COASTAL AND OCEAN JOURNAL

Article

The Impact of Mangrove on Water Quality and Milkfish Productivity in The Silvofishery Ponds in Sawojajar Village, Brebes Regency

Rika Novida [1,*], Tatang Mitra Setia [1], Nyoto Santoso [2], and Bambang Widigdo [3]

[1] Program Study of Magister Biology, Faculty of Biology and Agriculture, Nasional University
[2] Department of Forestry Resources Conservation and Ecotourism, Faculty of Forestry and Environment, IPB University
[3] Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, IPB University
* Correspondence: novidarika@gmail.com

Abstract: The mangrove ecosystem plays a crucial role in maintaining coastal ecological balance and providing economic benefits through aquaculture. However, the widespread conversion of mangroves into shrimp ponds has contributed to environmental degradation and increased coastal vulnerability. This study evaluates the effectiveness of the silvofishery system, which integrates mangrove planting with fish farming, in improving water quality and milkfish (*Chanos chanos*) productivity in Sawojajar Village, Brebes Regency. Three types of ponds were analysed: silvofishery with 40% mangrove vegetation (T40), silvofishery with 20% mangrove vegetation (T20), and conventional ponds without mangroves (T0). Water quality parameters, plankton and benthic diversity, and milkfish growth were measured and compared among the ponds. The results indicate that mangrove-integrated ponds exhibited better water quality stabilization, particularly in terms of salinity, pH, and Dissolved Oxygen (DO), which positively influenced overall ecosystem health. Mangrove vegetation also enhanced fish survival rates and supported long-term ecosystem stability. In contrast, conventional ponds exhibited higher short-term productivity but faced greater environmental risks due to unstable water quality. This study underscores the ecological and economic benefits of the silvofishery system as a sustainable model for coastal resource management.

Keywords: silvofishery; mangrove; milkfish

Citation: Novida, R.; Setia, T. M.; Santoso, N.; Widigdo, B., 2025. The Impact of Mangrove on Water Quality and Milkfish Productivity in The Silvofishery Ponds in Sawojajar Village, Brebes Regency. *Coastal and Ocean Journal*, (9)1: 70-86. https://doi.org/10.29244/coj.v9i1.62550

Received: 08-02-2025
Accepted: 14-06-2025
Published: 26-06-2025

Publisher's Note: Coastal and Ocean Journal (COJ) stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Indonesia, as the world's largest archipelagic country, is home to abundant natural resources, including mangrove ecosystems that play crucial role in maintaining coastal ecological balance. Mangroves not only protect coastal areas from abrasion and flooding but also serve as habitats for various flora and fauna, and contribute to carbon sequestration (Alongi, 2012; Suprayitno, 2024). Additionally, mangroves support the coastal economy by providing fisheries resources and non-timber forest product (Munasikhah & Wijayati, 2022).

However, in recent decades, mangrove ecosystems have been under pressure due to land conversion for shrimp and fishponds (FAO, 2020; Hashim, 2021). The increasing demand for food and economic growth has driven the expansion of milkfish and shrimp farming, contributing to a significant reduction in mangrove area (Sambu, 2013). Between 2009 and 2019, approximately 50,696 hectares, or 36% of the total mangrove deforestation in Indonesia, occurred due to conversion for aquaculture ponds (Arifanti *et al*., 2021). The loss of mangroves has led to an increased risk of coastal erosion and a decline in coastal environment quality, resulting in ecosystem degradation and reduced pond productivity (Khairuddin *et al*., 2016; Munasikhah & Wijayati, 2022).

In response to this issue, one approach to preserving mangrove ecosystem is through the silvofishery system. The silvofishery system has been developed as an alternative solution that integrates mangrove conservation with aquaculture in a single pond system (Sambu, 2013; Harefa, 2021). Silvofishery aims to maintain the ecological functions of mangroves while enhancing pond productivity and providing economic benefits to coastal communities (Widigdo *et al*., 2024). The advantages of this system include improved ecosystem stability, provision of habitat for marine organisms, reduced risk of abrasion, and enhanced water quality and availability of natural feed for pond organisms (Purwiyanto, 2014; Hilmi *et al.*, 2019).

Several studies have highlighted the importance of mangrove integration in aquaculture for sustaining water quality and fish productivity. For example, Ilhami *et al.* (2021) emphasized the role of integrated mangrove landscape design in supporting ecosystems based coastal management and silvofishery practices. Nurhayati and Yuliana (2019) demonstrated that water quality parameters significantly influence fish productivity in silvofishery ponds, while Yulianto and Setyawan (2020) reported that mangrove vegetation density directly affects pond water quality and aquaculture yields. These findings align with global sustainability perspectives on silvofishery systems as outlined by FAO (2020), which stress the balance between ecological conservation and aquaculture production.

Despite offering various benefits, the implementation of silvofishery still faces challenges, such as lack of understanding and skills among farmers and limited capital to manage the system optimally. Technical issues that need attention include the ratio between mangrove coverage and water area within single pond unit.

This study aims to analyse the impact of mangrove plantation on water quality and milkfish productivity in the silvofishery system. The results of this study are expected to provide scientific recommendations for more sustainable and environmentally friendly silvofishery pond management, as well as to strengthen mangrove ecosystem conservation efforts. Furthermore, this research is expected to support adaptive coastal management policies in response to environmental and socio-economic changes. Through this approach, the study not only contributes to the development of knowledge in the field of aquaculture and coastal ecology, but also provided scientific evidence for policymakers and stakeholders in formulating more sustainable coastal resource management strategies.

2. Material and Methods

2.1. Time and Location of Research

The study was conducted from May to December 2024, with sampling carried out once a week. This research took place in Sawojajar Village, Brebes Regency, Central Java Province, comparing three types of silvofishery ponds: integrated with mangrove of about 40% mangrove coverage (T40), 20% mangrove coverage (T20), and conventional ponds without mangrove coverage (T0) (Figure 1). All mangrove coverage is from *Rhizopora mucronata* species, and the area of each pond presented in Table 1.

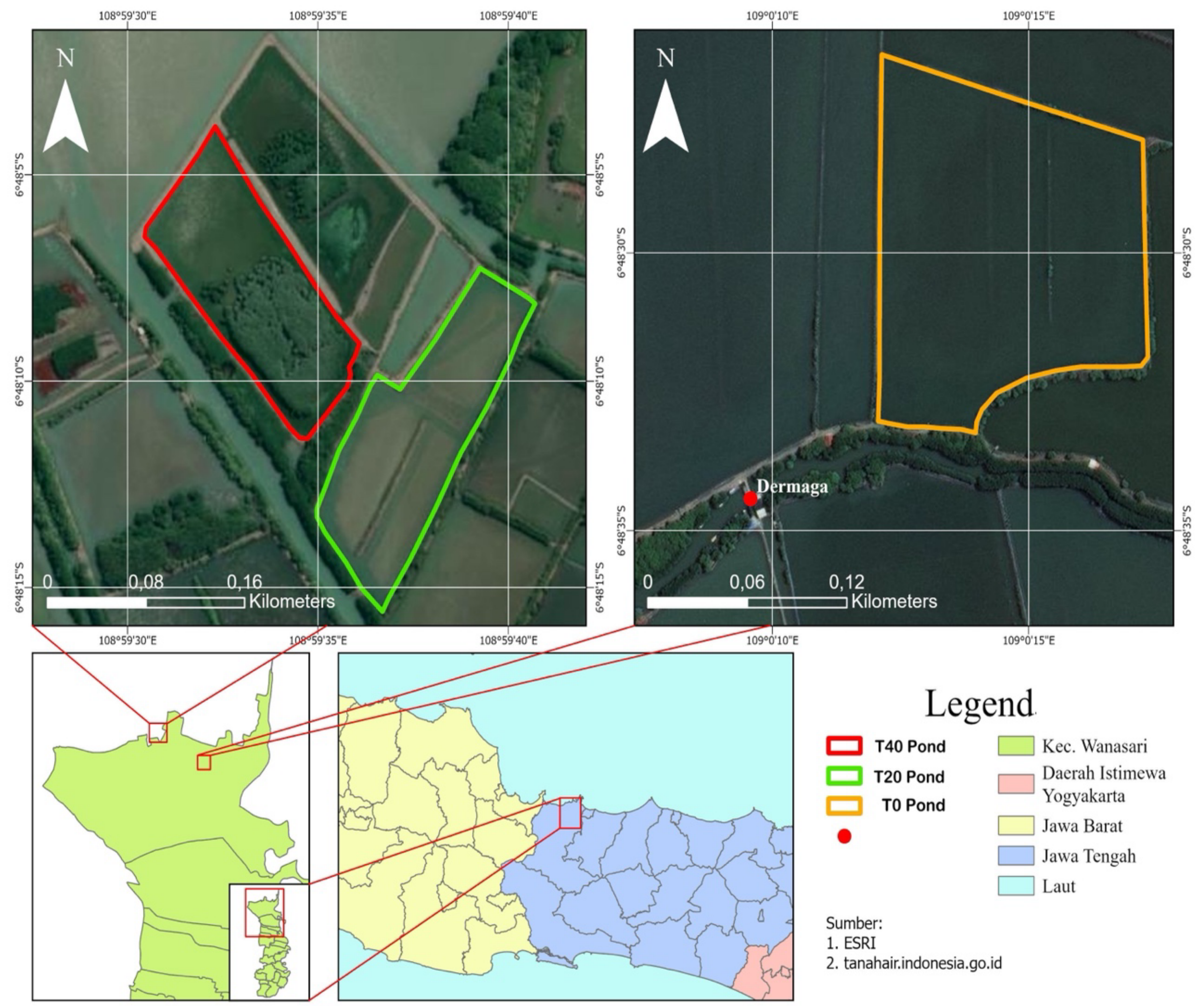

Figure 1. Research location at Sawojajar Village, Brebes Regency

Table 1. The Area of Ponds and Mangrove at the Research Site

Location	Pond area	Mangrove area
T40 pond	1,85 Ha	0,83 Ha
T20 pond	1,8 Ha	0,19 Ha
T0 pond	2,65 Ha	0 Ha

2.2 Data Collection

2.2.1 Water Quality and Nutrient Indicator

The physical parameters were measured in this study include water quality indicators (temperature, salinity, dissolved oxygen (DO), and pH) and nutrients (ammonia, nitrate, nitrite, and phosphate). Water quality parameters were measured using a multi parameter water quality meter, equipped with integrated sensors for real time water quality detection. The device is used by immersing the sensor into the water and selecting the parameters to be measured, with the results automatically displayed on the device's screen. Nutrient concentrations were determined using a nutrient test kit. The process involved transferring a water sample into a reaction tube, adding specific reagent for each parameter, and allowing the reaction to occur for a specified period. After this reaction, the resulting colour was compared to a standard colour chart to determine the nutrient concentration in the water.

2.2.2 Plankton

Plankton samples were collected from the surface of the pond water using a plankton net with a mesh size of 25 μm**.** A total of 60 litres of water was filtered from each pond, and the plankton retained in the net were transferred into 150 ml sample bottles and preserved with 5-10 drops of Lugol's solution. For identification, the samples were examined under a microscope at 40x magnification using a Sedgewick Rafter Cell (SRC).

2.2.3 Bentos

Macrobenthos samples were collected using a grab sampler at three randomly selected sampling points in each pond, representing the study area. The sediment collected was then filtered using a 0.5 m mesh sieve to separate the benthic organism from sediment particles. The filtered benthic organisms were preserved in a 5% formalin solution and stored in sample bottles for further identification.

2.2.4 Milkfish Production

Fish productivity data were obtained through measurements conducted during two stocking periods. For each stocking, the number of fish and their total weight were recorded at the beginning of the cultivation period. Measurements were taken again during harvest to record the number of fish harvested and their total weight. The observed variables included stocking density, which is the number of fish stocked per unit area of the pond at the beginning of cultivation; Survival Rate (SR), which is the percentage of fish survival calculated based on the number of fish harvested compared to the number of fish stocked at the beginning; and the total weigh of fish harvested. Data collection was carried out at each harvest season to calculate the growth rate and productivity of the fish in the pond.

2.3 Data Analysis

Plankton and benthos diversity were analysed using the Shannon Wiener Index to assess environmental quality (Odum, 1971).

$$H' = -\sum(pi \times \ln(pi)) \quad (1)$$

pi = proportion of total sample represented by species-i. Divide number of individuals of species i by total number of samples.
ln(*pi*) = natural logarithm of *pi*

The Shannon Wiener Evenness Index was used to measure the ecological diversity of a community (Odum, 1971).

$$E = \frac{H'}{\ln S} \quad (2)$$

H = Shannon Wiener Diversity Index
lnS = natural logarithm of the total number of species S

The Simpson's Dominance Index is used to assess the dominance of specific species within a community (Odum, 1971).

$$D = \sum_{i=1}^{S} (pi)^2 \quad (3)$$

pi = *ni*/N, *ni* represent the individual numbers of the species-i, and N represents the total number of individuals of all species.
S = The total number of species (or categories) in the community

The study used a descriptive approach to better understand the relationship between mangrove coverage, water quality, and milkfish productivity.

3. Result

3.1 General Conditions of Study Site

Sawojajar Village is in the northern coast of Brebes Regency, Central Java, covering an area of 19,87 km^2 or 1.987 hectares. Most of the land use in the village is dedicated to non-paddy agriculture, covering 1,4073.38 hectares, which includes ponds, fish farms, state forests, and other areas. The population of Sawojajar Village is 12,381 people, with 1,774 individuals working in the fisheries sector, either as fishermen or fish pond operators (Brebes Regency Statistic Centre, 2024).

Most of the ponds in Sawojajar Village are traditional ponds. The characteristic feature of these pond is their relatively large size, typically ranging from 1 to 2 hectares per unit, only few units exceeding 3 hectares per plot. These ponds are managed simply, without the application of modern technology. Many ponds in the Sawojajar Village are used for milkfish (*Chanos chanos*) and vannamei shrimp (*L. vannamei*) cultivation, both in monoculture and polyculture systems. Additionally, some ponds are used for salt production, particularly during the dry season.

The total number of ponds in this area is 1.005 units, with milkfish production reaching 2,701 tons per year. According to the secondary data on the profile of Sawojajar Village, the capture fisheries yield obtained by the local community around the mangrove area include 20 tons of crabs and 15 ton of the blue crabs annually. This indicates that the mangrove area in this village still provides direct benefits to the community, both in supporting aquaculture and capture fisheries (Pusat Statistik Kabupaten Brebes, 2024).

3.2. Water quality in Silvofishery System

The analysis of water quality in three silvofishery ponds with varying levels of mangrove presence (T40, T20, and T0) reveals significant fluctuations in key parameters, namely salinity, temperature, dissolved oxygen (DO), and pH. Table 2 summarizes the observed values for each pond in relation to the optimal thresholds outlined by PP 22/2021 (Marine water quality standards for aquatic biota).

Table 2. Parameters of Silvofishery Pond Quality

Parameters	T0	T20	T40	Threshold PP 22/2021*
Salinity (ppt)	min: 21,9 max: 49,6 range: 27,7	min: 22,8 max: 38,1 range: 18,5	min: 22,4 max 41,3 range: 18,9	Up to 34
Temperature (^{0}C)	min: 26,7 max: 33,4 range: 6,7	min: 27,0 max: 35,6 range: 8,6	min: 27,5 max 34,6 range: 7,1	28-32
DO (mg/l)	min: 3,5 max: 7,3 range: 3,8	min: 3,30 max 6,5 range: 3,2	min: 2,61 max 7 range: 4,4	>5
pH	min: 7,6 max: 8,5 range: 0,9	min: 7,6 max: 8,5 range: 0,8	min: 7,50 max 8,5 range: 1,0	7.0 – 8.5

*Marine water quality standards for aquatic biota, PP 22/2021 attachment VIII

Salinity is a critical factor influencing osmotic regulation in fish, particularly milkfish (*Chanos chanos*). In the T40 pond, salinity fluctuated between 22.4 ppt and 41.3 ppt, with a range of 18.9 ppt. The maximum salinity slightly exceeds the optimal range for milkfish, which is up to 35 ppt, potentially causing osmotic stress, especially for juvenile fish. The T20 pond exhibited a lower salinity range (22.8–38.1 ppt, with a range of 18.5 ppt), but the maximum value still exceeded the ideal threshold. This suggests that the mangrove vegetation in the T20 pond helped moderate salinity to some extent but did not fully mitigate salinity spikes. The T0 pond showed the highest variation, with a salinity range of 21.9–49.6 ppt (range of 27.7 ppt). This extreme variation significantly exceeds the tolerance limit for milkfish, increasing the risk of stress, metabolic disturbances, and even mortality, particularly for larvae and juvenile stages.

Temperature plays a key role in fish metabolism and growth. The temperature values in all three ponds exceeded the optimal range for milkfish, which is 28–32°C. The T40 pond recorded a temperature range of 27.5–34.6°C (fluctuation of 7.1°C), while the T20 pond ranged from 27.0 to 35.6°C (fluctuation of 8.6°C). The T0 pond experienced the widest temperature variation, with temperatures ranging from 26.7°C to 33.4°C (fluctuation of 6.7°C). Although these temperatures fall within a tolerable range for milkfish, the fluctuations observed in each pond, especially in the T20 and T0 ponds, may contribute to thermal stress. The presence of mangrove vegetation in the T40 and T20 ponds likely helped reduce solar radiation, creating a more stable microclimate and mitigating extreme temperature fluctuations. However, even in these ponds, the temperatures occasionally exceeded the optimal range for milkfish, which can lead to heat stress.

Dissolved oxygen is essential for fish respiration and overall health. In the T40 pond, the minimum DO value recorded was 2.61 mg/L, which is below the recommended threshold of 5 mg/L for optimal fish health. While the maximum DO in T40 reached 7 mg/L, the low minimum level suggests that periods of oxygen depletion may have occurred, potentially leading to hypoxic conditions that could stress fish. The T20 pond had a DO range from 3.3 mg/L to 6.5 mg/L, which, although slightly better than T40, still falls below the ideal minimum for fish health. The T0 pond exhibited a relatively higher range of 3.5–7.3 mg/L. While this pond remained within acceptable DO limits, the fact that DO levels in T40 and T20 ponds were lower than optimal indicates potential risks to fish health, particularly during periods of low oxygen availability.

The pH levels in all three ponds remained within the optimal range for milkfish (7.0–8.5). The T40 pond showed a pH range of 7.5–8.5 (fluctuation of 1.0), while the T20 and T0 ponds exhibited similar pH ranges of 7.6–8.5, with fluctuations of 0.8 and 0.9, respectively. These values suggest that the mangrove vegetation in the T40 and T20 ponds may have helped stabilize the pH by contributing organic materials that interact with microorganisms to buffer changes in pH. The T0 pond, lacking mangrove vegetation, showed similar pH values but exhibited greater vulnerability to fluctuations due to the absence of ecological stabilization. Despite these fluctuations, all ponds maintained pH levels suitable for milkfish, indicating a generally favourable environment for aquaculture.

In summary, while all ponds maintained pH levels within optimal ranges, the salinity and temperature exceeded the ideal thresholds for milkfish, especially in the T0 pond. Additionally, DO levels in T40 and T20 ponds were below the optimal threshold, which could pose risks to fish health. These results highlight the importance of managing water quality parameters, particularly in ponds with lower mangrove coverage, to improve aquaculture conditions

3.3 Plankton Community Composition and Structure in Silvofishery Ponds

This study analysed the diversity, evenness, and dominance of the plankton community in the observed waters. The parameters analysed included species richness, individual abundance, Shannon-Wiener Diversity Index, Shannon-Wiener Evenness Index, and Berger-Parker Dominance Index. Overall, eight plankton classes were identified in the analysed samples, covering taxonomic groups such as Bacillariophyceae, Cyanophyceae, and Crustaceae.

Out of 50 species identified, the Bacillariophyceae (Diatoms) displayed the highest dominance with 31 species, making it the most species-rich group within the observed plankton community. Diatom species found include *Bacillaria sp*, *Bacteriastrum sp*, *Chaetoceros sp*, *Navicula sp*, *Nitszchia sp*, and *Rhizosolenia sp*. Additionally, plankton species from Cyanophyceae class, such as *Anabaena sp*, *Chlorella sp*, and *Oscillatoria sp*, were also abundant. Crustaceans, particularly from the order Copepoda, were also found in significant numbers. Copepods play a crucial role as zooplankton and serve as food source for various marine organism.

Table 3. Summary of Plankton Diversity, Evenness, and Dominance Indices Among Ponds

Ponds	Index	Minimum	Maximum	Mean	Standard Deviation
T0	Diversity	1.454	2.668	2.049	0.366
	Evenness	0.830	0.987	0.930	0.039
	Dominance	0.725	0.928	0.847	0.051
T20	Diversity	1.234	2.597	2.050	0.312
	Evenness	0.763	0.984	0.922	0.044
	Dominance	0.670	0.912	0.848	0.056
T40	Diversity	1.115	2.316	1.759	0.331
	Evenness	0.791	0.971	0.907	0.052
	Dominance	0.590	0.888	0.795	0.071

Table 3 presents the descriptive statistics for three plankton indices: the Shannon-Wiener Diversity Index, the Shannon-Wiener Evenness Index, and the Simpson Dominance Index. The Shannon-Wiener Diversity Index reveals that the T20 pond exhibits the highest mean value (mean = 2.050), which is slightly higher than that of the T0 pond (mean = 2.049), followed by a decrease in the T40 pond (mean = 1.759). This pattern suggests that species diversity tends to increase under moderate mangrove coverage, potentially reflecting a positive influence of mangrove vegetation on plankton communities. However, the decline observed at higher mangrove density may indicate the involvement of other ecological factors, such as increased competition or environmental changes associated with denser mangrove stands.

The Shannon-Wiener Evenness Index remains relatively stable across all conditions, with mean values ranging between 0.91 and 0.93. This suggests that the distribution of individuals among plankton species is fairly even, irrespective of variations in mangrove vegetation cover.

The Simpson Dominance Index shows a decreasing trend from ponds without mangroves to ponds with higher mangrove coverage, suggesting a shift toward a more diverse plankton community with less dominance by a few species as mangrove vegetation density increases.

Overall, these results indicate that the presence of mangroves positively influences plankton diversity in silvofishery ponds, with moderate mangrove coverage (20%) creating the most favourable ecological conditions. The observed decline in Shannon-Wiener Diversity in the T40 pond highlights the need for further research to better understand the effects of dense mangrove stands on the dynamics of plankton communities.

3.4 Benthos Community Structure in Silvofishery Ponds

Based on observations in the silvofishery ponds, the benthos community consists of several species distributed across different taxa. The data show that three main groups were identified in the benthic community: Diptera, Gastropod, and Polychaeta. Within the Diptera group, one species identified was *Chironomus sp.* The Gastropod group contained eight species: *Cerithidea sp.*, *Cerithium sp.*, *Fissilabia sp.*, *Littoraria sp.*, *Nassarius sp.*, *Planaxis sp.*, and *Terebralia sp.* Additionally, the Polychaeta group, represented by *Neptis sp.*, was found, though in lower abundance compared to Gastropod. The diversity, evenness, and dominance indices between ponds are shown in Table 4.

Table 4. Summary of Benthos Diversity, Evenness, and Dominance Indices Among Ponds

	T0	T20	T40
Number of Taxa	6	5	9
Abundance (ind/m2)	362.5	404	261
Diversity Index	1.550	1.229	1.742
Evenness Index	0.865	0.763	0.773
Dominance Index	0.248	0.329	0.227

The T20 pond shows the highest abundance of benthos, with 239 individuals per hectare, which is greater than T40 (138 individuals/ha) and T0 (147 individuals/ha). The higher abundance in T20 may indicate more favourable conditions for benthic organisms, such as nutrient availability, water quality, or habitat complexity. In contrast, T0 and T40 show similar, lower densities, suggesting more limited resources or environmental constraints.

In terms of diversity, the T40 pond has the highest Shannon-Wiener Diversity Index (1.47), indicating a relatively rich and heterogeneous benthic community. Despite its higher abundance, T20 pond has a lower diversity (0.91), suggesting that a few species dominate numerically, reducing overall diversity. T0 pond shows intermediate diversity (0.969), reflecting a moderate balance between species richness and evenness.

The evenness index complements the diversity data by reflecting how evenly individuals are distributed across species. Both T40 and T0 ponds show high evenness (0.864 and 0.907, respectively), indicating a more equitable distribution of individuals across species. Interestingly, T20 pond has the highest evenness (0.904), despite its lower diversity. This suggests that although fewer species dominate, the individuals within these species are relatively evenly distributed.

The dominance index measures the extent to which a few species numerically dominate the community. T0 and T40 have high dominance indices (0.736 and 0.724, respectively), indicating strong numerical dominance by certain species within these ponds. T20 has the lowest dominance index (0.555), which is consistent with its relatively higher evenness.

The data suggest that the T20 pond supports a high abundance of benthic individuals, but with lower species diversity and dominance. This may reflect an ecosystem dominated by a few tolerant species in favourable conditions. In contrast, T40 supports a more diverse community with moderate dominance, potentially indicating a more stable or heterogeneous habitat structure.

3.5 Milkfish Productivity in Different Pond Types

Table 5 presents the milkfish productivity by pond type. The variables observed include pond area, stocking density, , total weight and survival rate (SR). The results show notable differences in productivity and efficiency between the three types of ponds (Table 5).

Table 5. Milkfish Production in Different Pond Types

Pond	Area (Ha)	Stocking (indv)	Density (indv/ha)	Yield (indv)	Total Biomass (kg)	Productivity (kg/ha)	Duration (month)	SR (%)
T0	2.65	17,000	6,415	9,100	2,300	95.38	6	54
T20	1.8	10,000	5,556	5,770	845	81.36	4	58
T40	1.85	3,235	1,749	2,232	774	187.45	4	69

The productivity of milkfish in the silvofishery ponds varied across the three pond conditions. The T0 pond had a productivity rate of 95.38 kg/ha, which is the lowest among the three ponds. The T20 pond followed with 81.36 kg/ha, while the T40 pond exhibited the highest productivity at 187.45 kg/ha. In terms of yield, the T0 pond had the highest yield (9,100 individuals), followed by T20 (5,770 individuals), and T40 (2,232 individuals), corresponding to the stocking densities of 6,415, 5,556, and 1,749 individuals per hectare, respectively.

Survival rates (SR) were highest in the T40 pond at 69%, compared to 58% in the T20 pond and 54% in the T0 pond. The harvest durations were consistent at 4 months for both T40 and T20, while the T0 pond had a longer harvest duration of 6 months.

These differences suggest that pond conditions, particularly stocking densities, harvest duration, and potentially other environmental factors, influence milkfish productivity and survival rates. The T40 pond, with its lower stocking density and optimal conditions, supported higher productivity and survival rates. In contrast, the T0 pond, with a higher density and longer harvest period, showed lower productivity and survival, pointing to the negative impact of overcrowding and extended harvest periods.

4. Discussion

4.1. The Effect of Mangrove Presence on Water Quality in the Silvofishery System

The results of this study demonstrate that the presence of mangroves significantly contributes to stabilizing water quality parameters, including salinity, temperature, dissolved oxygen (DO), and pH. The pond with 40% mangrove plantation (T40) exhibited more stable water quality compared to ponds with lower mangrove coverage (T20) and those without mangroves (T0). This underscores the important role of mangroves in maintaining ecosystem balance, providing a more resilient environment for aquatic life. This finding supports the idea that mangrove ecosystems enhance water quality and provide long-term ecological stability (Harefa, 2024).

While mangrove presence helped to stabilize water quality in several areas, not all parameters showed the same level of improvement across all ponds. For instance, DO levels in the T40 pond ranged from a minimum of 2.61 mg/L to a maximum of 7.0 mg/L. The occasional reduction in oxygen levels could be attributed to microbial activity driven by organic material from mangrove litter. Decomposition of mangrove leaves and roots in the sediment increases microbial respiration, leading to higher oxygen consumption, especially in the bottom layer of the pond (Alongi, 2018). This microbial activity can cause temporary decreases in DO, especially during periods of intensive decomposition (Pradisty *et al*., 2022). However, these fluctuations did not significantly disrupt the overall stability of water quality in the T40 pond, which remained more stable than the T0 ponds. This suggests mangroves continue to play a key role in buffering environmental stressors over the long term (Alam *et al*., 2022).

Despite short-term fluctuations in DO, T40 ponds exhibited a more balanced and sustainable water quality system compared to non-mangrove ponds (T0). This aligns with Sa'diyah *et al*. (2017), who emphasized that mangrove forests are critical for stabilizing environmental parameters, thereby supporting the long-term sustainability of coastal fisheries. Mangroves act as natural buffers that reduce extreme fluctuations in water quality, which is crucial for sustaining healthy fish populations.

In contrast, T0 ponds without mangroves exhibited more extreme fluctuations in salinity and temperature. For example, the salinity range in T0 pond was considerably broader, ranging from 21.9 ppt to 49.6 ppt, reflecting 27.7 ppt variation. This finding aligns with Matatula (2019), who highlighted the role of mangroves in stabilizing salinity through their influence on water absorption and tidal cycles. Without the buffering effect of mangroves, salinity and temperature fluctuations in T0 ponds were more pronounced, likely causing increased osmotic and physiological stress on milkfish. This stress may have contributed to reduced fish productivity and lower survival rates, especially during the critical larval and juvenile stages, as high salinity is significantly associated with decreased survival.

The results of this study correspond with Hardi *et al*. (2023), who demonstrate that silvofishery practices improve water quality and support natural feed growth, offering a sustainable solution to enhance productivity without expanding land use. Integrating mangrove trees into the pond system regulates water quality, minimizes organic waste, and maintains ecosystem stability, thereby supporting both shrimp and fish cultivation. Meanwhile, Muthoh (2023) reported that the silvofishery, commonly used by milkfish farmers, is considered optimal for mangrove restoration and pond maintenance. This design features approximately 30-40% mangrove area and 60-70% pond area.

4.2 Biodiversity of Biotic Communities in the Silvofishery System

Biodiversity in silvofishery ponds is shaped by species composition and interactions influenced by environmental factors such as water quality and vegetation cover. This study shows that the presence of mangroves significantly impacts the biodiversity of plankton and benthos communities. These biotic communities were found to be more diverse and balanced in ponds with higher mangrove cover compared to ponds with no mangroves.

The T40 pond, with 40% mangrove coverage, demonstrated a mean plankton diversity index of 1.759 (ranging from 1.115 to 2.316), as shown in Table 3. Despite being slightly lower than the diversity found in the T0 (mean = 2.049) and T20 (mean = 2.050) ponds, the T40 pond showed the lowest dominance index (0.795), indicating a more balanced plankton community. This suggests that mangrove presence helps to promote a more even distribution of plankton species, reducing the dominance of a few species. In comparison, T0 exhibited a higher dominance index of 0.847, suggesting that fewer species dominated the plankton community. The evenness index in T40 (0.907) was also higher than in both T20 (0.922) and T0 (0.930), showing that mangrove presence in T40 supported a more evenly distributed plankton community, even though the diversity was slightly lower. This finding suggests that mangroves, by enhancing habitat complexity and water quality, likely help maintain a more stable and balanced ecosystem. The increase in plankton evenness in T40 could be a result of better water quality (as discussed in 4.1), which minimizes environmental stressors that often favour the dominance of a few species.

The diversity of benthic organisms in the ponds also followed similar patterns to that of plankton. T40 pond supported the highest diversity of benthic organisms, with a diversity index of 1.742 and the highest number of taxa (9 species), as shown in Table 4. In contrast, T0 pond had the lowest diversity (1.550) and only 6 benthic taxa. The increased abundance of benthic organisms in the T20 pond (404 individual/m^2) did not lead to higher diversity, indicating that although the pond supported a high number of organisms, the species richness was limited. This could be attributed to the limited mangrove coverage, which may not provide enough ecological structure to support a diverse benthic community. The dominance index of benthos was lowest in the T40 pond (0.227), suggesting that no single species dominated the benthic community, and the species were more evenly distributed. On the other hand, T20 had a higher dominance index (0.329), indicating that fewer species were numerically dominant, and T0 had the highest dominance index (0.248), reflecting a more balanced but less diverse benthic community.

The differences observed in the plankton and benthos communities across the ponds highlight the critical role of mangrove ecosystems in promoting biodiversity. Mangroves provide important ecological services, such as habitat provision, nutrient cycling, and organic matter input, which contribute to the growth and stability of plankton and benthic communities (Harefa, M.S., 2022; Hardi, E.H., 2023). The T40 pond, with 40% mangrove coverage, supported the highest biodiversity, suggesting that mangrove presence enhances habitat complexity, which in turn supports a more diverse array of species. Mangrove roots help trap sediments, reducing turbidity and providing more stable conditions for aquatic organisms. Moreover, mangrove leaf litter provides organic matter that supports detritivores and filter feeders, enhancing benthic biodiversity.

These findings are consistent with studies by Damayanti *et al*. (2017), who emphasized the role of mangroves in stabilizing plankton communities through nutrient management and water quality regulation. Similarly, Hardi *et al*. (2024) highlighted that mangrove-integrated silvofishery systems help maintain stable environmental conditions that support greater biodiversity by buffering environmental stressors and promoting habitat stability.

In contrast, T0 ponds, which had no mangrove coverage, exhibited reduced biodiversity and higher dominance indices for both plankton and benthic communities. The lack of mangroves likely led to less habitat complexity and greater fluctuations in water quality, which can reduce species diversity and lead to the dominance of a few hardy species. The findings suggest that ponds without mangrove cover are more vulnerable to ecological imbalance, which can affect the long-term sustainability of aquaculture systems.

4.3 Milkfish Productivity in Silvofishery System

Milkfish (*Chanos chanos*) productivity in silvofishery ponds is influenced by a variety of interconnected factors, including water quality parameters, mangrove vegetation, stocking density, and biotic communities. The results of this study indicate that the presence of mangroves in the ponds significantly contributes to improved water quality, supports a more stable ecosystem, and enhances milkfish productivity. The ponds with higher mangrove coverage (T40) exhibited better environmental conditions, which in turn facilitated higher productivity and better fish health compared to ponds without mangroves (T0).

In particular, T40 pond, with 40% mangrove coverage, demonstrated the highest productivity, achieving a mean productivity rate of 0.221 kg per stocking individual in the first harvest period and 0.275 kg per stocking individual in the second period, with survival rates of 66% and 74%, respectively (Table 5). The T40 pond also had stable water quality, with lower salinity fluctuations, higher dissolved oxygen (DO) levels, and more consistent pH values, which are critical for milkfish growth and survival. Mangroves help stabilize salinity and pH, creating a favourable environment for fish. This aligns with findings by Hilmi *et al*. (2019) and Siahaan (2020), who emphasized that mangroves act as natural buffers against environmental extremes, improving water quality and supporting the health of aquaculture species.

Moreover, mangrove presence fosters a diverse and balanced biota, including plankton and benthic communities, which are vital food sources for milkfish. In the T40 pond, the plankton diversity index was 1.759, and the evenness index was 0.907 (Table 3). These indices reflect a balanced distribution of plankton species, suggesting that the mangrove root system, by trapping sediments and providing organic material, supports a diverse community of plankton, which are essential for the growth of milkfish. Similarly, the benthic diversity index in T40 was 1.742, the highest among the ponds, and the dominance index was the lowest (0.227) (Table 4), indicating a more diverse and evenly distributed benthic community. This enhanced diversity is likely a result of the mangroves' ability to provide shelter and organic matter for benthic organisms, which play a key role in nutrient cycling and maintaining water quality. These findings align with the work of Damayanti *et al*. (2017), who reported that mangrove ecosystems significantly contribute to maintaining the stability of plankton and benthos communities, supporting healthy and productive aquaculture systems.

In contrast, T0 pond, without any mangrove cover, showed the lowest productivity with 0.110 kg per stocking individual and 0.171 kg per stocking individual in the first and second harvest periods, respectively, and a survival rate between 51% and 55% (Table 5). The absence of mangroves in T0 led to unstable water quality, characterized by wider salinity and pH fluctuations, which likely contributed to physiological stress in milkfish. The higher stocking densities in T0 (3,774 individuals/ha and 2,642 individuals/ha) exacerbated the negative impact of poor water quality, increasing organic waste and oxygen demand. The longer harvest duration in T0 (6 months) further highlights the slower growth under unstable environmental conditions. This is consistent with studies that have found high stocking densities combined with unstable water quality led to lower growth rates and increased stress in fish (Hardi *et al*., 2023; Siahaan, 2020). The lack of mangrove buffering likely resulted in poor nutrient cycling and inadequate habitat for plankton and benthic organisms, which negatively impacted the overall health of the system.

The T20 pond, with 20% mangrove coverage, exhibited moderate productivity with a mean productivity ranging from 0.070 kg to 0.099 kg per stocking individual, and survival rates between 50% and 56% (Table 8). While the presence of mangroves in T20 provided some improvement in water quality and ecosystem stability, it was insufficient to fully support high levels of productivity compared to T40. The higher stocking density in T20 (2,778 individuals/ha) likely contributed to the stress experienced by the milkfish, and despite the partial mangrove cover, the pond did not achieve the same level of environmental buffering as T40. As a result, productivity was lower, and the fish did not grow as quickly or survive as well as those in T40.

In summary, the presence of mangroves in silvofishery ponds significantly enhances milkfish productivity by improving water quality and supporting diverse biotic communities. The T40 pond demonstrated the highest productivity and survival rates, highlighting the critical role of mangroves in providing a stable environment for aquaculture. Mangroves act as natural filters, stabilize water parameters like salinity and pH, and enhance the growth of plankton and benthic organisms, which are essential food sources for milkfish. In contrast, the absence of mangroves in the T0 pond led to unstable environmental conditions and lower productivity, underscoring the importance of mangrove integration for sustainable silvofishery practices.

The results of this study underscore the importance of integrating mangrove ecosystems into silvofishery management. Mangrove not only improve water quality but also enhance biodiversity, making them essential for the sustainability of coastal aquaculture systems (Hashim, 2021; McSherry, 2023). By integrating mangroves into silvofishery ponds, the pond owner can achieve higher productivity, improve fish survival rates, and promote long-term ecological stability, offering a sustainable solution for the growing demands of coastal aquaculture.

5. Conclusion

Based on the results and discussion, the following conclusions can be drawn:

1. Mangrove presence significantly enhances milkfish productivity and aquaculture sustainability. The study found that ponds with higher mangrove coverage (T40) exhibited better productivity and survival rates, demonstrating that mangroves stabilize water quality, reduce ecological stress, and promote healthier fish growth.
2. The results suggest a trade-off between stocking density and fish health, where higher densities in T0 ponds, combined with unstable water quality, reduced fish growth and survival. Lower stocking densities in mangrove-integrated ponds (T40) resulted in optimal productivity and faster growth.
3. Mangroves play a crucial role in maintaining biodiversity, supporting plankton and benthic communities, which in turn contribute to improved fish nutrition. The presence of mangroves helps create a more resilient ecosystem, supporting sustainable aquaculture.
4. Mangrove integration into silvofishery systems is a key strategy for enhancing both economic productivity and environmental sustainability. Mangroves provide natural buffers against environmental extremes, offering long-term benefits for coastal aquaculture.

5. The study recommends increasing mangrove cover in silvofishery ponds as a means to optimize productivity and ecosystem stability, supporting both aquaculture sustainability and coastal ecosystem health.

Funding:

This research was funded by the Japan ASEAN Integration Fund (JAIF) through the project "Mangrove Ecosystem Management in the ASEAN Region.".

Acknowledgements

The authors would like to express their deepest gratitude to the Indonesian Mangrove Research and Development Institute (LPPM) for their financial support of this research. Special thanks are also extended to the Zoology Laboratory, Faculty of Biology and Agriculture, National University (Dra. Hasni Ruslan, M.Si., as the Head of the Zoology Laboratory), and the Botany Laboratory, Faculty of Biology and Agriculture, National University (Dra. Endang Wahyuningsih, M.Si., as the Head of the Botany Laboratory). We also thank Dr. Sri Handayani, M.Si., and Ms. Anisa Widyastuti, S.Si., for their support and assistance in the identification and analysis of phytoplankton samples.

We would also like to extend our appreciation to Prof. Bambang Widigdo for his technical guidance and supervision during the fieldwork. Our gratitude goes to the field team of the AMNET Project, including Semuel, Habib, and Hafiz, for their support in sample collection and data gathering in the field.

Furthermore, we appreciate the cooperation of the pond owners and managers in Sawojajar Village, including Mr. Kardina, Mr. Sentot, Mr. Roi, and Mr. Nasir, for providing access and supporting this research.

Lastly, the author would like to express sincere thanks to Dr. Tatang Mitra Setia, M.Si., Dr. Ir. Nyoto Santoso, M.S., and Noriaki Sakaguchi, Ph.D for their academic guidance, critical input, and invaluable support throughout the research process.

Reference

Alam, M. I., Yeasmin, S., Khatun, M. M., Rahman, M. M., Ahmed, M. U., Debrot, A. O., Ahsan, M. N., & Verdegem, M. C. J. (2022). Effect of mangrove leaf litter on shrimp (*Penaeus monodon*, Fabricius, 1798) growth and color. *Aquaculture Reports, 25*, 101185. https://doi.org/10.1016/j.aqrep.2022.101185

Alongi, D. M. (2012). Carbon sequestration in mangrove forests. *Carbon Management, 3*(3), 313–322. https://doi.org/10.4155/cmt.12.12

Alongi, D. M. (2018). Impact of global change on nutrient dynamics in mangrove forests. *Forests, 9*(10), 596. https://doi.org/10.3390/f9100596

Arifanti, V. B., Novita, N., Subarno, & Tosiani, A. (2021). Mangrove deforestation and CO2emissions in Indonesia. *IOP Conference Series: Earth and Environmental Science, 874*(1). https://doi.org/10.1088/1755-1315/874/1/012006

Damayanti, N. M. D., Hendrawan, I. G., & Faiqoh, E. (2017). Distribusi Spasial Dan Struktur Komunitas Plankton Di Daerah Teluk Penerusan, Kabupaten Buleleng. *Journal of Marine and Aquatic Sciences, 3*(2), 191. https://doi.org/10.24843/jmas.2017.v3.i02.191-203

FAO. (2020). *The State of World Fisheries and Aquaculture 2020: Sustainability in action*. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/ca9229en

Hardi, E. H., Susmiyati, H. R., Diana, R., Palupi, N. P., Agriandini, M., Saptiani, G., Asikin, A. N., Safitri, M. A., Sihite, D., & Agustina, A. (2023). A Comparison of the Silvofishery Models for Mangrove Restoration in East Kalimantan. Proceedings of the 2022 Brawijaya International Conference (BIC 2022), 614-626 https://doi.org/10.2991/978-94-6463-140-1_61.

Hardi, E. H., Susmiyati, H. R., Diana, R., Palupi, N. P., Agriandini, M., Saptiani, G., Asikin, A. N., & Agustina, A. (2023). Traditional polyculture as a mangrove restoration solution in Delta Mahakam, East Kalimantan Indonesia. *IOP Conference Series: Earth and Environmental Science, 1208*(012056). https://doi.org/10.1088/1755-1315/1208/1/012056

Hardi, E. H., Mustofa, A. S., Agriandini, M. (2024). Smart silvofishery to mitigate climate change impacts on food security. *The 1st International Conference on Forest City (1st ICFC)*, *IOP Conf. Series: Earth and Environmental Science, 1447*, 012007. IOP Publishing. https://doi.org/10.1088/1755-1315/1447/1/012007

Harefa, M. S., Nasution, Z., Mulya, M. B., & Maksum, A. (2022). Silvofishery: In what mangrove coverage condition can this system provide benefits for the community? Retrieved from https://www.researchgate.net/publication/361835243_Silvofishery_In_What_Mangrove_Coverage_Condition_Can_this_System_Provide_Benefits_for_the_Community

Harefa, M.S (2024). The effect of water quality on production results of silvofishery ponds in Tanjung Rejo Village. Retrieved from https://papers.ssrn.com/sol3/Delivery.cfm/a4d82d6e-a530-486a-9ce3-ac3c18926247-MECA.pdf?abstractid=4930659

Hashim, T.M.Z., Engku Azlin Rahayu Engku Ariff, & Mohd Nazip Suratman. (2021). Aquaculture in mangroves. Dalam R. P. Rastogi *et al*. (Ed.), *Mangroves: Ecology, biodiversity and management* (hlm. 419–438). Springer Nature Singapore. https://doi.org/10.1007/978-981-16-2494-0_18

Hilmi, E., Sari, L. K., & Setijanto. (2019). The mangrove landscaping based on Water Quality: (Case Study in Segara Anakan Lagoon and Meranti Island). *IOP Conference Series: Earth and Environmental Science*, *255*(1). https://doi.org/10.1088/1755-1315/255/1/012028

Ilhami, W. T., Christian, Y., & Affandy, A. (2021). Integrated mangrove landscape design and coastal disaster risk mitigation. *Coastal and Ocean Journal*, *5*(1), 28–36. https://doi.org/10.29244/COJ.5.1.28-36

Khairuddin, B., Yulianda, F., Kusmana, C., & Yonvitner. (2016). Degradation Mangrove by Using Landsat 5 TM and Landsat 8 OLI Image in Mempawah Regency, West Kalimantan Province year 1989 - 2014. *Procedia Environmental Sciences*, *33*, 460–464. https://doi.org/10.1016/j.proenv.2016.03.097

Matatula, J. (2019). Keragaman Kondisi Salinitas Pada Lingkungan Tempat Tumbuh Mangrove di Teluk Kupang, NTT. *Jurnal Ilmu Lingkungan*, *17*(3), 425. https://doi.org/10.14710/jil.17.3.425-434

McSherry, M. (2023). Integrated mangrove aquaculture: The sustainable choice for mangroves and aquaculture? *Aquatic Conservation: Marine and Freshwater Ecosystems*. Advance online publication. https://doi.org/10.1002/aqc.3860

Munasikhah, S., & Wijayati, P. A. (2022). Dari Hutan Mangrove Menjadi Tambak : Krisis Ekologis Di Kawasan Sayung Kabupaten Demak 1990-1999. *Journal of Indonesian History*, *10*(2), 129–140. http://journal.unnes.ac.id/sju/index.php/jih

Muthoh, R. F. (2023). *Analisis tingkat keberlanjutan pengelolaan tambak silvofishery di wilayah pesisir Kota Semarang* (Tesis, Institut Pertanian Bogor). Tersedia di https://repository.ipb.ac.id/handle/123456789/116319

Nurhayati, S., & Yuliana, M. (2019). Water quality and fish productivity in silvofishery ponds in

coastal regions. *Jurnal Perikanan dan Kelautan*, *10*(2), 150–160.
Odum, E. P. (1971). *Fundamentals of ecology* (3rd ed.). W.B. Saunders Company.
Pradisty, R., Kurniawan, A., Sahubawa, L. M., & Ariyanto, T. (2022). Litterfall and associated macrozoobenthic of restored mangrove forests in abandoned aquaculture ponds. *Sustainability*, *14*(13), 8082. https://doi.org/10.3390/su14138082
Purwiyanto, A. I. S. (2014). Effect of Silvofishery on Ponds Nutrient Levels. *Jurnal Ilmu Kelautan*, *19 (2)*(Juni 2014), 81–87. file:///C:/Users/Hp/Desktop/Research/Research/17 Effect of silvofishery on ponds nutrient levels.pdf
Pusat Statistik Kabupaten Brebes. (2024). *Kecamatan Wanasari Dalam Angka*.
Sa'diyah, H., Hendrarto, B., & Rudiyanti, S. (2017). Determinasi Faktor Penting Berdasarkan Aktivitas Masyarakat Untuk Pengembangan Kawasan Rehabilitasi Hutan Mangrove di Pantai Karangsong, Kabupaten Indramayu (Determination of Important Factorson Society Activity for The Development of The Mangrove Forests. *SAINTEK PERIKANAN : Indonesian Journal of Fisheries Science and Technology*, *13*(1), 12. https://doi.org/10.14710/ijfst.13.1.12-18
Sambu, A. H. (2013). *Optimasi Pengelolaan Tambak Wanamina di Kawasan Pesisir Kabupaten Sinjai*. *66*(1997), 37–39.
Siahaan, N. (2020). Mangrove management strategy to support fisheries in mangunharjo village, semarang city. *E3S Web of Conferences*, *202*. https://doi.org/10.1051/e3sconf/202020206016
Suprayitno. (2024). Analisis Dampak Budidaya Tambak Udang Terhadap Kondisi Lingkungandan Sosisal Ekonomi Masyarakat di Kelurahan Setokok Kota Batam Supriyanto. *UGM*.
Widigdo, B., Ilma, B., Santoso, N, Sulistiono, Kusmana, C., Krisanti, M., 2024, Performance of Integrated Mangrove Aquaculture (IMA) in District of Sidoarjo, East Java Indonesia. BIO Web of Conferences 92, 01022 (2024) https://doi.org/10.1051/bioconf/20249201022
Yulianto, A., & Setyawan, H. (2020). Effect of mangrove vegetation density on water quality and aquaculture productivity. *Jurnal Akuakultur Indonesia*, *19*(1), 55–64.