

Economic And Environmental Sustainability In Silvofishery Of Mangrove Ecosystem In Ogan Komering Ilir Protected Forest, Ogan Komering Ilir Regency, Indonesia

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1 **Economic And Environmental Sustainability In Silvofishery Of Mangrove Ecosystem In**
2 **Ogan Komering Ilir Protected Forest, Ogan Komering Ilir Regency, Indonesia**

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12
13 **Abstract**

14 The Ogan Komering Ilir Protected Forest (OKIPF) area in South Sumatra, Indonesia, has
15 experienced significant degradation due to land conversion into ponds, which has hurt the
16 mangrove ecosystem and the socioeconomic life of the local community. Silvofishery is
17 implemented to curb the rate of illegal conversion while improving the welfare of the
18 surrounding community. This study aims to determine the impact of silvofishery
19 implementation on economic sustainability and the sustainability of mangrove forests. This
20 study uses a quantitative descriptive approach, which was conducted by the survey. The
21 subjects of the economic sustainability study were Pond farmers, The head of the farmer group,
22 The head of the KPH, The Head of the BPDAS HL, and The Social Forestry Facilitator. At the
23 same time, The Object of the study is the sustainability of the mangrove environment,
24 vegetation, and species with high economic value. At the same time, they were sampling
25 vegetation and species with high economic value using a 100-200 meter transect perpendicular
26 to the coastline. The sample was selected purposively, with as many as 65 respondents. Data
27 collection was carried out through observation, documentation, and interviews. Data analysis
28 used the Normalized Difference Vegetation Index (NDVI) to evaluate the ecological conditions
29 of the mangrove forest. Analysis of income, revenue-cost ratio, break-even point, net present
30 value, net benefit-cost ratio, and internal rate of return to assess the economic sustainability of
31 silvofishery. Percentage analysis and poverty threshold to determine the welfare of pond
32 farmers. The study results indicate that the silvofishery system contributes to the restoration of
33 the mangrove ecosystem and increased biodiversity. The economic sustainability of the
34 silvofishery system is seen in the increase in farmer income and the feasibility of long-term
35 investment and strengthened one-way analysis of variance (ANOVA) to determine the
36 difference between traditional ponds and silvofishery system ponds. The study results show
37 that silvofishery can improve the welfare of pond farmers. Implementing the silvofishery
38 system offers a promising solution to overcome the dilemma between short-term economic
39 needs and long-term ecological sustainability. The practice of silvofishery system cultivation
40 can bring economic and environmental benefits simultaneously. This study introduces a new
41 perspective by showing the integrated benefits of the silvofishery system. It recommends
42 stakeholder commitment and cooperation to promote the silvofishery system as a sustainable
43 cultivation model.

44
45 **Keywords:** Silvofishery, Forest Degradation, Farmer Welfare, Ecological Sustainability.

46
47 **BACKGROUND**

48 The Ogan Komering Ilir Protected Forest (OKIPF) is a mangrove forest area of great
49 ecological, economic, and social importance. Still, external pressures and increasing land

50 conservation have resulted in significant degradation in recent years. OKIPF is managed under
51 PFMU (Protected Forest Management Unit) Region IV Sungai Lumpur Riding OKI Regency.
52 The physical function of the mangrove ecosystem plays an important role in protecting the
53 coast from storms, abrasion, and wind (da Costa et al., 2016; Fithor et al., 2019; Salampessy
54 et al., 2015; Sumarmi & Purwanto, 2017). The ecological function of the mangrove ecosystem
55 plays an important role for various aquatic and terrestrial organisms; mangrove forests as a
56 place to find food, breed, and provide care (Amjad et al., 2016; Bachri & Abdullah, 2020;
57 Sarath & Puthur, 2021). The economic function of the mangrove ecosystem plays an important
58 role as a source of livelihood for communities around the forest (Putra et al., 2019; Sumarmi
59 et al., 2019, 2020, 2022). Apart from that, mangrove ecosystems also play an important role in
60 controlling global climate through carbon sequestration (Gnanamoorthy et al., 2020;
61 Jennerjahn et al., 2017; Osland et al., 2017; Sumarmi et al., 2021; Wang & Gu, 2021).

62 The economic activities of the people who benefit from the OKIPF area are based on the
63 characteristics of an agricultural society. Agriculture, plantations, and ponds are characteristics
64 of an agrarian society (Mithun et al., 2021; Popp et al., 2019; Su et al., 2020; Sumarmi, 2018).
65 Agriculture, forestry, and fisheries in 2022 in Ogan Komering Ilir Regency will contribute the
66 largest GRDP (Gross Regional Domestic Product), namely 60.07 percent or
67 IDR13,212,080,000. All Ogan Komering Ilir Regency pond fishing activities are carried out in
68 the OKIPF area (BPS OKI, 2023). BPS OKI noted that in 2022, the number of pond farming
69 families in Ogan Komering Ilir Regency will be 18,166 families, with pond production of
70 52,210,846 tons (BPS OKI, 2023).

71 OKIPF was designated as a protected forest on 10 February 2010. The area of OKIPF is
72 70,003 Ha of protected forest, and the function of production forest is 544,172 Ha. Despite its
73 status as a protected area, OKIPF continues to experience external pressure, which causes the
74 area of this mangrove forest to decline due to land conversion. The results of Landsat image
75 analysis in 2013 and 2023 showed that OKIPF mangrove land degradation was 28.54% of the
76 protected area. The leading cause of the reduction in mangrove forests is land conversion into
77 agricultural land, coconut plantations, and traditional ponds (Eddy et al., 2021; Utomo &
78 Septinar, 2022a). This finding is in line with global findings that tropical forest degradation is
79 mainly caused by human factors (Duguma et al., 2019; Eddy et al., 2022; Houghton, 2012;
80 Kleinschroth & Healey, 2017; Tegegne et al., 2016; Tun et al., 2021; Zeb et al., 2019). Thus,
81 HLOKI is experiencing local degradation and reflects global challenges in forest conservation
82 and climate change mitigation.

83 The impact of reducing the area of primary and secondary forests in the OKIPF area causes
84 damage to the mangrove ecosystem (Eddy et al., 2023; Hasan et al., 2021; Rudianto et al.,
85 2020). Damage to the ecosystem causes the disappearance of various living creatures, such as
86 fish and land animals (Nichols et al., 2019). It even harms the farmers by reducing pond
87 production (R. B. A. Nugraha et al., 2019; Ronnback, 1999). Farmers' losses from decreasing
88 production levels have declined by an average of 19 percent over the last eight years (BPS
89 OKI, 2023). Apart from being detrimental to pond farmers, it also harms fishermen who catch
90 fish in the sea around the OKIPF area because their fish catch is reduced by 1.4 percent yearly
91 (BPS OKI, 2023). The number of fishermen who depend on fishing in the sea along the east
92 coast of the OKIPF area in 2022 will be 12,394 families (BPS OKI, 2023).

93 Given the complexity of this problem, innovative approaches such as silvofishery have
94 emerged as promising solutions. Silvofishery is a pattern of fish, shrimp, and other types of
95 cultivation combined with mangrove plants (Fitzgerald, 2002; McSherry et al., 2023). The
96 principle of silvofishery is protecting mangroves and producing fish together. Recent studies,
97 such as those conducted by Musa et al. (2020) and Perwitasari et al. (2020), show that
98 silvofishery not only improves water and soil quality in ponds but can also maintain the
99 sustainability of mangrove forests (Musa, Mahmudi, et al., 2020a; Perwitasari et al., 2020).
100 Therefore, silvofishery can be considered a sustainable alternative to overcome forest damage
101 while improving the welfare of local communities. This contrasts traditional ponds that damage
102 mangroves because farmers prioritize pond expansion at the expense of mangroves (Tinh et al.,
103 2022; Tran et al., 2024).

104 The government currently accommodates legal access to area management in protected
105 forests through social forestry programs (Permen LHK No. 9, 2021). One form of technical
106 approach to social forestry is the silvofishery system. People who want to get approval for
107 social forestry, namely people, both individuals and groups, who have used the forest for at
108 least 5 (five) consecutive years. Based on information from the Head of KPH Region IV Sungai
109 Lumpur Riding, the community around the OKIPF area had been managing ponds long before
110 OKIPF, Ogan Komering Ilir Regency, was designated a Protected Forest in 2010.

111 Research on mangrove sustainability has been widely conducted (Hua et al., 2024;
112 Setiacahyandari & Hizbaron, 2024; Utomo & Septinar, 2022b), and research on mangrove
113 economic sustainability has also been widely conducted (Musa, Mahmudi, et al., 2020b;
114 Wulandari et al., 2022; Zhang et al., 2024). However, research on mangroves and economic
115 sustainability is still separate. This article combines the analysis of mangrove sustainability and

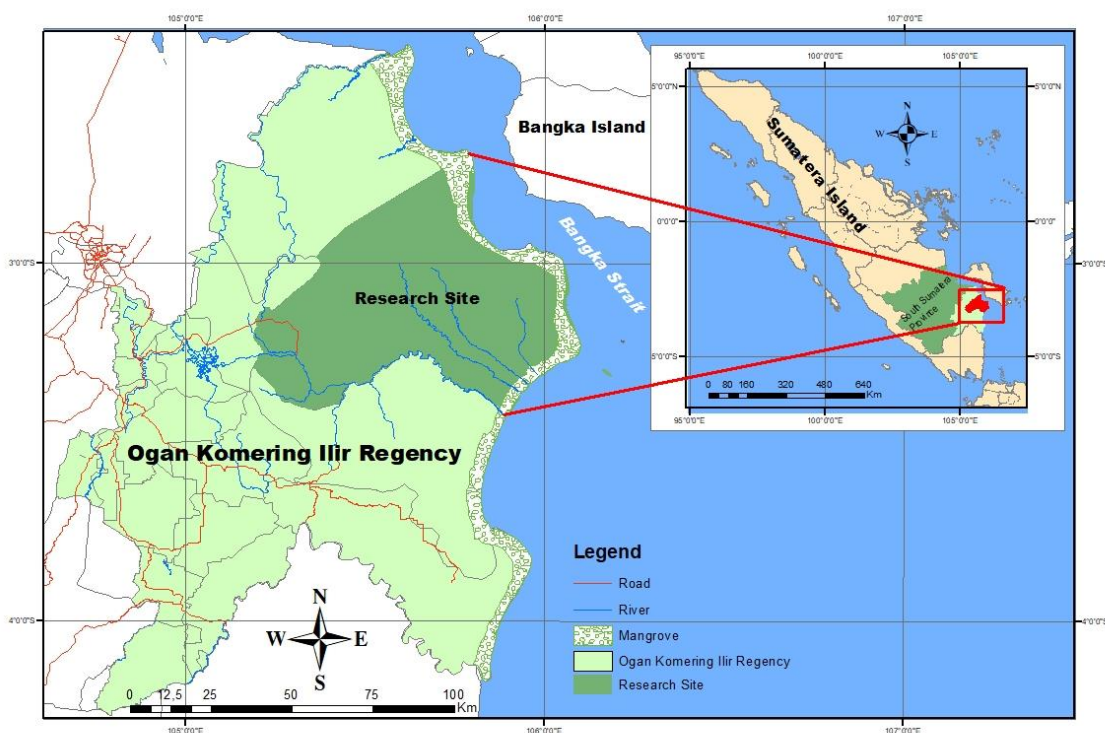
116 mangrove economic sustainability comprehensively. This article can significantly contribute
117 to solid ecological conservation policies impacting a sustainable economy.

118

119 **METHOD**

120 **Research sites**

121 This research was conducted at OKIPF and focused on Tulung Selatan District. The
122 research location was selected because Tulung Selatan District has implemented a silvofishery
123 system fish pond cultivation since 2020, with a silvofishery system pond area of 230 Ha, which
124 increased to 480 ha in 2021 (Figure 1).



125

126 Figure 1. Research Site, South Sumatra, Indonesia

127 The communities involved are the Peduli Mangrove Group (Mangrove Care Group),
128 Bakau Abadi Group (Eternal Mangrove Group), Bakau Jaya Abadi Group (Eternal Glory
129 Mangrove Group), Hutan Mangrove Group (Mangrove Forest Graoup), Sumber Jaya Graoup
130 (Source of Glory Graoup), Sumber Rejeki Graoup (Source of Prosperity Graoup), Lestari
131 Mangrove Hijau Graoup (Sustainable Green Mangrove Group), Mekar Hijau Group (Green
132 Bloom Graoup), and Sumber Makmur Group (Prosperous Source Group). The ponds in Tulung
133 Selatan District are all located in the Protected Forest Area of KPHL Region IV Sungai Lumpur
134 Riding (Table 1).

135
136
137
138

Table 1. Group name silvofishery system pond

No	Group Name (In Indonesian)	Group Name (In English)	Planting Area (Ha)	Planting Year
1	Peduli Mangrove	Mangrove Care	60	2020
2	Bakau Abadi	Eternal Mangrove	60	
3	Bakau Jaya Abadi	Eternal Glory Mangrove	60	
4	Hutan Mangrove	Mangrove Forest	50	
1	Sumber Jaya	Source of Glory	50	2021
2	Sumber Rejeki	Source of Prosperity	50	
3	Lestari Mangrove Hijau	Sustainable Green Mangrove	50	
4	Mekar Hijau	Green Bloom	50	
5	Sumber Makmur	Prosperous Source	50	
Total			480	

139

140 **Research data**

141 Data collection for the economic feasibility of silvofishery consists of primary and
 142 secondary data (Table 2). Secondary data is in the form of data on pond area, pond history,
 143 ownership status, number of farmers, institution of the farmer group, and members of the
 144 farmer group. Meanwhile, primary data is in the form of area of pond ownership, the status of
 145 pond ownership, types of commodities cultivated, number of workers, labor wages, amount of
 146 costs that must be incurred from start to harvest, capital owned, amount of production, selling
 147 price of commodities per kilogram, quantity income, equipment used, number of family
 148 dependents, and investments made.

149 Table 2. Data collection methods for economic feasibility analysis of silvofishery ponds and
 150 traditional ponds

Shrimp Farmers Group	Silvofishery System Ponds	Traditional Pond
Population	656 people	4 192 people
Sample	45 people	20 people
Reasons why the Pond Farmers Group was surveyed	Shrimp farmers who have implemented <i>silvofishery ponds</i>	Shrimp farmers who have implemented traditional shrimp farming
Technical Survey Approach	Secondary data collection and semi-structured interviews	Secondary data collection and semi-structured interviews
Survey Date (Month/Year)	March - April 2023 October - December 2023	March - April 2023 October - December 2023

Interviewees and Functions	Their	<ul style="list-style-type: none"> • Head of KPH (Government party responsible for managing protected forests) • Head of BPDAS HL (Government is responsible for managing river basin areas) • Social Forestry Facilitator (Non-Government facilitating silvofishery ponds) • Head of Silvofishery Farmers Group • Members of the Silvofishery Farmers Group 	<ul style="list-style-type: none"> • Head of KPH (Government party responsible for managing protected forests) • Head of BPDAS HL (Government is responsible for managing river basin areas) • Social Forestry Facilitator (Non-Government facilitating silvofishery ponds) • Traditional Fish Farmers
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151

152 Meanwhile, vegetation and species with high economic value were sampled using the
 153 *transect technique* by establishing six stations. Observation. Samples were taken at each
 154 observation station. A number of *transect lines* of 100-200 meters were set perpendicular to
 155 the coastline, stretching from the sea boundary where mangroves grow to the land boundary
 156 where mangroves still grow. At each transect, observation plots were placed for tree-level
 157 plants, saplings, seedlings/understory plants, and species with high economic value at the
 158 sampling location.

159 **Data analysis**

160 **a. Ecological analysis.**

161 Ecological condition of mangroves using the *Normalized Difference Vegetation Index*
 162 (*NDVI*) method. The data analyzed combines 654 bands from CITA Landsat 8 Operational
 163 Land Imager (OLI) sensors. Field surveys are recommended to validate the identification of
 164 CITA Landsat. The NDVI formula used is $NDVI = (Band\ 5 - Band\ 4) / (Band\ 5 + Band\ 4)$
 165 (D’Ercole et al., 2024). From the calculation of the results, the NDVI value will produce a
 166 value of -1 to 1. Then, If NDVI value ≥ 0.22 conditions sustainable mangrove forests, and vice
 167 versa, NDVI < 0.22 conditions damaged mangrove forests.

168 The result data analysis image satellite was then cross-checked in the field. Then, the
 169 analysis of Vegetation and animal biodiversity data used quantitative analysis, namely by
 170 calculating the Important Value Index (INP) and the Shannon Diversity Index (H'). The
 171 number of trees and the base area were calculated for each type of plant at the tree level

172 obtained in each plot. For each animal obtained in each plot, the number of animals in each
173 plot area was calculated. This data is used to determine the density value (individuals/ha),
174 frequency (%) and dominance (m/ha) of each type of plant and animal so that the relative values
175 of density, frequency and dominance are obtained, which are used to calculate the INP (Neelo
176 et al., 2015). H' is used to calculate the diversity index of plant and animal species (Herrera et
177 al., 2023), with categories of very high ($H' \geq 4$), high ($4 \geq H' \geq 3$), medium ($3 \geq H' \geq 2$), low
178 ($2 \geq H' \geq 1$) and very low ($H' \leq 1$).

179

180 **b. An analysis of economic sustainability.**

181 Analysis of the economic sustainability of silvofishery in the mangrove ecosystem in
182 PFMU Region IV Sungai Lumpur Riding using financial analysis. Financial analysis is carried
183 out through business analysis and investment criteria analysis. The first stage begins with an
184 analysis of business income. The purpose of this analysis is to determine the amount of profit
185 obtained from a business activity. Mathematically, the analysis of silvofishery business income
186 can be formulated as follows:

187
$$\Pi = TR - TC$$

188 Where Π = income (IDR), TR = total revenue (IDR), TC = total cost (IDR), which consists
189 of FC (fixed price) and VC (variable cost). Where $TR > TC$, the silvofishery business is
190 profitable, $TR = TC$, the silvofishery business is at the break-even point, and $TR < TC$, the
191 silvofishery business is at a loss.

192 The next stage is a revenue-cost ratio analysis to determine to what extent each rupiah
193 value (cost) used in business activities can provide a certain amount of revenue value as a
194 benefit. The revenue and cost balance analysis is formulated as follows:

195
$$R/C = \frac{TR}{TC}$$

196 Where $R/C > 1$, the silvofishery business is profitable, $R/C = 1$, the silvofishery business
197 is at the breakeven point, and $R/C < 1$, the silvofishery business is at a loss.

198 The third business analysis stage is BEP (break-even point) analysis, a value where the
199 results of production sales (revenues) equal production costs so that the entrepreneur
200 experiences a break-even point. In pond farming, the BEP value shows the minimum annual
201 income that farmers must obtain so that they can return their capital.

202
$$BEP: \frac{FC}{1 - \frac{CV}{GI}}$$

203 The next stage of investment criteria analysis begins with net present value analysis. Net
 204 present value analysis is the difference between benefits' total present value and costs' present
 205 value at a certain interest rate. Formula used:

$$206 \text{ NPV} = \sum_{t=1}^n \frac{B_t - C_t}{(1-i)^t}$$

207 Where NPV = net present value, B_t = gross benefit from a project in year t , C_t = gross
 208 costs from a project in year t , i = prevailing interest rate, n = year, and t = time.

209 The second stage is the net benefit-cost ratio (net B/C ratio) analysis. Net benefit-cost ratio
 210 analysis compares the total NPV of net benefits to the total net costs. The formula used is:

$$211 \text{ Net B/C ratio} = \frac{\sum_{t=1}^n \frac{B_t - C_t}{(1-i)^t}}{\sum_{t=1}^n \frac{C_t - B_t}{(1-i)^t}}$$

212 Where the net B/C ratio is > 1 , the silvofishery business is worth running; if the net B/C
 213 ratio is < 1 , the silvofishery business is not worth running.

214 The final stage is IRR (internal rate of return) analysis. IRR analysis is an interest rate that
 215 shows the net present value (NPV) is equal to the sum of all project investment costs, or NPV
 216 is zero. The reference interest rate is Bank Rakyat Indonesia in 2023, which is 8% per year
 217 (BRI, 2023). The formula used is:

$$218 \text{ IRR} = i' + \frac{\text{NPV}'}{\text{NPV}' - \text{NPV}''} (i'' - i')$$

219 Where i = A low-interest rate, which causes the NPV to be still positive, close to zero, i''
 220 = A high-interest rate, which causes a negative NPV to approach zero, NPV' = positive NPV
 221 close to zero, and NPV'' = negative NPV close to zero. Whatever the interpretation criteria,
 222 $\text{IRR} > i$: then the silvofishery business is worth running, $\text{IRR} < i$: then the silvofishery business
 223 is not worth running, $\text{IRR} = i$: then the silvofishery business returns capital exactly at the level
 224 of capital.

225 Further analysis of welfare begins with an analysis of the income contribution from the
 226 aquaculture sector to family income, which can be used to see how significant the percentage
 227 of aquaculture business is in terms of total revenue for one year. The formula used is:

$$228 \text{ KSP} = \frac{Y_p}{Y} \times 100\%$$

229 Where KSP = Contribution to pond business income (%), Y_p = Income from pond business
 230 (Rp/year), and Y = Total family income (Rp/year).

231 Analysis of welfare levels uses the poverty line figure in rural areas according to Sajogyo's
 232 (1996) theory, which states that the equivalent annual income for rice is 320 kg/person/year. It
 233 is said to be poor if the income is below 320 kg/person/year, it is said to be at the poverty

234 threshold if the income is the same as 320 kg/person/year, and it is said to be prosperous if the
235 income is above 320 kg/person/year. Apart from that, we also use welfare level analysis using
236 the poverty limit developed by Word Bank, namely \$2.15 per person/day (Andres Castaneda
237 Aguilar et al., 2023).

238 Determination of the economic sustainability of the silvofishery system pond business is
239 based on three criteria, namely Net B/C ratio > 1, IRR > 1, and the business results are to
240 improve the welfare of the farmer's family. To determine the differences between traditional
241 ponds and silvofishery system ponds, a one-way analysis of variance (ANOVA) was used.
242 Before conducting ANOVA, data normality was tested using the Kolmogorov-Smirnov Test
243 with a p-value greater than 0.05, indicating that the data were normally distributed. In addition,
244 homogeneity of variance was evaluated using the Levene test, with a p-value greater than 0.05
245 confirming the same variance across groups.

246

247 **RESULTS**

248 **a. Condition of the Ogan Komering Ilir Protected Forest Area**

249 Identification of the OKIPF area is based on NDVI analysis. NDVI is used due to its high
250 accuracy for vegetation cover analysis (Neinavaz et al., 2020; Spadoni et al., 2020; Xu et al.,
251 2022). Based on NDVI analysis, we divide land cover into four types, namely thick mangrove
252 forests, medium mangrove forests, sparse mangrove forests, and ponds. The existence of ponds
253 in the OKIPF area is due to the conversion of forests into ponds.

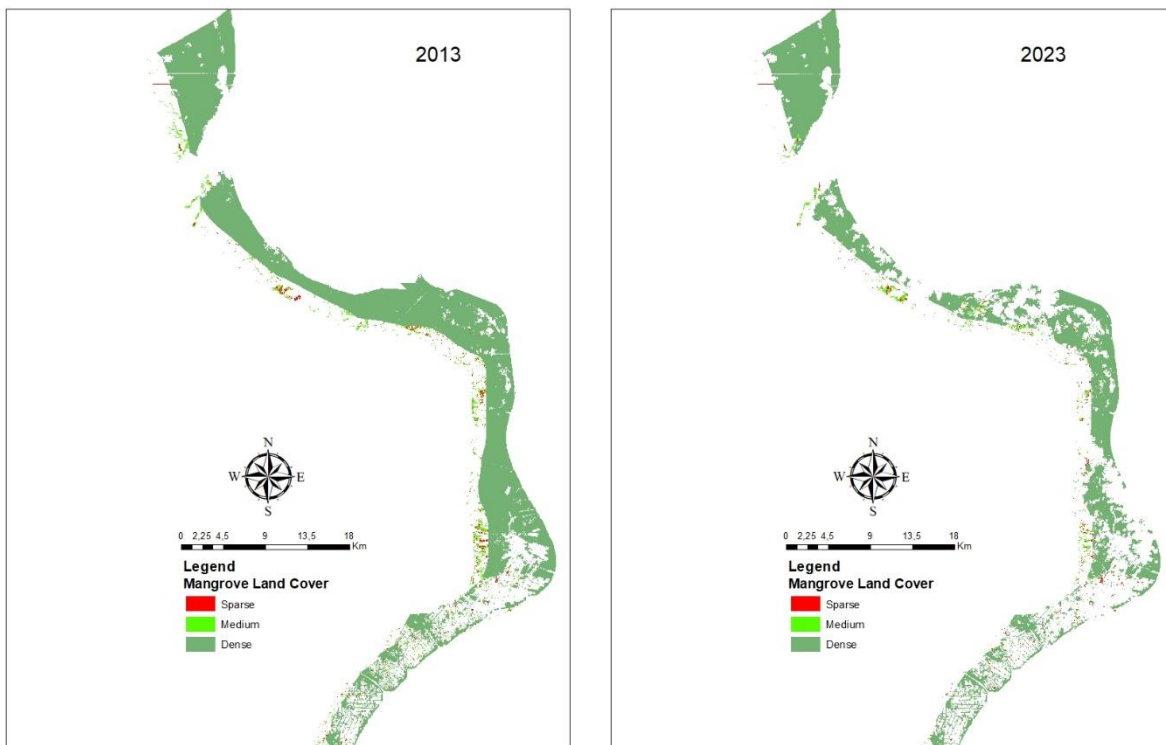
254 The OKIPF area was designated as a protected forest based on the Decree of the Minister
255 of Forestry Number: SK.76/Menhut-II/2010. When in 2010, the OKIPF area was designated
256 as a protected forest; its area was 70,003 Ha. The condition of the OKIPF area until 2013
257 continues to be deforestation of mangrove forests, reaching 36,392.95 Ha or 51.99%, and in
258 2023, there will continue to be deforestation of 46,281.60 Ha or 66.11% of mangrove forests.
259 So, the remaining OKIPF area in 2023 will have a forest cover of 23,721.40 Ha or 33.89%
260 (Table 3).

261 Table 3. The Mangrove Forest In The OKIPF Area, South Sumatra In 2013, and 2023

No	Mangrove forests	2013 (Ha)	2023 (Ha)
1	Dense Mangrove	30,470.76	21,774.88
2	Medium Mangrove	2,103.04	11,022.03
3	Sparse Mangrove	1,036.25	813.14
4	Pond	36,392.95	46,281.6

262

263 In the OKIPF area, over the last 11 years, from 2013 to 2023, there have been varying
264 degrees of deforestation of mangrove forests (Figure 3). Deforestation of mangrove forests can
265 be seen from the reduction in the area for each density. Dense mangrove forests saw a decrease
266 in area of 8,695.88 Ha or 28.54% from the area in 2013. Mangrove forests with medium density
267 saw an increase in area of 969.66 Ha or 46.12% from the area in 2013. Mangrove forests with
268 rare density saw a reduction of 223.11 Ha in area or 21.53% of the 2013 area. The pattern of
269 mangrove forest deforestation in the OKIPF area starts from the south towards the north (Figure
270 2). Pressure to expand pond areas has caused significant degradation of mangrove forest areas.
271 Conversion of mangrove forests into traditional ponds causes long-term losses.



272
273 Figure 2. The Mangrove Forest In The OKIPF Area, South Sumatra In 2013, and 2023.

274
275 The mangrove forests in OKIPF are quite diverse. Seven types of mangroves are found in
276 OKIPF (Table 4). The dominant mangroves in OKIPF belong to the *Rhizophora* sp group,
277 *Avicennia* sp., and *Sonneratia* sp. The many types of mangrove forests in Kawawan OKIPF
278 attract fish, shrimp, and crabs to breed and find food. The roots of several mangrove plants
279 such as *Rhizophora* sp., *Avicennia* sp., and *Sonneratia* sp., the condition of the forest floor, and
280 the interconnected channels that protect the larvae of various marine populations. Conditions
281 like these are also important because they provide spawning and rearing areas and feeding areas
282 for many small fish and shrimp.

283 Table 4. Types of mangroves in the OKIPF area, South Sumatra

No	Latin name	Local Name
1	Rhizophora sp	Bakau
2	Avicennia sp	Api- Api
3	Sonneratia sp	Pedada
4	Brugulera sp	Tanjang putih
5	Kandelia sp	Candel
6	Ceriops sp	Tengar
7	Nypa fruticans	Nipah

284

285 The mangrove ecosystem is a habitat for fish, crabs, and crustaceans and has high
 286 economic value. The results of field surveys and fishermen's catches looking for fish, crabs,
 287 and shrimp in Kawawan OKIPF found 16 species (Table 5). The species with high economic
 288 value include tiger prawns, white prawns, mangrove crabs, milkfish, white snapper, Sembilan,
 289 and grouper. The remaining species need to be more marketable. Generally, crabs live under
 290 mangroves, making holes. The existence of crabs is a way of decomposing mangrove litter by
 291 eating it.

292 Meanwhile, fish and shrimp are in the water, both in water channels and in puddles under
 293 mangrove trees. The results of interviews with fishermen at the research location reported that
 294 shrimp and fish were much more plentiful and easy to find before the opening of traditional
 295 ponds from the mangrove forest.

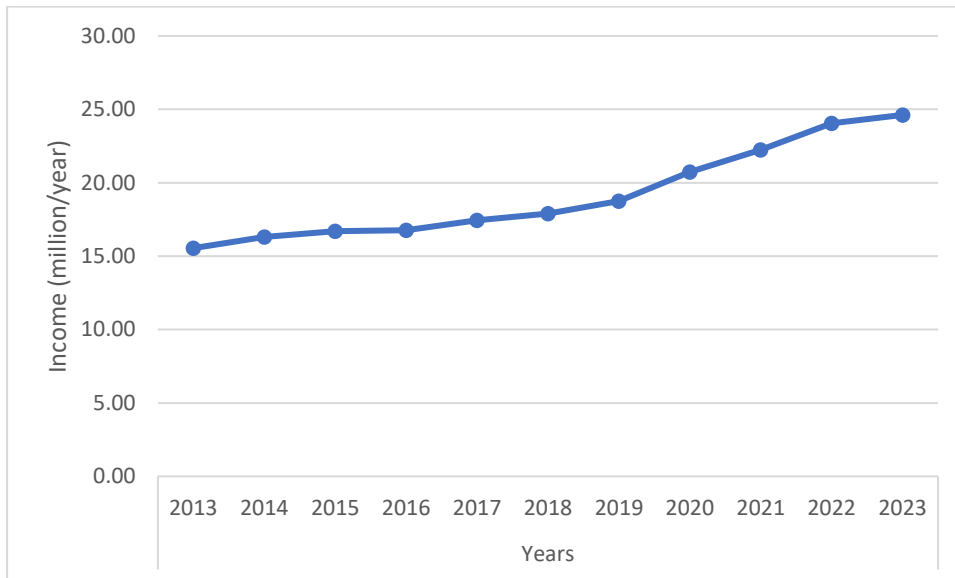
296 Table 5. Fish Species, Shrimp and Crab Found in The OKIPF Area, South Sumatra

No	Species	Local Name
1	Penaeus monodon	Udang Windu
2	Penaeus indicus	Udang Putih
3	Scylla sp.	Kepiting Bakau
4.	Uca Sp.	Kepiting Biola
5	Otolithoides biauritus	Terusan Perak
6	Muraenesox Bagio	Pucuk Nipah
7	Chanos chanos	Bandeng
8	Chelon subviridis	Belanak
9	Setipinna breviceps	Pupuk Kuning
10	Boleophthalmus pectinirostris	Gelodok
11	Gymnura poecilura	Pare
12	Late calcarifer	Kakap Putih
13	Plotosus lineatus	Sembilang
14	Mystus singaringan	Lundu
15	Scatophagus argus	Kiper
16	Epinephelus coiodes	Kerapu

297

298 What is interesting about this research is that converting mangrove forests into traditional
 299 ponds from an economic perspective increases the income of the surrounding community.

300 Tulung Selapan District is a regional administrative area. OKIPF residents earn their living as
301 pond farmers and fishermen. Tulung Selapan District, with the characteristics of a coastal area,
302 has residents who depend on fishing for their livelihood. BPS OKI Regency 2024 recorded the
303 number of fishing households at 4,848 families out of 12,023 agricultural households, or 40.32
304 percent. Tulung Selapan District residents' income from 2013 to 2023 continues to increase
305 (figure 4). The highest income was IDR. 24,619,226 in 2023. The average income from shrimp
306 and milkfish farming is IDR. 19.18 million/year.



307

308 Figure 3. Income in the Tulung Selapan District, South Sumatra in 2013, and 2023

309 Tulung Selapan District residents' income is obtained from fish and shrimp cultivation by
310 converting mangrove forests into ponds. The impact of conversion is converting mangrove
311 forests into ponds, namely the reduction in area and degradation of protected forests. Protected
312 forests are supposed to be protected, but their area continues to be reduced. On the other hand,
313 the residents of Tulung Selapan District are becoming increasingly prosperous from the
314 cultivation of traditional ponds.

315 To slow down the rate of conversion of mangrove forests into ponds, the Indonesian
316 Government created a national economic recovery (PEN) policy. The PEN program is
317 implementing a silvofishery system pond covering an area of 230 Ha in 2020, and in 2021, it
318 will be 250 Ha. So, the total is 480 Ha of silvofishery system ponds. The silvofishery system
319 is fish and shrimp cultivation integrated with mangrove plants. Mangrove plants of the
320 *Rhizophora* sp type were chosen to be planted in ponds, between plants for cultivating fish and
321 shrimp (Figure 4).



322

323 Figure 4. System pond silvofishery.

324 System silvofishery, which integrates mangrove planting within the pond, offers an elegant
325 solution. The research results show that this system has proven effective in curbing the
326 conversion of mangrove forests into ponds. Furthermore, this approach allows the restoration
327 of degraded mangrove ecosystems while enriching biodiversity in and around ponds.
328 Communities that initially destructively managed ponds by expanding ponds by cutting down
329 mangrove forests are now switching to more sustainable practices. They are becoming more
330 aware that converting mangrove forests into traditional ponds damages the environment and
331 reduces the area's long-term ecological and economic resilience. With the silvofishery system,
332 people can increase the productivity of their ponds while improving and maintaining the health
333 of the mangrove ecosystem.

334 The research results show that the implementation of silvofishery not only improves the
335 ecological conditions of coastal areas but also increases biodiversity. Planting mangrove trees
336 in pond systems attracts various types of fauna, from fish to birds, which use this new habitat
337 to breed and find food. This way, silvofishery enriches the pond ecosystem and its
338 surroundings, creating a healthier and more productive environment.

339 The implementation of the silvofishery system, thus, is a significant step forward in the
340 Indonesian government's efforts to achieve sustainable development. This is a real example of
341 how the Indonesian government can manage Indonesia's natural resources to benefit both
342 people and the environment. The Indonesian government can balance economic needs and
343 environmental conservation through this integrative approach, securing a greener and more
344 sustainable future for future generations.

345

346 **b. Economic sustainability analysis.**

347 The OKIPF area has high economic potential but continues to be degraded due to land use
348 as ponds. In 2020, the government will continue with 2021 by rehabilitating protected forests

349 converted into ponds using an intercropping system, better known as silvofishery. The
 350 silvofishery pattern is a model that utilizes mangrove forests combined with ponds. The
 351 existing mangroves result from mangrove restoration in traditional ponds carried out by the
 352 Indonesian Government through BPDAS HL Musi in collaboration with local fish farmers. The
 353 implementation of mangrove planting in traditional ponds in 2020 covered an area of 230 ha
 354 with 396 farmers involved, divided into four groups. The names of the groups are Mangrove
 355 Care, Bakau Abadi, Bakau Jaya Abadi, and Mangrove Forest. Meanwhile, in 2021, mangrove
 356 planting in traditional ponds covering an area of 250 ha will involve 260 fish farmers. The
 357 names of the farmer groups are Sumber Jaya, Sumber Rejeki, Lestari Mangrove Hijau, Mekar
 358 Hujau, and Sumber Makmur.

359 The silvofishery pattern is considered the most suitable for mangrove forest conservation
 360 in the OKIPF area. With this pattern, it is hoped that the economic aspects of the community
 361 can be fulfilled through fish and shrimp cultivation activities under mangrove trees. The
 362 activities of planting mangrove forests and building ponds form the concept of social forestry.
 363 The pond used in this research is a traditional pond with mangrove plants that are around 2
 364 years old. The mangroves found in the ponds in this study are of the *Rhizophora* type.
 365 Mangrove plants are planted with a spacing of 5x5 meters, and each hectare contains 1600
 366 stems.

367 Table 6. Financial Analysis of Traditional Pond and Silvofishery Cultivation Businesses in the
 368 OKIPF area, South Sumatra.

No	Business analysis	Average value	
		Traditional	<i>Silvofishery</i>
1	Total Revenue	IDR 18,835,174 /ha/ year	IDR 19,460,000 /ha/ year
2	Total Expenditure	IDR 13,313,676 /ha/ year	IDR 12,925,000 /ha/ year
3	Investment	IDR 24,812,819 /ha/ year	IDR 24,116,331 /ha/ year
4	Benefits (TR-TC)	IDR 5,521,498 /ha/ year	IDR 6,535,000 /ha/ year
5	R/C	1.4	1.5
6	PP (Investment/Benefit x 1 year)	4.6	3.7
7	ROI (Benefit/Investment x 100%)	22%	27 %
8	NPV	IDR 6,001,628 /ha/ year	IDR 7,103,261 /ha/ year
9	Net B/C	1.2	1.3
10	IRR	18 %	19%

369 Information R/C = benefit ratio
 370 PP = Payback periode
 371 ROI = Return on investment
 372 NPV = *Net* present value
 373 Net B/C = *Benefit/Cost Ratio*
 374 IRR = Internal Rate of Return

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The business feasibility analysis in this research is based on business analysis and business feasibility analysis of silvofishery system ponds. Based on the feasibility analysis, the silvofishery system of ponds is more profitable than traditional ponds (Table 6). The profit from silvofishery system ponds is IDR. 6,535,000/year, and traditional ponds produce IDR. 5,521,498/year. The total income of the silvofishery system pond is IDR. 19,460,000/year with a total expenditure of IDR. 12,925,000/year.

In contrast to traditional ponds, the revenue is smaller, namely 18,835,174/year, and what is burdensome for conventional businesses is that the expenditure is greater, namely IDR. 13,313,676/year compared to the silvofishery system. The feasibility of the silvofishery system and traditional ponds was further analyzed from the benefit ratio R/C, payback period, and return on investment (table 4). There is a significant difference in comparison of the benefits between silvofishery system ponds and traditional ponds. Silvofishery system ponds have a faster return on investment, namely 3.7 years of capital return or % return on investment of 27%. Meanwhile, for traditional fish farms, the rate of return on investment is slower, namely 4.6 years of capital return or a return on investment of 22%.

The feasibility of a business must also take into account the investment. This research uses investment criteria: NPV, Net B/C, and IRR. Analysis of investment criteria for traditional pond cultivation and shrimp and milkfish silvofishery in the HLOKI area refers to the interest rate of 8% per year, which will apply in 2023 at Bank Rakyat Indonesia. The NPV value in Silvofishery system ponds is greater than in traditional pond systems (table 6). The NPV value for Silvofishery system ponds is IDR. 7,103,261, while traditional ponds IDR. 6,001,628.

Criteria for investment in traditional and traditional fish ponds over the life of the project business provide a profit of IDR 1.3 and IDR. 1.3 for every rupiah cost incurred with a reference interest rate of 8%. The IRR values are 18 % and n, respectively, 19 % (table 5). In this way, the traditional fish farming system and the traditional fish farming business provide significant internal benefits. It originates from investment , which is held in place between the ages of 19% and 18 % per year. So, it can be concluded that the fish farming system and traditional fish farming business can be carried out sustainably and can even continue to be developed.

409 Table 7. Comparison table of pond statistics traditional with Silvofishery system pond

	Group	N	Mean	SD	DF	Sig. (2-tailed)
Income	Traditional Pond	20	7.29E6	2624923.485	63	.0333
	Silvofishery	45	8.02E6	2857245.077		
Internal rate of return	Traditional Pond	20	17.90	.718	63	.000
	Silvofishery	45	18.67	.707		
Net B/C	Traditional Pond	20	5.52E6	746160.098	63	.000
	Silvofishery	45	6.54E6	747688.559		

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411 Based on the data presented in Table 7, the analysis shows that ponds with the Silvofishery
 412 system significantly have superior economic performance compared to traditional ponds. Key
 413 indicators such as income, internal rate of return (IRR), and benefit-to-cost ratio (Net B/C)
 414 provide consistent profitable results for Silvofishery Ponds. Net income in Silvofishery ponds
 415 is recorded as higher, reflecting production efficiency that integrates ecological approaches
 416 with economic strategies. The Net B/C ratio exceeding one indicates that each unit of cost
 417 incurred provides more significant economic benefits, strengthening this system’s
 418 attractiveness for pond managers. In addition, the higher internal rate of return in Silvofishery
 419 ponds indicates significant investment efficiency, making it a more profitable option than
 420 traditional ponds. The high IRR reflects the project’s financial viability and shows this system’s
 421 ability to accommodate sustainability aspects.

422 The existence of traditional ponds and silvofishery systems has a very big role for pond
 423 farmers in the OKIPF area. The pond business is one of many businesses in the OKIPF area.
 424 They have side businesses, namely fishing and trading. This means that people in the OKIPF
 425 area earn income apart from farming; they also get a side business while waiting for the ponds
 426 to harvest. Based on the calculation results (table 8), the pond business has the largest
 427 contribution compared to side businesses.

428 Table 8. Contribution of Income from Traditional Pond Cultivation and Silvofishery
 429 Businesses in The OKIPF Area, South Sumatra

No	Contribution	Average value	
		Traditional	Silvofishery
1	Pond Income	IDR 18,835,174/ha/ year	IDR 19,460,000/ha/ year
2	Side Income	IDR 6,818,348/ha/ year	IDR 6,744,010/ha/ year
3	Income Contribution	77	78
4	Well-being	Prosperous	Prosperous

430

431 The income contribution of the silvofishery system is large for pond farmers, which is
 432 more profitable than the traditional pond system. The average income of silvofishery system

433 ponds is IDR. 1 9,460,000, or a contribution of 78% of the total revenue received. Meanwhile,
434 the average income of traditional fish farming systems is IDR. 18,835,174 or has a contribution
435 of 77% of the total revenue received. If we look more deeply at both the conventional pond
436 system and the silvofishery system, the welfare of pond farmers, according to the Sajogjo
437 welfare indicator, is 320 kg/person/year or the equivalent of IDR. 4,448,000 person/year with
438 the 2020 rice price of IDR. 13,900/kg. However, if measured by the World Bank poverty line
439 of \$ 2.15 per person/day or the equivalent of Rp. 12,069,864 people/year for \$ 1 as much as
440 Rp. 15,594.15 silvofishery system pond farmers are prosperous, amounting to 6.67% or 3
441 families from 45 samples of silvofishery system pond farmers. This number is higher than
442 prosperous traditional pond farmers, which is 5% or 1 family out of 20 samples of conventional
443 pond farmers. Thus, if farmers choose traditional ponds as their business, it will reduce the
444 existence of mangrove forests even more in the future, so there is a need for an environmentally
445 friendly and prosperous system, namely the silvofishery system.

446

447 **DISCUSSION**

448 **Mangrove Ecosystem Conditions**

449 Mangrove forests are an important ecosystem that plays a role in maintaining ecological
450 balance and supporting the lives of coastal communities. However, economic pressure and the
451 need for land to meet needs have encouraged the conversion of mangrove forests into ponds,
452 especially for shrimp and fish cultivation. This conversion causes significant ecological
453 damage, including reduced mangrove biodiversity and reduced fish and shrimp populations
454 (Carrasquilla-Henao et al., 2019; Sarathchandra et al., 2018). Meanwhile, these land-use
455 changes also impact local communities' income, making a significant contribution to the local
456 economy (Gashaye et al., 2023).

457 Research results show that the conversion of mangrove forests to ponds causes a
458 significant reduction in the area and quality of mangrove habitat, consistent with previous
459 findings (Thomas et al., 2017). This is manifested in the decrease in mangrove species found
460 and the decline in fish and shrimp populations that depend on the mangrove ecosystem (Alongi,
461 2002). In line with research by YA Nugraha et al. (2021), which found a direct relationship
462 between the decline in mangrove areas and fisheries productivity (Y. A. Nugraha et al., 2021).
463 This decline can be attributed to the loss of the ecological function of mangroves as producers
464 of nutrients, protection against erosion, and important habitat for various species (Soedibya et
465 al., 2023). Factors contributing to mangrove forest conversion and destruction include

466 economic pressure on local communities and a lack of awareness of mangrove forests' long-
467 term ecological and monetary value (FAO, 2007).

468 The area was previously a mangrove forest converted into shrimp and milkfish ponds. The
469 number and location are increasing in number and width. Efforts to restore the OKIPF area
470 have been carried out since 2020. This restoration effort was not easy at first because pond
471 farmers felt that the government would take their land and that their results would decrease due
472 to the large number of shrimp and fish predators perching on the branches of the mangrove
473 trees in the pond. Rejection of mangrove restoration occurs not only in the OKIPF area but also
474 in various countries such as the Andaman Islands and Bangladesh (Chakraborty et al., 2019;
475 Rahman & Mahmud, 2018). Restoration efforts start with planting mangrove trees, especially
476 the *Rhizophora* sp type because they are considered suitable for shrimp cultivation. The roots
477 of *Rhizophora* spare in the form of *Tunjang Nyangkang* (Stilt-Roots) as a place for fish and
478 shrimp to hide and spawn (Arceo-Carranza et al., 2021). On the other hand, the conversion of
479 mangrove forests into ponds brings economic improvements to local communities. As revealed
480 by interviews with local communities, income from silvofishery system pond cultivation has
481 doubled compared to traditional pond cultivation.

482 Facts on the ground show that although initially pond farmers felt forced to follow the
483 government program related to the silvofishery system, they later realized that this program
484 provided many economic benefits. The silvofishery system, which combines fish farming with
485 mangrove forest conservation, has proven superior economic performance to traditional ponds.
486 (Fitzgerald, 2002; Musa, Mahmudi, et al., 2020b). This approach supports environmental
487 sustainability and provides significant income for farmers. The average income of ponds with
488 a silvofishery system reaches IDR 19,460,000, contributing to 78% of their total income. This
489 figure is higher than the income from traditional ponds, which on average only reaches IDR
490 18,835,174, contributing 77% of total income.

491 Although the silvofishery system dominates the economic contribution in the Ogan
492 Komering Ilir Protected Forest area of Indonesia, local communities generally have diversified
493 sources of income, such as becoming fishermen or traders. This diversification reflects the
494 community's adaptation to the economic challenges in the area. However, the role of ponds,
495 especially with the silvofishery system, remains the backbone of their income. This shows that
496 the implementation of the silvofishery system not only supports environmental sustainability
497 but also improves the economic welfare of the community. With these results, silvofishery is
498 clear evidence that environmental-based interventions can provide more economic benefits
499 than traditional practices.

500 **The Silvofishery System Pond Business**

501 The silvofishery system pond business ensures that a company can be relied on in the
502 future. Silvofishery systems offer greater economic advantages compared to traditional pond
503 systems. The main advantage of the silvofishery system lies in higher operational cost
504 efficiency and more stable income. This aligns with previous research, which shows that
505 integrating fisheries activities with agroforestry systems can increase productivity and business
506 sustainability (Paramesh et al., 2022).

507 Additionally, silvofishery systems offer significant environmental benefits, including
508 increased biodiversity and reduced negative impacts on mangrove ecosystems (Perwitasari et
509 al., 2020). The success of silvofishery systems in minimizing costs and growing income can be
510 attributed to using more sustainable and environmentally friendly farming practices.
511 Silvofishery ponds have higher total revenues, and large expenses make this system more
512 profitable than traditional systems. This shows the importance of cost efficiency and
513 sustainability in increasing the viability of shrimp farming businesses. In the context of return
514 on investment, the differences between silvofishery and traditional systems highlight the
515 importance of adopting more efficient technologies and methods. The faster rate of return on
516 capital in silvofishery systems shows the potential for financial sustainability and attractiveness
517 for investors (Kamalii et al., 2021; Muthoh et al., 2022).

518 The research results show that the NPV value for the silvofishery system is greater than
519 that of the traditional pond system (table 4). Silvofishery systems have the potential for a higher
520 return on investment than conventional methods (Rahman & Mahmud, 2018). Other
521 investment criteria, such as Net B/C, show that every rupiah of costs incurred provides a profit
522 of IDR. 1.3 for both systems, indicating that both systems are quite efficient in using capital.
523 Meanwhile, the IRR values for the silvofishery system and traditional ponds are 18% and 19%,
524 respectively, indicating that both systems provide significant internal benefits from the
525 investment invested.

526 Greater NPV values indicate higher financial returns. This suggests that the silvofishery
527 system can generate net profits above the initial investment costs more than traditional pond
528 systems. In addition, integrating fish cultivation with mangrove plants can increase
529 biodiversity, reduce erosion, and improve water quality, increasing productivity and
530 environmental sustainability (Musa, Lusiana, et al., 2020). Factors determining investment
531 success in a silvofishery system include strategic location selection, sustainable management
532 of natural resources, appropriate cultivation technology, and access to markets to distribute

533 harvests (Arifanti, 2020). Adequate knowledge and training for farmers or managers is also
534 important in ensuring productivity and operational efficiency.

535 Cultivating the silvofishery system can improve the welfare of pond farmers in the OKIPF
536 area. The existence of ponds, both traditional and through the silvofishery system, plays a
537 significant role in the local economy. However, the research results show that the silvofishery
538 system contributes more to farmers' income than traditional pond systems and offers substantial
539 environmental benefits by preserving mangrove forests.

540 Overall, silvofishery system ponds are economically feasible. Research (Rahman &
541 Mahmud, 2018) has assessed that silvofishery systems in Bangladesh are financially viable for
542 development in the long term. In line with Rahman (Primavera, 2005), research in 5 Southeast
543 Asian countries has shown that the most economically viable silvofishery model integrates
544 crabs with mangroves.

545 It must be pointed out here that the traditional pond system is economically profitable and
546 even makes pond farmers prosperous. However, the silvofishery system is much better. Shorter
547 return on capital and greater profits (table 6). Integrating fish and shrimp with mangroves will
548 provide the distinct advantage of mangrove litter becoming natural food for fish and shrimp
549 (Amjad et al., 2016; Badola & Hussain, 2005; Kathiresan & Bingham, 2001). This advantage
550 will save feed for farmers. In contrast to traditional ponds, feed costs will be higher. These
551 findings inspire farmers that, in the long term, it will be increasingly profitable to cultivate in
552 integrated ponds with mangrove plants. Judging from the sustainability of investment in ponds,
553 both traditional ponds and silvofishery system ponds provide benefits and are worth
554 developing, even in the future. In line with research (Pardona et al., 2016), pond cultivation
555 businesses, both traditional and silvofishery systems, are worthy of development in the future.

556 Furthermore, when comparing the welfare of pond farmers based on the Sajogjo indicator,
557 the silvofishery system shows more profitable results. With the World Bank's poverty threshold
558 of \$2.15 per person per day, the analysis indicates that silvofishery system pond farmers
559 achieve a higher level of welfare, with 6.67% or 3 of the 45 sample families above the poverty
560 line. This is compared to only 5% or 1 in 20 sample families of traditional pond farmers who
561 achieve a similar level of prosperity.

562 It is important to note that the choice of traditional pond systems tends to put greater
563 pressure on the existence of mangrove forests (Eddy et al., 2022). This underlines the
564 importance of transitioning to a silvofishery system that not only improves the welfare of pond
565 farmers through increased income but also protects and maintains mangrove ecosystems.
566 Healthy mangrove ecosystems are key to environmental and local economic sustainability,

567 offering broad ecological benefits, including protection against erosion and habitat for
568 biodiversity (Abidin et al., 2021).

569 Restoration efforts involve local officials, starting from BPDAS HL (Protected Forest
570 Watershed Restoration Agency) of the Ministry of Forestry, KPH (Forest Management Unit)
571 of the forestry service, Village Heads, Community Leaders, and pond owners. Even though at
572 first it was difficult, persuasive efforts to explain the economic and ecological benefits, as well
573 as continuous counseling, finally five groups agreed, namely the Mangrove Abadi Group, the
574 Mangrove Care Group, the Mangrove Forest Group, the Jaya Abadi Mangrove Group, and the
575 Mangrove Lovers Group to restore the ponds with a silvofishery pond system. Environmental
576 education and environmental awareness need to be developed so that the commitment of fish
577 pond farmers continues to grow to maintain sustainable forests, and ultimately, the long-term
578 benefits of protected forests remain sustainable. The community will also become more
579 prosperous.

580

581 **CONCLUSION**

582 Mangrove forests play a crucial role in maintaining ecological balance and supporting the
583 socio-economic life of coastal communities. The conversion of mangrove forests into ponds
584 has had significant negative impacts, including decreased biodiversity and reduced fish and
585 shrimp populations. However, implementing the silvofishery system improves the ecology of
586 mangrove forests and increases biodiversity by planting mangrove trees in ponds. The
587 silvofishery system's economic sustainability can be seen from increasing farmers' income and
588 long-term investment feasibility. The research results are very important that silvofishery can
589 improve the welfare of pond farming communities. Integrating silvofishery systems, which
590 combine shrimp farming with mangrove conservation, has offered a promising solution to
591 overcome this dilemma by providing economic and environmental benefits.

592 The novelty of this research lies in an in-depth economic analysis of the silvofishery
593 system. The study results show that silvofishery is more financially profitable and
594 environmentally sustainable than traditional pond systems. The success of this system is rooted
595 in operational efficiency, increasing biodiversity, and reducing negative impacts on mangrove
596 ecosystems. Thus, investment in silvofishery systems provides higher financial returns and
597 promotes environmental sustainability. This is reinforced by the increased welfare of pond
598 farmers involved in silvofishery systems, indicating that adopting more sustainable farming
599 practices can simultaneously bring economic and ecological benefits.

600 However, this study also acknowledges that there is still room for further research,
601 especially in revealing the physical and ecological benefits of mangroves in more depth and
602 analyzing the suitability of land for optimal mangrove plants for ponds and the most suitable
603 fish species for cultivation. Therefore, commitment and cooperation from all stakeholders,
604 including the government, local communities, and the private sector, are needed not only to
605 promote and implement the *silvofishery system* as a sustainable cultivation model but also.

606

607 **Recommendation**

608 To balance the need for mangrove economy and conservation, we recommend :

- 609 1. Pond system *silvofishery* needs to become a choice. The answer is the need for economy
610 and sustainable management of mangrove forests.
- 611 2. Conversion pond traditional pond system *silvofishery*, so that the ponds are bare without
612 mangrove plants, they become green—lots mangrove plants.
- 613 3. Prioritize the preservation of remaining mangrove forests, with No penetrating mangrove
614 forests again. Increase quality pond system *silvofishery*.
- 615 4. When planting mangroves in ponds, use type suitable plants to grow maximum.
- 616 5. Commitment and cooperation between stakeholders are needed to promote silvofishery
617 systems as a sustainable aquaculture model.

618

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625

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