A Comparison of the Silvofishery Models for Mangrove Restoration in East Kalimantan

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Abstract. East Kalimantan is one of nine provinces selected for mangrove rehabilitation until 2024. Despite disappointing, it needs to be confirmed that the mangrove ecosystem in East Kalimantan has shrunk from year to year. However, it is encouraging to know that there is still a hope for mangrove ecosystem rehabilitation. Mangrove rehabilitation is expected to have an impact not only on the environment, but also on economy, social aspect, and wisdom of the coastal communities in East Kalimantan. Ponds are designated for more than 70% of the Mahakam Delta's mangrove. Although traditional management is still in the progress of development, the community still uses extensification to increase shrimp production. Local community has developed two pond models, namely environmentally-friendly ponds in Muara Badak Subdistrict, trench pond model in Salo Palai village, and *komplangan* model in Muara Badak Ulu Village. This trial was carried out in 1 ha of pond area using a fish and shrimp polyculture system for four months. Traditional maintenance was performed without adding artificial feed, but fertilization and management were carried out to monitor water quality, growth, survival rate, and total production. Trench pond and *komplangan* models have good environmental condition, like total nutrient base on mangrove litter. Production from both ponds was excellent, exceeding 300 kg/Ha for all cultures or polyculture systems. Application of the silvofishery model with these two models was sufficient to restore the mangrove ecosystem. However, *komplangan* model have two functions, as a conservation area and shrimp pond in one place, while it is associated with aquaculture production and sustainability for mangrove forest.

Keywords: empang parit · *komplangan* · restoration · polyculture · silvofishery

Y. A. Yusran et al. (Eds.): BIC 2022, AEBMR 235, pp. 614–626, 2023.
https://doi.org/10.2991/978-94-6463-140-1_61

1 Introduction

Delta Mahakam is the biggest mangrove ecosystem in Indonesia, and the dominant type of mangrove plant is Nipah (*Nypa fruticans*) [1–3]. However, many mangrove forests in Mahakam Delta are damaged as the consequence of conversion into traditional pond. In 2008, the width of mangrove forest decreased into 60,000 Ha or approximately 55% of total Mahakam Delta width [1, 2, 4]. Moreover, 54% of mangrove forest width (or 57,912 Ha) was used as the pond area, while this conversion kept increasing into 75,311 Ha or approximately 70% of delta land width [1, 2]. This fact is confirmed by the statement of Fitzgerald [5] in which mangrove tree logging is a consequence of the conversion into shrimp pond.

Rehabilitation and restoration efforts for the mangrove have been made since 2000, by government institution and private institution. These efforts have been continued to date, while the rehabilitation is not yet effective because of frequent land opening for fish and shrimp cultivation. Thus, it needs to introduce a mangrove restoration method with an approach of pond management associate with mangrove.

The concept of pond, associated with mangrove, has been frequently introduced by Bengen in which mangrove forest is inside the pond and its surrounding environment. Mangrove forest means a group of trees. According to Fitzgerald [5], the management of silvofishery pond has low input, but it prioritizes sustainable aquaculture and cultivation by integrating with mangrove tree. Folk and Kautsky [6] stated that biota is cultivated as natural as possible like in nature, with less resource input, and low negative effect to the environment. As stated by Fitzgerald [5], some fundamental principles in the management of silvofishery pond are reduction of the additional input in pond, avoiding the use of chemical and medical compound, producing waste as minimum as possible, prioritizing recirculation of the nutrient use in pond to improve the pond productivity. The concept of shrimp pond management associated with mangrove ecosystems or silvofishery is in line with the green economy concept. The green economy can be interpreted as an economic idea that aims to improve people's welfare while significantly reducing the risk of environmental damage. In this case, the economic activities carried out by the community have low carbon dioxide emissions, save natural resources, and produce as little waste as possible.

The use of antibiotic, chemicals, and others must be reduced because they have many negative effects, while the use of antibiotic only controls temporary diseases and even causes infection from other pathogens. Almost all chemicals are not environmentally friendly, while they are even prohibited in some countries and do not support the idea of a green economy. One of the save methods to increase production in shrimp pond is through the use of sour eggplant (*Solanum ferox*), finger root (*Boesenbergia pandurate)*, and lempuyang (*Zingiber zerumbet)* extracts. These three plants have phytochemicals, namely flavonoid and alkaloid with antibacterial and immunostimulant functions [7–11].

Pond management model in an effort of mangrove ecosystem restoration is known as silvofishery, a management model synergizing ecological and economic aspects. Silvo or forest cultivation as an effort of preservation represents ecological aspect, while fishery is an activity as an effort to use by representing the economic aspect [12, 13]. Silvofishery model was introduced for the first time in Indonesia by Bengen [2], with three main models managed by Indonesian people, trench pond, trench plus, and *komplangan.* This idea fits with the notion of the "green economy." This article describes the management of silvofishery pond, between trench pond and *komplangan*, in which the management is performed sustainably by applying plant extract in Salo Palai Village and Muara Badak Ulu Village, Muara Badak Subdistrict, Kutai Kartanegara Regency, East Kalimantan, Indonesia as one of green economy concept aquaculture.

2 Methodology

2.1 Location Selection

Ponds used for this experiment were trench pond in Muara Badak Village and *komplangan* model in Salo Palai Village, Muara Badak Subdistrict, Kutai Kartanegara Regency, East Kalimantan, Indonesia. Trench pond was 7.3 Ha of mangrove, with pond width at 70–80% and water depth at 60–80 cm with one floodgate. Types of the mangrove were *Rhizophora apiculata, Avicennia, Sonneratia*, while some *Ceriops tagal* trees were also found.

Second model was *komplangan* type with pond width at 4 Ha, while pond was divided into two areas, mangrove forest (1 Ha) and pond (3 Ha). These two areas were interconnected with a simple floodgate made of wood, while water depth was 50–70% in mangrove forest and 70–80 cm for pond area. Area in mangrove forest had *Rhizophora spp.* And *N. fruticans* grew in pond area. This pond is exactly between 0°19′–0°55′ S and 117°15′–117°40′ E (Fig. 1).

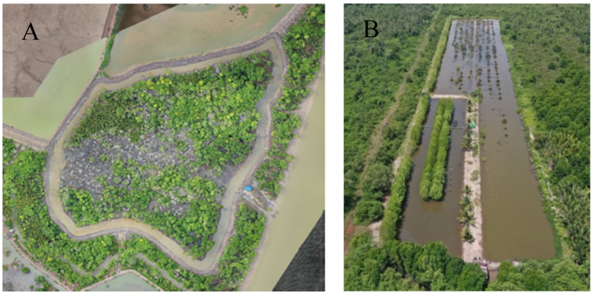

Fig. 1. Location of silvofishery pond, trench pond (A) and *komplangan* model (B) in Muara Badak Subdistrict.

2.2 Pond Management

Pond was managed before the cultivation, while 10 preparation steps in sequential order for these two ponds were as follows:

1. Floodgate repair, to make sure that there was no leakage in floodgate and filter mesh for reducing the inflow of trash into pond, on 8^{th}–10^{th} day of high tide.
2. Mud disposal, to dispose the mud in pond bottom for optimizing the growth of natural feed and maintaining water quality during cultivation process, on 8^{th}–10^{th} day of tides of the sea.

3. Flushing and drying of pond bottom to get rid of mud residue left in pond bottom, on 11^{th}-13^{th} day.
4. Filling and deposition of water flowing into mangrove forest/conservation area for one night at high tide, performed on *komplangan* model on 4^{th}–7^{th} tidal day. And water filling and disinfection using the *Z. zerumbet* extract at 800–1,000 ppm into trench pond and left for one night on 4^{th}–7^{th} tidal day.
5. In *komplangan* pond, water in mangrove forest area was flown into pond area.
6. Liming and prebiotic adding on these two ponds on 1^{st}–3^{rd} tidal day.
7. Fertilization in these two pond models were performed on 7^{th}–8^{th} tidal day.
8. Seed preparation, by preparing and sorting healthy seed with screening method and the mass of Natural Feed Growth mass on 9^{th}–13^{th} tidal day.
9. Seeds were spread on tidal day, and Breeding period was 100 days for juvenile shrimp, 45 days for seaweed, 30–50 days for snapper, and 30 days for crab.
10. Monitoring on health of the cultured organism and water quality. For monitoring DO, pH, salinity, and availability of organic material, observation was performed every month until harvest.

2.3 Seeds Preparation

In polyculture cultivation, organisms cultivated were tiger prawn (*Penaeus monodon*) and shrimp (*Litopenaeus vannamei*), snapper (*Lates calcarifer*) and milkfish (*Chanos chanos*), seaweed (*Gracilaria verrucose*), and crab (*Scylla* spp.). Tiger prawn (3 g) and snapper (50 g) were taken from Shrimp Breeding Centre in Manggar, Balikpapan City. 100 crabs at weight of 180 g were taken from people in Muara Badak village. Seaweed used was *Gracillaria* in which weight of seed was 100 g for every knot.

2.4 Plant Extracts

Plant extract used in research followed the procedure of Hardi, et al., [14] as prebiotic; pond at stage 7 in pond management used extract of *S. ferox* in Biofeed [15]. To improve immunity in fish, shrimp, and seaweed, they were soaked for 20 min with Fitoimun products containing extract of *B. pandurata* and *S.* ferox [16–18].

2.5 Measurement of Cultivation Productivity in Silvofishery Pond

Parameters measured in this research were Survival Rate/SR, estimate of harvest (shrimp population), and Average Body Weight at harvest.

– ABW (gram per shrimp) = (total weight of shrimp)/(amount)
– Estimate of Shrimp Population: Population = (t Biomass (g))/ABW
– Survival rate (SR) = Population/(Amount spread) × 100

2.6 Litter Production

Litter production in mangrove was measured by installing four litter trap tools made of waring at size of $1 \times 1 \times 0.5$ m in every pond model. Points for putting litter trap were determined at west, south, east, and north of pond. Litter in mangrove was collected for three months (one cultivation period) every two weeks. Litter in 4 spots was collected, while its leaves, fruits, flower, and branches were separated. Calculation stage in the laboratory was started through the drying method using oven at a temperature of 80 °C for 24 h. After dry, they were measured using Sasekumar and Loi [19] methods.

TL = L (A/a)
TL = total weight of litter (kg)
A = average weight of litter in every trap (kg)
a = size of litter trap (m^2)

This research studied availability of nutrient in pond, including organic material, nitrogen, phosphor, and potassium. Analysis of nutrient in mangrove litter was conducted in several stages. Some 30 g of litter from oven was grinded using blender until resembling flour, before examining its organic material (IKM/5.4.12), nitrogen (IKM/5.4.15), phosphor and potassium (spectrophotometer).

3 Result and Discussion

3.1 Management of Trench Pond

In this pond type, mangrove cover is extensive, ranging from 70–80% at the centre and edge of pond. This model is applied by many people in Muara Badak Subdistrict because of its simple design, affordable price, and capability to cultivate in wide area. This shape is highly natural in general, but the fact that mangrove forest and pond are in the same area leads to several disadvantages.

People consider this model less effective because mangrove forest area is still one stretch of land for shrimp and fish farming. Some issues found in the management of trench pond are as follows:

1. Mangrove forest land is still unified as a conservation area and pond land, so the process of mangrove litter deposition potentially causes a decrease in soil and water's quality in the pond area.
2. Pests, penetrating from public waters through the merging of mangrove forest land and pond, disturb the cultivated organism.
3. Shrimp and farmed fish hide in tree roots and make harvesting difficult.

Result of experiment in the demonstration plot of Muara Badak Ulu Village shows that this model is also feasible as cultivation land, provided with some recommendations, namely mangrove tree thinning (particularly for path modal), distance between trees at 1 m, replacing trees older than five years with the new ones, crab and shrimp cultivation with crab box and floating cage to ease monitoring and harvesting. Fertilization and liming need to adjust to the availability of nutrient in pond, by adjusting to the dose. Liming for pH in pond bottom at 4.0–4.5 was approximately 10.740 kg/Ha when the pond bottom was clay or sandy clay and only 5.37 kg/Ha for sandy clay subtracts. Most of people do not consider substrate pH during the liming process, thus leading to non-optimal result. Liming dose can use Hardi et al. [20].

3.2 Management of Komplangan Pond

Komplangan pond is seldom found in society of Muara Badak Village, but they have simple *komplangan* with comprehensive construction that is more environmentally friendly. In this model, pond is divided into mangrove forest (conservation area) and cultivation area (pond). The separation of mangrove land and fishpond land in the *komplangan* pattern is bounded by a bund between two gates. Mangrove forest land is used as a place to restore water quality before it is used for cultivation. This pond type has two floodgates, in which each of them serves to link sea and pond and to link mangrove forest and pond area.

Mangrove forest area has three primary functions for water filtering and settling, nutrient circulation, and organism conservation [21]. For the centre of mangrove forest, *R. apiculata* species were planted or with a path system. Pond and centre of the pond were covered with mangroves, at 70–80% of the area. Width of the main pool area is one hectare, while the depth of pond was 50–80 cm. Pond management pattern was applied through polyculture method.

For function in water filtering and settling, deposition of organic and inorganic materials in the form of mud and sand particles penetrating sea water before used for cultivation, water goes through a filtering process and overnight deposition in an ideal mangrove forest. Functions as nutrient circulation are (1) from the sea when penetrating water, (2) from the pond area as a result of cultivation, and (3) from the decomposed mangrove litter (organic matter, nitrogen, phosphorus, potassium, and other nutrients). Functions as organism conservation were wastewater containing residual feces, dead biota, and toxic compounds (e.g., ammonia and hydrogen sulfide), which were deposited first. Cultivation activities produce nutrients that are reused by organisms in the mangrove forest plot and are beneficial to the mangrove forest.

3.3 Litter Production of Mangrove in Trench Pond and Komplangan Pond

Total litter resulted in these two models of silvofishery pond is shown in Fig. 2. Based on the type of litter observed per ratio of silvofishery pond, leaves were most frequently disposed in these two pond types at 40–50% of total litter resulted in four months, because mangrove slightly produces flower.

Amount of mangrove litter was 2,547 kg/m^2/year in trench pond model and 2,024 kg/m^2/year in *komplangan* pond model. This litter was from leaves, fruit, flowers, and nagging. Litter affects the availability of nutrients in pond and conservation area. According to Odum [21], nutrient (e.g., organic material, nitrogen, phosphor, and potassium) are required for growing natural feed in pond, besides micro element of iron (Fe), manganese (Mn), zinc (Sen) required at small quantity. Availability of the nutrient in pond is explained in detail in Table 1.

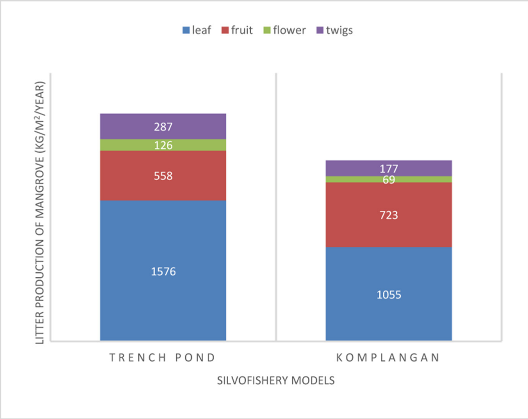

Fig. 2. Litter production of mangrove in trench pond and *komplangan* pond.

Table 1. Availability of nutrient in trench pond and *komplangan* pond

Nutrient	Unit	Trench pond	Komplangan
Total Nutrient	ppm	2.04	5.28
Nitrogen	ppm	0.65	0.2
Phosphor	ppm	150.36	0.2
Potassium	ppm	18.34	11.02

Availability of nutrient in traditional pond is highly important for determining feed availability for fish and shrimp. For correlation between organic material (dead plankton or other natural feeds in pond) and fish production, pond with organic material at 1.23 ppm will result in natural feed at 15,000 kg with fish production rate at 1,200 kg/ha/year [22, 24].

3.4 Harvest in Silvofishery Pond Management

In both shrimp farming methods using polyculture system, this system has some advantages for environment. This system is capable of reducing the nitrogenous wastes [22], reducing contamination [23], and improving the health of fish and shrimp [22]. With polyculture, second harvest of silvofishery pond was quite feasible, but pond management with *komplangan* model has some advantages. Mangrove forest, as a water reservoir area, has positive effects to the water filter from river, thus making growth and survival of the cultivated biota excellent. After cultivation period of 30–100 days for every organism, it can identify growth, survival, and production of silvofishery ponds with two models.

Survival of the whole organism cultivated was approximately 64–90% in cultivation with trench pond (Table 2) and 73.85–100% in *komplangan* model (Table 3). Tables 2 and 3 show that polyculture cultivation in *komplangan* model had SR and population

Table 2. Production in trench pond model

Type of the Cultivated Biota	Breeding Period (month)	SR (%)	ABW (g/fish)	Population Estimate (fish)
Tiger prawn	4	79.05	33.333	1185.75
Whiteleg shrimp	3	70.00	50	350
Crab	1	64.62	342.02	42
Snapper fish	3	90.00	333.33	288
Milkfish	3	89.25	333.33	446.25

Table 3. Production in *komplangan* model

Type of the Cultivated Biota	Breeding Period (month)	SR (%)	ABW (g/fish)	Population Estimate (fish)
Tiger prawn	4	95.33	90.91	1,430
Whiteleg shrimp	3	85	58.8	425
Crab	1	73.85	500.00	48
Snapper fish	3	93.75	333.33	300
Milkfish	3	100	500.00	500

higher than cultivation in trench pond. Average weight of fishes and shrimps in the end of breeding period was also higher, in which tiger prawn had average weight of 90.91 g in the end of cultivation in *komplangan* model and 33.33 g per shrimp in trench pond. It was possible because of optimal process in filtering and sedimentation of water before used for cultivation. Optimal growth of natural feed was because of pond preparation process as the factor to support optimal growth in cultivation of fishes and shrimps. Snapper was fed with trash fish at 5%, once every two days. It was also applied to whiteleg shrimp bred in floating cage of pond, fed with shrimp feed at dose of 5%, once every two days. Besides cultivation of fishes and shrimps, seaweed was also harvested in trench pond with production of 400 kg.

Difference of management method or cultivation between trench and *komplangan* models was in the water management before and after cultivation. From data of SR, ABW, and population estimate, it is shown that *komplangan* model increased production until twice.

Harvest in these two models shows that *komplangan* model got profit of IDR 36,405,000 in every harvest; this amount was twice of harvest from trench pond, IDR 17,444,050. In three years, farmers performed cultivation for three periods, so total income for every year from trench pond model was IDR 52,332,150 and *komplangan* model reached IDR 109,215,000 (Table 4) (Fig. 3).

Table 4. Total harvest and income estimate from cultivation performed in silvofishery pond with trench pond and *komplangan* models.

Organism species	Total Harvest (kg)		Price per fish (IDR)*	Income (IDR)/harvest	
	Trench pond	Komplangan		Trench pond	Komplangan
Tiger prawn	40	130	176,000	6,956,400	22,880,000
Whiteleg shrimp	18	25	55,000	962,500	875,000
Crab	14	24	60,000	861,900	1,440,000
Snapper fish	96	100	65,000	6,240,000	6,500,000
Milkfish	148.75	250	15,000	2,231,250	3,750,000
Seaweed	16	80	12,000	192,000	960,000
Per harvest				**17,444,050**	**36,405,000**
Per year (three periods)				**52,332,150**	**109,215,000**

Explanation *price in December 2021 for Kutai Kertanegara, East Kalimantan

Fig. 3. Harvest of tiger prawn, tiger prawn, and mud crab in silvofishery pond (*komplangan* model) in Muara Badak Subdistrict, Kutai Kertanegara Regency, East Kalimantan

Harvest in silvofishery pond with *komplangan* model was higher, because of optimal filtering, water deposition before the start of cultivation. Data of water quality is shown in Table 5.

This production is quite decent, while the management of water and pond bottom before the start of cultivation and the use of plant extract in Biofeed and Fitoimun product were factors to determine the success of harvest in two models of silvofishery ponds. In the past few years, most of the cultivators in Mahakam Delta found that their harvest was drastically reduced due to poor water quality, environmental deterioration, and outbreaks of shrimp diseases. WSSV and AHPND diseases are currently main factors in the failure of cultivation since 1990s [24–28].

Management of pond bottom and water before use will improve the fertility of pond in the growth of natural feed. Availability of nutrient at total 2.04 ppm (trench pond) and 5.28 ppm (*komplangan*) shows that these two pond models belong to good category, though *komplangan* model is higher. The use of extract from *S. ferox* containing solasodine had a good effect to the improvement of nutrient and amount of probiotics bacterium. Hardi et al. [14] explains positive correlation in the use of *S. ferox* extract in

Table 5. Water and substrate parameters in silvofishery pond, trench pond and *komplangan* models.

Water Parameter	Unit	Pond Model	
		Komplangan	**Trench pond**
Temperature	°C	18–30	16–28
Salinity	‰	15–25	15–20
Water pH	-	5.5–8	4,5–6
OxygenDiluted (DO)	mg/L	4–5	2–3
Substrate pH	-	6–8	5–7
Pyrite	%	1.46–2.98	1.5–3

improving the growth of *Lactobacillus cassei*. The use of extract from *S. ferox* and *B. pandurata* in fishes and shrimps have positive effect in improving fish immunity [15–17]. Although immunity system in fishes and shrimps is different, shrimp has immunity system that is simpler (dominated by non-specific immunity), so the effect of extract in improving immunity of fishes and shrimps are almost the same. Traditional culture in silvofishery and using plant extracts produced a satisfactory yield. Aside from shrimp growth and survival rate, the quality of meat containing amino acids and fatty acids was also improved [29]. Shrimp farmers and local governments should reconsider using plant extract products in aquaculture because they provide more economic and environmental benefits, and this concept will be related with green economy.

4 Conclusion

This study shows that silvofisheries can result in optimal production and rehabilitation of the mangrove ecosystem concept. The trench and *komplangan* models developed by the community have a positive impact on both economics and the rehabilitation and restoration of mangrove ecosystems, but the *komplangan* model has a greater positive impact on both economics and the environment. Overall, the silvofishery pond model of *komplangan* is insufficient for mangrove rehabilitation and restoration, but it is adequate for community income in the Mahakan Delta, East Kalimantan.

Acknowledgments. Researchers express their gratitude to the Ministry of Education and Culture of the Republic of Indonesia for funding this research through the Kedai Reka program, Matching fund, with contract no. 0463/E/TU.00.01/2021. Researchers also thank the Peatland and Mangrove Restoration Agency of the Republic of Indonesia, or BRGM, for being an excellent partner in this research, not only in terms of funding, but also in terms of guidance and direction throughout the research. Thank you to the Ministry of Fishery and Marine Affairs of the Republic of Indonesia and the Department of Marine Affairs and Fisheries of Kutai Kartanegara for providing research equipment, facilities, and infrastructure. Thanks to CV Borneo Seaweed Group for providing research facilities and infrastructure, as well as Bapak Basri, who manages the embankment, for his assistance during the research. Mulawarman University's Faculty of Fishery and Marine Sciences, as well as all lecturers and students, have helped to ensure the success of this research.

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