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Research article

Assessing the monetary value of ecosystem services provided by Gaung – Batang Tuaka Peat Hydrological Unit (KHG), Riau Province

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ABSTRACT

Peatland plays a pivotal role in providing natural resource production and environmental services for human welfare. However, many studies have mentioned the impact of dryland cultivation in peatland on the shifting carbon balance in the ecosystem that clearly will alter the interaction of these two ecosystem services. The goal of this study, conducted under the framework of the System of Environmental-Economic Accounting (SEEA) framework, was to monetary value the ecosystem services (ES) of provisioning and carbon regulating services of the Gaung-Batang Tuaka Peat Hydrological Unit (KHG). We focused on KHG in response to Regulation No.57/2016, which highlights ecosystem boundary as a new basis for peatland management. Under the SEEA framework, ecosystem services become a benefit when utilized by ecosystem beneficiaries. In this case, provisioning services will be valued only for cultivated land, while carbon services calculated for the entire study area (global beneficiaries). Our study showed that the provisioning services and carbon services are under the trade-off condition, where the monetary value of provisioning services increased at a slower rate (0.50 million USD annually) than the monetary loss of the benefit of carbon services (5.28 million USD annually), greatly exceeded the monetary value of provisioning services. We highlight two main strategies to increase the monetary value of the KHG towards a synergy condition, namely increased value-added by reducing the productivity gap among ES beneficiaries and large-scale adoption of a profitable cultivation system with minimum peat disturbance. The main enablers required include financing access and incentives (e.g., reduce tax) and disincentives to allow for peat-adaptive commodities to compete with dryland commodities in the future market.

1. Introduction

Peatland is a unique ecosystem formed through a biomass decomposition process under an anaerobic environment and is mainly situated in high precipitation areas (Rieley and Page 2016). Peatland provides ecosystem services (ES), including provisioning services of natural resources (horticulture plantation, timber, and non-timber product) and habitat maintenance of biodiversity, as well as carbon regulating services—with carbon being stored in plant biomass and soil (Osaki et al., 2016; Rahajoe et al., 2016). Among all the ES provided by the peatland ecosystem, the carbon regulating service has the most vital role (Kimmel and Mander 2010). The peatland areas in Southeast Asia reach a total of 247,778 km^2, with the largest areas located in Indonesia, storing approximately 68.5 Gt of carbon (Page et al., 2011).

Limited available land in mineral soil for plantation expansion has transferred the land demand to peatland, causing deforestation and adding pressures to the peat ecosystem (Boer 2016; Uda et al., 2018; Nurrochmat et al., 2020). The pressure from land demand, exacerbated by the building of canals to make peatland feasible for dryland cultivation, has led to the peatland becoming increasingly exposed to the aerobic environment (Hooijer et al., 2006; Carlson et al., 2015) and thus more susceptible to peat fires (Wösten et al., 2006; Putra et al., 2008; Taufik et al., 2017), which could worsen with climate change (Osaki et al., 2016; Cobb et al., 2017; Rossita et al., 2018). It has been reported that under massive peat degradation, the peat ecosystem could lose its capacity to provide ES as carbon flux dynamics shift (Hooijer et al., 2010; Gunawan et al., 2016; Hirano et al., 2016).

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Land management and ES interactions, which either produce a trade-off or synergy between ES (Law et al., 2015), justify the ecosystem accounting framework as the best approach for peat ecosystem assessment that integrates biophysical and monetary data of ES and ecosystem assets. It can be used to evaluate the impacts of ecosystem change on economic activity, among others (UN et al., 2014). There has been an increased number of studies related to ecosystem accounting in Indonesia, to assess the physical and monetary value of ES (Sumarga and Hein 2014; Suwarno et al., 2016), to integrate environmental value into the fiscal policy (Nurfatriani et al., 2015), to develop indicators for a green financing mechanism (Sheriffdeen et al., 2020), to utilize non-timber forest products (Adalina et al., 2014), and to use spatial information of ES as the basis for future forest governance and land use strategy (Sumarga and Hein 2014; Uda et al., 2017; Suwarno et al., 2018). However, none of the studies specifically discuss the interaction between multiple ecosystem services in a long term and this study will fill the gap.

In this study, we attempt to highlight the peatland ecosystem exclusively by conducting the assessment at the ecosystem boundary, rather than at the administrative scale. This study also reflects the Government Regulation (PP) No. 57/2016 which indicates the peat ecosystem boundary, known as the Peat Hydrological Unit (*Kesatuan Hidrologi Gambut*, KHG), as the main scale for peatland management. With this study, we aimed to address the objectives to monetary value ES at one KHG scale and evaluate the result to make it applicable for simulating the dynamics of future ES of KHG-based peat management.

2. Data and method

2.1. Study site

The Gaung–Batang Tuaka is one of the seven priorities KHG in Riau Province (Peat and Mangrove Restoration Agency, 2017) and one of the regions with wide spatiotemporal hotspot distribution in Sumatra Island (Kirana et al., 2016). The total area of Gaung–Batang Tuaka KHG is approximately 315,326 ha, of which 87% is a peatland. The Gaung–Batang Tuaka is a cross-district KHG of Indragiri Hilir and Indragiri Hulu Districts (0°03′50‴ - 0°32′44″ S and 102°11′51” – 103°28′15″ E), covering the nine subdistricts of Lirik, Rengat Barat, Rengat, Kuala Cenaku, Kempas, Tempuling, Batang Tuaka, Gaung Anak Serka, and Gaung (Figure 1).

2.2. Data collection

The data used in this study consisted of primary data from field visits and secondary data from the statistical reports and related institutions. Primary data to identify the monetary value of provisioning services were collected from field visits from April to May 2019. Data collection activities were supported by the local agriculture instructors, organized under Research and Development of the Ministry of Agriculture in Riau. The total respondents were 21, most of whom were leaders of the local Farmer Groups known as the Gabungan Kelompok Tani (Gapoktan). Tabular secondary data used in the study were obtained from statistics on agriculture and estate crop commodities from 2001 to 2017, as collected in Statistics Indonesia (BPS) reports, for the entire nine subdistricts. Another type of secondary data was the spatial data obtained from various institutions, shown in Table 1. All the data were processed with Microsoft Excel and ArcMap 10.5 as the spatial analysis tool. In this study, we used USD currency as a monetary unit of ES, with the currency conversion rate of IDR to USD in 2019, the year when we conducted the study (USD 1 = IDR 13,901).

2.3. Methods

The development of the ecosystem accounting and the category of ES in this study is based on the main concepts elaborated in the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA-EA) (UN et al., 2014). In this sense, ES is defined as the contributions of the ecosystem to the benefits from economic activity (UN et al., 2014). This definition will determine the location of the ecosystem services, for instance, the provisioning services will be accounted only in cultivated land, where smallholder and private sector are the beneficiaries, while

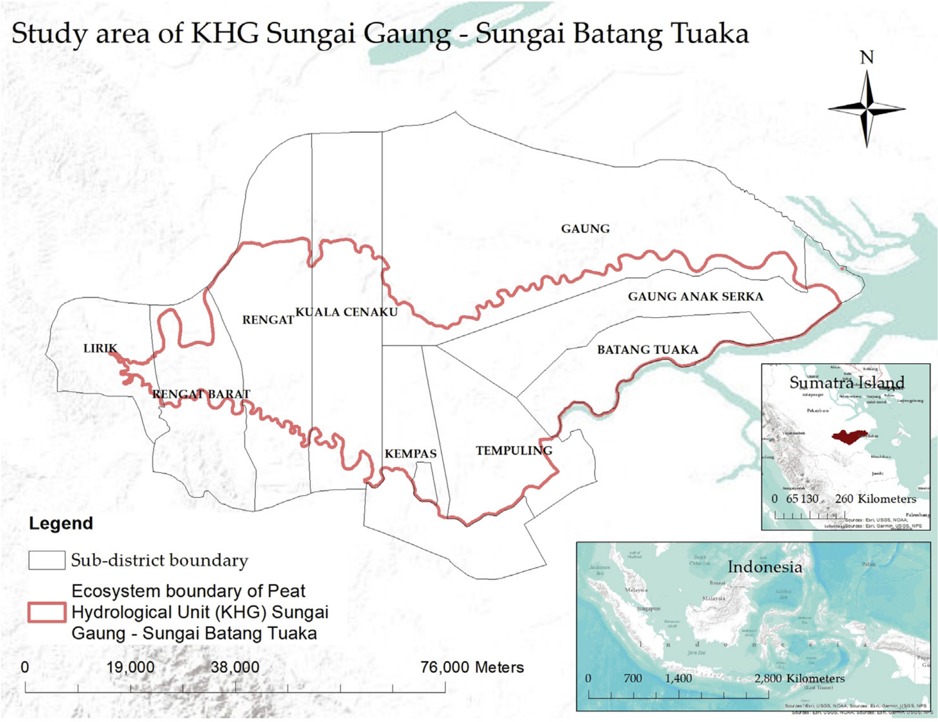

Figure 1. Study area of Gaung–Batang Tuaka KHG, Riau.

Table 1. Spatial data and the source of the data from the related institution. All spatial data were available online, except for the peat maturity map.

No	Spatial data	Date	Institution
1	Land cover map	2000–2017	Ministry of Environment and Forestry (KHLK)
2	Peat maturity map	2017	
3	KHG map	2017	
4	Forest function map	n/a	
5	Peatland map	2010	Ministry of Agriculture
6	Historical hotspot data	2001–2017	Moderate – Resolution Imaging Spectroradiometer (MODIS)
7	LANDSAT Thematic Mapper	2001–2017	United States Geological Survey (USGS)
8	Wood and oil palm concession	n/a	Forest Watch Indonesia (FWI)
9	Administrative map	n/a	Rupa Bumi Indonesia (RBI)

Note: All spatial data were available online, except for the peat maturity map.

the carbon services will be accounted in the entire study area, which depicts the global community as the beneficiaries of the carbon services.

In this study, we limited the analysis of the ES to the provisioning and regulation/maintenance services, due to the competition between these two services. We use the ecosystem services reference classification of the SEEA-EA to describe ES. The specific services we consider are crop provisioning, timber provisioning, latex provisioning, and Crude Palm Oil (CPO) provisioning. For the regulation and maintenance services, we consider carbon sequestration (global climate regulation). The research flow consists of four main processes: 1) collection of secondary data, 2) field visits to collect primary data, 3) calculation of physical and monetary value for provisioning and carbon regulating services, and 4) accounting of ES at the KHG scale. The technical method to assess each of the ecosystem services following the process is as in Figure 2.

To develop the ecosystem accounts in this study, we first calculated the extent of the ecosystem depicted in land cover information. In this approach we take into consideration that ES are relatively easier to measure based on Land Cover/Ecosystem Functional Unit, hence the accuracy of land cover maps is crucial to our estimation of ES. There are 14 land cover classes identified in the study area (Table 2).

The species-based information of the cultivated area was defined by combining statistical data from the BPS reports with spatial land cover maps. To connect extent to ES, we disaggregated land cover maps from KLHK into the annual land cover using the proportion of deforestation rate for the periods, following the approach used for national GHG monitoring (Ministry of Environment and Forestry, 2017). The time range for the calculation of ES and ecosystem accounting in this study is 2001–2017.

2.3.1. Provisioning services

In this study, the benefits of provisioning services were assumed to be generated only from land that is economically used for cultivation (Sumarga et al., 2015) to highlight an indication of market transaction or economic activity. Seasonal crop production (comprised of 10 commodities) occurs in paddy fields and dryland agricultural land, whereas perennial crops (comprised of 9 commodities) are grown on estate cropland and forest plantation land. While the unmanaged land can provide provisioning services (e.g., fodder for livestock, medicinal plants from the forest), unrecorded official statistic information for this economic activity, particularly to divide the extracted and non-extracted area, become a limitation to provide a detailed result of the ecosystem services extracted in the unmanaged land. This assumption is acknowledged as one of the sources of uncertainty in this study.

In calculating the physical value of the provisioning services, information on cropping intensity and the proportion of harvested area was required to adjust the actual productive area from the cultivated land. These two parameters were obtained from the BPS report. Cropping intensity is the average ratio of harvested area divided by the planting area. For perennial trees, the proportion of harvested area was obtained annually from the proportion of the area of trees in the production phase to the total land area per commodity.

The monetary value of provisioning services is estimated using the resource rent valuation approach, which is consistent with the SEEA-EA accounting approach. The resource rent is the residual of the total revenue after all costs from labor and capital are subtracted (UN et al., 2014; Remme et al., 2015). The Resource Rent (RR) approach is the most common method used to estimate ecosystem contribution to product profits and is often used for provisioning services like those related to

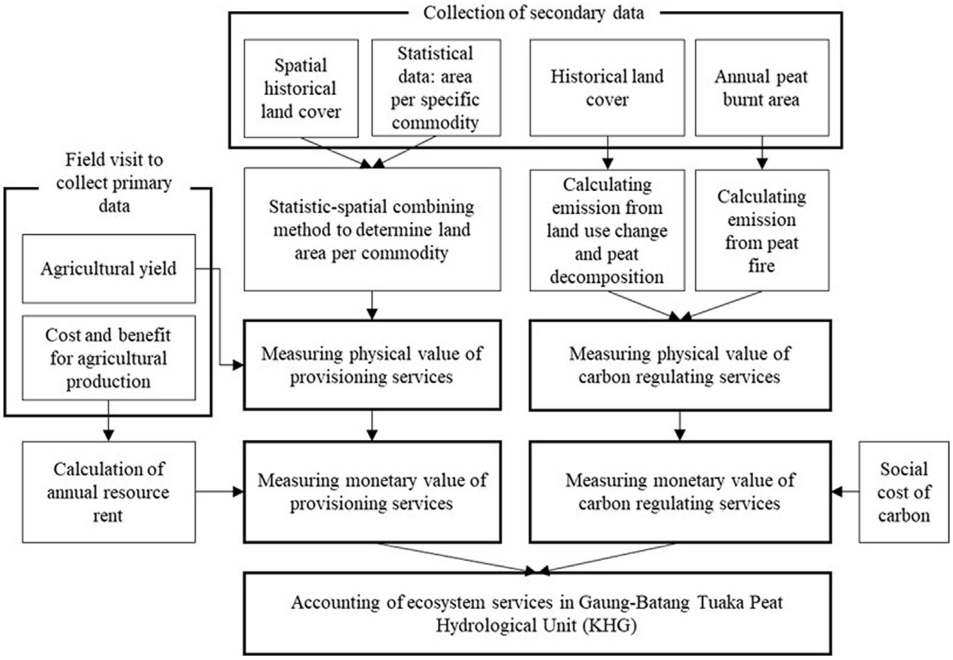

Figure 2. Research flow consists of four main processes: 1. Collection of secondary data, 2. Field visit to collect primary data, 3. Calculation of physical and monetary value for provisioning and carbon regulating services, 4. Accounting of ecosystem services at KHG scale.

Table 2. Emission and/or sequestration from land-use change.

Land cover	Year 1	Year 2													
		PSF	TP	Sr	EP	Se	Br	WB	SMF	SSF	SSr	AUA	MxUA	Rc	Sw
Primary swamp forest	PSF	0.0	−158.2	−200.6	−171.1	−216.8	−218.3	−220.8	−19.1	−69.4	−202.7	−213.3	−198.3	−216.4	−220.8
Timber plantation	TP	158.2	0.0	−42.4	−12.9	−58.6	−60.1	−62.6	139.1	88.8	−44.5	−55.1	−40.1	−58.2	−62.6
Dry shrub	Sr	200.6	42.4	0.0	29.5	−16.2	−17.7	−20.2	181.5	131.2	−2.1	−12.7	2.3	−15.8	−20.2
Estate crop	EP	171.1	12.9	−29.5	0.0	−45.7	−47.2	−49.7	152.0	101.7	−31.6	−42.2	−27.2	−45.3	−49.7
Settlement areas	Se	216.8	58.6	16.2	45.7	0.0	−1.5	−4.0	197.7	147.4	14.1	3.5	18.5	0.4	−4.0
Bare ground	Br	218.3	60.1	17.7	47.2	1.5	0.0	−2.5	199.2	148.9	15.6	5.0	20.0	1.9	−2.5
Open water	WB	220.8	62.6	20.2	49.7	4.0	2.5	0.0	201.7	151.4	18.1	7.5	22.5	4.4	0.0
Secondary mangrove forest	SMF	19.1	−139.1	−181.5	−152.0	−197.7	−199.2	−201.7	0.0	−50.3	−183.6	−194.2	−179.2	−197.3	−201.7
Secondary swamp forest	SSF	69.4	−88.8	−131.2	−101.7	−147.4	−148.9	−151.4	50.3	0.0	−133.3	−143.9	−128.9	−147.0	−151.4
Wet shrub	SSr	202.7	44.5	2.1	31.6	−14.1	−15.6	−18.1	183.6	133.3	0.0	−10.6	4.4	−13.7	−18.1
Dryland agriculture	AUA	213.3	55.1	12.7	42.2	−3.5	−5.0	−7.5	194.2	143.9	10.6	0.0	15.0	−3.1	−7.5
Mixed dryland agriculture	MxUA	198.3	40.1	−2.3	27.2	−18.5	−20.0	−22.5	179.2	128.9	−4.4	−15.0	0.0	−18.1	−22.5
Paddy field	Rc	216.4	58.2	15.8	45.3	−0.4	−1.9	−4.4	197.3	147.0	13.7	3.1	18.1	0.0	−4.4
Open swamp	Sw	220.8	62.6	20.2	49.7	4.0	2.5	0.0	201.7	151.4	18.1	7.5	22.5	4.4	0.0

agriculture outputs. Under this valuation approach, RR represents an estimated price for the ES. The RR calculation differed depending on whether the crop is seasonal or perennial crop. The monetary value of provisioning services for seasonal crops was estimated using Eq. (1), and RR for perennial crops using Eqs. (2) and (3), where the annual RR was calculated from the Net Present Value (NPV) of Benefit (Suwarno et al., 2016).

$$RR_s = TR - (IC + LC + UCF) \tag{1}$$

where RR_s is resource rent for a seasonal crop (USD/production unit/yr), TR is total revenue (USD/production unit/yr), IC is intermediate consumption (USD/production unit/yr), LC is wages (labor costs) (USD/production unit/yr), and UCF is user costs of fixed assets (USD/production unit/yr).

$$RR_p = NPV \quad \frac{i \quad (1+i)^{-t}}{(1+i)^{-t} - 1} \tag{2}$$

where RR_p is resource rent for the perennial crop (USD/production unit/yr), NPV is the sum of discounted value revenues minus cost (USD/ha), estimated from Eq (3), t is the lifetime of investment (year), and i is the discount rate (%), which was set to 17% in this study according to the interest rate of the People's Bank of Indonesia (BRI).

$$NPV = \sum_{t=1}^{T} (TR - Ct)(1+i)^{-t} \tag{3}$$

where TR is the total revenue (USD/ha), Ct is all costs required for production (USD/ha).

2.3.2. *Carbon regulating services*

We consider that peatlands, when protected or used without drainage, are able to store and even sequester carbon. When drained, the peatlands emit carbon, due to oxidation and possibly also fire. Carbon accumulation in peat occurs when there is a natural peat forest; however, these areas are largely absent from the case study area. We focus therefore on the emissions from drained peat, considering that peat drainage leads to a loss of the carbon regulation service. Assessment of the net carbon regulating services in this study was based on the IPCC Guideline for Agriculture, Forestry, and Other Land Use sector (AFOLU) (IPCC 2006; Ministry of Environment and Forestry 2015). Initially, we calculated the emissions and removal from LUC, based on the transition of the land system detected by remote sensing data of a given place and period. Subsequently, we added other disturbances—arising from peat decomposition and peat fires—that degrade the carbon service (Eqs. (4) and (5)). Emissions and/or sequestration from LUC were calculated using the stock difference approach (see Table 2). Emissions and/or sequestration from LUC was generated from the land cover data of the entire land cover of the KHG. In contrast, emissions from disturbance of peat decomposition were calculated only for the peatland in the KHG. In the context of ES, the sign for carbon sequestration is positive, whereas for other disturbances/emissions it is negative. Due to the inclusion of carbon loss from land conversion, peat decomposition, and peat fires, carbon regulating services in the peat ecosystem are more likely to produce negative value that indicates carbon emission rather than sequestration.

$$C \text{ (carbon)} = C \text{ (LUC)} + C \text{ (disturbance)} \tag{4}$$

where C (carbon) is net carbon regulation (ton of $C{\cdot}yr^{-1}$), C (LUC) is sequestration/emission due to land-use change (ton of $C{\cdot}yr^{-1}$), and C (disturbance) is carbon loss due to drained peat soil and fire (ton of $C{\cdot}yr^{-1}$).

$$C \text{ (disturbance)} = C \text{ (peat oxidation)} + C \text{ (peat fire)} \tag{5}$$

where C (peat oxidation) is carbon loss due to peat decomposition from exposure to aerobic condition (ton of $C{\cdot}yr^{-1}$), and C (peat fire) is carbon loss due to peat fire occurrence (ton of $C{\cdot}yr^{-1}$).

The value of emission factor (EF) for decomposition per land cover class refers to the value obtained from various methods reported in the literature (e.g., subsidence approach, flux measurement, etc.) as provided in Table 3. For the estate crop and plantation forest, the EF per land cover type per subdistrict is the weighted average value based on the proportion area of each species per subdistrict (Eqs. (6) and (7)).

$$C \text{ (peat oxidation)} = A \text{ x } EF \text{ (peat oxidation)} \tag{6}$$

where A is activity data or area per land cover type (ha) and EF is the carbon emission factor of peat decomposition for each type of land cover class (ton of $C{\cdot}ha^{-1}{\cdot}yr^{-1}$).

Table 3. Emissions from peat decomposition.

No	Land cover class	Emission (t C ha^{-1} yr^{-1})	Source
1	Primary Swamp Forest	7.63	(Furukawa et al., 2005; Hirano et al., 2009; Comeau et al., 2013)
2	Secondary Swamp Forest	12.07	(Inubushi et al., 2003; Furukawa et al., 2005; Ali et al., 2006; Hirano et al., 2009; Comeau et al., 2013; Husnain et al., 2014; Khasanah and van Noordwijk 2019)
3	Secondary Mangrove Forest	12.07	Assumed to be similar to secondary swamp forest
4	Plantation forest		
	a. Acacia	23.24	(Hooijer et al., 2012; Jauhiainen et al., 2012; Sumawinata et al., 2012; Couwenberg and Hooijer 2013; Husnain et al., 2014)
	b. Oil palm	20.89	(Hooijer et al., 2012; Comeau et al., 2013; Couwenberg and Hooijer 2013; Dariah et al., 2013; Marwanto and Agus 2013; Husnain et al., 2014; Khasanah and van Noordwijk 2019)
5	Dry Shrub	12.07	Assumed to be similar to secondary swamp forest
6	Estate Crop		
	a. Oil palm	20.89	(Hooijer et al., 2012; Comeau et al., 2013; Couwenberg and Hooijer 2013; Dariah et al., 2013; Marwanto and Agus 2013; Husnain et al., 2014; Khasanah and van Noordwijk 2019)
	b. Rubber	17.50	(Husnain et al., 2014; Wakhid et al., 2017; Khasanah and van Noordwijk 2019)
	c. Coconut	14.90	(Furukawa et al., 2005; Carlson et al., 2015)
	d. Areca nut	14.90	Assumed to be similar to coconut
	e. Sago	11.73	(Watanabe et al., 2009)
	f. Coffee	21.25	(Khasanah and van Noordwijk 2019)
	g. Cocoa	21.25	Assumed to be similar to coffee
7	Settlement Areas	12.15	Assumed to be similar to paddy field
8	Bare Ground	21.75	(Husnain et al., 2014)
9	Open Water	0	-
10	Wet Shrub	12.07	Assumed to be similar to secondary swamp forest
11	Dryland Agriculture	13.08	(Inubushi et al., 2003; Furukawa et al., 2005; Ali et al., 2006; Hirano et al., 2009)
12	Mixed Dryland Agriculture	13.08	(Inubushi et al., 2003; Furukawa et al., 2005; Ali et al., 2006; Hirano et al., 2009)
13	Paddy Field	12.15	(Inubushi et al., 2003; Furukawa et al., 2005)
14	Open Swamp	0	-

$$\text{EF (peat oxidation)} = n_1 EF_1 + n_2 EF_2 + \ldots + n_n EF_n \quad (7)$$

where n refers to the coefficient obtained from the weighted area method, and EF is the carbon emission factor per specific commodity (ton of C·ha^{-1}·yr^{-1}) (Table 3).

Carbon emissions from organic soil fires was calculated using the formula based on the guidelines of the Intergovernmental Panel on Climate Change (IPCC 2014a). In our study, the value of organic carbon content (C org) was assumed to depend on the peat maturity type. We estimated the annual burned area using a semi-automatic approach, analysis through the visual process, and identification of hotspot data, which could provide a more accurate peat burned area than the automatic approach as used in the Forest Reference Emission Level document (Rossita et al., 2019). We suggest referring to the previous study for a detailed explanation of the method (Rossita et al., 2019).

$$\text{C (peat fire)} = \text{MB} \times \text{Cf} \times \text{Gef} \times 10^{(-3)} \ \text{(peat fire)} \quad (8)$$

where MB is mass of fuel available for combustion (t/ha) (obtained from Eq. 9) CF is the combustion factor (default factor = 1.0) and Gef is the emission factor (kg/t), and the 10^{-3} value is for the conversion from kg to ton. In this study, we limit the emission factor (Gef) only for the CO_2-C emission source (Eq. 10).

$$MB = A \times D \times BD \times 10^{4} \quad (9)$$

where A is activity data or annual burned area (ha), D is the mean depth of burned peat (m): 0.33 m (Ballhorn et al., 2009), and BD is bulk density (t·m^{-3}): 0.153 t·m^{-3} (Mulyani et al., 2012). The area with recurrent peat fire was assumed to occur in half of the depth of burned compared to the first burning: 0.165 m (Ministry of Environment and Forestry, 2015). The 10^{-4} value is for the conversion from m^2 to ha.

$$\text{Gef } CO_2 - C = ((1 - \ (\text{Mash}/\text{Ms}))/1.724) \times 10^{3} \quad (10)$$

where Gef is derived from the organic carbon content (% of weight or kg/kg) and depends on peat maturity, indicated by the ratio of Mash and Ms for saprist 9.98%, hemist 8.89%, and fibrist 5.69% (Agus et al., 2011). The 1.724 value is used to convert organic matter estimate to organic carbon content (Agus et al., 2011), while the 10^{-3} value is for the conversion from kg/kg to kg/ton.

$$(\textit{The existing Equation } 11 \textit{ is deleted. Then, Equation } 12 \textit{ is becoming Equation } 11) \quad (11)$$

The physical value of carbon services obtained from Eq. 4 is then multiplied by the monetary value of carbon. Two possible approaches to value carbon regulating services in monetary terms are carbon price and the social cost of carbon. Although it is possible to quantify the value of carbon services based on the carbon price in the voluntary market (UN et al., 2014), this value is rarely used due to the high range of the price as set by institutions. Also, concerning the main objective of the research, which is expected to serve as the basis for the peatland management plan, the social cost of carbon is the better approach, given that it describes the negative value of the impact of carbon emissions. Therefore, in this study, we used the social cost of carbon (SCC), an estimate of the monetized damages associated with the incremental increase in carbon emissions in a given year, usually measured in metric tons per year (IPCC 2014b; Remme et al., 2015; Sumarga et al., 2015). The SCC value is then multiplied by the physical value of carbon sequestration to obtain the monetary value of carbon sequestration within the study area (Equation 12). Because the two valuation methods, carbon services (SCC) and provisioning services (RR), are different, they cannot be compared or summed together.

$$\text{C (carbon services)} = \text{C (carbon)} \times \text{SCC} \quad (12)$$

where C (carbon services) refers to the monetary costs of carbon emissions (USD), C (carbon) refers to the value obtained from Eq. (4), and SCC refers to the present value of the social cost of carbon: USD 38/tCO_2 (United States Government 2016).

3. Results

3.1. Ecosystem services

3.1.1. Provisioning services

Due to a lack of data on local variations in productivity (yields), we assess changes in provisioning services based on changes in the area used for different cultivars. Therefore, in the present study, the land cover change indicates the shift in the benefit type of ecosystem services. For example, in the study area, timber plantation for acacia production is expanded in 2006 (the initial year in service provisioning) and reaching

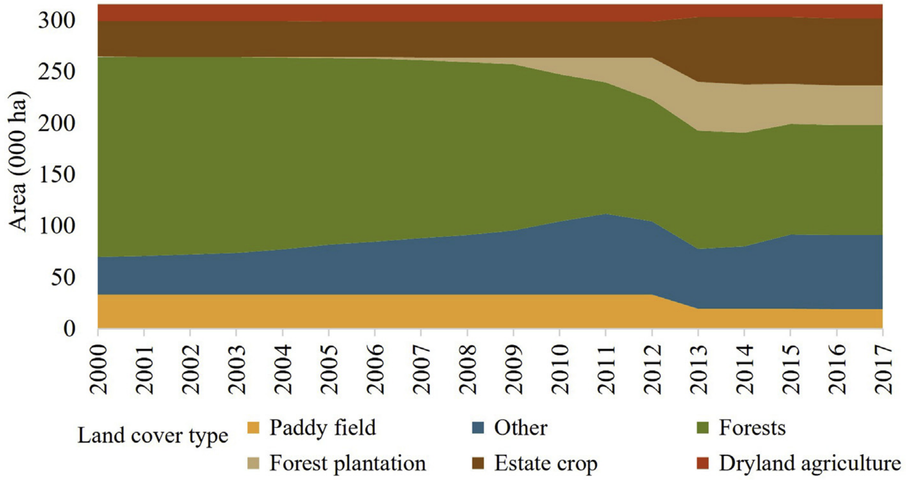

Figure 3. Area of land cover change from 2000 to 2017 in Gaung–Batang Tuaka KHG. Other types consist of shrub, settlement, bare ground, open swamp, and open water.

the highest level in 2013. Estate crop plantations (e.g., areca nut, oil palm, etc.) also showed an increasing pattern, in conjunction with declining areas of paddy fields. The land cover pattern will later affect the pattern of the monetary value for the respective commodities. In Figure 3, we show the area of land under land cover change from 2000 to 2017 in Gaung-Batang Tuaka KHG.

During the field visits, we found that the main commodity preferences in the study area were oil palm and areca nut. Despite the low annual RR, oil palm has a more promising market than other commodities and requires low IC or agricultural inputs (Table 4). In the study area, the areca nut is considered a fast cash commodity due to its high TR; however, the areca nut requires a post-harvesting process before sell (high labor cost) (Table 4). Of all commodities, rubber plantation is more fluctuating. Though there is still rubber plantation in the study area, we found that the area of rubber plantations had declined in the study period. This was confirmed by the declining credit application of rubber estate in Riau Province due to a situation of oversupply in the global market and low latex demand in the domestic market, noting that only 20% of the total Indonesian rubber production is for domestic consumption (Ministry of Industry 2020). This is reflected in rubber being one of the commodities with a relatively low RR (Table 4).

To compare the physical and monetary value results with the land use dynamic, we present the results in terms of land cover class category. As shown in Figure 4, the paddy field contributed the most to the monetary value of provisioning services in the study area before experiencing a major decrease from 2013 to 2017 due to the rapid conversion of paddy fields into estate crops. In contrast, forest plantations and estate crop plantations showed an increasing trend for both the physical and monetary value of provisioning services. However, both land cover categories experienced a rapid decline in monetary value from 2015 to 2017.

Table 4. The physical and monetary value of provisioning services.

Crop type	The benefit of provisioning services	Productive age (year)	Physical value (ton/ha)	Product price (USD/ton)	TR (USD/ha)	IC (USD/ha)	LC (USD/ha)	UCF (USD/ha)	Annual RR (USD/ha)
Seasonal crop	Sweet corn	n/a	4.04	285.97	1,155.31	379.47	442.41	36.69	296.74
	Cucumber	n/a	5.00	179.84	899.22	70.35	496.37	36.69	295.81
	Cassava	n/a	26.00	68.34	1776.85	912.88	496.37	36.69	330.91
	Cayenne pepper	n/a	2.41	503.56	1213.01	157.54	496.37	36.69	522.41
	Long beans	n/a	2.29	539.53	1232.92	272.64	496.37	36.69	427.23
	Soybeans	n/a	1.28	791.31	1011.78	82.01	496.37	36.69	396.72
	Red chili	n/a	2.06	539.53	1113.45	111.36	496.37	36.69	469.03
	Spinach	n/a	2.57	431.62	1108.56	135.96	496.37	36.69	439.54
	Water spinach	n/a	2.81	431.62	1211.53	135.10	496.37	36.69	543.37
	Paddy rice production	n/a	2.875	379.50	1091.05	330.43	424.91	39.45	296.92
Perennial crop	Oil palm production (community)	4–25	12.00	74.10	548.43	92.62	145.94	14.35	295.52
	Oil palm production (private sector)[1]	4–25	19.00	142.55	2,314.46	901.68	491.40	129.80	791.58
	Acacia production[2]	5	11.46	60.46	493.85	231.15	107.06	13.97	141.66
	Coconut (local)	4–30	6.00	93.52	348.43	60.40	115.01	14.27	158.75
	Coconut (hybrid)	4–30	8.40	86.32	450.27	68.25	155.35	14.27	212.41
	Areca nut	4–30	3.50	431.62	938.07	133.33	422.72	14.27	367.76
	Sago	7–30	0.60	1654.56	381.50	10.55	65.09	14.27	291.60
	Rubber (latex)	4–30	2.40	517.95	771.90	184.49	367.46	14.27	205.67
	Coffee	4–20	0.95	1798.43	1004.61	362.38	139.11	14.54	488.58
	Cocoa	4–20	1.02	1438.75	891.34	225.81	196.66	14.54	454.33

Source of the data: [1](Suwarno et al., 2016) [2](Rossita 2016). Other data without citations were obtained from this study.

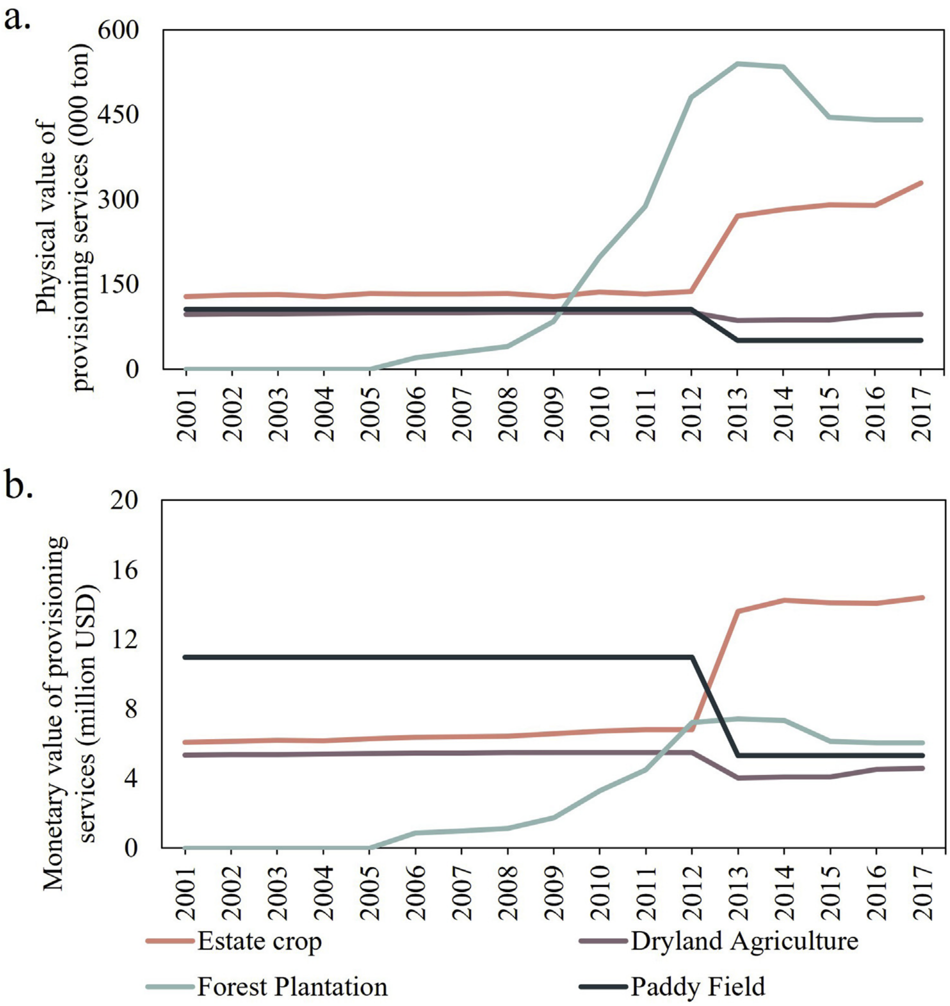

Figure 4. Provisioning services of Gaung-Batang Tuaka KHG for each land cover type presented in terms of (a) physical value and (b) monetary value.

3.1.2. Carbon regulating services

Compared to provisioning services, carbon regulating services are more directly affected by ecosystem conditions. Disturbance to the ecosystem could produce a negative benefit in the form of carbon regulating services, thus diminishing the main function of the ecosystem in storing carbon. We found that peat decomposition was the main cause of emission in the study area (Figure 5). The negative trend of the peat decomposition indicates a continued expansion of drained area which increases the exposure of the peat soil to an aerobic state.

In Figure 5, we show the physical and monetary value of carbon regulating services of Gaung-Batang Tuaka KHG for each type of disturbance. Land conversion could provide both positive and negative benefits of carbon regulating services. In 2013, land conversion led to the sequestration of approximately 824,406 tons of C as massive conversions of land cover with low-carbon stock into high carbon stock of estate crop plantations (27,378 ha) and forest plantations (4,622 ha) occurred. In this study, the emission from land conversion also comprises the aboveground biomass emission from a peat fire. As inferred from Figure 5, peat fire in the study area occurred almost every year and its pattern was influenced by the El-Niño Southern Oscillation (ENSO), a climate variability triggered by an atmospheric-oceanic phenomenon in Equatorial Pacific which cycles for 3–7 years (McPhaden 2002). The emissions from peat fires show an increasing trend, similar to the emission from peat decomposition. This strongly supports studies that suggested the impact of peat degradation on the increased fire susceptibility (Taufik et al., 2017; Sinclair et al., 2020).

Due to the resulting negative values from carbon regulating services, we can conclude that disturbances from peat fires, peat decomposition, and LUC accounted for approximately USD 40, 511, and 77 million, respectively, of the annual loss of social benefits of carbon, due to the reduced carbon regulating function in the ecosystem.

3.2. Ecosystem accounting of Gaung–Batang Tuaka KHG

Historical analysis revealed the trade-off condition between the provisioning and carbon regulating services in Gaung-Batang Tuaka KHG (Figures 6 and 7), which indicates the peat ecosystem was under continuous pressure due to land-based economic growth. The trade-off condition is less apparent during pre-2011, where the monetary value of provisioning services increased at a slow pace. Compared to provisioning, the physical and monetary value of carbon services are more dynamic. The pressure on the peat ecosystem was highest when annual deforestation peaked in 2010 and 2011 (Figure 3), resulting in a decrease in carbon services (Figures 6 and 7). After the peak of deforestation, low-carbon land cover began to be converted into estate crops and forest plantation, resulting in the sudden increase of carbon services and both the physical and monetary value of provisioning services (Figures 6 and 7).

In the pre-2011 period, the total monetary value of provisioning services held steady, in the range of USD 22–26 million and increased to above USD 30 million afterward. In 2014 and 2015, carbon services declined, impacted by strong El-Niño events that led to the largest burned

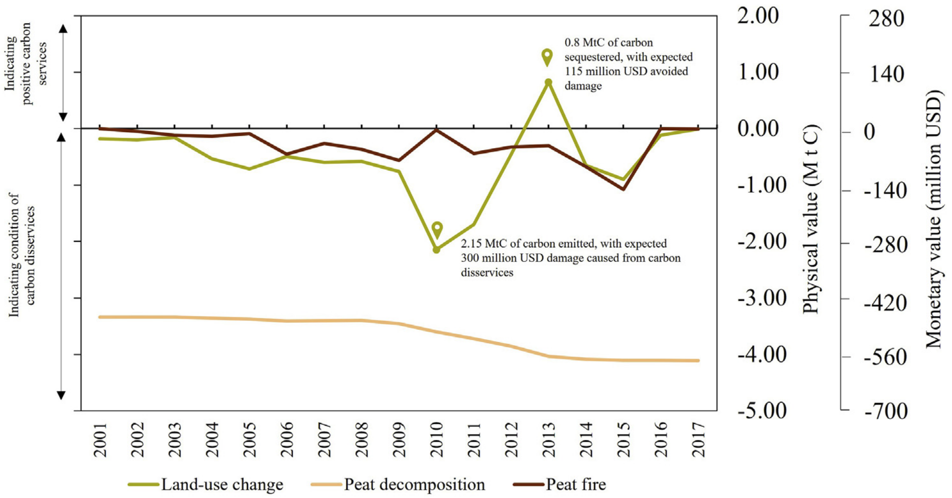

Figure 5. The physical and monetary value of carbon regulating services of Gaung–Batang Tuaka KHG for each type of disturbance.

area and loss of biomass from peat soil and above-ground vegetation. The peat fires reduced the monetary value of provisioning services as the extensively cultivated land was burned.

In Figure 7 we show the total monetary value of provisioning and carbon regulating services in Gaung-Batang Tuaka KHG. As clearly shown in Figure 7, the monetary value of carbon disservices has greatly exceeded the value of provisioning services, with an average annual loss of social benefits of carbon totaling USD 628 million. From 2001 to 2010, the monetary value of carbon services decreased by an average rate of 5.85% annually. Having passed a short-term increase in 2012 and 2013, followed by a sudden decrease in 2014 and 2015, the loss of social benefit of carbon stabilized at approximately USD 577–591 million from 2016 to 2017.

4. Discussion

KHG-based ecosystem accounting is motivated by Government Regulation No.57/2016 which states the urgency to execute ecosystem-based peatland management and make use of the release of Indonesia's KHG mapping under Decision Letter of KLHK No.129/2017. With the KHG map as the scope of the study, the ecosystem accounting we carried out will aid in understanding how economic activity and land dynamics affect the interaction of provisioning and regulating services. This method, however, does not allow for cross-KHG comparison, as ES value is highly determined by the extent of each KHG and the historical condition of the ecosystem. Nonetheless, we believe that our assessment of the interaction of these two ES will be of value in ranking approaches to peatland restoration: the greater the trade-off, the more carbon-intensive the current land-based economic activity in the KHG.

While the non-spatial analysis in this study could investigate the interaction between provisioning and carbon services at the KHG level, locally, the interaction between the two ecosystem services is varied spatially. Referring to Law No. 26/2007 regarding spatial management plans and Government Regulation No. 46/2016, the regional government must execute Strategic Environmental Assessment (KLHS), an integrated assessment of regional development based on the principle of sustainable development. Under this policy, it will become necessary to improve the study of KHG-based ecosystem accounting in spatial analysis. Such an analysis will be an advantage for land-based policy simulations, including ecosystem services (ES) hotspot mapping (Jiang et al., 2013) and measurement of the ecosystem capacity to provide multiple ES (Raudsepp-Hearne et al., 2010).

Our study of provisioning services revealed forest plantations as the main booster of the monetary value of provisioning services in the study area, due to the extensive area of acacia plantations (38,000 ha in 2017). Our results also indicated that the expansion of forest plantation and estate crops has shifted the main benefit of provisioning services from food to non-food products. With this trend in mind, it becomes a potential study gap to highlight the diversity of the benefit type for provisioning services. In spatial-based studies, this will have relevance in landscape biodiversity assessment, for example, and habitat heterogeneity (Strauch et al., 2019).

Further, assessing whether ES has been equally distributed to beneficiaries in the peatland ecosystem is necessary. This direction is prompted by the finding in our study of the productivity gap and the difference in the monetary value of provisioning services between private firms and smallholder oil palm plantations (Table 4). Increased land productivity (e.g., high-quality seeds, improved agricultural technology, etc.) will increase the total revenue and value-added of the commodity; hence, increase the resource rent or monetary value of the provisioning services.

The government of Indonesia has issued regulations to grant local communities' access and rights of use of forested areas through a social forestry scheme (Ministerial Law of MoEF No.83/2016) and to legalize land owned by the state that has long been occupied by the community through Agrarian Reform (TORA) scheme (Presidential Decree No.86/2018). With the implementation of these regulations, the community could have better access to incentive schemes from the government as well as the opportunity to form partnerships in the private sector, with the expected benefit of increased crop productivity for the community and improved product quality and market access (Nurrochmat et al., 2016; Erbaugh et al., 2017; Erbaugh and Nurrochmat 2019). These forestry schemes will potentially increase the monetary value of the KHG.

To apply the ES approach for future ES projection, it is important to add peat-adaptive commodities in the long-term ecosystem accounting projection, including the benefit for non-timber forest products. To promote paludiculture practices in the future, we encourage the use of the potential price of the product. As paludiculture commodities still lack a promising market, using the current price in the accounting will not increase the interest of either the smallholder or private plantation manager toward the cultivation of native peatland species (Yuniati et al., 2018). However, under supportive legal instruments (such as taxes, incentives, and disincentives), native species should be competitive with commercial commodities and attract private investment in paludiculture. This would have the effect of shifting the benefit of provisioning services as the demand-supply relationship changes.

Another main finding of this study is the negative value of carbon regulating services, so-called disservices/emissions, with the loss of social benefits of the carbon greatly exceeding the value of provisioning services *per se* (Figure 7). This emission amounted to 4.46 Mt of carbon

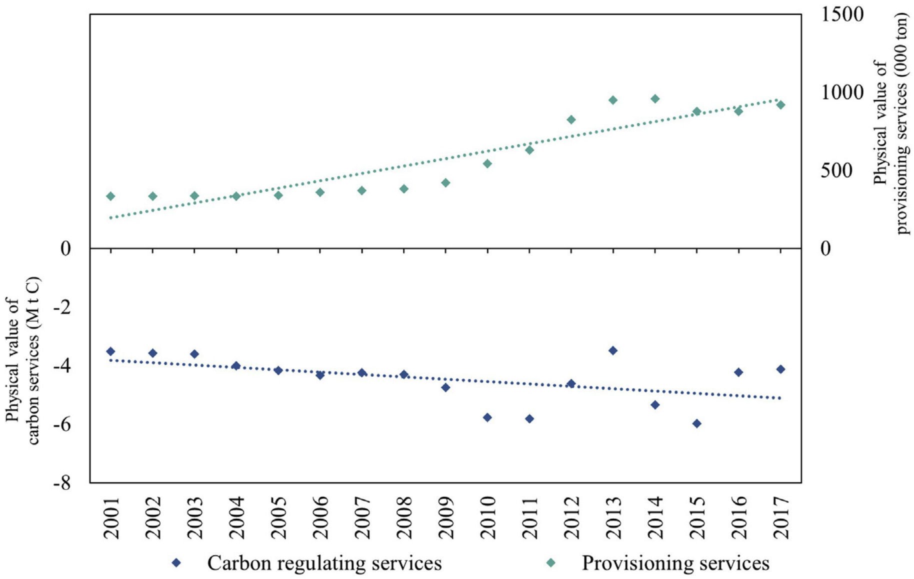

Figure 6. The total physical value of provisioning and carbon regulating services in Gaung–Batang Tuaka KHG. The dashed line indicates the main pattern of these two ecosystem services, which consists of five main stages.

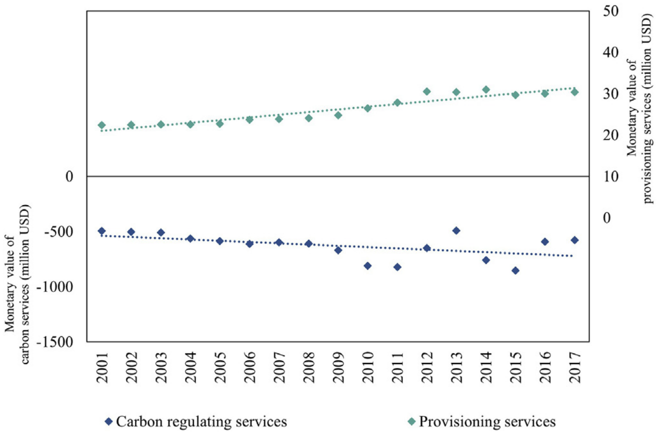

Figure 7. The total monetary value of provisioning and carbon regulating services in Gaung–Batang Tuaka KHG. The dashed line indicates the main pattern of these two ecosystem services, which consists of five main stages.

annually is from peat decomposition. At this stage, we are unable to state the role of extensive draining to emissions from peat decomposition, due to the limitation of activity data we use in this study. We estimated the emission from peat decomposition solely based on the land conversion activity. However, several studies have recommended linking peat water level to the carbon emissions from peat decomposition (Hooijer et al., 2006; Carlson et al., 2015). Derivation of peat decomposition emission from hydrology data should improve the analysis as it would highlight the volume of peat soil exposed to aerobic conditions due to draining.

We note that we did not yet analyze all ecosystem services and externalities of peat use in the case study area. Specifically, we did not analyze the effects of peat fires on public health; peat fires increase ambient particulate matter concentrations leading to health costs (Uda et al., 2019). Also, we did not yet analyze flooding impacts. Soil subsidence is irreversible in drained peatlands, and with drained soil subsiding by up to 5 cm per year, flood risks are likely to increase in the future (Sumarga et al., 2016). Hence, our assessment of the costs of peat drainage is likely to be underestimated. Further research is needed to quantify this aspect.

Because the land area of the KHG is dominated by peatland, a similar pattern for carbon disservices might also be found in other KHGs. Under this circumstance, KHG will always have a negative value for carbon services if there is still degradation activity in the ecosystem. Therefore, the main goal of KHG-based peatland management is the upscaling of profitable cultivation systems with the least amount of degradation, which highlights the necessity of including paludiculture systems in future studies. Although several studies have mentioned paludiculture practices in many regions in Indonesia, there is no uniform approach to restoring the peat soil moisture in these areas (e.g., planting without rewetting, partially rewetted project area due to limited canal blocking, and rewetting after several years of revegetation) (Yuniati et al., 2018; Budiman et al. 2020). On contrary, this study emphasizes that improving the hydrological condition of the peat is the key to increasing the physical and monetary value of carbon regulating services (Figure 5).

It is estimated by the Peat and Mangrove Restoration Agency (BRGM) that the total restoration cost for Gaung-Batang Tuaka KHG from the state budget amounts to USD 20.9 million, excluding restoration payments required from private holdings and concession areas and communities in the KHG (Peat and Mangrove Restoration Agency, 2017). Integrated peatland management at the KHG level demands not only sufficient funding but also equal understanding across beneficiaries and/or stakeholders of the KHG of the rescaling process of peatland governance (Astuti, 2020), as well as the technicalities of data transfer for cross-jurisdiction KHG. It is important to note that the process of ecosystem accounting *per se* could facilitate an effort of multi actors in the ecosystem to improve their ability to plan, execute, and monitor land-based policy by utilizing data from various institutions (Hein et al., 2020).

5. Conclusions

We found that in the study period (2001–2017), Gaung-Batang Tuaka KHG was consistently under peat disturbance, leading to the condition of excessive carbon emission or negative carbon services, in other words, carbon “disservices”. Regarding provisioning services, there was a shift of benefit type from food to non-food products, with forest plantations and estate crops as the major contributors of the monetary value of provisioning services in the ecosystem. The trade-off is dominating the pattern between provisioning services and carbon regulating services, and the decline in carbon regulating services accelerated while the monetary value of provisioning services increased at a slow pace. The annual monetary value of the provisioning services in post-2010 held steady at an average of 30.3 USD million annually. However, it was found that the loss of social benefits of the carbon due to carbon disservices greatly exceeded the value of provisioning services, amounting to a loss of USD 628 million annually. Compared to provisioning services, the pattern of carbon regulating services was more dynamic and was dominated by the effects of LUC and peat fire. Based on the results of our study, we propose that ecosystem accounting is a suitable approach to evaluate future peatland management based on the peat ecological function as well as socio-economic considerations. To accommodate the interaction of land-ES, we suggest including other types of ES and peat-adaptive species or paludiculture in the accounting process. Improving the spatial scale will be an advantage to ensure that governance of KHG based on peat rescaling will not just simply relocate the emissions from the protected peat area or peat dome but, rather, provide an integrated assessment for a peatland management plan.

Declarations

Author contribution statement

Annuri Rossita: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Dodik Ridho Nurrochma & Rizaldi Boer: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Lars Hein & Akhmad Riqqi: Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

TBC.

No additional information is available for this paper.

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