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Research article

Growth and survival of milkfish (*Chanos chanos*), tiger prawns (*Panaeus monodon*), and oysters (*Crassostrea* sp.) in integrated multi-trophic aquaculture system with varying stocking densities

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Abstract

Integrated Multi-trophic Aquaculture System (IMTA) is a sustainable approach to aquaculture, utilizing ecosystem dynamics by integrating various species. This study examined the growth and survival of milkfish (*Chanos chanos*), tiger shrimp (*Penaeus monodon*), and oysters (*Crassostrea* spp.) in IMTA systems with different stocking densities. A 30-day experiment using a nonfactorial-completely randomized design with four treatments and three replications was conducted. The results showed that the implementation of IMTA had no significant impact on the survival rate of milkfish, tiger prawns or oysters in all treatments. However, important variations in growth parameters were observed. Milkfish and tiger prawns showed the highest weight and length gain in treatment B, followed by treatments A, C, and D. Similarly, oysters showed optimal growth in treatment B, followed by A, C, and D, based on weight gain, length, width, and shell thickness. Throughout the study, the physicochemical parameters of the water remained within acceptable ranges, thus supporting ideal growth conditions for the cultured species. These findings underscore the potential of IMTA to increase aquaculture productivity while upholding the principles of environmental sustainability. By optimizing stocking density and encouraging species diversity, IMTA presents a promising avenue for advancing integrated aquaculture practices, in line with the FAO's blue economy concept and ecosystem approach to aquaculture. Future research should concentrate on refining the IMTA system and evaluating its long-term ecological and economic consequences.

Keywords: Mariculture, sustainability, stocking density, multitrophic biota, fish pond

Introduction

The concept of integrated aquaculture for aquaculture is relatively unexplored. The ecosystem approach to aquaculture formulated by the FAO (2010) is a concrete step toward the application of environmentally sound aquaculture. Some aquaculture activities, such as polyculture, silvofishery, and integrated multitrophic aquaculture (IMTA), are examples of the application of the concept of the blue economy in several locations in Indonesia. However, the concept is still not fully implemented since it is generally still in the learning phase. In the field, generally, the cultivator community is still focused on developing a single species (monoculture), and often, aspects of the environment are not a serious concern.

Indonesia possesses an extensive aquaculture potential, estimated at 17.9 million hectares, distributed across freshwater (2.8 million hectares), brackish water (2.9 million hectares), and seawater (12.12 million hectares) environments. Despite this considerable resource availability, the utilization rates remain notably low, averaging ca 6.7% (The Indo-

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nesian Ministry of Marine Affairs and Fisheries, 2018). This low level of utilization is generally caused by environmental degradation due to overexploitation in the intensive use of fishponds in the 1980s (Yayasan Inisiatif Dagang Hijau, 2018). According to the implementation in the area, in general farmers are still focused on cultivating a single species in one pond, which, as a result, can only harvest one species, and there are still many unutilized fishponds. To overcome the decline in production and the low level of utilization of this farmland, it is necessary to have a technological breakthrough (innovation) in aquaculture that is environmentally friendly, productive, and continuous (sustainable). The development of a concept of integrated aquaculture technology, IMTA, is expected to increase the productivity of ponds at the local, regional, and even national levels.

IMTA is a form of mariculture that utilizes ecosystem services by lower trophic organisms, which are adapted as mitigation against waste from higher trophic-level organisms (such as fish) (Loayza-Aguilar et al., 2023). IMTA is different from polyculture because polyculture involves cultivating more than one species without regard to the use of species in the ecosystem. On the contrary, IMTA focuses on the ability of species to maintain ecological balance so that each species has a different function, for example, as a carnivore, herbivore, detritus, and filter feeder (particle absorber) so that ecosystem health is adequately maintained (Reid et al., 2018).

The application of IMTA is based on the use of waste materials as a source of nutrients closely related to the food chain cycle in the culture system (Nederlof et al., 2021). Through this understanding, environmental problems caused by aquaculture activities can be minimized, including change and land use pollution, either externally or within the culture operation (Hossain et al., 2022). IMTA can be used in almost all marine and terrestrial aquaculture ponds due to the implementation of ecosystem balance (Azhar & Memiş, 2023). The potential of IMTA development in Indonesia can be implemented through floating net cages or fishing net cages, which have been widely applied in Indonesia. This system can be modified by utilizing various organisms in an ecosystem; the used ecosystem is a natural or native habitat of these organisms. The advantages of the IMTA system can be recognized on the basis of the economic, environmental, and food safety of cultured organisms and humans.

In fact, the implementation of aquaculture development should be integrated with the entire existing ecosystem, such as milkfish (*Chanos chanos*), tiger shrimp (*Penaeus monodon*), and oysters (*Crassostrea* spp.) culture, in one pond/ maintenance tank to be sustained. Milkfish, tiger prawns, and oysters are aquaculture commodities that have comparative and strategic benefits compared to other fishery commodities because their enlargement and hatchery technology have been developed in farmer communities; their life conditions do not require high eligibility requirements because it is tolerant to changes in environmental conditions, and is a potential source of fish protein for the fulfillment of nutrition and farmers' income. This study focused on applying an integrated multitrophic aquaculture (IMTA) system with different fish stocking densities to the survival of milkfish, prawns, and oysters. Stocking density is the number of fish stocked in a culture medium per unit of area or volume.

Methods

Experimental design

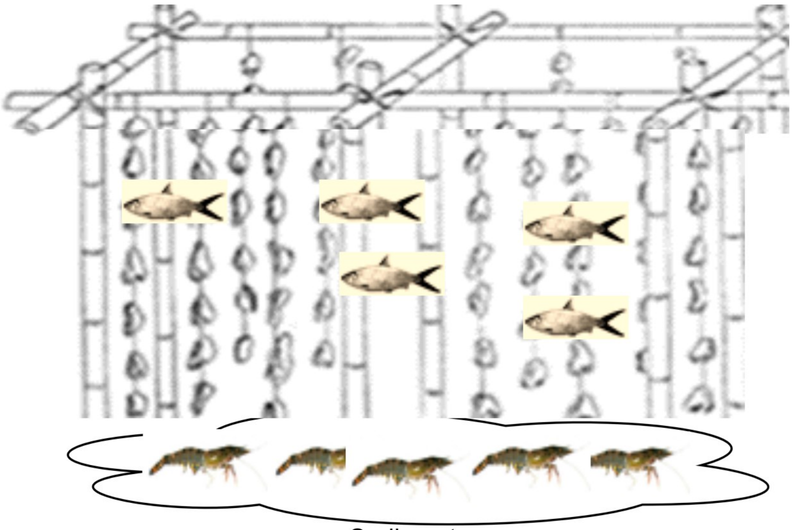
The research method used in this study is an experimental approach with data collection techniques carried out by direct observation, which directly measures the variables on the object studied. The experimental design used was a complete and non-factorial randomized design with four treatments and three replicates. The treatments used are as follows: treatment (A) Stocking density of 10 milkfish, 15 tiger prawn fry and 20 oysters, (B) Stocking density of milkfish 15 tails, tiger prawn fry 20 tails and oyster 30 tails, (C) Stocking density of milkfish 20 tails, tiger prawn fry 25 tails and oyster 40 tails, and (D) Stocking density of 25 milkfish, 30 tiger prawn fry and 50 oysters.

The experimental medium used in this study was a rectangular net that was 1 m long, 1 m wide, and 1 m high (Figure 1). The net was washed clean with detergent, dried, and stored for 24 hours. Before this investigation, all equipment used in this experiment was sterilized to ensure that it was hygienic and contamination-free. The test oysters, milkfish, and tiger prawns used in this study were obtained from a local farmer. Milkfish, tiger prawn, and oyster were housed in 12 rectangular nets with different densities per container. The oyster's size ranged from 23-36 mm in length and weighed 3-7 grams. The milkfish in this study measured 9-10 cm in length and weighed 6-7.2 grams, while the fingerlings of the tiger prawn were 3-5 cm long and weighed 2-3 grams.

In this study, oyster rearing was carried out using a vertical hanging method (so that oysters can use their food optimally), where each oyster was placed in a net and then tied at the top, connected to a rope, and hung on top of a wooden net containing milkfish seeds and fingerlings of tiger prawn. The net will float in the aquaculture pond, which was given a border to experiment. The upper section of the net was covered with a fish mesh to prevent milkfish and tiger prawn fingerlings from escaping from the experimental pool.

Milkfish, tiger prawns, and oysters that were used in the experiment were acclimatized for two days to ensure environmental adaptability. During acclimatization, milkfish and tiger prawns were fed, while oysters used natural feed. The feeding of milkfish and tiger prawns was 3% of the body weight provided three times a day (7:00 am, 12:00 pm and 5:00 p.m.). The feed was administered as a pellet.

Figure 1. Experimental design of the IMTA system.



Observation parameters

Growth of the test biota

The growth of the length, width, and thickness of the shell was measured every 10 days. The length of the oyster shell was measured from dorsal to ventral and the width was measured from posterior to anterior using a Vernier caliper. The formula for measuring length, width, and thickness: P = Pt – Po; L = Lt – Lo; K = Kt – Ko, where P = absolute length growth, Pt = mean length of oysters on day t (cm), Po = mean length of oysters on day 0 (cm), L = absolute width growth, Lt = mean width of oysters on day t (cm), Lo = mean width of oysters on day 0 (cm), K = absolute width growth, Ko = mean thickness of oysters on day 0 (cm).

To determine the growth rate, length and weight measurements were taken. Length measurements were made using a roller measured from the leading edge to the outer end of the tail curve using the formula: P = Pt – Po, where: P = absolute length growth, Pt = mean length on day t (cm), Po = mean length on day 0 (cm). The weight was measured by weighing with analytical scales after measuring the length. The weight growth was calculated using the formula:

W = Wt-Wo, where: W = growth of the absolute weight (gr), Wt = final weight (gr), Wo = initial weight (gr).

The length measurements were made using a roller measured from the leading edge to the tip of the outer curve of the tail using the following formula P = Pt – Po, where: P = absolute length growth, Pt = mean length on day t (cm), Po = mean length on day 0 (cm).

Weight was measured by weighing using analytical scales after length measurements. The weight growth was calculated using the formula: W = Wt-Wo, where: W = growth in absolute weight (gr), Wt = final weight (gr), Wo = initial weight (gr).

Survival rate

Observations of the survival number of milkfish, tiger prawns, and oysters were measured at the beginning and end of the experiment by calculating the total number of survivors using the formula SR = Nt/No x 100%, where: SR = survival rate (%), Nt = number of living biota at the end of the study (tail), No = number of biota that live at the beginning of the study (unit species).

Water quality

Water quality measurements were taken once a day. The measured parameters were pH, temperature, dissolved oxygen (DO), salinity, ammonia, nitrate, and nitrite.

Data analysis

The data used in this study were used as a nonfactorial completely randomized design (CRD) with four treatments and three replicates (Yitnosumarto, 1990), with the equation: Yij=m + αi + Ɛij, where: Yij= variables observed in milkfish, tiger prawns, and oysters growth in the *i* treatment (i = A, B, C, D) and *j* replication (*j* = 1, 2, 3), μ = general mean, αi = 1, 2, 3 (replicates), Ɛij = error.

The research data were presented in the form of tables and graphs and then analyzed by analysis of variance (ANOVA) using Microsoft Excel. If there are treatments that are significantly different (F count > F table), then further tests are carried out using the least significant difference (LSD). The data of the water parameters were descriptively analyzed.

Result

Survival rate

The results of the 30-day experiment indicated that the application of the IMTA system had no effect on the survival rate of milkfish, tiger prawns and oysters. The mean survival rate (SR) of milkfish, tiger prawns, and oysters was 100% in treatments A, B, C, and D. Based on statistical analysis with the F test, the application of the IMTA system is not significantly different from the survival of milkfish, tiger prawns, and oysters ($p > 0.05$).

Biota growth

Milkfish

The mean increase in the weight of the milkfish for each treatment is presented in Figure 2. The highest mean weight gain rate for milkfish is found in treatment B, which is 14.45 ± 0.36 grams. Furthermore, treatment A is 8.92 ± 1.10 grams. Then, the lowest mean weight gain rate is found in treatment C, which is 6.01 ± 0.93 grams, and in treatment D, which is 4.37 ± 0.77 grams. Statistical analysis with the F test showed that the application of the IMTA system in the maintenance of milkfish, tiger prawns, and oysters showed significantly different results on the weight gain of milkfish with a value of F_{count} (2431) > F_{table} (0.01). The LSD test obtained the results that in each treatment there is a significant difference between treatment B with A, C, and D, treatment A with C and D, and treatment C with D.

Furthermore, the application of the IMTA system showed a different result for each treatment in terms of the gain in length of the milkfish. The mean growth length of the milkfish for each treatment is presented in Figure 3. The highest mean length gain rate of milkfish was found in treatment B, which was equal to 0.90 ± 0.05 cm. Then, the length gain of treatment A is 0.48 ± 0.08 cm, while the lowest length gain is in treatment C, which is 0.34 ± 0.05 cm, and in treatment D, which is 0.23 ± 0.07 cm. Based on statistical analysis with the F test, the IMTA application showed very significantly different results on milkfish length gain with the value of Fcount (1042) > Ftable (0.01). Then the results of the LSD test showed that the length gain of the milkfish was different between treatments and the maximum length gain was found in treatment B.

Tiger prawns

The IMTA system was found to affect the weight and length gain rate of tiger prawns. The mean weight gain of tiger prawns for each treatment is shown in Figure 4. The highest mean weight gain of tiger prawns was found in treatment B, which was 4.26 ± 0.33 grams. Furthermore, the weight gain in treatment A was 2.71 ± 0.27 grams, while the lowest weight gain of tiger prawns was found in treatment C 1.99 ± 0.39 grams and in treatment D 1.51 ± 0.38 grams.

Statistical analysis of the F test showed that the application of the IMTA system showed a significant effect on weight gain in tiger prawns with a value of F_{count} (151) > F_{table} (0.01). The results of further tests (LSD) obtained showed that in each treatment it was significantly different between treatment B

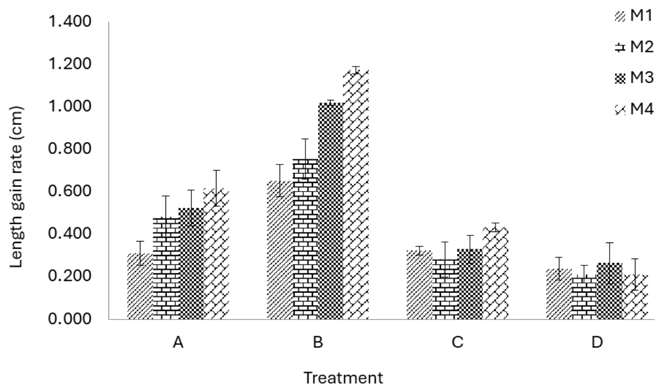


Figure 2. Mean weight gain rate of milkfish. A = Stocking density of 10 milkfish, 15 tiger prawns and 20 oysters; B = Stocking density of 15 milkfish, 20 tiger prawns and 30 oysters; C = Stocking density of 20 milkfish, 25 tiger prawns and 40 oysters; D = Stocking density of 25 milkfish, 30 tiger prawns, and 50 oysters. M1, M2, M3, M4 = weeks of weight measurement.

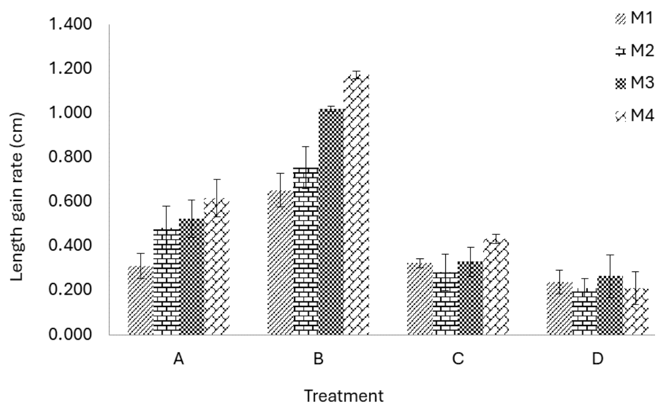


Figure 3. Mean length gain rate of milkfish. A = Stocking density of 10 milkfish, 15 tiger prawns and 20 oysters; B = Stocking density of 15 milkfish, 20 tiger prawns and 30 oysters; C = Stocking density of 20 milkfish, 25 tiger prawns and 40 oysters; D = Stocking density of 25 milkfish, 30 tiger prawns, and 50 oysters. M1, M2, M3, M4 = weeks of weight measurement.

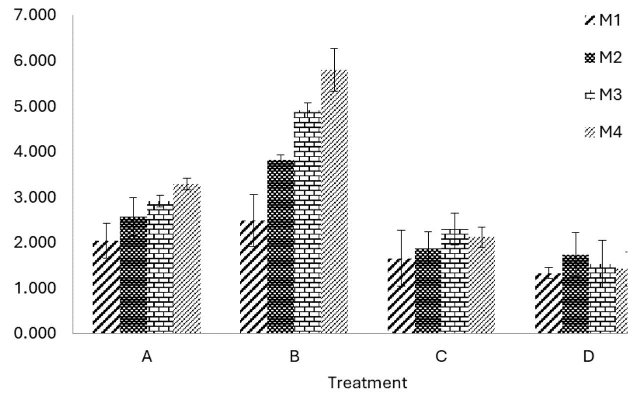


Figure 4. Mean weight gain rate of tiger prawns. A = Stocking density of 10 milkfish, 15 tiger prawns and 20 oysters; B = Stocking density of 15 milkfish, 20 tiger prawns and 30 oysters; C = Stocking density of 20 milkfish, 25 tiger prawns and 40 oysters; D = Stocking density of 25 milkfish, 30 tiger prawns, and 50 oysters. M1, M2, M3, M4 = weeks of weight measurement.

with A, C and D, treatment A with C and D, and treatment C with D. Furthermore, treatment B with A, C and D was significantly different.

The mean length gain of the tiger prawns during rearing for each treatment is shown in Figure 5. The highest mean increase rate in the length of the tiger prawn was found in treatment B, which was 1.07 ± 0.07 cm. Furthermore, in treatment A with a length of 0.67 ± 0.11 cm and the lowest gain in the length of the tiger prawn was found in treatment C 0.41 ± 0.09 cm and in treatment D, which was 0.34 ± 0.08 cm. Based on statistical analysis with the F test, the application of the IMTA system shows the results of a very real effect on the length gain of tiger prawns with the value of F_{count} (472) > F_{table} (0.01). The results of the additional tests (LSD) showed that each treatment was different between treatments, and the best gain in tiger prawn length was also found in treatment B.

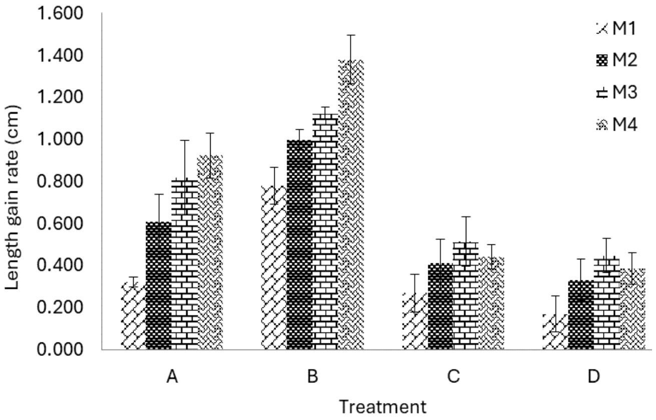


Figure 5. Mean length gain rate of tiger prawns. A = Stocking density of 10 milkfish, 15 tiger prawns and 20 oysters; B = Stocking density of 15 milkfish, 20 tiger prawns and 30 oysters; C = Stocking density of 20 milkfish, 25 tiger prawns and 40 oysters; D = Stocking density of 25 milkfish, 30 tiger prawns, and 50 oysters. M1, M2, M3, M4 = weeks of weight meas-

Oyster growth

The application of the IMTA system affected the weight gain and length of the oysters. The mean weight gain of the oysters from the initial to the end of the study for each treatment is presented in Figure 6. The highest rate of weight gain of oysters was found in treatment B, which was 9.23 ± 0.80 g. Furthermore, treatment A was 5.69 ± 0.61 grams and treatment C was 2.33 ± 0.71 grams. Then the lowest mean weight gain was found in treatment D, which was 1.50 ± 0.49 g. Based on statistical analysis with the F test, it shows that oyster growth showed a significant effect on oyster weight gain with a value of Fcount (2291) > Ftable (0.01). The results of further tests (LSD) showed that treatment B was different from treatment A, C, and D, as well as treatment A was significantly different from treatment C and D.

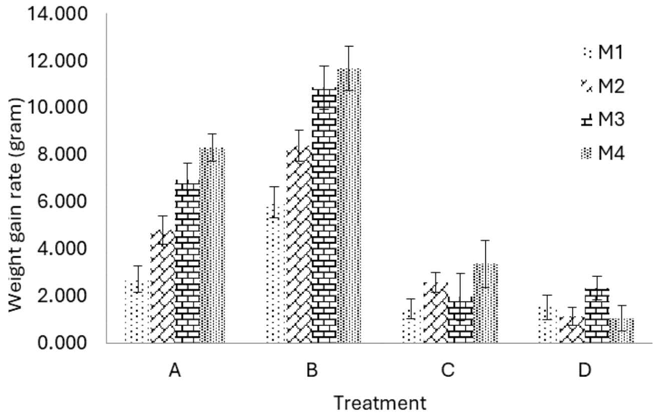


Figure 6. Oyster mean weight gain rate. A = Stocking density of 10 milkfish, 15 tiger prawns and 20 oysters; B = Stocking density of 15 milkfish, 20 tiger prawns and 30 oysters; C = Stocking density of 20 milkfish, 25 tiger prawns and 40 oysters; D = Stocking density of 25 milkfish, 30 tiger prawns, and 50 oysters. M1, M2, M3, M4 = weeks of weight measurement.

The application of the IMTA system showed the mean results of the increase in oyster length for each treatment, as presented in Figure 7. The highest mean length gain of oysters was found in treatment B, which was 0.66 ± 0.06 mm, then the length gain of treatment A, which was 0.39 ± 0.04 mm. The lowest length increase was found in treatment C, which was 0.20 ± 0.06 mm and treatment D, which was 0.17 ± 0.04 mm. Statistical analysis with the F test showed that the IMTA system has a significant effect on oyster length gain with the value of Fcount (282) > Ftable (0.01). The results of the LSD test showed that the length gain between treatments was significantly different, with the best length gain also found in treatment B.

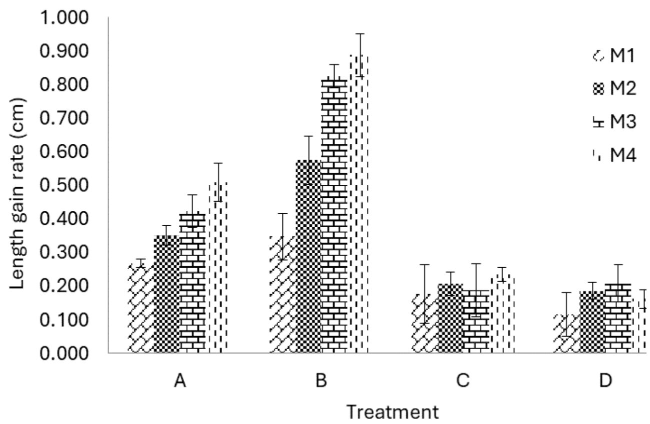


Figure 7. Oyster length gain rate. A = Stocking density of 10 milkfish, 15 tiger prawns and 20 oysters; B = Stocking density of 15 milkfish, 20 tiger prawns and 30 oysters; C = Stocking density of 20 milkfish, 25 tiger prawns and 40 oysters; D = Stocking density of 25 milkfish, 30 tiger prawns, and 50 oysters. M1, M2, M3, M4 = weeks of weight measurement.

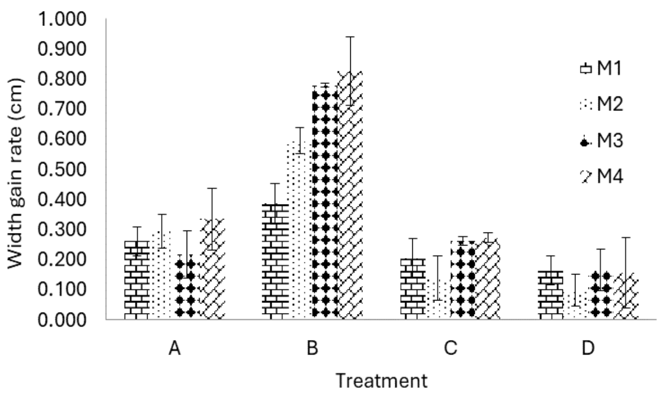


Figure 8. Mean oyster width gain rate. A = Stocking density of 10 milkfish, 15 tiger prawns and 20 oysters; B = Socking density of 15 milkfish, 20 tiger prawns and 30 oysters; C = Stocking density of 20 milkfish, 25 tiger prawns and 40 oysters; D = Stocking density of 25 milkfish, 30 tiger prawns, and 50 oysters. M1, M2, M3, M4 = weeks of weight measurement.

The application of the IMTA system affects the increase in the width and thickness of the oyster shell. The mean increase in oyster width for each treatment is shown in Figure 8. The mean increase rate in oyster width was found to be highest in treatment B, which was 0.65 ± 0.06 mm. Subsequently, the width increase in treatment A was 0.28 ± 0.07 mm and in treatment C 0.22 ± 0.04 mm. The lowest increase in oyster width was found in treatment D, which was 0.15 ± 0.07 mm. Statistical analysis of the F test showed that the application of the IMTA system showed significant effects on the increase in oyster width with a value of Fcount (425) > Ftable (0.01). Further test analysis (LSD) showed that treatment B was significantly different from treatments A, C, and D, and treatment A was significantly different from treatment D.

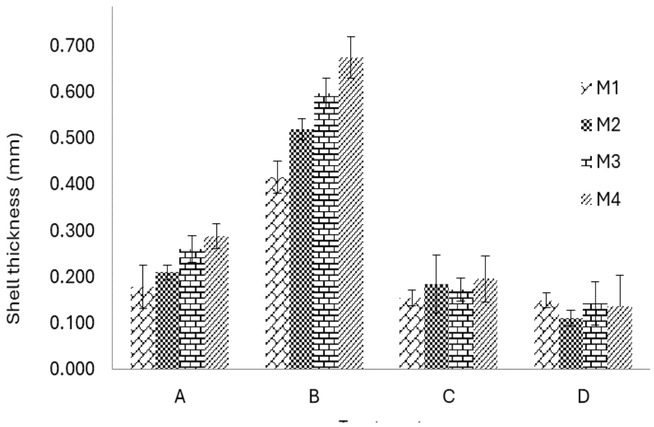


Figure 9. Oyster shell thickness gain rate. A = Stocking density of 10 milkfish, 15 tiger prawns and 20 oysters; B = Socking density of 15 milkfish, 20 tiger prawns and 30 oysters; C = Stocking density of 20 milkfish, 25 tiger prawns and 40 oysters; D = Stocking density of 25 milkfish, 30 tiger prawns, and 50 oysters. M1, M2, M3, M4 = weeks of weight measurement.

Mean increase in oyster shell thickness was highest in treatment B of 0.55 ± 0.03 mm (Figure 9). Subsequently, in treatment A with a shell thickness of 0.23 ± 0.03 mm. The lowest increase in shell thickness was found in treatment C, which was 0.18 ± 0.04 mm and in treatment D, which was 0.13 ± 0.04 mm. Statistical analysis with the F test showed that IMTA significantly affected the increase in oyster shell thickness with the value of Fcount (13) > Ftable (0.01). The results of the LSD test showed that treatment B was significantly different from treatments A, C, and D.

Water parameter

The physicochemical parameters of the water observed in the study (30 days) were temperature, pH, DO, salinity, ammonia, nitrate, and nitrite. The quality of the water during the study showed a low fluctuation, which is presented in Table 1.

Table 1. Water quality parameter during the experiment.

Parameter	Range	Mean	St. Dev.
Temperature (°C)	25 - 29	27,1	0,74
pH	7 - 7,5	7,26	0,12
Dissolved oxygen	4,5 - 7	5,7	0,63
Salinity (ppt)	20 - 25	23,2	1,29
Ammonia (mg/L)	0,056 – 0,075	0,067	0,009
Nitrate (mg/L	0,048 – 0,050	0,049	0,001
Nitrite (mg/L)	0,131 – 0,154	0,139	0,01

Discussion

Survival rate

The survival rate of milkfish, tiger prawns, and oysters reared in the IMTA system did not significantly affect the survival of the respective biota. The high and low mean survival values of milkfish, tiger prawns, and oysters are attributed to the availability of food according to their needs, the suitable life following their natural habitat, and the quality of water during the experiment under favorable conditions for the development of the biota. Furthermore, the three types of species had different living habitats and feeding habits. Food availability factors (phytoplankton, zooplankton, suspended organic matter) and habitat support a species' survival and growth (Wotton, 2020).

The horizontal arrangement did not hinder the oysters from filtering their food. Bivalves get their food by filtration with a siphon to prevent competition for food among species (Gosling, 2008). To maintain their survival, organisms interact with the surrounding environment and prefer to select optimal environmental conditions and habitat types to continue to grow and reproduce. Oysters can pump suspended particles using their gills; during pumping, the oyster shell is widely opened and the mantle is elongated, resulting in water pressures and flows (Riisgård & Larsen, 2010). The suspended particles that are required, phytoplankton and organic matter, will enter the oral cavity and then the unneeded particles will be converted into pseudofeces and discarded (Beninger & Veniot, 1999). Furthermore, fish survival is primarily determined by the availability of good food and good water quality management. Fish survival is determined by several factors, including water quality, such as temperature, ammonia, nitrite levels, dissolved oxygen, acidity (pH) of the water, and the ratio between the amount of food and density (Verma et al., 2022)

Biota growth under IMTA system

The application of the IMTA system in the rearing of milkfish, tiger prawns, and oysters significantly affects the growth of the three biota. Treatment B showed the highest growth mean of the biota tested because treatment B (stocking density of 15 milkfish, 20 tiger prawns, and 30 oysters) has different habitats and feeding habits. The milkfish in the fingerling stage live in the water column, which causes extensive movement and active swimming in search of food, while the tiger prawns in the fingerling stage live at the bottom of the water, where their movement at the bottom of the water is influenced by its land contour. At the same time, the arrangement of hanging oysters prevents competition for food with milkfish and tiger prawns. Then, the hanging location of the oyster makes it easier for oysters to utilize food directly, such as phytoplankton, which is carried by the current, as the current strongly affects the food supply; benefits of water currents are food supply, oxygen solubility, plankton distribution, and removing CO_2 and remnants of marine biota products (Lalli & Parsons, 1997). The more food supplies in the water, the faster the growth. In addition, water currents play an important role in the success of culture activities in both water circulation and nutrient transport (Xuan et al., 2019).

Growth is the total energy converted into body constituents; this energy requirement is obtained from food. Growth is also a process of increasing the weight and length of the body of the biota, whereas differences in growth rates can be caused by the influence of dense stocking and competition on food supply (Elliott & Hurley, 1995). Treatment B, with a maintenance container size of 1 m long, 1 m wide, and 1 m high, is the treatment with the best growth; it significantly affects the growth of the three test biota due to the absence of competition for food and space. Milkfish use food that is on the surface of the water; milkfish have a grouping nature and live in the water column so that they do not experience competition in getting food due to a low stocking density, while tiger prawns utilize food at the bottom of the water because tiger prawns have an individual nature, with a low stocking density so that there is no competition. The higher the density of fish, the lower the growth rate per individual; a low density of fish has the ability to utilize food well compared to a high density, as food is an external factor that plays a role in growth (Goodrich & Clark, 2023). Meanwhile, oysters use phytoplankton that drifts with the current; bivalves in nature consume various types of suspended particles such as bacteria, phytoplankton, microzooplankton, detritus, and dissolved organic matter; phytoplankton is the most popular food source (Gosling, 2008).

The density of the stock dramatically affects the growth of the biota; this is the case in treatment D, which shows the lowest mean growth results due to unbalanced stocking factors. Treatment D had the highest stocking density of the other treatments. The density of prawns that are too dense leads to different variations in mortality due to cannibalism. If the bottom of the container used is too narrow compared to the number of biota accommodated, it will cause the species to pile up on top of each other; as a result, there will be competition for space. The higher the stock density, the lower the growth of the test biota. The high stock density interferes with the growth rate despite the adequate food needs, a high stocking density will cause high competition for food and space, reducing the survival rate of organisms (Li et al., 2021).

Water quality

The application of the IMTA system did not have a significant effect on water quality. The range of water quality during the study was temperature (25-29 °C), pH (7-7.5), DO (4.5-7 ppm), salinity (20-25 ppt), ammonia (0.056-0.075 mg/L), nitrate (0.048-0.050 mg/L) and nitrite (0.131-0.154 mg/L). The availability of sufficient food and the quality of the supporting water greatly affects the survival rate of fish. Water quality also affects the survival and growth of cultured aquatic organisms (Nair & Nayak, 2023).

Tiger prawns have a high tolerance to temperature changes and can still grow and develop in the temperature range of 26-32 °C. The salinity level for the rearing of tiger prawns in ponds is between 15-30 ppt. Tiger prawns are euryhaline, so they have a wide tolerance to salinity (Chaitanawisuti et al., 2013). Changes in salinity in a body of water cause the molting process in prawns to be disrupted so that the growth of the prawns is inhibited. At a salinity of 5-10 ppt, molting prawns can be faster but more sensitive to disease attacks. The usual pH range for the rearing of tiger prawns ranges from 7.5 to 8.5. Prawns die at pH < 4 and > 10 (Robertson, 2006). Low pH values cause acidic waters and interfere with the absorption process of chitin so that prawns become porous, while high pH causes alkaline waters, resulting in increased ammonia toxicity (González-Vera & Brown, 2017). The optimal water temperature for the life of milkfish fingerlings is 27-30 ℃. Its life begins to be disrupted when the water temperature drops to 15-20 ℃ or increases above 35 ℃. Its activity stops in waters where the temperature is below 6 ℃ or above 42 ℃ (Hanke et al., 2019). The optimal dissolved oxygen content for milkfish is 3 to 7 mg/l (Su et al., 2002).

Ammonia is a toxic compound that results from excretion or excretion of feces in the form of gas. Furthermore, ammonia can come from food that is not eaten by fish, so it dissolves in water. Ammonia will undergo a process of nitrification and denitrification according to the nitrogen cycle in water so that it becomes nitrite (NO_2) and nitrate (NO_3). The nitrification and denitrification process can run smoothly if enough Nitrobacter and Nitrosomonas bacteria are available. Nitrobacter plays a role in the conversion of ammonia to nitrite, whereas Nitrosomonas converts nitrite to nitrate (Hargreaves, 1998; Preena et al., 2021)

Oyster growth and survival occur well at temperatures ranging from 15 to 33 °C, salinity ranging from 15 to 35 ppt, dissolved oxygen (DO) ranging from 3-6 ppm, and pH ranging from 6 to 8 (Le Moullac et al., 2007; Pourmozaffar et al., 2020). The high and low water quality parameters are influenced by temperature; if the temperature increases, the others will also rise. The pH value is significant in oyster culture because the pH of water is a limiting factor in the life of oysters and other microorganisms. The pH of the water suitable for oyster life is neutral to slightly alkaline 6-8, and the dissolved oxygen (DO) ranges from 3-6 ppm. Water quality is very influential on oyster growth because if changes occur, it forces bivalves to adapt (Quayle, 1980). Temperature plays an essential role in the physiological activities of oysters in water, such as filtration and metabolic activities (Lannig et al., 2006). Changes in pH in water can affect physiology, including oyster reproduction, breeding, and activities. Changes in dissolved oxygen in water can affect breathing, metabolic processes, or substance exchange, producing energy for growth (Mallya, 2007). It can be concluded that the water quality parameters at the time of the study were still within the standard water quality range for the survival of milkfish, tiger prawns, and oysters.

Conclusions

This study highlights that IMTA systems effectively support the survival and growth of milkfish, tiger prawns and oysters. Key factors contributing to their success include adequate food availability, emulation of suitable habitats, and maintenance of optimal water quality parameters. The IMTA configuration minimizes inter-species competition for food and optimizes environmental conditions, resulting in favorable outcomes for the cultured biota. Future research efforts could focus on several ways to further improve the understanding and implementation of IMTA systems. investigating the long-term sustainability and resilience of IMTA systems under varying environmental conditions would be valuable. In addition, exploring the potential integration of additional species or trophic levels into IMTA arrangements could broaden the scope of benefits and optimize resource utilization.

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Authorship contribution

MA: Conceptualization, methodology, investigation, resources, sample processing and analysis, data curation, formal analysis, visualization, writing - original draft preparation, writing - review and editing. **MU**: Methodology, writing - review and editing, supervision. **MK:** Conceptualization, methodology, writing - review and editing, supervision. All authors gave final approval for publication and agreed to be held accountable for the work performed therein.

Data availability

Datasets generated during and/or analyzed throughout the present study are available from the corresponding author upon reasonable request.

Conflict of interest

On behalf of all authors, the corresponding author states that there are no conflicts of interest.

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References

Azhar, M., & Memiş, D. (2023). Application of the IMTA (integrated multitrophic aquaculture) system in freshwater, brackish and marine aquaculture. *Aquatic Sciences and Engineering*, *38*(2), 106-121. https://doi.org/10.26650/ase20231252136.

Beninger, P. G., & Veniot, A. (1999). The oyster proves the rule: mechanisms of pseudofeces transport and rejection on the mantle of *Crassostrea virginica* and *C. gigas*. *Marine Ecology Progress Series*, *190*, 179-188.

Chaitanawisuti, N., Santhaweesuk, W., & Wattayakorn, G. (2013). The combined effects of temperature and salinity on survival of postlarvae tiger prawn *Penaeus monodon* under laboratory conditions. *Agricultural Sciences*, *04*(06), 53-56. https://doi.org/10.4236/as.2013.46A008.

Elliott, J. M., & Hurley, M. A. (1995). The functional relationship between body size and growth rate in fish. *Functional Ecology*, *9*(4). https://doi.org/10.2307/2390153.

FAO. (2010). Aquaculture development. In *4. Ecosystem approach to aquaculture* (pp. 53). FAO.

González-Vera, C., & Brown, J. H. (2017). Effects of alkalinity and total hardness on growth and survival of postlarvae freshwater prawns, *Macrobrachium rosenbergii* (De Man 1879). *Aquaculture*, *473*, 521-527. https://doi.org/https://doi.org/10.1016/j.aquaculture.2017.03.016.

Goodrich, H. R., & Clark, T. D. (2023). Why do some fish grow faster than others? *Fish and Fisheries*, *24*(5), 796-811. https://doi.org/10.1111/faf.12770.

Gosling, E. (2008). *Bivalve molluscs: biology, ecology and culture*. John Wiley & Sons.

Hanke, I., Ampe, B., Kunzmann, A., Gärdes, A., & Aerts, J. (2019). Thermal stress response of juvenile milkfish

(*Chanos chanos*) quantified by ontogenetic and regenerated scale cortisol. *Aquaculture*, *500*, 24-30. https://doi.org/10.1016/j.aquaculture.2018.09.016.

Hargreaves, J. A. (1998). *Nitrogen biogeochemistry of aquaculture ponds* (Vol. 166).

Hossain, A., Senff, P., & Glaser, M. (2022). Lessons for coastal applications of IMTA as a way towards sustainable development: A review. *Applied Sciences*, *12*(23). https://doi.org/10.3390/app122311920.

Lalli, C., & Parsons, T. R. (1997). *Biological oceanography: an introduction*. Elsevier.

Lannig, G., Flores, J. F., & Sokolova, I. M. (2006). Temperature-dependent stress response in oysters, *Crassostrea virginica*: Pollution reduces temperature tolerance in oysters. *Aquatic Toxicology*, *79*(3), 278-287. https://doi.org/https://doi.org/10.1016/j.aquatox.2006.06.017.

Le Moullac, G., Quéau, I., Le Souchu, P., Pouvreau, S., Moal, J., René Le Coz, J., & François Samain, J. (2007). Metabolic adjustments in the oyster *Crassostrea gigas* according to oxygen level and temperature. *Marine Biology Research*, *3*(5), 357-366.

Li, L., Shen, Y., Yang, W., Xu, X., & Li, J. (2021). Effect of different stocking densities on fish growth performance: A meta-analysis. *Aquaculture*, *544*. https://doi.org/10.1016/j.aquaculture.2021.737152.

Loayza-Aguilar, R. E., Huamancondor-Paz, Y. P., Saldaña-Rojas, G. B., & Olivos-Ramirez, G. E. (2023). Integrated Multitrophic Aquaculture (IMTA): Strategic model for sustainable mariculture in Samanco Bay, Peru. *Frontiers in Marine Science*, *10*. https://doi.org/10.3389/fmars.2023.1151810.

Mallya, Y. J. (2007). The effects of dissolved oxygen on fish growth in aquaculture. *The United Nations University Fisheries Training Programme, Final Project*.

Nair, N. V., & Nayak, P. K. (2023). Exploring water quality as a determinant of small-scale fisheries vulnerability. *Sustainability*, *15*(17). https://doi.org/10.3390/su151713238.

Nederlof, M. A. J., Verdegem, M. C. J., Smaal, A. C., & Jansen, H. M. (2021). Nutrient retention efficiencies in integrated multitrophic aquaculture. *Reviews in Aquaculture*, *14*(3), 1194-1212. https://doi.org/10.1111/raq.12645.

Pourmozaffar, S., Tamadoni Jahromi, S., Rameshi, H., Sadeghi, A., Bagheri, T., Behzadi, S., Gozari, M., Zahedi, M. R., & Abrari Lazarjani, S. (2020). The role of salinity in physiological responses of bivalves. *Reviews in Aquaculture*, *12*(3), 1548-1566.

Preena, P. G., Rejish Kumar, V. J., & Singh, I. S. B. (2021). Nitrification and denitrification in recirculating aquaculture systems: the processes and players. *Reviews in Aquaculture*, *13*(4), 2053-2075.

Quayle, D. B. (1980). *Tropical oysters: culture and methods*. IDRC, Ottawa, ON, CA.

Reid, G. K., Lefebvre, S., Filgueira, R., Robinson, S. M. C., Broch, O. J., Dumas, A., & Chopin, T. B. R. (2018). Performance measures and models for open‐water integrated multitrophic aquaculture. *Reviews in Aquaculture*, *12*(1), 47-75. https://doi.org/10.1111/raq.12304.

Riisgård, H. U., & Larsen, P. S. (2010). Particle capture mechanisms in suspension-feeding invertebrates. *Marine Ecology Progress Series*, *418*, 255-293.

Robertson, C. (2006). *Australian prawn farming manual: health management for profit*. The State of Queensland, Department of Primary Industries and Fisheries.

Su, M.-S., Lee, C.-S., & Liao, I. C. (2002). Technical responses to challenges in milkfish aquaculture. *Reviews in Fisheries Science*, *10*(3-4), 451-464.

The Indonesian Ministry of Marine Affairs and Fisheries. (2018). *Indonesia's marine and fisheries in numbers 2018*.

Verma, D. K., Satyaveer, N. K. M., Kumar, P., & Jayaswa, R. (2022). Important water quality parameters in aquaculture: An overview. *Agriculture and Environment*, *3*(3), 24-29.

Wotton, R. S. (2020). Particulate and dissolved organic matter as food. In *The biology of particles in aquatic systems, second edition* (pp. 235-288). CRC Press.

Xuan, J., He, Y., Zhou, F., Tang, C., Zheng, X., Liu, H., Yu, L., & Chen, J. (2019). Aquaculture-induced boundary circulation and its impact on coastal frontal circulation. *Environmental Research Communications*, *1*(5). https://doi.org/10.1088/2515-7620/ab22cd.

Yayasan Inisiatif Dagang Hijau. (2018). *Investment Guideline for Sustainable Aquaculture in Indonesia*. Yayasan Inisiatif Dagang Hijau.