covers a range of important ecosystem services provided by peat, but not all services are as yet included (they could be added in the future should the Government of Indonesia decide to continue the approach). In particular, what is missing are first the health effects of peat fires. The costs of fires are an externality of peat use, related to drainage. They lead to smog that can cover large parts of Indonesia and parts of nearby countries. The account (chapter 4) shows in which land cover types the fires are generated, the area burned, and the amount of CO_2 emitted due to the fires, but the health effects are not yet analysed. Second, flooding is not well captured in the accounts yet. Seasonal flooding occurs in peatlands where the surface has subsided. Following several decades of subsidence, peatlands may become the lowest parts in the landscape, and thereby be under water for periods of weeks or months each year. These peatlands can no longer be used for plantations and will be abandoned (this is happening already in parts of South Sumatra). The flood risk and the associated impacts on production are not yet in the accounts. Third, the list of ecosystem services covered in the account is incomplete. For example, the production of non-timber forest products such as rattan, as well as a range of crops such as sago and liberica coffee are missing. Fourth, the accounts use an SNA-consistent monetary valuation approach based on exchange value (aligned with market prices); they do not measure welfare effects of peat use. Hence, the monetary information in the accounts cannot be used for an environmental CBA without further economic analysis. Fifth, the accounts have as one of the key inputs the land cover map of MoEFRI. However, the land and extent accounting report suggests that the plantation area may be underestimated in these maps, and the forest cover could be overestimated. This adds uncertainty to the figures (among others it may lead to an underestimate of the CO2 emissions since drainage levels were modelled based on among others land use). Finally, it is important to report that soil subsidence is an irreversible process. Choices made to drain peatland now will be felt for decades to come, also because restoring peatlands by rewetting them is very expensive. It is not yet clearly shown in this account that over time the value of drained peatlands will convert to zero, since production of plantation crops cannot be maintained when the area is seasonally flooded. An alternative is to use profitable crops in peat that do not require drainage (note that even low drainage levels will lead to irreversible soil subsidence over time), such as jelutung rubber or sago (which can be used for starch-based food products as well as bioplastics). These options are also not yet included in the account (the current production of these so-called paludiculture crops is low and further data are needed to include them).

Chapter 3. Methodology

This section describes the methods and the data sources that were used to estimate the value of the indicators in the ecosystem extent account (land cover), the ecosystem condition account (vegetation biomass, water level and hotspots), the ecosystem services account (physical and monetary values) and the carbon account, for peatlands in Sumatra and Kalimantan.

3.1 Ecosystem extent account

The types of land cover (LC) were classified based on the regulation of director general of forestry planology No. P.1/VII-IPSDH/2015 [42] as seen in Table 1. In this study, the land cover of dry shrub, wet shrub, open swamp and savanna are grouped as degraded lands. Following the land account of Indonesia, the ecosystem extent account is developed for the years, 1990, 1996, 2000, 2006, 2009, and 2014. Along with the total area, this account also monitors the additional and the reduction areas of each LC type for every time-period (1990-1996, 1996-2000, 2000-2006, 2006--2009, and 2010-2014. The results are presented as annual data in tables and maps. It is important to note that the account is based on land cover data from MoEFRI. In this dataset, information on land cover for the year 2010 is mostly based on remote sensing images of 2009; and information for the year 2015 is mostly based on remote sensing images of 2014. Hence, the land cover changes would lead to inaccuracies in this account (since there will in some areas have been further land use conversion from 2009 to 2010 and from 2014 to 2015). This underestimation also occurs in the published government data and may lead to an inaccuracy of several percent in the land cover data (thereby affecting estimates of ecosystem services and carbon stocks and emissions). In order to align the estimates of carbon as close as possible to the actual land cover, the carbon stocks and emissions are calculated for 2009 and 2014.

The peatland area is included based on government data, including the peatland map of the MoARI [41] and the land cover maps of the MoEFRI [43]. These maps were overlaid to calculate the total area of each LC category using ArcMap 10.5. To measure the total area, projected coordinate system of Asia South Lambert Conformal Conic was selected by modifying the parameters with central meridian at 115, standard parallel 1 at 2, standard parallel 2 at -7, and latitude of origin at 0.

Table 1. The class description of Indonesian peatland cover

Type of land cover	Description
Undisturbed forest	Primary and well-preserved secondary forest
Disturbed forest	Secondary (degraded) natural forest
Water	Open water areas
Degraded peatland	Bush (dry shrub), shrub swamp (wet shrub), savanna and grasses, and open swamps
Bare ground	Bare areas
Urban	Transmigration and settlement areas
Forest plantation	Forest vegetation in large areas, dominated by homogeneous trees species, and planted for specific purposes, including reforestation area, industrial plantation forest and community plantation forest
Perennial crops	Estate areas, mostly with perennials crops or other agriculture trees commodities
Dry agricultural land	Pure and mixed dryland agriculture
Paddy field	Agricultural land for paddy
Other LCs	Fish ponds (aquaculture), mining areas, ports and harbours
No data	Clouds and no-data areas

3.2 Ecosystem condition account

Following the ecosystem extent account, this study tries to develop ecosystem condition account for the same years. However, the available data are limited for specific years: vegetation biomass for 1990, 1996, 2000, 2006, 2009, and 2014, water level only for 2013, and hotspots data for 2006, 2009, and 2014.

3.2.1 Vegetation biomass

The estimated biomass is the sum of dry biomass of tree and dead organic matter as displayed in Equation 1. The measurement of dry tree biomass consists of two parts, aboveground biomass (AGB) and belowground biomass (BGB)[44]. The biomass of dead dry matter is the sum of litter biomass (L) (such as fallen leaves, fruits and flowers) and biomass of woody debris (WD) (such as dead trees, fallen trees and part of trees like stems, branches, twigs on the ground).

$$\text{Vegetation biomass (tdm)} = A_t \times (AGB_t + BGB_t + L_t + WD_t)$$

Equation 1

The calculation was conducted based on the total area of each LC type in the extent account (A_t). Biomass data from a report of the MoEFRI [45] were applied. However only the estimated AGB values (22 different LC classes) were available. This study presents a more detailed information by adding the values of BGB, L and WB collected from various data sources (see details in Annex 1). The values are expressed in an average tonne of dry biomass (tdm) per hectare for each LC category. Some of data are available as the total carbon (C) stored in the vegetation, therefore this unit was converted to tdm with an assumption that 1 tdm contains 0.5 tC (tonne of carbon) [45].

3.2.2 Groundwater level

The distribution of peat drainage depth, indicated by data on water table depth, was mapped by a combination of two mapping techniques: kriging interpolation and lookup tables. The selection of the method was based on land cover types. Kriging interpolation was applied in perennial crop area, plantation forest, bare land, and degraded peat swamp forest in areas less than 500 m from perennial crop or plantation forest areas (given that groundwater only gradually – in space - reverts to the natural level, close to the surface). For the rests of land cover and land use types, a lookup table technique was applied.

The availability of spatial information (coordinates) of water table depth data measured from various drained peat areas allows the application of kriging interpolation. This technique uses some parameters derived from analysis on the spatial autocorrelation between measured data to estimate the water table depth in un-measured locations. In total 166 depth data points for Sumatra and 40 depth data points for Kalimantan were used as the input for interpolation. The depth data represent the average level of water table depth in a year. The procedures of kriging interpolation technique include spatial autocorrelation analysis, variogram modelling, kriging interpolation, and accuracy assessment. A brief explanation of the procedures is described in the Annex 13. The period of measurement is for the year of 2013 only.

A lookup table technique was applied by assigning a value of water table depth to a related land cover type, using the spatial analysis tool of ArcMap 10.5. The water table depth data were selected based on a literature review. Annex 14 lists the water table depth values used in this mapping.

3.2.3 Hotspots

The number of hotspots in peat areas was detected from MODIS (Moderate Resolution Imaging Spectroradiometer) collection 6 near real-time fire data from Fire Information for Resource Management System (FIRMS), NASA [46]. The fire products contain temporal and spatial distribution information globally with 1 km pixel resolution from two satellites, Aqua (MOD14) and Terra (MYD14). These data are available on The Earth Observing System Data and Information System (EOSDIS) website from NASA. Fire products for Terra satellite can be accessed from November 2000 and from July 2002 for Aqua satellite. The determination of a hotspot in MODIS fire product is explained in Giglio et al. [47].

The number of fires in peat areas was extracted using ArcMap 10.5. Peatland distribution map from the MoARI [41] and MODIS fire data were intersected to show the distribution of hotspots in Sumatra and Kalimantan peatlands. It is assumed that hotspots in the same or nearest location (approximately 1 km resolution) within one year are assumed as one pixel hotspot [48, 49]. To improve the certainty of the result, this study also compares the number of hotspots in different confidence levels according to the information in Table 2. This indicator is divided into three classes, which are hotspots with confidential level 0-100%, 30-100% and 80-100%.

Table 2. The meaning of confidence interval in hotspot information

Confidence value	Class	Action
0% ≤ C < 30%	Low	Important to note
30% ≤ C < 80%	Nominal	Alert
80% ≤ C ≤ 100%	High	Immediate countermeasures

Source: [47, 50]

It is noted that this indicator indicates the detected number of fire accidents in peat areas, not the total burned area. The measurement of burned area was done separately using different satellite product (see details in section 3.4.2).

3.3 Ecosystem services account

An ecosystem services account is developed for 2000, 2006, 2009 and 2014. The methods to estimate the physical and monetary values are explained in Table 3 and Table 4. For physical values, the total production of each commodity was estimated by multiplying the production rate in peat area (Annex 4 and Annex 5) and the total area (ecosystem extent account and Annex 3)[6]. Next, monetary values were calculated based on the physical values, using resource rent (RR) approach for provisioning services, the social cost of carbon (SCC) for CO_2 sequestrations, and restoration cost for the protected habitat. Several studies and sources (Annex 6) were referred to estimate the production costs and the total revenue. Monetary values of ES were standardised into IDR for 2017 by considering inflation rates (6.96 in 2010; 3.79 in 2011; 4.3 in 2012; 8.38 in 2013; 8.36 in 2014; 3.35 in 2015; 3.02 in 2016)[51] and exchange rate of Bank Indonesia (BI)[52].

Table 3. Indicators for physical valuation of ES provided by peatland ecosystem in Indonesia

Type of ES	ES specification	Indicator	Method
Provisioning services	Timber production[a]	Annual timber harvested (m^3/year)	Timber production rate × total forest area (excluding forest in protected area)
	Oil palm production	Annual fresh fruit branch (FFB) of oil palm harvested (ton/year)	Oil palm (FFB) production rate × total area of oil palm plantation
	Biomass production for pulp[a]	Annual acacia biomass harvested (m^3/year)	Biomass (acacia) production rate × total area of acacia plantation
	Paddy production[a]	Annual paddy harvested (ton/year)	Paddy production rate × total area of paddy field
Regulating services	CO_2 sequestration[a]	Net carbon (CO_2) flux of undisturbed forests (ton CO_2/year)	Net carbon (CO_2) flux of undisturbed forests × total area of undisturbed peat forest
Cultural services	Protected habitat[a]	Total area of peat swamp forests inside protected areas that are not converted to other land uses since 2000 (ha)	Total area of forest in protected area

Note: methods were taken from [6]

[a]ES estimated from MoEFRI land cover data

Table 4. Indicators for monetary valuation of ES provided by peatland ecosystem in Indonesia

Type of ES	ES specification	Indicator	Method
Provisioning services	Timber production[a]	Resource rent (IDR/year)	(Timber price × total production) - production cost
	Oil palm production	Resource rent (IDR /year)	(FFB price × total production) - production cost
	Biomass production for pulp[a]	Resource rent (IDR /year)	(Biomass price × total production) - production cost
	Paddy production[a]	Resource rent (IDR /year)	(Paddy price × total production) - production cost
Regulating services	CO_2 sequestration[a]	Social cost of carbon (IDR /year)	Total CO_2 sequestration × cost of carbon (CO_2)
Cultural services	Protected habitat[a]	Restoration cost (IDR /year)	Total area of forest in protected area × restoration cost

[a]ES estimated from MoEFRI land cover data

Resource rent (RR)

The value of RR is counted as the total revenue from the market price of output minus the total production cost [35, 53, 54] (Table 4). Data needed for this measurement are the market price (P), the total production (the physical value of ES) and the total production cost (see details in Annex 6).

Restoration cost (not applied)

It needs to be noted that the restoration cost approach is not recommended for the SEEA EEA. This because it is unclear if society would indeed restore the peatlands (or any other ecosystem) for these costs if given the choice. If not, it is not realistic to use these costs in the context of accounting. Therefore, the Restoration cost method has been excluded from the accounts, and the habitat service is expressed only in physical indicators. In order to give an idea of potential values that would accrue for restoration, costs for reforestation in peat swamp forest in tropical peatlands have been estimated at 1054 US$/ha (value for 2014) [55, 56]. The cost consists of planning cost, planting cost of 500 trees and the average of annual maintenance cost. Based on the inflation rates of Statistics Indonesia [51] and exchange rate in BI [52] (US$ is equal to 11081 IDR in 2014), the restoration cost would be equivalent to 11,856,417 IDR/ha (value for 2017). In addition, costs may be required for restoring the hydrology of the peatlands. These costs may be substantially higher but will vary strongly as a function of local characteristics (e.g. density and size of drainage canals).

Social cost of carbon

The monetary value of CO_2 sequestration is valued based on marginal social damage cost technique, the social cost of carbon (SCC)[35]. This study selects the value of SCC for 3% discount rate at 35 US$/t CO_2 (value in 2007)[57]. Based on the inflation rates [51] and exchange rate in BI [52] (1 US$ is equal to 9,136 IDR in 2007), therefore the SCC value for 2017 was equal to 348,17 IDR/t CO_2.

3.4 Carbon account

A carbon account for peatland is developed for 1990, 1996, 2000, 2006, 2009 and 2014 for carbon stocks and net carbon flux, while the indicator of peat fire emissions is only presented for 2006, 2009, and 2014.

3.4.1 Carbon stocks (vegetation)

The total of carbon stocks in vegetation was estimated from biomass data in the ecosystem condition account and the references (in Annex 1) using Equation 2 and Equation 3. Carbon fraction used in this report is equal to 50% of dry biomass [45]. The total carbon stocks were converted into CO_2-eq by multipying estimated carbon content with 3.67 (44/12, ratio molecular weight of CO_2 and carbon). Second, using ArcMap 10.5, mapping the carbon stocks applies look up table methods by asigning the value based on land cover types (Annex 1).

$$\text{Vegetation Carbon Content (tC)} = \text{Dry matter (t)} \times \text{Carbon Fraction (C)} \quad \text{Equation 2}$$

$$CO_2\text{-eq} = \text{Carbon Content} \times 3.67 \quad \text{Equation 3}$$

3.4.2 Carbon emissions

Oxidation

The total net carbon flux was calculated as the sum of carbon sequestration (positive value) and carbon emission (negative value) multiplied by the total area for every type of land cover. The references of net carbon flux for specific land cover are summarised in Annex 5.

Peat fires

Carbon emissions from peat fires were estimated from the emission of burned scar in peatlands. The size of the burned scar was estimated from burned area products by MODIS (MCD64A1) collection 6 [58]. This product contains the information of burned area (daily) with a resolution of 500 m. It can be accessed online on http://modis-fire.umd.edu/index.php. Data (.shp) that cover regional win 19 were selected for South-East Asia, including Indonesia. Burned area products then were overlaid with the peat map from MoARI and land cover maps from MoEFRI for the selected year and type of LC (forest, plantation area, agricultural land, bare ground and degraded land). The method was conducted in a software, ArcMap 10.5. In the measurement of total burned peatlands, it is assumed that overlapped burned area in the same location (pixel) within the same year was calculated as one datum.

Equation 4 was applied to estimate the total carbon (CO_2-eq) emissions from burned peat (E_{fire}). The formula was taken from IPCC supplement 2013 [59] as reviewed by MoEFRI [48]. The total carbon emissions (E_{fire}) are the sum of the burned area (BPF) multiplied with the mass of fuel available for combustion per area (MB), the combustion factor (CF, default factor = 1.0) and the CO_2 emission factor (G_{ef}). Assuming the depth of burned peat is 33-cm for all land cover types[48], MB is equivalent to 504.9-ton biomass/ha, and G_{ef} 1,828.2 CO_2 kg/ton dry biomass burned [48, 60, 61].

$$E_{fire} = BPF \times MB \times CF \times G_{ef}$$

Equation 4

Chapter 4. Results

4.1 Ecosystem extent account

Sumatran peatlands

Table 5 shows the total areas of seventeen land covers (LCs) in Sumatra peatlands 1990-2014/2015, with information of additions and reductions in LC classes between the selected years (five periods). Total peat areas in Sumatra is approximately 6.4 Mha. It can be seen from the table that the total LC changes are diverse in each period. A peatland area of 0.46 Mha (7%) has changed during the first period (1990-1995/1996). This number went up dramatically during the second period (1995/1996-2000) to 1.42 Mha (22%). In the next three periods, the total converted areas were still significant, around 1.1 Mha, 1.09 Mha and 1.3 Mha respectively.

The most notable change of LC in Sumatra peatlands is the reduction of natural forests. In 1990, 73% of peatlands in Sumatra was covered by forests. However, according to government data, in 2014/2015, there was only 22% of peatlands remained as forests as seen in Figure 3. The highest number of deforestations, around 1.2 Mha, was recorded in the second period (1995/1996-2000). After that, the trend of deforestation was going down even though the proportions were still considerably high (0.7 Mha (third period), 0.6 Mha (fourth period) and 0.5 Mha (last period)). On the other hand, the plantation area and agricultural land were escalated, from 0.9 Mha in 1990 to 3 Mha in 2015, which is equal to 48% of total peatlands in Sumatra.

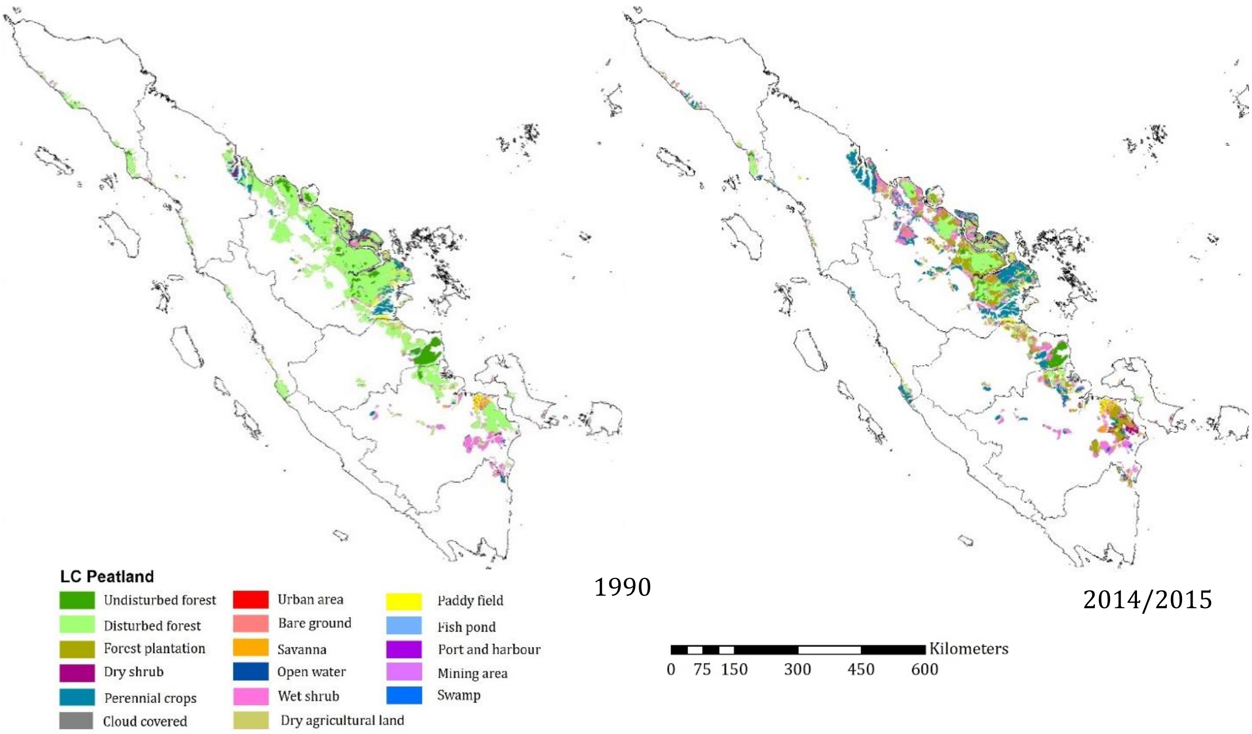

Figure 3. Spatial distribution of land cover types in Sumatra in 1990 and 2015.

Another noticeable change is the expansion of the degraded lands (wet shrub, dry shrub, savanna, swamp) and the bare ground. Most of the degraded land was wet shrub (79-86% of total degraded lands). This type of land increased significantly by 55% in twenty years (1990-2009/2010) then decreased during last period by 17%. The similar trend is also found for dry shrub, savanna, and open swamp areas. Furthermore, the bare ground was also widened dramatically since 1990 even though it had decreased once during 2005/2006-2009/2010. Other LCs such as the fish pond, port/harbour, urban and mining areas show no significant changes. These types of LC only took a small part of total peatland in Sumatra, around 0.6-0.8%.

Kalimantan peatlands

As seen in Table 6, Kalimantan island has approximately 4.9 Mha of peatlands. In twenty-five-year period (1990-2014/2015), parts of land covers in Kalimantan peatlands have been changed (Figure 4). It was recorded that the highest total peatland conversion (14% or 0.7 Mha of Kalimantan peatlands) is during the first period, 1990-1995/1996. This number is lower compared to the percentage of peatland cover change in Sumatra.

Deforestation is still the main issue for Kalimantan peatlands. Natural forest covered approximately 80% of Kalimantan peatlands in 1990, then 32% (1,5 Mha) of them have been converted until 2014/2015. About 0.6 Mha of deforestation area was found during the first period, then the number decreased to 0.23-0.28 Mha per period in the next terms. On the other hand, the total degraded land (dry and wet shrub, open swamp) and the cleared area in Kalimantan peatlands were widened significantly from 13% (of total peatland) in 1990 to 35% in 2015, or around 1.1 Mha where 0.57 Mha of it was added during the first period.

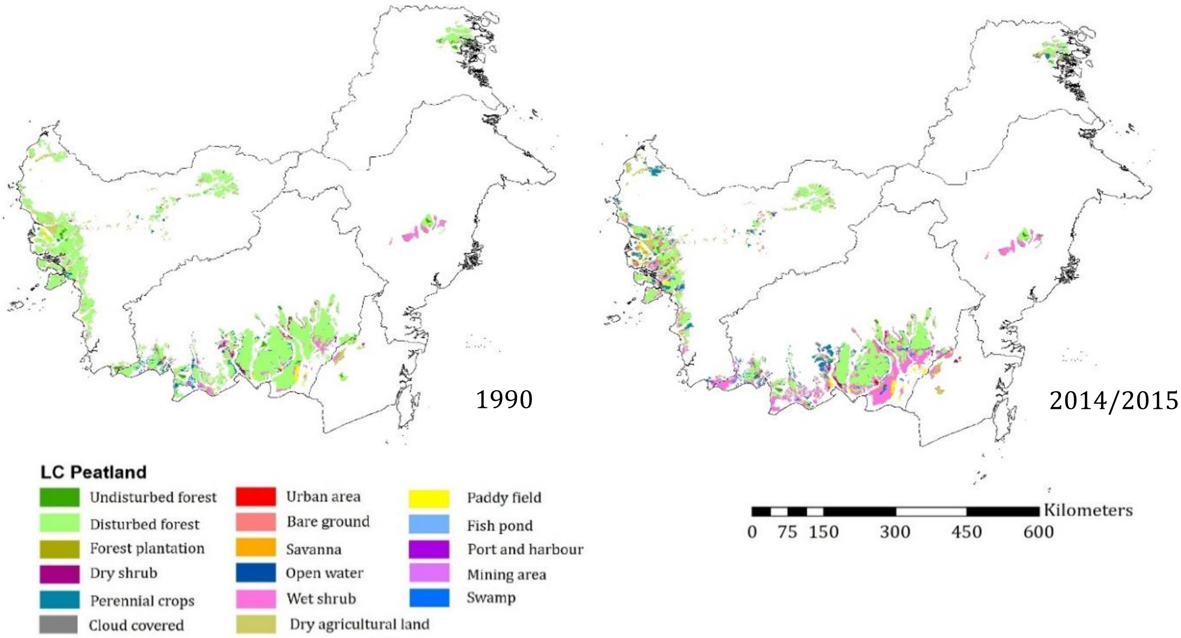

Figure 4. Spatial distribution of land cover types in Kalimantan in 1990 and 2015.

Plantation and agricultural lands were also widespread in Kalimantan peatlands. In 1990, there were only 0.36 Mha of these types of LC (dominated by dry agricultural lands). However, this number was doubled to 0.77 Mha until 2015. Plantation and agricultural lands were expanded in every period. The highest changes were found during 2005/2006-2009/2010 for perennial crops, during 2010-2014/2015 for forest plantation and 1990-1995/1996 for agricultural lands. Looking at trend for other types of LCs, urban areas in Kalimantan peatlands increased during 1990-1995/1996 and then remained constant in the next period (0.02 Mha). Meanwhile, mining areas went up during the last period.

Table 5. Extent account of peatlands in Sumatra

Total area (in 1000 ha)																		
Peatland cover Sumatra	Undisturbed forest	Disturbed forest	Degraded peatland				Bare ground	Forest plantation	Perennial crops	Dry agricultural land	Paddy field	Water	Urban	Mining area	Fish pond	Airport	Cloud coverage	Total
			Dry shrub	Wet shrub	Savanna and Grasses	Open swamps												
Opening stock 1990	481	4159	106	617	7	38	33	7	378	317	192	5	30	6	1	0	1	6376
Additions	0	22	25	75	0	0	64	30	158	68	15	0	1	0	0	0	0	456
Reductions	30	357	2	37	0	0	1	6	0	20	5	0	0	0	0	0	0	456
1995/1996	450	3824	128	656	7	38	96	32	535	365	202	5	31	6	1	0	0	6376
Additions	0	2	49	608	59	26	131	16	421	91	10	0	4	1	6	0	3	1426
Reductions	73	1166	26	92	2	3	14	0	15	35	0	0	0	0	0	0	0	1426
2000	37	2659	150	1173	63	61	213	48	941	422	213	5	35	6	7	0	3	6376
Additions	50	94	19	292	0	0	344	225	81	7	2	0	0	0	1	0	0	1116
Reductions	26	673	17	267	6	0	91	12	15	8	0	0	0	0	0	0	1	1116
2005/2006	402	2081	152	1198	57	61	466	262	1007	421	214	4	35	7	8	0	2	6376
Additions	0	59	33	347	0	0	149	219	215	65	1	0	0	0	0	0	0	1087
Reductions	121	497	16	111	0	2	260	61	11	7	0	0	0	0	0	0	2	1087
2009/2010	281	1642	169	1434	57	60	355	420	1211	479	215	4	35	6	8	0	0	6376
Additions	0	50	64	166	0	10	183	493	201	154	3	0	0	0	0	0	0	1324
Reductions	56	435	134	405	6	22	158	50	13	20	25	0	0	0	0	0	0	1324
2014/2015	225	1257	100	1195	52	47	380	864	1398	612	192	4	34	7	8	0	0	6376

Table 6. Extent account of peatlands in Kalimantan

Peatland cover Kalimantan	Total area (in 1000 ha)																	
	Undisturbed forest	Disturbed forest	Degraded peatland				Bare ground	Forest plantation	Perennial crops	Dry agricultural land	Paddy field	Water	Urban	Mining area	Fish pond	Airport	Cloud coverage	Total
			Dry shrub	Wet shrub	Savanna and Grasses	Open swamps												
Opening stock 1990	113	3790	86	398	0	105	27	0	59	231	68	6	16	1	0	0	0	4898
Additions	0	19	12	435	0	102	23	1	33	30	46	0	7	0	0	0	0	708
Reductions	33	575	25	20	0	11	6	0	19	19	1	0	0	0	0	0	1	708
1995/1996	80	3234	73	814	0	196	44	1	73	243	113	5	22	1	0	0	0	4898
Additions	0	9	7	251	0	1	5	0	11	12	2	0	0	0	0	0	0	299
Reductions	11	265	0	8	0	0	4	1	1	7	2	0	0	0	0	0	0	299
2000	68	2978	79	1058	0	198	44	0	83	248	113	5	22	1	0	0	0	4898
Additions	0	52	4	274	0	29	21	0	48	26	5	0	0	0	0	0	0	459
Reductions	6	231	3	107	0	99	3	0	0	6	3	0	0	0	0	0	0	459
2005/2006	62	2799	80	1225	0	127	62	0	131	268	115	5	22	1	0	0	0	4898
Additions	0	1	5	139	0	2	41	1	126	11	10	0	0	0	0	0	0	337
Reductions	6	236	11	66	0	1	9	0	0	9	0	0	0	0	0	0	0	337
2009/2010	58	2565	74	1298	0	128	94	1	256	270	126	5	22	2	0	0	0	4898
Additions	0	14	3	86	0	1	119	29	81	15	1	0	0	1	0	0	0	349
Reductions	7	271	1	52	0	5	9	0	1	1	1	0	0	0	0	0	0	349
2014/2015	50	2308	77	1332	0	123	203	30	336	284	126	6	22	3	0	0	0	4898

4.2 Ecosystem condition account

4.2.1 Vegetation biomass

Table 7 summarises the total dry biomass matter in Sumatra and Kalimantan peatlands, estimated based on references in Annex 1. In a twenty-five-year period (1990 to 2015), 35% and 27% of total vegetation biomass was lost in Sumatra and Kalimantan, respectively. The loss of biomass was mainly caused by the LC changes as explained in the ecosystem extend account. Referring to data sources (Annex 1), the undisturbed forests have the highest biomass density (419 tdm/ha in Sumatra and 383 tdm/ha in Kalimantan), followed by disturbed forests (275 tdm/ha and 276 tdm/ha). Around 91% (Sumatra) and 95% (Kalimantan) of total biomass in 1990 was stored in the form of forests, but this number decreased to 46% and 76% in 2015. The converted areas such as plantation forest, perennial crops, agricultural and degraded lands only had a slight contribution to the additional biomass because of the low density of biomass. The loss from deforestation was much higher (Figure 5).

Table 7. Total vegetation biomass in Sumatra and Kalimantan peatlands 1990-2015.

Indicator	Peatlands in	1990	1995/1996	2000	2005/2006	2009/2010	2014/2015
Vegetation biomass (Mtdm)	Sumatra	1475	1409	1170	1079	991	965
	Kalimantan	1148	1015	959	928	887	835

Mtdm: Million tonne of dry matter

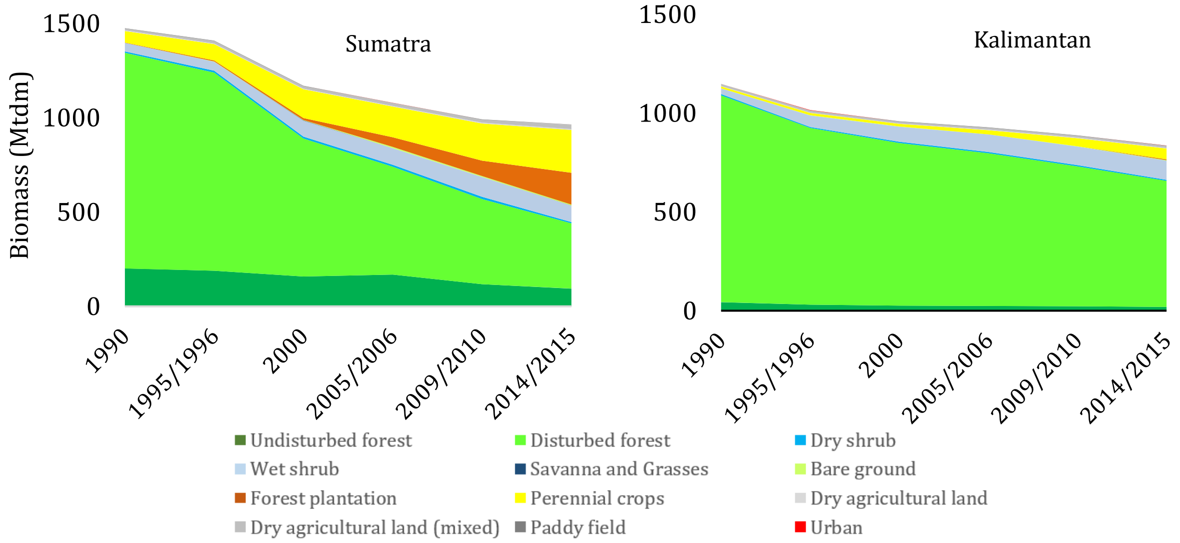

Figure 5. Total biomass (vegetation) in different land cover types of peatland in Sumatra and Kalimantan 1990-2015.

4.2.2 Groundwater level

The estimated groundwater level is retrieved using interpolation of the (limited set of) available data points. The result (Figure 6) shows that the annual average of water level in 2013 varied from 0-117 cm in Sumatra and from 0-96 cm in Kalimantan. The deepest drainage was in the areas of perennial crop, plantation forest, bare land and degraded peat swamp forest in the distance less than 500 m from those areas. It was deeper in north-eastern parts of Sumatra. The value of coefficient of variation (CV) of root mean square error (RMSE) for the model are 0.15 (Sumatra) and 0.19 (Kalimantan). These numbers are close to 0 (range 0-1) which means that the models are sufficiently accurate, with regards to representing the data points (see details in Annex 13).

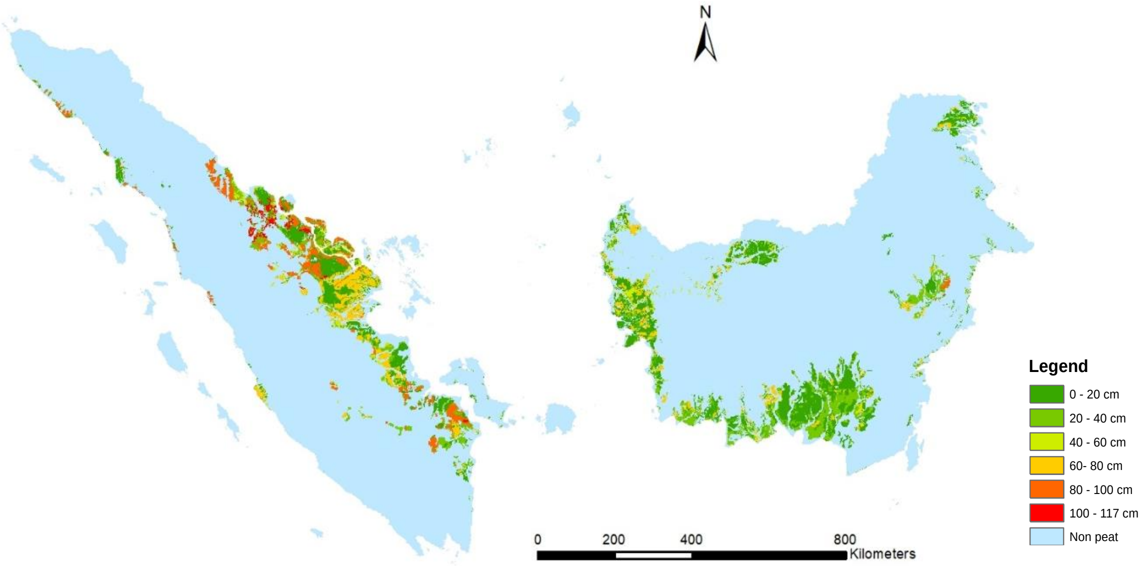

Figure 6. Estimated water level map of Sumatra and Kalimantan peatlands in 2013.

4.2.3 Hotspots

The hotspots are detected in different LC types (Figure 7). The highest percentage of total hotspots was in peatlands covered by wet shrub (33-45% in Sumatra, 46-57% in Kalimantan). Hotspots in Sumatra were also found in bare ground (10-22%), perennial crops (11-14%), disturbed forest (9-14%), and other LC types (below 10%). A significant increasing number of hotspots was showed in forest plantation from 1% in 2006 to 18% in 2014. Meanwhile in Kalimantan, other than in wet shrub, 17-25% of total hotspots was detected in disturbed forest, while other LCs experienced hotspots under 8% except the in perennial crops (14% in 2009 and 11% in 2014).

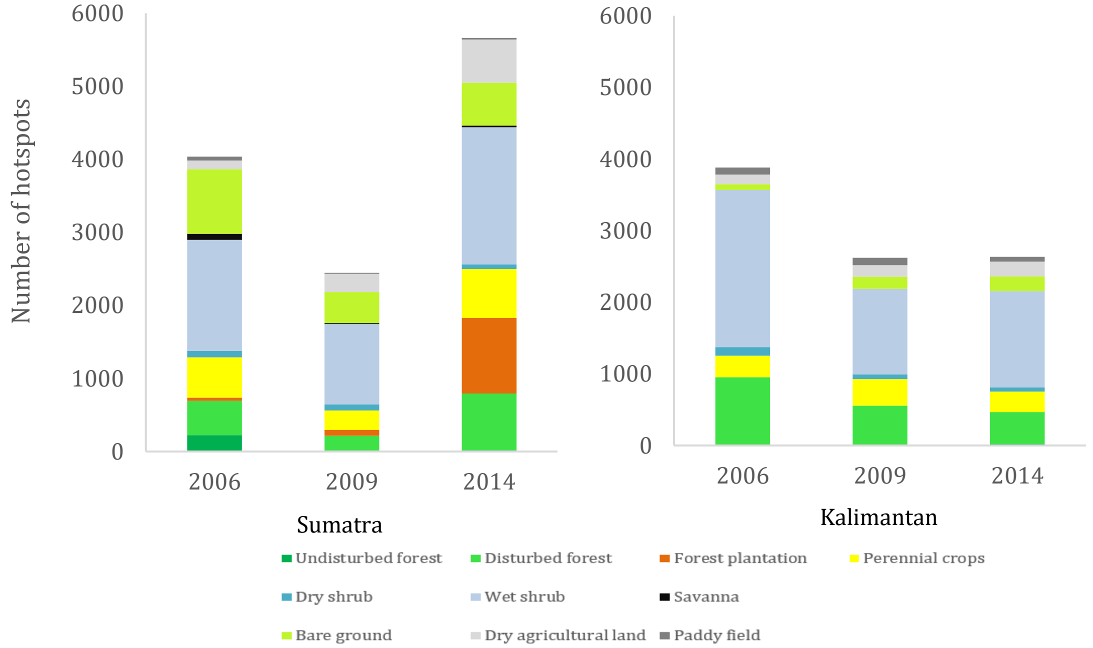

Figure 7. Number of hotspots (with confidence value ≥ 80%) in different land cover types of peatland in Sumatra and Kalimantan for 2006, 2009 and 2014.

MODIS reports uncertainty of hotspot measurements. The higher the applied confidence level, the lower the number of hotspots detected. Around 95-96% of total hotspots have minimal confidence level 30, meanwhile 42-55% of hotspots was found in the higher level (confidence level ≥80). The total hotspots also vary temporally. In total, the least number of hotspots was during 2009, and the highest ones were in 2006 and 2014. A lower number in 2009 could be affected by a La Niña phenomenon in the previous year, where the climate condition of Indonesia is wetter than average (see details about ENSO years in Annex 11). The spatial distribution of hotspots can be seen in Annex 2.

4.3 Ecosystem service account

Table 8 shows the physical values of five ES estimated based on MoEFRI land cover data. The values of three ES, timber production, CO_2 sequestration and protected habitat decreased since 2000. Timber production in Sumatra and Kalimantan peatlands went down by 59% and 27%. The total CO_2 sequestration declined by 40% (Sumatra) and 26% (Kalimantan) while the total protected habitat was narrowed by 6% (Sumatra) and 11% (Kalimantan). On the other hand, the expansion of forest plantation led to the increasing of total biomass (acacia) production dramatically, in particular Sumatra, from 1 Mt/year in 2000 to 18 Mt/year in 2015. Besides, the results show no notable change on paddy production. The production of paddy has slightly increased from 2000 to 2010, then remained constant (in Kalimantan) and has decreased (in Sumatra) in 2015. The spatial distribution of each ES can be seen in Annex 7.

Table 8. Physical values of ecosystem services in Sumatra and Kalimantan peatlands.

ES specification	Unit		Physical value of ES			
			2000	2005/2006	2009/2010	2014/2015
Timber production	1000 m^3/year	Sumatra	1893	1482	1094	777
		Kalimantan	794	741	666	576
Biomass production for pulp	1000 t/year	Sumatra	1011	5503	8833	18161
		Kalimantan	0	2	24	624
Paddy production	1000 t/year	Sumatra	620	625	627	561
		Kalimantan	192	196	214	214
CO_2 sequestration	1000 t/year	Sumatra	7175	7629	5337	4282
		Kalimantan	1299	1182	1099	958
Protected habitat	1000 ha	Sumatra	442	451	423	416
		Kalimantan	892	851	816	794

Table 9. Monetary values of ecosystem services in Sumatra and Kalimantan peatlands.

ES specification		Monetary value of ES (IDR billion/year)			
		2000	2005/2006	2009/2010	2014/2015
Timber production	Sumatra	1278	1001	739	525
	Kalimantan	536	500	450	389
Biomass production for pulp	Sumatra	95	518	831	1709
	Kalimantan	0	0	2	59
Paddy production	Sumatra	1510	1522	1526	1365
	Kalimantan	338	344	375	376
CO_2 sequestration*	Sumatra	2498	2656	1858	1491
	Kalimantan	452	412	383	334
Protected habitat	Sumatra	-	-	-	-
	Kalimantan	-	-	-	-

Comparing the monetary value of five ES in 2000, CO_2 sequestration had the highest value, following by paddy production and timber production (Table 9). Note that if a restoration cost approach would be followed to value biodiversity based on the values presented in the previous section, then this service would have the highest value (reflecting the high costs of restoring peatlands). Due to the decreasing physical values of timber production and CO_2 sequestration over time (related to land conversion), the monetary values of these ES went down as well. Timber production that provided IDR 1,814 billion throughout 2000 decreased to IDR 914 billion in 2015, the lowest value among five ES.

Oil palm production

Table 10 explains the total area of oil palm plantation in peatlands from several data sources. According to the references (Annex 3), there were only 0.6 Mha (Sumatra) and 840 ha (Kalimantan) of oil palm plantation in 2000. The areas of plantation in both islands expanded dramatically, and in 2014, they took 22% and 10% of total peatlands in Sumatra and Kalimantan. In total, there were 1.9 Mha of oil palm plantation in peatlands in 2014.

Table 10. Total area of oil palm plantation in Sumatra and Kalimantan peatlands in 2000, 2005, 2010, and 2014

ES specification		Total area in peatland (1000 ha)			
		2000	2005/2006	2009/2010	2014
Oil palm production	Sumatra	621[a]	1007[b]	1210[a]	1414[c]
	Kalimantan	1[a]	131[b]	256[a]	480[c]

[a]: estimated from Gunarso et al. [34], the values were adjusted from Wetlands International map [62, 63] with estimated peat area of 20.8 million ha to MoARI map (14.9 million ha of peatland);[b]: the total area of perennial crops of LC map of MoEFRI, we used this source because estimated oil palm plantation in peatland from Gunarso et al. [34] in 2005 and 2010 was larger, which could be located in other LC; [c]: estimated from plantation map from WRI and Transparent World [37], overlaid with peatland map from MoARI (see details in Annex 3).

The expansion of oil palm plantation resulted to the increasing of total production. It is estimated that there were 32 Mt of FFB produced in 2014, triple times higher than the total production in 2000. The estimated economic value of the production reached IDR 4,336 billion in 2014, of which 93% was produced in Sumatra peatlands (Table 11).

Table 11. Physical and monetary value of oil palm production in Sumatra and Kalimantan peatlands in 2000, 2005, 2010, and 2014

ES specification		Physical value (1000 t FFB/year)				Monetary value of ES (IDR billion/year)			
		2000	2005/ 2006	2009/ 2010	2014	2000	2005/ 2006	2009/ 2010	2014
Oil palm production	Sumatra	10389	16837	20242	23635	1764	2858	3436	4012
	Kalimantan	14	2185	4282	8022	1	88	173	324

4.4 Carbon account

4.4.1 Carbon stocks (vegetation)

Table 12. Total carbon (CO_2-eq) stocks as vegetation in Sumatra and Kalimantan peatlands 1990-2015.

Indicator	Peatlands in	Mt CO_2-eq /year					
		1990	1995/1996	2000	2005/2006	2009/2010	2014/2015
Carbon stock (vegetation)	Sumatra	2707	2585	2148	1980	1819	1770
	Kalimantan	2107	1862	1759	1702	1628	1533

Deforestation and land use changes in peatland lead to the decrease of carbon stored in vegetation. Table 12 explains that vegetation of peatlands in 1990 stored around 4.8 Gt of CO_2-eq, however, 31% (1.5 Gt of CO_2-eq) of this stock was lost in 2015. Spatially, the decrease in carbon stocks was found in every province as seen in Figure 8. The extensive green areas (indicating high carbon stocks) in 1990 faded in next twenty-five years (2014/2015). The largest carbon loss was detected during the first period (1990-1995/1996) and second period (1995/1996-2000), Afterwards, the rate of total carbon loss decreased.

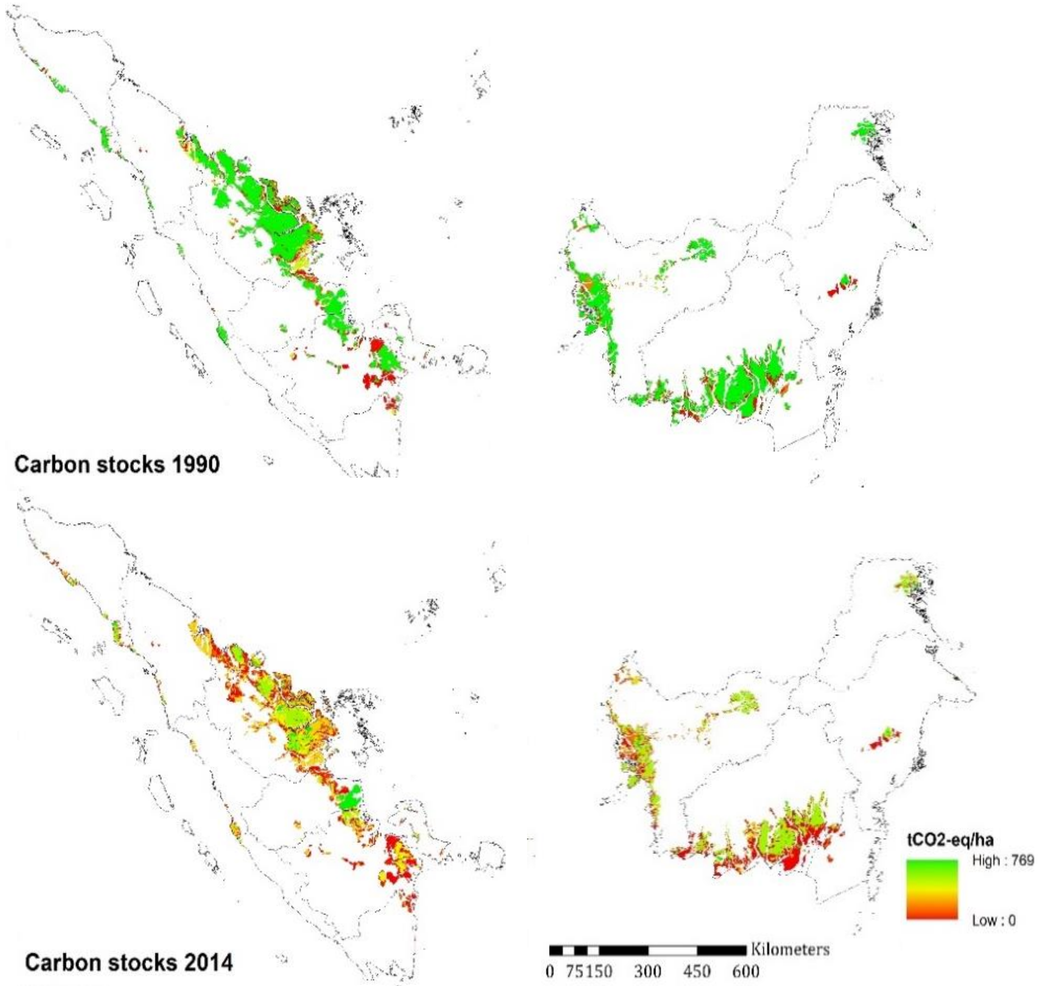

Figure 8. Spatial distribution of carbon stocks (vegetation) in Sumatra and Kalimantan peatlands in 1990 and 2014.

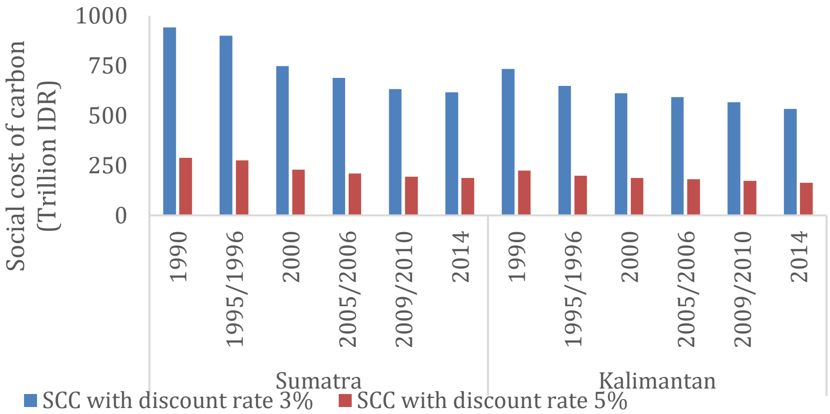

Figure 9. Social cost of carbon of carbon stocks (vegetation) in peatlands of Sumatra and Kalimantan 1990-2014/2015.

Decreasing of carbon stocks in peatlands lead to the increasing of damage costs of releasing carbon as emissions by the vegetation in peatlands. Figure 9 explains that based on SCC, peatlands of both islands are valued 1676 Trillion IDR (discount rate 3%) or 512 Trillion IDR (discount rate 5%) in 1990. These numbers went down significantly to 1150 Trillion IDR (discount rate 3%) or 351 Trillion IDR (discount rate 3%) in 2014/2015. The estimated cost of damages from carbon stock loss during the period was about 526 Trillion IDR (discount rate 3%) or 161 Trillion IDR (discount rate 3%).

4.4.2 Carbon emissions

Oxidation (estimate)

Indicator	Peatlands of	Mt CO_2/year					
		1990	1995/1996	2000	2005/2006	2009/2010	2014/2015
Sequestration	Sumatra	9	9	7	8	5	4
	Kalimantan	2	2	1	1	1	1
Emissions	Sumatra	-140	-155	-185	-202	-230	-276
	Kalimantan	-93	-96	-96	-100	-109	-116
Total	Sumatra	-131	-146	-178	-195	-225	-272
	Kalimantan	-91	-94	-95	-99	-108	-115

Table 13. Total CO_2 sequestration and emissions (from oxidation) in peatlands 1990-2015.

Table 13 displays the net carbon flux (sequestration and emission) from peatlands in Sumatra and Kalimantan based on referenced data (Annex 5). The estimated values also include the emission effected from drainage but not cover the emissions from peat fires. The total carbon fluxes were negative, indicating that CO_2 emissions were higher than the sequestrated CO_2. In total, net CO_2 emissions from peatlands in Sumatra and Kalimantan from drainage were 222 $MtCO_2$/year in 1990, then increased by 74% to 387 $MtCO_2$/year in 2015. Around 70% of total CO_2 emissions were released from Sumatran peatlands.

Based on SCC, the estimated cost of damages of the carbon emissions released due to oxidation (Figure 10) in peatlands in 1990 was around 77 Trillion IDR (discount rate 3%) or 23.6 Trillion IDR (discount rate 5%) in total. In 2014/2014, the cost increased as the total emission went up by 74% or 57 Trillion IDR (discount rate 3%) or 17.5 Trillion IDR (discount rate 5%).

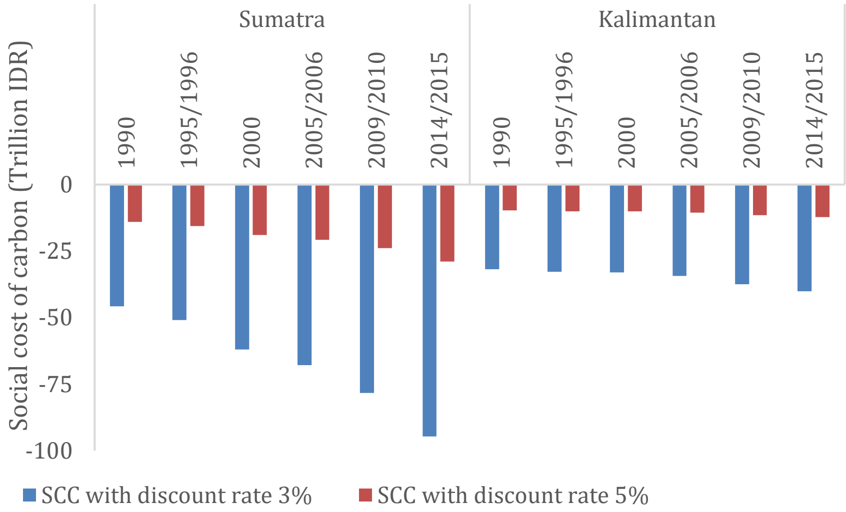

Figure 10. Social cost of carbon of carbon (CO_2-eq) emissions from oxidation in peatlands 1990-2014/2015.

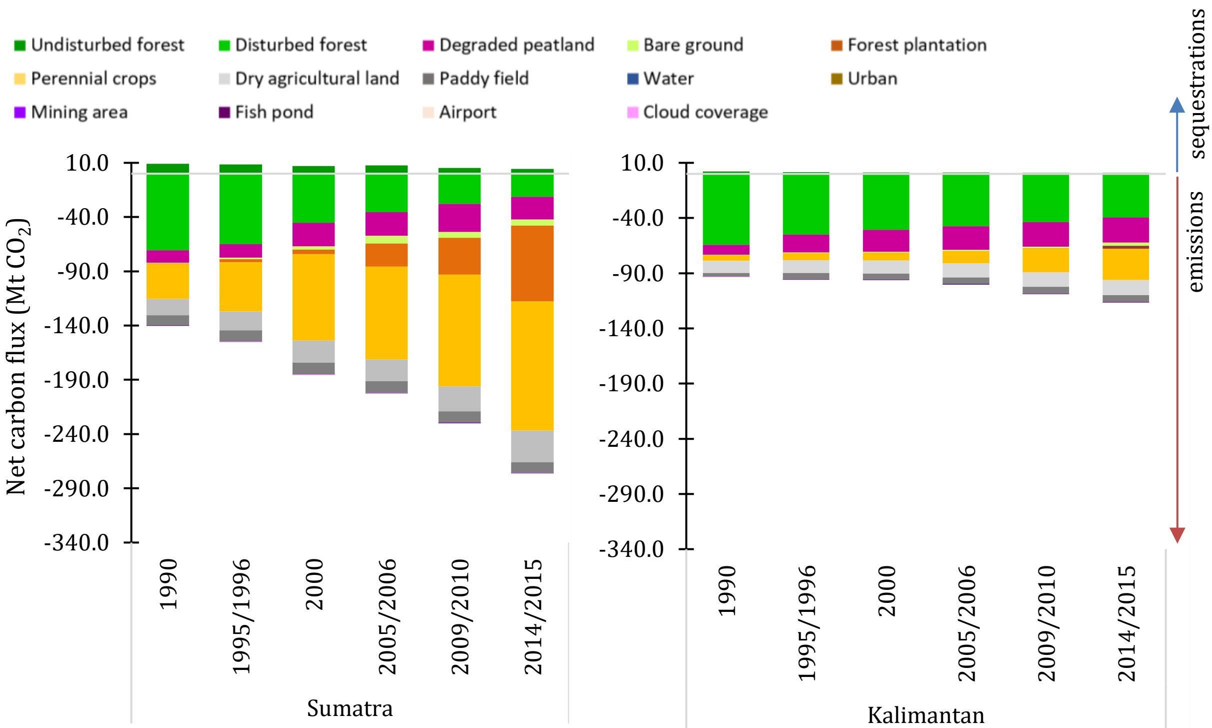

Figure 11. Trend of CO_2 emissions and CO_2 sequestrations in Sumatra and Kalimantan peatlands 1990-2015 based on land cover types. The bars depict the emission from each land cover type. These emissions are a function of drainage. Note that it is assumed that all plantations and dry agricultural land are drained. Disturbed forests and degraded peatlands only emit CO_2 when they are drained.

In Sumatra, perennial crops and forest plantations contributed to 43% and 25% of total CO_2 emissions in 2015 (Figure 11). Note however that this assessment is based on the MoEFRI land cover map. In case the MoEFRI map underestimates the area covered with plantations, the contribution of plantations to these emissions may be higher. Depending upon accuracy of the land cover map, this is a very relevant policy finding – in particular that 32% of CO_2 emissions from peatlands in Sumatra are not from oil palm, hevea or plantation forestry peatlands but from other land, in particular degraded land and drained forest edges close to plantations. These areas should be a first priority for rehabilitating peatlands since their rehabilitation would make a very large contribution to reducing global CO_2 emissions and not cause losses of crop production. The expansion of plantations in Kalimantan peatlands, in 2015, was not as significant as in Sumatra, and this sector (both perennial crops and forest plantation) contributed to 22% of CO_2 emissions in 2015. Around 34% of CO_2 emissions in Kalimantan was released from drained forests and 20% from drained, degraded lands. Restoring the hydrology of these areas should be a global priority in the mitigation of climate change, given the magnitude of emissions involved, the irreversibility of the effects of drainage, and the low costs of restoration compared to the carbon volumes involved.

Peat fires

Table 14 presents the total burned peatland areas and the carbon emission emitted from burned peat. Compared to the value of net carbon flux in the previous section, carbon emissions from peat fires were much higher, 704 Mt CO_2-eq in 2006), 508 Mt CO_2-eq in 2009), and 610Mt CO_2-eq in 2014. Although the total peatland in Sumatra is larger than in Kalimantan, the results show that the carbon emissions from Kalimantan peatlands were higher due to larger burned areas every year.

Table 14. Total burned peatlands and total carbon (CO_2-eq) emissions from burned peat in Sumatra and Kalimantan in 2006, 2009, and 2014.

Peatlands in	Total burned peatlands (1000 ha/year)			Carbon emissions from peat fires* (Mt CO_2-eq)/year		
	2006	2009	2014	2006	2009	2014
Sumatra	345	198	310	318	183	286
Kalimantan	418	352	351	386	325	324

Method are taken from MoEFRI [48] *estimated 33-cm burned peat depth for all types of LCs.

Based on SCC, high carbon emissions from burned peat cause loss which were estimated costed 184-256 Trillion IDR (discount rate 3%) or 56-78 Trillion IDR (discount rate 5%) each year in total (both islands, Sumatra and Kalimantan).

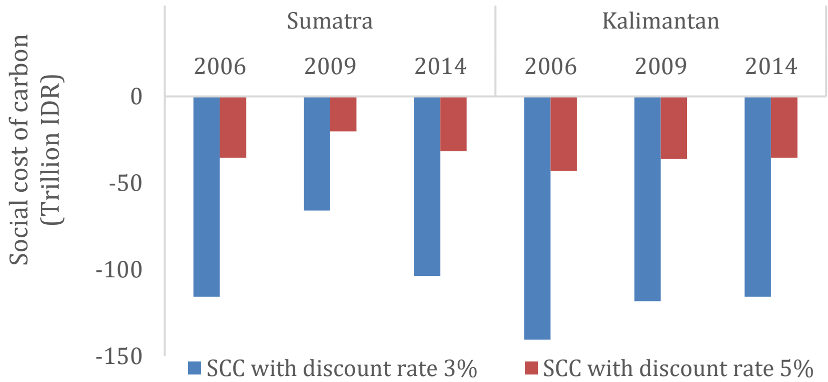

Figure 12. Social cost of carbon of carbon (CO_2-eq) emissions from burned peat 1990-2014/2015

Figure 13 presents the CO_2-eq emissions from different types of LC. Similar to the pattern of hotspot distribution, the highest emissions were from wet shrub 26-58% in Sumatra and 60-83% in Kalimantan. The details for the spatial distribution of burned scars can be seen in Annex 9.

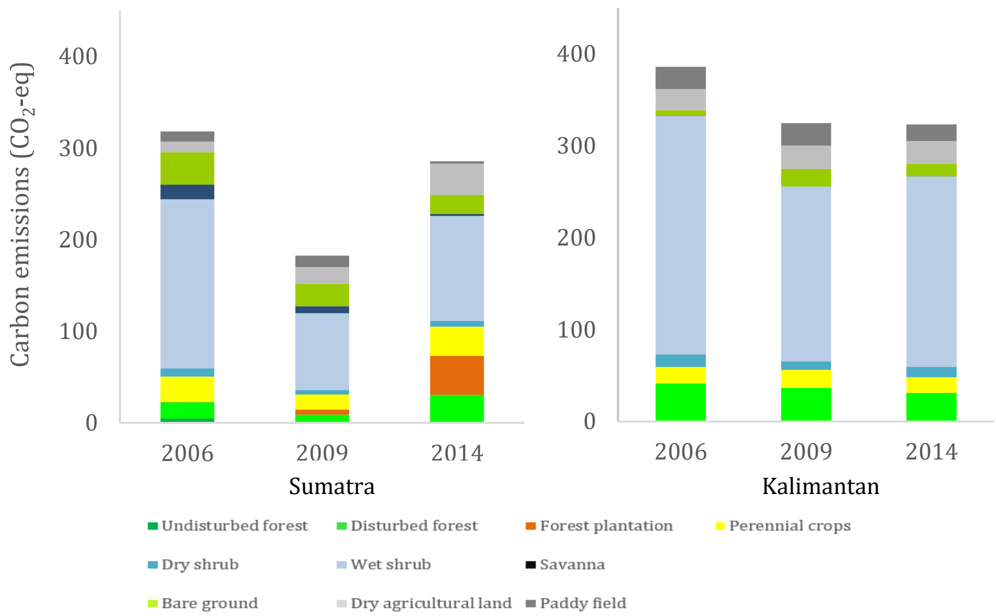

Figure 13. Carbon (CO_2-eq) emissions from burned peat in several types of peatland covers in 2006, 2009, and 2014. Note that the emissions were from 33-cm burned peat, applied for all types of land cover. Note that the land cover classes were attributed based on the MoEFRI or KLHK land cover map.

Chapter 5. Discussions

5.1 Uncertainties and Limitations

Peatland map and land cover maps

There are several sources of uncertainty in this pilot ecosystem account. The first concerns the peatland area and land cover data. Several peatland maps have been published in the period 1952-2016 by different authors (and using different assumptions and methods) with total areas reported varying from 13 Mha to 26.5 Mha [6,16]. The account uses the peat map of the Indonesian government, BBSDLP, MoARI, which is the result of combined analyses of Landsat and ground survey data with 2,409 observation points for peat thickness and maturity [16]. Comparing to the other versions of peat map from Wetland International ([62, 63, 64]) for example, the total peatlands in MoARI map are 5.7 Mha smaller. In addition, the same peat map is used for the whole period of analysis (1990-2015). This means that the assumption is that the peatland areas have remained the same and the changes of the spatial distribution and peat characteristics including peat depth are excluded [16].

Also, as mentioned, the account is based on land cover data from MoEFRI. In this dataset, information on land cover for the year 2010 is partly based on remote sensing images of 2009; and information for the year 2015 is partly based on remote sensing images of 2014. Hence, the land cover changes are underestimated in this account (since there will in some areas have been further land use conversion from 2009 to 2010 and from 2014 to 2015). This underestimation may lead to an inaccuracy in the land cover data (affecting also the accounts for ecosystem services and carbon stocks and emissions).

Second, there are uncertainties in land cover in peatlands, related to the accuracy of land cover maps from the MoEFRI. Over time these maps have been increasing in quality, with particularly for the years before 2000 a somewhat higher uncertainty due to a lack of ground truth data. With the improvement of methodology, the newest map (2015) reached overall accuracy 67% (forest) and 93% (non-forest) using stratified random sampling approach ([18] as reviewed in the report of FAO [19]). These uncertainties, as reported by the government of Indonesia, are confirmed when the peat map is compared with the land cover map. For instance, some (relatively small) areas are classified as mangrove in the land cover map and peat in the peat map, mostly in Papua (which is not ecologically consistent). In addition, some inconsistencies are found between the government maps and the maps of WRI and OFI (as explored in Annexe 8). In particular, some parts of plantation areas indicated in WRI and OFI maps are located outside the plantation area of MoEFRI maps.

Satellite products

Satellite products are commonly used due to large coverage area and data scarcity in the field. Satellite products are also applied in this study, in particular to estimate the number of fire hotspots and burned area in peatlands. The gridded 500m burned area products from MODIS were used in the carbon account to estimate burned peatlands. Hotspot data from MODIS have an accuracy of 64-84% in estimating fire occurrence in Indonesia (66% for peatlands), when compared to higher resolution maps such as SPOT-4 images and SPOT-5 [65, 66]. However, this accuracy is higher than another hotspot product, Indofire hotspot product [65]. In response, this account, in line with government practices, uses only MODIS fire detection data with a high confidence value (≥80, around 45% of total hotspots). Note that this may lead to an underestimate of hotspots, since also areas with a lower confidence value may have been subject to fire [65, 67].

Further improvement of methods and data to estimate peat fire occurrence in Indonesia is needed. There is a new fire product from NASA, called VIIRS I-Band 375 that has a finer spatial resolution (375 m) than MODIS, available from 2012 to present [68]. It is recommended to validate this data source in order to increase the accuracy of hotspot monitoring in Indonesia [69] [70]. Note also that it was found that burned area products from MODIS perform better than other products like L3JRC, even though MODIS product could underestimate the burned area in the forest [71].

Data scarcity
Lack of available ground truth information is also a main source of uncertainty. First, there was a lack of sufficient data points to estimate groundwater level. The groundwater level varies within and between land cover classes, in peat in particular as a function of drainage. More data are available on groundwater levels in peat (e.g. with Deltares and Hokkaido university) but in spite of repeated requests data holders were not willing to share any data for the peat account. Ultimately, the account has been based on 206 measurement points of groundwater levels in peat in combination with an extrapolation process that considers land cover and distance from (drained) plantations. Further improvements to the account are possible if access to more data are provided.

Second, the ecosystem service (ES) account has uncertainties related to the flows of ecosystem services. This study tries to develop the account by using governmental data. However only data of market prices can be accessed in some governmental publications. Information regarding average production rate of provisioning services are also available, however as average value, not specifically from particular ecosystem type (peatland). Therefore, data from research articles were applied (Annex 4, 5, and 6). Still, the available data are generalised at island (Sumatra and Kalimantan) and national level, not at specific area (provincial or district level) due to the limited number of sources. Further refinements would be possible with inserting production data specific for peatlands.

Uncertainty is also found in the combustion and emission factor for carbon emissions [71]. It is assumed that all categories of LC have the same value, and that the emission factor is only a function of burned peat depth and standing biomass (not of the type of vegetation). However, this could affect the accuracy of the results because the depth of burned peat could vary between 25 and 85 cm [72] in different LC types. Compared to other sources, the total carbon emissions estimated in this account are lower number than the estimation in [10, 72] (value in 2006) but higher numbers than recent estimates by FAO (http://www.fao.org/faostat/en/#data)[73]. The estimation of this study and FAO used the same burned product MODIS, but different land cover data and emission factors [73, 59, 74], see details in Annex 12).

Possible improvements
This pilot study does not yet cover all aspects relevant for managing peat ecosystem, including for instance a lack of information on the hydrological ecosystem services provided by peatland, and a lack of information on the health effects of peat fires. In addition, more data would increase the quality of the accounts, in particular on fire occurrence and drainage depth. Additionally, more provisioning services such as rattan and sago cultivation could be included. Also, the habitat service could be mapped in more detail, for example by including habitats for two iconic species occurring in the peatlands, tiger and orangutan. The effects of seasonal flooding in subsided peatlands (already occurring in parts of Sumatra) and the effects of further soil subsidence on crop production should be included in an ecosystem asset account that would be an important

part of a peat account (reflecting the natural capital contained in the peat ecosystems, under current management). Furthermore, the accounts should be extended to Papua to inform land management (and rapid land use change) in this part of the country. Lastly, MoEFRI has published a new map of peat hydrology unit (called KHG in Indonesian) with finer resolution (1:50,000). This map could be applied (reanalysis) to improve the certainty of total peat area in Indonesia, therefore the quality of the results of peat accounts can be improved.

5.2 Policy applications

By integrating and reporting on various aspects of environment and human activities in peat ecosystem, the pilot ecosystem accounts can support a range of policies in Indonesia.

First, the accounts can support the rehabilitation of peatlands. Formed in 2016, the peat restoration agency (BRG) has a target to restore approximately 2.5 Mha degraded peatlands by 2020 (SK.05/BRG/Kpts/2016)[15]. Pilot ecosystem accounts for Indonesian peatlands can facilitate identifying areas that can be considered a priority for rehabilitation for example because they emit high amounts of carbon and do not have a productive use at present. This can help increase effectiveness and efficiency of the BRG work programme. Also, the accounts can support monitoring the peat restoration activities and the impacts of changes that have been implemented. In particular, the peat accounts can support the local, provincial governments and the BRG in monitoring the progress of the restoration program. This pilot account presents maps for the two islands, but the resolution is high (30m grid size) and local level maps can also be produced using the same data. These data can support activities at district or provincial level including monitoring and reporting land-cover change in degraded peatlands, vegetation rehabilitation, restoration of hydrology, and rehabilitation of carbon sequestration and storage[13, 75].

Second, the pilot ecosystem accounts can support projects of the MoFRI on financial reporting of natural resources use (policy under development), and of the MoEFRI on assessing the Carrying Capacity and Resilient Power in the Environment (DDDTLH) under regulation (UU) No.32/2009. These are basic information sets for planning and development control supporting related policies including the preparation or evaluation of spatial plans (RTRW), long-term and medium-term development plans (RPJP and RPJM) as well as policies, plans and/or programs that have potential to impact and/or risk the environment through a Strategic Environmental Assessment (KLHS). The pilot ES account in this study is consistent with the project since ecosystem services are the main method used in DDDTLH, and peatland is one of the targeted ecosystems in this policy instrument. The developed ES account can be used to facilitate further analysis concerning land use planning in diverse types of ecosystem. Comparing ES values between peatland and mineral soil, for example. It is found that oil palm plantation in peatland emits high CO_2 emissions but produces less around 12-18 tFFB/ha/year, which is classified as the third class of oil palm production in mineral soil [77-79]. Furthermore, the production costs of plantation in peatland are much higher compared to in mineral soil. This is mainly because there are additional costs for drainage and for constructing and maintaining infrastructure (for example roads need more regular upkeep in peat areas due to subsidence) [35, 36]. Note also that the basic framework of ecosystem accounting is flexible. The list of ecosystem services can be adjusted depending on the priority of policy and location.

Third, peatlands in Indonesia contribute substantially to the total carbon (CO_2) emissions of the country. The carbon account in this study can support the National Action Plan to Reduce

Greenhouse Gas (GHG) Emissions as per Presidential Decree No.61/2011, by monitoring carbon emissions from peatlands. Furthermore, the carbon account facilitates monitoring not only the carbon emissions, but also the change of carbon stocks. Both carbon stocks and emissions are also related to the National forest reference emissions level for REDD+, in the Context of Decision 1/CP.16 Paragraph 70 UNFCCC [48]. The carbon account provides very detailed and spatially explicit information by combining several sources of carbon stocks for all land cover classes of peatland, in combination with models for estimating carbon emissions from peat drainage and fire.

Fourth, the peat account can support the design of fiscal transfer programs. The Government of Indonesia is currently considering if and how the sustainability of natural resource management could be an indicator to be considered as a basis for evaluating the performance of district governments. The peat account provides information on, for example, the sustainability of land use, fire occurrence or CO2 emissions by district (for those districts that have peat soils in their territory).

Another relevant application is the payment for ecosystem services (PES) in Indonesia. There are at least fourteen regulations and several projects that are related to the application of PES in Indonesia [80]. Ecosystem services implemented for PES projects in Indonesia are mostly related to preserving regulation and cultural services such as watershed protection, landscape/seascape beauty, recreation/biodiversity and carbon sequestration. The results (ES account) of this study are consistent with the potential application of PES in Indonesian peatlands, particularly for carbon sequestration, watershed protection and biodiversity habitat. The framework is flexible to be applied depending on the data availability and policy priority, not limited by the listed ecosystem services. The accounts can be used both to use the effectiveness of the payments (in terms of actual changes in ecosystems compared to nearby ecosystems) and to analyse co-benefits (e.g. of REDD+ projects).

Chapter 6. Conclusions

The pilot ecosystem account for peatlands is developed to test the SEEA EEA framework for a specific, highly policy-relevant ecosystem. Data were available to produce four pilot ecosystem accounts (extent, condition, services, carbon) for peat ecosystems in Sumatra and Kalimantan for multiple years in the period 1990-2015.

The ecosystem extent account summarises the trend of land cover changes spatially and temporally. The overlay of the peat distribution map and the land cover maps provide information on seventeen peatland land cover categories. The results show that the trends in land cover change in Sumatra and Kalimantan are different. The conversion of peat forests in Sumatra started earlier than in Kalimantan, and has been more thorough, to date. In the period 1990 to 2015, Sumatra has lost 47% of peat forest while in Kalimantan this was 32%. As a result, according to government data, in 2015, Sumatran peatlands were covered dominantly by plantation and agricultural land (48%). Meanwhile, only 16% of Kalimantan peatlands was covered by plantation (7%) and agricultural land (8%), in 2015. However, land cover change is still ongoing in Kalimantan whereas it has slowed (but not stopped) in Sumatra.

The condition account comprises three key indicators for the state/health of peatland ecosystems (vegetation biomass, water level and fire hotspots). The condition account shows both temporal (1990-2015) and spatial patterns (30m grid) in these indicators. The account shows that land cover change evokes a reduction in total above ground biomass in the ecosystem – since annual and perennial crops and plantation forests have overall a much lower standing biomass than natural forests. The account shows that groundwater levels in peatlands in Indonesia range from 0 to 117 cm – for the points for which data were available. In undrained forests, the annual average groundwater table is close to the surface (allowing the peat to keep on accumulating carbon) and in plantations and drained, degraded lands the groundwater level varied from 30 to 117 cm. The deepest drained areas where the located in the north-eastern part of Sumatra. The recording of fire hotspots (based on MODIS) also provides a number of insights relevant for peat management. First, there were no fire hotspots in forests located at least 500m away from plantations where water tab les are still high. The number of fires was highest in drained, degraded (i.e. unused) peatlands followed by annual and perennial croplands and forestry plantations. Also, in the peatland zones close (<500 m) to the plantations, where forests are heavily degraded, and land is drained due to spill-over effects of drainage in plantations (near a drained area, the groundwater table reverts to close to the surface over a distance of around 500 meters), there are frequent fires. Draining and converting these lands to plantations, of course, does not solve the problem since this case the next strip of land to become drained and vulnerable to fire. Lastly, the number of hotspots varies considerably from one year to the next. It was highest in 1997 and 2017 (years not covered in the accounts) when there was an El Nino effect, and relatively low in 2015 which was a year in which the rainfall patterns were dominated by ENSO.

The ecosystem service account includes the physical and monetary values of the main services provided by peat ecosystem in Indonesia. The expansion of plantation and agricultural areas has led to increased agricultural production of, in particular, oil palm and acacia biomass (for pulp). On the other hand, there was a decline in timber production, CO_2 sequestration and in the area of protected peatland as biodiversity habitat. It is noted that the monetary values in the account do not cover all aspect of ecosystem services in peatlands. It is also not an indicator of sustainability since the externalities and ecosystem disservices were not quantified.

Lastly, the carbon account points to the contribution of Indonesian peatlands to greenhouse gas emissions in the country. The results indicate that peatland in Indonesia is a large source of carbon emissions. The total emissions from peat oxidation have increased over time while also fires in peatland release high carbon emissions every year, depending on the total burned area. In addition to this, the carbon account also shows that the total carbon stocks in above ground biomass (vegetation) have been decreasing.

The pilot peatland account has numerous potential policy applications including the monitoring of ongoing land conversion in peatlands and the success of rehabilitation programs (in terms of both area and positive impacts achieved on CO_2 emissions and ecosystem services). The accounts can also support local land use planning. In particular, the peatlands can identify areas that are of priority for rehabilitation because they lead to high CO_2 emissions and have a low current productive use. It is also helpful for local governments including district and provincial level governments) to have access to the peat account for their jurisdiction, and at high resolution. This would assist local governments with better managing peat resources for example by supporting the allocation of permits to convert (or decisions to protect) land, and by allowing them monitoring of economic impacts of peat uses. Various projects indicate that local governments often have a major lack of information on peat (location, depth, CO_2 emissions, biodiversity) and that their management decision are hampered by a lack of such information.

It is also recommended to explore how the account (at high resolution) can be made available to local governments, potentially using a specific app/ tool with which information can be downloaded for specific areas of interest (e.g. a district, province, or part thereof). This because detailed information on land use, ecosystem services and natural capital is often lacking at lower government levels (provinces, districts) – where nevertheless much of the policy making and implementation on land use is conducted. Furthermore, the condition account could be expanded with the location of peat domes (an important aspect to be considered in peat management, data are available but have not yet been included in the account) and the location of canals (data are available for part of the country, including at BRG). In addition, it is recommended to update the account to a recent year, for example 2017 and potentially to add more ecosystem services (e.g. water regulation, control of fires and avoiding health effects from smoke, supply of non-timber forest products, and habitat for key species such as tiger and orangutan).

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Annexes

Annex 1. Estimated carbon stocks in vegetation by land cover type

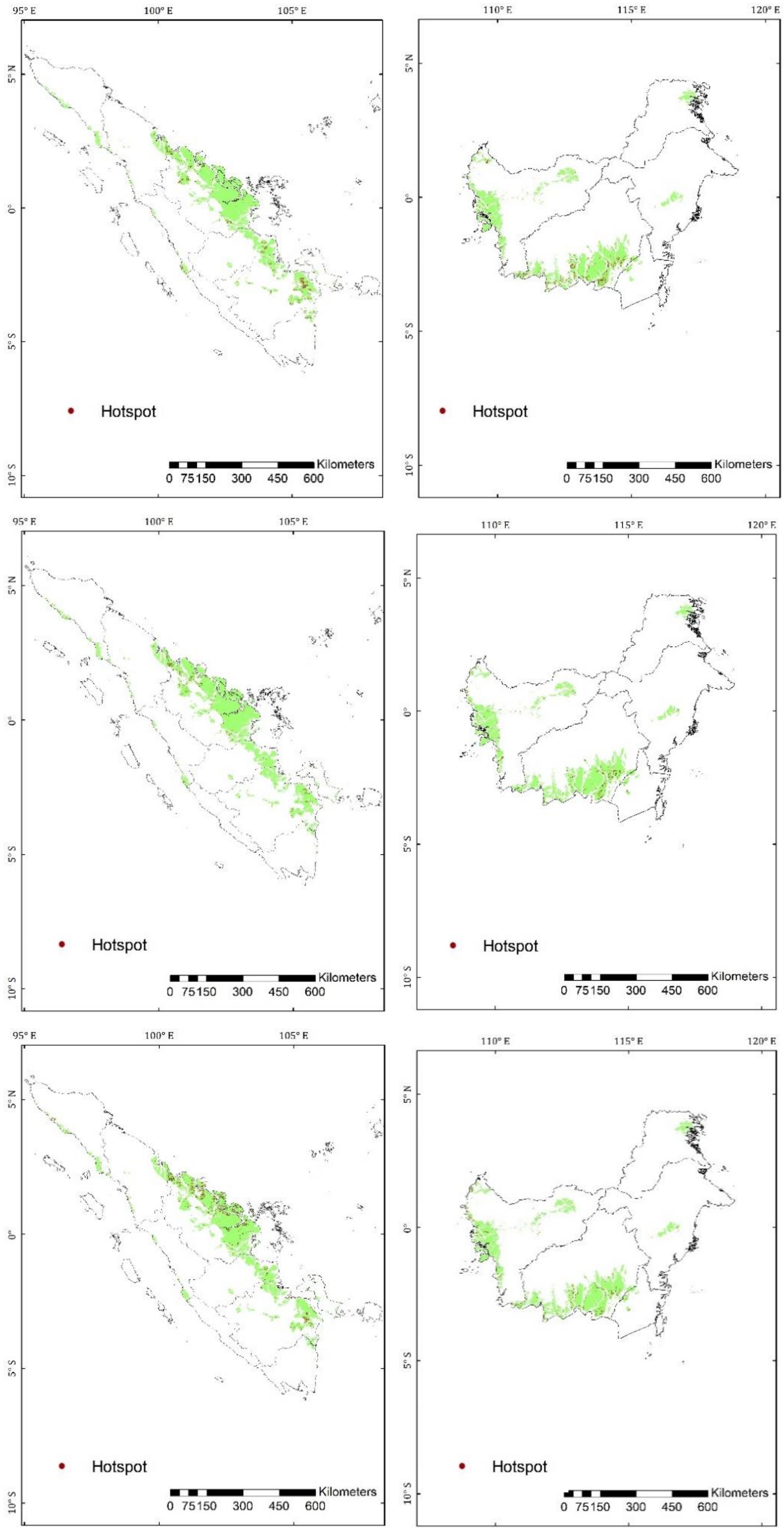
Land cover		Carbon stocks (tC) in			
		AGB	Root	Dead wood	Litter
Primary peatland forest	Sumatra	157.1 [a]	27.7 [a]	1.95 [a]	22.75 [a]
	Kalimantan	125.95 [a]	34.55 [a]	2.45 [a]	28.4 [a]
Secondary peatland forest	Sumatra	96.15 [a]	19.2 [a]	1.95 [a]	20.1 [a]
	Kalimantan	91.65 [a]	21.65 [a]	2.2 [a]	22.65 [a]
Plantation forest	Sumatra	76.7 [b]	18.2 [d]	n.a.	2.9 [e]
	Kalimantan	54.7 [b]	18.2 [d]	n.a.	2.9 [e]
Perennial crops		63 [c]	11 [d]	5.2 [f]	1.8 [e]
Settlement		4 [c]	1 [d]	n.a	n.a
Transmigration areas		10 [c]	1 [d]	n.a	n.a
Bare ground		2.5 [c]	4 [g]	n.a	n.a
Savannah		4 [c]	2 [d]	n.a	n.a
Dry agricultural land		10 [c]	1.0 [d]	n.a	n.a
Dry agricultural land (mixed)		30 [c]	1.0 [d]	n.a	n.a
Paddy field		2 [c]	1.0 [d]	n.a	n.a
Open water/mining area/open swamp		0 [c]	n.a	n.a	n.a
Shrub		30 [c]	3.9 [d]	1.8 [f]	0.6 [e]

Notes: n.a: data are not available.

[a]: [44]; [48]. [b]: [81] as reviewed in [45]. [c]: Juknis PEP RAD GRK (2013) as reviewed in [45]. [d]: Estimated from above ground carbon based on the ratio from GOFC-Gold [82] as reviewed in [83]. [e]: Estimated from above ground carbon based on the average ratio from [84] and [85] as reviewed in [83]. [f]: Estimated from above ground carbon based on the ratio from [86] as reviewed in [83]. [g] : [87]

Annex 2. Hotspots

2.A Spatial distribution of hotspots (CV ≥ 80%) in 2006. 2009 and 2014



Data sources: peatland map [41] and fire product MODIS [46]

2.B Number of hotspots in Sumatra and Kalimantan peatlands 2006, 2009, and 2014 estimated from the MODIS fire product

Number of hotspots in peatlands	At minimum confidence level (≥)								
	0			30			80		
	2006	2009	2014	2006	2009	2014	2006	2009	2014
Sumatra	8638	5856	10246	8236	5538	9777	4035	2448	5663
Kalimantan	8456	5904	5778	8005	5638	5527	3879	2619	2635
Total	17094	11760	16024	16241	11176	15304	7914	5067	8298

Note: hotspots in the same or nearest location (approximately 1 km resolution) detected in the same year are assumed as one hotspot.

Annex 3. Estimated total area of oil palm plantation in Sumatra and Kalimantan peatlands.

Year	Estimated total peatlands	Oil palm plantation (ha) in				Source
		Sumatra	Kalimantan	Papua	Total	
2000*	Indonesia (20.8 Mha). Sumatra (7.21 Mha). Kalimantan (5.83 Mha). Papua (7.8 Mha)	700000	1000	0	701000	34
	Sumatra (7.23 Mha). Kalimantan (5.77 Mha)	512341	15982	n.a	528323	88
2005*	Indonesia (20.8 Mha). Sumatra (7.21 Mha). Kalimantan (5.83 Mha). Papua (7.8 Mha)	1200000	50000	1500	1251500	34
2010*	Indonesia (20.8 Mha). Sumatra (7.21 Mha). Kalimantan (5.83 Mha). Papua (7.8 Mha)	1400000	308000	1700	1709700	34
	Sumatra (7.23 Mha). Kalimantan (5.77 Mha)	1026922	258299	n.a	1285221	88
2014	Indonesia (14.9 Mha). Sumatra (6.4 Mha). Kalimantan (4.9 Mha). Papua (3.6 Mha)	1413628	479816	1850	1895294	37
2015*	Sumatra (7.23 Mha). Kalimantan (5.78 Mha)	1315830	730750	n.a	2046580	89

**data were taken from [6]*

Annex 4. Annual production rate of ecosystem services in peatlands of Sumatra and Kalimantan

ES specification	Unit	Peatlands in		Source
		Sumatra	Kalimantan	
Timber production	m^3/ha	0.73*	0.37*	Statistics Indonesia [90]
Oil palm production	ton FFB/ha	16.7	14.8	[79, 35, 91]
Biomass production for pulp	ton biomass/ha	21.03	21.03	[92]
Paddy production	ton paddy/ha	2.92	1.7	[36, 93, 94]
CO_2 sequestration	ton CO_2/ha	19	19	[95] as reviewed in [6]

**average value 2004-2015*

Note: the values might vary at provincial or district level

Annex 5. Estimated net carbon flux by land cover type

Land cover	Net carbon (CO_2) flux	Source
Undisturbed natural forest	19	[9, 10, 95-97]
Disturbed natural forest	-17	
Forest plantation (Acacia)	-81	
Oil palm. other types of plantation	-85	
Dry land agriculture	-48	
Paddy field	-48	
Open water	0	
Degraded land. bare ground	-15	
Other land uses	-15	

Note: data are taken from [6]

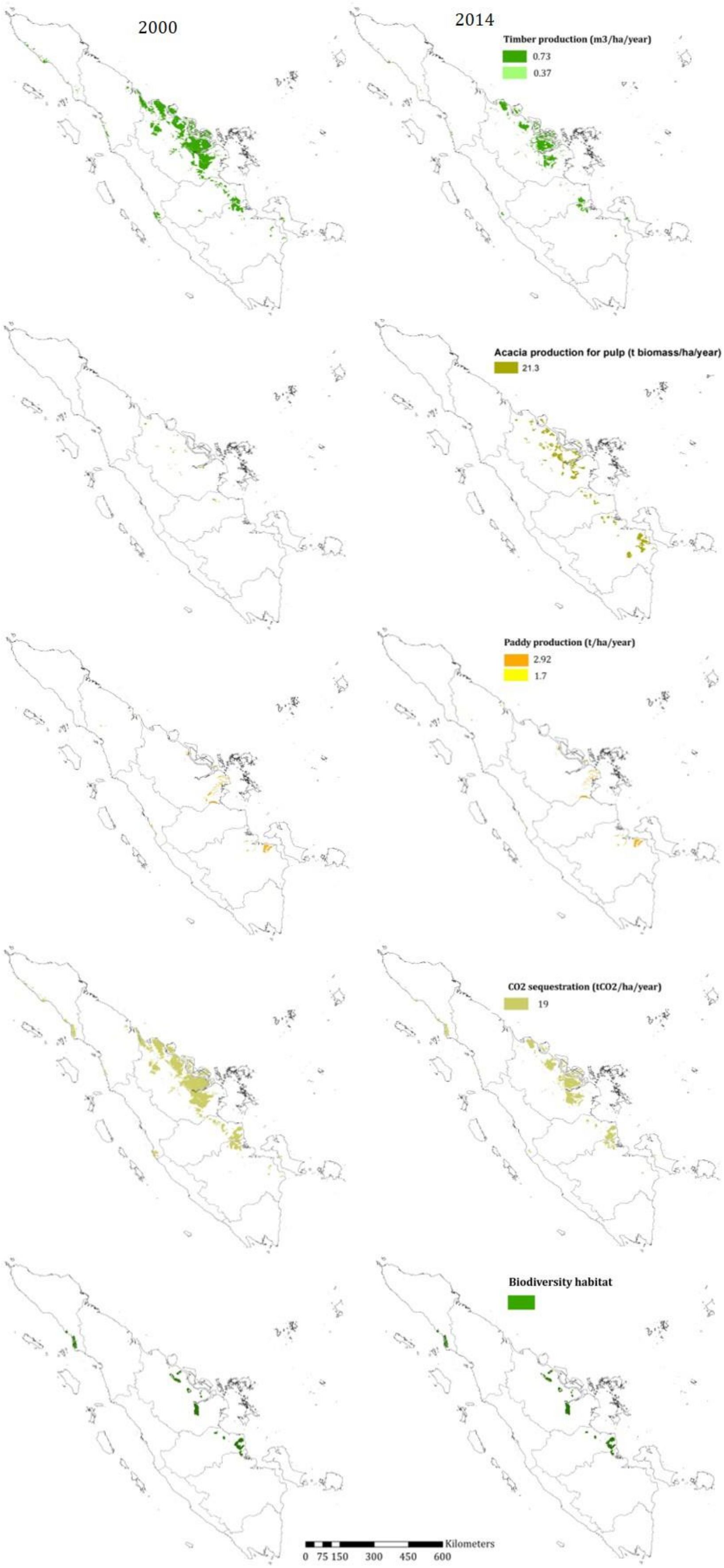
Annex 6. Production cost and market price of commodities

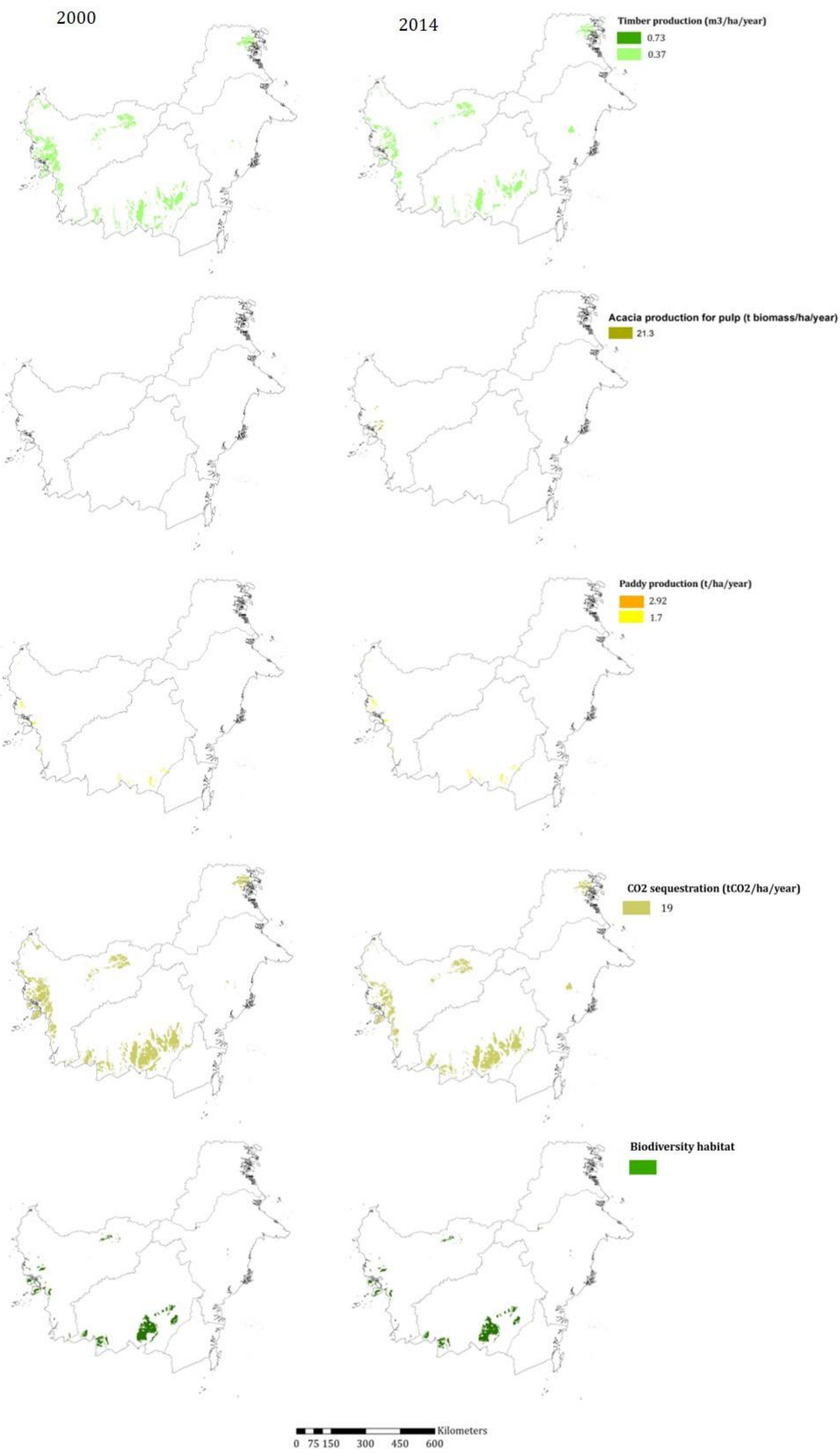
ES	Indicator	Unit	Value	Value at	Source
Timber production	Price	1000 IDR/m3	1658.5[a]	2012	[98]
	Production cost	1000 IDR/m3	991	2010	[36]
Oil palm production	Price	1000 IDR/tFFB	1102	2013	[99]
	Production cost	1000 IDR/ha	15424	2010	[35]
Acacia biomass production	Price	1000 IDR/t	350	2009	[92]
	Production cost	1000 IDR/ha	5459	2009	[92]
Paddy production	Price	1000 IDR/ton	3.3	2013	[100]
	Production cost	1000 IDR/ha	2652	2010	[35]
CO_2 sequestration	Social cost of carbon	US$/ton$CO_2$	36[b]	2007	[57]
Protected habitat	Restoration cost	US$/ha	1054	2014	[55]

[a]: average timber (of several types) price. [b]: value with discount rate at 3%

Note: the values, particularly the production cost, might vary at provincial or district level. In the calculation of monetary values, all data were converted to the values at 2017 (considering inflation rates 6.96 in 2010; 3.79 in 2011; 4.3 in 2012; 8.38 in 2013; 8.36 in 2014; 3.35 in 2015; 3.02 in 2016 [51], and exchange rates based on Bank Indonesia [52].

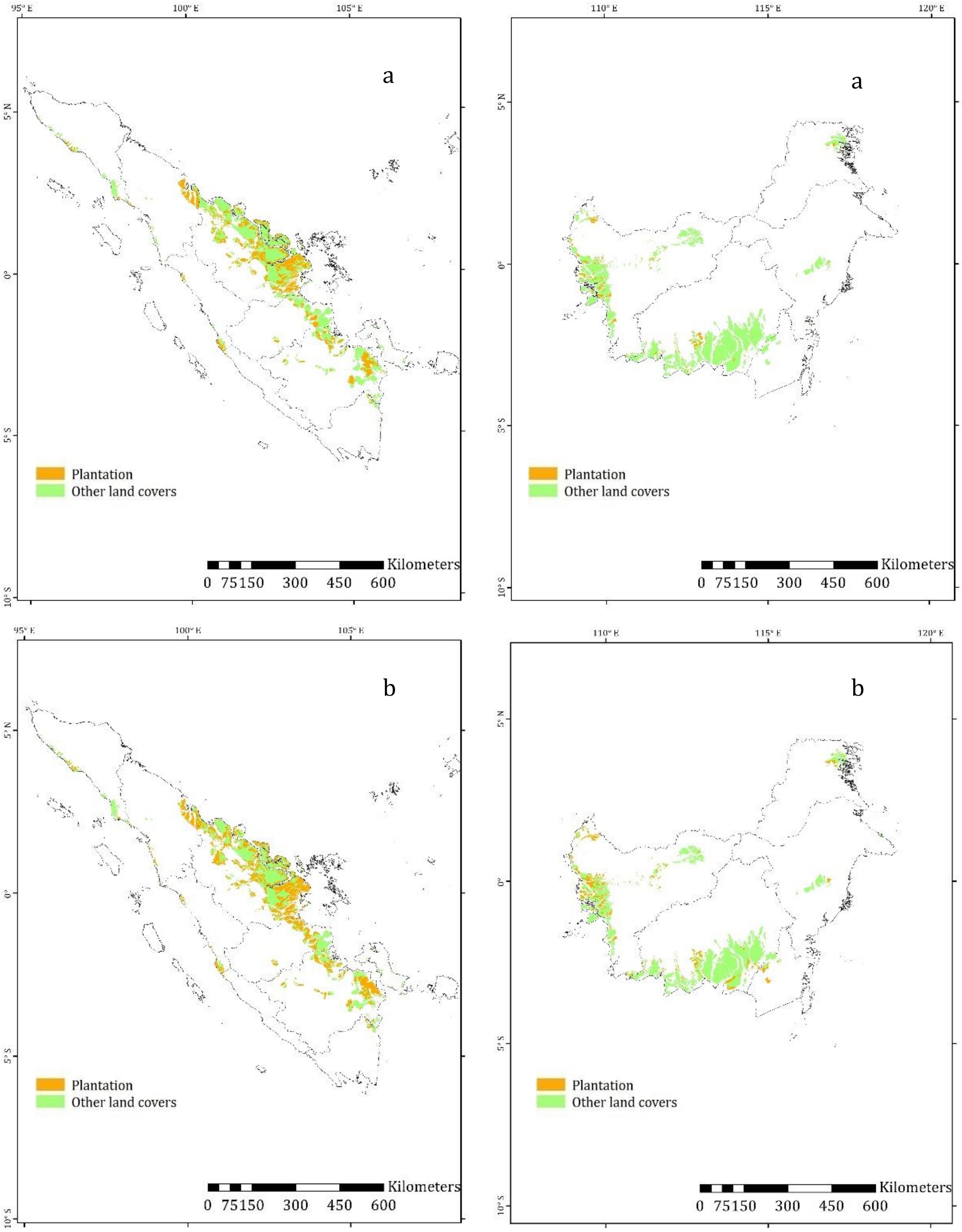
Annex 7. Spatial distribution of ecosystem services (physical values) in Sumatra and Kalimantan peatlands for 2000 and 2014




2000
2014
Timber production (m3/ha/year)
0.73
0.37
Acacia production for pulp (t biomass/ha/year)
21.3
Paddy production (t/ha/year)
2.92
1.7
CO2 sequestration (tCO2/ha/year)
19
Biodiversity habitat
Kilometers
0 75 150 300 450 600

Annex 8. Comparison of total area and spatial distribution of plantation in peatlands

8.1 Plantation in peatlands of Sumatra and Kalimantan 2014



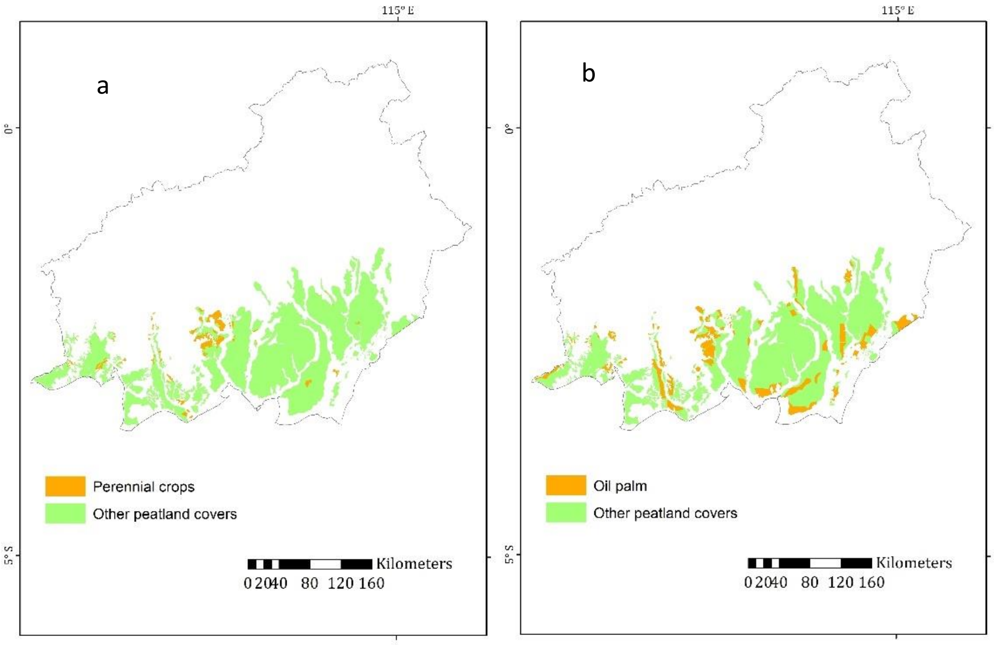
a: plantation map from MoEFRI land cover 2014 (forest plantation and perennial crops)
b: plantation map 2013/2014 from WRI, accessed through Global Forest Watch [37]

Table 15. Total plantation area in peatlands 2014 (MoEFRI and WRI maps)

Source	Total area (1000 ha) in	
	Sumatra	Kalimantan
MoEFRI land cover map 2014*	2262	366
WRI[37]	3307	749

**for forest plantation and perennial crops*

8.2 Plantation (oil palm) in peatlands of Central Kalimantan 2012



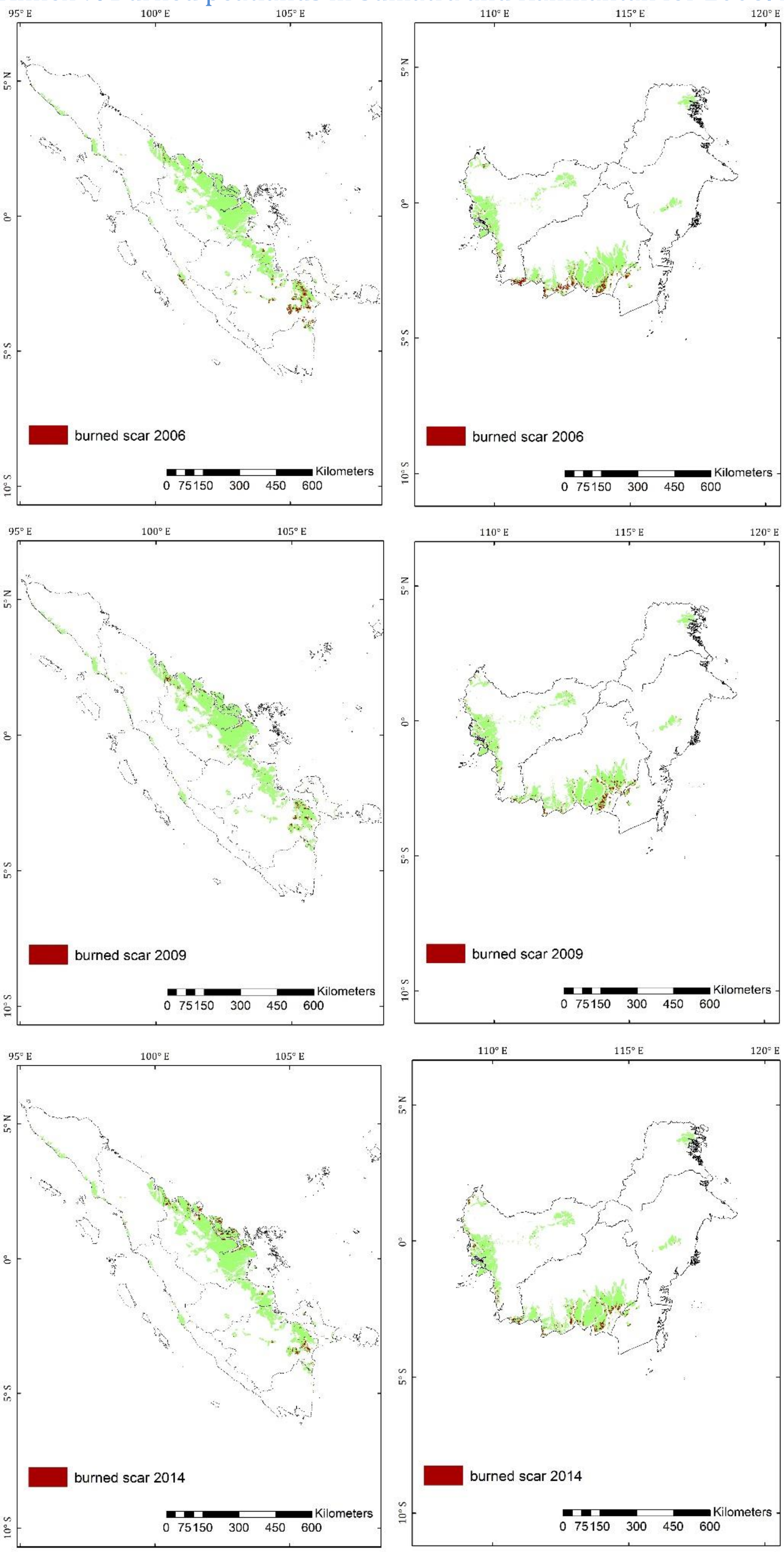
a: plantation map from MoEFRI land cover 2012 (perennial crops)
b: oil palm *plantation map 2012 from OFI (Orangutan Foundation Indonesia)*

Table 16. Total plantation area in peatlands of Central Kalimantan 2012

	Total area (1000 ha)	Source
Plantation (perennial crops)	112	MoEFRI land cover map 2012*
Plantation (oil palm)	290	OFI (2012)

**land cover of perennial crops*

Annex 9. Burned peatlands in Sumatra and Kalimantan for 2006. 2009 and 2014



Data sources: peatland map [41] and burned area product MODIS [58]

Annex 10. Precipitation

Introduction: Peat swamp forest is one of the main water storages for the surrounding environment. The water content in peatland has various functions for the ecosystem such as preventing land subsidence, flood and fire [26]. Water supply is one of the relevant indicators that can be added to the ecosystem condition account. In this annex, the precipitation is presented as a basic information to monitor the main element (water supply) of the hydrological system in peatlands. Monitoring precipitation is also essential to understand the rainfall pattern in the context of climate variability (e.g. ENSO and IOD), as well as to understand the changes in fire risk. However, at the same time, it needs to be recognised that precipitation is not dependent upon human management of peatlands or reflecting the environmental state of peatlands. It is therefore an indicator of the overall environment (indicating impacts of climate change on peatlands) rather than a specific peatland related indicator.

Method: The Tropical Rainfall Measuring Mission (TRMM) data organised by NASA and Japan National Space Development Agency were used for identifying the annual rainfall of Indonesian peatlands. Due to research need and data availability. this study extracted monthly precipitation data from TRMM 3B43. a precipitation estimate resolution 0.25 degree V7 [101]. This data has been available from January 1998 until present.

The rate of precipitation from TRMM product was extracted and accumulated to estimate the total precipitation annually using spatial analysis (ArcMap 10.5) tools. Firstly. data (.NetCDF) were converted into raster. Then, to cover the whole study area that is distributed in a small resolution (compared to the resolution of TRMM products). the precipitation raster map was resampled to 100 metres gridded raster. The resample raster then was extracted by mask with peatland distribution maps from [41]. Raster calculator tool and zonal statistic tool were applied to get the annual precipitation of peatlands for every province. The average of annual precipitation was calculated using Equation 1.

$$\overline{Precipitation} = \frac{\sum(precipitation\ on\ peatland\ province\ t\ \times total\ pixel\ of\ peatland\ province\ t)}{\sum total\ pixel\ of\ peatland\ province\ t}$$

Equation 5

Results: The average of annual precipitation (at island level) in peatlands is presented in Table 17. following the same time-period as in the ecosystem extent account. From these data. it is estimated that Indonesian peatlands received precipitation varied between 1849-2941 mm/year in Sumatra and between 2610-4031 mm/year in Kalimantan. The year of 2015. known as one of El Niño years, a phenomenon resulting in warmer climate condition in Indonesia [102] (see details in Annex 11), is recorded as a dry year with the lower precipitation. Meanwhile. peatlands received a high amount of rainfall in 2010 when La Niña, an event resulting in cooler climate condition in Indonesia (mainly in seven last months), was detected.

Table 17. The average of annual precipitation in Sumatra and Kalimantan peatlands.

Indicator	Peatlands in	1990	1996	2000	2006	2009	2010	2014	2015
Average precipitation	Sumatra	n.a	n.a	2633	2571	2520	2941	2119	1849
	Kalimantan	n.a	n.a	3056	2610	2740	4031	2757	2804

Data source: TRMM [101]. n.a: data are not available

It is also noticed that the average of rainfall is significantly varied in spatial distribution. As seen in Figure 11, for example, peatlands in Sumatra during 2014, received less rainfall below 2000 mm/year particularly in the eastern part (Riau, Jambi, South Sumatra, Riau islands, and Bangka-

Belitung provinces). On the other hand. most of the peat areas in Kalimantan and western Sumatra had quite high precipitation which was more than 3000 mm/year.

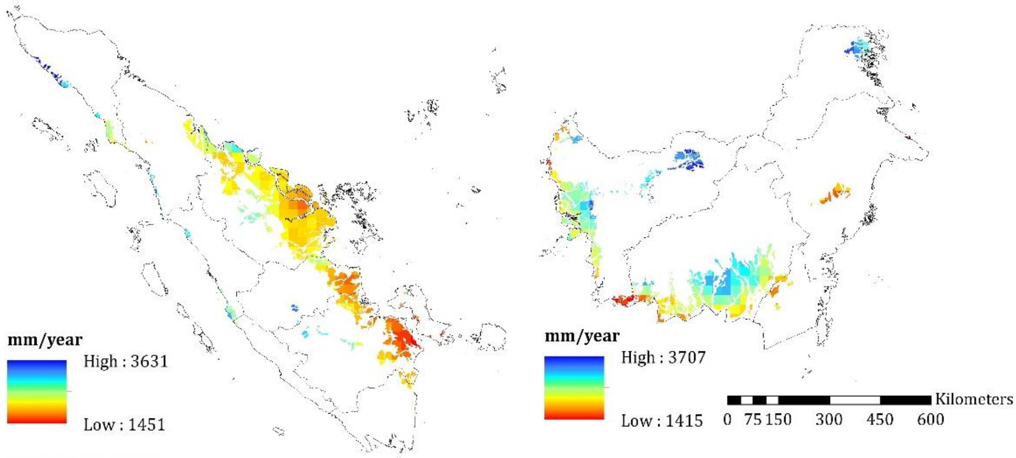
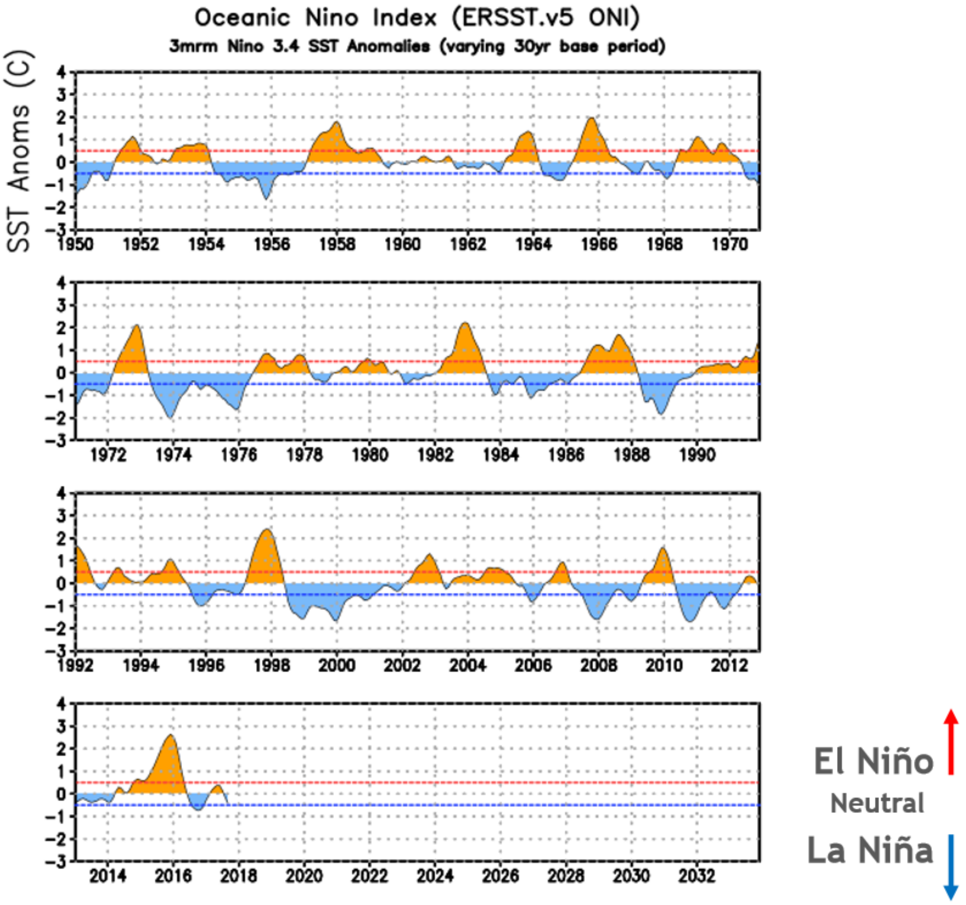


Figure 14. Spatial distribution of precipitation in Sumatra and Kalimantan peatlands in 2014. estimated from TRMM (2011).

Data validation process is vital to be considered since there would be some differences in values when they are compared to observation or survey data. The coefficient correlation between TRMM precipitation product for Indonesia and the observation data from BMKG (Meteorological, Climatological, and Geophysical Agency) is 0.8 [103]. This number is relatively high although there are still 20% of possibility for error estimation.

Annex 11. Oceanic Niño index 1950-2017



Data source: NCEP [102]. Warm and cold periods based on a threshold of +/- 0.5⁰C for the Oceanic Niño Index (ONI) [3 month running mean of ERSST.v5 SST anomalies in the Niño 3.4 region (5⁰N-5⁰S, 120⁰W-170⁰W)], based on centred 30-year base periods updated every 5 years.

Annex 12. Estimated emission factor and biomass consumption of burned peat

Indicator	Data taken from	
	MoEFRI [48]	IPCC supplement 2013 as reviewed in [74]
Mass of fuel available for combustion (tdm/ha)	504.9[a]	353[b]
Emission factor (CO_2 kg/ton)	1828.2	1703

[a]Estimated as 33-cm burned peat depth in forest
[b]Estimated for drained peatland

Annex 13. Kriging interpolation method

A kriging interpolation technique was applied to map peat drainage depth in certain land uses (perennial crop area, degraded peat swamp forest in the distance less than 500 m from perennial crop area, plantation forest, and bare land), based on geostatistical analysis of available drainage depth data. Geostatistics is a general term for a spatial model of spatial structure that considers the spatial autocorrelation between values in the sampled locations, where these models can then be used to predict the values of unsampled locations. The procedures of the krigring interpolation technique is briefly described in Figure 12. The procedures were separately applied for Sumatra and Kalimantan.

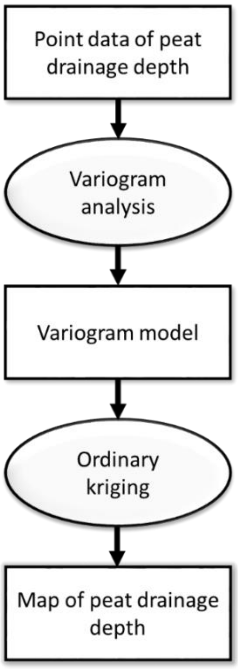


Figure 15. Flow chart of kriging interpolation technique

At the first step, the spatial structure of the drainage depth data was analyzed using variogram analysis. Variogram is a scatter plot describing the relationship between semivariance and distance. Ideally, the increase of separation between point-pairs will also be followed by the increase of semivariance until a certain separation called the range. In total 166 drainage data from Sumatra and 40 data from Kalimantan were analyzed. The gstat package of "R" [104] was used for this analysis. After fitting some variogram models to the sample variogram, the parameters of the best model (partial sill, range, and nugget) were used for kriging interpolation. Figure 13 and 14 show the selected variogram model for Sumatra and Kalimantan.

Ordinary kriging was selected as interpolation method. Ordinary kriging is a best linear unbiased predictor since it tries to have a mean error of zero and to minimize the variance error [105]. An interpolation tool in spatial analysis tools of ArcMap was used for the interpolation to produce the map of peat drainage depth. Finally, a cross validation (leave-one-out method) was applied to analyze model accuracy by calculating coefficient of variation (CV) of root mean square error (RMSE). This value represents the deviation of the prediction error from the mean of input data, whose value ranges from 0 to 1. A CV of RMSE of 0 indicates a perfect accuracy. The cross validation gave a CV of RMSE of 15.1% for Sumatra and 19.1% for Kalimantan.

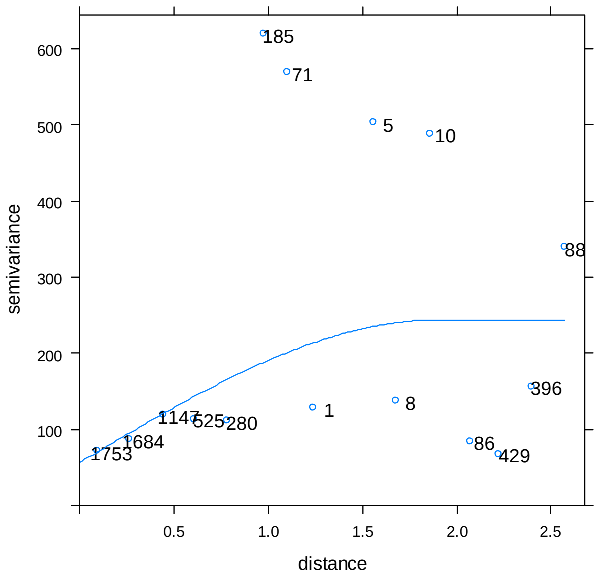


Figure 16. Selected variogram model for Sumatra with parameters: partial sill 187.35, range 1.9 and nugget 56.39

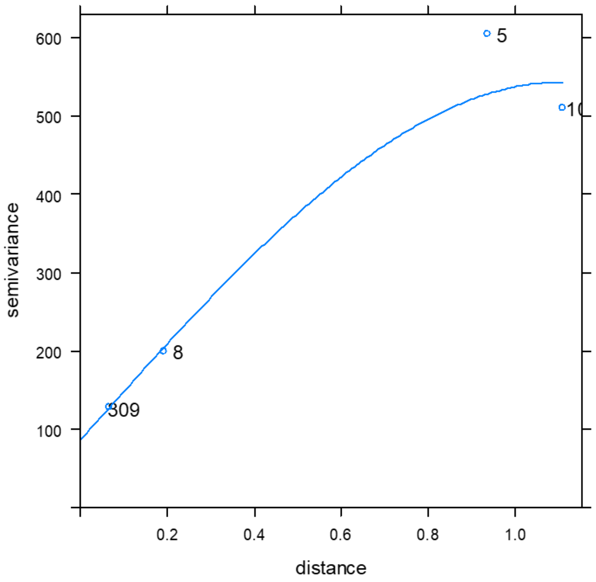


Figure 17. Selected variogram model for Kalimantan with parameters: partial sill 457.15, range 1.1 and nugget 85.8

Annex 14. Selected water table depth data

Land cover	Water level (m)
Undisturbed natural forest	0*
Disturbed natural forest in the distance more than 500 m from perennial crops or plantation forests	0*
Mixed cropland; small-scale agriculture	0.6[a]
Shrubland	0.33[a]
Lowland paddy field	0.05[b]
Others (water, savanna, etc.)	0*

*Note: * 0 means undrained*

Sources: [a]: [9], [b]: [106]