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LAND COVER AND LAND USE CHANGE IN KAYAN SEMBAKUNG DELTA 2013-2019: PATHWAYS FOR GHG EMISSIONS AND REDUCTIONS IN PEATLAND AREAS

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Land Cover and Land Use Change in Kayan Sembakung Delta 2013-2019, North Kalimantan Province: Pathways for GHG Emissions and Reductions in Peatland Areas

Mei 2022

INTRODUCTION WORD

GIZ PROPEAT is a collaboration program between the German Federal Government and the Government of Indonesia, in order to support the Provincial Government of North Kalimantan and East Kalimantan in encouraging land use (management) in peat and wetland eco systems in East Kalimantan and North Kalimantan to be more ecologically sustainable through the supports to integrative planning, promoting the principles of sustainable management and protection, capacity building and disseminating lessons learned and good practices to all stakeholders.

The programmatic scope of support from GIZ PROPEAT basically starts from the development of basic information, facilitation of policy development, support for the implementation of sustainable land use concept management, alternative economic development and livelihoods with environmentally friendly concepts, action research, and dissemination of various knowledge related to sustainable peat protection and management.

Kayan Sembakung Delta landscape is a unique area because it has two mangrove ecosystems and peat ecosystems, which at the same time shows the importance of this landscape as a storage area for carbon reserves so that it needs to be maintained sustainability. But this landscape has been intensively converted from year to year, so it is necessary to know the approximate value for various calculation scenarios both in the BAU scenario and by implementing rehabilitation programs and other preservation efforts.

This study focuses on the calculation and estimation of existing carbon reserves in peat areas, calculations of greenhouse gas emissions (GHG) that occurred during the period 2013 to 2019, as well as calculation scenarios with business as usual (BAU) schemes and scenarios that optimize rehabilitation and reforestation efforts.

This publication is expected to be a reference for the various stakeholders both at the national, provincial and district/municipality levels in the North Kalimantan Province in order to promote the sustainable protection and management of the peatlands.

Samarinda, May 2022

Tunggul Butarbutar

Principal Advisor

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ABSTRACT

Reliable reporting on Greenhouse gas (GHG) emissions from LULUCF on peatlands and developing GHG emission scenarios to inform politics and a sustainable management requires high quality peatland and Land Use (LU) data. In many tropical regions, peatland data exists only in fragments and LU monitoring from optical satellites is challenging due to limiting factors such as high cloud covers.

In a case study on the Peat Hydrological Units (PHUs) of the Kayan-Sembakung delta in North Kalimantan, Indonesia, we were able to assess the LU in the study area between 2013 and 2019 in 3-year steps by successfully using data driven spectral-temporal metrics (STMs) of Landsat 7/8 and Sentinel-2 in combination with a hybrid approach to delineate drained peatland area. We developed a set of GHG emission scenarios (Business-as-usual (BAU), BAU light, no new drainage, rewet all) for the Peat Hydrological Units of the Kayan-Sembakung delta.

The yearly medians of spectral bands were used for land classification in cloudy regions supporting land monitoring and GHG emission balancing. Further field investigations into the derived classes are recommended, though, for a better understanding of their dynamics and a better proven alignment with IPCC LU classes.

Peatlands cover about 2900 km^2 of the PHUs, of which half was still covered by primary Peat Swamp Forest (PSF) in 2019. Land use expanded from 390 km^2 in 2013 to 856 km^2 in 2019 to cover nearly 30 percent of the total peatland area. Oil palm plantations are the main drivers for land conversion and represent more than 50% of the total plantation surface. Consequently, GHG emissions from LU on peatlands doubled reaching 3.24 Mt CO_2-eq in 2019.

Since, only 8% of the peatland area falls under the Moratorium, but on 69% plantation concessions are issued for exploitation, we expect a continued expansion of PSF conversion and peatland degradation. In the "Business-as-usual" scenario GHG emissions would reach about 10 Mt CO_2-eq annually by 2050. In the "Stop new drainage" scenario the expansion of LU stops in 2020, and the yearly GHG emission would remain at 3.24 Mt CO_2-eq annually. The avoidance potential of this scenario is 103.3 Mt CO2-eq, i.e. 48 % of the BAU scenario. The complete rewetting of all drained peatlands by 2025 and halting any new drainage would lead to avoidance of 190.5 Mt CO2-eq, i.e. 89% of the BAU scenario. This is only true if rewetting means that the average annual water table depth is kept at 0 cm, i.e. at the peat surface.

In conclusion, our analysis identifies various points, where the management of LU on peatlands can be improved towards less GHG emissions, less peatland conversion and also less other negative impacts on livelihoods, economy and nature within the existing regulations and beyond:

The -40-cm water level rule means that GHG emissions are reduced but continue at 5 $tCO_2\text{-eq.ha}^{-1}.\text{yr}^{-1}$ for each 10 cm below surface. For effectively reducing unsustainable expansions of drainage-based land use, all Kayan-Sembakung peatlands not being in concessions should fall under the Indonesian Moratorium. In parallel, it is recommended to reconsider and perhaps suspend the existing concessions, for alternative LU forms of wet peatland use, such as Paludiculture. An MRV system would permit continuous official quantification of LU impacts on peatlands and all other negative impacts could be assessed using a risk assessment framework on peatland use.

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ABBREVIATIONS

BAU	Business-as-usual
EF	Emissions factor
ES	Ecosystem services
GFW	Global Forest Watch
GHG	Greenhouse Gases
GIZ	Gesellschaft für Internationale Zusammenarbeit
IPCC	Intergovernmental Panel on Climate Change
LU	Land Use
LULUCF	Land Use, Land Use Change and Forestry
MRV	Monitoring, Reporting and Verification
PHU	Peat Hydrological Unit
PSF	Peat Swamp Forest
SRTM	Shuttle Radar Topographic Mission
STM	Spectral-temporal metrics
UNFCCC	United Nations Framework Convention on Climate Change
WI	Wetlands International

CHAPTER I: INTRODUCTION AND METHODOLOGY

I.1. INTRODUCTION

Peatlands occupy about 7.8% of Indonesia's land area, of which about 30% are located in Kalimantan (Hooijer et al., 2006; Wahyunto et al. 2011, Xu et al. 2018), mainly occupying interfluvial areas of coastal plains or to a smaller extent inland (Dommain et al. 2011). The majority of coastal peatlands in Kalimantan is dome-shaped and rain-water fed (Dommain et al. 2010) with PSF as natural vegetation. Coastal peatlands transition to mangrove forests towards the shorelines (Rydin and Jeglum 2013). Local and international communities benefit from a whole range of ecosystem services provided by PSF (Dommain et al. 2016).

Only 7.4% of the peatlands in Kalimantan are still covered by pristine PSF (Miettinen et al. 2016). A drastic decline caused by an increase in peatland drainage and conversion for agriculture anthropogenic pressure for arable land, e.g. oil palm and pulpwood (Miettinen et al. 2017). After 2007, nearly half of the existing industrial plantations, especially oil palm, were developed on peatlands from converted PSF (Miettinen et al. 2016). As a consequence of peatland drainage, peat is oxidized, and large amounts of sequestered carbon released, making peatlands in Kalimantan an important global source of atmospheric CO_2 (Couwenberg et al. 2010, Dommain et al. 2014, Ribeiro et al. 2021).

Peat fires extremely affect the health of the impacted population and cause economic damage (Tacconi 2016). Subsidence of the peatland surface leads to more frequent floodings (Lupascu et al. 2020), ultimately leading to losses of vast coastal regions for livelihoods (Hooijer et al. 2015) forcing thousands of people to migrate (Hooijer and Vernimmen 2021). Losses of natural habitats and biodiversity occurring at high rates (Yule 2008, Sharma et al. 2018) are amongst a whole set of other ecosystem functions at risk.

The Land Use, Land Use Change and Forestry (LULUCF) sector contributes 63% to Indonesian GHG emissions (Tacconi and Muttaqin 2019). Emissions from drained peatlands are accounted for under this sector, and land use on peatlands is one of the largest sources of anthropogenic GHG emissions to the atmosphere in Indonesia (Warren et al. 2017). It has strongly increased over the past decade. Peat fires additionally increase GHG from peatlands. In 2015, around 8,000 km^2 of peatlands burnt in Indonesia due to an extreme drought caused by an El Niño event, generating 81% of the country's GHG emissions of this year (Giesen and Nirmala 2018, Leng et al. 2019).

To reduce forest loss and GHG emissions from LULUCF, already in 2011, the Indonesian government established a moratorium on concession developments in primary forest and on peatlands (Government of Indonesia 2011). In 2016, the Peatland Restoration Agency BRG was established and the goal of reducing its emissions by 26-41% and restoring 20,000 km^2 of peatlands by 2020 set (Evers et al. 2017, Harrison et al. 2020), as a response to the increasingly alarming GHG emissions, peatland degradation rates (2.6% per year; Hergoualc'h et al. 2018), and the risk that peat fires represent to public health (Marlier et al. 2012, Crippa et al. 2016, Koplitz et al. 2016, Evers et al. 2017, Uda et al. 2019, Kiely et al. 2020).

Ground water levels in peatlands including plantations should be raised to 40cm below surface. In 2019, the Moratorium was finally made permanent. Moreover, the government has pledged commitments towards international conservation and restoration goals such as the Bonn challenge, Paris agreement under the UNFCCC, Ramsar convention (Evers et al. 2017, FAO 2020).

Correct Monitoring, reporting and verification (MRV) for reporting peatland emissions to the UNFCCC is mandatory for countries as it is important to assess to what extent countries' efforts to reduce GHG emission are effective -also, in line with reduction targets under the Paris climate agreement (UNFCCC 2015). The correct quantification of peatland related GHG emissions for MRV requires accurate baseline data spatially on peat extent and land use and quantitatively on the amount GHG emission per land use type per area and time (IPCC 2006, 2014).

Since 2000, peatlands in North Kalimantan have been converted to a significant extent, mainly for industrial plantations (GFW). The Wetlands International (WI) peatland map for Kalimantan, which indicates peatlands in the Kayan-Sembakung delta does not provide neither a sufficiently high level of detail nor has it been based on sufficient field data (Wahyunto and Suryadiputra 2008). Quantification and consequences for GHG emissions and other negative impacts have yet not been evaluated by analysing frequent LU data.

In our study we aim to acquire this information at a high level of detail for the PHUs in North Kalimantan between 2013 and 2019 to support peatland management planning in support of the GIZ-led PROPEAT project, to allow reliable GHG emission calculations and GHG emission predictions for the future. Additionally, the information can help inform about the risk related to further LU development as part of a Risk Assessment of peatland use. Therefore, we developed and attached a peatland use Risk assessment framework concept.

I.2. METHODS

I.2.1. Study Area

The Kayan-Sembakung delta, North Kalimantan, Indonesia, is situated at the north-eastern coast of Borneo at the Celebes Sea around 3-4 degree north and 116 to 117 degree east. Climate is tropical with mean annual temperature of 26°C and mean annual rainfall of 3000 mm (Climate Data, 2021). Altitude is 15-20 m above NN and locally mineral outcrops rise above 100m NN. Population density is 10 persons per km^2 (BPS, 2020).

The rivers Sembakung and Kayan drain the uplands of North Kalimantan across the coastal plains into the Celebes Sea. Coastal raised bog peatlands covered with PSF developed on the interfluvial areas and in flats adjacent to the rivers. Towards the coast and along the river branches with marine influence mangroves are found between the shore and the PSFs (Seftianingrum et al. 2020).

The North Kalimantan PHUs constitute our study area (Figure 1). They cover nearly 3500 km^2 in total. As a general indication, a PHU covers hydrologically independent peatland units. The occurrence of peat in the area has been proven by a few, and not representative, field samplings, which built the base of the WI Indonesian Peatland map (Wahyunto and Suryadiputra 2008).

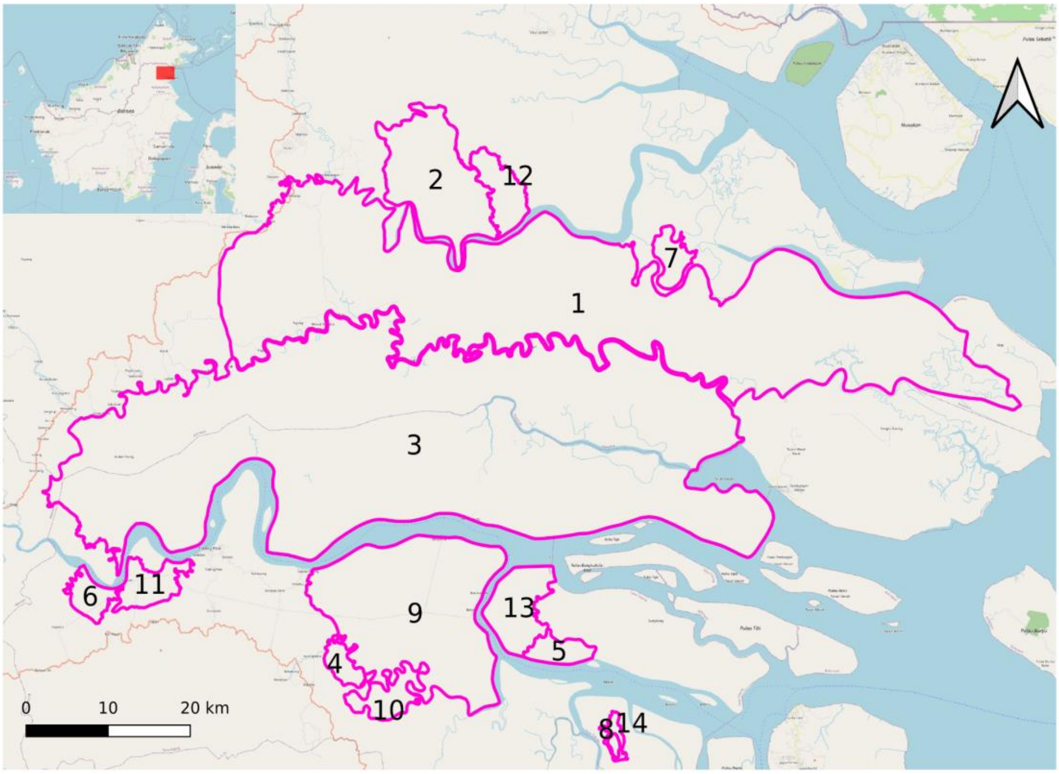


Figure 1: violet contour - Peat Hydrological Units of the Kayan-Sembakung area in North Kalimantan Province, Indonesia. own numbering.

I.2.2. Remote Sensing – Land Cover/Land Use Change

The presented land use analysis covers the period from 2013 to 2019 in 3-year-intervals, based on spatial analysis of freely available satellite imagery from Landsat 7/8 and Sentinel-2 a/b sensors. In combination with additional information on land use concessions and the moratorium area the past and current situation of the Kayan-Sembakung peatlands was evaluated

In parallel to the presented study, peat measurements in the field were and are being conducted through the PROPEAT project. Groundwater level measurement systems are being established in pilot communities. Also, options of a MRV system for greenhouse gas emission monitoring are being explored.

I.2.3. Data Processing for Land Cover Classification

All scenes per year (2013, 2016, 2019) from the sensors with less than 70 percent cloud cover were downloaded as Level 1 products from Google Cloud Storage and processed within the FORCE processing framework version 3.6.3. (Frantz 2019). First step was the generation of Level 2 Analysis Ready Data (ARD) in a data cube.

This includes cloud detection, correction of atmospheric water vapor, topographic correction, resolution merge of Sentinel-2 bands and co-registration of Sentinel-2 imagery with Landsat to reduce nominal geolocation uncertainty and data cubing (Frantz 2019, Rufin et al. 2021, Figure 2).

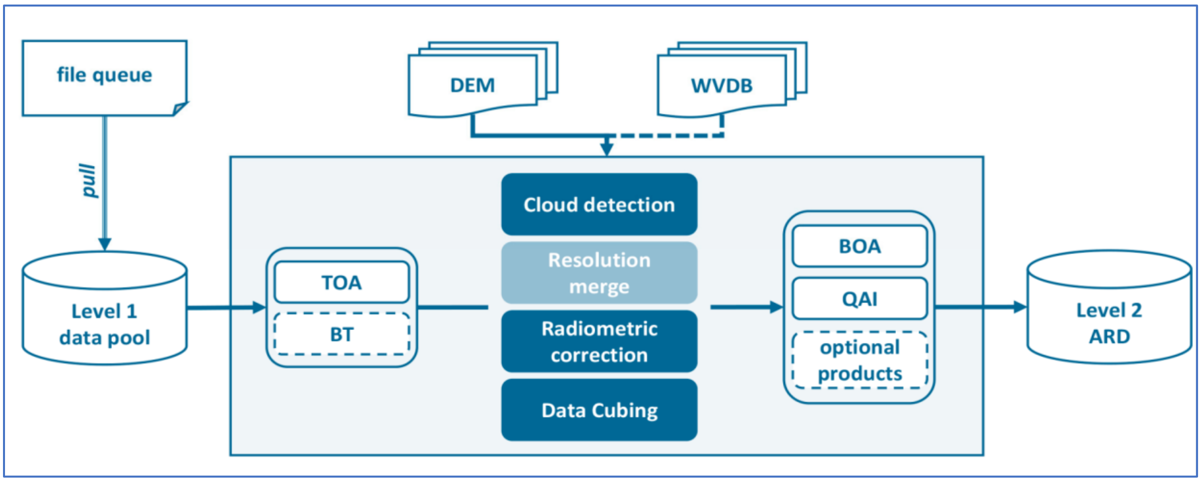


Figure 2: FORCE Level 2 Processing System workflow (from Frantz 2019). TOA—top-of-atmosphere; BT—brightness temperature; BOA—bottom-of-atmosphere; QAI—quality assurance information; DEM - Digital Elevation Model; WVDB - Water Vapor Database.

The number of Clear-Sky-Observations (CSOs) helps to assess data availability for the three target years. To overcome year-round high cloud cover, problems in cloud detection and thus low data availability, yearly spectral-temporal metrics (STMs) were used to create high resolution, gap-free land cover maps using a buffer of 200m around detected clouds. STMs are statistical aggregations that take advantage of all available observations in the respective period (Müller et al. 2015).

In this case, the annual medians of Normalized Differentiated Vegetation Index, tasselled-cap brightness, greenness and wetness, Soil-Adjusted Vegetation Index, Mean Normalized Differentiated Wetness Index were calculated and used as inputs for a Random Forest classification (Breiman 2001).

Training and verification points were chosen based on visual interpretation of high-resolution imagery from google earth and Bing. Out of the total points, 70% were randomly selected and used for training the classifier with the other 30% serving the validation of accuracy. Several runs were conducted to derive the combination of Indices with highest accuracy and visually coherent classification results. No direct ground-truthing could be conducted to verify the chosen classes due to travel restriction in times of COVID-19.

Besides high-resolution sat-images, class characterization was based on auxiliary information on land cover, concessions, the moratorium area from project partners, notably GIZ PROPEAT and third parties, accessed via GFW platform (accessible online). The SRTM Digital Elevation Model was used for visual interpretation too.

The post-processing of the classification maps, conducted in QGIS 3.16 (as well as all further steps), consisted in a rule-based year-to-year comparison of class changes to eliminate unlikely and wrong classifications. For example, the change of an oil palm class pixel to pristine or secondary swamp forest was considered unlikely and thus not accepted. In a last step, the classification maps were smoothed by applying a majority filter.

The land classes derived and applied in the classification are slightly different from official Indonesian land classes. For coherence with official national land cover data sets, official land classes were attributed to those of our classification afterwards based on the best of our knowledge. After post-processing land cover changes in the 3-year periods were quantified. Deforestation rates were calculated as the means over the 3-year steps 2013-2016, 2016-2019.

Change rates based on 3-year- steps were compared against data from Global Forest Watch (Annex 1) (Hansen et al. 2013). Furthermore, an analysis of the LU development between 2013 and 2019 in the three pilot communities – Atap, Lubakan and Bebatu – of the PROPEAT project has been made (Annex 2).

I.2.4. Drainage and Peatland Area

The direct identification of drained areas was not possible via our classification approach (4.1.3.). Drainage infrastructure commonly shows regular patterns on large scale plantations in peatlands in Kalimantan (Vernimmen et al. 2019). Areas with artificial drainage have thus been identified and outlined by target year by visual interpretation of the land cover maps in combination with high-resolution google and Planet imagery.

The update of the regional peatland map was in progress at the time of the writing of this report. The existing Wetlands International (WI) Indonesian Peatland map leaves out important areas of the PHUs (Wahyunto and Suryadiputra 2008). Indications, based on visual inspections of satellite images and field data suggest, that i.e. areas with drainage networks and PSF - both indicating peat - exist in larger areas, even if mangroves converted into shrimp ponds and the forest along undulating rivers were expected to show peat presence only irregularly.

We, therefore, produced an own estimate of the peatland extent based on two assumptions: 1- the need of drainage in an area indicates permanent wet conditions and thus the presence of peat (Ritzema et al. 2014, Hoekman 2007), and 2- areas covered by primary swamp vegetation according to our classification (3.1.2.), indicate the presence of peat (Page et al. 1999). Areas falling under one of the two assumptions were summed up. A verification of the derived peatland map could be done for four of the PHUs using the field sampling data provided by PROPEAT and subsequently compared to the WI peatland map.

I.3. SCENARIOS OF LAND USE CHANGE AND GREEN HOUSE GAS EMISSIONS

Emissions for the period from 2013-2019 were calculated using IPCC emission factors (EF) for tropical drained peatlands (IPCC 2014). Each land use class from the detected land cover map was assigned to its respective IPCC category (Annex 3). Then, four scenarios were developed for land use to estimate the avoidance potential of greenhouse gases between 2020-2050.

These scenarios were developed on the basis of the land cover mapping for the years 2013, 2016 and 2019 and complemented with available information on land use concessions for resource exploitation in the study area (2.2.1).

The first scenario is "business-as-usual: BAU". Land use was assumed to follow a linear extrapolation of the conversion rate of primary swamp forests using the average conversion rates between 2013 and 2019 for each land use category (i.e. palm oil and plantations A and B). The second scenario is "business-as-usual light: BAU-light". In this scenario, the change in the conversion rate of peatlands for the period between 2016 and 2019, i.e. after the large peat fires in 2015, was taken into account. The third scenario "Stop new drainage" assumed that no new areas would be drained after 2020, i.e. areas drained for oil palm or other plantations would however remain drained. The fourth scenario "Rewet all" assumed that all new drainage stops in 2020 and all drained peatlands, prior to 2020, are rewetted by 2025. It was also assumed in this scenario that the water table would be 0 cm from the peat surface on an average annual basis after rewetting.

CHAPTER II: RESEARCH RESULTS

II.1. REMOTE SENSING – LAND COVER AND LAND COVER CHANGE

II.1.1. Land Cover Classes – Characterization

Visual inspection of high-resolution satellite imagery and classification trials led to a comprehensive list of 13 land cover classes, which have been grouped into overarching natural vegetation, secondary vegetation and Land-use classes with anthropogenic origin (Table 1). The present land cover classes are, except for class 7, fully based on their spectral-temporal characteristics.

Table 1: Used land cover classes

	ID	Land Class	Indonesian Official Land Class (translation)	IPCC LUC emission category on drained peatland
	1	Water	Water body	
Natural Vegetation	2	Primary Peat Swamp forest	Primary swamp forest	Primary Swamp Forest
	3	Primary Swamp shrub	Swamp shrubs	Primary Swamp Forest
	4	Mangrove	Primary mangrove forest	Drained Mangrove
	5	Forest	Primary dryland forest	Drained Swamp forest
Secondary Vegetation	6	Grassland	Savannah	Drained Swamp forest
	7	Degraded Peat Swamp forest	Secondary swamp forest / logged over	Drained Swamp forest
Land-use classes	8	Oil Palm plantation	Estate crop plantation	Oil Palm
	9	Plantation A (Pulp Wood)	Forest plantation, Estate crop plantation	other plantation
	10	Plantation (B/ on mineral soil)	Estate crop plantation	other plantation
	11	Clearcutting	Estate crop plantation, Forest plantation	Oil Palm
	12	Bare soil/ drainage	Base soil, Settlement	Oil Palm
	13	Shrimp ponds	Pond	

Classes Primary Peat Swamp forest and Primary swamp shrub are considered the pristine vegetation of the interfluvial peatlands in the Kayan-Sembakung delta. The Peat Swamp forest covers the interfluvial areas of the delta with no signs of anthropogenic influence. Swamp shrubs are largely found at the peatland margins in transition towards either mangroves or (upland) forest on mineral soil. Since no vegetation studies or field information from the peatland areas could be consulted, no more detailed statements on vegetation composition or character of the respective classified areas can be made.

Adjacent to the peat swamp vegetation towards the rivers with tidal influence and the coast line, mangroves can be found (Seftianingrum et al. 2020). The "Forest" class is expected to occur upland and in the fluvial areas along rivers and streams, and in small patches within the oil palm class. This class is assumed to be found on mineral soils based on distribution patterns and interpretation of a SRTM Digital Elevation Model based on data from 2000. Here again, no field data or vegetation studies were available for a more detailed class description or verification.

Class 7 "Degraded peat swamp forest" is a class derived from land cover changes of the swamp forest class towards swamp shrub. Since this class is change-based, it does not occur in the first target year. Visual interpretation of satellite images allows to allocate such change to human influence, notably tree cutting activities. The grassland class occurs in patches only, either in the fluvial areas along rivers or linked to land-use change within land-use classes.

The oil palm plantation class represents the planted oil palm area - named Estate Crop plantations in the official Indonesian LU classifications. Available concession information (GFW) as well as high-resolution Google satellite images are confirming this assumption. Class Plantation A only occurred in 2019 (Figure 3, Annex 5). Information on Forest Plantation concessions indicate hardwood plantation, which could explain spectral similarity to swamp forests. Class Plantation B occurs on supposed upland/ mineral soil areas, as well as on assumed peat areas.

The class "Clearcutting" indicates a land cover change within the respective year with a strong reduction in vegetation cover. Class "Bare soil/ drainage" shows bare soils and includes drainage structures (canals) within plantations. Characteristic for this class is most likely low ground cover and a spectral mix of low ground cover and open water of the drainage canals. Drainage is mainly, but not in all places, appearing together with the overarching group of land use classes.

To avoid overestimation, drained areas have been delineated separately (see below). The class shrimp ponds are found along the coast and rivers with tidal influence. Settlements could not be discriminated as an own class.

II.1.2. Land Classes – Coverage and Change

In 2013 pristine peat swamp forest and shrub together covered 73% or 2557 km² of the study area, combined Land use classes Oil palm, plantation A and B, Clearcutting and bare soil/ drainage covered 13.5% or 471 km². Mangroves covered 126 km² against 112 km² of Shrimp ponds (Annex 5). The share of pristine peat swamp vegetation decreased to 53% in 2016 and reached 41% in 2019 compared to 2013.

Simultaneously, the area of combined Land use classes Oil palm, plantation A and B, Clearcutting and bare soil/ drainage increased to 22% and 775 km² in 2016 and 28.5% or 994 km² in 2019 (Figure 4). Degraded peat swamp forest as a class of change increased from zero in 2013 to 12 % of the study area in 2016 and 17% in 2019. Primary Vegetation decreased by 27.5% in the period 2013/16 and by another 22.7% in the period 2016/19. Land use classes on the other hand had a 64% increase from 2013 to 2016 and a lower 28.4% increase between 2016 and 2019.

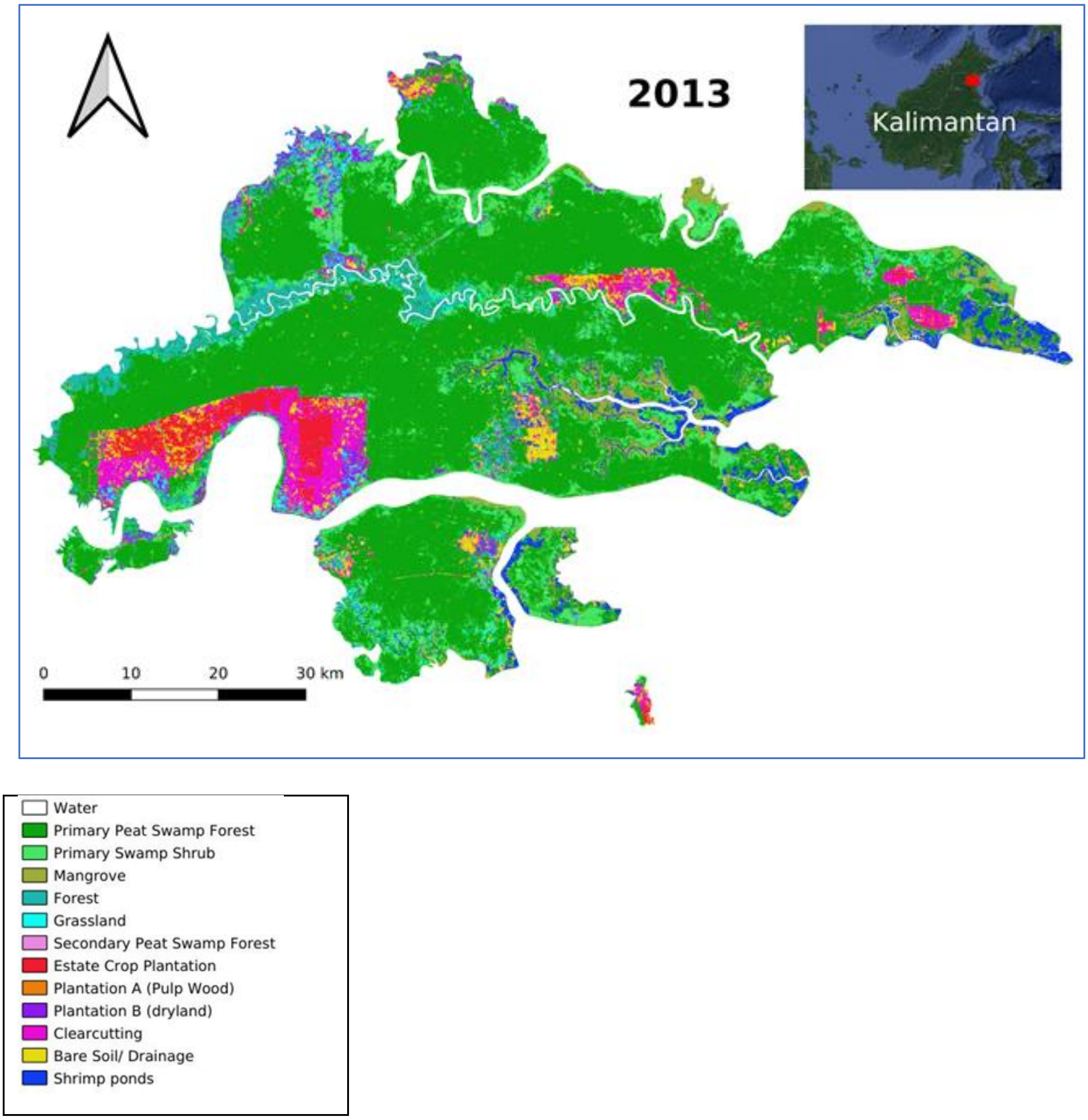
The area covered by mangroves slightly reduced in 2016 and nearly by 30% from 2016 to 2019. The area covered by shrimp ponds increased reciprocally. Lastly, The validation of classification results returned 80.7% accuracy for 2013, 76% in 2016 and 83.4% in 2019.

II.1.1. Drainage and Peatland Area

The drained area comprised 391 km² in 2013 and more than doubled until 2019 (Annex 6, Table A6, Figure 5). The increase of drainage area has slowed down from 4.2 % of the total area per year in 2014-2016 to 1.15 % per year in 2017-2019. Within the drained area, the share of natural vegetation remains stable in 2014-2016 and decreases to 8 % in 2017-2019.

Land use class area remains stable covering the majority of two thirds of the drained area 2013 and 2016 and nearly 80 % in 2019. The Classes shrimp ponds, mangrove and water are not present in the drained areas. Area shares of classes Grassland and Forest, but also Pristine Peat Swamp forest remain low over the investigated period with 2 to 3% each.

The estimate of the peatland extent, which was derived from the combination of Land Cover in 2013 and identified drainage areas in 2013, is 2893 km² (Figure 5), which is about 83 % of the PHU area. Overall accuracy based on field data from 1097 points is 80 %. The WI peatland map outlines 1700 km² of peatlands and shows an accuracy of 65 % (Annex 6).



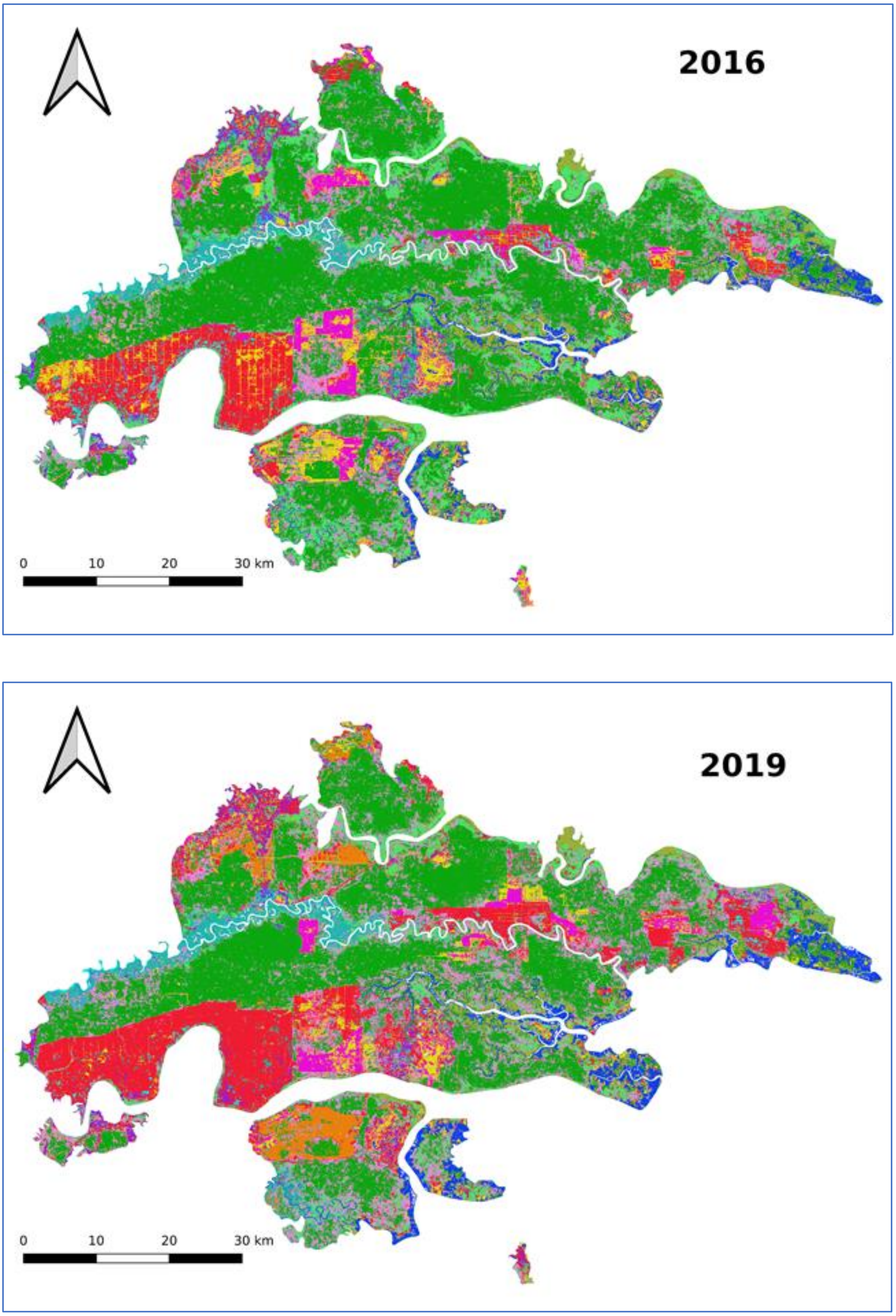


Figure 3: Land cover maps of the Kayan-Sembakung Peat Hydrological Units, North Kalimantan, Indonesia; overview map: red rectangle shows the study area

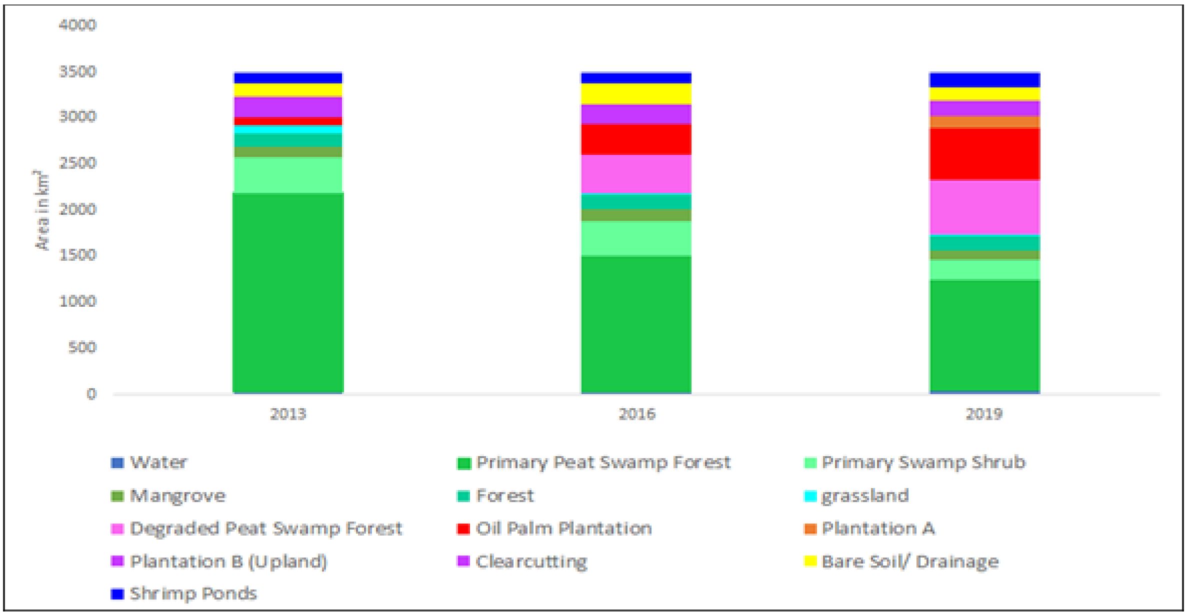


Figure 4: Area of Land cover classes on land of the PHUs of the Kayan-Sembakung delta, North Kalimantan Province

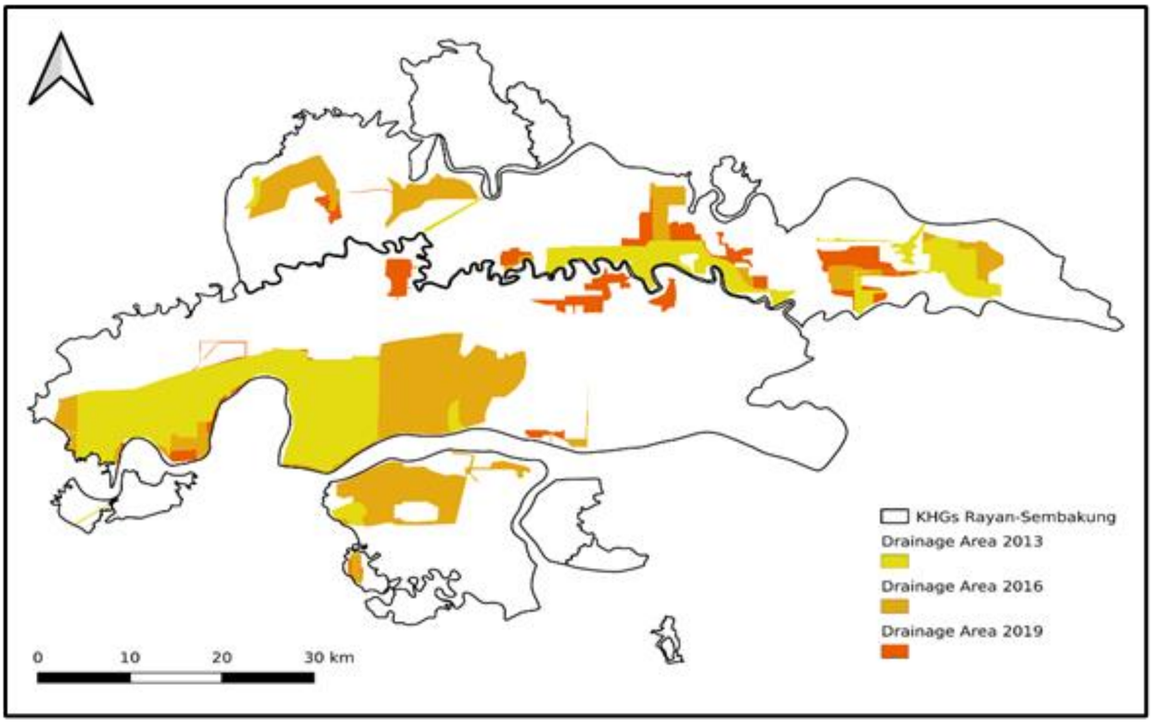


Figure 5: Change of area drained by target year of the PHUs of the Kayan-Sembakung delta, North Kalimantan Province, Indonesia

The ground-truthing points from the field are not equally distributed over the area (Figure 6). Whereas five smaller PHUs are representatively covered by field points, the coverage of larger PHUs is spatially limited (PHUS No 1 and 9) yet or non-existent (PHU No 3). The measured peat depth ranges up to 13 m (Annex 6).

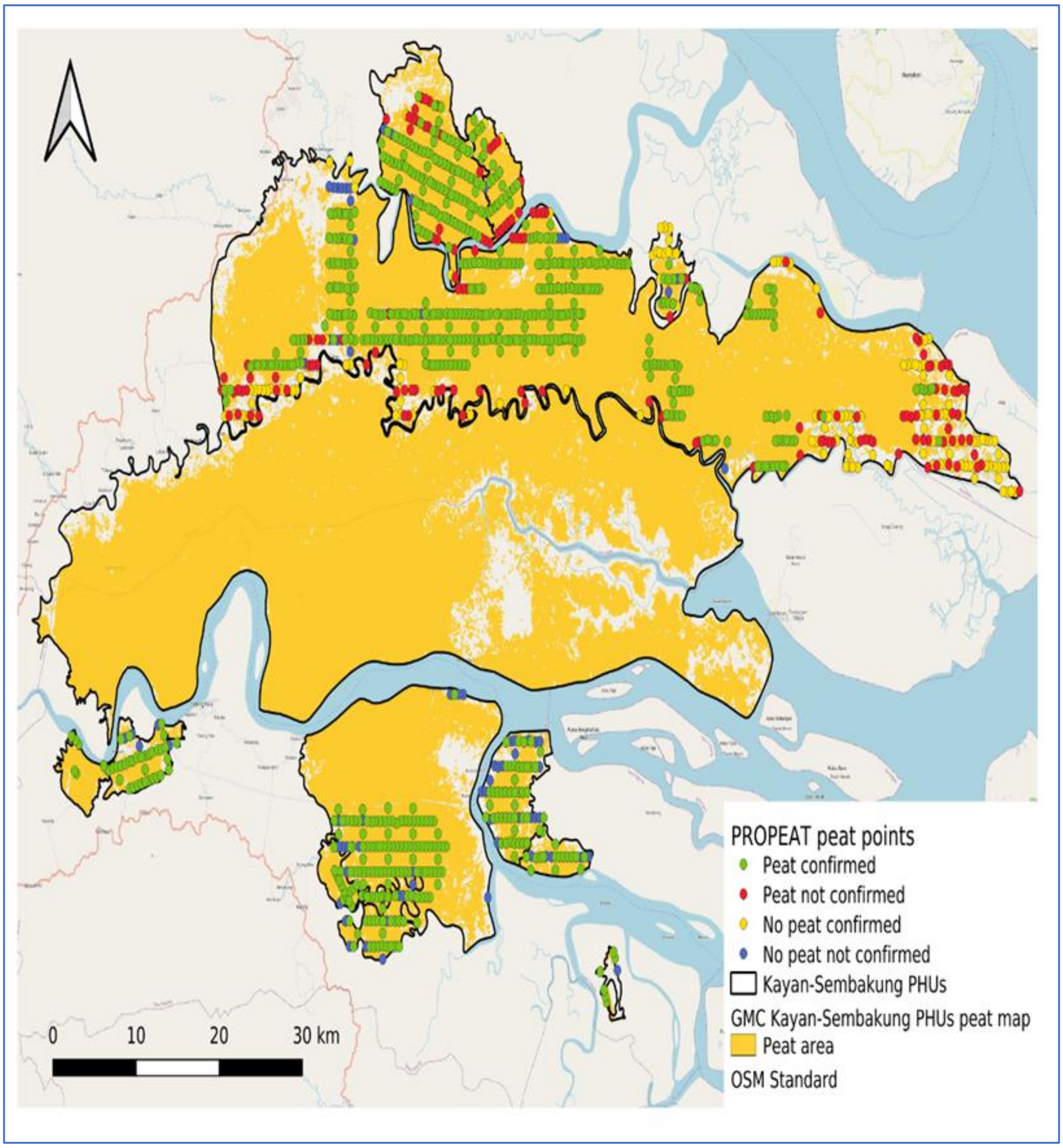


Figure 6: yellow - peat extent estimate by GMC for the Kayan-Sembakung area. Green points - field points confirming peat presence by map, red points - field points not confirming peat presence by map, yellow - field points confirming non-peat areas by map, blue - field points with peat, where map doesn't indicate peat, all point data provided by PROPEAT.

II.2. GREEN HOUSE GAS EMISSIONS AND FUTURE SCENARIOS

The estimated annual greenhouse gas emissions from peatland drainage and conversion for the period between 2013 and 2019 show an increase from 1.46 to 3.24 Mt CO_2-eq, which is about 122 %. The emissions increase rate is lower between 2016-2019 than 2013-2016, 126 % and 177 % respectively. Oil palm contributed to about 80% of the total annual emissions in 2013 and 2016, which is highest in the land use categories. In 2019, it saw a decrease to about 70 % of the total annual emissions, while the other plantations increased by 450 % to reach about 16 % of the total annual emissions, with the total in 2019 reaching 0.52 Mt CO_2-eq.

The drained peatland area saw an increased contribution to the total annual emission between 2013- 2016 from 0.18 to 0.52 Mt CO_2-eq, but it decreased to 0.41 Mt CO_2-eq, which is about 14 % of the total annual emissions in 2019.

In the BAU scenario, the primary peat swamp forest on peatland concession is 31 %, which may undergo conversion from about 2037 onward (Figure 7). Around half of all the peat swamp forests and shrubs would be converted by 2030 and only 10 % would be left by 2050. The 10 % primary swamp forest/shrub area is more than the current area conserved by the moratorium area, which is limited to 7.26 % as of 2020 (down from 7.95 % in 2016; See Annex xxx Moratorium xxx).

Oil palm is expected to make up about 60 % of the peatland area land cover in 2050, which is lower than the concession areas permitted for oil palm (65 %; Annex 7).

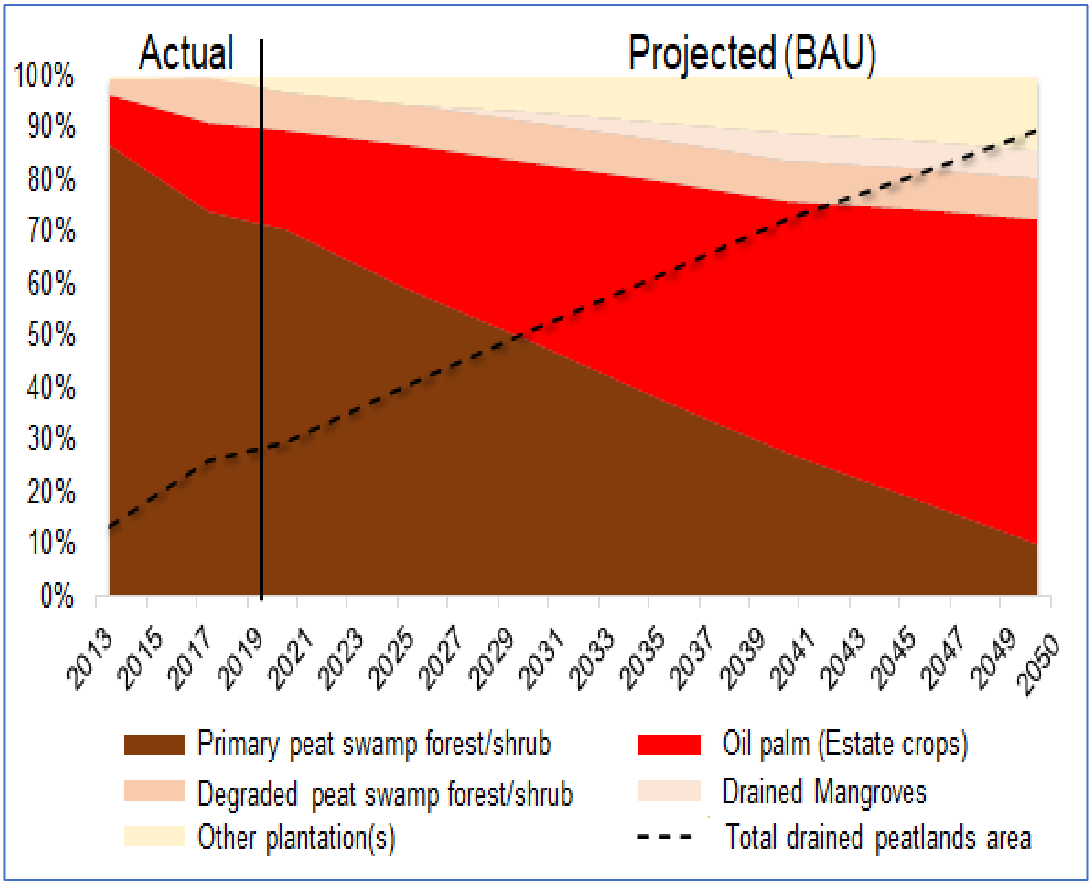


Figure 7. Scenarios of peatland conversion from 2020-2050, based on the land use trends detected by remote sensing from 2013-2019.

The BAU scenario with the steady increase in palm oil appears to lead to an increase in the total GHG annual emissions by three folds to about 10.2 Mt CO_2- eq. Oil palm would be the main contributor with about 7.38 Mt CO_2- eq, which is about 72.5 % of the total annual missions. GHG emissions from other plantations also show an increase by more than fourfold to about 2.32 Mt CO_2-eq annually, which is about 22.8 % of the total annual emissions. The remaining emissions would be from the land intended for continued peatland drainage for conversion.

Alternative scenarios appear to decrease emissions, but only the Rewet all scenario leads to 0 by 2025 (Figure 8). The emissions avoidance potential is directly proportional to the measures taken. The BAU light has a cumulative avoidance potential of about 45.4 Mt CO_2-eq, which is about 25 % of the total emissions for the period from 2020 to 2050. The savings appear to be up to 90% in case peatlands are all rewetted by 2025. In comparison, stopping peatland conversion would lead to savings of about 103.3 Mt CO_2-eq, which is only 48 % of the total cumulative emissions for the period 2020-2050.

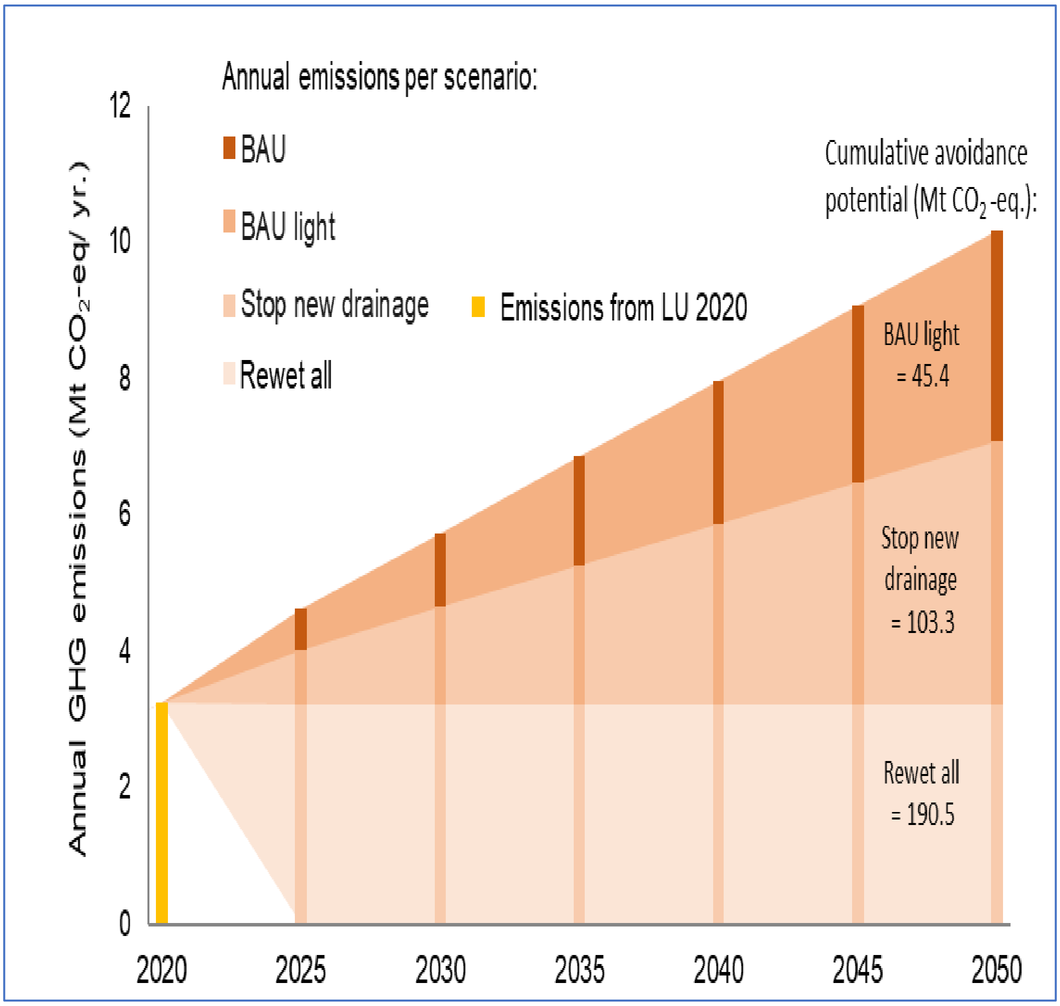


Figure 8. Business-as-usual (BAU) scenario's total cumulative annual emissions in Mt CO_2-eq.yr^{-1} (columns) from drainage and conversion of peatlands into oil palm and other plantation and the cumulative avoidance potential (area) from the alternative scenarios: BAU light, Stop new drainage and Rewet all.

CHAPTER III: DISCUSSION

III.1. LAND USE

III.1.1. Land Use 2013-2019

The trend of expanding plantations on peatlands and a reduction in extent and degradation of PSF, which happen all over Indonesia (Austin et al. 2019, Nikonovas et al. 2020), can also be observed in the Kayan-Sembakung peatlands of North Kalimantan between 2013 and 2019. The reduction of forest conversion rates, which is also reflected by the reduced expansion of drainage canals in 2017-2019 compared to 2014-2016 could be attributed to the Indonesian Moratorium (Chen et al. 2019), which came into place in 2011 for the first time.

More recent studies, however, find other factors more likely to explain the development (for further discussion see 4.1.5.). Main drivers of PSF conversion were industrial plantations, foremost oil palm and pulpwood to a smaller extent. Smallholder plantations, which constitute up to 40% of Indonesian plantations (Directorate of Estate Crops 2020), were found only in the pilot community Atap (Annex 2) and play a minor role in LU of the Kayan-Sembakung peatlands.

Pristine PSF might have originally had an extent of up to 2800-2900 km² in the study area. Thus, the deforestation that took place in the PHUs led to losses of nearly only PSF and Swamp Shrub (Annex 1, Annex 5). While in 2013 about 76% of the pristine vegetation was left, this reduced to 43% in 2019. Degraded swamp forest increased to 17% of the total PHUs (Annex 5). Initially in 2013, one main oil palm plantation of 500 km² existed in the central and largest PHU number 3 (Figure 3).

Two smaller plantations of about 100 and 50 km² were situated in the neighbouring PHU number 1. A reason for the higher conversion rate in the 2014-2016 period could be the establishment of new plantations at different locations in nearly all PHUs, while existing ones were extended. In 2017-2019, nearly no new plantation occurred, while the existing plantations were further extended, then covering 30% of the peatland area (Annex 5).

The reduction of the mangroves is clearly caused by shrimp pond expansions, a finding that confirms a former study on mangroves in North Kalimantan (Seftianingrum et al. 2020).

III.1.2. Peatland Extent

Peatlands cover a major part of the PHUs. Places without peat are supposedly mineral outcrops based on DEM interpretation. Sections along the Sembakung river floodplains, which might be subject to strong sedimentation dynamics, and mangroves mostly show no peat appearance according to the ground truthing. In these areas, which show a patchy peat distribution according to the peat map, differences between the estimated peat distribution and the validation data can be observed leading to an overestimation of peat extent there (Figure 6).

Towards the edges of the peatlands, peat layers are rather shallow compared to more central parts. In the smaller southern PHUs the distribution along the edges of the peatlands is underestimated when compared with the field points. There, the size of the peatland and thickness of the peat layers are not necessarily correlated (Annex 6.).

Given the accuracy and results from the validation, the indicative peatland map seems fairly well predicting peat and providing a drastically improved and increased estimation of peat extent compared to the WI Indonesian peatland map (Annex 6), despite limitations due to important sampling gaps.

Thus, it represents the best base for further analysis on GHG emission scenarios. It should be noted that the unequal field data distribution is mainly due to restricted access to plantations by project partners. Once the peat surveys by PROPEAT are finished, the updated official peat map will hopefully provide a precise and reliable base for all further assessments related to the North Kalimantan peatlands.

III.1.3. Concessions, Moratorium

A big divergence exists between the extent of concessions for LU in the PHUs and the protected peatland areas under the Moratorium. According to the different sources (GFW and PROPEAT), concessions for different purposes covered 69% of the peatland area. About 48 % of this is occupied by oil palm concessions and 17% by Wood fibre/Forest plantations (corresponding to Pulpwood plantations).

However, 134 km² of plantations have also been detected outside the identified concession boundaries on peatlands (Annex 7). Therefore, either our information on concessions is not complete or some plantations were not legally established or extended.

On the other hand, less than 8% of the peatland area falls under the Moratorium area in 2020 (Figure 9, Annex 7). From 2016 to 2019 this number has diminished from 243 km² by 8%, due to the biannual update of the Moratorium map. The distribution pattern of Moratorium sites over the PHUs, with very narrow stretches and rather patchy appearance (Figure 9), cannot provide sufficient protection of the remaining intact parts of the peatlands without drainage.

The concept of a peatland as one hydrological unit, which is reflected in the Indonesian concept of PHUs, implies that any drainage in parts of the hydrological unit is necessarily going to also impact the other parts without drainage, ultimately leading to drying and losses of peat carbon and various ESs (Bonn et al. 2016).

Preserving only small parts of a peatland, while in parallel draining large parts of the peatland adjacent, would not lead to the intended protection of a peatland and preservation of its functionalities.

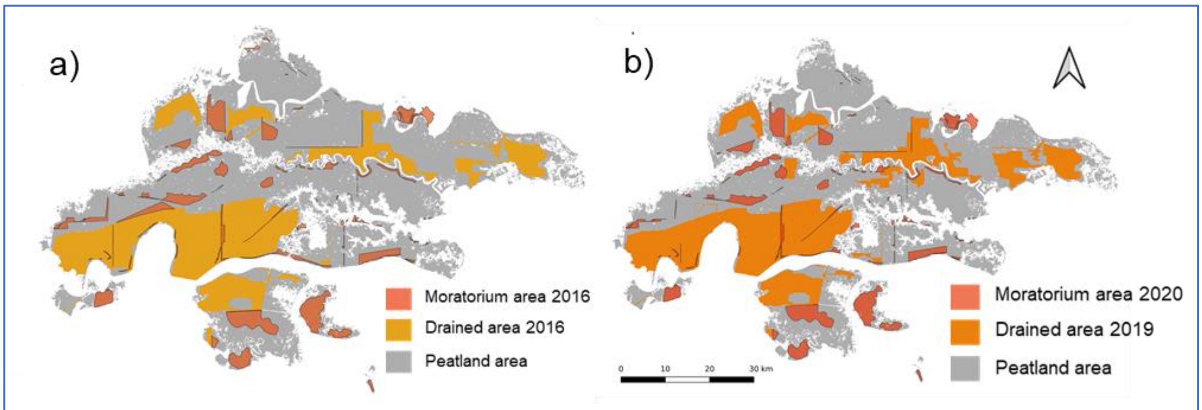


Figure 9: maps of Kayan-Sembakung PHUs showing the drained areas in 2016 (a- yellow) and 2019 (b-orange) with Moratorium areas overlain (red).

Furthermore, the moratorium maps are evaluated and changed biannually leading to a reduction of the area that is protected under the moratorium area, due to continuously degraded

Primary forests. This can be considered problematic, as forest loss is reduced but ultimately not stopped (Nikonovas et al. 2020). Deforestation rates in Indonesia dropped after 2016, in particular in Kalimantan (Chen et al. 2019), which was described in particular between 2017 and 2019 (Gaveau et al. 2021).

Our results are in line with these findings, although the present distribution of moratorium areas in the Kayan-Sembakung PHUs seems unlikely to have a significant effect on PSF loss and reduced peatland drainage expansion. Other studies indicate reduced market prices for palm oil and large fires in 2016 as factors that affected the slowdown of land conversion after 2016, that was observed over Indonesia (Gaveau et al. 2021).

To achieve effective peatland conservation or management, the remaining peatland parts without drainage would need to be kept as such, even if the PSF cover is degraded. If drainage-based LU on peatlands cannot be stopped for political and socio-economic reasons, at least the Moratorium area should cover all peatlands in the PHU, which are not covered by concessions.

The official outline of primary against secondary swamp forest seems to show inconsistencies with actual distribution of those two Swamp Forest types (Box 1).

Ground water levels should be raised to the peat surface through canal blocking. Better and compulsory in the longer term (UNFCCC 2015) is a replacement of all drainage-based activities on peatlands by wet LU practices, which are summarized in by the Paludiculture concept (Box 2).

Additionally, restoration efforts by Indonesia of degraded peatlands (BRG 2020) needs to be upscaled. These restoration efforts would need to be monitored. Indonesia, therefore set up various monitoring systems, e.g. the Peatland Restoration Information and Management System (PRIMS) and the peatland water monitoring system (SIPALAGA) both from the Peat Restoration Agency (BRG), and the SiMATAG -0.4m from the Ministry of Environment and Forestry (BRG 2019, FAO 2020).

However, these platforms are not covering the whole of Indonesia yet, particularly not North Kalimantan.

BOX 1: Primary vs secondary forest

The official Indonesian land cover maps indicate only 3 % as Primary Swamp Forest on peatlands in the PHUs in 2018, and about 58 % as Secondary Swamp forest. Large parts of the official Secondary Swamp forest exist in PHU 1 to 3, that are apparently pristine with no signs of visible disturbances (based on the following sources: SRTM DEM, high resolution satellite imagery, own classification, see figure A3.1). Our impressions are based on a first quick assessment based on limited data. Therefore that this apparent discrepancy of the delineation of Primary and Secondary Swamp Forest in the Kayan-Sembakung peatlands should be investigated in depth. Moreover, this analysis could have a significant impact on the area, which is protected under the Moratorium (see 4.1.3.).

Finally, the Moratorium limits only new concessions. In the Kayan-Sembakung area, concessions which had been issued already before the Moratorium came into use. If LU on peatlands in the PHUs is to be developed according to the present information on LU and concessions, long-term and increasing peatland degradation and GHG emissions can be expected (4.2.).

III.2. REDUCTION PATHWAYS

Our data indicate that the LU and associated emissions have continued to rise after 2012, in line with the projection of the emissions from peatland degradation in Indonesia's FREL (MoEF 2016). The increase, however, has seen an accelerated rate between 2013-2016. For instance, the total drained peatland area in 2012 in North Kalimantan was estimated at 276.28 km^2 (INCAS; Krisnawati et al. 2015), which has increased in 2013 to 391.3 km^2 in 2013, reaching 756.7 km^2 in 2016 and finally 856.9 km^2 in 2019.

The fold of the detected peatland conversion, which took place in the period between 2013-2016, is about 2.78 times that detected in 2012. The associated emissions increase in that period is about 4.5 times the emissions of 2012, if the drained areas in 2012 are considered to be oil palm only, i.e. using IPCC emission factors for oil palm.

It should be noted that the estimated emissions from peatland decomposition for Indonesia in 2012 ranges between 226 to 357 Mt CO2-eq or 226 Mt CO2-eq according to the 2016 FREL and the second BUR submissions respectively (MoEF 2016, BUR Indonesia 2018). This means that the emissio ns estimated for North Kalimantan are about 1 % of the total emissions from peatland degradation in Indonesia.

This share may change if restoration takes place in priority areas, which are mentioned in Indonesia's FREL (MoEF 2016), while other areas, e.g. North Kalimantan, continue to be drained, i.e. problem shifting. This is particularly true if the basic information (e.g. peat depth, carbon stocks and land cover types) and MRV systems in North Kalimantan are not quickly developed to provide sufficient information on the current situation and the future implications.

BOX 2: PALUDICULTURE

A general understanding

Drainage based agriculture and forestry on peatlands lead to a loss of ecosystem services, e.g. climate and water regulation and biodiversity. Both increase the frequency of hazards, e.g. fire and flooding, with diverse negative consequences such as, amongst others, enhancement of climate change by CO_2 emissions, health dangers caused by smoke, and the loss of fertile land by fire and flooding. A sustainable alternative can be paludiculture, which is the productive use of peatlands under peat conserving conditions, i.e. wet or rewetted (Wichtmann et al. 2016[MK1]). However, as natural peatlands have become scarce and should be protected, paludiculture focuses on rewetted peatlands.

Paludiculture excludes both drainage-based agriculture and drainage-based forestry, and cultures with frequent tillage such as rice, but includes many other options. These options comprise a large variety of plant species in the tropics (Giesen 2013). Such plant species can be harvested without disturbance of the peat. The harve st can be directly used as fibre, fuel, food, and feed, and can furthermore be the raw material basis for many other uses. The aim is to fulfil human needs under peat preserving conditions, as without peat preservation no sustainable development in and around peatlands can be reached.

Best references and options for Indonesia

[HW2] [MK3] According to a recent publication (Giesen 2021), at least 541 suitable peat swamp plant species exist in Indonesia, of which 81 have a major economic use; yet only 12 are ready for testing (Giesen and Nirmala 2018). For a comprehensive list see Giesen (2013). The most promising species are listed as follows: Sago palm (sagu, *Metroxylon sagu*), Illipe nut (tengkawang, *Shorea* spp.), Purun *(Eleocharis dulcis*), Water spinach (kangkong, *Ipomoea aquatica*), Kelakai (*Stenochlaena palustris*) and Jeluntung (*Dyera* spp.)

Sago palm, Illipe nut, Water spinach, and Kelakai are reported as suitable paludiculture plants from Central Kalimantan. Sago and Illipe have the lowest CO_2 [MK4] emissions and Sago offers the best profitability (Uda et al 2020). However, local investigations are needed to check the applicability of results from Central Kalimantan in North Kalimantan as different peatland types and climate regions have their distinct and suitable plants. Sago for example is rather growing on minerotrophic peatlands whereas Jeluntung or Illipe are typical ombro trophic peat swamp forest species in Southeast Asia. It thus has to be checked beforehand which plant species are suitable for a specific peatland.

Common misconceptions of paludiculture

It has to be noted that most paludiculture species can also grow under partially rewetted conditions, i.e. a water table depth of 25 cm, 40 cm, or even deeper below the peat surface. However, neither the planting of paludiculture species without the full rewetting of a peatland nor the mere planting of dryland species on peatland can be considered as paludiculture (Tata 2019, Budiman et al. 2020, Giesen 2021).

Unfortunately, many dryland species such as oil palm, *Acacia crassicarpa*, pineapple, coffee, rubber, *Aloe* spp., and many others are incorrectly labelled and promoted as paludiculture. These plants require drainage and are thus no paludiculture by definition. Even though these plants might offer an income option for a short time, cultivation will most likely fail in the long run as it causes strong CO_2 emissions, increased fire likelihood, and land subsidence with flooding in the end (Giesen and Nirmala 2018, Tan et al. 2021, Giesen 2021, see also Annex 9 of report “Risk Assessment Framework”). Rice cultivation is another example for non-sustainable peatland use, as even with high water levels tillage and the strong use of fertilizer lead to high microbial activity and peat decomposition (Giesen 2021).

Implementation of paludiculture in North Kalimantan

Complete rewetting is the prerequisite for revegetation. Paludiculture is one option for revegetation with a strong opportunity for revitalisation for local communities to live sustainably with peatlands. Several steps have to be taken into account and implemented to boost paludiculture in North Kalimantan. For all steps, it is important for local and regional authorities to be supportive as the legal framework is currently not tailored for paludiculture (Giesen and Nirmala 2018).

1. Identification of potential areas

Potential areas for paludiculture have to be found. For the time being, it is important to find areas for pilot trials of paludiculture in communities. It is important to take a participatory approach in doing this and working together with the local communities. Once determined, the area has to be fully rewetted prior to or in parallel to the next step.

2. Testing of paludiculture plants on pilot sites

Several different species are an option for paludiculture but there are still knowledge gaps in terms of suitability in regard to different environmental parameters, the provenance, best propagation methods, accessibility of the paludiculture, and harvest. It seems thus advisable to investigate different species (maybe even from different provenances) and to test intercropping on pilot sites. Such pilot sites are important to show local farmers the opportunities they have and thus convince them on the benefits.

3. Development of value chains and business models

The direct sale of harvests is not easy for some paludiculture species, for others it means low revenue. In both cases, local value chains have to be developed. This can include the local processing of raw materials or the collaboration with other communities. With a subsequent business model, it is easier to identify financing options.

4. Implementation

With the results of the aforementioned steps, implementation with local communities is possible. It is important that local communities want to participate, as a top down approach is neither useful nor desirable.

North Kalimantan with its vast areas of partly degraded peatlands offers a good basis for a successful development of locally adapted paludiculture. The road lies ahead, the journey just has to be started.

Further, the data indicate that there is a change in the trends of LU, resulting in lower conversion rates after 2016, which are driven by the absence of establishment of new plantations (4.1.3.). Despite that logging and conversion seem to continue to take place, even within areas designated within the Indicative Moratorium Map (4.1.4.). Therefore, the BAU scenario is a risk that may take place, where it would be assumed that all planned concessions would continue to be implemented, and the emissions from peat oxidation only may reach 10 Mt CO_2-eq. yr^{-1}.

It is likely, however, that the BAU-Light will take hold in the future. This is dependent on the criteria for obtaining permits to create new plantations, here assuming that the original concessions would not be completely implemented. This is noted in the observed conversion rates discrepancy before and after 2016, i.e. the government establishment of BRG and peatland restoration promises (MoEF 2016). The alarming point to this scenario is the conversion taking place within the current Moratorium areas.

In case the conversion rates remain consistent to this observed between 2016-2019, it may already lead to a saving potential for GHG emissions of about 25 % in comparison to the BAU scenario. Further ambitious savings can be made through stopping new drainage and rewetting all peatlands, where a reduction up to nearly 90 % can still be achieved in North Kalimantan from the BAU scenario. Alternative economic activities can be implemented to compensate for the direct economic losses from stopping drainage-based LU on peatlands (BOX 2).

Water level and peat depth are two criteria that dictate the peatland management policy discussion. Peatland management plans, or wise use, dictate that water level should not fall below 40 cm below the peat surface. The higher water level may lead to emission reductions in line with the Indonesian goals to reduce part of their GHG. It also might less than half of the current estimated emissions of oil palm and other plantations. The 40 cm water level depth would lead to only 20 tCO_2-eq.ha^{-1}.yr^{-1}, instead of at about 40 and 55 tCO_2-eq.ha^{-1}.yr^{-1} for oil palm and other plantation, respectively, but it would not lead to zero emissions (Couwenberg et al. 2010, Murdiyarso et al. 2019).

The peat depth criteria dictate that management plans are limited to peatlands with a peat layer > 3-meter thick (Presidential Decree No. 32/1990; Silvius and Suryadiputra 2005, WRI 2012). This criteria however, is not clearly indicated in the most recent official Indonesian documents (e.g. Indonesia's FREL; MoEF 2016). The current estimates of the peat distribution, on the indonesian level, indicate that 69 % of all the peatlands are within 50 - 300 cm thickness range (Wahyunto et al. 2011).

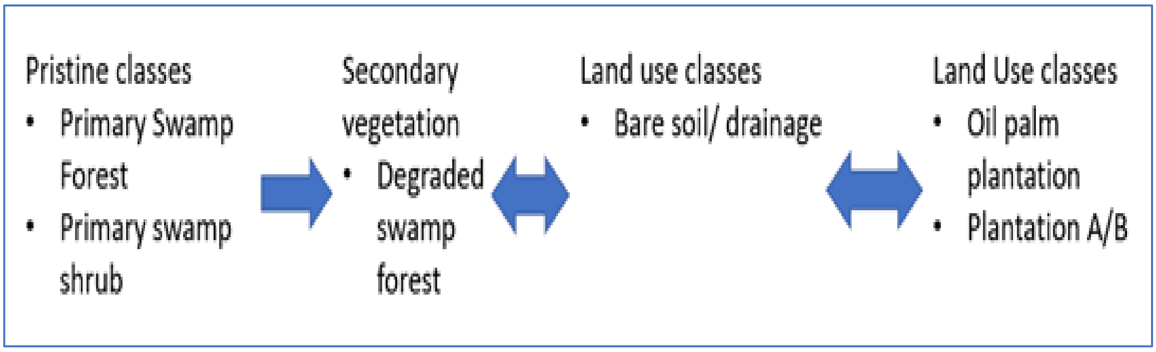
This means that if these peatlands continue to be drained and/or water managed, i.e. used with the water level depth at - 40 cm, then emissions from peatlands may contribute to the reduction goals up to 2030 (29 or 41 %), but it would not lead to the zero emissions goal in 2050. Additionally, since the information on the peat depth in North Kalimantan is very limited, there are no present means to estimate the effect this plays on future management plans.

Existing MRV systems focus mainly on LU and GHG emissions. The evaluation of range of other negative effects of peatland drainage and degradation requires a more holistic framework to capture and quantify those effects. A threat and risk assessment framework are provided in Box 3.

III.3. UNCERTAINTIES AND LIMITATIONS

III.3.1. Classification Approach

As part of the establishment of industrial plantations, two kinds of initial activities could be observed: 1. logging - as indicated by degraded forests, and/ or 2. construction of drainage canals. Thus, we derived the following sequence of change between land classes in a peatland in the target area:



The class “degraded Peat Swamp forest” is not necessarily recorded for all land changes in the 3-year periods. In a 3-year period either the intermediary “degraded vegetation” step happened, but was not recorded, or the direct change from Primary Peat Swamp Forest to Bare soil/drainage or Oil palm occurred by immediate forest clearing.

The apparition of drainage canals and bare soils in preparation of plantations can be identified via STMs as one land cover class. A clear separation between the two LU types was not possible. The two classes “bare soil/ drainage” and “clearcutting” appear in all types of plantations and are not specific to one of them.

BOX 3: Risk assessment Framework

The development of a Risk Assessment framework may allow us to merge the results of this study with additional information on socio-economics, fire hotspots and frequency and other (a)biotic measurements (e.g. peat depth, carbon stock, etc) to quantitatively evaluate short and long-term effects of peatland use not only in North Kalimantan.

The assessment in the framework is made according to the risks, which are calculated using the following formula: Risk = Hazard x Exposure x Vulnerability. Each threat (hazard) is scored according to its likelihood of occurrence in certain peatland. Ecosystem service (ES) exposure to the threat is scored depending on the affected peatland territory. ES vulnerability is scored by the value of its indicator(s). The framework was built following the steps identified below:

Step 0. Define terms used in the article

IPCC definitions (Oppenheimer et al., 2014) are followed where: **Risk** is the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. **Hazard (threat)** is the potential occurrence of a human-induced or natural physical event or trend or physical impact that may cause” damage or loss of peatland ecosystems or ES they provide.

Exposure is the presence of ES in places and settings that could be adversely affected by hazards. **Vulnerability** is the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Ecosystem services are “ecological processes or functions having monetary or non-monetary value to individuals or society at large (IPCC, 2014).

Step 1. Identify ES of peatlands in North Kalimantan

ES were categorised according to Common International Classification of Ecosystem Services (CICES) V5.1 because it is comprehensively structured, regularly reviewed and its usage is growing. There are numerous provisioning, regulation and maintenance and cultural services delivered by PSFs to local, national and international communities. The literature review was done to find ES provided by PSFs mentioned in peer-reviewed papers.

Only the papers where authors stated they are talking about ES were used, e.g. ecosystem functions were not included. Search word combinations were “ecosystem services of tropical peatlands”, “ecosystem services of peatlands in Indonesia” and the similar.

Then it was counted in how many papers each ES is mentioned, their title was changed according to the most common wording and CICES and most common ones were included in the framework. If several papers shared the same authors and those where mentioned ES were exactly the same were combined into one. However, in most cases there were other points added and those were left unprocessed.

Step 2. Identify current and possible hazards (threats) to peatlands in North Kalimantan

A combination of brainstorming and literature review should be used to include as many threats as possible and classify them in detail. The threats that peatlands might experience may be driven by climatic, geologic and/or anthropogenic factors.

Step 3. Find which hazards (threats) influence which ES

Based on the information in peer-reviewed papers direct consequences of each threat on the peatland ecosystem properties which worsen them should be described (e.g. Table Box 3.1). Then the ES that correspond to these properties were selected.

Table Box 3.1 Example of the threat and its effect for a tropical swamp forest.

Step 4. Assign indicators to ecosystem services

Indicators are commonly used in Integrated environmental assessments; their advantage is they are not dependent on subjective judgements of the assessor.

However, vulnerability of ES is difficult to measure with the indicators that assess the current state because it might change considerably under the influence of the threat. Literature on recommendations for selecting indicators, such as credibility, salience, legitimacy and feasibility criteria, may be followed, e.g. Oudenhoven et al. (2008).

In order to select an indicator, the following questions were asked:

- What is the main condition of factor of the ES in question being provided with no change in quality of quantity?
- How to measure this condition or factor?

For example, the condition that allows *carbon storage in peat soils* is that peat stays in non-oxidised state and thus waterlogged. The *depth of drainage* was selected as the most important ES indicator. For each ES, three possible indicators were proposed, and the primary is the one that meets four criteria mentioned above the best.

Step 5. Assign Vulnerability scores to indicators

Each of the ES indicators gets a score in the range from 0 (not susceptible to the threat) to 4 being the highest vulnerability. This may be done considering information from relevant literature, e.g. after van Oudenhoven et al. (2008).

Step 6. Assign scores to hazard (threat) and exposure

Exposure score shows how large is the area delivering ecosystem services affected by the threat and how irreversible are the negative consequences. Remote sensing can be used to study the spatial attributes of an exposure and/or the temporal ones.

Step 7. Risk characterisation

The chances for an adverse outcome of the threat compared to other threats are assessed in this step using the risk formula for each threat.

Annex 9 shows the direct hazards from the most common threats likely to occur in Indonesia generally, and North Kalimantan in particular (Table A9.2), and a framework for threat and risk assessments of peatlands in the Sembakung-Kayan Delta (Table A9.3).

In 2017-2019 an additional spectrally distinct plantation type, class 9 “Plantation A (Pulpwood)”, could be delineated. This is potentially pulpwood, as indicated by data provided by PROPEAT. We conclude that this plantation type was only established in 2014-2016 without showing its spectral characteristics at a young stage but becoming distinguishable in 2017-2019 only.

Plantation type B was initially detected as a plantation type occurring in the upland and hilly region with mineral soils. However, fragments occur within the plantations of the peatlands, yet assumably a misclassification.

The validation of the classifications shows reasonable classification accuracy (Annex 6). Despite the limitations described, one shortcoming was the lack of direct field data for validations, which reduces the significance of the classification. We overcame this issue by falling back on field data provided by PROPEAT, other auxiliary information on LU and high-resolution satellite imagery. The discrepancy, however, remains that the identification of plantation types is often but not in all places in line with official Land Use maps.

In the southern PHU No. 9 officially Oil palm plantations occupy an area that we classified as ”Plantation A” area (Pulp wood/ wood fibre plantation), whereas in PHU No. 1 official maps are in line with our classification. This inconsistency requires further analysis and field data to be understood and solved.

Data scarcity posed another limitation. Despite relying on all available satellite images of the study area from Landsat 7/8 and Sentinel 2 a/b with less than 70% cloud cover for the respective years, the number of the available Clear-Sky-Observations (CSO) per pixel is low in some parts of the PHUs. While mean CSO numbers are 5.8 in 2013 and 10.6 and 11.3 in 2016 and 2019, respectively, the minimum CSO number could be as low as 1 per pixel and year (Annex 4).

This most likely led to artefacts in classification, where round patches of e.g. bare soil or "Degraded Swamp Forest" were detected within large areas of Primary Swamp Forest (Figure 10). This shortcoming is expected to be overcome with more observations per pixel or by combining optical sensors with radar sensors (Lopes et al. 2020).

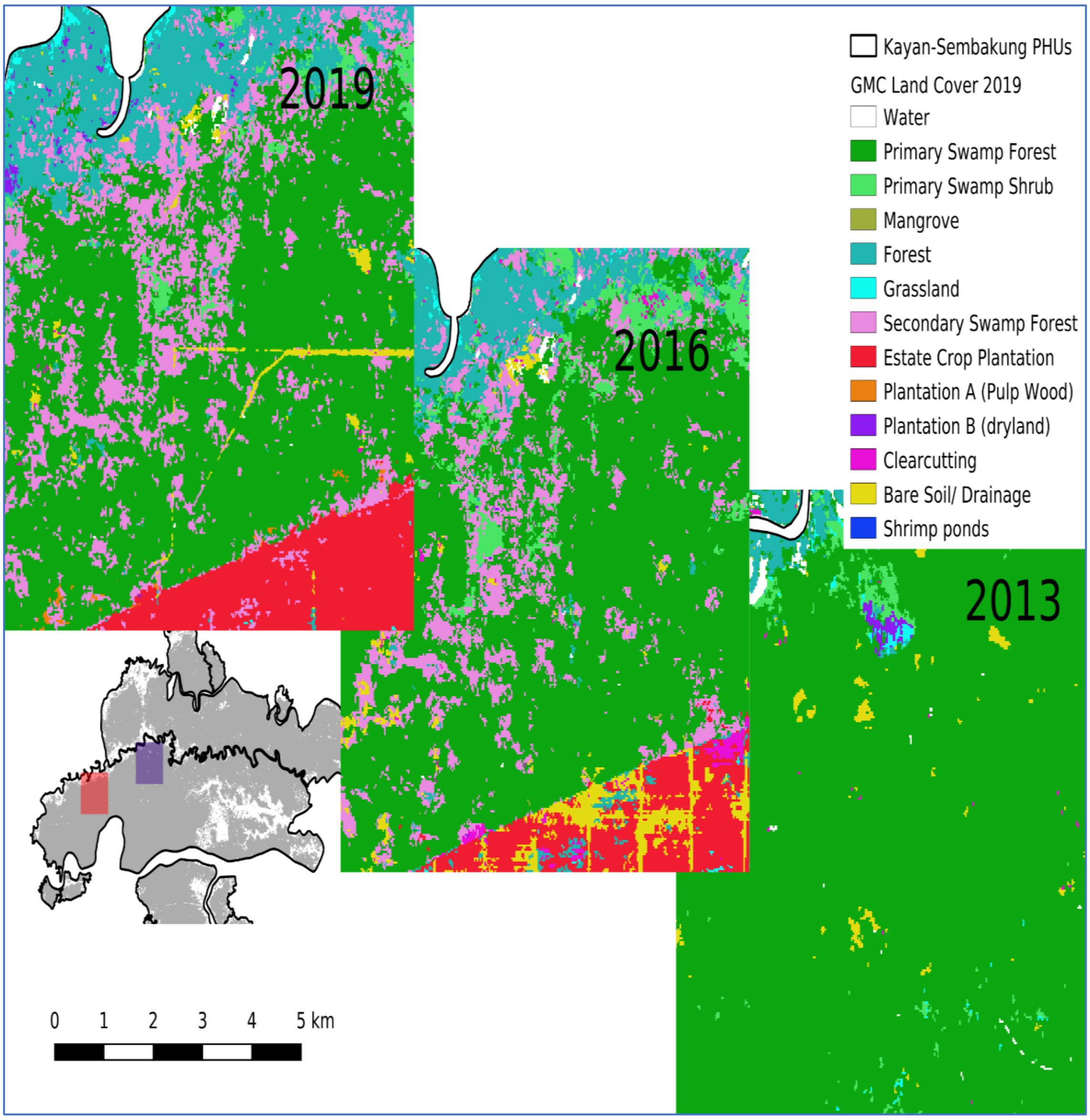


Figure 10: 2013: yellow dots - bare soil/ drainage; 2016, 2019: Violet - Secondary Swamp Forest - Examples of classification artefacts, which might be caused by very low data coverage. Inset map - red square: position of 2016 and 2019 examples, violet square: position of 2013 example.

Furthermore, did the separate classification of each year with partly different sets of reference points and data sets naturally lead to slight difference in the classification. The post-processing check of unlikely class changes and subsequent corrections was thus necessary to clean up and improve the maps. That was used too to correct the above-mentioned misclassifications, where errors were apparent, e.g. in case of "mangrove" occurrence in central parts of the PHUs, where "Primary Swamp Forest" prevailed.

The class "degraded peat swamp forest" is also a product of this post-processing step. Particularly, since forest degradation couldn't be delineated directly as an own class. Settlements and

Mining were two Land cover/ land use types that play a role in the study area. They could not be directly identified, which is a shortcoming of the classification.

III.3.2. GHG Estimates

The classes “bare soil/ drainage” and “clearcutting”, could not be attributed directly to the plantation type. In order to assure a conservative GHG estimation approach, we assigned both of them to oil palm plantations for emission calculations. “Other plantations” show higher emissions factors than “oil palm” (Annex 3).

Emissions from drainage ditches, which can be significant, were not included in the GHG emission estimates for the fact that the presence and length of drainage was not delineated in particular. We also did not include carbon losses through release of dissolved organic carbon in the water.

Furthermore, the estimated GHG emissions so far do not include estimates for fire-induced emissions, which may increase the estimates for both emissions and avoidance potential. A report indicates that fires have been so far limited, in particular during the study period, in North Kalimantan compared to peatlands in East and Central Kalimantan, however not completely absent (Annex 8). Therefore, future monitoring of burnt areas and fire frequencies may change the emissions outlook.

Lastly, the present estimates do not take into account the depletion of the carbon stock, i.e. the peat layers. The current estimates of peat loss are about 5 cm per year (Hooijer et al, 2012). If the average peat layers’ thickness is 1 meter, then the carbon stocks would deplete within 20 years. The peat layers in Kalimantan are often found to be deeper than 2 m, i.e. at least 40 years of peat decomposition and emissions (Wahyunto et al. 2011). Until there are adequate peat depth measurements in the Kayan-Sembakung Delta, it would be difficult to estimate the data of peat depletion.

CHAPTER IV: CONCLUSION AND RECCOMENDATION

IV.1. CONCLUSION

- Between 2013 and 2019, the conversion of the Peat Swamp Forests of the Kayan-Sembakung delta for industrial plantations continued at high rates between 1.2 and 4.2 %.
- Peatlands are estimated to cover around 2890 km². One third is drained and more is expected to follow, as concessions for industrial plantations cover 69% of the peatland area.
- On the other hand, the present implementation of the moratorium - as small and fragmented areas which cover barely 8% of the peatlands - does not provide long-term protection of the remaining undrained Kayan-Sembakung peatlands and their Ecosystem service.
- GHG emissions from peatland use more than doubled between 2013 and 2019. If past developments are to continue in the future at the same pace and all given concessions on peatlands were used, peatland degradation from North Kalimantan would contribute with 10 Mt CO2-eq annually to North Kalimantan's total anthropogenic GHG emissions by 2050.
- The potential for avoiding future GHG emission through restoration measures could lead to reduction of GHG emission between 48-90 % from the BAU scenario projected between 2020-2050.
- We covered only LU and GHG emissions on the Kayan-Sembakung peatlands. More negative effects of peatland drainage and conversion occur with relevant impacts on livelihoods, economy and nature without being accounted for at the moment.

IV.2. RECOMMENDATIONS

- A change in peatland policy and management for the future for a sustainable development of the Kayan-Sembakung delta is required and should consider the following:
  - All undrained non-concession peatlands in the PHUs should be included in the Moratorium regardless if the original vegetation cover is degraded or not.
  - Stopping new drainage channels should be considered in the whole PHUs of the Kayan-Sembakung area. Therefore, a revision and eventually suspension of yet to be implemented concessions (i.e. the ones with a prior license) should be considered.
  - For future sustainable developments in the region, we suggest exploring and implementing the technical and economic options for rewetting drained secondary forest and plantations on peatlands through the implementation of Paludiculture or Carbon Credits systems for avoided emissions.
- Furthermore, we recommend an analysis of the attribution of secondary and primary swamp forest since indications suggest that the primary swamp forest area might be in fact larger and the secondary swamp forest area are smaller than official land cover maps suggest.

- PROPEAT is making an effort to update the regional peatland map with dense field sampling. For completeness and to avoid big gaps it is recommended to include all areas of plantations. This is particularly important also for transparency and MRV.
- The MRV capacity in North Kalimantan needs to be urgently built up and integrated within the national systems to allow up-to-date GHG emission calculations.
  - An MRV system should be easy-to-implement and participatory for local communities.
  - A network of water level monitoring points should be established over the PHUs, as part of the national monitoring efforts.
- An update of the IPCC EFs, which date back to 2014, with more and more recent data is highly recommendable for strengthening the EFs database and would be beneficial for the whole tropics.
- A risk assessment, which would include all negative short and long-term impacts of peatland degradation, would help evaluate the manifold related problem for society, economy and nature in North Kalimantan.

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ANNEXES

Annex 1. Deforestation

The deforestation in the PHUs is basically due to the loss of peat swamp forest and swamp shrub. The loss rate was slightly higher in the first 2014-2016 period with 286 km² than in the second period with 267 km², resulting in yearly mean deforestation rates of 95.3 and 89 km², respectively. As main drivers for forest conversion in the Kayan-Sembakung area the establishment of Plantations on concession areas has been identified (Annex 5).

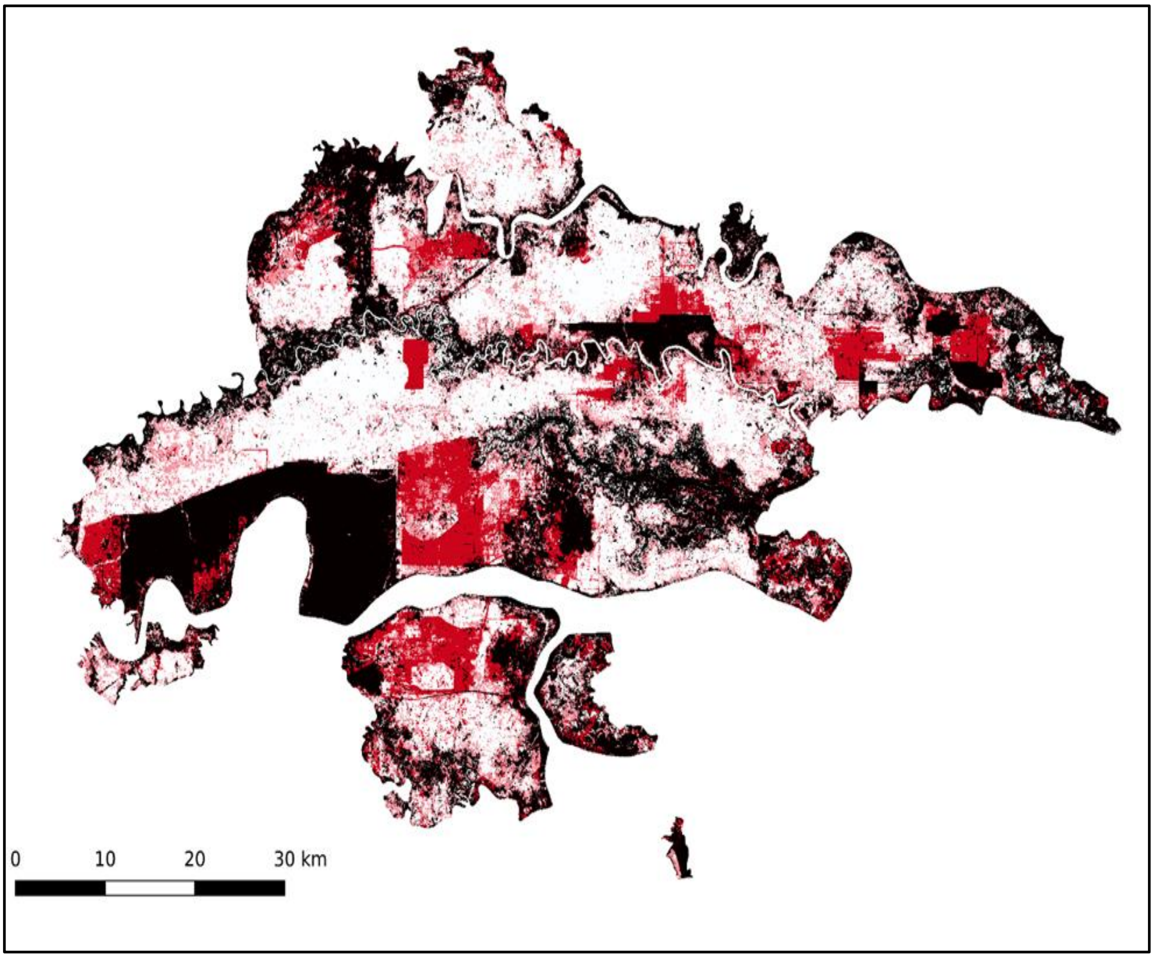


Figure A1.1: dark-red - Swamp Forest loss 2013-2019 in the Kayan-Sembakung area; light red - swamp forest degradation, white – pristine swamp vegetation

A comparison with forest loss data provided by Global Forest Watch (GFW) confirms a similar total loss from 2013 to 2019 but displays a more detailed and partly different dynamic due to yearly availability (Figure A2.2). According to GFW, the respective area of forest lost 2013-2016 is higher with 344 km². A peak in forest loss occurred in 2014 with 162 km² and a low in 2016 with 41 km². The loss is lower 2016-2019 with 197 km².

Differences in the respective periods between our study and the GFW data might be explained by the different classification approaches. Whereas our classification is based on statistics of spectral values, the GFW approach defines all areas with more than 30 % tree cover forest (Hansen et al. 2013) and identifies larger changes in forest cover as deforestation. The small difference in total areas of deforestation 2013-2019 of 12.4 km² or 2.2% probably lies in the fact that they are turned into plantations, which are clearly identifiable.

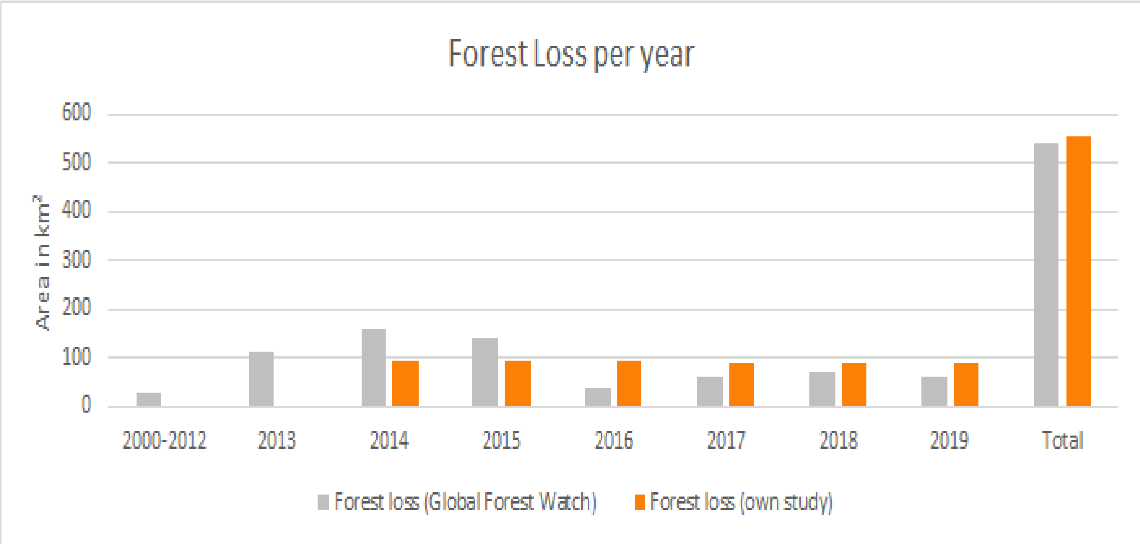
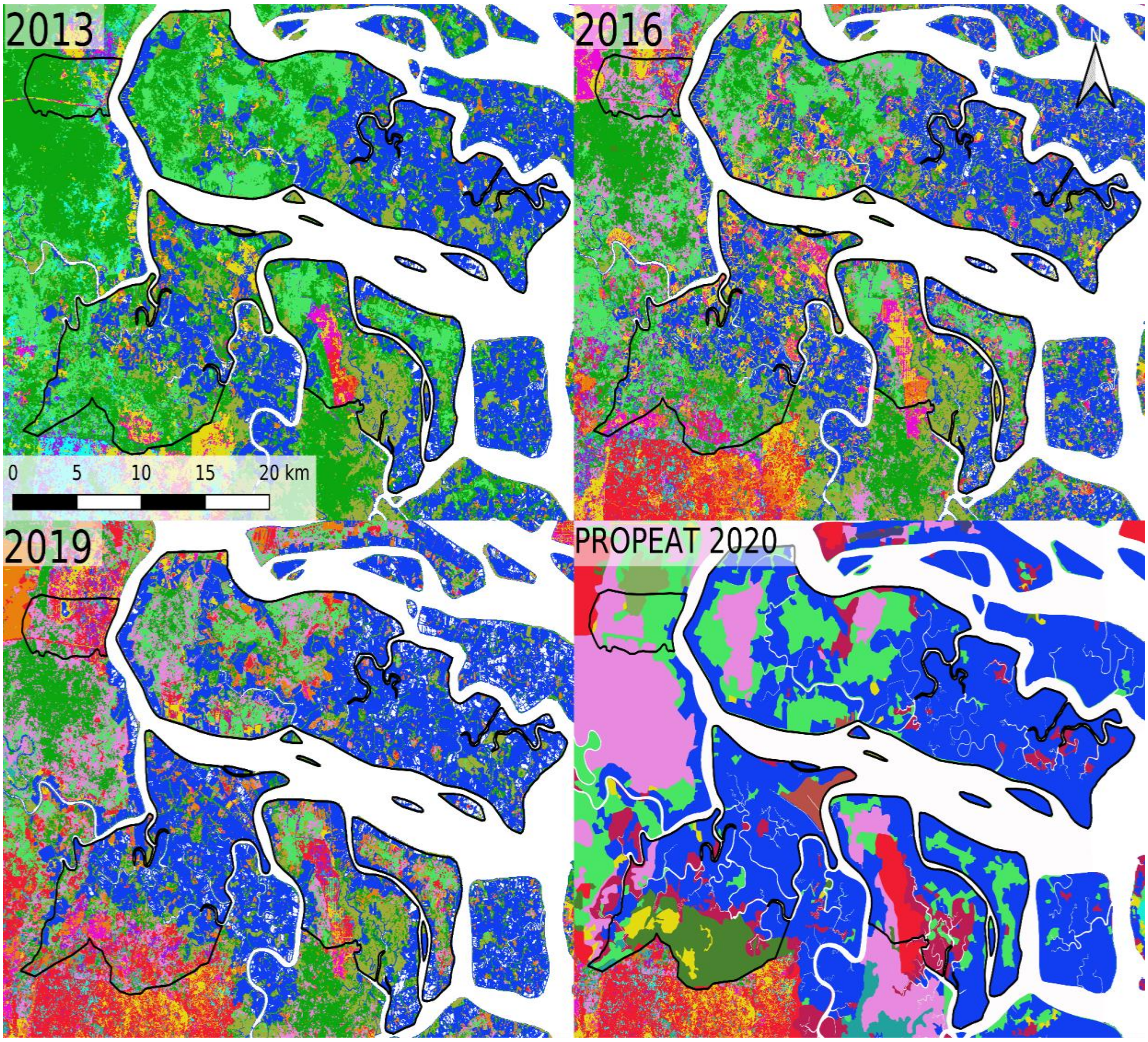


Figure A1.2: Forest loss (in km²) per year. Own study provides mean values for the periods 2014-2016 and 2017-2019. For the period 2000-2012 mean loss rate per year is shown, Global Forest Watch data accessed online March 2021.

Annex 2. Pilot Villages

The PROPEAT project assigned two pilot villages - Atap and Bebatu (Figure A6.1, Table A6). A close-up on the development of land cover / use in the limits of the communities reveals alignments and discrepancies between the classification of this report and the 2020 PROPEAT land cover/ land use assessment (Figure A6.2). The classification provides a more detailed level of information inside the delineated land use units of the PROPEAT land use assessment allowing to follow the progressing transformation of swamp vegetation into plantations with roads and canals.

Spots of degradation within the swamp forest can also be observed (see also 5.1.3). In all communities natural vegetation was converted for land use purposes, but to different degrees. Atap and Lubakuan communities cover central parts of the largest PHUs and show developments of industrial plantations. The establishment of roads and drainage canals are characteristic structures. Bebatu village, being situated on an island with peat cover and at the coastal mainland with significant mangrove extents, is marked by a high and increasing share of supposedly shrimp ponds.



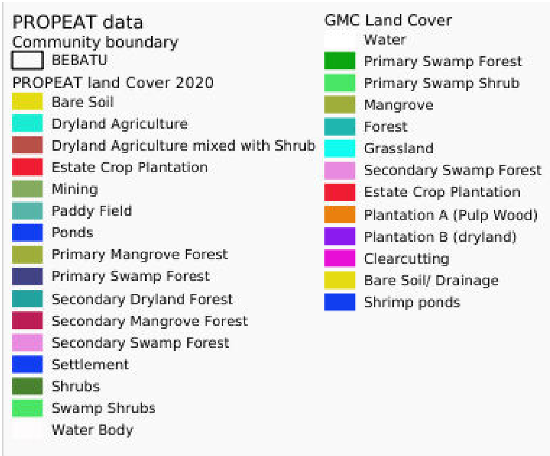


Figure A2.1: Land Cover classification of the Bebatu community 2013, 2016 and 2019 in comparison to PROPEAT land use assessment 2020

Mangroves and fish/ shrimp ponds of the Bebatu area are surprisingly well aligned between the two maps as well as the "Swamp Shrub" class of the PROPEAT map matches with "Primary Swamp Shrub", "Secondary Peat Swamp Forest" and "Primary Peat Swamp forest" classes of this report's classification.

In 2019, only the occurrence of small patches of "Oil palm plantation" class, would need to be investigated, as they occur on supposedly mineral soil. The structure of a plantation in the south-eastern part of the community is discriminated against all year as well as in the official land cover map provided by PROPEAT.

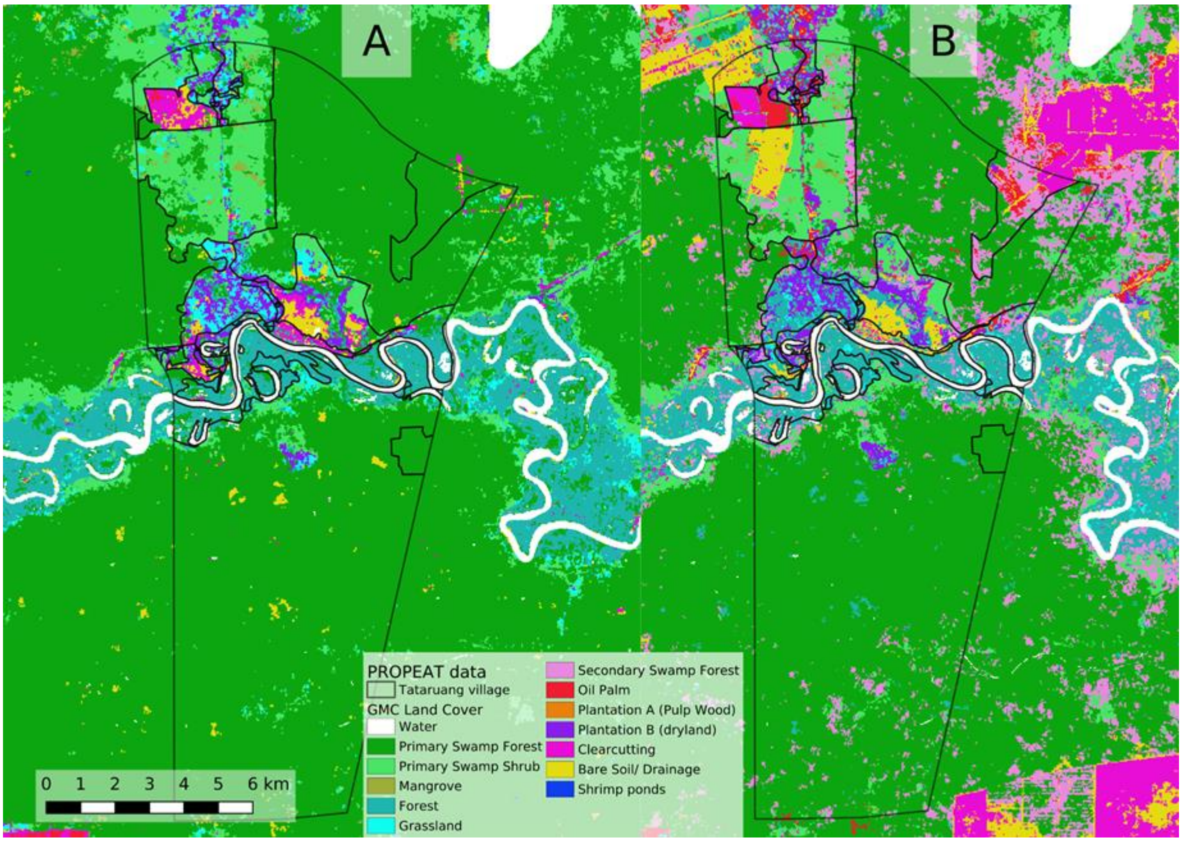
Settlements are not shown in a separate class but are included in the class "bare soil/ Drainage" and "Clearcutting". The PROPEAT land use class "mining" is not directly reflected by our land cover classification. Bare soil, water and other land cover types are found in the mining area of the Bebatu community.

To verify the accuracy of the classification, field data would need to be collected in all present land cover classes for ground verification.

Table A2: Land Cover of Pilot Communities per year

		Atap			Lubukan			Bebatu		
Class name	**class value**	**2013 km²**	**2016 km²**	**2019 km²**	**2013 km²**	**2016 km²**	**2019 km²**	**2013 km²**	**2016 km²**	**2019 km²**
Water	1	2	2	2	0	0	0	12	12	22
Primary Peat Swamp Forest	2	106	92	84	75	39	32	170	99	65
Primary Swamp Shrub	3	15	14	4	5	4	3	85	64	40
Mangrove	4	1	1	1	0	0	0	61	51	33
Forest	5	10	13	13	3	4	4	7	12	9
grassland	6	4	1	1	1	0	0	0	0	0

Degraded Peat Swamp Forest	7	0	11	17	0	12	14	5	30	53
Oil Palm Plantation	8	0	3	5	0	2	19	3	8	38
Plantation A	9	0	0	9	0	0	1	15	16	36
Plantation B (Upland)	10	4	5	5	0	0	0	4	7	7
Clearcutting	11	3	2	3	0	12	4	7	34	6
Bare Soil/ Drainage	12	3	5	5	0	11	8	21	57	13
Shrimp Ponds	13	0	0	0	0	0	0	172	172	238
Total		**148**	**148**	**148**	**86**	**86**	**86**	**560**	**560**	**560**



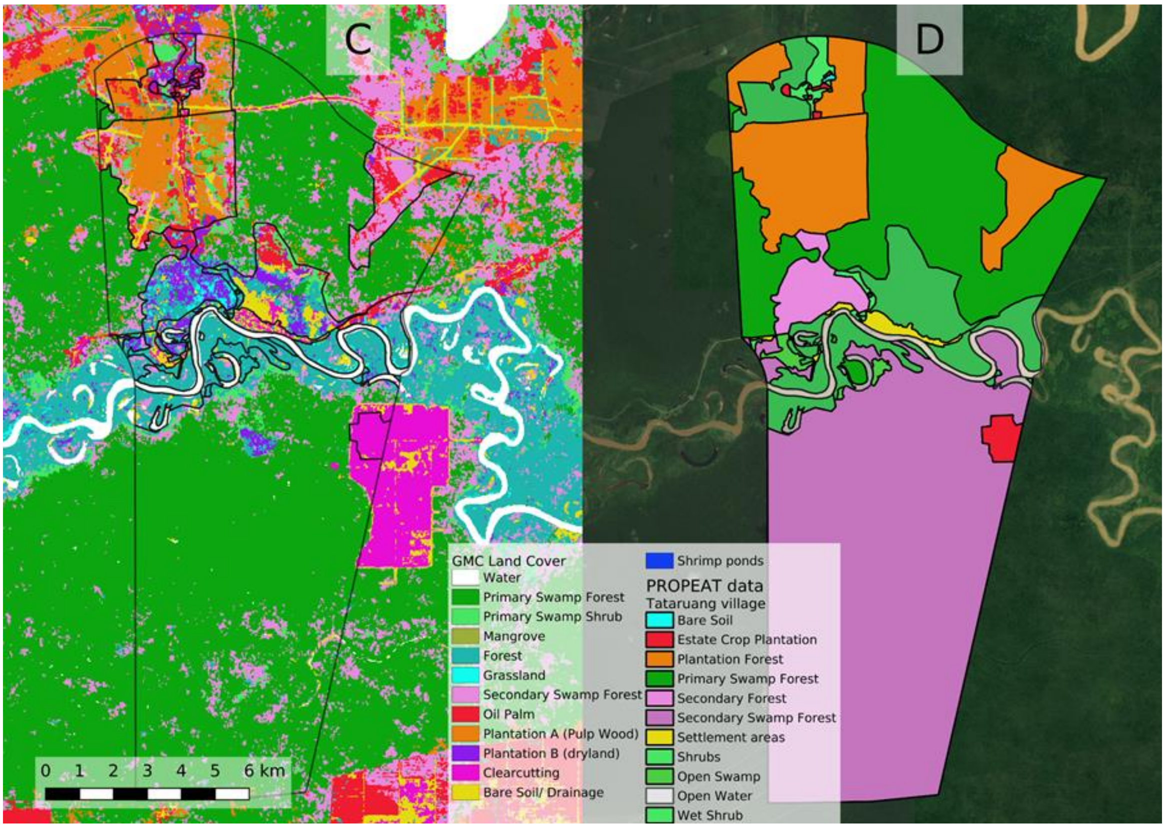
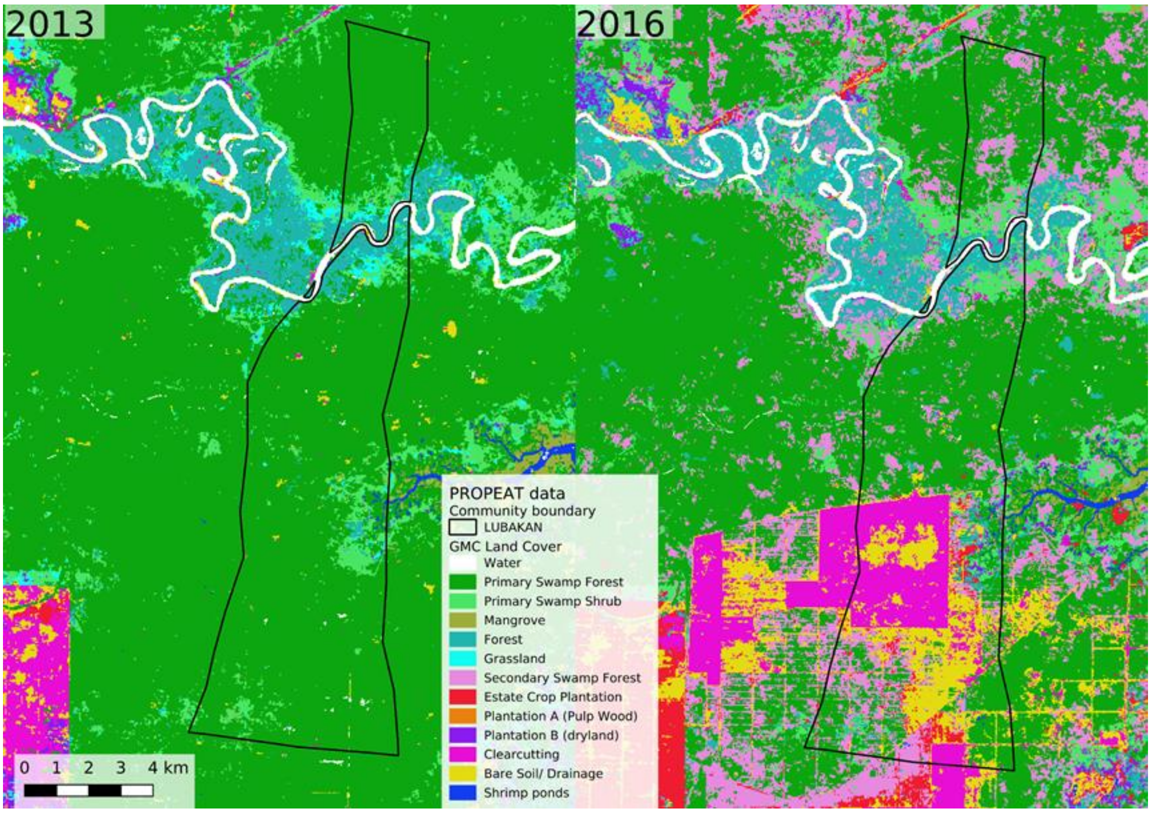


Figure A2.2: Land Cover classification of the Atap community 2013 (A), 2016 (B) and 2019 (C) in comparison to PROPEAT (D) land use assessment 2020.



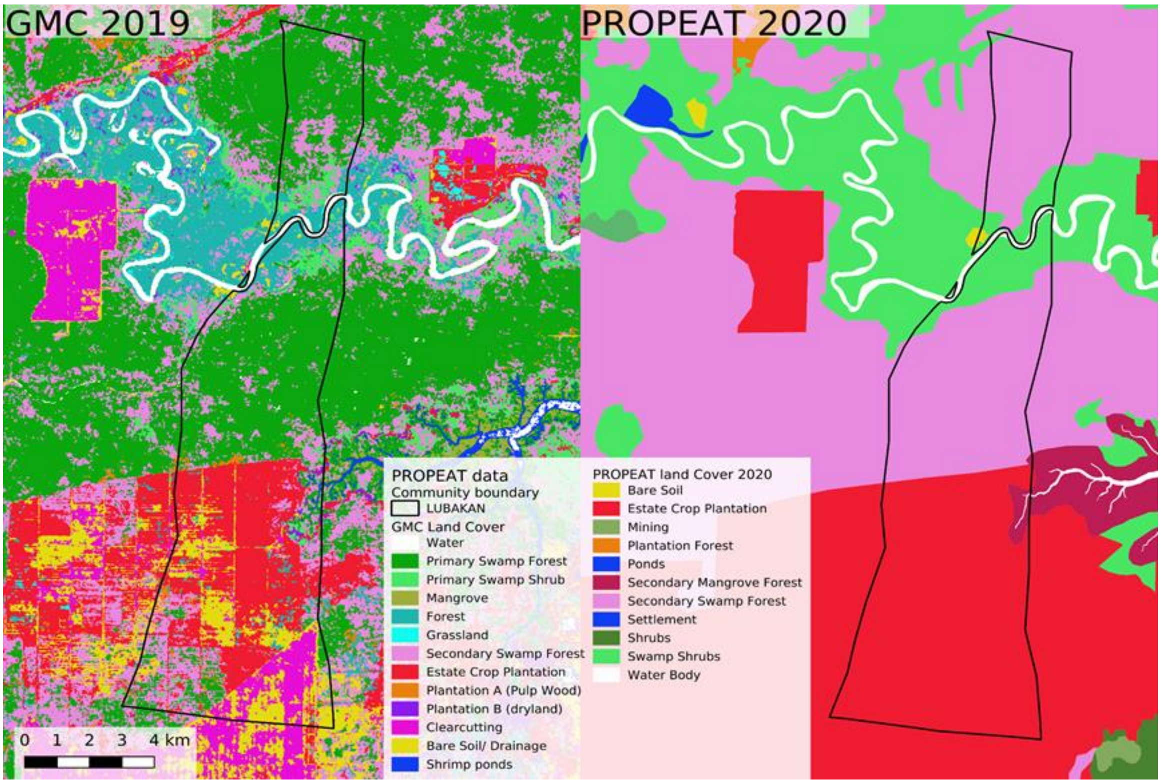


Figure A2.3: Land Cover classification of the Lubukan community 2013, 2016 and 2019 in comparison to PROPEAT land use assessment 2020.

Annex 3. Emission Factors

Emission factors of each respective IPCC land use category for CO_2, CH_4 and N_20 were converted from the unit given in IPCC to CO_2-eq, based on the 100-year global warming potential of each gas. For the CO_2 emissions, 1 kg CO_2-C = 3.667 kg CO_2-eq, which is the result of the division of the CO_2 atomic weight (=44) by the C atomic weight (=12).

This is then directly CO_2-eq as 1 CO_2 = 1 CO_2-eq. CH_4 (kg.ha^{-1}.yr^{-1}) was converted to CO_2-eq using the following: 1 tCO_2-eq= 34 x 1000 kg CH_4. N_2O-N (kg.ha^{-1}.yr^{-1}) was converted first to kg N_2O as the following: 1 kg N_2O-N = 1.57 kg N_2O, then to CO_2-eq using the following: 1 t CO_2 eq. = 298 x 1000 kg N_2O.

Table A3: Land cover classes detected in North Kalimantan and their corresponding IPCC land use categories and GHG emission factors.

Land cover class	IPCC land use category	IPCC emission factors (tCO_2-eq. ha^{-1}. yr^{-1})		
		CO_2	CH_4	N_2O
Primary Peat Swamp Forest	Primary Swamp Forest	N/A	N/A	N/A
Primary Swamp Shrub				
Peat Swamp Forest drained	drained Swamp forest	19.5	0.222	1.123
Swamp Shrub drained				
Forest				
grassland				
Degraded Peat Swamp Forest				
Oil Palm Plantation	Oil palm	40.37	0	0.561
Clearcutting				
Bare Soil/ Drainage				
Plantation A	Other plantation	55.05	0.092	1.123
Plantation B (Upland)				

Annex 4. Data Availability

Satellite data availability increased significantly from 2013 to 2019 with the launch of Sentinel-2 A in 2015 and Sentinel-2 B in 2017, reducing the repeat coverage from 16 days of each Landsat satellite to 6 days of the two Sentinel-2 satellites) and nearly doubling overall availability of observations (Table A1, Figure A1).

Table A4: available Satellites and number of cloud-free observations per year and pixel

Year	2013	2016	2019
Available Sensors	Landsat 7 ETM+, Landsat 8 OLI	Landsat 7 ETM+, Landsat 8 OLI, Sentinel-2 A MSI	Landsat 7 ETM+, Landsat 8 OLI, Sentinel-2 A/B MSI
Mean of Clear-Sky-Observations per pixel and year	5.8	10.6	11.3
Maximum number Clear-Sky-Observations per pixel and year	25	41	48

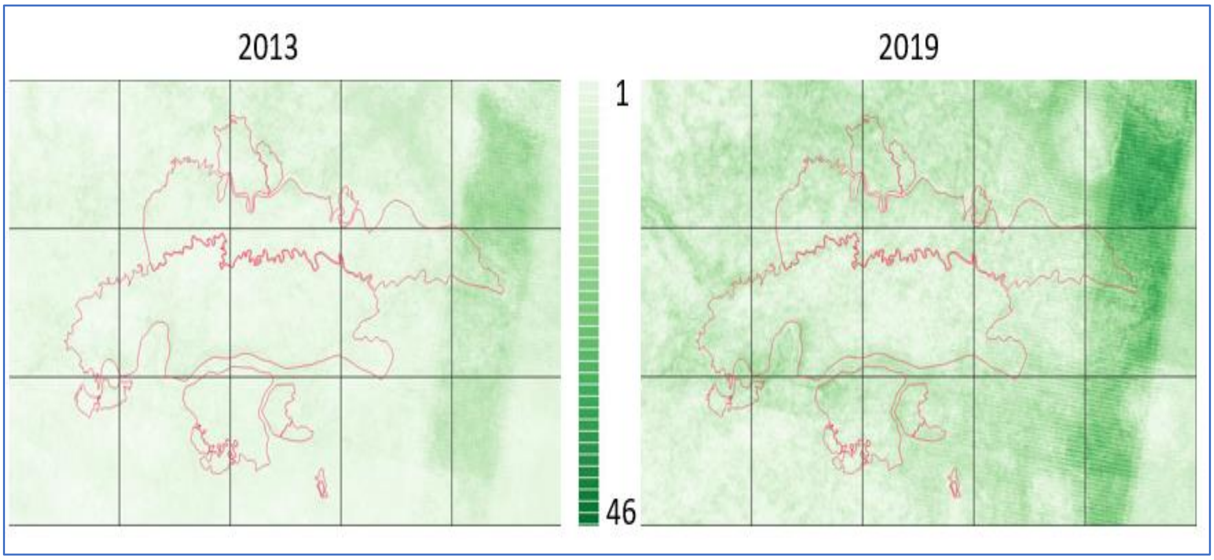


Figure A4: Number of Clear-Sky-Observations in 2013 and 2019 for the study area

Annex 5. Land Cover Class Area

Table A5: Area of Land cover classes per target year

ID	Land class	Cover 2013 (km^2)	Cover 2016 (km^2)	Cover 2019 (km^2)
1	Water	36	35	42
2	Primary Peat Swamp forest	2150	1475	1208
3	Primary Swamp shrub	381	371	219
4	Mangrove	126	123	94
5	Forest	144	157	152
6	Grassland	76	27	19
7	Degraded Peat Swamp forest	0	416	598
8	Oil Palm plantation	73	327	558
9	Plantation A (Pulp Wood)	0	0	127
10	Plantation B (upland)	142	59	68
11	Clearcutting	112	150	103
12	Bare soil/ drainage	142	238	151
13	Shrimp ponds	112	114	153

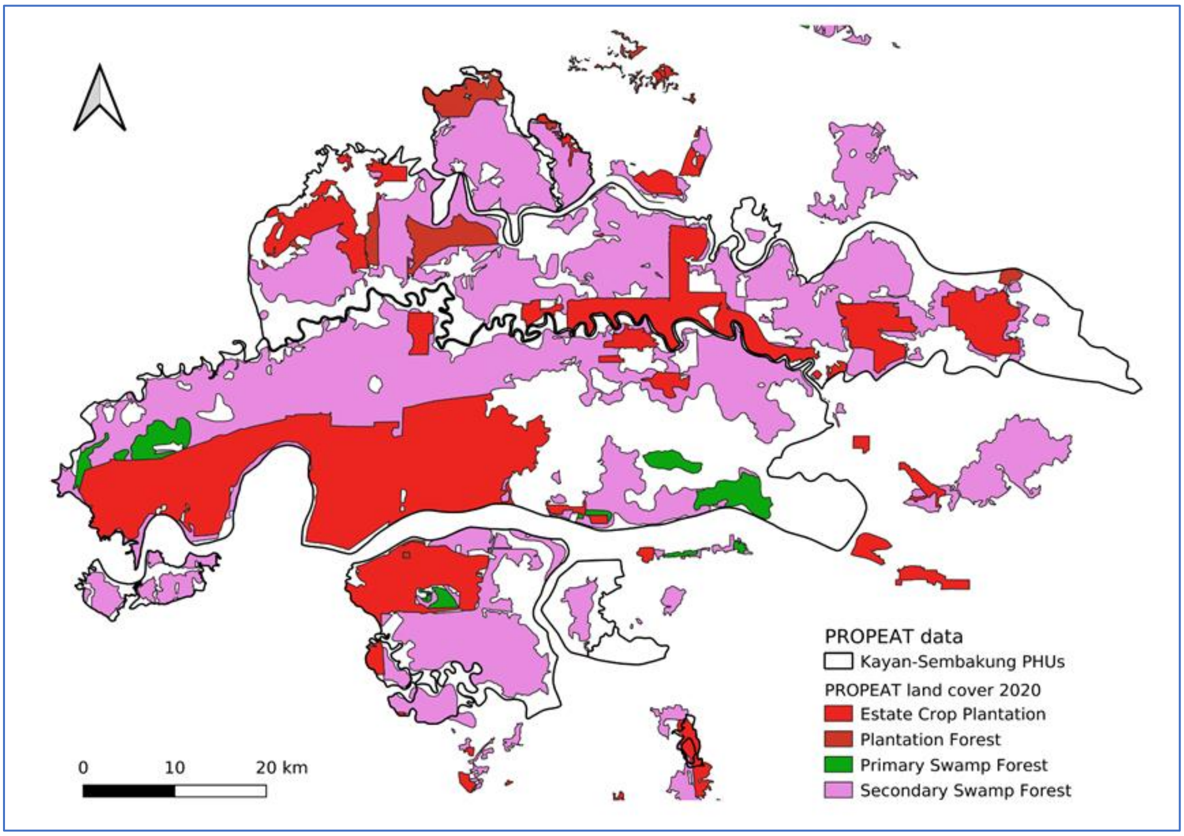


Figure A5: Official Indonesian Land Cover map 2018 with classes, Estate crop plantation (Oil palm), Secondary Swamp Forest and Primary Swamp Forest.

Annex 6. Drainage Area and Peatland Map

Drained area as identified by optical interpretation of high-resolution satellite imagery for the three target years.

Table A6.1: Drained Area in the PHUs of the Kayan Sembakung Area and changes

	2013	***2016***	***2019***
total drainage area (km²)	391.3	756.7	856.9
of total PHU peatland area	13.5%	26%	30%
change in percent of total peatland area compared to target year before		12.6%	3.5%

Confusion matrix of own peatland map based on validation points provided by PROPEAT.

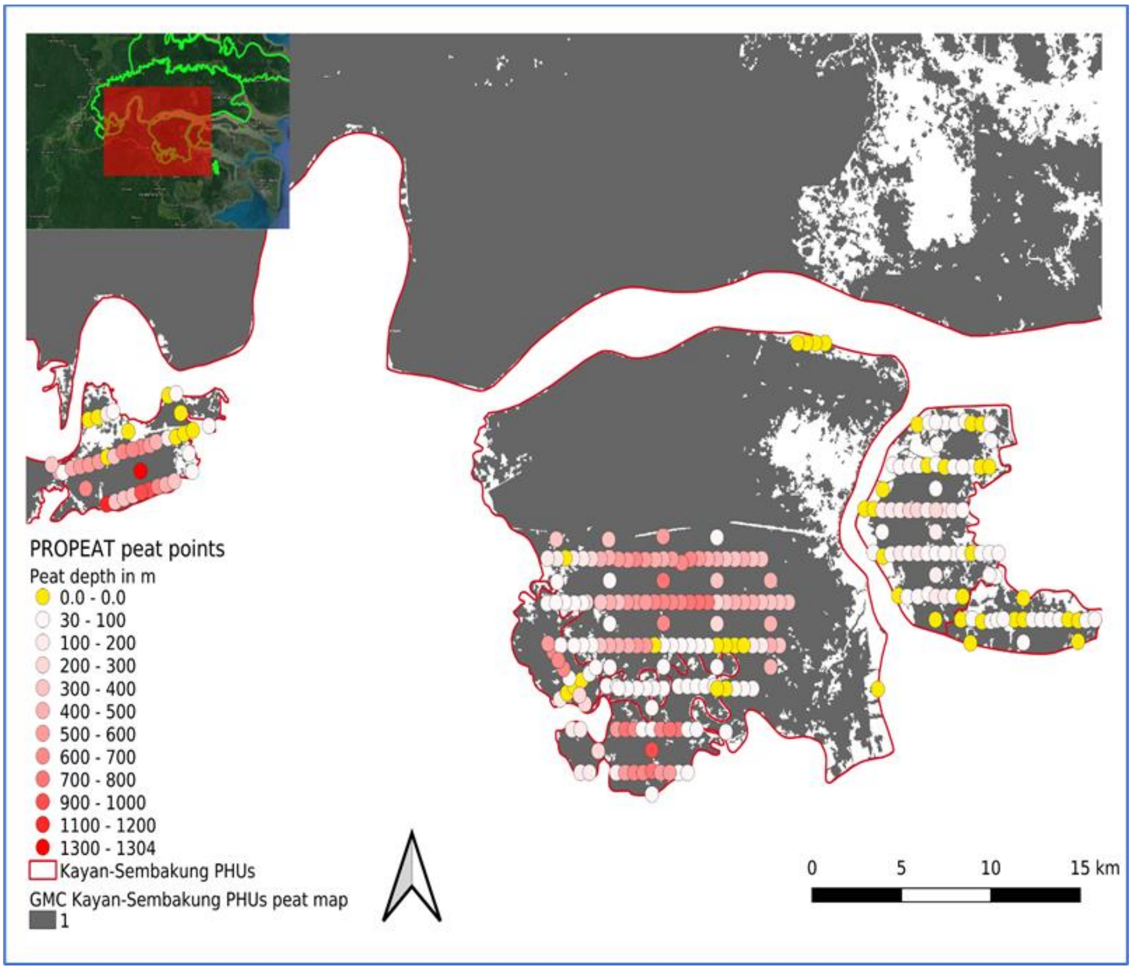
Table A6.2: Confusion matrix accuracy assessment Peatland map

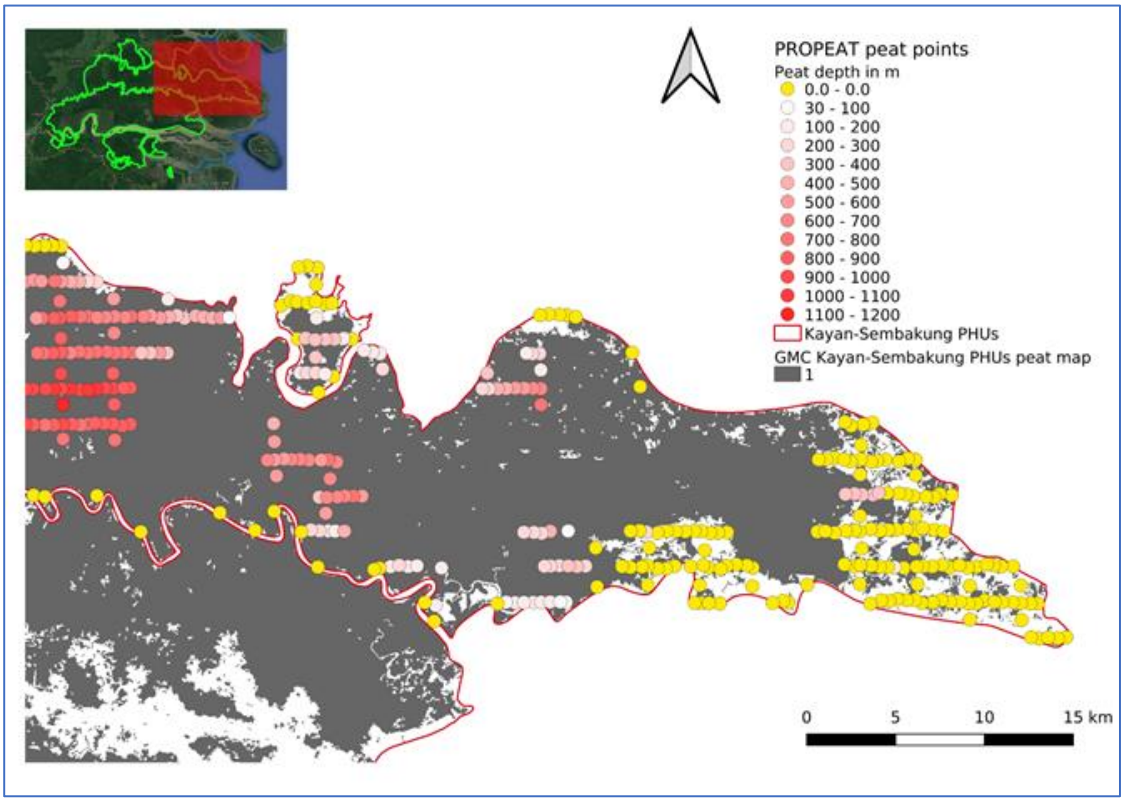
			PROPEAT (reference)			
			peat	no peat	Totals	User's Accuracy
Map data	peat		731	144	875	83.54%
	no peat		76	146	222	65.77%
	Totals		807	290		
	Producer's Accuracy		90.58%	50.34%		**79.95%**

Confusion matrix of Wetlands International peatland map and validation points provided by PROPEAT.

Table A6.3: Confusion matrix accuracy assessment WI Indonesian peatland map for North Kalimantan

			PROPEAT (reference)			
			peat	no peat	Totals	User's Accuracy
Map data	peat		423	3	426	99.30%
	no peat		386	298	684	43.57%
	Totals		809	301		
			52.29%	99.00%		**64.95%**


PROPEAT peat points
Peat depth in m
0.0 - 0.0
30 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
900 - 1000
1100 - 1200
1300 - 1304
Kayan-Sembakung PHUs
GMC Kayan-Sembakung PHUs peat map
1
0
5
10
15 km


PROPEAT peat points
Peat depth in m
0.0 - 0.0
30 - 100
100 - 200
200 - 300
300 - 400
400 - 500
500 - 600
600 - 700
700 - 800
800 - 900
900 - 1000
1000 - 1100
1100 - 1200
Kayan-Sembakung PHUs
GMC Kayan-Sembakung PHUs peat map
1
0
5
10
15 km

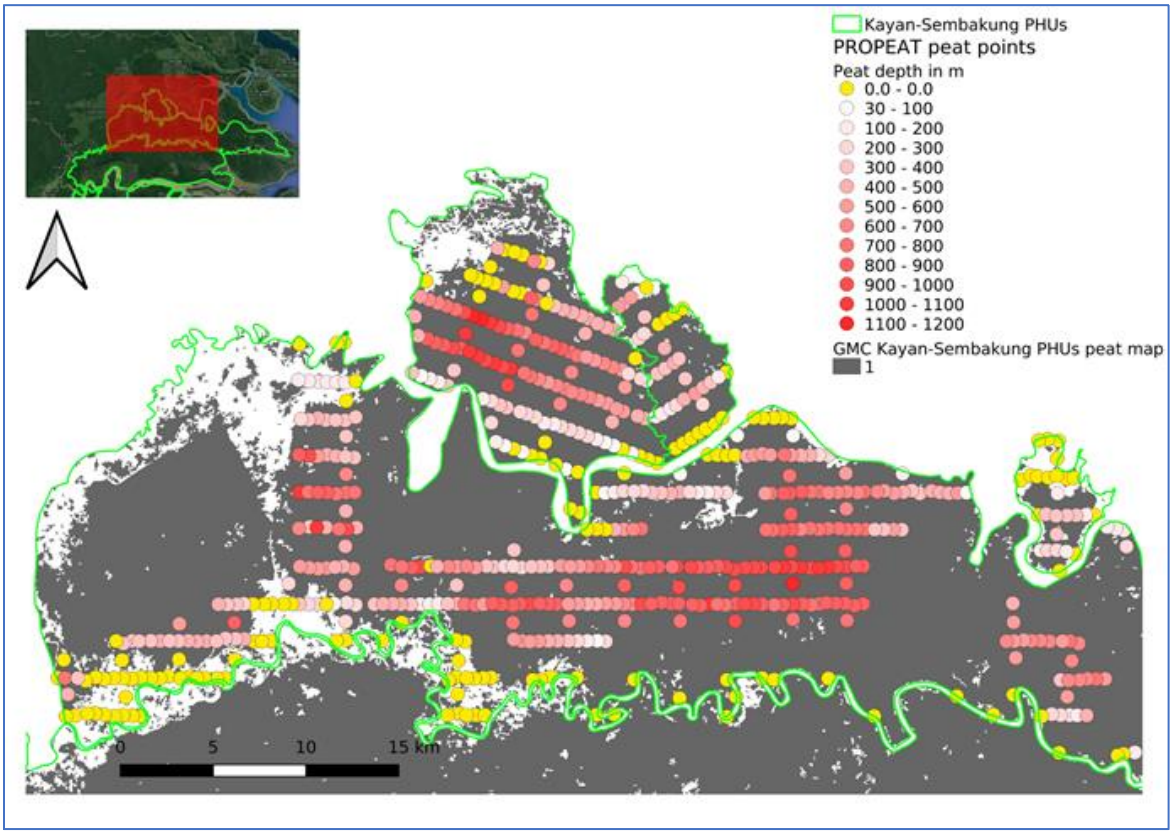


Figure A6: points - peat depths measured in the field, grey background - GMC peatland map.

Annex 7. Concession and Moratorium

The situation of concessions in the PHUs of the Kayan-Sembakung area could not be clarified 100%. We base the analysis on two sources of information on concessions:

1. Ministry of Environment, Asia Pulp and Paper and April, provided by the Global Forest Watch platform (accessed in March 2021. www.globalforestwatch.com))
   - Wood fibre
   - Oil palm

2. Ministry of Environment and Forestry, provided by PROPEAT
   - Natural forest
   - Forest Plantation
   - Mining

It may be that the present information on concessions is not the latest or not complete, but the analysis has been done to best knowledge of the authors.

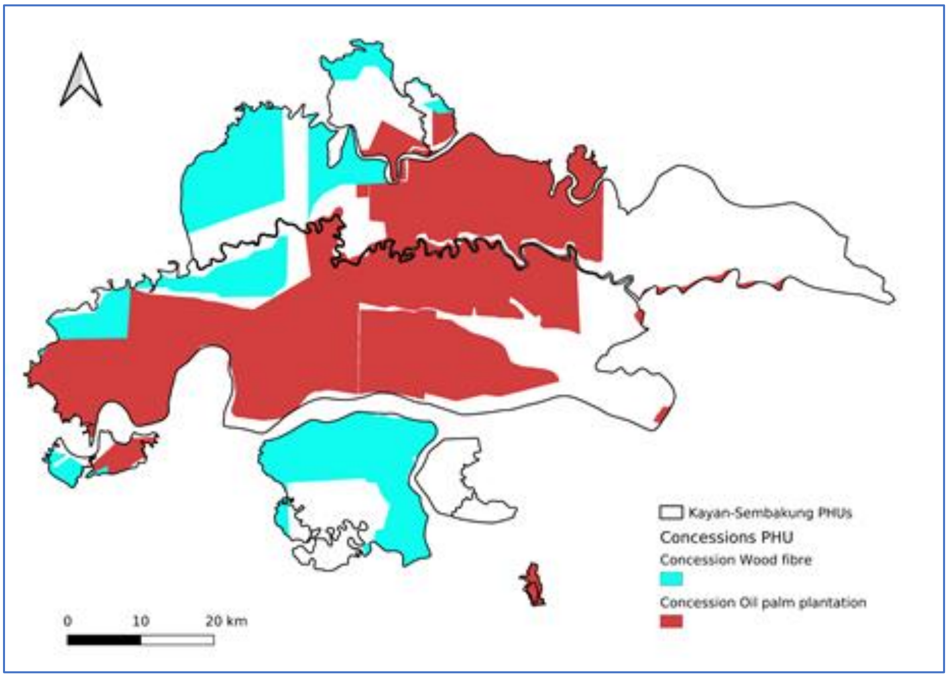
Concessions from the two sources partly overlap and partly complement each other (Figure A7). The Forest Plantation concessions appear to cover a smaller portion of the Wood fibre concessions. They also overlap with the Natural Forest concessions in one place.

The oil palm concessions mainly cover areas of the PHUs free of other concessions. Overlaps exist though at the concession edges and to a larger extent with the eastern natural forest concession.

All together 69 percent of the peatland area in the PHUs is covered with one or more concession types, 31 percent are not covered with concessions. Oil palm concessions cover nearly 50% of the peatland area.

However, of the 895 km², which are not covered by concessions, 134 km² or 15 percent are actual Oil palm plantations.

719 km² of the concessions on peatlands or 36% are already covered by Plantations.



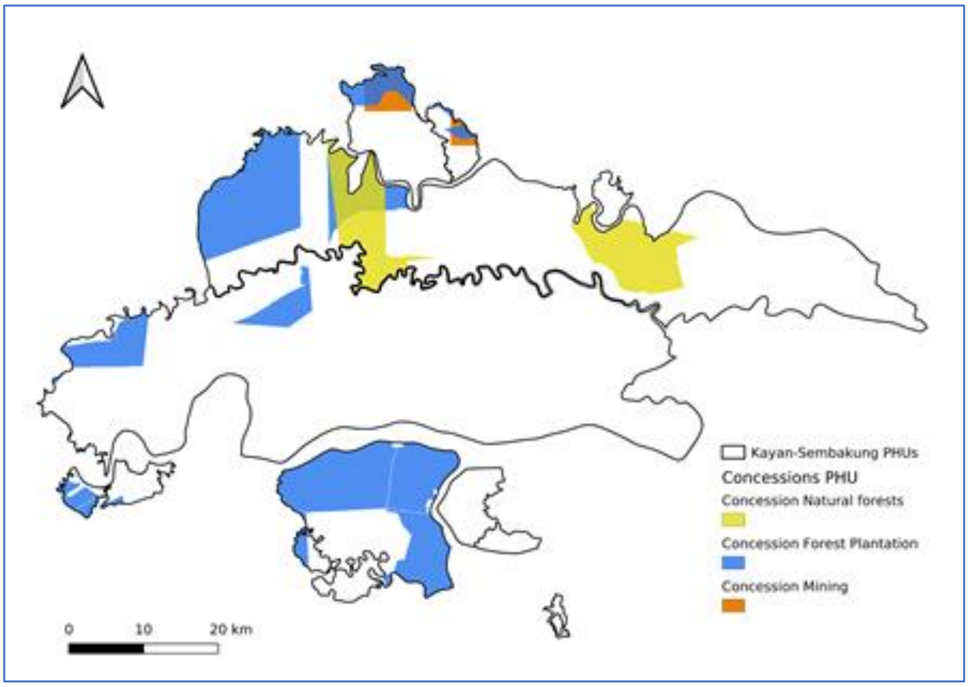


Figure A7: Concession areas by source Global Forest Watch (left) and PROPEAT (right)

Within the PHUs, the Moratorium area protected as a peatland was 230 km² in 2016 and 211 km² in 2020, or 8 and 7.3% of the peatland area. The moratorium area for primary forest was around 13 km² in both years or 0.45% of the peatland area

Annex 8. Fires in the Kayan-Sembakung Peatlands, North Kalimantan

Mahara, R. (2020). Analysis of fire dynamics in relation to land-use on Kayan-Sembakung Peatland in North-Kalimantan. Report. University of Greifswald, Greifswald, Germany.

Annex 9. Framework of Threat and Risk Assessment for Peatlands in Kayan-Sembakung Delta

Table A9.1 – Direct hazards corresponding to most common threats to peat swamp forests in Indonesia.

THREAT	RISK
Selective logging w/o drainage (wooden trails possible)	Reduced biodiversity/Damaged or lost habitat/Reduced vegetation cover/Damaged ecosystem resilience/Reduced above-ground biomass/Reduced below-ground biomass growth/Reduced water storage Dommain et al. (2016)
Selective logging with new or existing logging infrastructure and drainage canals	Reduced biodiversity/Damaged or lost habitat/Reduced vegetation cover/Damaged ecosystem resilience/Reduced above-ground biomass/Reduced below-ground biomass growth/Reduced water storage/ Increased evapotranspiration/Increased runoff/Increased accessibility Dommain et al. (2016)
Intense logging with new or existing drainage and logging infrastructure, incl. clear cutting	Biodiversity loss/Populations loss/Habitat loss/Vegetation cover loss/Regeneration disruption/Damaged ecosystem resilience/Loss of above-ground biomass and below-ground biomass growth/Increased ET and soil exposure/Increased runoff/Decreased water storage/Increased accessibility/Peat erosion/Water and nutrients loss Dommain et al. (2016)
PSF conversion to industrial plantations incl. deep (>40cm) drainage, fertilisation (e.g. oil palm, pulp wood, rubber and other deeply drained plantations)	Biodiversity loss/Populations loss/Habitat loss/Decreased water storage/Increased accessibility/Peat oxidation/Peat subsidence/Change of peat physical properties Dommain et al. (2016)
PSF conversion to agricultural plantations incl. shallow drainage (<40cm) (e.g. food crops, rice and other shallow drained plantations)	Biodiversity loss/Populations loss/Habitat loss/Decreased water storage/Increased accessibility/Peat oxidation/Peat subsidence/Change of peat physical properties Dommain et al. (2016)
Fish ponds	Fish populations loss/Vegetation loss (clearance)/Peat oxidation/Peat subsidence/Decrease in peat water storage capacity/Fire susceptibility
Deep drainage (>40cm)	Water loss/Increases runoff/Disrupted water regime/Increased peat oxidation, consolidation and shrinkage/Decrease in peat water storage capacity/ Fire susceptibility Dohong et al. (2017)
Shallow drainage (<40cm)	Water loss/Increases runoff/Disrupted water regime/Increased peat oxidation, consolidation and shrinkage/Decrease in peat water storage capacity/Fire susceptibility Dohong et al. (2017)
Wildlife hunting	Populations loss

Peatland fragmentation (by drainage canals, roads, trails, railways, other linear objects)	Increased accessibility/Connection disruption of populations
Mining	Biodiversity loss/Populations loss/Habitat loss/Decreased water storage/Increased accessibility/Peat oxidation/Peat subsidence/Change of peat physical properties
Fires on drained peatlands, incl. associated air pollution	Smog and haze in the air (more)/Burnt peat layer down to the water table/ Dead or injured animals/Additional GHG emissions (more)/Burnt and dead vegetation/Increased fuel load for next fires/Smoke blocks sunlight/Changes peat properties to hydrophobic Harrison et al. (2009)
Fires on peatlands without drainage	Burnt peat layer down to the water table(less)/Dead or injured slow-moving animals/Additional GHG emissions (less)/Burnt and dead vegetation/Increased fuel load for next fires/Smoke blocks sunlight Harrison et al. (2009)
Extreme drought events	Peat desiccation/Peat loss/Regeneration disruption/Vegetation loss/Fire susceptibility
River flooding	Additional GHG emissions/Vegetation loss/Regeneration disruption/Oxygen depletion
Sea water flooding	Change of chemical properties of soil/Additional GHG emissions/Vegetation loss/Habitat loss

Table A9.2 Framework for threat and risk assessment of peatlands in Indonesia (orange – ES that could be affected by each threat).

Threats to peatland / Affected ecosystem services	Carbon storage in peat soils	Carbon storage above ground	Flood regulation and mitigation (by water retention)	Sustainable timber and NTFPs (non-drained)	Protection against sea water intrusions	Nutrient cycling and retention	Fire prevention	Provisioning of water for drinking, washing and irrigation	Providing habitats for wide variety of flora and fauna	Cultural, spiritual and aesthetic services	Recreation and ecotourism
Indicators	**Average depth of drainage, cm** Peat thickness, cm Annual mean GWL	**Land cover type** Aboveground carbon stock, MgC per km2 Aboveground biomass, t/ha	**PSF cover, %** Area with peat surface below 5m, % Population living in flood-risk zone, thous.	**Area used sustainably of all area used to obtain timber and NTFPs, %** Land cover type	**Peatland area lower 6 m, %** Annual peat median WT, cm PSF cover, %	**Land cover type** Surface runoff	**Canal density, m/ha** Depth of drainage, cm Peat moisture content, %	**Annual PSF loss, %** Population density in the watershed Annual mean GWL	**Forest Landscape Integrity Index (FLII)** Conservation areas, % Threatened species, Nr	**Authentic land cover, %** Annual PSF loss rate, % Indigenous people population	**Nr of species interesting for tourists** Revenue from tourism to the peatland Nr of tourists to the peatland
Vulnerability scores	0 – ≥0 cm 1 – 0 to -10 cm 2 – -10 to -20 cm 3 – -20 to -40 cm 4 – ≤-40 cm	0 – Primary PSF and mangrove forest (MF) 1 – Sewal, ≥60% PSF + MF 2 – Sewal, ≥60% PSF + MF 3 – Sw, ≥60% non-forest 4 – Sw, ≥75% non-forest	0 – 100 1 – 80-100 2 – 50-80 3 – 30-50 4 – <30	0 – ≥95% 1 – 70-95% 2 – 40-70% 3 – 15-40% 4 – ≤15%	0 – ≤2% 1 – 2-5% 2 – 5-10% 3 – ≥10% 4 – ≥20%	0 – Primary PSF + MF 1 – Sw, ≥60% primary forest 2 – Sw, ≥60% primary forest 3 – Sewal, ≥60% agricultural plantations 4 – Bare land + other	0 – No canals 1 – 0-0.50 2 – 0.50-1.00 3 – 1.00-4.00 4 – ≥4.00	0 – 0-0.3% 1 – 0.3-≤1.5% 2 – 1.5-2.5% 3 – 3.5-8.0% 4 – ≥8%	0 – NA 1 – High integrity 2 – Medium integrity 3 – Low integrity 4 – No information	0 – 90-100% 1 – 50-90% 2 – 30-50 3 – 10-30 4 – ≤10%	0 – 0 1 – 1 2 – 2-5 3 – 5-10 4 – ≥10
Selective logging without drainage (wooden trails possible)											
Selective logging with new or existing logging infrastructure and **drainage** canals											
Intense logging with new or existing **drainage** and logging infrastructure, incl. clear cutting											
PSF conversion to **industrial plantations** incl. deep (>40cm) drainage, fertilisation (**e.g. oil palm, pulp wood, rubber** and other deeply drained plantations)											
PSF conversion to agricultural plantations incl. **shallow drainage** (<40cm) (**e.g. food crops, rice** and other shallow drained plantations)											
Fish ponds											
Deep drainage (>40cm)											
Shallow drainage (<40cm)											
Wildlife hunting											
Peatland fragmentation (by drainage canals, roads, trails, railways, other linear objects)											
Mining											
Fires on drained peatlands, incl. associated air pollution											
Fires on peatlands w/o drainage											
Extreme drought events (e.g. El Niño drought)											
River flooding											
Sea water flooding											

All tables based on Raiskaya, I. (2021). Design of socio-environmental Threat and Risk Assessment Framework to peatlands in North Kalimantan. Report. University of Greifswald, Greifswald, Germany.

ABOUT PROPEAT

The Peatland Management and Rehabilitation Project (PROPEAT) is a bilateral collaborative project between the Government of Indonesia and the German Federal Government through the German Federal Ministry for Economic Cooperation and Development (BMZ), and implemented by the Directorate of Peat Degradation Control under the Ministry of Environment and Forestry's Directorate General for Environmental Pollution and Degradation Control, and the German Agency for Interna- tional Cooperation (GIZ).

The primary aim of PROPEAT is to make the management of peat and wetland ecosystems in North Kalimantan and East Kalimantan provinces more ecologically sustainable. This is achieved through an integrative planning process in a framework of protection and sustainable management; supporting improvements to peat and wetland management practices; and disseminating results of applicative research and lessons from the field to local, national and international stakeholders.

PROPEAT operates in 13 Peatland Hydrological Units (KHGs) covering an area of 342,000 hectares in North Kalimantan, and 16 KHGs with a total area of 347,000 hectares in East Kalimantan. Some peatlands in North Kalimantan are situated in the Kayan-Sembakung Delta region adjacent to mangrove ecosystems. KHG areas in the provincial span the districts of Tana Tidung, Nunukan, Bulungan and Malinau. In East Kalimantan, the largest peatland areas are found mainly in the Central Mahakam region, which covers the districts of Kutai Kartanegara, East Kutai and West Kutai, with smaller peat- land areas in Berau and Paser districts.

Together with its main partners and stakeholders, PROPEAT supports various activities relating to the development of baseline information; policymaking and integrated planning processes; implementing sustainable land use management; strengthening livelihood and economic development; implementing action research; and supporting the dissemination of knowledge, lessons learned and best management practices.

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