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Aquaculture Development Monitoring on Mangrove Forest in Mahakam Delta, East Kalimantan

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Abstract. Aquaculture development is thriving to provide fish product demand. One-fifth of mangrove forest destruction in the coastal region is from aquaculture, where ninety percent occurred in South East Asia. The mangrove forest conversion for aquaculture development is also mirroring in Mahakam Delta which started in the early 1980s. In this paper, we examined the impact of aquaculture development in Mahakam Delta on the mangrove forest ecosystems using remote sensing. Thirty years of monitoring data were used using six Landsat images series (Landsat 5 and 8). The result found a massive development of aquaculture in the Mahakam Delta occurred in the late 1990s, in which 41% of mangrove forests converted into ponds. The unstable political situation in Indonesia and the decrease of rupiah exchange rate against the US dollar are the leading factors. Since the mid-2010s, aquaculture productivity has been declining and that many farmers decided to abandon their ponds. The condition made mangrove cover increase up to 4,000 hectares due to natural regeneration. Nevertheless, aquaculture ponds cover 54.8% of Mahakam Delta in 2020. To minimize the impact on the ecosystem, it needs to manage aquaculture sustainably with mangrove conservation.

1. Introduction

The total area of mangrove forest in Indonesia is estimated to be around ± 3 million hectares and declining [1]. Nearly one million hectares of mangrove forests in Indonesia have been deforested since 1800, which 80% is used for aquaculture development [2]. The development will be ongoing, which may potentially cause an additional 700,000 hectare of mangrove loss. The early development of aquaculture resulted in the cultural and economic improvement of the people. However, in the last half-century, negative environmental and social impact has emerged [3]. The product of mangrove forest conversion and aquaculture activities have high carbon emission that are comparable in degraded peatland emission [4]. At the same time, the aquaculture production depleted due to pollution and erosion, affects the social-economic of coastal communities [5].

Mangrove forest conversion into aquaculture also occurred in Mahakam Delta, Eastern part of Kalimantan. The aquaculture was developed for traditional shrimp and fish ponds. Since the early 1990s, it was estimated that 5% of mangrove forest had been converted into ponds [6]. The development of aquaculture also changes mangrove zonation's evolution due to the modification of biophysical factors that determine the mangrove growth [7]. Besides that, mangrove loss to shrimp ponds led to carbon loss from the mangrove forest itself and depleted soil carbon stock [8]. The annual amount of carbon loss



over 16-years of mangrove conversion in Mahakam Delta is $120 \text{ Mg CO}_2\text{e ha}^{-1} \text{ yr}^{-1}$, which similar to the amount of carbon emission from peatland [9]. In total, the potential of carbon emission from the aquaculture development and activities in Mahakam Delta is $1,920 \text{ Mg CO}_2\text{e ha}^{-1}$, higher than potential emission in mangrove conversion in Brazil which $1,390 \text{ Mg CO}_2\text{e ha}^{-1}$ [10]. The uncontrollable mangrove forest conversion is mainly due to the complexity of coastal ecosystems management with rapid human activities and non-conducive policy environment [11]. Therefore, the development of sustainable management is needed in the utilization of mangrove forests [12].

This research aims to monitor aquaculture development in the Mahakam Delta and its impact on the mangrove forest ecosystem using remote sensing technique. The impact definition in this research is changing in the mangrove forest ecosystem in Mahakam Delta due to anthropogenic activities on aquaculture development. Monitoring mangrove forests can be done using remote sensing techniques which show promising results at any scale—the first monitoring of mangrove forests was conducted in the late 1980s using SPOT XS images [13]. After that, several pieces of research were done by utilizing broad data of remote sensing, such as Landsat and MODIS [14–16]. But none of them shows the result in recent years of explaining about aquaculture development in the Mahakam Delta.

This research tries to fill that gap and support government policy to focus on sustainability issues in intensive ponds. It is necessary because aquaculture has become the primary livelihood for eighty percent of the Mahakam Delta [17]. This research also continues our research in order to explain aquaculture development in recent years with up-to-date data and the impact on the changes in the mangrove ecology in the Mahakam Delta [18]. Therefore, monitoring the changes is important for improvement policy and activities that support the environment and socio-economic sustainability.

2. Material and Method

The research was conducted at the Mahakam Delta (fig. 1). Mahakam Delta is on the east coast of East Kalimantan Province, located between coordinates $0^\circ 19' 39''$ to $0^\circ 53' 42''$ S and $117^\circ 17' 13''$ to $117^\circ 37' 47''$ E. The Mahakam Delta is a fan-shaped lobate formed at the Mahakam River's estuary, directly adjacent to the Makassar Straits. The Mahakam Delta formed mainly due to the high discharge on the Mahakam River and high erosion in the upper Mahakam watershed. The Mahakam Delta has an area of approximately $1,500 \text{ km}^2$, which previously is fully covered with mangrove forests [19].

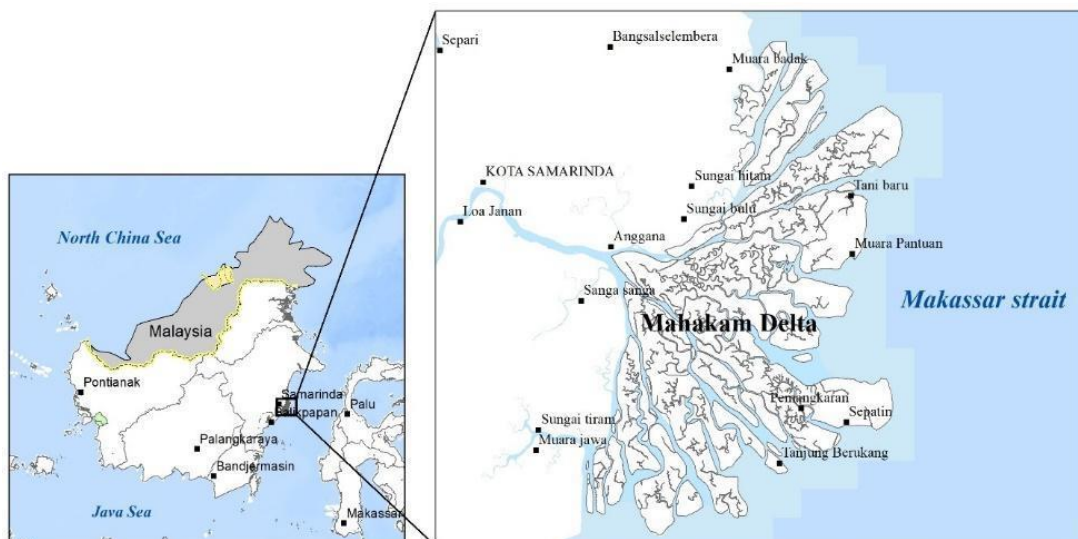


Figure 1. The location of Mahakam Delta, located at the east coast of Borneo island.
(Source: data analysis, 2020)

The typical climate condition of Mahakam Delta is tropical, with an average of annual temperatures ranging from 23-32 degrees Celsius. Rain occurs throughout the year with average rainfall on July-September is 25-40 cm/month and, on average, on October-June is 67-70 cm/month. This high rainfall causes the Mahakam River's discharge to be quite large, namely 1000 - 1,500 m³/second. This massive discharge carries sediment, which is estimated to reach 8 million m³/yr. This ecosystem is characterized by a high supply of freshwater carried by rivers, high sedimentation, and is not susceptible to environmental changes. Changes in salinity, inundation (tides), the composition of the land substrate will affect the types of flora and fauna that inhabit, including the vegetation zone.

This research used a multitemporal Landsat satellite to analyze mangrove forest change at Mahakam Delta. The images of the path/row used are the path/row 116/60 and 116/61. There were two types of cloud-free Landsat satellite images used in this study; the details were presented in table 1. The data did not represent the arithmetic order of the year or the same month. This was because of the limited cloud-free imagery. The Landsat satellite data used were downloaded on the USGS's official website (United States Geological Survey). The spatial resolution for both Landsat 5 and Landsat 8 images used was 30 meters. All remote sensing data had been geometrically corrected for level 1T with the Universal Transverse Mercator (UTM) projection for the 50 M zone with the WGS 1984 datum.

Table 1. Remote sensing data in this research.

Satellite	Acquired date	Year	Note for selection of observation year*
Landsat 5 TM	17 January	1989	Benchmark year for the analysis for pristine mangrove forest in the Mahakam Delta.
	3 August	1997	The occurrence of an economic crisis in Indonesia and a point of reference for increasing ponds' development.
	31 March	2004	The era of the culmination of development and increased pond production [16].
	17 June	2009	Twenty years after the benchmark year
Landsat 8 OLI	1 May	2015	The current condition of the mangrove and aquaculture in the delta
	12 April 17 July	2020	The current condition of the mangrove and aquaculture in the delta

*Beside the consideration of cloud cover factor.

The ecosystem mapping using visual interpretation was aided by maximum likelihood classification method. We classified the Mahakam Delta with mangrove formation and focus on aquaculture development. Thus, the classes used in this research were (1) *Avicennia* and *Rhizophora* formation, (2) *Nypa* formation, (3) transition formation, (4) freshwater forest, (5) pond, and (6) abandoned pond. After classification and conducting ground check to assess map accuracy, we found that our classification has the accuracy of over 95%.

3. Results and Discussion

3.1. Result

The development of aquaculture in the Mahakam Delta was strongly influenced by settlement history. In the early 1970, oil exploration was carried out by the company Total E&P Indonesia which opened up land speculation and attracted residents in the Mahakam Delta [17]. In the end, residents use mangroves in the delta to convert them into ponds. In early development, creating ponds for shrimp and fish farming used a traditional method by digging manually. The use of the traditional method was why only a small number of aquacultures in the late 1980s presented.

The first observation in 1989 found only 2% of Mahakam Delta utilized aquaculture (table 2 & fig. 2). The rest of the Mahakam Delta ecosystem was a pristine mangrove forest. *Sonneratia* spp. and *Avicennia* spp. became the dominant species in sea-facing areas because of their adaptation to high salinity. In addition to that, *Rhizophora* spp. grows on small islands formed by delta accretion. The central delta is dominated by *Nypa fruticans* species (*Nypa formation*) or a mixture of many species (*Avicennia* spp., *Sonneratia* spp., *Rhizophora* spp., *Bruguiera* spp., *Xylocarpus* spp. and *Nypa fruticans*). In initial condition, species *Nypa fruticans* cover around 70% of Mahakam Delta's mangrove. In the transition zone, the mangrove species included *Oncosperma* spp., *Heritiera* spp., and *Excoecaria* spp.

Table 2. The change of mangrove forest in Mahakam Delta from observation

No.	Land-use	Year of observation					
		1989	1997	2004	2009	2015	2020
1.	<i>Avicennia</i> and <i>Rhizophora</i> formation	20.296,94	14.921,23	6.022,98	5.960,57	8.082,84	7,881.48
2.	<i>Nypa</i> formation	77.368,09	66.492,03	27.713,51	28.859,13	33.276,21	31,451.03
3.	Transition formation	8.603,33	9.791,00	9.776,23	9.776,51	8.462,52	8.462,52
4.	Freshwater forest	1.516,14	1.516,14	1.516,14	1.516,14	1.516,14	1.516,14
5.	pond	1.848,44	13.988,37	58.848,47	61.575,74	53.861,57	55,888.07
6.	Abandoned pond	323,44	3.225,83	5.680,97	1.745,57	4.136,58	3,828.95
Total		109.956,38	109.934,60	109.558,30	109.433,67	109.335,85	109,028.19

The potential benefits of pond development activities for shrimp farming are to open-up efforts to expand the area for converting mangrove forests. In 1997, the economic crisis and the unstable political situation in Indonesia stimulated mangrove forest conversion. Nearly a decade later, 15.7% of the delta area was converted into ponds using a mechanical method. The increased demand for aquaculture products and the use of an excavator for creating ponds accelerated mangrove forest conversion. The observation year in 2004 found that 58.9% of the Mahakam Delta area was converted into ponds. On the other hand, Zwieten et al. (2006) found only 41.8% of Mahakam Delta was converted into ponds in 2004 [20]. Different results showed by Rahman et al. (2013), where he found that 75% of mangrove forest in Mahakam Delta already deforested [14]. The difference in result is because of the use of different remote sensing data and scale, especially MODIS images that have very low resolution.

There are two main reasons that caused the fast rate of mangrove forest conversion in the Mahakam Delta. First, the demand for aquaculture products increased, especially for the export market. The economic crisis in the late 1990s made Indonesian rupiah rate weaken against the US dollar. Exported aquaculture products were paid with USD; when they converted to Indonesia rupiah, then they gave a huge amount of profit. This condition attracted the investor to open a new pond in the Mahakam Delta. Opening new ponds resulted in more migrants moving from Sulawesi to Mahakam Delta [21]. Second, government transition after the collapse of the New Order created a lack of control in the Mahakam Delta. The permit to open a new pond was easy without environmental consideration. There was no government institutions who guarded the mangrove forest or guided the aquaculture development in Mahakam Delta [11]. Those two reasons made the pond development at a frenzied rate.

Shrimp and fish farming in brackish water needed certain salinity for optimal growth and productivity [22]. Hence, opening new ponds would not give optimal result for productivity. Beside the conservation effort to restore mangrove forest in the delta was raised. Even farmers, NGO, and the government were pessimists about the future of the delta because of environmental degradation [20]. The degradation from mangrove loss, also affected the degradation in shrimp and fish productivity. In the first year after opening ponds, the shrimp productivity was between 100 – 300 kg ha⁻¹ yr⁻¹ [17]. The productivity was declining gradually due to pyrite poisoning. Oxidation of pyrite in ponds has leached the pyrite acid into the system, which then reduces the yield of aquaculture [23]. After 3–5 year of pond

operation, soil acidification made the productivity decrease to only 45 kg ha⁻¹ yr⁻¹. The declining productivity became the main reason the aquaculture development in Mahakam Delta was halted from 2004 onward; that made the rate of mangrove conversion into pond in 2009's observation is at the same rate as 2004. Some farmers were also opening new ponds to achieve high rate productivity again.

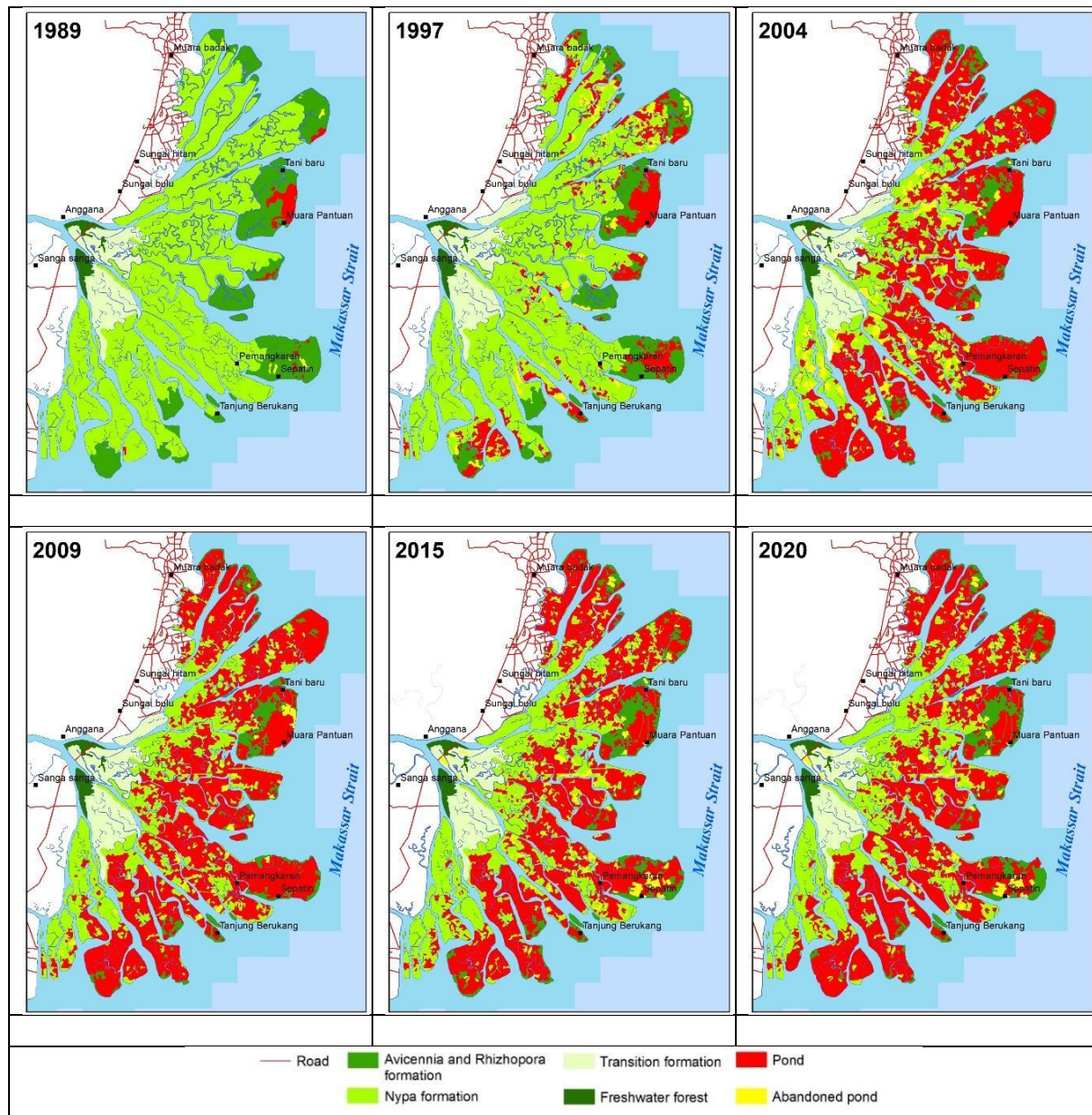


Figure 2. The maps of aquaculture development on mangrove forest in Mahakam Delta from 1989 to 2020 (Source: data analysis, 2020).

In 2015 and 2020, the abandoned pond regained its ability to regenerate naturally. The field observation and images interpretation show regeneration mostly takes in *Nypa* formation, following in *Avicennia* and *Rhizophora* formation. The reason mangrove recolonizing the pond naturally is because the abandoned pond let the sea water flow into the pond. The flow brings seed – without farming activities, let the seed grow. The new mangrove recolonization which differs from the previous one changes the mangrove evolution and structure. At the same time, restoration programs are also

conducted by the government and NGOs. But still, there are 54% of the pond area that covers Mahakam Delta (summarized in table 3). The condition made the delta declining due to erosion, which eroded 928 hectares. The erosion disrupts the transportation system in regions because of silting in the river [21]. Hence, it is needed for aquaculture industries in Mahakam Delta to shift method into sustainable practice and stop opening new ponds in mangrove forest.

Table 3. The summary of mangrove forest monitoring in Mahakam Delta related to aquaculture development

Year	Mangrove (ha)	Ponds (ha)	Notes	Caused
1989	107,784.50 [98.0%]	2,171.88 [2.0%]	-	<ul style="list-style-type: none"> Prohibition of using fishing trawl [19]. Ponds development initially triggered by an oil company (offshore) di Mahakam Delta. The small number of ponds due to creation with manual/ traditional method.
1997	92,720.40 [84.3%]	17,214.20 [15.7%]	Pond area ↑ Mangrove area ↓	<ul style="list-style-type: none"> Aquaculture looked promising result in economic and profit. Using excavator in development, fast and efficient. Poor governance and permit.
2004	45,028.86 [41.1%]	64,529.44 [58.9%]	Pond area ↑ Mangrove area ↓	<ul style="list-style-type: none"> Prawn demand for export increased, especially high profit due to Rupiah devaluation – made people open new ponds. Creating a new pond was very easy in terms of capital and permit.
2009	45,504.23 [41.6%]	63,929.44 [58.4%]	No change	<ul style="list-style-type: none"> Most of the suitable areas for aquaculture were already developed or utilized. Aquaculture in the Mahakam Delta requires a certain salinity value. Fish products from aquaculture gradually decreased. The reason was export bans by developed countries from the results of the conversion of mangrove ponds. Biophysical quality of the pond decreased and made productivity yield decrease due to pyrite poisoning. The decline in production made "investors" rethink opening fishponds. Starting to develop participation in mangrove conservation.
2015	50,537.98 [46.2%]	58,797.86 [53.8%]	Pond area ↓ Mangrove area ↑	<ul style="list-style-type: none"> Declining productivity yield, made the pond abandoned by the farmers. At the same time, new abandoned land with no pyrite. Secondary succession that made mangrove naturally regrow on abandoned ponds.
2020	49,311.2 [45.2%]	59,717.95 [54.8%]	Pond area ↑ Mangrove area ↓	<ul style="list-style-type: none"> Opening a new pond takes account for one percent due to the increase of demand of fish products.

				<ul style="list-style-type: none"> ▪ Mangrove recolonization below the rate of opening a new pond for fulfil productivity. ▪ Erosion since 1989 up to one percent of delta area.
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3.2. Discussion

The primary aim of natural resource monitoring was for sustainability evaluation. Sustainable aquaculture was supplying fish products continuously without harming the environment [24]. The aquaculture practice in Mahakam Delta could be defined as unsustainable practice. The solution to managing sustainability aquaculture is needed more presence of mangrove cover. Especially for the pond areas that were not productive. The mangrove cover presence has been successfully neutralizing heavy metal in Mahakam Delta [25]. Integrated mangrove – ponds in aquaculture of silvofisheries became a visible solution for the problem in Mahakam Delta. In silvofisheries, leaf litter can boost shrimp growth and improve long-term productivity, especially for mangrove species *Avicennia marina* and *Rhizophora apiculata* [26]. On the other hand, it is still challenging due to ineffectiveness of silvofisheries method in sustainable development of aquaculture, because it is only focused on economic factors [27].

Aquaculture is an important sector to support food security and the national economy. Mahakam Delta is an opportunity both in improvement of food security and the economy for the local community. Restoring the mangrove cover is the only answer to increase the productivity of fish and shrimp farming [29]. Integrated aquaculture with 30-50% mangrove cover has shrimp yield above farming in Mahakam Delta, but below 400 kg ha⁻¹ yr⁻¹ [30]. With the overfishing problem, the demand for aquaculture is always increasing in the following year. In order to achieve both environmental restoration and economic improvement in the Mahakam Delta, it is necessary for sustainable governance to address mangrove forest restoration in a large-scale [21], besides the technical guideline for farmers about sustainable farming.

4. Conclusion

The development of aquaculture in the Mahakam Delta started in the late 1980s. Three decades later, the aquaculture development facing uncertainty because reduction of yield and mangrove recolonize abandoned ponds. At a glance, it was good for the ecosystem because mangrove cover increased. But in synoptic view, aquaculture ponds cover 54% of Mahakam Delta with reduction of yield productive and economic profitability. This research shows the opportunity for remote sensing to monitor mangrove forest change in Mahakam Delta. The restoration of mangrove forests is a necessity to improve environmental quality and aquaculture yield in Mahakam Delta.

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