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OPTIMIZATION OF INTEGRATED MULTI-TROPHIC AQUACULTURE (IMTA) CULTIVATION IN AQUARIA: A REVIEW OF PRODUCTIVITY, ECOSYSTEM BALANCE, AND ENVIRONMENTAL SUSTAINABILITY

Optim alisasi Budidaya Integrated Multi-Trophic Aquaculture (IMTA) Dalam Akuarium: Tinjauan Terhadap Produktivitas, Keseimbangan Ekosistem, dan Keberlanjutan Lingkungan

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ABSTRACT

This study aimed to evaluate the effectiveness of an aquarium-based Integrated Multi-Trophic Aquaculture (IMTA) system compared to a monoculture system. The research was conducted from November to December 2024 at the Aquaculture Laboratory, Faculty of Fisheries and Marine Sciences, Universitas Padjadjaran. The experimental design used was a Completely Randomized Design (CRD) with five treatments and three replications, involving combinations of guppy fish (Poecilia reticulata), Egeria densa aquatic plants, Ramshorn snails (Planorbella duryi), and Orange Rili shrimp (Neocaridina davidi). Parameters observed included water quality (pH, DO, nitrate, phosphate, turbidity, temperature), organism growth, benefit-cost ratio (BCR), and aesthetic value using a 1–5 scale. The results showed that Treatment E (combining fish, plants, snails, and shrimp) provided the best performance, with the most stable water quality, highest organism growth, highest BCR, and an average aesthetic score of 4.89. The IMTA system was shown to improve resource efficiency, reduce biological waste, and enhance the visual appeal of aquarium-based aquaculture. These findings support the application of aquarium-scale IMTA as a sustainable aquaculture model that is ecologically, economically, and aesthetically adaptive.

Key words: integrated multi-trophic aquaculture; sustainable aquaculture; aesthetics; IMTA; benefit-cost ratio

ABSTRAK

Penelitian ini bertujuan untuk mengevaluasi efektivitas sistem Integrated Multi-Trophic Aquaculture (IMTA) berbasis akuarium dibandingkan dengan sistem monokultur. Penelitian dilaksanakan pada November hingga Desember 2024 di Laboratorium Akuakultur, Fakultas Perikanan dan Ilmu Kelautan, Universitas Padjadjaran. Metode yang digunakan adalah

Rancangan Acak Lengkap (RAL) dengan lima perlakuan dan tiga ulangan, melibatkan kombinasi ikan guppy (Poecilia reticulata), tanaman Egeria densa, siput Planorbella duryi, dan udang Neocaridina davidi. Parameter yang diamati meliputi kualitas air (pH, DO, nitrat, fosfat, turbiditas, suhu), pertumbuhan organisme, rasio manfaat-biaya (BCR), dan nilai estetika (skala 1–5). Hasil menunjukkan bahwa Perlakuan E (gabungan ikan, tanaman, siput, dan udang) memberikan performa terbaik dengan kualitas air yang lebih stabil, pertumbuhan organisme tertinggi, nilai BCR tertinggi, serta skor estetika rata-rata 4,89. Sistem IMTA terbukti mampu meningkatkan efisiensi sumber daya, mengurangi limbah biologis, dan memperbaiki aspek visual dalam budidaya akuarium. Temuan ini menunjukkan bahwa sistem IMTA berbasis akuarium memiliki potensi sebagai model budidaya berkelanjutan yang adaptif secara ekologis, ekonomis, dan estetis.

Kata kunci: akuakultur multistrofik; budidaya berkelanjutan; estetika; IMTA; rasio manfaat-biaya

INTRODUCTION

The rapid development of fisheries cultivation has the potential to cause environmental pollution and disrupt ecosystem balance. One strategy that can be implemented to support sustainable cultivation is the selection of adaptive and environmentally friendly methods, such as Integrated Multi-Trophic Aquaculture (IMTA). This system integrates various species from different trophic levels to create a more stable and efficient ecosystem balance (Costa-Pierce, 2008).

The IMTA system combines feed-feeding species (e.g., fish) with inorganic-absorbing species (e.g., aquatic plants) and organic-absorbing species (e.g., mollusks or detritivorous shrimp). The waste produced by the primary commodity in this system is utilized by other organisms as a nutrient source, thus contributing to waste reduction and increased resource efficiency (Troell *et al.,* 2009; Barrington *et al.,* 2009). This system has been shown to reduce nutrients such as nitrogen, carbon, and phosphate and supports the concept of nutrient trading credits (Chopin *et al.,* 2010; Yuniarsih *et al.,* 2014).

Various studies have demonstrated the success of IMTA in improving production efficiency and the quality of the aquaculture environment. Radiarta *et al.* (2014; 2015) and Alexander et al. (2016) noted that IMTA can reduce sedimentation and enrich water nutrients. Ren *et al.* (2012) emphasized that the main principle of IMTA is recycling waste into a source of energy and nutrients for other organisms in the system. Although much research has been conducted on large-scale IMTA systems and for consumer commodities, the application of IMTA systems on a small scale, particularly for ornamental fish in aquariums, remains limited.

Guppies (*Poecilia reticulata*) are freshwater ornamental fish with high economic value, popular for their attractive colors and ease of maintenance (Malik *et al.,* 2019; Sukrillah *et al.,* 2013). Egeria densa is known as a fast-growing aquarium plant that helps maintain water quality (Hussner, 2005). The ramshorn snail (*Planorbella duryi*) plays a role as a decomposer and is a vital part of the food web in freshwater ecosystems. Meanwhile, the ornamental shrimp Neocaridina davidi, particularly the red cherry shrimp variety, is popular in aquascapes for its striking color and ability to clean up leftover food and algae (Nur & Christianus, 2013; Rao, 2001).

Previous research by Nidejovi (2020) showed that implementing the IMTA system for catfish and tilapia can increase production cost efficiency by 20–30% and reduce nutrient waste by more than 70%. A study by Saimima *et al.* (2020) also revealed that rabbitfish and seaweed growth increased significantly in the IMTA system compared to conventional systems.

However, to date, few studies have examined the application of aquarium-based IMTA systems to ornamental fish and other aquatic organisms on a small scale.

Therefore, this study was conducted to evaluate the effectiveness of the IMTA system in an aquarium with a combination of *P. reticulata, E. densa, P. duryi*, and *N. davidi*, compared to a monoculture system. This study aimed to examine the effect of interactions between organisms on productivity, economic efficiency, and aesthetic aspects of the system, as well as to identify components that play a critical role in improving the performance of small-scale IMTA systems. The findings of this study are expected to contribute to the development of sustainable, adaptive, efficient, and environmentally friendly aquaculture models in confined aquatic environments such as aquariums.

RESEARCH METHODS

This research was conducted at the Aquaculture Laboratory, Faculty of Fisheries and Marine Sciences, Padjadjaran University, from November 2024 to January 2025. The objective was to evaluate the optimization of the Integrated Multi-Trophic Aquaculture (IMTA) cultivation system in aquariums through the approaches of fish growth, survival, water quality, economic value, and aesthetic value.

The main materials used included guppy fish (*Poecilia reticulata*), the aquatic plant Egeria densa, Ramshorn snails (*Planorbella duryi*), and Red Cherry shrimp (*Neocaridina davidi*). The feed used was NRD 3/5, the substrate was Malang sand, and a potassium permanganate solution was used for container sterilization.

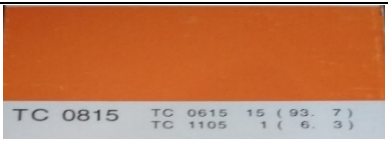
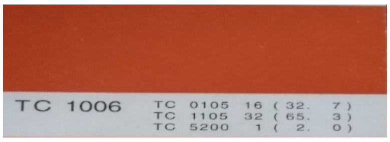
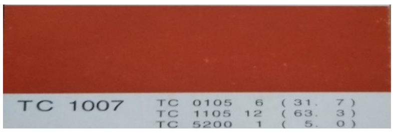
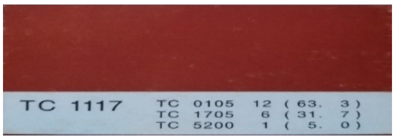
The main equipment used included a 40x30x30 cm glass aquarium, an aerator, a digital scale (accuracy 0.01 g), a digital water thermometer, a DO meter (Lutron DO-5510), a pH meter (Lutron pH-207), a turbidimeter, and nitrate and phosphate test kits.

The research design used was a Completely Randomized Design (CRD) with five treatments and three replications. Each treatment represented a different composition of organisms to test the effectiveness of the IMTA system. The study was conducted for 40 days, with observations every 10 days.

The observed parameters included guppy color using the Toca Color Finder using a scale of 1-10 (Table 1), growth and survival, water quality, and aesthetic and economic assessments. Fish color data were analyzed using the Kruskal Wallis Test, growth and survival data were analyzed using the ANOVA test, while water quality and aesthetic value were analyzed descriptively. Aesthetic assessments were conducted by three panelists based on the visual aspects of the aquarium's appearance. The economic analysis used a simple cost-to-revenue ratio approach.

Table 1. Toca Color Finder Color Codes used

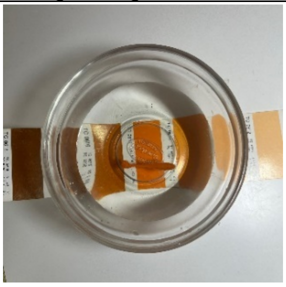
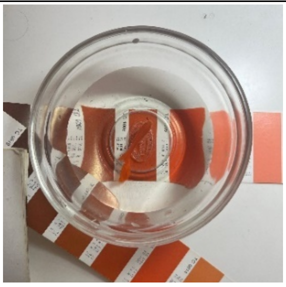
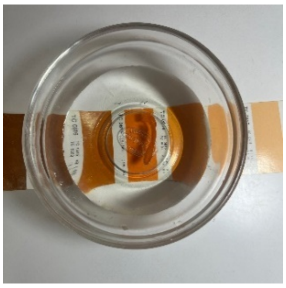
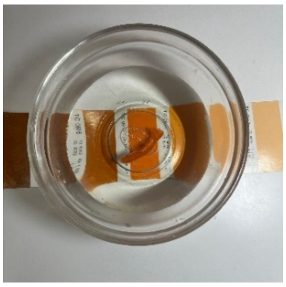
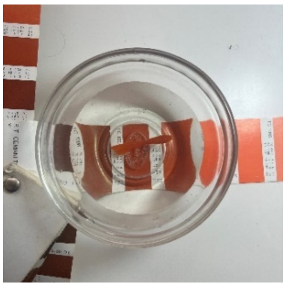
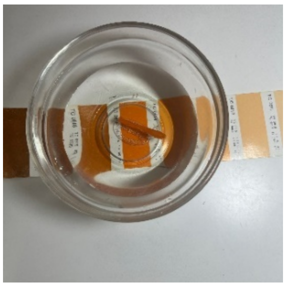
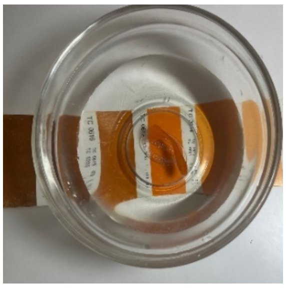
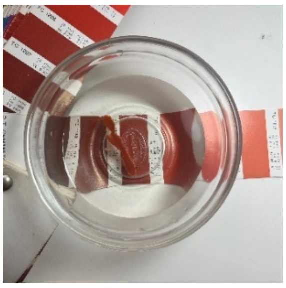
No	TCF Image	Description
1		Score 1 TCF Code 0615
2		Score 2 TCF code 0715

No	TCF Image	Description
3		Score 3 TCF code 0815
4		Score 4 TCF code 0816
5		Score 5 TCF code 0915
6		Score 6 TCF code 1006
7		Score 7 TCF code 1007
8		Score 8 TCF code 1017
9		Score 9 TCF code 1116
10		Score 10 TCF code 1117

RESULT

The results showed that the Integrated Multi-Trophic Aquaculture (IMTA) system contributed significantly to increasing the color intensity of guppy fish (*Poecilia reticulata*). The increase in color scores was consistently observed in all IMTA treatments, with the highest score being in Treatment E (TCF score of 1117), compared to Treatment A (control) which only achieved a TCF score of 1006. The highest water clarity was recorded in Treatment E, which also showed a significant increase in fish color scores. The comparison results can be seen in Table 2.

Table 2. Comparison of Guppy Fish Color at the Beginning and End of the Study.

Treatments	at the Beginning of the Research	End of Research
A.	 Score 1 Code TCF 0615	 Score 6 Code TCF 1006
B.	 Score 1 Code TCF 0615	 Score 6 Code TCF 1006
C.	 Score 1 Code TCF 0615	 Score 7 Code TCF 1007
D.	 Score 1 Code TCF 0615	 Score 7 Code TCF 1007
E.	 Score 1 Code TCF 0615	 Score 10 Code TCF 1117

Description:
Treatment A: Guppy fish (*Poecilia reticulata*) without additional organisms.
Treatment B: Guppy fish with *Egeria densa* plants.
Treatment C: Guppy fish, *E. densa*, and Ramshorn snails (*Planorbella duryi*).
Treatment D: Guppy fish, *E. densa*, and *Neocaridina davidi* shrimp.
Treatment E: Guppy fish, *E. densa*, Ramshorn snails, and *N. davidi* shrimp.

The IMTA system not only supports the intensity of fish color but also significantly contributes to fish welfare, as observed through swimming behavior and interactions with their surroundings. Guppy welfare was evaluated based on ethological observations over a 40-day period. In Treatment A, which lacked supporting organisms, the fish exhibited passive behavior and spent more time at the aquarium bottom. Guppies in systems with a more complex organism composition (Treatments B to E) exhibited increased swimming activity, interactions with the substrate and vegetation, and the formation of small swimming groups. Treatment E, the most comprehensive IMTA system, exhibited active, stable behavior, and responsiveness to feeding.

The environmental stability created in the aquarium system enabled all cultured organisms, such as guppies (*Poecilia reticulata*), *Egeria densa* plants, *Planorbella duryi* snails, and *Neocaridina davidi* shrimp, to achieve a 100% survival rate across all treatments. This indicates that the aquarium environment is generally supportive of the cultured organisms. The superiority of the IMTA system is seen in its more complex ecological contribution in creating balanced environmental conditions.

The addition of multitrophic organisms in the IMTA system has been shown to improve growth performance in all commodities. Guppy fish in Treatment E experienced the highest growth with a final weight of 0.45 g and a Specific Growth Rate (SGR) of 1.31%, much higher than the SGR of 0.60% in Treatment A. The aquatic plant Egeria densa also showed a positive response with the highest SGR value of 1.54% in Treatment E. Ramshorn snails recorded the highest final weight of 0.77 g with an SGR of 1.21%, while *Neocaridina davidi* shrimp reached a maximum length of 3.2 cm and an SGR of 1.32%. The SGR values can be seen in Table 3.

Table 3. Value of SGR each teratments

Organism	**SGR Value (%)**				
	Treatment A	Treatment B	Treatment C	Treatment D	Treatment E
Guppy Fish	0.60	0.89	1.04	1.15	1.31
Egeria densa	-	1.30	1.42	1.48	1.54
Ramshorn Snail	-	-	0.97	-	1.21
Neocaridina Shrimp	-	-	-	1.21	1.32

Description:
Treatment A: Guppy fish (*Poecilia reticulata*) without additional organisms.
Treatment B: Guppy fish with *Egeria densa* plants.
Treatment C: Guppy fish, *E. densa*, and Ramshorn snails (*Planorbella duryi*).
Treatment D: Guppy fish, *E. densa*, and *Neocaridina davidi* shrimp.
Treatment E: Guppy fish, *E. densa*, Ramshorn snails, and *N. davidi* shrimp.

Water quality observations during the maintenance period showed that all treatments were within the optimal range of values recommended for guppy cultivation, in accordance with the Indonesian National Standard (SNI) and applicable government regulations (Table 4). Water quality parameters measured included temperature, dissolved oxygen (DO), pH, nitrate, phosphate, and turbidity, all of which support the survival of guppies and other organisms in the IMTA aquarium system. The results of water quality observations can be seen in Table 4.

Table 4. Results of Water Quality Observations of the IMTA Aquaculture System.

Parameter	**Result**	**Optimal Value**	**Source**
Temperature (ºC)	24,3 – 25,2	24 - 27	(SNI 9308:2024)
DO (ppm)	5 - 6,3	> 4,00	(SNI 9308:2024)
pH	6,5 – 7,2	6,0 - 8,0 mg/L	(SNI 9308:2024)
Nitrate	16 – 21,3	< 20 mg/L	(SNI 9308:2024)
Turbidity	0,83 – 1,12	< 25 NTU	Government Regulation (PP) No. 82 of 2001
Phospate	0,13 – 0,25	< 0,5 mg/L	Arief *et al.* (2023)

Description:
Treatment A: Guppy fish (*Poecilia reticulata*) without additional organisms.
Treatment B: Guppy fish with *Egeria densa* plants.
Treatment C: Guppy fish, *E. densa*, and Ramshorn snails (*Planorbella duryi*).
Treatment D: Guppy fish, *E. densa*, and *Neocaridina davidi* shrimp.
Treatment E: Guppy fish, *E. densa*, Ramshorn snails, and *N. davidi* shrimp.

All water quality parameters were within the ideal range, supporting the performance of aquatic organisms throughout the culture period. Differences in values between treatments reflect the important role of organism diversity in influencing water conditions. The most optimal water quality values were recorded in Treatment E. The presence of Egeria densa plants, which absorb nutrients, and snails and shrimp, which decompose organic waste, contributed to maintaining water clarity, reducing nitrate and phosphate concentrations, and increasing dissolved oxygen levels. The opposite was observed in Treatment A, which contained only guppies without supporting organisms, with nitrate and phosphate values approaching or slightly exceeding the ideal threshold.

Water turbidity levels in all treatments were low, with values <1.2 NTU, indicating a clean culture system free from suspended particle accumulation. Treatment E continued to exhibit the highest water clarity compared to the other treatments. The stability of water quality, optimal growth, and high organism survival in the IMTA system demonstrate the advantages of the multitrophic approach to aquaculture. Economic analysis based on the benefit-cost ratio (BCR) showed that all treatments had a BCR value > 1. Treatment E recorded the highest BCR of 1.61, followed by Treatment D (1.58) and Treatment C (1.53). The results of the BCR value assessment are shown in Figure 1.

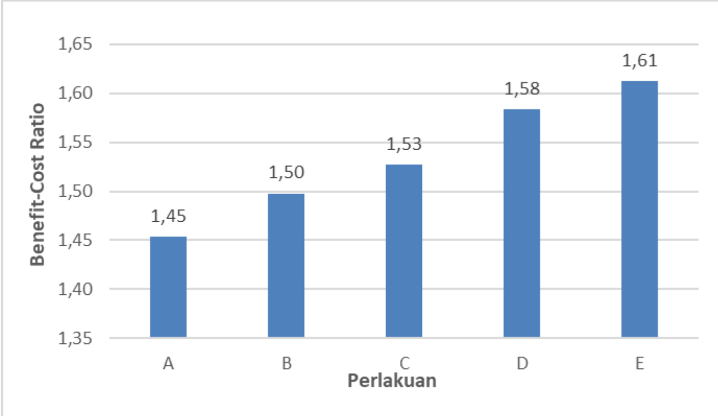


Figure 1. Comparison of Benefit-Cost Ratio Values between Treatments.

Description:
Treatment A: Guppy fish (*Poecilia reticulata*) without additional organisms.
Treatment B: Guppy fish with *Egeria densa* plants.
Treatment C: Guppy fish, *E. densa*, and Ramshorn snails (*Planorbella duryi*).
Treatment D: Guppy fish, *E. densa*, and *Neocaridina davidi* shrimp.
Treatment E: Guppy fish, *E. densa*, Ramshorn snails, and *N. davidi* shrimp.

The results showed that Treatment E achieved the highest Benefit-Cost Ratio (BCR), at 2.25. This treatment represents the most complex IMTA system, reflecting that increased trophic integration within the cultivation system contributes to resource utilization efficiency and crop diversification. Treatment A, a monoculture system, only achieved a BCR of 1.45, indicating lower economic efficiency.

The high economic efficiency of Treatment E was matched by its aesthetic value, which also achieved the highest score, at 4.73 on a scale of 1–5. The visual combination of water clarity, organism diversity, and color harmony made the aquarium more visually appealing. Conversely, Treatment A demonstrated the lowest aesthetic value, at 2.93, due to a lack of organism variety and dominant colors. The interconnectedness between economic and aesthetic aspects in the IMTA system strengthens the potential of the multitrophic approach as a productive and visually appealing cultivation solution. The results of the aesthetic value assessment are shown in Figure 2.

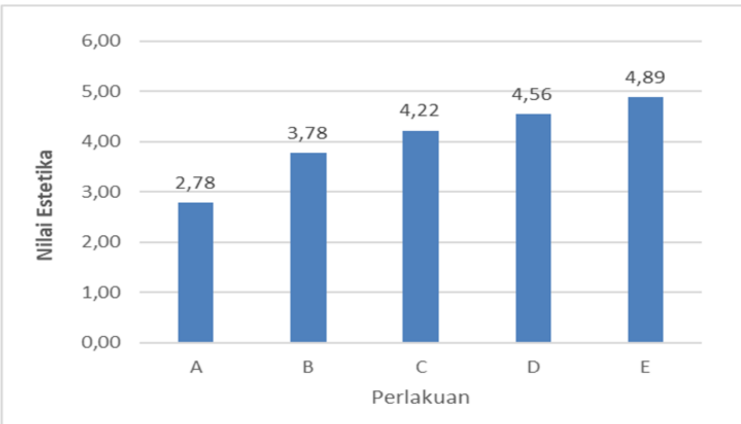


Figure 2. Aesthetic Value of IMTA System per Treatment

Treatment E ranked highest with an average score of 4.89, falling into the "Very Good" category. This aquarium featured the most comprehensive combination of multitrophic organisms: guppies (*Poecilia reticulata*), *Egeria densa* plants, *Planorbella duryi* snails, and

Neocaridina davidi shrimp. This diversity created a harmonious visual display resembling a natural environment, characterized by bright fish colors, active interactions between organisms without aggression, and optimal water clarity.

Treatments D and C scored 4.56 and 4.22, respectively, falling into the "Good" category. The presence of both shrimp and snails contributed to increased aesthetic value, although not as optimal as a system that included both simultaneously. Treatments B and A showed lower scores of 3.78 and 2.78, with the most significant decrease seen in Treatment A. This monoculture system consisted solely of guppies without other supporting components, resulting in a monotonous visual appearance. The high concentration of suspended particles in the water and the absence of vegetation as a visual backdrop also reduce the overall aesthetic quality.

DISCUSSION

The increased color intensity of guppies in the IMTA system demonstrates the significant contribution of supporting organisms such as plants, snails, and shrimp in creating a more ecologically stable aquarium environment. This stability supports the physiological health of the fish and stimulates optimal color pigment expression (Correia *et al.,* 2020; Andriani *et al.,* 2024). Plants such as *Egeria densa* function as absorbers of excess nutrients, while snails and shrimp play a role in decomposing organic waste. This combined role creates clear and stable water quality, which is known to reduce stress levels and support fish color performance (Bachtiar, 2002).

These results align with the findings of Santoso *et al.* (2023) and Han Yang *et al.* (2025), which state that the presence of vegetation and supporting organisms in aquaculture systems plays a crucial role in reducing nitrate and phosphate levels, as well as water turbidity. Treatment A, which lacked supporting organisms, exhibited lower water clarity and poorer fish color intensity. This fact strengthens the relationship between water quality and the phenotypic expression of fish color as an indicator of the health of the aquarium environment.

The ecological conditions of the IMTA system not only affect physiological aspects but also fish behavior. The passive behavior of guppies in Treatment A indicated stress due to the monotonous environment and minimal protective structures (Tschirren *et al.,* 2021). In contrast, the IMTA system provides a complex environment that mimics a natural habitat, reducing stress levels and supporting the comfort and ethological health of the fish (Almaas & Harlita, 2023; *Chung et al.,* 2022). This type of environment is crucial for ensuring the physiological and behavioral sustainability of the cultured organisms.

The presence of plants, snails, and shrimp in the IMTA system provides significant ecological contributions. All three perform complementary trophic functions: plants absorb nitrogen and phosphate compounds, while snails and shrimp decompose leftover food and detritus (Hamsiah *et al.,* 2021; Cahya *et al.,* 2021). This process maintains water clarity, stabilizes pH, and maintains dissolved oxygen levels. The stability of water physicochemical parameters is a key factor in ensuring the growth and survival of aquaculture organisms.

The high survival rate (SR) of all supporting organisms demonstrates their adaptability to the closed system and their contribution to ecosystem balance. Although SR did not differ significantly between treatments, the presence of multitrophic organisms contributes to environmental stability, strengthening the carrying capacity of a sustainable cultivation system (Putra & Mulyono, 2023; Yang *et al.,* 2025). A stable environment encourages active behavior and optimal growth of guppies, which are indicators of the well-being of the cultivated organisms.

Furthermore, the IMTA system has been shown to maintain consistent water quality through the utilization of organic waste by secondary organisms. This stability is demonstrated by temperature, DO, pH, nitrate, phosphate, and turbidity values that are within the optimal range for cultivation (see Table 4). Nutrient uptake by plants and waste decomposition by snails and shrimp are key to achieving healthy and productive environmental conditions.

Treatment E demonstrated the highest environmental and aesthetic performance, reflecting the effectiveness of the complex trophic structure in maintaining clarity, reducing waste, and enhancing system visualization. Studies by Han Yang *et al.* (2025) and Correia *et al.* (2020) confirmed that the integration of vegetation and detritivores in closed aquaculture systems maintains the balance of organic and inorganic compounds, thus supporting environmental stability and the growth of cultured organisms.

Treatment A, containing only guppies, exhibited waste accumulation and decreased water quality due to the absence of biological filtration mechanisms. This highlights the importance of trophic diversity in stabilizing the aquarium's physical and chemical parameters. The effectiveness of IMTA was reflected in the high water clarity and low turbidity, particularly in Treatment E, indicating optimal nutrient utilization efficiency by all organisms.

From an economic perspective, the IMTA system also demonstrated superior performance. The high BCR value in Treatment E reflects that the integration of organisms with both commercial value and ecological functions can increase production efficiency and financial returns. This system offers a sustainable approach that is not only ecologically sound but also economically viable.

The efficiency of the IMTA system is enhanced by crop diversification and low waste accumulation, which supports the optimization of input conversion into productive output. Studies by Chopin *et al.* (2008) and Ghosh *et al*. (2025) show that multitrophic systems enhance interconnectedness between organisms in utilizing waste and nutrients, thus generating added value from both ecological and economic perspectives.

The advantages of this system are inseparable from the functions of each organism. Aquatic plants as phytoremediation agents, snails as economically valuable detritivores, and Neocaridina shrimp as aquascape commodities contribute to creating a culture system that is attractive to both hobby and non-consumer markets (Zhou *et al.,* 2020; Rusco *et al.,* 2024). Commodity diversification expands market opportunities and increases the system's resilience to economic risks.

Conversely, monoculture systems have limitations both ecologically and economically. Dependence on a single commodity makes the system more vulnerable to price fluctuations and disease outbreaks. Troell *et al.* (2009) emphasized that monoculture tends to produce higher levels of waste and requires additional management, which increases operational costs.

IMTA also offers advantages through nutrient cycling efficiency. In conventional systems, most feed nutrients are lost as waste (Drozdz *et al.,* 2020). However, in IMTA systems, waste is reused by other organisms, reducing the need for mechanical filtration and waste treatment, thus enhancing the system's efficiency and sustainability.

The aesthetics of an IMTA system serve as an additional indicator of the success of an aquarium ecosystem. The visual combination of multitrophic organisms creates a harmonious and natural impression that is attractive to the aquascape market. This visual beauty is not only aesthetic but also reflects the quality of the environment and the health of the organisms.

The diversity of organisms in an IMTA system enhances visual harmony and supports market appeal. Research by Rusco *et al.* (2024), Keer *et al.* (2024), as well as Kortet (2024) and Sarkodie (2024) stated that good visual aesthetics correlate with ecosystem stability and positive consumer perception, particularly in the ornamental fish segment. Therefore, integrating aesthetic values into the design of the IMTA system is an important aspect in sustainable and value-added cultivation.

CONCLUSION

This study demonstrates that the Integrated Multi-Trophic Aquaculture (IMTA) system at the aquarium scale is capable of delivering superior cultivation performance compared to conventional monospecific systems. The integration of various organisms in the IMTA system, such as *Poecilia reticulata* fish, *Egeria densa* plants, *Planorbella duryi* snails, and *Neocaridina davidi* shrimp, creates a more balanced, healthy, and efficient micro-ecosystem. The treatment with the most complete trophic structure (Treatment E) produced the best results in terms of organism growth, survival, water quality stability, and the highest economic value with a Benefit-Cost Ratio of 1.61.

In addition to biological and economic performance, the IMTA system also demonstrated a positive impact on visual aspects, with the intensity of guppy body color, water clarity, and aquarium ecosystem harmony showing significant improvements in systems with high organism diversity. Aesthetic parameters evaluated through scoring also placed Treatment E as the system with the best visual appearance, reflecting a healthy and visually appealing rearing environment.

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REFERENCES

Abreu, M. H., Varela, D. A., Henriques, V., Ferreira, G. D., & Buschmann, A. H. (2011). Traditional vs. integrated multi-trophic aquaculture of *Gracilaria chilensis*: Productivity and quality of seaweed. *Aquaculture, 293*(3–4), 211–220.

Ahmed, N., & Thompson, S. (2019). The blue dimensions of aquaculture: A global synthesis. *Science of the Total Environment, 652*, 851–861.

Andriani, Y., Yustiati, A., & Cahya, F. (2024). Efektivitas pakan berbasis astaxanthin terhadap peningkatan warna ikan hias. *Jurnal Akuakultur Tropis, 9*(1), 22–31.

Arief, M., Wibowo, E. S., & Purnomo, A. (2023). Studi kandungan fosfat pada perairan budidaya ikan hias. *Jurnal Perikanan Air Tawar, 13*(2), 44–51.

Astria, E. (2014). Pengaruh pH terhadap kelangsungan hidup ikan nila. *Jurnal Akuakultur Indonesia, 2*(1), 37–43.

Bachtiar, I. (2002). Pengaruh stres terhadap kualitas warna ikan guppy. *Jurnal Ilmu Perikanan Indonesia, 4*(1), 14–18.

Cahya, F., Yustiati, A., & Andriani, Y. (2021). Performa ikan dalam sistem akuakultur multistrofik. *Jurnal Akuakultur Indonesia, 20*(3), 101–110.

Cassel, D. K., & Barao, J. M. (2000). Nitrate toxicity in aquaculture systems. *Aquatic Research Reports, 8*(2), 18–24.

Chopin, T., Cooper, J. A., Reid, G., Cross, S., & Moore, C. (2012). Open-water integrated multi-trophic aquaculture: Environmental biomitigation and economic diversification. *Aquaculture Environment Interactions, 2*(3), 199–213.

Chopin, T., Yarish, C., & Bastarache, S. (2001). Nutrient removal by seaweeds in integrated aquaculture. *Journal of Applied Phycology, 13*(5), 463–472.

Chopin, T., Robinson, S. M. C., Troell, M., Neori, A., Buschmann, A. H., & Fang, J. (2008). Multitrophic integration for sustainable marine aquaculture. *Aquaculture Economics &*

Management, 12(2), 99–113.

Correia, M., Neves, A., Valente, S., & Rosa, R. (2020). Effect of IMTA systems on fish health and performance. *Aquaculture Reports, 17*, 100339.

Craig, S. R., Gatlin, D. M., & Overton, J. L. (2017). Nutritional strategies in closed-loop aquaculture. *Journal of the World Aquaculture Society, 48*(3), 245–260.

Dahril, T., Suyanto, A., & Ali, H. (2017). Studi kualitas air pada kolam intensif. *Jurnal Ilmu Perairan, 6*(2), 90–97.

Drozdz, A., Wystalska, K., Malina, R., & Zieminska, M. (2020). The sustainability of aquaculture: The role of IMTA. *Sustainability, 12*(3), 1239.

Dyah Ayu, A., Puspitasari, N., & Haryanto, A. (2020). Performa udang *Neocaridina* dalam akuarium sistem tertutup. *Jurnal Akuakultur Hias Indonesia, 6*(1), 11–18.

Effendie, M. I. (1997). *Biologi perikanan*. Yogyakarta: Yayasan Pustaka Nusatama.

El-Sayed, A. F. M. (2020). *Tilapia culture* (2nd ed.). London: Academic Press.

García, M. E., & Feijoó, C. (2000). Aquatic plants in nutrient removal. *Hydrobiologia, 432*(2–3), 101–109.

Ghosh, S., Das, R., & Roy, D. (2025). Ecological functions of aquatic plants in IMTA systems. *Journal of Aquatic Systems, 29*(1), 45–56.

Gomez, K. A., & Gomez, A. A. (1984). *Statistical procedures for agricultural research* (2nd ed.). New York: John Wiley & Sons.

Han Yang, L., Chang, Y., & Tang, R. (2025). Role of aquatic macrophytes in nutrient uptake. *Aquaculture Environment Research, 36*(2), 109–119.

Hasan, M. R., & Soto, D. (2017). *Guidelines for sustainable aquaculture* (FAO Fisheries Technical Paper No. 567). Rome: FAO.

Hendrayana, D., Rachmawati, Y., & Rahayu, T. (2022). Pengaruh kadar fosfat pada pertumbuhan fitoplankton. *Jurnal Perikanan Tropis, 8*(2), 28–34.

Hepher, B. (1988). *Nutrition of pond fishes*. Cambridge: Cambridge University Press.

Hamsiah, N., Yustiati, A., & Cahya, F. (2021). Evaluasi sistem IMTA terhadap performa ikan nila. *Jurnal Akuakultur Berkelanjutan, 7*(3), 134–143.

Indarti, N., Setiawan, H., & Widodo, A. (2012). Pengaruh pH terhadap aktivitas metabolik ikan. *Jurnal Perikanan Universitas Diponegoro, 5*(1), 49–57.

Kelabora, J. L., & Dominggas, Y. (2010). Hubungan suhu air dan metabolisme ikan. *Jurnal Ilmiah Perikanan, 2*(2), 25–32.

Khanjani, M. H., Sajjadi, M. M., & Alizadeh, M. (2022). Aquatic species responses to water parameters. *Aquaculture Reports, 19*, 101412.

Keer, T. S., Janzen, S., & Bell, M. (2024). Aesthetic scoring of aquaculture systems. *Aquaculture Design Journal, 13*(1), 14–24.

Kortet, R. (2024). Perceptions of aquaculture ecosystem aesthetics. *Fisheries and Society, 11*(1), 33–41.

Mahmudur, R. A., Elahi, F., & Zaman, M. A. (2024). Nutrient uptake efficiency of aquatic plants. *Journal of Aquatic Botany, 16*(1), 55–66.

Macqy, L. M., Rachman, R. M., & Utama, A. (2013). Dissolved oxygen dan dampaknya terhadap budidaya. *Jurnal Air Tawar Tropis, 4*(2), 69–74.

Putra, A. D., & Mulyono, H. (2023). Strategi IMTA untuk sistem akuakultur urban. *Jurnal Perikanan Berbasis Ekosistem, 15*(1), 18–27.

Ricker, W. E. (1979). Growth rates in fish populations. *Fisheries Research Board of Canada Bulletin, 191*, 1–34.

Rusco, A., Kurniawan, D., & Hendarto, Y. (2024). Diversifikasi trofik dan nilai estetika dalam akuarium IMTA. *Jurnal Akuakultur Tropis, 9*(1), 12–22.

Santoso, A., Rinaldi, D., & Jaya, I. (2023). Analisis kualitas warna air dalam sistem budidaya.

Jurnal Ilmu Perairan, 14(3), 55–64.

Sri-uam, J., Kulseng, P., & Pongprapan, P. (2016). Nutrient management using aquatic plants. *Asian Journal of Environmental Biology, 15*(2), 145–150.

Stoltenow, C. L., & Lardy, G. P. (1998). Nitrate poisoning in fish systems. *Aquatic Safety Reports, 3*(1), 1–5.

Subamia, I. W., & Himawan, W. (2018). Budidaya ikan hias dengan pendekatan ekologi. *Prosiding Seminar Nasional Perikanan dan Kelautan, 1*, 79–85.

Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A. H., & Fang, J. G. (2009). Ecological engineering in aquaculture. *Bioscience, 59*(1), 27–38.

Wijesinghe, W., & Senavirathna, K. (2024). Resilience of *Egeria densa* in aquaculture tanks. *Journal of Aquatic Plant Research, 7*(1), 31–40.

Zhou, Q., Zhao, Y., & Tan, Y. (2020). Marketing ornamental aquatic species. *Aquaculture Economics and Management, 24*(4), 367–379.

Zulhisyam, A. K., Ismail, I. S., & Wahid, R. (2023). Siput air tawar sebagai indikator kesehatan akuarium. *Jurnal Biologi Perairan, 12*(2), 65–74.