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ASSESSING THE IMPACT OF MANGROVES IN TRADITIONAL SHRIMP FARMING IN THE MAHAKAM DELTA USING A COST BENEFIT ANALYSIS

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Abstract: Mangroves began rapidly converting into shrimp-farming ponds in the Mahakam Delta, East Kalimantan, Indonesia. In 2000, the government launched the mangrove reforestation project, but the expected outcome was not achieved. Evaluation and recommendations are needed to attain the economic and environmental sustainability benefits of ponds with planted mangrove plants mandated by the government. This study examined the feasibility indicators of ponds with and without mangrove systems and analysed the feasibility of aquaculture pond performance. The results showed that the polyculture ponds with mangroves were more beneficial than the other pond systems, accruing more than 3.55 million IDR/ha/yr in net income. The polyculture pond with 10% mangroves showed the highest feasibility and benefits. The NPV, IRR, BCR, and PP were IDR72 million/ha/yr, 22%, 2 and 4.8 years, respectively. Therefore, the polyculture ponds with 10% mangroves were the best recommendation for farmers for the next 25 years. Government policy should facilitate improving environmental quality and sustainability in the Mahakam Delta.

Keywords: Integrating mangrove and shrimp farming, cost-benefit analysis, Mahakam Delta.

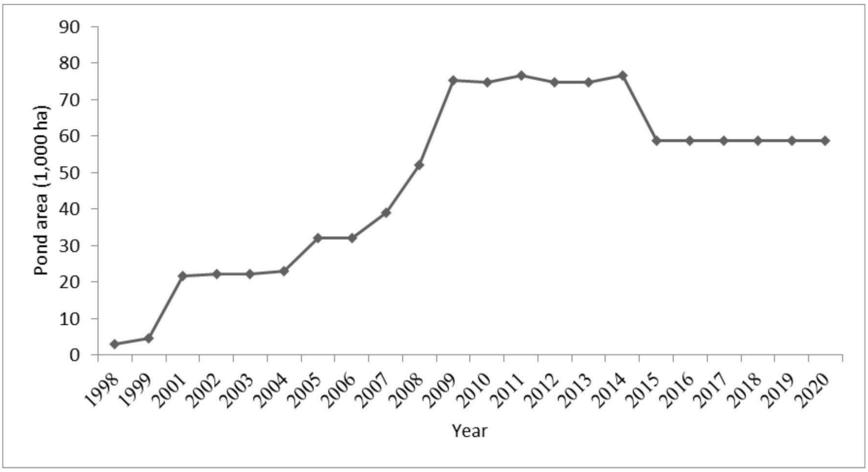
Introduction

The evolution of the increasing pond area in the Mahakam Delta in the last 23 years (1998-2020) from a very small area to about 75 thousand hectares in 2009 is shown in the statistical data from the Marine and Fisheries Office (MFO) of Kutai Kartanegara Regency, East Kalimantan causing a massive reduction in total mangrove area [Figure 1(a)]. Two factors have encouraged this pond expansion: The national economic crisis in 1998 that increased shrimp prices (MFO, 2020) and the arrival and use of excavators to facilitate pond construction, resulting in a faster rate of pond expansion. In 2016, 54% of the forest area in the Mahakam Delta was transformed into shrimp ponds, i.e., 61.5 of 113.3 thousand hectares (FPO-Kukar, 2016). Many studies have mentioned that the conversion of mangroves to shrimp ponds in the Mahakam Delta started in approximately 1990 and the transformation has since become uncontrollable (Choong *et al*., 1990; Sidik, 2008; Bosma *et al*., 2012; Persoon & Simarmata, 2014;). Meanwhile, other locations, such as the Philippines (starting in 1982), have prohibited mangrove cutting (Primavera, 1993). Furthermore, Vietnam has applied concepts of integrated mangrove–shrimp farming (Keenan, 1999; Johnston *et al*., 2000).

The pond area first massively increased from 1998 to 2009 and stagnated from 2009 to 2014. In 2015, the pond area decreased by approximately 23% due to abandonment. The pond area did not expand from 2015 to 2020. From 2007 to 2015, tiger shrimp production continually increased along with pond expansion [Figure 1(b)].

In the context of the history of pond area and aquaculture production in the Mahakam Delta, proper pond management is needed to

(a)



(b)

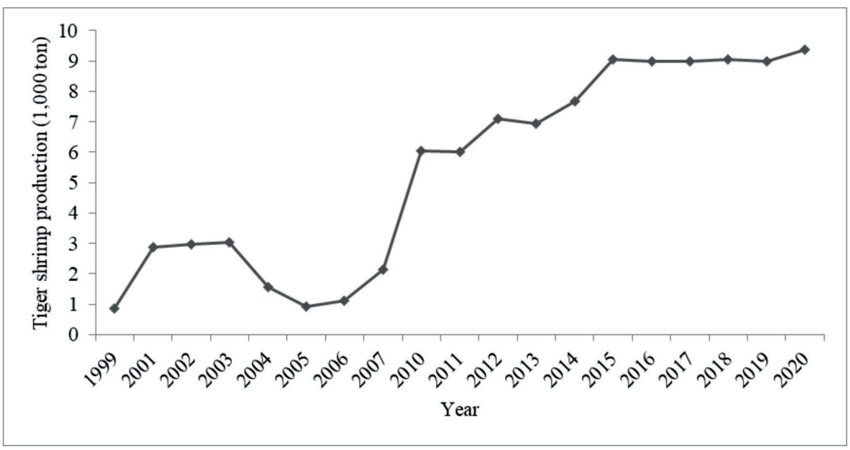


Figure 1: Evolution of the total (a) pond area and its (b) tiger shrimp production in the Mahakam Delta, Indonesia (based on MFO 1999, 2004, 2016, 2018, 2019 and 2020)

obtain more economical and profitable results. Many studies have recommended formulating an appropriate management model for certain areas. Mangroves have served many functions that benefit coastal environments, but pond farmers still believe that integrating mangrove planting and shrimp farming is challenging. Zain *et al*. (2014) stated that the massive conversion of mangroves into ponds had impacted fish and shrimp source regeneration and resulted in the loss of ecological functions for feeding, nursery and spawning fish and other animals. Large-scale encroachment and expansion of ponds reduced the presence of mangrove plants, so most of the livelihood activities of pond farmers related to mangroves were hampered (Bosma *et al*., 2012).

The government realized the mangrove planting program in the Mahakam Delta in 2000, a year after the program was launched in 1999 (MFO, 2020). In addition to mangrove tree planting in the green belt, inactive ponds, and barren areas, the mangrove planting program introduced the concept of combining shrimp farming and mangrove planting inside the ponds as a preferred strategy for pond farmers. Das *et al*. (2008) and Chowdhury & Khairun (2014) have mentioned that proper pond management is needed to achieve the desired result in more economical and profitable ponds. Shrimp farming contributes to national production and has helped increase the farming community income level from 25 to 36% (Ray *et al*., 2021). Although the integration of mangroves and aquaculture was introduced for ponds in the Mahakam Delta, having pond farmers who understand the direct benefits (e.g., income) would support the extension of this practice.

The objectives of this study are to examine the feasibility indicators of ponds with and without mangroves and to analyse the feasibility of aquaculture pond performance by comparing ponds with and without mangroves. We discuss the prospect of integrating mangrove planting and shrimp farming in the Mahakam Delta by considering the costs and benefits. The main hypotheses are that integrated mangrove planting–shrimp farming ponds are more feasible than shrimp-alone farming ponds and that polyculture systems generate better benefits than monocultural systems. The underlying assumptions are that increasing the mangrove-planting area in ponds improves pond feasibility and the direct benefits (income) to pond farmers. We perform financial and sensitivity analyses to compare the costs and benefits of ponds with and without mangroves after calculating pond feasibility indicators such as yield, cost, revenue/benefit, and profit.

Methods

Data Collection and Sampling

Primary and secondary data were employed for this study. The primary data were collected from farmers and key informants through questionnaires and in-depth interviews over seven months in 2020. The secondary data were collected from relevant statistical data of the government, related private sources and research reports. The research used a purposive random-sampling method, and the sample size estimation was performed by using the Taro Yamane formula at a 95% confidence level for each stratum surveyed; hence, the total sample was 272 farmers, using proportionate sampling to get the number of participants, of which 3.6% were farmers with monocultural ponds with mangroves (10 farmers), 11.4% were farmers with polyculture ponds with mangroves (31 farmers), 11.4% were farmers with monocultural ponds without mangroves (31 farmers), and 73.5% were farmers of polyculture ponds without mangroves (200 farmers).

Analytical Techniques

A cost-benefit analysis was applied to estimate the costs and benefits associated with a shrimp-farming business in the Mahakam Delta. The calculated study parameters were the NPV (Net Present Value), BCR (Benefit-cost Ratio), PP (Payback Period) and IRR (Internal Rate of Return). According to Law (2004), Nielsen *et al*. (2016) and Levin *et al*. (2018), the NPV is positive if the present value of revenue is higher than the investment value; it is negative if otherwise. The value of BCR would thus be greater (smaller) than one for a positive (negative) NPV investment. Then, the PP and IRR must be the shortest time and the most significant percentage, respectively, to be profitable (Nielsen *et al*., 2016). In this study, the IRR must be greater than the chosen interest rate of 9.75%. The NVP, BCR, PP and IRR were calculated for 25 years. The 9.75% interest rate chosen was based on a local commercial bank located near villages in the Mahakam Delta area, i.e., the BRI (Bank Rakyat Indonesia), whose interest rates included those for small and medium enterprises. The interest rate was the same as that offered by the Bank of Indonesia (BI) as a proxy of the OCC (opportunity cost of capital).

Sensitivity analyses were made of three scenarios based on the cost of planting mangroves in ponds without them, i.e., increasing the mangrove areas in the ponds to 10%, 15% or 20%. Limitations in this study are that the pond input and product prices were adjusted to the current prices; the depreciation costs of the investment assets were calculated on the straight-line basis method and adjusted by the economic age or lifetime of investment;

the yields and revenues were not available in the first investment year, and the yields at the first harvest cycle were not stable; and the duration/ project life (t) in the analysis referred to the average lifetimes of the pond embankments, water gates, and huts.

Study Site

The study site was in the Sepatin village, Anggana subdistrict, East Kalimantan. The Sepatin village is located in the Mahakam Delta area and covers 625 km^2 (BPS-Kukar, 2020). Its active ponds cover 446 km^2, which is 71% of the total area (MFO, 2020).

Characteristics of Pond Farmers and their Households

All interviewed farmers were pond owners, male, married, and in a network of Punggawa. Punggawa is the local entrepreneurial elites who have the local power networks. Hence, the local communities depend on these patrons (Kusumawati & Visser, 2016). The age of farmers ranged from 25 to 65 (Table 1). Eighteen farmers had no formal education while 254 farmers had formal education. Among the farmers with formal education, 223 finished primary school, 15 finished junior high school and 16 finished senior high school.

Almost all families had more than four members: the farmers; their wives, sons, and daughters; and other persons who stayed in the farmer's household as helpers. The farmers, farmers' wives, adult sons, adult daughters and helpers have cultivation roles. Adult males work in pond construction, embankment repair, harvesting, and the monitoring and maintenance of water gates. Farmers' wives and adult daughters provide logistical help and food needs as well as make farm finance arrangements.

Shrimp-farming Practices

In this study, 85% of the ponds surveyed during the field studies had no mangroves, and 15% had mangroves. Eighty-five per cent of the sample used the polyculture pond system, while the rest used the monocultural pond system. In the polyculture ponds, tiger shrimp were cultivated with milkfish, whereas in the monocultural ponds, only tiger shrimp were cultivated.

Table 1: Characteristics of the sampled pond farmers and their households

All (n = 272)					
	Ponds with Mangroves		**Ponds without Mangroves**		**Total**
	Monoculture	**Polyculture**	**Monoculture**	**Polyculture**	
1. Farmer age (year)					
Range	35-57	33-60	33-60	25-65	-
Mean	47	46	46	52	-
2. Education (person):					
No school	2	8	4	4	18
Primary school	1	9	22	191	223
Junior high school	2	6	4	3	15
Senior high school	5	8	1	2	16
Subtotal	10	31	31	200	272
3. Farm household family (person):					
≤ 4	1	0	0	0	1
> 4	9	31	31	200	271
Subtotal	10	31	31	200	272

These ponds were built on a large area of land that practised the concept of extensive ponds (traditional method).

The pond sizes in this study ranged from 2–15 ha for the monocultural ponds with mangroves, 4–18 ha for the polyculture ponds with mangroves, 10–22 ha for the monocultural ponds without mangroves, and 15–25 ha for the polyculture ponds without mangroves; the mean sizes were 10, 15, 18 and 20 ha, respectively. The average and largest pond sizes were 16 and 25 ha, respectively. In the field, most of the ponds were located close to a river or canal, without surrounding mangrove trees. In the government and the energy company reforestation program, ponds near the green belt zone and ponds with mangrove trees were considered ponds with mangroves. A buffer zone of approximately 5–10 m could be found between the main river or canal and pond dike in each pond. This distance was not following the government policy implemented by the Directorate General of Forestry Planning and Environmental Management in 2012, which stated that the distance should be a minimum of 50 m.

The ponds with mangroves in this study had approximately 5% per hectare of mangroves planted or naturally growing in the pond area. Farmers had to selectively prune some branches of the 5 to 7 year-old mangrove trees to decrease canopy density. The in-depth interviews with the farmers revealed that most farmers did not have enough knowledge to manage the mangrove leaves that fell into the pond. Overhanging mangroves drop their leaves into the pond, resulting in rotting organic matter at the pond storm. These rotten leaves cause water fouling and affect the fish and shrimp environment. Other obstacles were the inconvenience in harvesting due to the accumulation of rotten leaves and the prop roots of the trees. The farmers also feared that the dense trees in the ponds would attract predators such as crocodiles and other animals or fish, endangering people and the shrimp. The farmers had their shrimp farming skills and knowledge from their parents. The farmers started a career in shrimp farming as family helpers and then gradually became skilled in pond management and were entrusted with the task.

The water exchange from the adjacent rivers or canals was timed according to the tidal cycle. Aquatic animals such as shrimp, fish and crabs could enter the ponds through the water intakes, resulting in a mixed harvest culture. One culture cycle for the monocultural and polyculture ponds was approximately 4 months and 6 months, respectively. Harvesting usually took 2–6 days. The method was to lower the water gate during the low tide until the water level in the pond was approximately 15–25 cm from the bottom of the pond. Fish and shrimp would move with the water flow to the mouth of the water gate installed with a net. The harvesting was usually done at night according to the lunar–tide cycle.

Results

Yield, Cost, Revenue, and Profit *of Shrimp Farming*

The average tiger shrimp yield was 52.2 kg/ha/yr from the monocultural ponds with mangroves, 48 kg/ha/yr from the polyculture ponds with mangroves, 44 kg/ha/yr from the monocultural ponds without mangroves, and 43 kg/ha/yr from the polyculture ponds without mangroves (Table 2). The average tiger shrimp yield of each pond system was 50 kg/ha/yr for the ponds with mangroves and 43 kg/ha/yr for the ponds without mangroves. In the polyculture system, the mean milkfish yield in the ponds with mangroves was 200 kg/ha/yr, which was also higher than the yield from the ponds without mangroves (170 kg/ha/yr).

The annual expenses of the pond consisted of IDR4 million of fixed costs and 5 million IDR/ha of variable costs. These fixed costs constituted depreciation of investment assets, namely IDR693 thousands of pond embankments, IDR708 thousand of the water gate, IDR637 thousands of hut, IDR734 thousands of gondola, IDR704 thousands of electric generator, IDR83 thousands of flashlight, IDR398 thousands of fishing gear, and IDR125 thousands of fishnets. Depreciation of investment assets involved the economic life (years) of each asset, namely 26, 27, 28, 10, 10, 3, 4, and 2, respectively. The variable costs were allocated for tiger shrimp fry, milkfish fry, saponin, manure, fertilizer, labour and maintenance. The mean total cost was 9.05 million IDR/ha/yr calculated from 8.96 million IDR/ha/yr of the monocultural ponds with mangroves, 9.5 million IDR/ha/yr of the polyculture ponds without mangroves, 8.35 million IDR/ha/yr of the monocultural ponds without mangroves and 9.4 million IDR/ha/yr of the polyculture ponds without mangroves (Table 2). The total costs for the ponds with and without mangroves were approximately equal, i.e., 9.2 million IDR/ha/yr and 8.9 million IDR/ha/yr, respectively.

The annual pond revenue per hectare was IDR10 million for the monocultural ponds with mangroves, IDR13.05 million for the polyculture ponds with mangroves, IDR 9.01 million for the monocultural ponds without mangroves, and IDR11.24 million from the polyculture ponds without mangroves. The average revenue was approximately 10.8 million IDR/ha/yr. Table 2 shows the revenue earned from the polyculture ponds; the highest revenue was approximately 21% and 4% from the ponds with and without mangroves, respectively.

The milkfish revenues in the polyculture ponds with and without mangroves were 3 million and 2.2 million IDR/ha/yr, respectively, or approximately 21% of the total revenues. Meanwhile, the tiger shrimp revenues were 10 million and 9 million IDR/ha/yr, respectively, or approximately 79% of the total revenues. Moreover, the average revenue from the S20-size tiger shrimp contributed approximately 50% of the total pond revenue, from which 24% and 15% of the revenue were derived from the

Table 2: Yield, cost, revenue, and profit of the ponds with and without mangroves

Items	Ponds with Mangroves		Ponds without Mangroves		Mean
	Monoculture	Polyculture	Monoculture	Polyculture	
Yield (kg/ha/yr):					
- Tiger shrimp	52	48	44	43	47
- Milkfish	-	200	-	170	
Fixed cost (thousand IDR/ha/yr)	3,910	4,400	3,976	4,238	4,131
Variable cost (thousand IDR/ha/yr);	5,044	5,088	4,362	5,162	4,914
- Tiger shrimp fry	530	450	530	470	495
- Milkfish fry	0	150	0	150	75
- Saponin	100	50	100	70	80
- Manure	270	300	300	340	303
- Inorganic Fertilizer	150	140	140	140	143
- Labour	2,000	1,700	1,800	2,100	1,925
- Maintenance	2,000	2,300	1,500	1,900	1,925
Total cost	8,960	9,490	8,346	9,408	9,051
Revenue (thousand IDR/ha/yr)	9,992	13,049	9,015	11,235	10,823
Profit (thousand IDR/ha/yr)	1,031	3,550	668	1,827	1,769

S30 and S40-size tiger shrimp, respectively. In this study, the tiger shrimp sizes were grouped into S20, S30, and S40, where larger numbers indicated smaller shrimp sizes; thus, the price of the S20 was the highest. The price ranges of the tiger shrimp were 245,000-289,000 IDR/kg for the S20, 185,000 IDR/kg for the S30, and 125,000 IDR/kg for the S40. The highest revenue (6.2 million IDR/ha/yr) from the S20 tiger shrimp was attained in the polyculture ponds with mangroves.

The cost–benefit margin reflects the pond profit, and all pond system margins were positive (Table 2). The mean pond profit was 1.8 million IDR/ha/yr, calculated from 1 million IDR/ha/yr of the monocultural ponds with mangroves, 3.6 million IDR/ha/yr of the polyculture ponds with mangroves, 0.7 million IDR/ha/yr of the monocultural ponds without mangroves and 1.8 million IDR/ha/yr of the polyculture ponds without mangroves. The polyculture ponds with mangroves earned the highest profit compared to the other pond systems.

Cost-benefit Analysis

The BCR of all pond systems was slightly above 1. The investments in cultivation systems, and ponds, either with or without mangroves were feasible that discounted at 9.75%. Each pond system had a positive NPV, the IRR was greater than the interest rate of 9.75%, the BCR was more than 1, and the PP was a short time on the investment cost (4.8–5.9 years). The monocultural ponds with mangroves, polyculture ponds with mangroves, monocultural ponds without mangroves, and polyculture ponds without mangroves exhibited NPVs of 46 million, 70 million, 43 million, and 55 million IDR/ha/yr, respectively; and the PPs were 5.8 years, 4.8 years, 5.9 years and 5.3 years, respectively. The financial return on shrimp farming in the ponds with mangroves was better than in ponds without mangroves considering the higher NPVs and the shorter PPs. The IRRs and BCRs of these ponds were not different (Table 3).

Applying the polyculture system increased the NPV amount by 52.5% for the ponds with mangroves and by 29.5% for the ponds without mangroves. The polyculture ponds with mangroves performed the best, with an NPV of 70 million IDR/ha/yr, a BCR of 21%, an IRR of 1.9, and a PP of 4.8 years.

Sensitivity Analyses

For the sensitivity analyses, in Scenario 1 (10% planted mangrove), the NPV, IRR, BCR and PP were 72 million IDR/ha/yr, 22%, 2, and 4.9 years, respectively. In Scenario 2 (15% planted mangrove), the NPV, IRR, BCR and PP were 68 million IDR/ha/yr, 21%, 1.9, and 5 years, respectively. For Scenario 3 (20% planted mangrove), the NPV, IRR, BCR, and PP were 61 million IDR/ha/yr, 20%, 1.8, and 5.3 years, respectively (Table 4).

The polyculture ponds with 10% planted mangrove (Scenario 1) were the most profitable, followed by Scenario 2 with 15% planted mangrove and Scenario 3 with 20% planted mangrove. Although Scenarios 2 and 3 resulted in lower financial benefits than Scenario 1, the ponds in Scenarios 2 and 3 might provide higher benefits in mangroves because these ponds have larger mangrove sizes.

Table 3: Cost-benefit analyses for the next 25 years (discounted at 9.75%)

Measurement	Ponds with mangroves		Ponds without mangroves	
	Monoculture	Polyculture	Monoculture	Polyculture
NPV (million IDR/ha/yr)	46	70	43	55
IRR (%)	17	21	17	18
BCR (time)	1.6	1.9	1.6	1.7
Payback period (PP) (yr)	5.8	4.8	5.9	5.3

Note: 5% planted mangrove (1 ha)

Table 4: Sensitivity analyses of three scenarios involving mangrove planting in the polyculture ponds over the next 25 years (discounted at 9.75%)

	Measurement	Scenario		
		1	2	3
Polycultural ponds with mangroves	NPV (million IDR/ha/yr)	72	68	61
	IRR (%)	22	21	20
	BCR (time)	2.0	1.9	1.8
	Payback Period (yr)	4.8	5.0	5.3

Note: 1: 10% planted mangrove
2: 15% planted mangrove
3. 20% planted mangrove

Discussion

The average tiger shrimp productivity from all systems in this study (47 kg/ha/yr) did not differ from other studies on traditional polyculture systems in the Mahakam Delta; for example, productivity has been reported at 42.5 kg/ha/yr (Noryadi *et al*., 2006), 50 kg/ha/yr (Setiawan *et al*., 2015), and 45/kg/ha/yr (Bosma *et al*., 2012). When we compared pond systems, the yields from the polyculture ponds (186 kg/ha/yr) were more profitable than those from the monocultural ponds. However, shrimp productivity in this study still did not reach the government target of 0.6 tons/ha/yr that set by the Marine and Fisheries Ministry in 2022 (MFO, 2022).

Optimizing existing ponds was a challenge in reaching the target and increasing production. Widowati *et al*. (2021) stated that traditional farmers of milkfish and shrimp in Indonesia used 80% of the production area to produce only 10% of the total shrimp. The yield could be increased using knowledge and technology. Meliko *et al*. (2021) also reported a case in Cameroon, Africa, where pond farmers could increase pond yields by training and increasing accessibility to fingerlings. Likewise, in Demak, Central Java, the aquaculture field school program of 16 sessions during one culture season training farmers in Low External Input Sustainable Aquaculture (LEISA) has proven to increase shrimp yields for the adopters (Widowati *et al*., 2021; Yuniati *et al*., 2021).

Farmer income is largely derived from pond production, therefore they prefer commercial pond species such as tiger shrimp and milkfish to other species because these species are demanding. The main market for milkfish was the local one, while most of the tiger shrimp were supplied to the international market through a cold storage company located in the Anggana subdistrict, which was established in 1974 for export (Persoon & Simarmata, 2014). Cultivating various species in the ponds (polyculture) permitted access to a broad market. Susilo *et al*. (2019) stated that the decision to adopt a polyculture system is determined by the family size and the educational level of farmers, where in small-scale ponds, species of shrimp, fish, sea crab, and sea grass may be cultured together in a way that improves the shrimp culture (Dat & Yoshino, 2013). Farmers must arrange the cultivation sections and the time for each species when multiple species are present in a pond to implement polyculture systems (Luom, 2019).

To start shrimp farming, pond farmers must invest money, including constructing pond dikes, water gates, and huts and purchasing fishing motor boats or gondolas, electric generators, flashlights, fishing gears, and fishnets. An additional cost to integrate mangroves with shrimp farming includes mangrove tree planting. The investment costs incurred by each pond system were similar, i.e., approximately IDR75 million. In the first year, farmers invested in assets. However, if farmers extended their pond sizes, they could use the same water gates and huts.

The variable costs were similar in the ponds with and without mangroves in both the monocultural and polyculture systems. The pond inputs were provided by traders that came directly from Anggana to the farmers' ponds in the Mahakam Delta. Farmers bought the same quantity of everything needed for one hectare at the same price per unit. The farmers employed external labour at approximately 1.9 million IDR/ha/yr. In addition, the farmers also employed internal labourers (helpers) to decrease expenses. Having a large family also helped reduce labour costs.

Farmers also incurred pond maintenance costs to repair embankments and water gates and maintenance of investment assets, costing approximately IDR 1.9 million/ha/year. The average maintenance cost was quite high, approximately 22% of the total cost. Other operating costs included energy for lighting during harvest time and daily activities, i.e., approximately 0.2 million IDR/ha/yr. The average revenue of the ponds with mangroves was approximately 28% higher than those without mangroves. Unfortunately, only 15% of the field samples applied the integrated mangroves and shrimp in the ponds. The main factors affecting the revenue increases were the sizes and prices of the tiger shrimp.

Susilo *et al*. (2018) also found that ponds with mangroves (silvofishery) positively affected farmers' incomes in the Mahakam Delta. The increased income for farmers who adopted the silvofishery system ranged from 1 million to 1.1 million IDR/ha/year. The practice of silvofishery is proposed to stop bioresource degradation and increase societal benefits (Rahman & Mahmud, 2018). The integration of shrimp farming and mangroves also provides natural feed through nutrients for phytoplankton inside the pond (Wahab *et al*., 2003; Bao *et al*., 2013; Saifullah *et al*., 2014) and preserves the biodiversity of the natural fish population in addition to the improvement in environmental quality (Ridlo *et al*., 2020; Hashim *et al*., 2021; Al Jufaili *et al*., 2021). The practice of silvofishery aquaculture systems with mangroves can also provide a decent livelihood for pond farmers if the area is large enough (Bosma *et al*., 2014). However, in our study, only a small number of farmers have adopted the practice of planting mangroves in pond areas. For those who adopted the practice, only 5% of the pond area was planted with mangroves.

Among the compared scenarios in the sensitivity analysis, the polyculture ponds with 15% planted mangroves (Scenario 2) were slightly more profitable than those in Scenario 3 with 20% planted mangroves but Scenario 1 with 10% mangroves ponds was the best profitable. The financial returns from the pond systems appeared to be sensitive to cost changes. The benefit decreased if the costs increased (i.e., Scenarios 2 and 3).

A mangrove area of 10% per hectare in ponds was considered suitable for farmers. Even though the mangrove area in the ponds in this study was quite low, the ponds with mangroves generated higher profits than those without mangroves, and the farmers of ponds with mangroves generated higher profits than did those with a lower percentage of mangrove area. The result from the study can be used to convince farmers to implement mangrove planting in ponds for their benefit and livelihood. The increase in mangroves in the pond will also benefit the government programs on mangrove restoration in achieving the goal.

Other researchers have mentioned that the mangrove density needed to be managed to allow light penetration and reduce decayed leaf litter. Johnston *et al*. (2000) found that the shrimp yield correlated negatively with an increase in mangrove density which could be explained by the decrease in light penetration and the increase in decayed leaf litter. This problem could be overcome by having a wider sluice gate to flush out decayed leaves, improving water quality and increasing shrimp larvae intake. In this study, the impact of planting mangroves in ponds has the potential to change the pond environment. As a substitute, ponds with separated mangroves can control leaf litter and rotting tree roots in ponds. Stakeholder collaborations with pond farmers in the Mahakam Delta are challenging in managing sustainable ponds that can increase income and maintain future environmental balance.

The stakeholders involved in aquaculture development in the Mahakam Delta include local investors, traders, private companies, the government, and community groups. Akber *et al*. (2020) studied the factors underlying the expansion of mangrove ponds to guide future policies for the sustainable management of coastal zones in Southeast Asia. The study suggested that strategies to enhance the integration of mangrove planting and shrimp farming should focus on government policy interventions, including those that support the program. Thus, the results from this study can be used to ensure farmers of the policy benefits.

Conclusion

The traditional ponds with mangroves were more beneficial than ponds without mangroves. The low yields and total costs were comparable in all pond systems. Culturing milkfish in a polyculture pond with mangroves increased the pond revenue by 21%. The polyculture ponds with mangroves yielded the highest profits, followed by the polyculture ponds without mangroves, the monocultural ponds with mangroves and the monocultural ponds without mangroves yielded 3.6 million, 1.8 million, 1 million and 0.7 million IDR/ha/yr, respectively. The polyculture ponds with mangrove systems increased the NPV by 52.5%, discounted at 9.75%, compared with monocultural ponds with mangroves. The sensitivity analyses revealed that the polyculture pond with mangroves in Scenario 1, with 10% planted mangroves, was the most profitable and more feasible than the other scenarios. Employing polyculture ponds with 10% planted mangroves for the next 25 years could increase profits by 3% or 2 million IDR/ha/yr, discounted at 9.75% for the NVP.

Hence, farmers should plant mangroves in at least 10% of the pond areas using a polyculture system in the Mahakam Delta. As stated by other researchers, pond farmers may adopt a separate farming system to control mangrove leaf litter decomposition and water quality in ponds. The separate farming system is suitable because field ponds are close to rivers or canals. This situation will benefit farmers and directly improve environmental quality in the Mahakam Delta. Shrimp farmers, the coastal community, local agencies, and all stakeholders must collaborate to ensure that shrimp farming in the Mahakam Delta will be sustained and environmentally friendly in the long term.

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