Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(6): 117 – 133 (2025)
www.ejabf.journals.ekb.eg

Application of a Modified Booster System in the Polyculture of the Swamp Eel (*Monopterus albus*) and the Nile Tilapia (*Oreochromis niloticus*) in Brackish Water

Niken A. Pamukas[1]*, Mulyadi[1], Iskandar Putra[1], Dwi Septiani Putri[2], Rahma Aprianti[1], and Randy Wiradharma[1]

[1]Department of Aquaculture, Faculty of Fisheries and Marine Science, Riau University, Pekanbaru, Indonesia

[2]Department of Aquaculture, Faculty of Marine Science adn Fisheries, Raja Ali Haji Maritime University

***Corresponding Author: niken.ayu@lecturer.unri.ac.id**

ARTICLE INFO

Article History:
Received: July 25, 2025
Accepted: Oct. 5, 2025
Online: Nov. 7, 2025

Keywords:
Polyculture,
Monopterus albus,
Oreochromis niloticus,
Recirculating Booster System,
Stocking Ratio,
Brackish Water

ABSTRACT

This study aimed to evaluate the optimal stocking ratio and the effects of a modified booster system with recirculation on growth performance, survival rate, physiological response, and water quality in the polyculture of Asian swamp eel (*Monopterus albus*) and saline tilapia (*Oreochromis niloticus*) cultured in brackish water (10 ppt). The experiment was conducted for 56 days, from July to September 2025, using a completely randomized design with seven treatments: P1 (eel monoculture), P2 (tilapia monoculture), P3 (1:1), P4 (1:1.5), P5 (1.5:1), P6 (1:2), and P7 (2:1), each with three replications. The booster system was equipped with mechanical and biological filtration units (biofoam, zeolite, and bioball) and supported by the application of probiotic boosters in the rearing medium, feed, and fish immunostimulants. The results showed that different stocking ratios significantly affected the growth and survival of both species ($P<0.05$). Treatment P3 (1:1 ratio) yielded the highest weight and length growth in both eel and tilapia, with specific growth rates of 2.15%/day and 2.57%/day, respectively. The highest feed efficiency was also observed in P3, reaching 46.22% for eel and 52.56% for tilapia, with the lowest feed conversion ratios (1.41 and 1.90). Survival rates reached 83.33% for eel and 90% for tilapia, indicating that a balanced species ratio created a stable environment that reduced stress and improved energy utilization. Hematological analysis showed the best physiological condition in P2 and P3, whereas elevated leukocyte and glucose levels in high-density treatments (P6 and P7) indicated stress responses. Water quality parameters during the experiment remained within the optimal range for both eel and saline tilapia.

INTRODUCTION

Indonesia has great potential for the development of brackish water aquaculture, with a total water area of approximately 2.96 million hectares **(Puspitawati *et al*., 2022)**; however, its utilization remains far from optimal. Many coastal and marginal lands are still underexploited due to limited aquaculture technology, low adoption of innovation, and a lack of knowledge regarding fish species that can adapt to high-salinity conditions. These constraints highlight the urgent need to develop water-efficient, productive, and environmentally friendly aquaculture systems suitable for marginal lands. Polyculture systems in brackish water represent an innovative approach to increasing spatial efficiency and maximizing ecological interactions among species.

The combination of swamp eel (*Monopterus albus*), a demersal species, and saline tilapia (*Oreochromis niloticus*), a pelagic species, offers great potential since both possess high economic value and tolerance to brackish environments. Swamp eel and saline tilapia can tolerate salinities up to 10 ppt or even higher in the case of saline tilapia **(Pedersan *et al*., 2012; Diego *et al*., 2023)**. Their different ecological niches allow the development of a vertically integrated culture system that optimizes the entire water column, thereby improving overall efficiency and productivity. The success of polyculture largely depends on the stocking ratio between species, as population balance determines spatial competition, oxygen availability, and nutrient utilization efficiency **(Aura *et al*., 2025)**. An appropriate stocking ratio can create a stable ecosystem, promote optimal growth, and minimize physiological stress among cultured species.

Probiotic-based booster technology has been developed as an alternative solution to improve the stability of aquaculture systems. The application of boosters in water, feed, and fish immunity has been shown to enhance water quality, accelerate growth, and improve immune response **(Pamukas *et al*., 2021)**. A modified booster system integrated with water recirculation is designed to increase water use efficiency, reduce daily water exchange frequency, and utilize nutrient-rich waste for natural bioremediation processes **(Pamukas *et al*., 2022)**. This approach establishes an interconnected ecological cycle among cultured species while minimizing environmental impacts from aquaculture activities. Although booster technology has been widely applied in monoculture systems, its implementation in stratified polyculture systems within brackish environments remains limited and has not been thoroughly investigated.

This study aimed to evaluate the optimal stocking ratio and the effect of a modified booster system in the polyculture of swamp eel and saline tilapia in brackish water. The research focuses on assessing the growth and survival performance of both species, as well as the environmental responses resulting from biological interactions and the application of the modified booster system. The findings are expected to provide a scientific basis for developing efficient and sustainable aquaculture systems suitable for coastal and marginal areas, contributing to food security and the economic welfare of aquaculture communities.

MATERIALS AND METHODS

Time and Place

This study was conducted from August to September 2025 at the Aquaculture Technology Laboratory, Faculty of Fisheries and Marine Sciences, Universitas Riau. The culture and data collection processes were carried out for 56 days of the rearing period.

Research Method

This experiment employed a Completely Randomized Design (CRD) with one factor, namely the stocking ratio between Asian swamp eel (*Monopterus albus*) and saline tilapia (*Oreochromis niloticus*). The approach of using stocking ratios in polyculture systems has been widely applied in previous studies to determine ecological balance and production efficiency in aquaculture systems **(Aura *et al*., 2025)**. The experiment consisted of seven treatments with three replications each. The treatments were as follows:

- P1: Monoculture of Asian swamp eel
- P2: Monoculture of saline tilapia
- P3: Polyculture of swamp eel and saline tilapia at a ratio of 1:1
- P4: Polyculture of swamp eel and saline tilapia at a ratio of 1:1.5
- P5: Polyculture of swamp eel and saline tilapia at a ratio of 1.5:1
- P6: Polyculture of swamp eel and saline tilapia at a ratio of 1:2
- P7: Polyculture of swamp eel and saline tilapia at a ratio of 2:1

Each treatment was replicated three times, resulting in a total of 21 experimental units. This design was chosen to ensure random data distribution and allow valid statistical analysis of the effect of stocking ratio differences on the growth and survival performance of both species.

Tank and Media Preparation

The experimental units consisted of circular fiberglass tanks with a diameter of 60 cm, a height of 35 cm, and a total volume of 100 L, each filled with 80 L of water. Before use, all tanks were cleaned with Boster Blue Copper solution and aerated intensively for 2–3 days to stabilize water conditions. A recirculating aquaculture system (RAS) was installed by adding a filter trough measuring 60 × 14 × 14 cm^3, placed above the rearing tanks. Water from each tank was pumped into the filter using an 18-watt water pump and returned through a 2.5 cm PVC pipe. The filter media consisted of biofoam, zeolite, and bioballs, separated by partitions within the trough to optimize physical, chemical, and biological filtration processes (Fig. 1).

Artificial seawater was prepared by dissolving 670 g of synthetic sea salt (ASW) in 19 L of freshwater to achieve a salinity of 30 ppt, measured using a refractometer.

Dilution to a working salinity of 10 ppt was calculated using the formula $V_1 \times M_1 = V_2 \times M_2$ **(Arrokhman *et al*., 2012)**. The water medium was enriched with a fermentation mixture consisting of 0.5 kg rice bran, 200 mL Boster Planktop, 10 g Boster Aquaenzym, and 20 mL Boster Amino Liquid. The mixture was diluted in 10 L of water, filtered, and applied to the culture medium at a dose of 0.45 mL/L every nine days between 09:00–10:00 a.m **(Pamukas *et al*., 2020)**. Additionally, Boster Manstap was applied in the afternoon at a concentration of 30 ppm to maintain biological system stability.

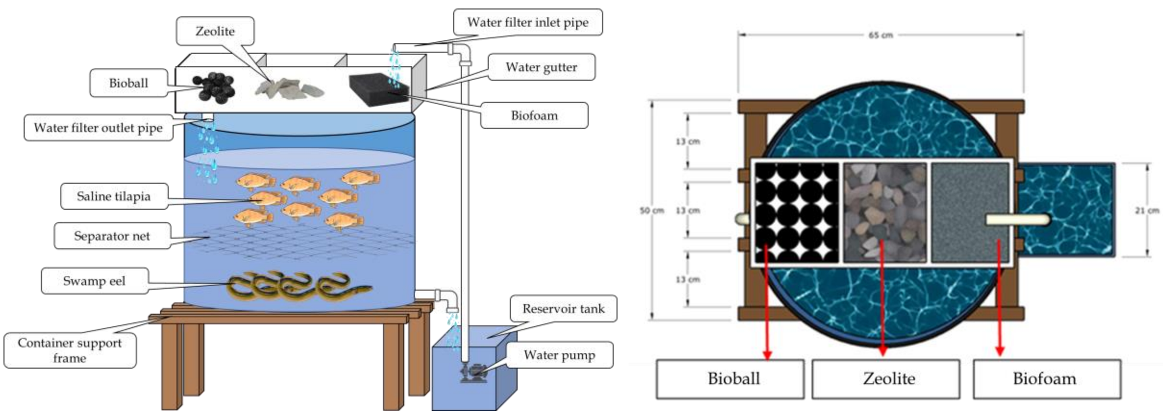


Fig. 1. Experimental Tank Design (side and top view)

Feed and Test Animals Preparation

Commercial pellets containing 38% crude protein were used as the main diet and enriched with Boster supplements according to the rearing phase. From day 1 to day 30, the feed was supplemented with 5 mL/kg Boster Amino Liquid, 8 g/kg Boster Grotop, and 2 g/kg Boster Premix Aquavita. From day 31 to day 56, the formulation was modified to 5 mL/kg Boster Amino Liquid, 8 g/kg Grotop, and 2 g/kg Boster Vitaliquid **(Pamukas *et al*., 2022)**. Before stocking, swamp eels (10–15 cm) and saline tilapia (5–7 cm) were immersed in a solution of Boster Immunovit (0.6 mL/L) for 15 minutes and Boster Stress Off (2 mL/5 L) to enhance immune response and reduce transport stress. After acclimation, the fish were stocked in the afternoon according to the respective density ratios **(Pamukas *et al*., 2021)**.

Rearing and Sampling

Fish were fed daily at 10% of total biomass, divided into three feeding times at 08:00, 13:00, and 16:00. Body weight and total length were measured every 14 days to monitor growth performance, while survival rate was recorded at the end of the rearing period. Blood sampling was performed on days 1, 28, and 56 by collecting 1 mL of blood from two individuals of each species per replicate. Prior to blood collection, fish and eels were anesthetized using clove oil at a concentration of 0.1 mL/L. Blood samples were drawn from the caudal vein using a 1 mL syringe pre-coated with 10% EDTA as an anticoagulant.

Response Parameters

Growth Performance and Survival

Growth performance of saline tilapia and swamp eel was evaluated based on absolute weight gain (W = Wt – Wo), absolute length gain (L = Lt – Lo), specific growth rate (SGR), feed conversion ratio (FCR), and feed efficiency (FE), as described by **Zonneveld *et al*. (1991)**. The survival rate (SR) was calculated using the formula SR = (Nt/No) × 100%, where Nt and No represent the number of fish at the end and beginning of the experiment, respectively **(Effendie, 1979)**.

Competition Index (CI)

The competition index (CI) was analyzed to evaluate the level of interspecific interaction between swamp eel (*Monopterus albus*) and saline tilapia (*Oreochromis niloticus*) in the polyculture system. The CI was calculated by comparing the biomass of each species in polyculture to that in monoculture using the formula $CI = (Bp - Bm) / Bm$, where Bp is the biomass of the species in polyculture and Bm is the biomass in monoculture **(Nurfadillah *et al*., 2021)**. A positive CI value (CI > 0) indicates interspecific competition, meaning that the total biomass in polyculture is lower than in monoculture. A CI value equal to zero (CI = 0) suggests no significant interaction effect, while a negative CI value (CI < 0) indicates no competition or a mutualistic relationship, where biomass in polyculture exceeds that in monoculture. This parameter was used to determine the ecological balance and the competitive or symbiotic relationship between the two species under different stocking ratios within the modified booster recirculating aquaculture system.

Blood Hematology

Hematological parameters analyzed included total erythrocytes, total leukocytes, hemoglobin concentration, hematocrit value, leukocrit value, and blood glucose concentration. Hematological analysis was conducted to evaluate the physiological response of fish to the modified booster system and different stocking ratios. Blood samples were collected from the caudal vein using a sterile 1 mL syringe containing 10% EDTA. Sampling was conducted at the beginning and end of the experiment after 24 hours of fasting to minimize the effect of feed on blood composition.

Total erythrocytes and leukocytes were counted using a Neubauer hemocytometer under a microscope at 400× magnification. Hemoglobin concentration was measured using the cyanmethemoglobin method with a spectrophotometer at 540 nm wavelength. Hematocrit and leukocrit values were determined using a microhematocrit method with centrifugation at 10,000 rpm for 5 minutes and read using a hematocrit reader. Blood glucose levels were analyzed using an enzymatic glucose kit based on the glucose oxidase (GOD-PAP) method and read spectrophotometrically at 500 nm. All analyses followed **Blaxhall (1971)** with modifications for brackishwater fish species.

Water Quality

Water quality parameters were monitored to evaluate environmental stability during the rearing period. Parameters measured included temperature, pH, dissolved oxygen (DO), ammonia (NH_3-N), nitrite (NO_2^--N), nitrate (NO_3^--N), and total organic matter. Temperature, pH, and DO were measured daily using a DO meter, while ammonia, nitrite, and nitrate were analyzed every 14 days using spectrophotometric methods **(APHA, 2017)**. Measured water quality parameters were compared with the optimal ranges for tilapia and swamp eel to assess the effectiveness of the modified booster system in maintaining environmental stability. According to Boyd (2015), optimal ranges for brackishwater fish culture are temperature 26–32°C, DO > 4 mg/L, pH 6.5–8.5, and ammonia < 0.1 mg/L.

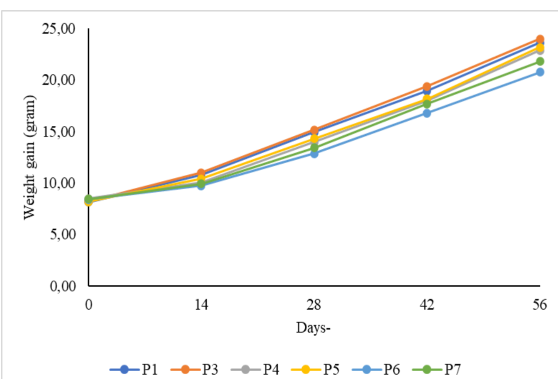
Data Analysis

Quantitative data obtained included growth performance, hematological parameters, and water quality. Growth and hematological data were analyzed using one-way analysis of variance (ANOVA) with a 95% confidence level in SPSS software. When significant differences were observed among treatments, the Least Significant Difference (LSD) test was applied to determine the treatment with the best response.

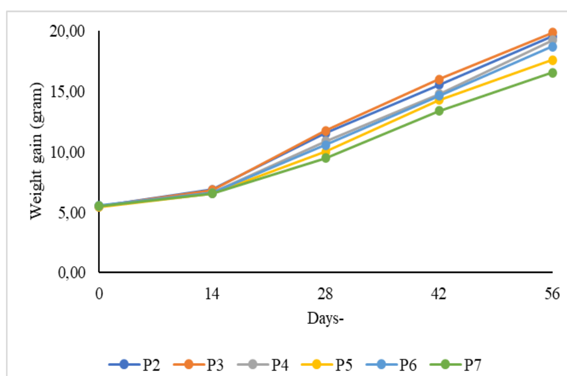
RESULTS

1. Growth and Survival of Asian Swamp Eel and Saline Tilapia

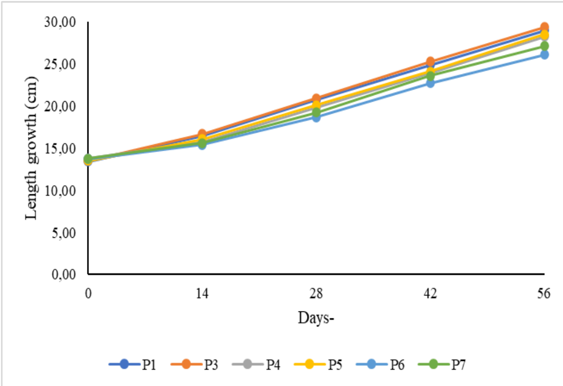
The growth performance of *Monopterus albus* and *Oreochromis niloticus* showed clear differences among treatments, indicating that the stocking ratio significantly influenced feed utilization and spatial distribution within the polyculture system. The mean body weight and length growth of both species are presented in Fig. (2).

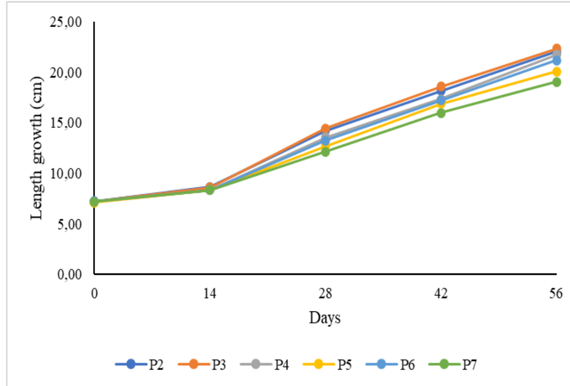


(A)



(B)





(C) (D)

Fig. 2. Average body weight and length growth of swamp eel (*M. albus*) and saline tilapia (*O. niloticus*); A (weight growth of swamp eel), B (weight growth of saline tilapia), C (length growth of swamp eel), D (length growth of saline tilapia)

Fig. (2) illustrates the growth patterns of *M. albus* and *O. niloticus* under different stocking ratios during the culture period. Overall, both species exhibited continuous increases in body weight and length over time, although with varying growth rates across treatments. The balanced ratio (P3, 1:1) produced the highest growth performance in both species, while the lowest growth was observed at the ratios of 1:2 (P6) and 2:1 (P7).

The specific growth rate (SGR) of swamp eel and saline tilapia also varied among treatments, influenced by stocking ratios and interspecific interactions within the culture environment. The SGR values for both species are shown in Fig. (3).

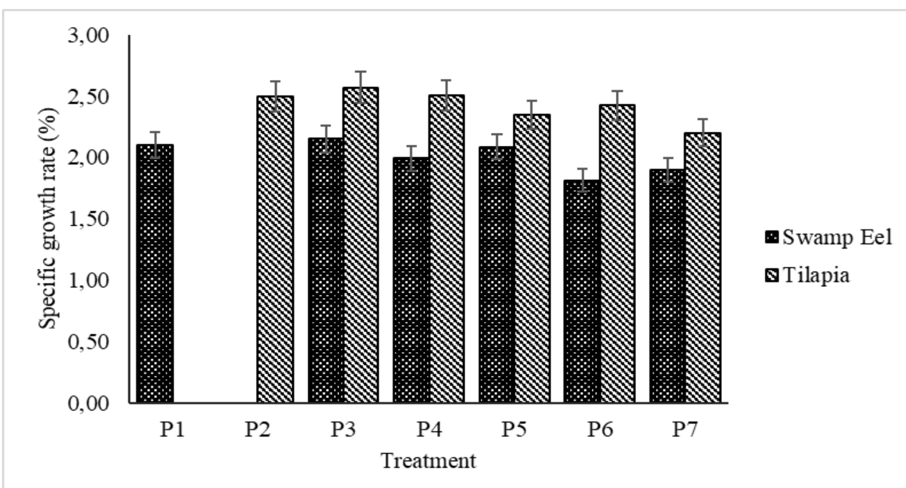


Fig. 3. Specific growth rate (SGR, %) of swamp eel (*M. albus*) and saline tilapia (*O. niloticus*) during the experiment

The highest SGR values were obtained in treatment P3, with 2.15% day^{-1} for swamp eel and 2.57% day^{-1} for saline tilapia. These results indicate that a balanced stocking ratio in polyculture systems enhances energy efficiency and feed utilization compared to monoculture systems.

The relationship between stocking ratio and SGR is shown in Fig. (4). Linear regression analysis revealed a positive correlation between stocking density and SGR for both species. The regression equations were $y = 0.094x + 0.7129$ ($R^2 = 0.5533$; r = 0.7438) for swamp eel and $y = 0.119x + 0.8016$ ($R^2 = 0.6127$; r = 0.7827) for saline tilapia. The relatively high determination coefficients indicate that 55.33% of SGR variation in swamp eel and 61.27% in saline tilapia were significantly influenced by stocking ratio. This positive linear relationship suggests that an increase in stocking density, within physiological tolerance limits, can improve growth performance when interspecific balance is maintained.

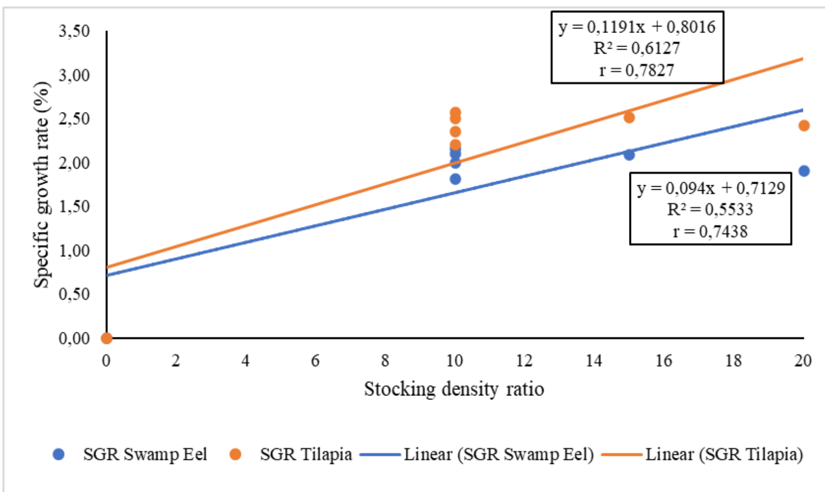


Fig. 4. Linear regression of specific growth rate (SGR) of swamp eel and saline tilapia at different stocking ratios

The observed growth performance parameters included absolute weight gain, absolute length gain, survival rate (SR), feed efficiency (FE), feed conversion ratio (FCR), and specific growth rate (SGR). The results showed differences in growth responses among treatments, which were influenced by the stocking density ratios and the presence of saline tilapia within the polyculture system. Detailed data on the growth performance of swamp eel are presented in Table 1.

Table 1. Growth performance parameters of *M. albus* after 56 days of rearing in four different treatments

Parameters	Treatments					
	P1	P3	P4	P5	P6	P7
Wt (g)	15.46±0.42^{de}	15.80±0.24^{e}	14.42±0.30^{c}	14.99±0.35^{cd}	12.37±0.40^{a}	13.35±0.38^{b}
Lt (cm)	15.54±0.31^{de}	15.82±0.24^{e}	14.44±0.30^{c}	15.01±0.35^{cd}	12.39±0.40^{a}	13.37±0.38^{b}
SGR (% day^{-1})	2.10±0.10^{c}	2.15±0.08^{c}	1.99±0.01^{bc}	2.09±0.11^{c}	1.81±0.03^{a}	1.90±0.04^{a}
FE (%)	42.66±1.95^{c}	46.22±2.85^{c}	34.29±2.1^{ab}	37.06±3.72^{b}	28.85±1.87^{a}	30.23±2.53^{a}
FCR	1.61±0.18^{ab}	1.41±0.18^{a}	2.13±0.16^{c}	2.03±0.19^{bc}	2.02±0.28^{bc}	2.64±0.13^{d}
SR (%)	83.33±5.77^{b}	83.33±11^{b}	80.00±10.0^{b}	64.44±10.0^{ab}	56.67±15^{ab}	53.33±10.4^{a}

Note: Wt = absolute weight, Lt = absolute length, SGR = specific growth rate, FE = feed efficiency, FCR = feed conversion ratio, SR = survival rate. Values are presented as mean ± standard deviation. Different superscript letters (a-d) in one row represent significant differences between treatments ($P < 0.05$). P1 (monoculture of swamp eel), P3 (polyculture of swamp eel and saline tilapia with a ratio of 1:1), P4 (ratio of 1:1.5), P5 (ratio of 1.5:1), P6 (ratio of 1:2) amd P7 (ratio of 2:1).

The growth performance parameters of saline tilapia were measured in terms of absolute weight gain, absolute length gain, specific growth rate (SGR), feed efficiency (FE), feed conversion ratio (FCR), and survival rate (SR). Variations in stocking density ratios and the presence of swamp eel in the polyculture system affected the feed utilization efficiency and growth rate of saline tilapia. Complete data on the growth performance of saline tilapia under each treatment are presented in Table (2).

Table 2. Growth performance parameters of *O. niloticus* after 56 days of rearing in four different treatments

Parameters	Treatments					
	P2	P3	P4	P5	P6	P7
Wt (g)	14.01±0.36^{d}	14.34±0.19^{d}	13.74±0.21^{d}	12.14±0.38^{b}	13.11±0.30^{c}	11.03±0.48^{a}
Lt (cm)	14.81±0.36^{d}	15.14±0.19^{d}	14.54±0.21^{d}	12.94±0.28^{b}	13.91±0.30^{c}	11.83±0.48^{a}
SGR (% day^{-1})	2.50±0.04^{d}	2.57±0.02^{d}	2.51±0.02^{d}	2.35±0.05^{b}	2.42±0.01^{c}	2.20±0.06^{a}
FE (%)	52.28±2.65^{b}	52.56±1.89^{b}	51.45±1.76^{b}	46.48±6.32^{b}	49.48±2.42^{b}	39.44±1.38^{a}
FCR	1.92±0.09^{a}	1.90±0.07^{a}	1.95±0.08^{a}	2.18±0.30^{a}	2.02±0.10^{a}	2.54±0.08^{b}
SR (%)	90.00±10.0^{b}	90.00±10.0^{b}	80.00±6.67^{ab}	76.67±15.2^{ab}	78.33±10^{ab}	60.00±10.0^{a}

Note: Wt = absolute weight, Lt = absolute length, SGR = specific growth rate, FE = feed efficiency, FCR = feed conversion ratio, SR = survival rate. Values are presented as mean ± standard deviation. Different superscript letters (a-d) in one row represent significant differences between treatments (P < 0.05). P2 (monoculture of saline tilapia), P3 (polyculture of swamp eel and saline tilapia with a ratio of 1:1), P4 (ratio of 1:1.5), P5 (ratio of 1.5:1), P6 (ratio of 1:2) amd P7 (ratio of 2:1).

Growth performance parameters included absolute weight gain, absolute length gain, specific growth rate (SGR), feed efficiency (FE), feed conversion ratio (FCR), and survival rate (SR). ANOVA results (Tables 1 and 2) showed significant differences among treatments ($P < 0.05$). Treatment P3 (1:1 ratio) achieved the highest values for absolute weight, absolute length, SGR, feed efficiency, and survival, along with the lowest FCR for both species. Conversely, treatments P6 (1:2) and P7 (2:1) recorded the lowest growth and feed performance with the highest FCR values. These findings suggest that a 1:1 stocking ratio provides the most effective balance for optimizing growth and feed efficiency of saline tilapia in brackish water polyculture systems.

The *Competition Index* (CI) was used to describe interspecific interactions, either competitive or mutualistic, based on biomass comparison between polyculture and monoculture. Table (3) presents the CI values of *M. albus* and *O. niloticus* at different stocking ratios.

Table 3. Competition Index (CI) values of swamp eel and saline tilapia under different stocking ratios

Treatments	Competition Index (CI)	
	Swamp eel	Tilapia
P3	-0,017	-0,016
P4	0,068	-0,313
P5	-0,139	0,232
P6	0,401	-0,664
P7	-0,183	0,436

As shown in Table (3), CI values varied across treatments, indicating differences in interspecific interactions. Negative CI values in P3 (–0.017 and –0.016) suggest a mutualistic relationship, where both species benefit without significant competition. In P4, swamp eel had a slightly positive CI (0.068) and tilapia negative (–0.313), implying mild competition, mainly affecting tilapia at higher densities. In P5, swamp eel showed a negative CI (–0.139) and tilapia positive (0.232), suggesting that eel benefited from tilapia activity in the water column. The highest CI was observed in swamp eel at P6 (0.401), while tilapia exhibited the most negative value (–0.664), indicating strong intraspecific competition among tilapia. At P7 (2:1), swamp eel again had a negative CI (–0.183) while tilapia had a positive value (0.436), reflecting tilapia's dominance when eel density increased. Overall, the balanced ratio (P3) demonstrated the most stable and efficient ecological relationship within the modified booster polyculture system in brackish water.

Hematological parameters, including erythrocyte count, hematocrit, leukocyte count, leukocrit, hemoglobin concentration, and blood glucose, were measured to evaluate fish physiological responses to environmental stress and interspecific interaction. Variations in these parameters reflected the adaptive and health status of fish during culture (Table 4).

Table 4. Hematological parameters (erythrocyte, hematocrit, leukocyte, leukocrit, hemoglobin, and glucose) of swamp eel and saline tilapia during the experiment

Treatments	Blood sample	Erythrocyte (10^6 sel/mm^3)	Hematocrit (%)	Leukocyte (10^3 sel/mm^3)	Leukocrit (%)	Hemoglobin (g/dL)	Glucose (mg/dL)
P1	Swamp eel	2.23±0.03[c]	26±1.52[b]	3.87±0.03[a]	1.7±0.57[a]	15.7±0.40[b]	70±4.56[b]
P2	Saline tilapia	2.37±0.03[d]	28±0.57[c]	3.57±0.20[a]	1.7±0.30[a]	16.4±0.80[b]	73±4.00[a]
P3	Swamp eel	2.27±0.01[c]	27±2.00[b]	3.96±0.05[a]	1.8±0.05[a]	16.0±0.37[b]	69±1.52[a]
	Saline tilapia	2.43±0.04[d]	28±2.08[c]	3.73±0.27[a]	1.8±0.05[a]	16.3±1.12[b]	74±5.56[a]
P4	Swamp eel	2.07±0.10[b]	18±1.52[a]	5.64±0.06[c]	2.0±0.10[ab]	12.5±0.37[a]	75±6.00[ab]
	Saline tilapia	2.17±0.05[c]	22±3.78[b]	4.67±0.29[b]	2.0±0.10[a]	15.0±0.60[b]	81±5.50[a]
P5	Swamp eel	2.21±0.01[c]	26±1.15[b]	4.73±0.23[b]	1.7±0.10[a]	15.5±0.52[b]	73±4.00[ab]
	Saline tilapia	2.16±0.05[c]	21±1.00[ab]	4.90±0.16[b]	1.8±0.10[a]	15.1±0.75[b]	79±6.35[a]
P6	Swamp eel	1.65±0.10[a]	17±0.57[a]	6.00±0.07[d]	2.5±0.40[ab]	12.3±0.30[a]	82±2.64[b]
	Saline tilapia	1.95±0.08[b]	17±1.52[a]	6.01±0.12[c]	2.1±0.20[a]	12.6±0.37[a]	95±5.29[b]
P7	Swamp eel	1.97±0.11[b]	16±1.00[a]	6.08±0.13[d]	2.7±0.30[b]	11.7±0.40[a]	91±6.65[c]
	Saline tilapia	1.83±0.08[a]	16±2.51[a]	6.11±0.17[c]	2.6±0.35[b]	11.3±0.30[a]	105±9.07[b]

ANOVA analysis indicated significant differences ($P< 0.05$) in leukocyte count, hematocrit, and glucose levels among treatments. The highest hematocrit and erythrocyte values were recorded in P2 and P3, indicating optimal physiological conditions. In contrast, elevated leukocyte and glucose levels in P6 and P7 reflected stress responses due to high stocking density. Overall, the modified booster recirculating system effectively maintained fish physiological stability by enhancing oxygenation and minimizing the accumulation of toxic compounds.

Water quality parameters remained within optimal ranges for both species throughout the study. Observed parameters included temperature, pH, dissolved oxygen (DO), carbon dioxide (CO_2), ammonia, nitrite, nitrate, and organic matter (Table 5).

Table 5. Water quality parameters during the experiment.

Parameters	Treatments						
	P1	P2	P3	P4	P5	P6	P7
Temperature (°C)	25.5-29.0	25.2-29.5	25.3-30.0	25.4-30.1	25.2-30.3	25.6-30.2	25.0-30.2
pH	6.5-8.2	6.6-8.0	6.9-8.0	6.4-8.5	6.7-8.3	6.6-8.6	6.1-8.4
DO (mg/L)	4.3- 6.5	4.3-6.7	4.9-6.7	4.0-5.9	4.7-5.7	4.2-6.6	4.1-5.7
CO_2 (mg/L)	3.0-6.0	3.0-5.0	3.0-5.0	3.0-5.0	3.0-6.0	3.0-7.0	3.0-8.0
Ammonia (mg/L)	0.01-0.05	0.01-0.10	0.01-0.17	0.01-0.27	0.01-0.16	0.01-0.48	0.01-0.52
Nitrite (mg/L)	0.03-0.43	0.03-0.56	0.03-0.50	0.03-0.75	0.03-0.61	0.03-1.05	0.03-0.84
Nitrate (mg/L)	0.21-0.54	0.21-0.68	0.21-0.70	0.21-0.84	0.21-0.59	0.21-1.16	0.21-0.95
Organic matter	21.3-30.1	21.0-38.3	20.7-29.1	21.2-39.3	21.0-30.9	28.5-38.2	21.3-44.3

All measured parameters remained within the tolerable range for both species, demonstrating that the recirculating system with probiotic boosters effectively maintained water quality and provided a suitable environment for the growth and survival of swamp eel and saline tilapia.

DISCUSSION

The growth performance of swamp eel (*M. albus*) and saline tilapia (*O. niloticus*) showed significant differences among treatments, indicating that variations in stocking ratios had a substantial effect on both species. Polyculture with a balanced ratio (P3, 1:1) produced the highest weight and length gain in both eel and tilapia, suggesting an ecological balance between the benthic (eel) and column-dwelling (tilapia) species, which created a stable environment and a mutually beneficial symbiotic relationship. At this ratio, habitat space was optimally distributed and feed competition was minimal, allowing more metabolic energy to be allocated to growth. Eels in P3 and P4 exhibited higher growth rates due to sufficient oxygen availability in the bottom layer and reduced aggressive interaction, whereas at higher densities (P6 and P7), eel growth declined significantly because of spatial competition and stress induced by crowding **(Roy *et al*., 2025; Su *et al*., 2025)**.

Saline tilapia exhibited a different growth pattern, with the best performance recorded in P3 (1:1) and P6 (1:2). Tilapia demonstrated higher social and physiological tolerance to increased density within certain limits **(Komal *et al*., 2024)**. The presence of eels contributed positively to the culture environment through bioturbation, which enhanced the decomposition of feed residues, improved oxygen circulation, and reduced toxic compound accumulation. However, excessive dominance of eels (P5 and P7) negatively affected tilapia growth due to increased turbidity, oxygen fluctuation, and mechanical disturbance between species **(Omach *et al*., 2025)**. Regression analysis revealed a positive correlation between density and specific growth rate (SGR), with tilapia responding more sensitively (slope = 0.119) than eels (slope = 0.094), indicating the superior physiological adaptability of tilapia to environmental fluctuations.

Optimal growth performance in P3 was strongly supported by microbiological stability within the modified booster recirculation system. The combination of mechanical and biological filtration (zeolite, biofoam, and bioballs) with multi-cell probiotics played a crucial role in maintaining microbial balance and reducing ammonia and nitrite accumulation through nitrification **(Pamukas *et al*., 2022)**. This condition enhanced feed efficiency since oxygen and nutrient levels remained stable throughout the water column. Treatment P3 showed the highest feed efficiency (FE) of 46.22% for eels and 52.56% for tilapia, along with the lowest feed conversion ratios (FCRs) of 1.41 and 1.90, respectively, indicating more efficient feed utilization due to ecological synergy between species. Tilapia’s swimming activity facilitated natural aeration, while eels utilized uneaten feed as an additional energy source **(Zhang *et al*., 2025)**.

The recirculating booster system also acted as a natural bio-enhancer, improving feed digestibility and energy utilization. Probiotic fermentation produced protease and lipase enzymes and functional amino acids that enhanced digestive efficiency **(Shekarabi**

***et al*., 2022; Li *et al*., 2025)**. In addition to enhancing metabolic energy efficiency, this system accelerated nitrogen conversion into non-toxic forms, maintaining a stable and productive culture environment.

The competition index (CI) values in this study revealed varied interaction patterns between swamp eel and saline tilapia in the brackish-water polyculture system. Positive CI values indicate interspecific competition, whereas negative CI values represent the absence of competition or even mutualistic interactions **(Nurfadillah *et al*., 2021)**. At P3 (1:1 ratio), both species exhibited negative CI values, suggesting synergistic interactions without significant competition. This reflects optimal ecological balance, as eels (benthic) and tilapia (surface-dwelling) occupy different niches, allowing efficient utilization of feed and space. Tilapia activity enhanced water oxygenation, while eels consumed residual feed at the bottom, forming a mutualistic system that improved growth and energy efficiency.

Changes in CI values across treatments indicated a shift from mutualistic to competitive interactions as density increased. At P4 (1:1.5), eel CI was slightly positive (0.068) and tilapia CI negative (–0.313), showing mild competition in the water column due to increased tilapia density, while eels benefited from their benthic behavior. In P5 (1.5:1), eels exhibited a negative CI (–0.139) and tilapia a positive one (0.232), indicating that eels were not affected or even benefited from tilapia presence, while tilapia experienced light competition due to eel dominance at the bottom. The highest CI occurred in P6 (1:2) for eels (0.401) and the lowest for tilapia (–0.664), showing that under high tilapia density, eels gained ecological advantage while tilapia suffered from space limitation and oxygen deficiency. Conversely, in P7 (2:1), eels had a negative CI (–0.183) and tilapia positive (0.436), indicating that eels benefited from symbiotic interaction, while tilapia experienced stress due to the strong bottom activity of eels. Overall, a balanced ratio (P3) provided the most ideal condition since both species interacted mutualistically and efficiently. The modified booster system with recirculation enhanced this relationship by increasing dissolved oxygen, reducing ammonia, and stabilizing water quality parameters, minimizing biological competition and maximizing polyculture productivity.

The highest survival rate (SR) was observed in P3, with eels achieving 83.33% and tilapia 90%. This result indicates that a balanced ratio minimizes competitive pressure and ensures optimal environmental conditions. Vertical habitat partitioning—eels occupying the bottom layer and tilapia the surface—reduced spatial overlap and direct competition. Conversely, at higher densities (P6 and P7), SR declined due to stress, limited space, and decreased bottom oxygen levels **(Duran & Cenesiz, 2025)**. The modified booster system effectively prevented SR reduction by maintaining dissolved oxygen above 5 mg/L and converting toxic ammonia into non-toxic nitrate through nitrifying bacteria **(Ali *et al*., 2022)**.

Physiological parameters supported these findings, as the highest erythrocyte, hematocrit, and hemoglobin levels were recorded in P2 and P3, indicating optimal blood function and oxygen transport capacity **(Esmaeili, 2021)**. Conversely, elevated leukocyte and glucose levels in P6 and P7 reflected physiological stress caused by high stocking density **(Kari, 2025)**. Increased glucose indicates activation of stress hormones such as cortisol and adrenaline **(Malini *et al*., 2018)**, while leukocytosis represents an immune response to environmental stressors **(Canosa & Baertucci, 2023)**.

Water quality parameters remained within the optimal range for brackish-water fish growth, with temperature between 25–30°C, pH 6.5–8.5, DO 4–6 mg/L, and CO_2 3–7 mg/L. Low ammonia and nitrite concentrations (≤0.5 mg/L) confirmed effective nitrification within the zeolite and bioball-based biofilter system **(Ende *et al*., 2024)**. The modified recirculating booster system improved water management efficiency and maintained micro-ecosystem balance **(Behjat *et al*., 2025)**. The integration of mechanical and biological filtration with probiotics accelerated organic matter decomposition and reduced toxic compound accumulation, such as ammonia and H_2S, creating a stable, oxygen-rich environment that supported high growth and survival rates **(Pamukas *et al*., 2022)**.

CONCLUSION

The application of a modified booster system with recirculation in the polyculture of swamp eel (*Monopterus albus*) and saline tilapia (*Oreochromis niloticus*) produced the best results at a stocking ratio of 1:1 (P3). This treatment yielded the highest growth performance, feed efficiency, and survival rates for both species. The balanced proportion between the benthic and column-dwelling species created a stable culture environment, reduced physiological stress, and enhanced the efficiency of feed and oxygen utilization. The booster system, which combines mechanical and biological filtration, proved effective in maintaining optimal water quality and supporting overall environmental stability.

REFERENCES

Alaerts, G. and Santika, S.S. (1984). *Methods for Measuring Water Quality*. Usaha Nasional.

Ali, B.; Anuska and Mishra, A. (2022). Effects of dissolved oxygen concentration on freshwater fish: A review. *International Journal of Fisheries and Aquatic Studies*, *10*(4), 113-127.

APHA. (2017). *Standard Methods for the Examination of Water and Wastewater* (23rd ed.). American Public Health Association.

Aura, C.M.; Awandu, H.; Mziri, V.; Awuor, F.; Nyamweya, C.S. and Musa, S. (2025). Optimizing stocking density for enhanced fish yield in lacustrine cage aquaculture. *Scientific African*, *28*, e02721.

Behjat, M.; Svanstrom, M.; Peters, G. and Wennberg, N. (2025). Life cycle assessment of recirculating aquaculture systems with innovative biochar filter for enhanced nutrient recirculation. *International Resources and Environment Sustainability*, *21*, 100233.

Blaxhall, P.C. (1971). The Haematological Assessment of The Health of Fresh Water Fish. A Review of Selected Literature. *Journal of Fish Biology*, *4*, 593-608.

Canosa, L.F. and Bertucci, J.I. (2023). The effect of environmental stressors on growth in fish and its endocrine control. *Frontiers in Endocrinology*, *14*, 1109461.

Diego, T.A.S.; Al-Shaer, M.A.Q. and Jamali, E.A.H. (2023). Re-evaluating eurahaline nature of Nile tilapia, *Oreochromis niloticus*: A hatchery perspective. *International Journal of Fisheries and Aquatic Studies*, *11*(5), 223-231.

Duran, U. and Cenesiz, S. (2025). The effect of different oxygen concentrations on oxidative stress and some biochemical parameters in the transfer of adult rainbow trout (*Oncorhynchus mykiss*). *Veterinary Research*, *30*(21), 302.

Effendi, M.I. (1979). *Methods of Fisheries Biology*. Gramedia Pustaka Utama.

Ende, S.; Henjes, J.; Spiller, M.; Elsjobaru, M.; Hanelt, D. and Abomohra, A. (2024). Recent advances in recirculating aquaculture systems and role of microalgae to close system loop. *Bioresource Technology*, *407*, 131107.

Esmaeili, M. (2021). Blood Performance: A New Formula for Fish Growth and Health. *Biology*, *10*(12), 1236.

Kari, Z.A. (2025). Abiotic and biotic factors affecting the immune system of aquatic species: A review. *Comparative Immunology Reports*, *9*, 200230.

Komal, W.; Fatima, S.; Minahal, Q. and Liaqat, R. (2024). Investigating the optimum stocking density of tilapia (*Oreochromis niloticus*) for intensive production focused to in-pond raceway system. *Science Progress*, *107*(2).

Li, B.; Boukhennou, A.; Shou, J.; Miao, L.; Du, Y. and Chen, J. (2025). Application status and development prospect of fermented ingredients in aquaculture. *Aquaculture Reports*, *42*, 102842.

Malini, D.M.; Madihah; Apriliandri, A.F. and Arista, S. (2018). Increased Blood Glucose Level on Pelagic Fish as Response to Environmental Disturbances at East Coast Pangandaran, West Java. *IOP Conference Series: Earth and Environmental Science*, *166*, 012011.

Ministry of Public Works. (2007). *PU-net: Compilation of Indonesian National Standards (SNI) in Public Works "Water Quality"*. Ministry of Public Works.

Nurfadillah, N.; Hasri, I.; Fahmi, R. and Misran. (2021). The competition index and growth performance between tilapia (*Oreochromis niloticus*) and native fish species Laut Tawar Lake in polyculture system. *IOP Conference Series: Earth and Environmental Science*, *674*, 012080.

Omach, Z.; Odhiambo, B.; Owoko, W.; Keyombe, J.L. and Alare, T. (2025). Comparative Analysis of Stocking Density Effects on Growth Performance and Water Quality in Nile Tilapia (*Oreochromis niloticus*) and African Catfish (*Clarias gariepinus*) in Pond Culture Systems. *Fisheries and Aquaculture Journal*, *16*(1), 1-7.

Pamukas, N.A.; Lukistyowati, I.; Syakti, A.D.; Fauzi, M. and Windarti. (2020). Types and abundance of plankton in the hybrid tilapia brackish water culture media enriched with mixed booster (plankton, aqua enzyme and amino liquid). *AACL Bioflux*, *13*(2), 1198–1210.

Pamukas, N.A.; Mulyadi; Putra, I.; Asiah, N.; Adelina and Kairoa, W.B. (2022). Effects of Bromealin on Digestive Enzyme Activities and Growth Performance of Asian Redtail Catfish (*Hemibragus Nemurus*). *IOP Conference Series: Earth and Environmental Science*, *1118*(1), 012003.

Pamukas, N.A.; Tang, U. and Mulyadi. (2021). Hematology of Asian redtail catfish (*Hemibagrus nemurus*) in different stocking densities using an aquaponic recirculation system. *AACL Bioflux*, *14*(3), 1534–1547.

Pedersen, P.B.M.; Hansen, K.; Houng, D.T.T.; Bayley, M. and Wang, T. (2012). Effects of salinity on osmoregulation, growth and survival in Asian swamp eel (*Monopterus albus*) (Zuiew 1793). *Aquaculture Research*, *44*, 1-12.

Puspitawati, D.; Susilo, E.; Cahyandari, D.; Maharani, D.P.; Fadli, M.; Lutfi, M.; Anggoro, S.A. and Liemanto, A. (2022). The design of regulatory reform in aquaculture in Indonesia: opportunities and threats of the implementation of SDGs in fisheries governance. *AACL Bioflux*, *15*(3), 1215-1225.

Roy, P.; Lee, D.H.; Choi, S.M.; An, Y.K. and Choi, S.D. (2025). Sustainable Development of Water Quality, Growth, and Production Efficiency of the Giant Mottled Eel (*Anguilla marmorata*) at Different Stocking Densities in the Indoor Media-Based Aquaponics System. *Animals*, *15*(18), 2705.

Shekarabi, S.P.H.; Ghodrati, M.; Masouleh, A.S. and Roudbaraki, A.F. (2022). The multi-enzymes and probiotics mixture improves the growth performance, digestibility, intestinal health, and immune response of Siberian sturgeon (*Acipenser baerii*). *Annals of Animal Science*, *22*(3), 1063-1072.

Su, J.; Guo, Y.; Li, J.; Tan, K. and Qin, C. (2025). Impact of stocking density on oxidative stress, digestive enzyme activity, ATPase function, and transcriptomic changes in juvenile Crimson snapper (*Lutjanus erythropterus*) during long-hour transportation. *Aquaculture Reports*, *41*, 102699.

Zhang, Y.; Xu, W.; Lv, W.; Yuan, Q.; Yang, H.; Huang, W. and Zhou, W. (2025). Impact of Rearing Duration on Nutritional Composition, Flavor Characteristics, and Physical Properties of Asian Swamp Eel (*Monopterus albus*). *Foods*, *14*(10), 1685.

Zonneveld, N.; Huisman, E.A. and Boon, J.H. (1991). *Principles of Fish Culture*. Gramedia Pustaka Utama.