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From Rice to Oil Palm: the Historical Evolution of Peatland Reclamation in the Berbak Delta, Indonesia

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ABSTRACT

The Berbak Delta in Jambi Province, Indonesia, underwent large-scale peatland reclamation in the 1970s as part of a transmigration program to develop rice fields. Initially, rice production averaged 3–4 tons/ha but declined to less than 1 Mg ha^{-1} due to the conversion of peat soils into acid sulfate soils. This decline was attributed to soil acidification from pyrite oxidation, which lowered soil pH. Currently, rice cultivation persists in areas near rivers influenced by tidal brackish water. In response to declining yields, a technological package for acid sulfate soil management was introduced, including canal water management, pH improvement, and fertilizer application. It increased rice yields to over 5 Mg ha^{-1} in a 100-ha pilot project in 2005. However, by 2008, farmers began shifting to oil palm plantations due to higher income potential. This study examines land-use change from rice fields to oil palm plantations and its impact on the livelihoods of communities in the Berbak Delta. Land cover change analysis from 2013 to 2023 revealed a decrease in rice fields from 58.30% to 25.79% and an increase in oil palm plantations from 15.37% to 55.70%. Oil palm cultivation has demonstrated sustainability on reclaimed acid sulfate soils, leading to economic prosperity through improved infrastructure and housing, as well as increased private vehicle ownership.

Keywords: Acid sulphate soil, Berbak delta, land-use change, oil palm plantation, rice fields, transmigration program

INTRODUCTION

Peatlands in Indonesia span approximately 13.43 million hectares and are distributed across Sumatra, Kalimantan, and Papua (BBSDLP, 2019). Peatlands are challenging for agriculture due to low fertility, poor drainage, and highly acidic pH. However, due to the scarcity of mineral soil land, agricultural expansion into peatlands is becoming more common (Miettinen et al., 2013; Lisnawati et al., 2015). The growing demand for crops and advancements in land conversion technologies further accelerate this trend. Recognizing the potential of peatlands, the Indonesian government initiated the Tidal Swamp Agriculture Development Project in the 1970s to enhance food production by reclaiming swamplands. This program successfully resettled around two million transmigrant families in Kalimantan and Sumatra (Suwanda & Noor, 2014). One of its focal points was the Berbak Delta in Jambi Province, where tidal waters from the Batanghari and Batangberbak rivers were used to convert swampy, peat-covered lowlands into productive rice fields (Hirayama et al., 2015). This reclamation effort marked a significant milestone in the use of peatlands for social and economic development.

For over a decade, the Berbak Delta served as Jambi Province's rice production center, bringing prosperity to local farmers. In the initial years, rice production reached 5 tons/ha, showcasing the potential of the reclaimed peatlands. However, over time, production sharply declined to less than 1 ton/ha due to the degradation of the peat layer (Suwardi et al., 2009a). The loss of the peat layer exposed acidic sulfate soils beneath, which are commonly associated with tropical peat swamps. These acidic sulfate soils formed due to pyrite oxidation during drainage and subsequent peat decomposition. Poor drainage systems and the absence of floodgate protection exacerbated this issue, leading to the rapid breakdown of organic matter and the oxidation of pyrite. This process resulted in high concentrations of toxic elements, including dissolved Al^{3+}, Fe^{3+}, and SO_4^{2-}, which significantly acidified the soil (Darmawan et al., 2009; Page et al., 2022). The extreme acidity and poor nutrient availability in acid sulfate soils made rice cultivation increasingly unviable. Toxic soil conditions hindered nutrient absorption by plant roots, causing root rot and stunted growth.

As a result, many rice fields were abandoned and became overgrown with shrubs, reflecting a broader trend of land-use change in the region. Farmers reported that soil acidity and poor crop performance were the primary reasons for abandoning rice cultivation (Sa'ad et al., 2010a). Efforts to increase rice production have been ongoing, including soil and water analysis and technology improvements, such as the application of red soil, lime, fertilizer, and water management. With these improvements, rice production can reach up to 5 Mg ha^{-1}. There are also opportunities to increase income by growing high-value crops suitable for acid soils, such as agarwood. Additionally, farming can be done with species that are peat-adaptive or peat-appropriate (Sari et al., 2021).

Since 2008, a shift in land use has emerged, with local farmers planting oil palm on abandoned rice fields and shrub lands. Oil palm, a highly adaptable crop, can thrive even in low-pH soils with acid sulfate characteristics (Kubitza et al., 2018). This adaptability has made oil palm cultivation a viable alternative in areas where rice production has failed. The transition from rice to oil palm plantations not only addresses the challenges of degraded peatlands but also offers a more profitable and sustainable agricultural system.

The success of oil palm cultivation in these challenging soil conditions highlights its economic and agronomic potential. Initially intended for rice cultivation, the reclaimed peatlands experienced significant soil degradation, leading to widespread abandonment. Over time, these lands were successfully converted into oil palm plantations, with positive socio-economic impacts. Studies have shown that the expansion of oil palm plantations has contributed to improved living standards, increased incomes, and enhanced community welfare (Nasution, 2020).

Therefore, the objective of this research is to determine land-use change in the Berbak Delta — from rice fields to oil palm plantations — and to assess the impact of this change on the community's livelihoods.

MATERIALS AND METHODS

Location of the Study

The research was conducted in the Berbak Delta, Berbak Sub-District, East Tanjung Jabung

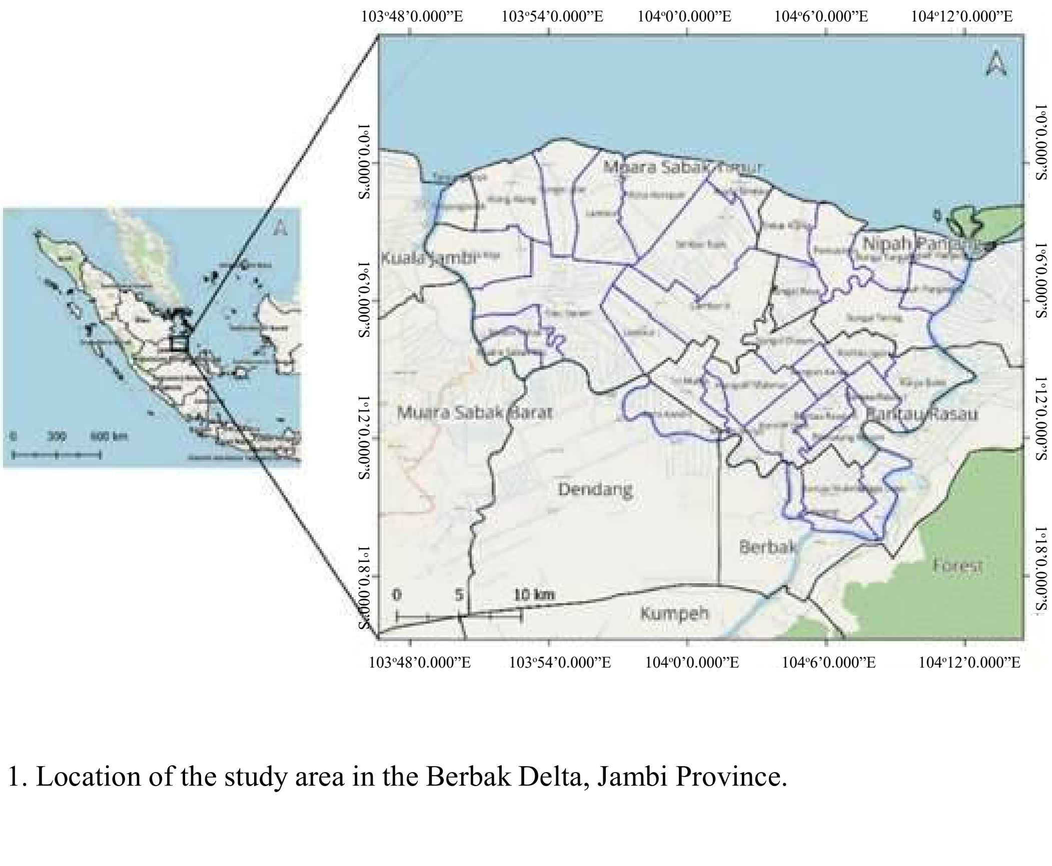


Figure 1. Location of the study area in the Berbak Delta, Jambi Province.

District, Jambi Province, Sumatra Island, Indonesia. Based on its geographical location, the Berbak Delta is bounded by the Strait of Malacca in the north, the Batangberbak River in the south and west, and, in the east, is bordered by the Batanghari River (Figure 1).

Soil Sampling and Soil Analysis

The soil sampling process was conducted to evaluate the current condition of soils in the study area (Figure 2), focusing on the impacts of reclamation processes and pre-expansion land-use dynamics. Data collection was carried out along four transects, A-A1, B-B1, C-C1, and D-D1 (Figure 3), representing the major land-use types in the region before the large-scale expansion of oil palm plantations. Soil sampling used a 1-meter gauge-type soil auger, which often extended to deeper layers as needed. Instead of using a rigid grid pattern, the sampling followed a “free-style” method, allowing researchers to focus on transitions between different land-use types and specific areas of interest.

Soil profiles were characterized based on their sediment types, including mangrove sediments (mgr..), oxidized mangrove sediments (mgr-ox), riverine sediments (riv), peat (pt), peaty clay (ptc), and tidal flat sediments (tdf). These were identified through detailed field observations, which included assessments of texture, color, organic matter content, plant remains, and the degree of natural ripening.

Chemical analysis of the soils began with the collection of labeled samples from various depths and horizons, which were then dried, ground, and sieved to obtain fine particles for laboratory testing. Soil pH was measured using a 1:2.5 soil-to-distilled water ratio with a pH meter, while electrical conductivity (EC) was determined using the same solution with an EC meter.

Calculation of Land-use and Land-use Change

This study employed a supervised classification method to map land cover changes. High-resolution satellite imagery from Landsat 8 and 9, obtained from the United States Geological Survey (USGS) for 2013, 2018, and 2023, was used. The imagery received standard radiometric and geometric corrections, eliminating the need for additional adjustments. The images were then subset to focus

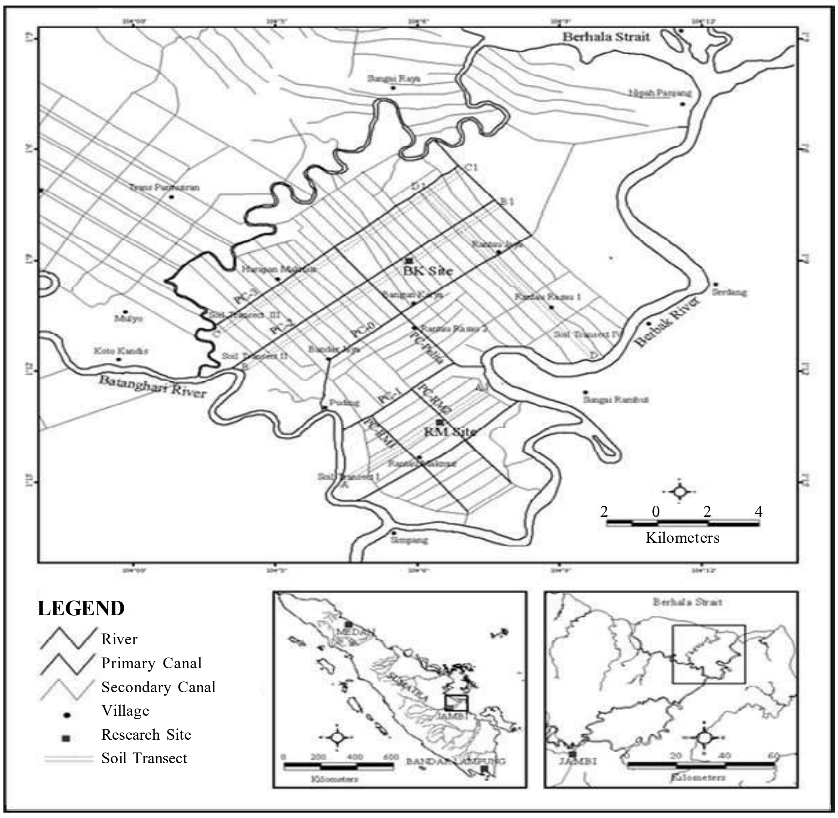


Figure 2. Map showing the soil sampling locations in the Rantau Rasau Transmigration Area, Berbak Delta, Jambi. The transects A-A1, B-B1, C-C1, and D-D1 indicate the locations of soil cross-sections presented in Figure 3.

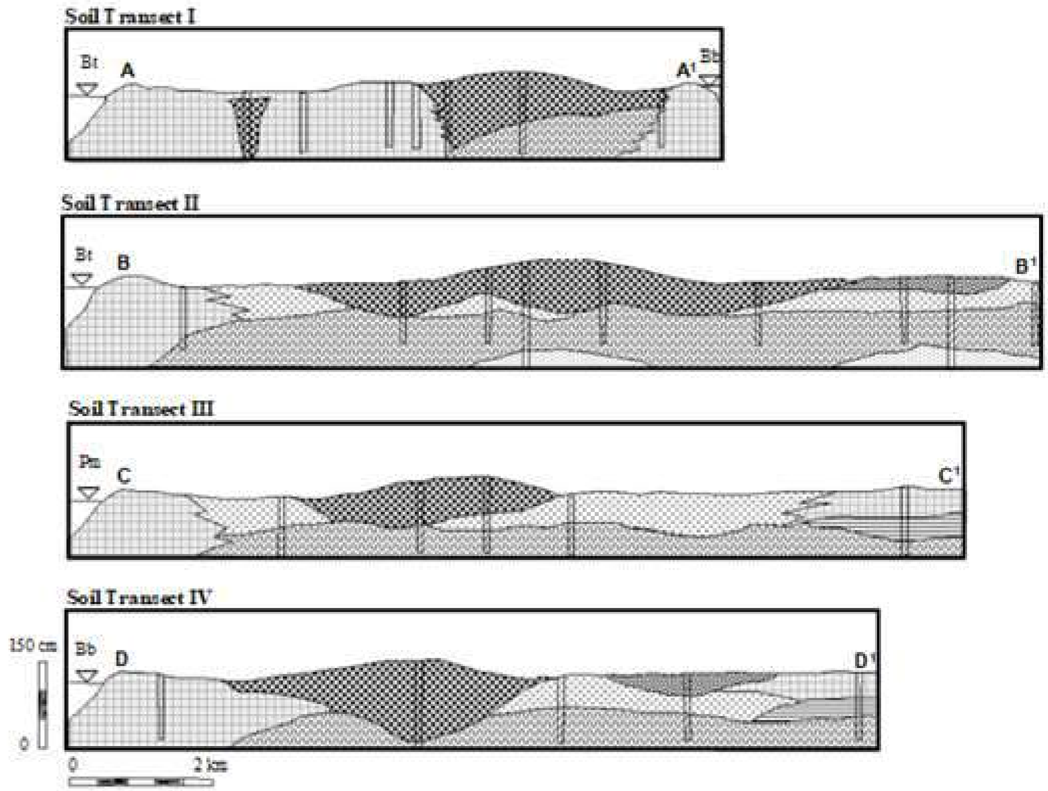


Figure 3. Topographic sequences of soils along the four transects (I, II, III, and IV). : Riverine sedimen, : peat, : peaty clay, : mangrove sediments-ox, : mangrove sediments, : tidal flat sediments, : sand ridges, : soil observation, Bt: Batanghari river, Bb: Berbak river, Pm: Pamusiran river.

specifically on the Berbak Delta, using boundary coordinates to clip the study area. Representative training sites for each land cover class were selected based on visual interpretation of the imagery and prior knowledge of the region. These sites included identifiable areas for the following classes: forest, oil palm, paddy fields, shrub, settlement, and water.

The Maximum Likelihood Classification (MLC) algorithm was used for classifying land cover types. MLC was chosen for its effectiveness in managing statistical variability and its capability to assign probabilities to each class. This method assumes a normal statistical distribution for each class and uses the mean and covariance to calculate the probability that a given pixel belongs to a specific class (Shivakumar & Rajashekararadhya, 2018). Land cover classes were defined based on spectral signatures and textural features observed in the imagery: Forest characterized by dense tree cover and high NDVI values, oil palm identified by distinct spectral signatures in plantations, rice fields noted for often being inundated agricultural areas with seasonal variation), shrubs marked by low vegetation cover and lower NDVI values, urban defined by high reflectance in built-up areas, and water identified by low reflectance in NIR and SWIR bands (Furusawa et al., 2023).

Post-classification processing involved applying a majority filter to reduce noise and enhance the classification map, ensuring a more coherent spatial pattern. For temporal analysis, change detection techniques were used to identify and quantify land cover changes over the study period by comparing classification maps from different years to detect and analyze variations in land cover types.

Collecting Data on Farmer Welfare

Data on farmer welfare were collected through direct interviews with farmers, which allowed researchers to obtain in-depth, specific information on their economic, social, and welfare conditions. These interviews were conducted using a structured or semi-structured questionnaire guide to ensure the data obtained were consistent and comparable. In addition, secondary data from previous studies are also used to strengthen the analysis, including statistical data from government agencies, academic research reports, and other related publications. This combination of methods enables a more comprehensive understanding of farmer welfare by utilizing direct empirical data and existing historical records.

RESULTS AND DISCUSSION

The History of Peatland Becomes Rice Fields

Rice fields in the Berbak Delta, Jambi region, Sumatra, Indonesia, have been created through systematic reclamation and degradation. This transformation was part of the government's efforts to achieve food self-sufficiency. Between 1969 and 1972, swamp areas were opened under the Tidal Swamp Agriculture Development Project, targeting 5.25 million hectares for agricultural use, supported by the transmigration program (Subagio et al., 2015). This project aimed to increase rice production by converting tidal swamps into productive rice fields, particularly in the fertile Berbak Delta. The influx of transmigrants led to widespread changes in land use, resulting in a transition from forest to rice fields (Sa'ad, 2012). The success of transmigrants and local farmers in managing tidal swamp land highlighted the potential of peat swamp ecosystems for agricultural use (Suwardi et al., 2005).

The reclamation and development of swamp areas are closely aligned with government policies that prioritize the use of the abundant resources and human capital in these areas. These lands were converted into rice fields and planted with high-yield rice varieties designed to maximize productivity. Consequently, the Berbak Delta emerged as Jambi's primary rice production center until 2004 (Daulay et al., 2018). However, successful swamp reclamation depended heavily on effective water management systems, including the construction of canals, levees, floodgates, and dams, to maintain the necessary water conditions for rice cultivation. Infrastructure projects, such as water canals and floodgates, were integral to reclamation efforts in the Berbak Delta during the 1970s–1980s (Hirayama et al., 2014).

Over time, the water canals suffered significant damage, often due to residents stealing components such as iron and wood. These damages disrupted water management systems, leading to drought conditions, reduced productivity, and crop failures. Changes in soil properties accompanied the decline in land productivity, exacerbating challenges for farmers. Research conducted in 2004/2005 (unpublished) covering nearly 10,000 hectares revealed that shrubs occupied the most significant area (3,658 hectares, or 38.6% of the total land-use change). The expansion of shrubland continued as rice fields declined, mainly due to climate change, environmental degradation, and farmers' inability to sustain rice cultivation. The deterioration of rice fields was closely linked to root rot and poor plant growth caused by highly acidic soils. As observed, many local farmers abandoned their fields, leaving them to be overtaken by shrubs (Sa'ad et al., 2010).

The failure of water infrastructure projects further exacerbated the issue. Overly deep waterways exposed the pyrite layer, which oxidized and increased soil acidity (Daulay et al., 2018). Continuous drainage also caused peat subsidence, raising the risk of flooding and adversely impacting plant growth. Subsidence exposed the underlying pyrite layer, leading to its oxidation and the formation of H, SO,, , which transformed the soil into highly acidic sulfate soil. (Agus & Subiksa, 2008) highlighted that these acid sulfate soils are characterized by low fertility, high acidity, and toxic concentrations of dissolved aluminum and iron. Consequently, many rice fields became unsuitable for cultivation (Sa'ad et al., 2010).

In response to the challenges of degraded peatlands, the government initiated efforts in 2007 to rehabilitate these lands and develop guidelines for their use in oil palm cultivation. Oil palm, known for its tolerance to acidic soils, emerged as a viable alternative to rice cultivation on acid sulfate soils when combined with appropriate management practices (Shamshuddin et al., 2014). The shift from rice fields to oil palm plantations began as a strategy to cultivate crops with higher economic value. Oil palm, a highly profitable crop, has gained prominence for its economic benefits, particularly in the short term (Uda et al., 2020).

By 2015, smallholder oil palm plantations had expanded significantly, yielding higher yields than large-scale commercial plantations. This success underscored oil palm's adaptability to challenging soil conditions and its role in improving local farmers' livelihoods. Smallholder plantations have become a cornerstone of rural economic development in the Berbak Delta, driving increased income and sustainable land use (Giesen & Sari, 2018).

Characteristic of Soil

Soil characteristics across the transects align with field observations of sediment types, including mangrove sediments, oxidized mangrove sediments, riverine sediments, peat, peaty clay, and tidal flat sediments (Table 1). These sediments were analyzed

Table 1. Stratigraphic Variation of Sediment and Soil Acidity Across Multiple Land Use Transects.

Transects/Soil Obsv. Number	Land Use	Soil Layers and Depth	Type of Sediments	Moist		Air Dried		
				pH H_2O	EC ($\mu S\ cm^{-1}$)	pH H_2O	pH H_2O	EC ($\mu Sc\ m^{-1}$)
				1 : 2.5	1 : 2.5	1 : 2.5	1 : 2.5	1 : 2.5
Transect I								
Sc5-s2	Tide-irrigated rice fields	I (0-30 cm)	Riverine sed.	4.45	143	4.40	3.40	188
		II (30-58 cm)	Riverine sed.	4.88	44	4.83	3.90	67
		III (58-80 cm)	Riverine sed.	4.82	91	4.51	3.25	93
		IV (80-100 cm)	Riverine sed.	4.50	100	4.44	3.01	148
Sc5-s5	Scrub	I (0-26 cm)	Peat	3.93	152	3.82	2.46	268
		II (26-65 cm)	Peat	3.79	228	3.67	2.27	301
		III (65-125 cm)	Peat-pyritic	4.10	1148	3.30	1.77	1390
		IV (125-200 cm)	Peat-pyritic	5.74	1300	2.89	1.65	2340
Transect II								
Sc5-s7	Tide-irrigated rice fields	I (0-40 cm)	Riverine sed.	4.70	38	4.64	3.46	65
		II (40-60 cm)	Riverine sed.	4.94	54	4.79	3.45	51
		III (60-80 cm)	Riverine sed.	4.31	120	4.32	3.07	146
		IV (80-100 cm)	Mangrove sed.	5.30	1078	3.17	1.97	1691
Sc13-s9	Scrub	I (0-12 cm)	Peat	3.52	236	3.46	2.79	256
		II (12-18 cm)	Peat	3.47	292	3.41	1.78	276
		III (18-27 cm)	Mangrove sed.-ox	4.51	244	3.49	2.34	297
		IV (27-45 cm)	Mangrove sed.-ox	4.54	278	3.51	2.63	328
		V (45-100 cm)	Mangrove sed.	5.50	1182	3.42	1.95	1388
Sc16-s10	Rubber garden	I (0-30 cm)	Peat	3.56	264	3.43	2.10	278
		II (30-44 cm)	Peat	3.58	77	3.50	1.95	239
		III (44-83 cm)	Mangrove sed.	4.15	918	2.85	1.89	1913
		IV (83-100 cm)	Mangrove sed.	4.91	2010	2.88	2.18	2270
Sc20-s11	Rain-fed rice field	I (0-40 cm)	Peat	4.03	177	3.91	2.15	263
		II (40-60 cm)	Mangrove sed.-ox	3.65	720	3.53	2.19	1220
		III (60-100 cm)	Mangrove sed.	4.17	1366	3.16	1.87	1838
Sc24-s12	Rain-fed rice field with coconut	I (0-26 cm)	Peaty clay	3.77	215	3.65	3.38	266
		II (26-60 cm)	Mangrove sed.-ox	3.72	528	3.7	2.68	259
		III (60-84 cm)	Mangrove sed.	4.02	1140	3.26	2.20	830
		IV (84-100 cm)	Mangrove sed.	5.54	3500	2.46	1.53	6140

based on pH, electrical conductivity (EC), and other properties (Figure 3).

Transect I is dominated by riverine sediments in tide-irrigated rice fields, with moderate pH (4.45–4.88) and low EC (38–143 µS/cm), indicating suitable conditions for rice cultivation. However, in scrub areas, peat and peat-pyritic layers are prevalent, with extremely low pH (3.79–4.10) and high EC (up to 1300 µS/cm), suggesting pyritic oxidation and potential acid sulfate conditions. These findings align with the discussion on how farmers abandoned rice fields due to declining productivity caused by acidic soils.

Continued from table 1.

Transects/Soil Obsv. Number	Land Use	Soil Layers and Depth	Type of Sediments	Moist pH H_2O	Moist EC (µS cm^{-1})	Air Dried pH H_2O	Air Dried pH H_2O	Air Dried EC (µSc m^{-1})
				1 : 2.5	1 : 2.5	1 : 2.5	1 : 2.5	1 : 2.5
Transect III								
Sc9-s14	Scrub	I (0-20 cm)	Mangrove sed.-ox	3.60	197	3.16	1.61	350
		II (20-49 cm)	Mangrove sed.-ox	3.41	265	3.14	1.68	624
		III (49-74 cm)	Mangrove sed.	4.17	645	2.93	1.14	1420
		IV (74-100 cm)	Mangrove sed.	5.52	4980	3.08	1.67	4990
Sc14-s15	Rubber garden	I (0-40 cm)	Peat	3.76	266	3.45	2.79	258
		II (40-67 cm)	Peat	3.77	293	3.40	2.78	296
		III (67-85 cm)	Mangrove sed.	4.83	1880	3.26	2.20	1830
		IV (85-100 cm)	Mangrove sed.	5.40	6010	3.46	1.53	6240
Sc16-s16	Rain-fed rice field	I (0-30 cm)	Mangrove sed.-ox	3.51	295	3.32	1.81	678
		II (30-68 cm)	Mangrove sed.-ox	3.60	256	3.37	1.90	490
		III (68-98 cm)	Mangrove sed.	4.41	668	3.30	2.00	1075
		IV (98->100 cm)	Mangrove sed.	4.42	1427	3.08	2.14	1180
Sc26-s18	Coconut garden	I (0-20 cm)	Riverine sed.	4.78	145	4.52	3.95	213
		II (20-40 cm)	Riverine sed.	4.77	32	4.58	3.66	61
		III (40-81 cm)	Tidal flat sed.	4.74	83	4.65	3.40	119
		IV (81-100 cm)	Tidal flat sed.	4.80	1496	3.50	3.17	1464
Transect IV								
Sc25-s19	Tide-irrigated rice fields	I (0-18 cm)	Riverine sed.	5.17	51	4.83	3.63	141
		II (18-30 cm)	Riverine sed.	4.88	80	4.70	3.70	172
		III (30-55 cm)	Riverine sed.	5.16	48	4.84	3.64	120
		IV (55-100 cm)	Riverine sed.	5.33	224	4.43	3.63	275
Sc25-s20	Scrub	I (0-55 cm)	Peat	3.13	1112	3.00	2.02	1376
		II (55-100 cm)	Peat-Pyritic	3.12	6010	1.73	1.13	8190
		III (100-140 cm)	Peat-Pyritic	3.23	5180	1.98	1.22	6980
		IV (140-165 cm)	Peat-Pyritic	3.29	4710	1.96	1.24	7010
Sc25-s21	Rubber garden	I (0-20 cm)	Peaty-clay	3.45	314	3.35	1.99	351
		II (20-53 cm)	Mangrove sed.-ox	3.69	184	3.59	1.86	247
		III (53-80 cm)	Mangrove sed.-ox	3.65	276	3.52	1.64	438
		IV (80-112 cm)	Mangrove sed.	4.30	669	2.94	1.55	2020
		V (112-140 cm)	Mangrove sed.	5.39	5550	2.34	1.40	7080
		VI (140-165 cm)	Mangrove sed.	5.60	3880	2.69	1.45	4870
Sc25-s22	Rain-fed rice field with coconut	I (0-38 cm)	Peat	3.43	664	3.48	2.05	1008
		II (38-75 cm)	Peat	3.48	973	3.57	1.98	1427
		III (75-100 cm)	Mangrove sed.	4.60	4870	2.12	1.29	6300

Transect II shows similar patterns, with upper layers of riverine sediments (pH 4.31–4.94, low EC) transitioning to mangrove sediments at deeper levels (80–100 cm), where EC increases sharply to 1078 µS/cm and pH drops to 3.17. This reflects salt accumulation and challenges with acidity. Scrub areas feature peat and oxidized mangrove sediments, with pH as low as 3.52 and moderate EC, highlighting pyritic oxidation.

Transect III is characterized by oxidized mangrove sediments in the upper layers and mangrove sediments below, showing high EC values (up to 6010 µS/cm) and extremely low pH (as low as 1.53 after H_2O_2 treatment). These conditions, combined with sulfidic characteristics, render the soil unsuitable for rice cultivation but favorable for oil palm under proper management. This supports the discussion of land-use changes from rice fields to oil palm plantations, which are attributed to oil palm's adaptability to acidic soils. Transect IV has riverine sediments supporting tide-irrigated rice fields, with pH values of 4.83–5.33 and low EC (51–224 µS/cm). However, deeper peat-pyritic layers exhibit high EC (up to 6010 µS/cm) and low pH, indicative of acid sulfate conditions.

The characteristics of mangrove sediments, as described by Furukawa (1994), align well with the data from Transects II, III, and IV, where deeper layers exhibit strongly reductive, sulfidic conditions with high EC values and significant pH drops upon H_2O_2 treatment. Oxidized mangrove sediments from Transects II and III display paler colors and lower pH after oxidation, indicating natural ripening. Peat and peat-pyritic layers, which dominate Transects I, II, and III, show extremely low pH values and high EC, confirming the presence of pyrite and the associated challenges of managing acid sulfate soils. Riverine sediments, which are prominent in Transects I and IV, have moderate pH and low EC values, making them more suitable for agricultural use. Tidal flat sediments, observed in Transect IV, consist of alternating layers of clay, sand, and silt, with moderate pH and increasing EC values in deeper layers, indicative of salt accumulation.

Maintaining a high soil pH through water management and pruning is one of the most important keys to rice cultivation on sulfuric acid soils (Suwardi et al., 2009b). Furthermore, agricultural development in acidic soils should include the addition of soil amendments such as organic materials, humic substances, lime, fly ash, steel slag, and fertilizers. Regular application of lime and organic materials is vital for neutralizing soil acidity and enhancing soil fertility, which supports sustainable agricultural practices (Suwardi, 2019a).

Oil palm cultivation has shown strong adaptability to marginal lands, including acid sulfate, acidic, and peat soils. With high annual rainfall and effective site management, particularly in maintaining controlled soil water regimes, oil palm can thrive in these challenging conditions (Suwardi et al., 2020). This makes oil palm cultivation a more economically viable option than rice cultivation on many reclaimed lands in the Berbak Delta.

These findings highlight the importance of site-specific land management practices to support long-term agricultural productivity, particularly in challenging acid sulfate soils. Strategies such as lime application, incorporation of organic materials, and effective water management are essential to mitigate acidity and salinity while improving soil fertility in this region.

Land-Use Change

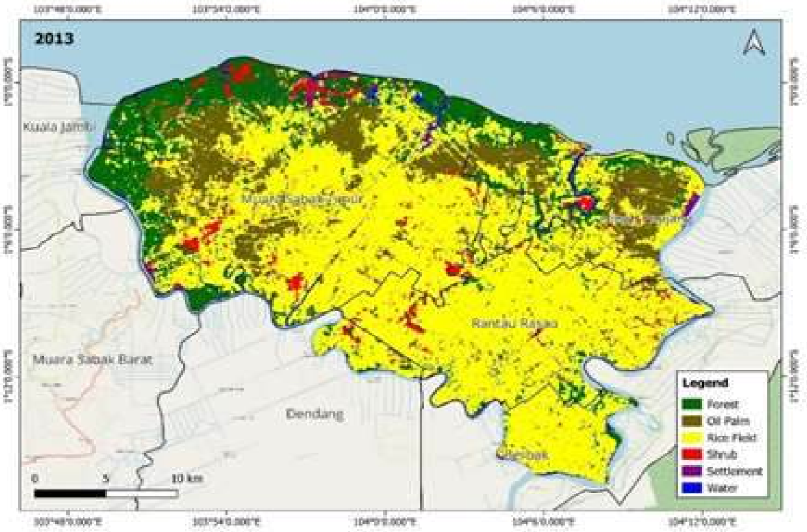
Based on the results presented in Table 2, the land use changes in the Berbak Delta, Jambi Province, from 2013 to 2023 show significant changes across various categories, as detailed in Figure 4. Forest cover decreased from 17.31% of the total area in 2013 to 4.98% in 2023, indicative of significant environmental shifts likely influenced by both natural processes and anthropogenic activities (Sa'ad et al., 2010). A study analyzed land-use change resulting from reclamation in tidal swamp areas of the Berbak Delta and its impact on the mangrove forest. In addition, human activities such as population expansion, resource extraction, forest clearance, dredging, filling, diking, water pollution, and urban development are specific factors contributing to the disappearance of swamp forests (Long et al., 2021).

On the other hand, the expansion of oil palm plantations increased dramatically from 15.77% in

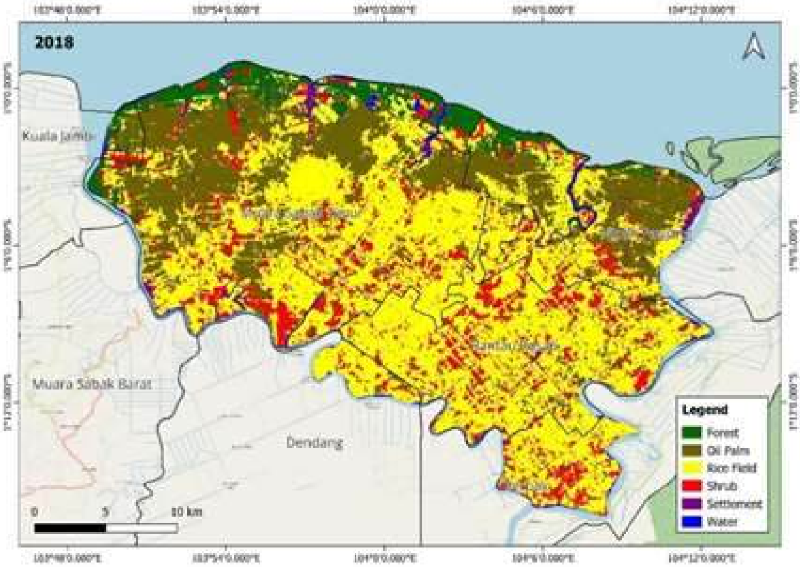
Table 2. Land use change in Berbak Delta, Jambi Province (2013, 2018, and 2023).

LULC	2013 (ha)	Precentage (%)	2018 (ha)	Precentage (%)	2023 (ha)	Precentage (%)
Forest	13,275.3	17.31	4,591.6	5.99	3,815.2	4.98
Oil palm	12,097,3	15.77	18,694.4	24.38	43,833.5	57.23
Rice field	45,878.7	59.82	36,607.9	47.75	20,300.2	26.49
Shrubs	4,008.8	5.23	14,606.4	19.04	4,924.8	6.43
Urban	1,230,8	1.60	1,991.1	2.60	3,617.7	4.72
Water	2,207,5	2.88	2,207.5	2.88	2,207.5	2.88
Total	76,698.9	100	76,698.9	100	76,698.9	100

Note: * LULC: Land Use/Land Cover



(A)



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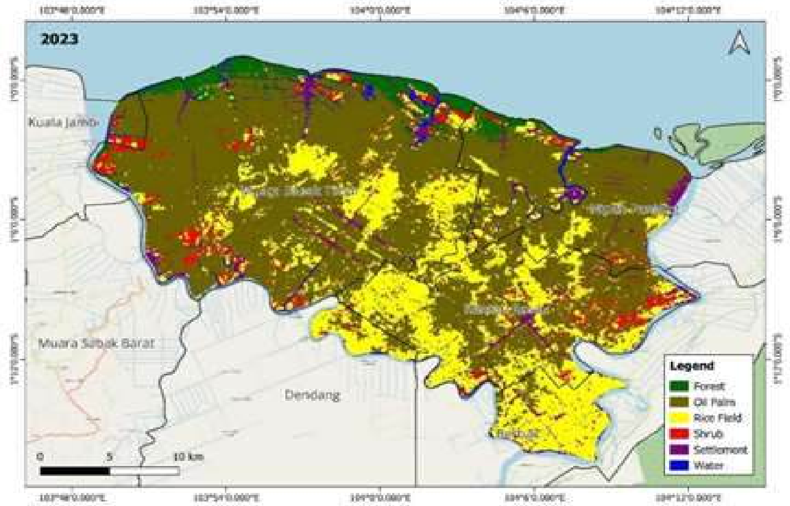

(C)

Figure 4. Map of Land Use Change in Berbak Delta, Jambi Province for (a) 2013, (b) 2018, and (c) 2023.

2013 to 57.23% in 2023. This expansion was driven by government policies supporting plantation farming and by demand for palm oil and rubber. In the Berbak Delta of Jambi, extensive peatlands were cleared and converted to agricultural land, particularly for oil palm cultivation, driven by the rapid growth of Indonesia's oil palm industry (Afriyanti et al., 2019).

Rice fields in the Berbak Delta, Jambi Province, decreased significantly from 59.82% in 2013 to 26.49% in 2023, potentially influenced by shifts in land use diversification and agricultural policies. Reclamation activities in tidal swamp areas led to changes in land-use types from forests and rice fields to coconut and mixed farming, which was driven by changes in land and hydrology, as well as government policy, as highlighted by previous research (Sa'ad et al., 2010). Another study suggested that the utilization and improvement of marginal soils for agriculture could be a solution to land degradation in the Berbak Delta (Suwardi, 2019). Urban areas saw an increase from 1.60% in 2013 to 4.72% in 2023. This growth may be attributed to the transmigration program, which facilitated the establishment of new villages in Jambi Province. These villages continued to grow and develop, particularly supported by economic success in palm oil cultivation (Yulmardi et al., 2018).

The remaining rice fields, however, are concentrated in tide-irrigated areas, which occupy the peripheral parts of the transmigration area and cover only 14.6% of the total land, as shown in Table 2. These fields benefit significantly from tidal irrigation. High tide water begins to inundate these rice fields in early November, with the water level remaining quite deep from mid-November to late January. A relatively prolonged dry spell usually occurs in February, followed by renewed inundation in March due to rainfall and tidal backflow. Despite differing hydrological conditions, nursery preparation, land preparation, and transplanting methods remain consistent with those used in rain-fed rice fields. Yields from tide-irrigated rice fields are generally higher than those from rain-fed fields. However, floods during the rainy season, driven by rising water levels on the Batanghari River, pose a recurrent threat.

These tide-irrigated rice fields are predominantly situated on riverine sediments that exhibit pale grey coloration, a lighter texture, light yellow-brown mottles, and a relatively coarse, blocky structure. Despite their favorable characteristics for agriculture, field identification has shown inconsistencies with laboratory pH measurements. Riverine sediments and peat, identified during field surveys, often exhibit a sharp pH drop after H_2O_2 treatment, with some moist samples also showing low pH values. This indicates that riverine sediments, while generally less acidic, are not entirely free of pyrite contamination in this environment.

Transect I clearly illustrates that tide-irrigated rice fields are located on riverine sediments, though some areas rest on mangrove sediments underneath. The presence of pyrite in the riverine sediments poses a risk of sulfuric acid release during extreme dry years, exacerbating soil acidity. The peripheral lower zone, predominantly utilized for tide-irrigated rice, is covered chiefly with riverine sediments, although some areas show pyrite contamination. In contrast, the higher central zone, which is largely scrubland —a type of land cover characterized by the dominance of woody shrubs and low-growing vegetation —is characterized by shallow peat layers overlying oxidized or oxidizing mangrove sediments. Some parts of this zone feature thick underground sand ridges, which enhance acid leaching and provide more favorable conditions for perennial crops such as rubber and coconut. Additionally, sub-zones within this higher area, characterized by relatively low depressions, are extensively used for rain-fed rice cultivation due to their higher water-inundation potential. Other sub-zones with lower acidity in mangrove sediments also provide viable sites for rain-fed rice cultivation.

The Sankey diagram (Figure 5) shows how land in the Berbak Delta changed from 2013 to 2018 and from 2018 to 2023. During the 2013-2018 period, there was a significant reduction in forest areas, which were largely converted to oil palm plantations and rice fields. Shrub areas also decreased, primarily being converted into oil palm and rice fields. Meanwhile, water areas remained relatively stable with no significant changes. From 2018 to 2023, the dynamics became more complex. Although some forest areas continued to be converted to other land uses, there were indications of reforestation or natural regrowth on previously cleared land, especially in oil palm and rice fields. Oil palm plantations experienced ongoing changes, with conversions both to and from other land uses, including reverting to forests and rice fields. Rice fields expanded in some areas as forests and oil palm plantations were converted to agricultural land. However, the total area of rice fields also decreased in other areas, as some were converted to oil palm plantations and urban land. Shrub areas continued to decline, mainly converting into rice fields and oil palm plantations. Lastly, there was a notable increase in urban areas, primarily from the conversion of rice fields and shrubs.

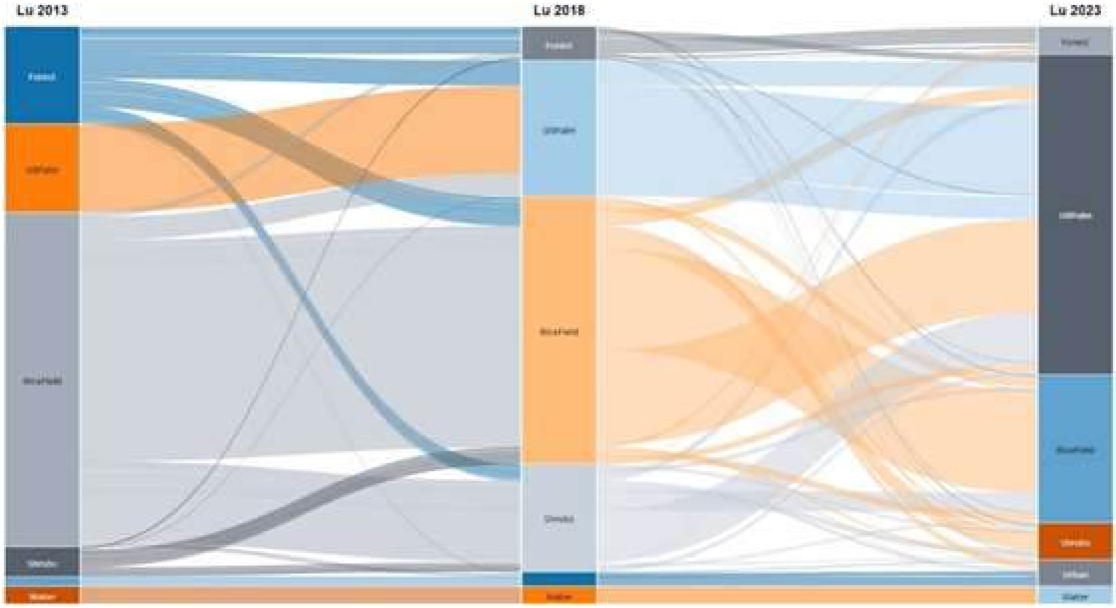

Figure 5. Sankey Diagram of land use change in Berbak Delta, Jambi Province in 2013, 2018, and 2023.

Overall, the diagram highlights significant pressure on forested areas due to agricultural expansion, particularly oil palm plantations, from 2013 to 2018 and from 2018 to 2023. This trend aligns with historical land use shifts in Indonesia. In the 1970s, the Transmigration program aimed to expand rice-growing areas to achieve food self-sufficiency. However, this effort failed when peatlands were converted to acid sulfate soils, leaving abandoned rice fields that later became overgrown with shrubs. This situation led to the idea of oil palm cultivation, which proved more economically viable. As a result, more land has been continuously converted into oil palm plantations due to their profitability.

Impact of Land Change on the Community's Livelihood in Berbak Delta

Oil palm significantly enhances livelihoods in rural communities by providing higher labor returns, shorter fallow periods, and lower labor requirements than other agricultural land uses (Rist et al., 2010). The oil palm economy dominates the household economy of middle and upper-class farmers. This has led to a high economic dependency on oil palm cultivation. Oil palm cultivation is an important source of direct and indirect income in rural Indonesia, as 41% of Indonesian palm oil is produced by smallholders. At the same time, large-scale corporate plantations provide employment (Hein, 2016). Based on land rent analysis in Rantau Rasau Sub-District by Daulay et al. (2016), rice farming generates a net income of Rp7,455,548 per hectare per year. In contrast, oil palm farming generates Rp14,617,828 per hectare per year, with a ratio of 1:2. This indicates a difference of Rp7,162,280 per hectare per year in favor of oil palm cultivation.

The expansion of oil palm has positively impacted the quality of human capital among farming households. Most farmers can now afford to send their children to high school and even college. Additionally, there has been an increase in purchasing power for electronic goods such as televisions, mobile phones, and refrigerators, as well as luxury items like jewelry and personal vehicles (Azzahra et al., 2017). The economic sustainability index of smallholder oil palm plantations is 54.11. It indicates that these plantations provide significant economic benefits by reducing poverty among farming communities (Saragih et al., 2020). In Jambi Province, the development of oil palm plantations has become the primary source of income and the main livelihood for many.

Compared to rice farming, the community prefers cultivating oil palm because it offers significantly higher profitability (BPS, 2022). Beyond the financial benefits, oil palm cultivation has improved the living standards of the Jambi community, boosted rural infrastructure development, and supported education and healthcare (BPS, 2024).

Based on land-use change findings supported by soil analysis, the shift from peatland to rice farming, then to shrub areas, and finally to oil palm cultivation demonstrates oil palm's adaptability to harsh soil conditions. Its successful growth in such environments highlights its ability to turn less productive land into economically viable plantations.

Farmers often struggle with suboptimal fertilizer use, which affects productivity. Supporting farmers with training and financial aid to ensure proper fertilizer application is crucial for boosting yields sustainably. Improving farmer knowledge and skills in this area is key to enhancing productivity and sustainability in oil palm farming. Livelihood training programs for farmers in Riau Province living near peatlands have been shown to significantly raise community awareness of the importance of trees and peatland conservation. These programs not only enhanced participants' knowledge and skills but also positively influenced their behavior, enabling them to quickly generate income while engaging in peatland planting and conservation activities (Rahmat et al., 2020).

Another challenge is the use of poor-quality seedlings in oil palm plantations. Government support is essential to promote high-quality seedlings and educate farmers through training programs. Despite these challenges, there is optimism about future income for oil palm farmers. By addressing fertilizer use and seedling quality issues through interventions, overall income is expected to rise. This positive outlook depends on ongoing support, effective farming practices, and continued cooperation between farmers and authorities to maximize long-term economic benefits. Overall, the transformation of land from rice cultivation to oil palm plantations has shown significant development in housing and regional growth. However, further socio-economic research is necessary to understand better the welfare of farmers engaged in oil palm cultivation.

CONCLUSIONS

The peatlands in the Berbak Delta, Jambi Province, initially converted to rice fields during the 1970s and 1980s under the Tidal Swamp Agriculture Development Project, have experienced significant land-use changes over the decades. Initially, the reclamation of peatlands for rice cultivation was successful, yielding high rice production. However, unsustainable practices, such as land-clearing by burning, led to the degradation of peatlands. Over time, this degradation caused a decline in rice productivity, prompting many farmers to abandon rice cultivation. These abandoned lands eventually became overgrown with shrubs. By the 2010s, farmers began transitioning from rice cultivation to oil palm plantations. From 2013 to 2023, the area dedicated to rice fields decreased from 59.82% to 26.49%, while oil palm plantations expanded significantly, increasing from 15.77% to 57.23%. This shifMg has brought notable economic benefits, boosting community incomes, improving infrastructure, and enhancing overall quality of life. The conversion to oil palm cultivation has provided local communities with a more sustainable and economically viable livelihood, driving regional development and advancing education and healthcare.

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