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RESEARCH REPORT

Towards sustainable and productive management of Indonesian peatlands:

Case Studies of Indonesia's Peat Restoration Agency (Badan Restorasi Gambut) Interventions in Siak, Riau and Pulang Pisau, Central Kalimantan

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EXECUTIVE SUMMARY

Peat fires and degradation are major sources of CO_2 emissions in Indonesia. Indonesia's Peat Restoration Agency (BRG), established partly in response to the 2015 major fire season, has implemented various interventions to reduce these emissions in seven key provinces. Targeting almost 2.5 million hectares of degraded peatlands, BRG's three-pronged approach to peat restoration, called the "3R", consists of rewetting, revegetation and revitalisation of local livelihoods. Rewetting and revegetation focus on raising the water table by building canal blocks and deep wells and revegetating degraded peatlands with native and economically viable tree species, which could slow and potentially reverse carbon emissions. Revitalisation is complementary, delivering strong incentives to local communities to participate in peat restoration and conservation. This study analysed the results of BRG interventions at the village level on peat fire occurrences and local livelihoods in the districts of Pulang Pisau (Central Kalimantan, Borneo) and Siak (Riau, Sumatra).

In this study, we used monthly MODIS (Moderate-resolution Imaging Spectroradiometer) satellite fire hotspot data from 2003-2019 and MODIS burned area data for comparison and estimation of emissions from peat fires. Early results indicate that fire hotspot density declined more significantly in areas within 250 meters of the rewetting infrastructure, indicating rewetting efforts are effective in reducing fire in vulnerable peatlands. We also found that annual hotspots and burned areas in the target districts since the BRG implementation are all lower, except in 2019, compared to the annual hotspot average from 2003 to 2015. The number of hotspots in Pulang Pisau peaks from August to October, corresponding to the typical dry season. In contrast, the number of hotspots in Siak peaks from June to August and exhibits a smaller peak in February or March. About 80% and 54% of hotspots in Pulang Pisau and Siak (respectively) occurred in previously cleared scrubland and bareland. At least 70% of hotspots in both districts occurred in deforested areas that were natural forests in 1990. From 2003 to 2019, the emission from peat fires in Pulang Pisau and Siak contributed 15% and 2% to the national peat fire emissions on average, respectively. Although fires have been relatively low since the BRG intervention, a further study is required to establish attribution, where fire occurrences in target areas with BRG interventions are compared with those in control areas that are excluded from BRG interventions.

In addition, a review of BRG's livelihood programs showcases positive impacts on local livelihoods in Pulang Pisau and Siak. Based on interviews conducted with representatives of local community groups, livelihood programs implemented by BRG in both districts, such as support for cattle farming, have provided local communities with alternative livelihoods that are intended to generate more stable income compared to their previous livelihoods and do not require burning and draining of peatlands. A portion of the profits generated from such programs is also channelled towards local fire prevention and control efforts. While this research report includes an overview of BRG interventions and fire occurrences, additional research is needed to further assess their social and environmental effectiveness.

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BACKGROUND

1. Peat fires: their history and impacts

Indonesian peatlands are among the most carbon-dense ecosystems in the world. Accounting for 36% (15 million hectares) of global tropical peatlands, they support diverse tropical forests and are habitat for numerous rare and endangered wildlife species, including orangutans and Sumatran tigers. The ombrotrophic peatlands of Indonesia, which receive all of their water and nutrients from precipitation, typically consist of about 90% water and 10% organic matter throughout the peat column in their natural condition [1]. Peatlands also play an important role in the global carbon cycle; peatlands in the tropics alone could store about 40–90 billion tons of carbon [2]. From a socioeconomic perspective, peatlands have provided Indigenous Peoples and Local Communities with a wide range of resources, such as timber, food, fish, clean water and non-timber forest products to sustain their livelihoods [3]–[6].

Over the past several decades, vast areas of peatland have been massively affected by deforestation, degradation, drainage, burning and conversion to agriculture, which increase their susceptibility to fires. In addition, both peat degradation and fires cause loss of hydrological and ecological functions. One major driver of peat degradation in Indonesia is the logging industry. In 1970, the Government of Indonesia expedited the issuing of concession licenses for selective logging [7]. In peat swamp forests, logging companies used rail systems to transport logs because logging roads were more difficult to build due to the deep peat soil and wet conditions [8]. Illegal loggers, however, chose to build canals as it was cheaper and easier than establishing roads and railways [9]–[12]. As a consequence, these canals lowered water tables and provided greater access to peat swamp forests [10], [12], [13].

Another major driver of peat degradation in Indonesia is the rise of large-scale agriculture. Prior to 1990, most agriculture on peatlands was conducted by smallholder farmers, and fires were used to clear land and burn crop residues, which also fertilized the acidic, nutrient-poor peat soils [4], [14], [15]. However, due to their availability and flat topography, along with high demand for agricultural lands, peatlands have been subjected to conversion at industrial scales over the past few decades [10]. One of the most notable peatland conversion events occurred in 1995 with the implementation of the Mega Rice Project, a national initiative intended to convert one million hectares of peat swamp forests in southern Borneo into rice paddies. The project failed due to the unsuitability of the soil in the project area, leaving a vast area of degraded peatland in Central Kalimantan abandoned [16]. By 2015, approximately 4.3 million hectares of peatlands had been converted into industrial oil palm and pulpwood plantations in Peninsular Malaysia, Borneo and Sumatra, while approximately 3.5 million hectares of peatlands had been converted into smallholders' plantations [17]. Peatland conversion for these agricultural uses requires drainage to produce soil conditions suitable for cultivation, building canal networks or taking advantage of existing canals, and deforestation to make way for crops [10], [14]. The widespread deforestation and drainage of peatlands for logging and agriculture greatly increase their susceptibility to fire.

Apart from the described anthropogenic factors, several natural factors also play an important role in influencing the frequency and magnitude of peatland fires. Two climate events, El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), have a strong relationship with long dry seasons in Indonesia. The El Niño phase of ENSO, in particular, has been clearly associated with peat fires, and such events have been recorded since the 15th and 16th centuries in southern Borneo and Sumatra [4], [28]. In 2015, dry conditions associated with a strong ENSO resulted in a significant number of fires, while IOD contributed to major fires in 2006 and 2019 [19]. While the causes of the 2019 fire season are not fully understood, data from the National Oceanic and Atmospheric Administration (NOAA) indicate the Multivariate ENSO Index in 2019 was only about 25% that of 2015, and similar to the 2006 index [20].

The interactions among human activities and climate have increased the frequency and severity of fires in Indonesian peatlands [4], [5], [18]. Lowered water tables lead to drying of the peat surface, enhancement of decomposition of the aerated peat, as well as increases in associated carbon emissions, soil subsidence and susceptibility to ignition [6], [21]–[23]. In addition, deforestation increases the likelihood of drought as it alters the regional climate by decreasing forest canopy cover, increasing local temperatures, increasing evaporation and decreasing precipitation and soil moisture [24], [25]. Deforestation on peatlands also greatly reduces the organic matter inputs from forest vegetation necessary for forming peat [21], [22], [26]. In general, areas with forest conversion experience six times as many fires compared to areas covered with intact forests, previously burned forests are much more fire-prone, and the recurrent fires are much stronger [16], [26], [27]. To make matters worse, the direct use of fire to clear land and burn crop residues, if conducted on peatlands, can lead to an uncontrollable spread of fire to adjacent areas as well as underground [10]. Smouldering peat fires are extremely difficult to detect and extinguish, and therefore persistent. The low temperature, incomplete peat combustion produces more air pollution than a typical brush fire or forest fires.

Uncontrolled fires and degradation in peatlands continue to be a major source of carbon dioxide to the atmosphere, and Indonesia is the largest source of CO_2 emissions from peatland degradation globally [21], [28]–[30]. Severe peat degradation could produce around 19.5 tons CO_2/ha per year, and peat fires could produce an additional 923.1 tons CO_2/ha [31], [32]. Between 2000 and 2012, Indonesia's emissions from peat degradation and fires averaged 0.3 and 0.2 billion tons CO_2 per year [22]. In 2012, peat fires accounted for 16% of national emissions and were the third largest source of emissions after land use change and energy [33], [34]. Because they also emit toxic smoke and particulate matter into the atmosphere, peat fires also damage human health, close down schools, disrupt air transportation and harm economies locally and internationally. Fires that occurred throughout Kalimantan and Sumatra in 2015, for example, resulted in an estimated USD 16.1 billion in economic losses, contributed to more than 100,000 premature deaths and 500,000 cases of acute respiratory disease, and caused political disputes with Singapore and Malaysia [11], [26], [35]. Over the particularly severe fire season in 2015, 33% of all detected fires occurred on peatlands [26]. Considering the damages and financial losses caused by peat fires, their economic benefits are small or even non-existent [35].

Peatland conservation and restoration are key to maintaining their ecological function, reducing peat fires and conserving their carbon storage properties to avoid massive greenhouse gas emissions into the atmosphere. Conservation and restoration efforts should consider the socioeconomic needs of the local communities living on and around peatlands. Peatland degradation and fires threaten the public health, food, water and income of adjacent communities, which can play a vital role in peatland conservation and are on the frontline in combating peat degradation. The interest and participation of local communities in restoring degraded peatlands can be part of a sustainable approach that supports the continuation of conservation and restoration efforts in the longer term. Incentives for local communities can shift people's behaviour away from draining and burning, towards conserving and restoring peatland [6].

2. Peat Restoration Agency: part of the solution to peat fires

A few approaches have been tested to conserve and restore peatlands and reduce peat fires in Indonesia, including the introduction of the moratorium on peatland conversion for oil palm, pulpwood and logging concessions and environmental laws against using fire to clear land for new plantations [36]. One main initiative is the establishment of Indonesia's Peat Restoration Agency (Badan Restorasi Gambut/BRG), a national agency tasked with restoring 2.49 million hectares of peatlands spread across seven priority provinces that collectively contain 86% of Indonesian peatlands: Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan and Papua. BRG's approach to peat restoration is collectively known as the 3R, in reference to local interventions focusing on Rewetting, Revegetation and Revitalisation of communities' livelihoods. BRG interventions also define co-benefits, including reduced carbon emissions, hydrological regulation, biodiversity conservation, and increased well-being of local communities.

REWETTING, REVEGETATION AND REVITALISATION: The BRG Approach to Peat Restoration

1. Rewetting

Rewetting aims to restore the hydrological conditions, structure and functions of degraded peat ecosystems to their near-natural state by building canal blocks, backfilling canals and installing deep wells [37], [38]. Research shows that canal blocks can raise the water table permanently in degraded peat from 1.12 meters to 0.37 meters below the soil surface on average within 170 meters from the canal, and increase soil moisture within approximately one kilometer from the canal block [1], [38], [39]. Deep wells, on the other hand, serve as water sources to rewet peatlands and extinguish surface fires [40]. The cost of building a canal block may vary from IDR 5 million to IDR 70 million (~USD 346 to USD 5,097) depending on the materials used, size of the canal and durability of the construction [11]. The establishment of rewetting infrastructures is mostly done in collaboration with local communities, although a few infrastructure projects have been established in collaboration with universities or through third parties [41].

2. Revegetation

Revegetation aims to restore vegetation cover in peatlands and re-establish processes and functions that slow peat decomposition and increase soil and air moisture, hence reducing its flammability and carbon emissions [11], [42]. Re-establishing forest cover also improves soil structure, porosity, and infiltration rates, and increased canopy cover decreases the surface temperature of the peat, helping to reduce peat decomposition rates [43], [44]. BRG's revegetation intervention prioritizes native peat swamp species that can provide key ecosystem services and increase biodiversity in protected zones, and other wetland-suitable species with economic value to be cultivated in designated peatland cultivation zones. This intervention also applies two cultivation systems: agroforestry and paludiculture. The former integrates enrichment planting of economically valuable species into the forest ecosystem, while the latter could be done in permanently flooded wetlands [11], [45]. Reforestation, especially in degraded peat forests far from settlement areas, is also a suitable option for revegetating peatlands designated for conservation, which can be done through intensive and enrichment planting [11], [45]. Revegetation requires the awareness, knowledge, and participation of local communities to ensure the viability and sustainability of the project.

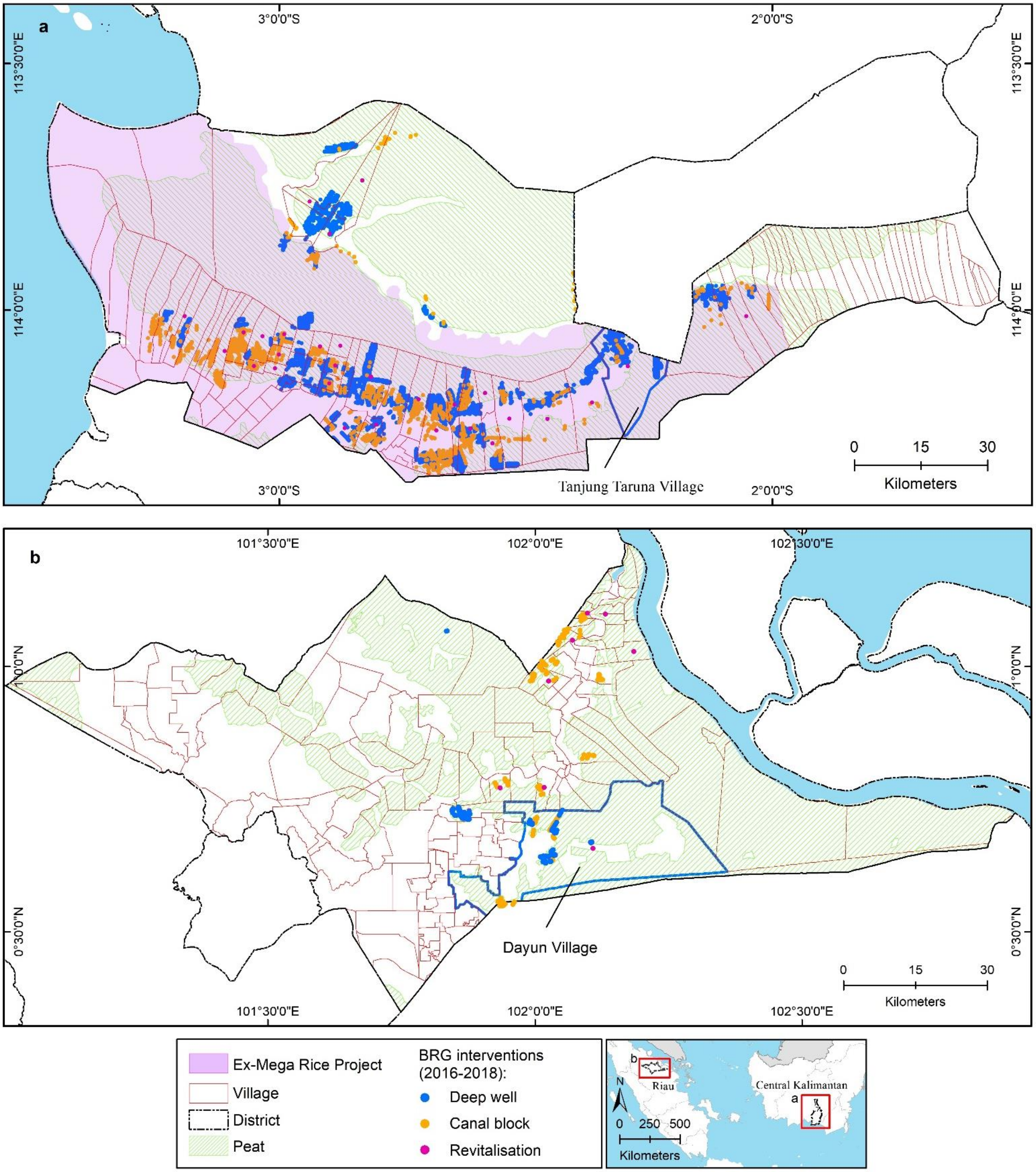
3. Revitalisation

Revitalisation aims to improve the overall economic and livelihood conditions of local communities in target villages through the provision of financial and technical support —referred to as a "livelihood package"— based on the development of small-scale, profitable livelihood projects together with peatland conservation measures. Such packages are provided to develop paludiculture (e.g. demonstration plots for wetland-suitable crops including sago, pineapple and rice without burning), local ecotourism (e.g. establishment of relevant infrastructure), livestock, aquaculture and fisheries. The types of packages provided are based on assessments of the current capacity, capability and interests of communitygroups, the potential profit generated and long-term prospects, and are given based on detailed proposals and management plans submitted by the community groups. Moreover, these livelihood packages provide alternatives to production models that rely on extensive draining and burning of peatlands and are managed by community groups. The revitalisation programs are accompanied by support to strengthen the supply chains and commercialization of the products produced from the programs through local community cooperatives and village-owned enterprises, which are expected to improve the overall economic and livelihood conditions of the targeted local communities. This intervention is also designed as an incentive to ensure community participation in peat restoration and fire reduction. Examples of BRG activities are illustrated in Figure 1.

Figure 1. Examples of a) canal block; b) Deep well construction; c) Revegetation; and d) peatland fisheries revitalisation. Source: BRG

PROFILES OF STUDY AREAS

This preliminary study focuses on two districts, Pulang Pisau District in Central Kalimantan and Siak District in Riau.



Map 1. Locations of BRG Interventions in *a) Pulang Pisau District; and b) Siak District*

Pulang Pisau District, Central Kalimantan

Pulang Pisau is located in Central Kalimantan province with an area of 983,200 hectares, of which approximately 67% (659,900 hectares) are peatlands. Unfortunately, a vast area of peatland in this district was heavily degraded due to peat deforestation and canalization during the Mega Rice Project between 1995 and 1996, creating a fire-prone landscape, with frequent fires occurring along the drainage canals. Ex-Mega Rice Project areas, therefore, are a particular focus of BRG's peat restoration efforts due to the scale of degradation and persistence of annual peat fires in the region. Pulang Pisau also consists of vast protected areas that are formally designated as a national park, totalling 211,300 hectares, and is also a desirable location for establishing plantations, with 152,900 hectares of oil palm plantations and 7,700 hectares of pulpwood plantations already established.

From 2016 to 2018, 1,650 canal blocks and 6,515 deep wells were installed by BRG in Pulang Pisau, as shown in Table 1. BRG has also provided various revitalisation packages ranging from crop-related support, including zero-burning land clearing practices, the farming of *Sengon* (*Paraserianthes falcataria*), watermelon, and support for livestock- and fishery-related activities including raising cattle, honeybees and catfish. Between 2016 and 2018, BRG provided 53 livelihood packages to 29 villages scattered in 8 sub-districts, with the most popular packages including those supporting cattle farming (17 packages), beekeeping (10 packages) and *Sengon* farming (8 packages). The locations of rewetting infrastructures and revitalisation programs are shown on Map 1.a, and the summary of the types of livelihood packages provided to target villages in Pulang Pisau is provided in Appendix A.

Table 1. BRG Interventions in Pulang Pisau District

BRG intervention	2016	2017	2018
Canal blocks (# of units)	9	834	807
Deep wells (# of units)	200	4150	2165
Revitalisation (# of packages)	1	23	29

Siak District, Riau

Siak, located in Riau province, has an area of 749,200 hectares, of which approximately 54% (404,500 hectares) are peatlands. Siak contains large areas of pulpwood and oil palm plantations, totalling around 240,000 hectares and 86,000 hectares, respectively. Siak also contains large protected areas including grand forest parks and wildlife reserves (60,400 hectares).

In Siak, 178 canal blocks and 202 deep wells were installed in 2017 and 2018, as shown in Table 2. Starting in 2017, BRG has also provided a range of livelihood packages to villages in Siak. The packages ranged from support for pineapple and watermelon farming to cattle farming and freshwater fisheries. Additionally, BRG also provided support for the development of village level small-to-medium enterprises in Sengkemang Village. Between 2017 and 2018, BRG provided 10 livelihood packages to 9 villages located in 7 different sub-districts in Siak, with cattle farming being the most common (6 packages). The locations in which the rewetting infrastructures were built and revitalisation programs were implemented are shown on Map 1.b, and the summary of the types of livelihood packages provided to villages in Siak is provided in Appendix B.

Table 2. BRG Interventions in Siak District

BRG intervention	2016	2017	2018
Canal blocks (# of units)	0	112	66
Deep wells (# of units)	0	200	2
Revitalisation (# of packages)	0	6	4

FIRE TRENDS AND PRELIMINARY ASSESSMENT OF BRG RELATED INTERVENTIONS

1. The extent of hotspots

1.1. Fire hotspots

Figure 2 illustrates the number of fire hotspots recorded monthly in the two studied districts between 2003 and 2019 based on MODIS (Moderate-resolution Imaging Spectroradiometer) observations.

Fire hotspots in Pulang Pisau mostly occurred during the dry season from July to November, as shown in Figure 2.a. Prior to BRG interventions, major fires in Pulang Pisau occurred in 2006, 2009 and 2015, rising sharply in September and October. The worst fire year during this period was 2015, where fires were exacerbated by a long dry season from July to November, and hotspots were detected not only in degraded peatlands but also in peat swamp forests within national parks [46]. Also, although the number of fire hotspots following BRG interventions initially declined, 2019 experienced some recurrence.

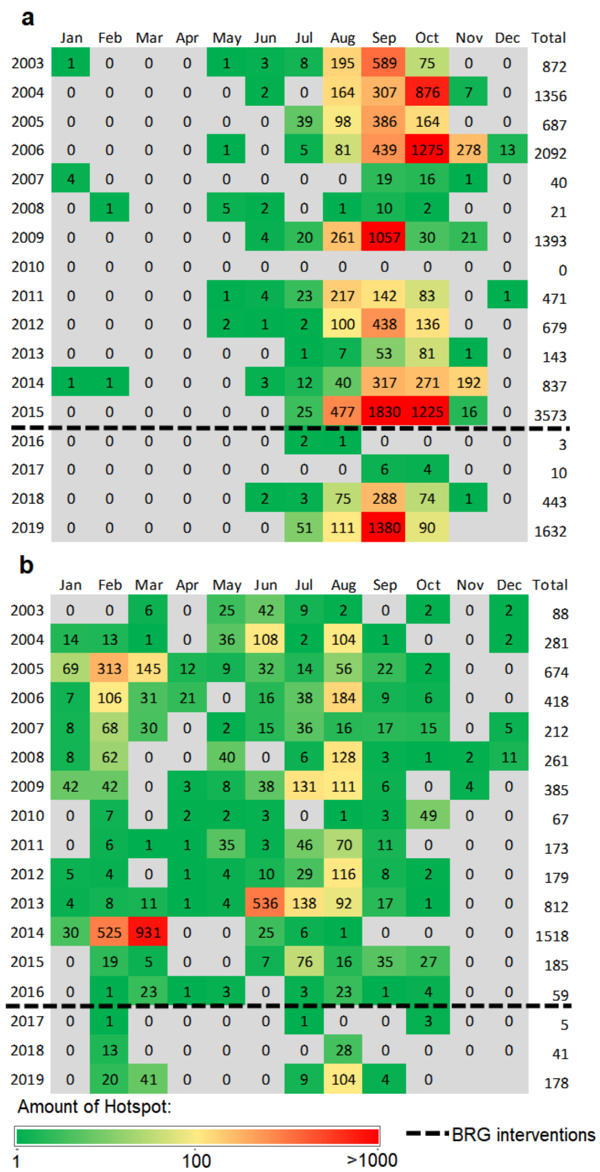


Figure 2. Monthly MODIS hotspots from 2003 to 2019 in a) Pulang Pisau; and b) Siak. The dashed line represents the beginning of BRG interventions in the area

The fire regime in Siak was slightly different from Pulang Pisau, with a lower number of fire hotspots scattered from January to October, as shown in Figure 2.b. In most years, the hotspots peaked from June to August with a small peak from February to March, as observed in 2005 and 2014. Similarly, in Riau Province, the major fires of 2005, 2013 and 2014 occurred within the shorter early dry season between February and June [47]. This pattern should be considered in developing and implementing fire management efforts according to historically dry months, as the timing of fire seasons are slightly different between Siak and Pulang Pisau. Although 2017-2019 annual fire reports were below the 2003-2016 average, the trend has been increasing since 2017.

1.2. Burned areas

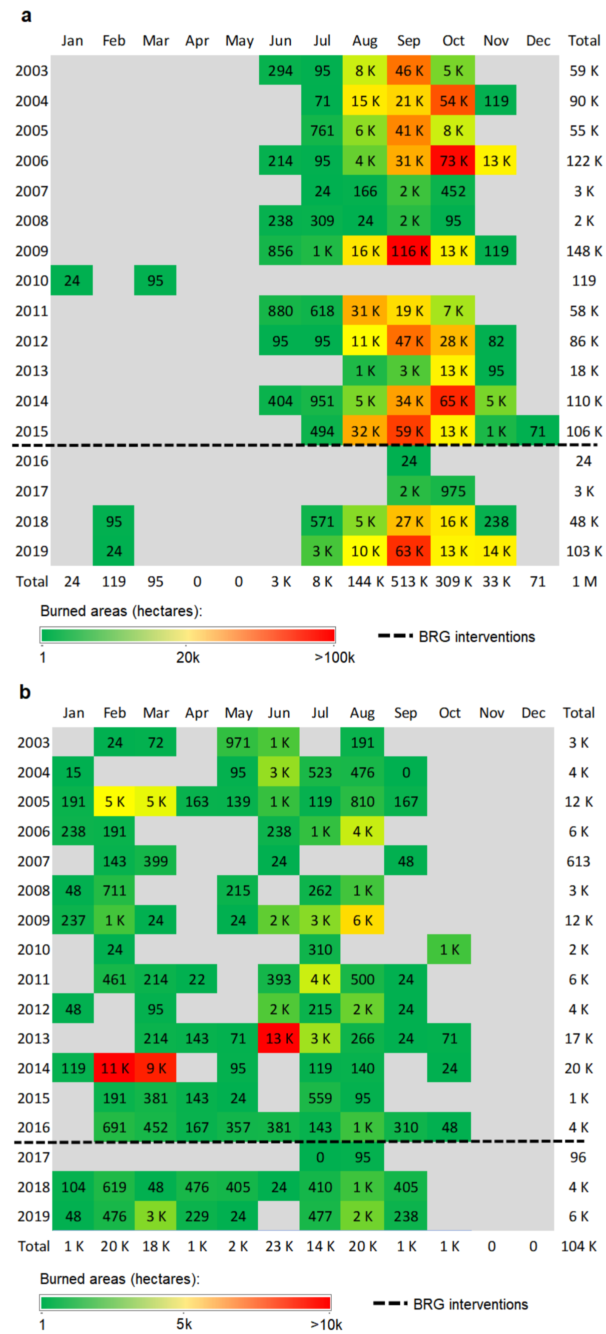


Figure 3. Monthly MODIS burned areas from 2003 to 2019 (hectares) in a) Pulang Pisau; and b) Siak. The dashed line represents the beginning of BRG interventions in the area

Figure 3.a and 3.b show the monthly burned areas in Pulang Pisau and Siak. The cumulative burned area in Pulang Pisau between 2003 and 2019 was around 1

million hectares, although many areas were burned more than once. From 2003 to 2019, more than 80% of burned areas, or about 800,000 hectares, were detected in September and October. Major fire years were 2006, 2009, 2015 and 2019 with a total burned area of more than 100,000 hectares. These findings coincide with the trends shown by the hotspot data. Although the burned areas had been increasing since 2016, the annual average burn area after BRG interventions is lower than that before BRG interventions.

In Siak, 104,000 hectares were burned between 2003 and 2019, and 91% or about 95,000 hectares were burned consistently in February-March and June-August. Some notable years were 2005, 2009, 2013 and 2014, when a total of more than 10,000 hectares were burned. Overall, the annual average of burned areas after BRG interventions is only a half of the annual average prior to BRG interventions.

2. Land cover associated with fire

Around 65% of the fire hotspots observed in Pulang Pisau were associated with scrubland areas (Figure 4.a), of which about 86% were in peatlands. This land cover type is generally located far from settlement areas and has limited accessibility in Pulang Pisau, which could present a major challenge to fire reduction efforts. Bareland accounted for 15% of hotspots in this district. Therefore, both scrubland and bareland, which are considered as unmanaged land covers, are related to about 80% of the total hotspots combined. Secondary swamp forests and plantations accounted for 5% and 3%, respectively. Only 2 hotspots (0.01%) were detected in primary swamp forests from 2003 to 2018. About 88% of the total hotspots in the whole district took place in peatlands, which cover 67% of Pulang Pisau.

In Siak, most fires also occurred in scrubland and bareland, as shown in Figure 4.b. The former accounted for 32%, while the latter accounted for 22% of the total hotspots. Around 12% of the hotspots occurred within plantations (mostly oil palm) and 8% in plantation forests (pulpwood). Both can be categorised as cultivated or fully managed land cover types. Around 15% of the hotspots took place within secondary swamp forests. In primary swamp forests, only 21 hotspots (0.4%) were detected from 2003 to 2018. Overall, 54% of fire hotspots from 2003 to 2019 in Siak occurred within lands considered unmanaged. In total, about 83% of the 2003-2019 hotspots in Siak took place within peatlands, which cover 54% of the district.

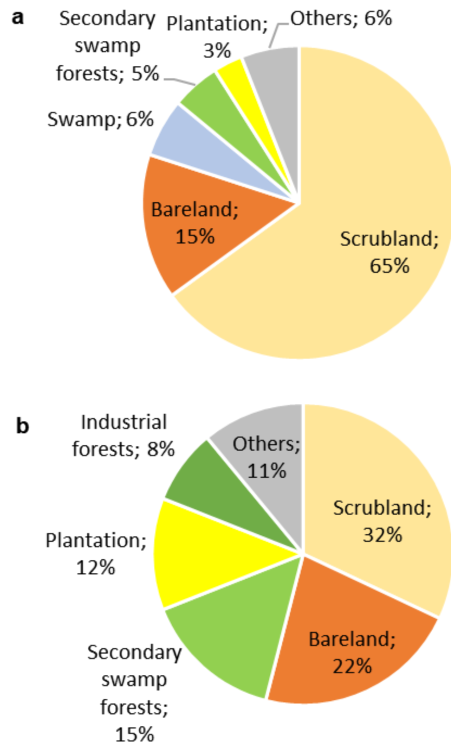


Figure 4. Land cover associated with 2003-2019 hotspots in a) Pulang Pisau; and b) Siak

3. Emissions estimation from peat fires

To provide an estimation of emissions from peat fires, a methodology from the Intergovernmental Panel on Climate Change (IPCC; [32]) was applied in this study using the following formula:

$$L = A \times M_B \times C_f \times G_{ef} \times 10^{-3} \quad (1)$$

where L is the amount of CO_2 and non-CO_2 emissions, A is the total burned area (hectares), M_B is the fuel mass for combustion, C_f is the combustion factor and G_{ef} is the emission factor (g/kg of dry matter burnt). The data used for the calculation was MODIS at a 500-meter resolution, while M_B, C_f and G_{ef} were obtained from the IPCC data [32]. In Pulang Pisau, about 79% or about 791,000 hectares of burned areas occurred within peatlands between 2003 and 2019. In fact, 100% of burned areas in 2007, 2010 and 2016 were located within peatlands. In total, emissions from peat fires from 2003 to 2019 were 194 million tons CO_2e, as shown in Figure 5.a.

The contribution of emissions from peat fires in Pulang Pisau in 2009 to the total annual emissions from peat fires in Indonesia was 31%, which was higher than the 2003-2012 average of 15% [48]. Emissions have been generally increasing after the significant decline in 2016. In Siak, the total burned areas within peatlands that occurred from 2003 to 2019 were 92,000 hectares or 90% of the total burned areas in the district. A total of 23 million tons CO_2e were emitted from these burned areas, which mostly occurred in 2005, 2009, 2013 and 2014, as shown in Figure 5.b. On average, the contribution of emissions from peat fires in Siak to the total emissions from peat fires in Indonesia from 2003 to 2012 was 2% [48].

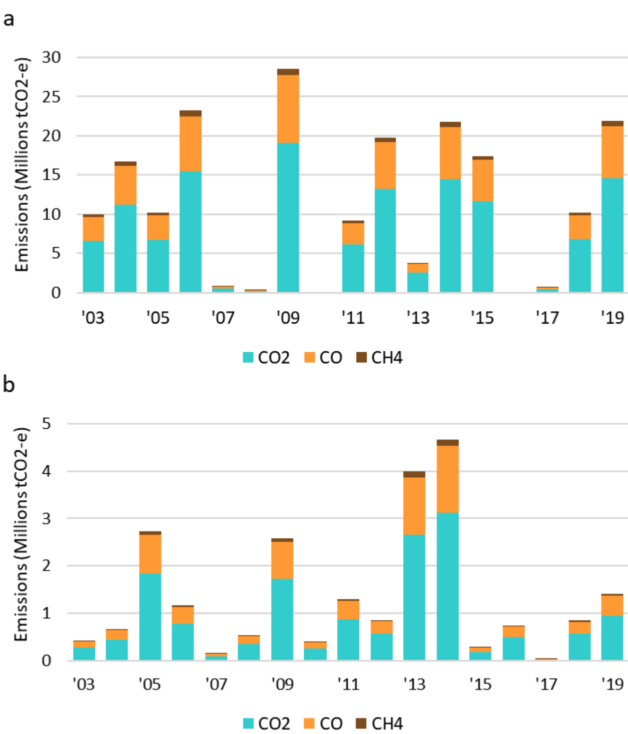


Figure 5. Estimated annual emissions from peat fire from 2003 to 2019 in a) Pulang Pisau; and b) Siak

4. Hotspots by the year of deforestation

On average, the annual deforestation from 1990 to 2018 was 15,700 hectares and 15,000 hectares in Pulang Pisau and Siak, respectively. In total, 61% (439,600 hectares) and 68% (420,000 hectares) of primary forest in Pulang Pisau and Siak had been deforested between 1990 and 2018.

In Pulang Pisau, 83% of the 2003-2019 hotspots were located within areas that were forested in 1990 and cleared between 1990 and 2018, as shown in Figure 6.a. About 71% of the total hotspots in this district were located in areas that had been deforested. This illustrates the high flammability of deforested areas, especially in peatlands. About 8% of hotspots occurred during the same year where deforestation also occurred and only 4% of hotspots occurred within forested areas that disappeared in the following years.

Similar to the figure in Pulang Pisau, only 11% of 2003-2019 hotspots in Siak were detected outside of areas that were deforested from 1990 to 2018, as shown in Figure 6.b. In total, 89% of hotspots occurred within deforested areas, with 70% taking place in already deforested areas, 14% occurring in the year of deforestation and 5% occurring before deforestation occurred. However, understorey fires in healthy forests are often undetected by satellites, especially for smouldering peat fires. Despite this limitation, some understorey fires in peat forests in Central Kalimantan have been detected by MODIS [49]. In this case, low fire frequency within forests is more likely caused by the high humidity of healthy peat forests.

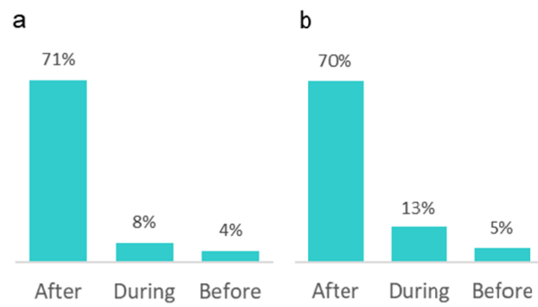


Figure 6. 2003-2019 MODIS hotspots by the year of deforestation in a) Pulang Pisau; and b) Siak

5. Hotspot density and distance to BRG's rewetting infrastructures

Figure 7.a and 7.b provide evidence on the spatial relationship between BRG infrastructure and fire occurrence prior to and post BRG intervention. In both districts, the hotspot density prior to the BRG interventions decreases when the distance is further from the BRG's intervention sites, which suggests a proper targeting of the program. After the BRG interventions, the highest fire density reduction occurred in areas within 0 to 250 meters from BRG

rewetting infrastructures at 0.04 and 0.07 hotspots/km^2 in Pulang Pisau and Siak, respectively.

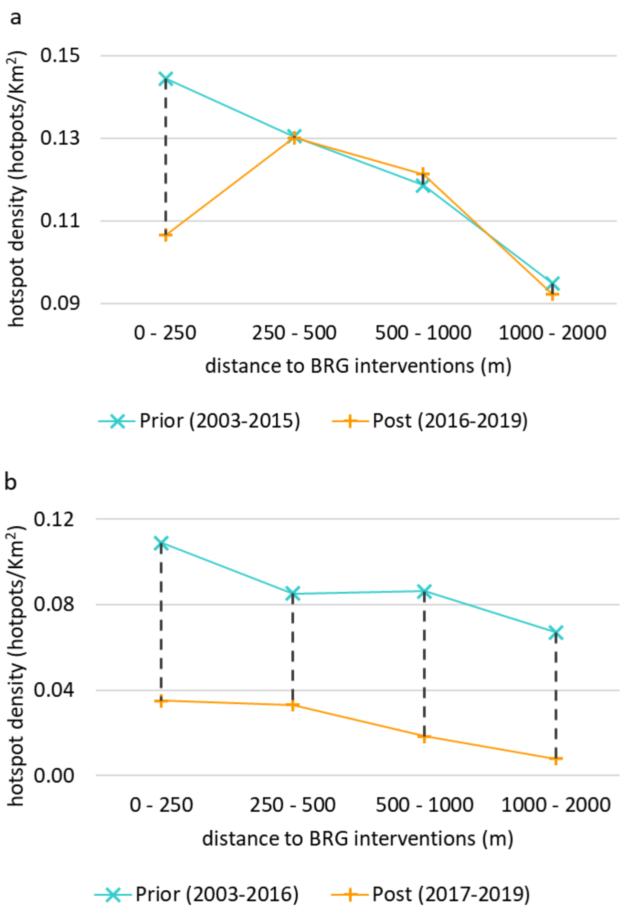


Figure 7. Density of fire hotspots prior to and post BRG interventions classified by distance to BRG interventions in a) Pulang Pisau; and b) Siak

Map 2.a and 2.b illustrates that, overall, BRG's rewetting infrastructures in Pulang Pisau were built in close proximity to fires occurring from 2013-2019, whereas in Siak, there are several fire-prone areas that are far from the infrastructures. In Pulang Pisau, there are also fire-prone areas that are not likely impacted by BRG infrastructures, likely due to their location being far from settlement areas and limited accessibility. The infrastructures were built within the peatland areas of the ex-Mega Rice Project in Pulang Pisau, thus the infrastructures established by BRG targeted areas with high historical fire occurrences.

BOX 1: Hotspots and burned areas data comparison

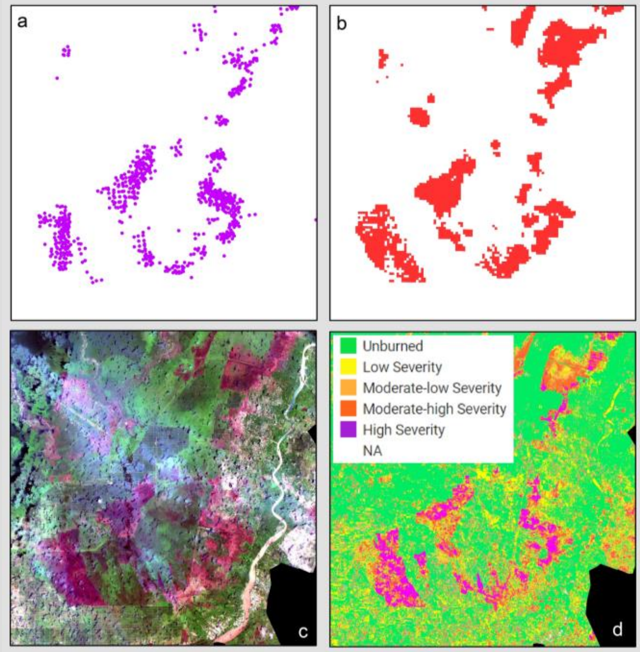
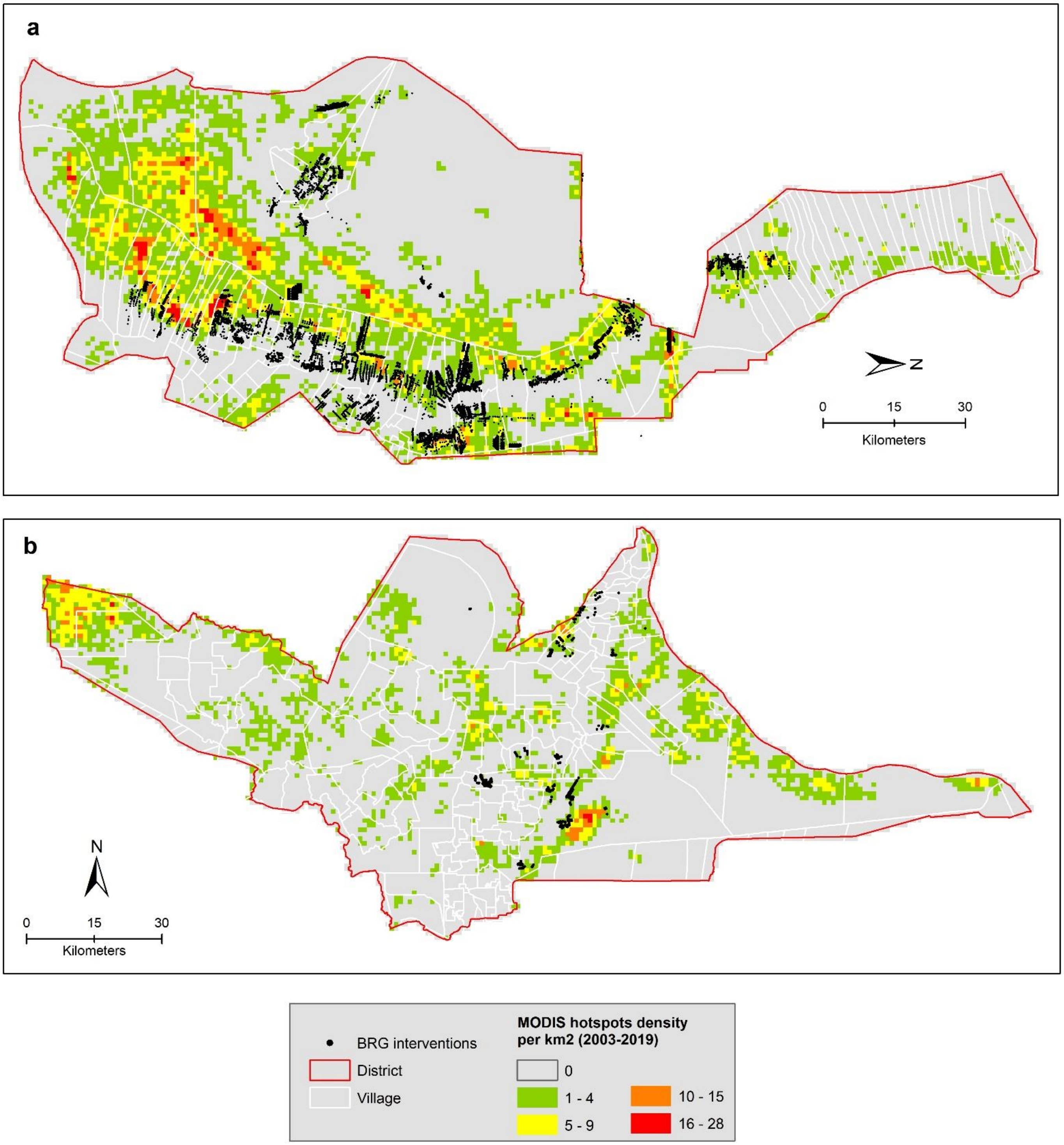


Figure: a. >80 confidence level MODIS hotspots; b. 500m burned area MCD64A1; c. 10m true colour Sentinel-2

We assessed the agreement of MODIS hotspot and MCD64A1 burned area data with the Sentinel-2 composite at a 10-meter resolution and burn severity analysis from Sentinel-2 to check the accuracy of MODIS-derived fire data [54]. The former is a true colour composite of Sentinel-2 collected for September 2019, while the latter is a burn severity map based on changes detected before and after the fires, where the pre-fire data start from 1 August 2019 to 31 August 2019 and the post-fire data start from 1 October 2019 to 31 October 2019. The output is the burn severity index map in September 2019 at a 10-meter resolution. The burn scars that are visible in the very-high resolution Sentinel-2 satellite image and detected in the burn severity index map, especially the burned areas that are classified as moderate-low, moderate-high and high severity, are also detected in lower resolution MODIS hotspots and burned areas. The comparison shows great consistency between MODIS hotspots and MCD64A1 burned areas with both data pointing to the same areas that were burned in September 2019 as observed in Sentinel-2.



Map 2. Hotspot density map of a) Pulang Pisau; and b) Siak. The map shows the total hotspots within 1 km^2 grid from 2003-2019. The green colour indicates the lowest hotspots density, while the red colour indicates the highest hotspots density. The grey colour indicates no hotspot

BOX 2: Data

Data	Sources	Date	Description
Hotspots	FIRMS [50]	2003 - 2019	Derived from 1-kilometer MODIS, Confidence level >80
Burned areas	MCD64A1 [51]	2003 - 2019	Derived from 500-meter resolution MODIS
Deforestation	MoEF [52]	1990 - 2018	Natural forest cover (intact and degraded) conversion to non-forest land cover types
Land cover	MoEF [52]	1990 - 2018	Land cover classification consists of 23 land cover types
Rewetting infrastructures	BRG	2016 - 2018	Georeferenced data was documented by BRG.
Administrative boundaries	BIG [53]	2019	Administrative boundaries at district level
Distance-based fire density	Data processing	2019	Distance analysed using multiple buffer analysis was performed. The annual fire density is the division of the total fires occurring in each area within a year
Revitalisation program	Primary data	2019	Interviews with relevant stakeholders (e.g. community groups) and BRG's local facilitators

IMPACTS OF BRG'S REVITALISATION PROGRAM ON LOCAL LIVELIHOODS

To improve the livelihoods of local communities in Pulang Pisau and Siak, BRG provided various livelihood packages to local community groups in the two districts. In Pulang Pisau, BRG provided 53 livelihood packages to 29 villages between 2016 and 2018. Of these packages, 17 support local cattle farming, 10 support beekeeping, 8 support *Sengon* farming, 6 support zero-burning land clearing and management, and the remaining packages support other livelihoods, including fisheries, fruit and vegetable farming and small-scale production of livestock feed and organic fertilizer. The summary of the livelihood packages provided to local community groups in Pulang Pisau is provided in Appendix A. In Siak, BRG provided 10 livelihood packages between 2017 and 2018. Similar to Pulang Pisau, most provided support for cattle farming, accounting for 6 of the 10 packages provided. Other packages include support for pineapple and watermelon farming and freshwater fish farming. The provision of these livelihood packages reached 9 different villages in Siak, as summarized in Appendix B.

Following BRG's review and approval of their proposals, the community groups receive between IDR 100 million and 200 million (~USD 7,300-14,600) of tangible support to start their program. The support provided depends on the type of livelihood package. For example, livelihood packages supporting cattle farming will consist of a number of male and female cattle, cattle pens and cattle feed; livelihood packages supporting aquaculture consist of fish of selected species, fish pond installation and fish feed; and livelihood packages supporting beekeeping include honeybee colonies, honey harvesting equipment and packaging materials for honey sales. In addition to the tangible support, community groups are also given business management and technical training, customized according to the type of packages received and the needs of the community groups.

Through these packages, many community groups are independently and sustainably managing the new flow of revenue. The sales and revenue generated, however, vary depending on the types of livelihood packages and the capacity and skills of local community groups in managing such projects. In Tanjung Taruna Village in Pulang Pisau, for example, the community group that received a livelihood package to support cattle farming consisting of 52 cows, cattle pens, cattle feed and medicine in 2016, has since managed to sell 21 cows and calves with a revenue of at least IDR 15 million (~USD 1,095) per cow sold or at least IDR 7.5 million (~USD 550) per calf sold, whereas a community group in Dayun Village in Riau, which received a similar package consisting of 10 cows, cattle pens and necessary tools in 2017, has sold one cow, generating revenue of IDR 16 million (~USD 1,170). In another example, the sale of honey produced by a community group in Sebangau Village in Pulang Pisau, which received 33 colonies of honeybees along with harvesting equipment and packaging, produced 15 liters and generated around IDR 2 million (~USD 145) of revenue per month. Finally, the sale of carp and silver catfish bred by a community group in Buntoi Village in Pulang Pisau has reached almost 2.5 tons of production valued almost IDR 40 million (~USD 2,900). While the financial management also varies across different community groups, BRG has encouraged these groups to dedicate a percentage of the revenue to fund operational activities needed to prevent and suppress local fire incidents.

While BRG's revitalisation program has been implemented in many villages, two success stories are presented to illustrate how this intervention has benefited local communities.

Success stories

1. Pulang Pisau District: Taruna Karya Bersama Community Group in Tanjung Taruna Village

Taruna Karya Bersama is a community group formed in Tanjung Taruna Village in Pulang Pisau. Tanjung Taruna Village is traversed by the Trans-Kalimantan Highway and the Kahayan River and consists mostly of peatlands, as illustrated in Map 1, some of which were damaged due to the Mega Rice Project.

Before the revitalisation package was provided, the majority of the members of Taruna Karya Bersama were fishermen. Fishing was usually conducted along the Kahayan River or in peat swamps. Peat swamps in the village were used as a storage area for fish caught by the fishermen as well as a source of fish caught using traditional practices, called *begalau*, that relied on natural tidal fluctuations and did not involve burning and degrading peatlands. The types of fish caught varied, ranging from *Kerandang* (*Channa pleurophthalma*), *Kapar* (*Belontia hasselti*), *Sepat* (*Trichogaster trichopterus*) and *Gabus* (*Channa striata*). However, fishermen often found that fishing in the village was challenging and did not yield a large enough catch to create a steady, adequate source of income. Declines in the number of fish caught by the fishermen were likely due to a combination of factors, including habitat degradation and overfishing.

In response to the need for alternative sources of income, the Taruna Karya Bersama community group was established in late 2016. Through rounds of discussions, the members of the group decided on cattle farming as a new potential business opportunity, considering the high profitability of the venture, capacity of the members to manage the project, and its low impacts on the existing peatlands. Upon this consideration, a proposal to support the initiative was approved by BRG under its revitalisation program. As part of the package, Taruna Karya Bersama received 52 cows, cattle pens, cattle feed and medicines, and technical support for cattle farming. The group also received training for organizational management to help strengthen the business and synergize work among its members. Taruna Karya Bersama has a total of 22 members and is led by an appointed group head and supported by a secretary and a treasurer, each of which has several clear, key roles in managing the group's activities, reporting and finances. Due to administrative reasons, official members registered in the group are men as they are heads of household, although many women in the village are also directly involved in the cattle farming activities.

Figure 8. Cattle Breeding by Taruna Karya Bersama Community Group

All of the members of Taruna Karya Bersama are responsible for taking care of the cows, making sure that they are healthy, well-fed and able to reproduce, all of which will ensure a continuous flow of benefits to the members. Rounds of training were given by BRG through a local facilitator with extensive experience in cattle farming, covering a wide range of topics such as proper cattle farming practices, cattle feeding, nursing and breeding and feed management. The group also received training for producing fertilizer derived from manure as well as cattle feed, which can be an additional source of income for members of the group. Through such proper care, the group has been able to sell 21 cows and calves. The cows were sold for Eid al-Adha, when cows and goats are slaughtered as part of the Islamic celebration, and the calves are sold throughout the year. To further develop the business, the community group is considering a Memorandum of Understanding with local religious groups to establish the group as the supplier of cows for the Eid al-Adha celebration every year. In addition, BRG has also promoted cattle markets to neighbouring villages and on social media. The group also limits the number and age of the cows that can be sold to ensure that they have enough cows to breed and maintain a stock that can be sold over time. The success of the program later inspired other people in the village, with about 30% of the village population depending on the cattle farming economy as opposed to 10% prior to the introduction of the program.

The financial management mechanism established by the group ensures that this package can be managed sustainably in the long term. For every cow sold, IDR 10 million (~USD 730) are set aside for purchasing more cows and further growing the business, IDR 500,000 (~USD 36) for funding operational activities of the group, and the remaining for individual profits for all of the members, reaching at least IDR 4.5 million (~USD 328) per cow sold. Similarly, for every calf sold, IDR 250,000-500,000 (~USD 18-36) are set aside for operational funds, while the remaining is for individual profits that could reach IDR 9.5 million (~USD 690) per calf sold. Based on this, the group allocates funds to the Fire Care Community (*Masyarakat Peduli Api* or MPA), which is responsible for controlling forest, land and peat fires in the village. These funds support operational MPA activities, such as transportation and personnel. The group is also considering business expansion to include the production and sale of manure.

2. Siak District: Maju Jaya Community Group in Dayun Village

Maju Jaya is a community group established at the end of 2017 in Dayun Village. Dayun Village is located in Siak, consisting of 53,500 hectares of peatlands out of 73,807 hectares of the total village area (Map 2). Similar to Taruna Karya Bersama, Maju Jaya also received a revitalisation package to support cattle farming in the village.

Figure 9. Cattle Breeding by Maju Jaya Community Group

Prior to the introduction of the revitalisation program, the majority of people in Dayun Village were oil palm farmers, with oil palm plantations established on peatlands, as well as honey collectors. These two livelihoods were also the two main livelihoods of the members of Maju Jaya, although they also raised one or two cows per person to generate additional household income.

Maju Jaya community group was formed by the village government, with members of the group appointed considering their ability and experience in cattle farming. The group consists of a head, a secretary, a treasurer and six members, each of which has their own roles and responsibilities, including managing and purchasing cattle, reporting the development of the project and managing the group's finances. Upon its establishment, the group received training from BRG on organisational and financial management. Through BRG's revitalisation program, the group received IDR 100 million (~USD 7,300), which was used to purchase 10 cows, cattle pens and necessary tools for maintenance. The group also received training on cattle farming practices, such as breeding, vaccination and feeding.

By the end of 2019, there had been 11 additional cows bred since the beginning of the program, totaling 21 cows. The group managed to sell one cow bred in 2019 for IDR 16 million (~USD 1,170) and has secured an order for four cows in 2020 for the Eid al-Adha celebration, when a cow could be valued at IDR 17 million (~USD 1,240). With around IDR 8 to 10 million set aside for purchasing more cattle, the remaining profit is shared with group members and some allocated for the group's operational funds and used for maintaining cattle pens, purchasing feed and funding a local MPA. Building on their success, the Maju Jaya community group received small-scale organic fertilizer production equipment and a grass chopper, along with training on its use, from BRG to better manage the cattle and further expand the business and diversify their products to generate additional income for the members. Although the organic fertilizer and feed production is not at a large enough scale to fulfill the high market demand, it is enough for household uses by the group members, who also aim to increase fertilizer production and its quality in the future.

The transition to cattle production has had positive impacts on peatland management, as increased fire prevention measures are now taken by community members. Fires are now seen as a threat to the growth of pasture grass, which will directly affect the amount of feed produced for the cattle. Constant surveillance by Maju Jaya community group, as well as other local community members who rely on the healthy growth of grass for cattle feed, ensures that burning is not used to clear vegetation, and warnings against burning are given to other community members. This direct motivation could be seen as an interesting and effective approach to the reduction of burning in the villages, which could consequently lead to a reduction of peat fires.

BOX 3: Underperforming revitalisation programs

While livelihood packages are intended to provide alternative, sustainable livelihoods to local communities, their success rates vary. Many factors contribute to the success and failure of a given program, which also vary across different packages. Natural factors, such as unpredictable seasonal changes, can impact the productivity of certain livelihoods. For example, one of the community groups that received a package supporting honey production experienced a sharp decline in productivity due to a prolonged dry season. Internal factors, such as the varying capacity of community groups to manage such packages, also plays an important role in ensuring that such packages are managed sustainably, and varying levels of success have been observed by BRG across different community groups.

Recommendations and Conclusions

Fire prevention and control measures in Pulang Pisau should prepare for the annual dry season from July to November to reduce the impact of forest and land fires. In contrast, preventative and control measures in Siak should take into account the periods of high fire occurrence between February and March and between June and August. The fire prevention efforts should also prioritize the previously cleared scrubland and bareland, as about 70% of hotspots detected from 2003 to 2019 took place within those land cover types. Examples of preventative measures include: warnings disseminated to communities and other relevant stakeholders to prohibit the use of fire to clear land, socialization activities to educate people on the negative impacts of fires and tightened patrol in fire-prone areas. Fire control measures should also be prepared, particularly in anticipation of these dry periods, with fire-fighting crews and equipment ready to be deployed in response to fire incidents.

Considering BRG's rewetting infrastructure in the two focus districts, most are close to areas prone to fire based on previous fire occurrences. In Pulang Pisau, the 26% reduction in fire hotspots within 0-250 meters from BRG rewetting infrastructures could indicate some success of the program. There are several areas that have had a high density of hotspots in the past that have not been directly impacted by BRG activities, especially in Siak. Considering the high potential of fire occurring in the future, it is highly recommended that BRG, together with other relevant stakeholders, expand the fire prevention work to include these areas while continuing to monitor the effectiveness of the existing infrastructure. In other cases, there are several fire-prone, degraded peatland areas in which rewetting infrastructures have not been built, and these areas are located far from settlements, making it difficult for local communities to build and maintain them. Cooperation with other stakeholders is needed to ensure that these less accessible areas are also equipped with rewetting infrastructure.

In regards to the revitalisation programs, the livelihood packages provided by BRG to local community groups are shown to benefit local communities by providing alternative income sources that increase their welfare, as illustrated in the two success stories presented above, although their success may also be dependant on other factors such as natural variability and internal capacity of the community groups to manage packages. These packages should be regarded as initial capital to build and develop small-scale businesses, which, with good financial management and proper business techniques, are expected to be profitable, independent and sustainable. This requires a shift in mindset of the recipients. Livelihood packages and other forms of assistance tend to be mistaken as continuous support, which creates a sense of dependence in the recipients and discourages reinvestment, possibly jeopardizing its sustainability. In this case, more livelihood packages will be expected from BRG, defeating the purpose of the program. Moreover, due to the limitations in the use of the national budget in funding the revitalisation program, only one livelihood package can be provided to the same community group for the same project, which is given as a one-off support. While proper business management practices are expected from the recipients of the support, this often requires more support from BRG beyond the provision of a livelihood package, particularly in the early stages of development of promising projects.

As revitalisation programs are perceived as an incentive for local communities to conserve and restore peatlands, incentives provided by high market demands and economic returns from agriculture made through peatland conversion and degradation present an opposing force. Such challenges should be taken into consideration, prioritizing direct and tangible benefits to local communities as the main driver for them to adopt sustainable peatland management practices. However, in order to generate direct economic benefits, there is a need to improve the technical knowledge, productivity, value chain and market of the products and commodities produced sustainably in peatlands [10]. The role of local facilitators tasked with providing technical assistance to community groups is crucial. However, in the case of Taruna Karya Bersama community group, the technical assistance provided was limited, particularly on cattle breeding, and in the case of Maju Jaya community group, the equipment provided to support organic fertilizer and feed production is inadequate for large-scale production. This demonstrates the need of expert assistance and adequate initial resources provided to the group.

After three years of BRG interventions in the study areas, the interventions, particularly the rewetting infrastructures and revitalisation programs, have demonstrated some success and brought positive impacts to local communities and peatland restoration. However, the gaps identified in this preliminary analysis have presented some opportunities for improvement and support needed for BRG. Considering that peat restoration, such as the increase in water table, may require adequate time to take effect after the establishment of rewetting infrastructures, peat restoration efforts and monitoring should be conducted beyond the five-year contract of BRG, which will end in 2020. Fortunately, President Joko Widodo has announced his decision to extend the contract and demanded BRG to continue its restoration efforts beyond 2020. In order to produce more positive impacts, the extension of BRG's work period should be accompanied by stronger political commitment from the national government, which could be demonstrated by issuance of relevant policies and ongoing impact monitoring. Such continuation should also consider local communities' responsibilities and capabilities, including maintaining rewetting infrastructures, monitoring their quality and impacts, identifying and reporting fire incidences and managing the use of the livelihood packages in a way that is sustainable and profitable in the long run so that they can be considered as a continuous incentive for peat restoration efforts. An analysis of BRG's efforts and their impacts in the initial five-year contract can become a good foundation for improving BRG's current approaches that should be implemented in the future.

Overall, this research provides a brief overview of BRG's interventions in Pulang Pisau and Siak, which indicate promising results. However, it is important to note that these interventions have only recently been introduced and the long-term impacts are still emerging, and this calls for more in-depth analyses over a longer period that cover the whole district. Further evaluation of the effectiveness should incorporate field studies, where fire-related geospatial data are ground-truthed and local communities and other stakeholders are interviewed. The in-depth analyses should also include control villages not included in BRG programs to evaluate the impacts of BRG rewetting infrastructures, revegetation and revitalization programs in villages included in the BRG programs.

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Appendix A. Summary of the Types of Livelihood Packages in Target Villages in Pulang Pisau

Year	Sub-district	Village	Type of Support
2016	Jabiren	Tanjung Taruna	Livestock - cow
2017	Jabiren	Garong	Beekeeping
			Zero-burning land clearing and management practices
		Pilang	Fishery - catfish
			Livestock - goat
		Simpur	Beekeeping
		Tumbang Nusa	Zero-burning land clearing and management practices (2 packages)
			Production - livestock feed
			Livestock - goat
			Farming - chicken; farming - organic vegetables
	Kahayan Hilir	Buntoi	Beekeeping (2 packages)
		Gohong	Farming - swiftlet
			Zero-burning land clearing and management practices
	Kahayan Tengah	Bukit Rawi	Fishery (2 packages)
			Beekeeping (2 packages)
	Sebangau Kuala	Mekar Jaya	Livestock - cow
			Zero-burning land clearing and management practices (2 packages)
		Sebangau Jaya	Beekeeping
2018	Jabiren Raya	Henda	Farming - watermelon
		Jabiren	Livestock - cow
		Sakakajang	Farming - chicken
		Simpur	Farming - Sengon
		Tumbang Nusa	Livestock - cow
	Kahayan Hilir	Buntoi	Fishery - silver catfish
		Gohong	Farming - Sengon
		Kalawa	Farming - Sengon (3 packages)
			Production - seedling
		Mentaren 2	Livestock - Balinese cow
		Mintin	Farming - Sengon
	Kahayan Kuala	Bahaur Hilir	Beekeeping
	Maliku	Kanamit Barat	Livestock - Balinese cow
			Livestock - cow
		Purwodadi	Livestock - cow
		Sidodadi	Production - organic fertilizer
		Wonoagung	Beekeeping
	Pandih Batu	Kantan Atas	Livestock - cow
		Kantan Dalam	Livestock - cow
		Kantan Muara	Livestock - Balinese cow
		Mulya Sari	Livestock - Balinese cow
		Pangkoh Sari	Livestock - cow
		Talio	Farming - Sengon (2 packages)
		Talio Hulu	Livestock - Balinese cow
	Sebangau Kuala	Mekar Jaya	Livestock - cow
		Paduran Mulya	Beekeeping
Total	**8 different sub-districts**	**29 different villages**	**53 livelihood packages**

Appendix B. Summary of the Types of Livelihood Packages in Target Villages in Siak

Year	Sub-district	Village	Type of Support
2017	Sungai Apit	Bunsur	Farming - pineapple
	Dayun	Dayun	Farming - watermelon
			Livestock - cow
	Koto Gasib	Sengkemang	SME development
	Mempura	Sungai mempura	Fishery - freshwater fish
		Teluk Merempan	Livestock - cow
2018	Bunga Raya	Tuah Indrapura	Livestock - cow
		Temusai	Livestock - goat
	Sungai Apit	Harapan	Livestock - cow
	Sabak Auh	Bandar Sungai	Livestock - cow
Total	**7 different sub-districts**	**9 different villages**	**10 livelihood packages**