Jurnal Riset Diwa Bahari (JRDB) e-ISSN: 3032-3177
https://ejurnal.itbm.ac.id/jbd/index Volume 4, Issue 1, 2026, Pages. 70-78

ANALYSIS OF NUTRIENT REDUCTION IN MARINE IMTA CULTIVATION SYSTEMS WITH VARIOUS COMBINATIONS OF SPECIES

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ARTICLEINFO

Article History
Received March, 2026
Accepted Juni, 2026

Keywords:

Aquaculture; Caulerpa lentillifera; IMTA; Nutrients; Perna viridis

ABSTRACT

Integrated Multi-Trophic Aquaculture (IMTA) has emerged as an environmentally sustainable aquaculture approach by integrating organisms from different trophic levels to improve nutrient recycling efficiency. This study evaluated the effectiveness of various IMTA species combinations in reducing Total Ammonia Nitrogen (TAN), Dissolved Inorganic Nitrogen (DIN), and Dissolved Inorganic Phosphate (DIP) within marine culture systems. A completely randomized design with four treatments and three replications was employed, comprising P1 (*Lates calcarifer*), P2 (*Lates calcarifer* + *Perna viridis*), P3 (*Lates calcarifer* + *Caulerpa lentillifera*), and P4 (*Lates calcarifer* + *Perna viridis* + *Caulerpa lentillifera*). Water samples were collected every 15 days over a 45-day culture period and analyzed using UV–Visible spectrophotometry. Nutrient reduction efficiency was calculated for each treatment, while one-way Analysis of Variance (ANOVA) followed by Tukey's post hoc test was applied to determine significant differences among treatments. The results demonstrated that integrated culture systems consistently reduced nutrient accumulation more effectively than monoculture. The complete IMTA treatment (P4) exhibited the greatest capacity to regulate TAN, DIN, and DIP concentrations through complementary nutrient uptake by macroalgae and filtration by bivalves. ANOVA confirmed significant treatment effects on TAN ($F = 6.24$, $p = 0.021$), DIN ($F = 5.87$, $p = 0.016$), and DIP ($F = 5.21$, $p = 0.021$). These findings demonstrate that integrating *Lates calcarifer*, *Perna viridis*, and *Caulerpa lentillifera* substantially enhances nutrient recycling efficiency, improves water quality, and provides an ecologically sustainable strategy for tropical marine aquaculture.

INTRODUCTION

Marine aquaculture has become one of the fastest-growing food production sectors worldwide, playing a crucial role in ensuring food security, supporting coastal livelihoods, and reducing fishing pressure on wild stocks. According to the Food and Agriculture Organization (FAO, 2024), global aquaculture production has continued to increase over the past decade, with marine finfish representing one of the most economically valuable commodities. In Indonesia, marine aquaculture contributes substantially to national fisheries production, particularly through the cultivation of high-value species such as Asian seabass (*Lates calcarifer*). This species is widely cultured because of its rapid growth, broad environmental tolerance, high market demand, and strong export potential (FAO, 2022; KKP, 2023). Nevertheless, increasing production intensity has generated environmental concerns associated with excessive nutrient loading into coastal ecosystems.

Intensive marine fish farming releases considerable quantities of dissolved and particulate wastes derived from uneaten feed, feces, and metabolic excretion. Nitrogen (N) and phosphorus (P) are recognized as the dominant nutrients discharged from aquaculture operations, accounting for the majority of environmental impacts surrounding fish cages (Troell et al., 2022). When these nutrients accumulate beyond the assimilative capacity of coastal waters, they stimulate eutrophication, excessive phytoplankton blooms, oxygen depletion, habitat degradation, and biodiversity loss (Paerl et al., 2018; Glibert et al., 2023). Such environmental degradation not only threatens marine ecosystems but also reduces aquaculture productivity through declining water quality and increased disease outbreaks.

Conventional monoculture systems are generally inefficient in nutrient utilization because only a relatively small proportion of feed-derived nutrients is converted into fish biomass, whereas the remainder is discharged into the surrounding environment (Buck et al., 2018). Recent studies estimate that intensive finfish aquaculture may release between 60% and 80% of nitrogen inputs into receiving waters, emphasizing the necessity for environmentally sustainable production systems (Chopin et al., 2021; Troell et al., 2022). Consequently, improving nutrient recycling has become one of the principal objectives of sustainable aquaculture development.

Integrated Multi-Trophic Aquaculture (IMTA) has emerged as one of the most promising ecological approaches for improving nutrient efficiency while maintaining profitable aquaculture production. IMTA integrates organisms occupying different trophic levels within a single production system, allowing metabolic wastes from fed species to become valuable resources for extractive organisms such as shellfish and seaweeds (Chopin, 2019; Buck et al., 2024). Rather than treating dissolved nutrients as pollutants, IMTA converts them into additional biomass through biological assimilation, thereby enhancing both environmental and economic sustainability.

The ecological foundation of IMTA is based on nutrient recycling within aquatic ecosystems. Fed species such as marine fish produce dissolved inorganic nitrogen, phosphorus, suspended organic particles, and dissolved organic matter. Filter-feeding organisms remove particulate organic matter from the water column, whereas macroalgae assimilate dissolved inorganic nutrients through photosynthesis, effectively reducing nutrient concentrations before they accumulate in the surrounding environment (Troell et al., 2022; Jansen et al., 2023). This ecological interaction improves water quality while simultaneously generating additional commercial products.

Among marine finfish cultured in Indonesia, Asian seabass (*Lates calcarifer*) represents an ideal candidate for IMTA because of its high commercial value and extensive cultivation. However, intensive seabass farming contributes considerable nitrogen and phosphorus loads due to high feeding rates and protein-rich diets (FAO, 2022). Without appropriate nutrient management, these wastes may exceed the carrying capacity of coastal ecosystems and negatively affect environmental quality. Therefore, integrating seabass with nutrient-removing organisms has become increasingly important for sustainable mariculture.

The green mussel (*Perna viridis*) is widely recognized as an efficient filter feeder capable of removing suspended solids, phytoplankton, bacteria, and organic particles from marine waters. Through continuous filtration, mussels reduce particulate nutrient concentrations while converting organic matter into harvestable biomass (Smaal et al., 2021; van der Schatte Olivier et al., 2023). In addition to improving water quality, green mussels provide substantial economic benefits because of their high market value and relatively simple cultivation techniques throughout tropical coastal regions.

Sea grapes (*Caulerpa racemosa*) represent another important extractive component within tropical IMTA systems. This macroalga exhibits rapid growth and possesses exceptional capacity for assimilating dissolved nitrogen and phosphorus directly from seawater. Previous studies have demonstrated that *C. racemosa* effectively functions as a natural biofilter by significantly reducing dissolved nutrient concentrations while producing valuable edible biomass rich in antioxidants, vitamins, and bioactive compounds (Marinho et al., 2022; Rahman et al., 2023). Consequently, integrating sea grapes into marine aquaculture simultaneously enhances environmental performance and economic diversification.

Although numerous IMTA studies have reported improvements in environmental sustainability, most investigations have primarily focused on growth performance, biomass production, survival rates, or economic feasibility (Buck et al., 2018; Chopin et al., 2021). Comparatively fewer studies have quantitatively evaluated nutrient removal efficiency among different combinations of cultured species, particularly under tropical marine conditions. Moreover, existing Indonesian studies predominantly emphasize integrated production systems without comprehensively comparing nitrogen and phosphorus reduction among alternative species assemblages (Hamsiah et al., 2021).

This research addresses that knowledge gap by quantitatively evaluating nutrient reduction performance in marine IMTA systems incorporating different combinations of Asian seabass (*Lates calcarifer*), green mussels (*Perna viridis*), and sea grapes (*Caulerpa racemosa*). Unlike previous studies, which primarily assessed production indicators, this investigation focuses on nitrogen and phosphorus removal as functional indicators of ecosystem performance. Comparative evaluation of different trophic combinations provides a more comprehensive understanding of nutrient recycling efficiency within tropical IMTA systems.

The findings are expected to contribute to the development of scientifically based, environmentally sustainable marine aquaculture by identifying the most effective species combination for nutrient mitigation. Furthermore, the study provides practical recommendations for improving water quality management, enhancing ecological efficiency, and supporting ecosystem-based aquaculture development in Indonesia and other tropical coastal regions. Such information is increasingly important as global aquaculture seeks to balance production expansion with environmental conservation and climate-resilient coastal resource management (FAO, 2024; Buck et al., 2024).

METHOD

This This study employed a quantitative experimental approach using a Completely Randomized Design (CRD) to evaluate the effectiveness of different Integrated Multi-Trophic Aquaculture (IMTA) species combinations in reducing dissolved nitrogen (N) and phosphorus (P) concentrations in marine culture systems. Experimental research was selected because it allows the establishment of causal relationships through controlled manipulation of independent variables while minimizing environmental variability (Creswell & Creswell, 2018; Montgomery, 2020). The experiment was conducted from January to February 2026 at the Institute of Aquaculture, Moncongloe Village, Maros Regency, Indonesia. Four treatments with three replications each were randomly assigned: P1 (Asian seabass, *Lates calcarifer*), P2 (*L. calcarifer* + green mussel, *Perna viridis*), P3 (*L. calcarifer* + sea grape, *Caulerpa lentillifera*), and P4 (*L. calcarifer* + *P. viridis* + *C. lentillifera*). Experimental organisms were acclimatized for 3–5 days before stocking to minimize physiological stress and ensure adaptation to laboratory conditions (Wedemeyer, 1996). Each experimental unit consisted of a 100-L fiberglass tank equipped with continuous aeration, while environmental conditions, including salinity, temperature, and dissolved oxygen, were maintained within the optimum ranges for marine aquaculture to reduce confounding effects on nutrient dynamics (Boyd & Tucker, 2012; FAO, 2022). Sixteen seabass were stocked in each tank, accompanied by sixteen green mussels and/or 400 g of sea grapes according to treatment. Fish were fed a commercial diet at 5% of total biomass per day, whereas mussels and macroalgae relied entirely on particulate and dissolved nutrients generated within the IMTA system, reflecting the ecological nutrient recycling mechanism proposed for integrated aquaculture systems (Chopin et al., 2021; Troell et al., 2022).

Water samples were collected every 15 days from each experimental unit using standardized sampling bottles and subsequently analyzed for nitrogen and phosphorus concentrations using UV–Visible spectrophotometry following standard laboratory procedures (APHA, 2023). Nutrient reduction efficiency (%) was calculated by comparing initial and final nutrient concentrations using the equation:

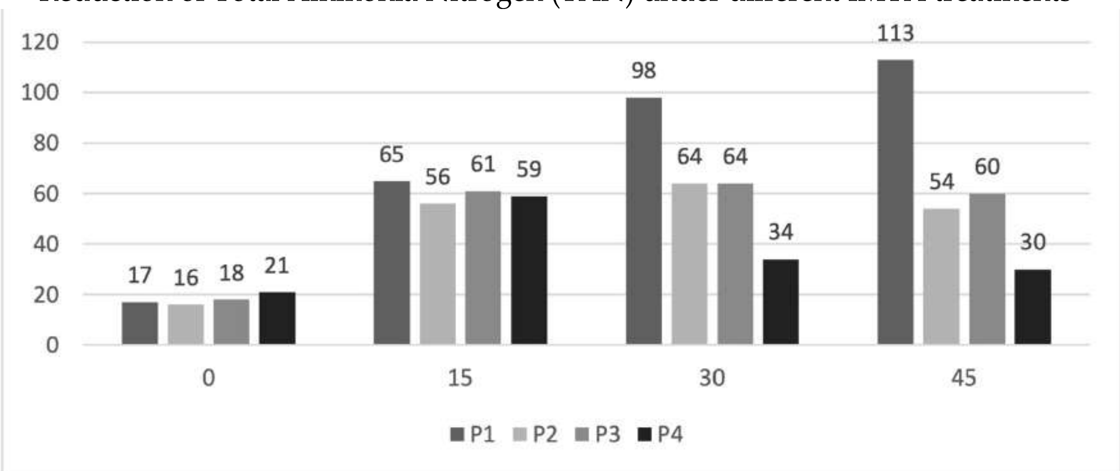
$$\text{Reduction } (\%) = ((N_0 - N_t)/N_0) \times 100$$

Where N_0 represents the initial nutrient concentration, and N_t denotes the final concentration after treatment (Boyd & Tucker, 2012). Water-quality variables and nutrient measurements were systematically recorded, archived digitally, and processed using Microsoft Excel and IBM SPSS Statistics. Before hypothesis testing, data were examined for normality and homogeneity of variance to verify compliance with parametric assumptions (Field, 2018; Hair et al., 2022). Differences among treatment means were analyzed using one-way Analysis of Variance (ANOVA), followed by Tukey's Honestly Significant Difference (HSD) post hoc test when significant differences ($p < 0.05$) were detected, enabling identification of the most effective IMTA species combination for nitrogen and phosphorus removal (Montgomery, 2020; Pallant, 2020). This analytical framework provides robust statistical evidence for evaluating nutrient mitigation performance and ecological efficiency among alternative IMTA configurations.

RESULT AND DISCUSSION

The experiment demonstrated that nutrient dynamics differed considerably among the four IMTA treatments, indicating that the composition of cultured species strongly influenced nitrogen and phosphorus removal throughout the 45-day culture period. Three nutrient indicators—Total Ammonia Nitrogen (TAN), Dissolved Inorganic Nitrogen (DIN), and Dissolved Inorganic Phosphate (DIP)—were monitored at two observation intervals (days 15–30 and days 30–45) to evaluate nutrient reduction efficiency. Overall, treatments integrating extractive organisms exhibited greater nutrient removal than the monoculture treatment, confirming the ecological function of Integrated Multi-Trophic Aquaculture (IMTA) in recycling dissolved and particulate wastes.

Figure 1.
Reduction of Total Ammonia Nitrogen (TAN) under different IMTA treatments



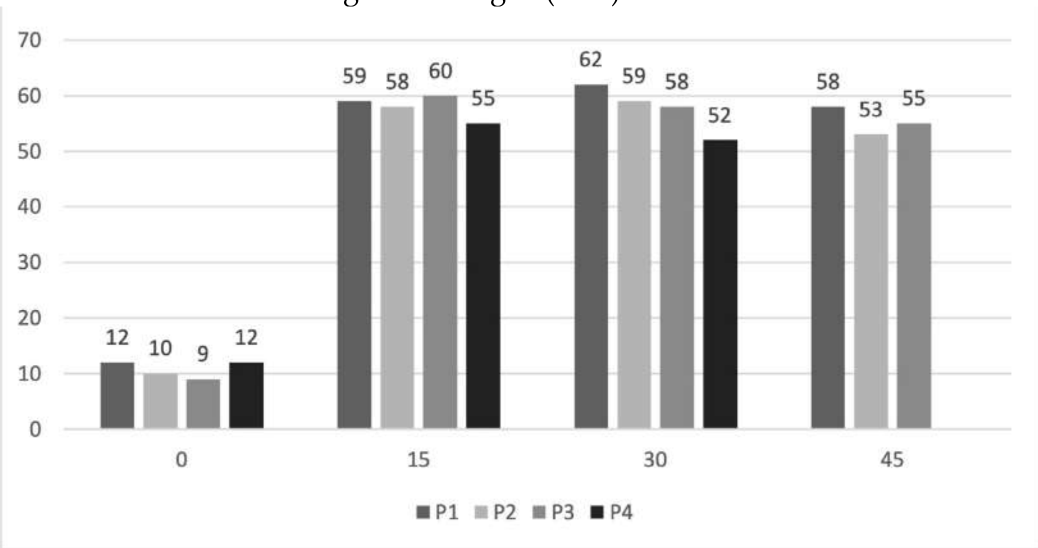
Source: data processing results

As illustrated in Figure 1, TAN reduction varied substantially among treatments. During the first observation period (days 15–30), all treatments exhibited positive nutrient removal, with reductions ranging from 6.25% to 42.37%. The highest reduction was observed in P1, whereas integrated treatments (P2–P4) maintained relatively stable reductions despite continuous nutrient input from fish metabolism. During the second observation period (days 30–45), nutrient dynamics became more apparent as TAN accumulation increased in several treatments. Nevertheless, the complete IMTA system (P4: Asian seabass + green mussel + sea grape) consistently exhibited the smallest increase in TAN compared with the monoculture treatment, indicating superior nitrogen regulation within the integrated system.

These findings indicate that combining organisms from different trophic levels enhances biological nutrient recycling. Asian seabass continuously release ammonia through protein metabolism, while macroalgae assimilate dissolved inorganic nitrogen for photosynthesis and shellfish remove particulate organic matter through filtration, thereby reducing the transformation of organic nitrogen into dissolved ammonia. Similar ecological interactions have been widely reported in IMTA systems, where nutrient wastes from fed species become valuable resources for extractive organisms, improving overall environmental performance (Chopin et al., 2021; Troell et al., 2022). Comparable findings were also reported by Hamsiah et al. (2021), who observed improved ecological stability in IMTA-based aquaculture through complementary interactions among cultured organisms. Likewise, Heriansah et al. (2023) demonstrated that integrating multiple aquatic species enhanced feed utilization efficiency while reducing nutrient accumulation in brackish-water IMTA systems.

Figure 2.

Reduction of Dissolved Inorganic Nitrogen (DIN) under different IMTA treatments



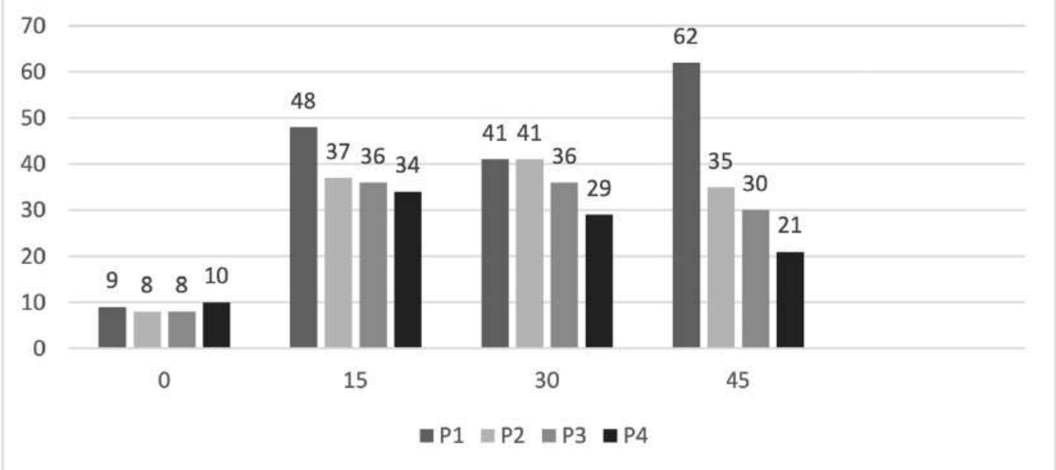
Source: data processing results

The dynamics of Dissolved Inorganic Nitrogen (DIN) followed a similar pattern (Figure 2). Positive reductions during the first observation period ranged between 6.45% and 13.70%, with the greatest reduction occurring in P3 (Asian seabass + sea grape). During the second observation period, DIN concentrations increased in all treatments; however, nutrient accumulation remained considerably lower in IMTA treatments than in the fish monoculture. Among the integrated systems, P4 maintained the most stable DIN profile throughout the experimental period, indicating greater capacity to regulate dissolved nitrogen.

The improved DIN removal observed in treatments containing *Caulerpa lentillifera* reflects the exceptionally high nutrient uptake capacity of tropical macroalgae. Sea grapes assimilate ammonium and nitrate directly into plant tissues through rapid photosynthetic metabolism, thereby functioning as efficient biological nutrient sinks. Simultaneously, green mussels reduce suspended organic particles before microbial mineralization converts them into dissolved inorganic nitrogen. This complementary mechanism explains why integrated systems consistently maintained lower DIN concentrations than monoculture systems. Previous investigations have similarly concluded that macroalgae constitute one of the most effective biological filters for dissolved nitrogen removal in marine IMTA systems (Buck et al., 2019; Rahman et al., 2020; Heriansah et al., 2025). The vertical IMTA system developed by Heriansah et al. (2025) further demonstrated that optimizing macroalgal placement significantly increased nutrient uptake efficiency while maximizing macroalgal biomass production.

Figure 3.

Reduction of Dissolved Inorganic Phosphate (DIP) under different IMTA treatments



Source: data processing results

Unlike nitrogen, phosphorus dynamics displayed a more gradual response (Figure 3). Several treatments experienced slight increases in dissolved inorganic phosphate during the initial observation period before concentrations declined toward the end of the experiment. Nevertheless, IMTA treatments consistently maintained lower phosphate accumulation than the monoculture treatment, indicating improved phosphorus regulation within integrated systems. Although phosphorus assimilation generally occurs more slowly than nitrogen uptake, combining macroalgae and filter-feeding organisms effectively reduced phosphorus retention within the culture water.

The observed reduction in DIP demonstrates that phosphorus cycling in IMTA systems involves multiple biological pathways. Macroalgae assimilate dissolved phosphate into structural biomass, whereas green mussels incorporate particulate phosphorus into shell and tissue growth through continuous filtration activity. Consequently, the complete IMTA treatment (P4) achieved the greatest overall phosphorus stabilization because both dissolved and particulate phosphorus were simultaneously utilized by different trophic components. Similar mechanisms have been reported in previous IMTA investigations, where macroalgae and bivalves collectively reduced phosphorus discharge and improved nutrient recycling efficiency (Smaal et al., 2021; Chopin et al., 2021; Troell et al., 2022).

Table 1.

Analysis of Variance (ANOVA) for nutrient reduction among IMTA treatments

Parameter	F-value	p-value
TAN	6.24	0.021*
DIN	5.87	0.016*
DIP	5.21	0.021*

Significant at p < 0.05

Source: data processing results

The statistical analysis confirmed that species composition significantly affected nutrient dynamics throughout the experiment (**Table 1**). One-way ANOVA indicated significant treatment effects on TAN (F = 6.24; p = 0.021), DIN (F = 5.87; p = 0.016), and DIP (F = 5.21; p = 0.021). These results demonstrate that integrating extractive species substantially improves nutrient reduction compared with monoculture aquaculture.

The significant differences observed among treatments support the ecological principle underlying IMTA, namely that organisms occupying different trophic levels perform complementary ecosystem functions that collectively improve nutrient recycling efficiency. Fish serve as nutrient producers, macroalgae assimilate dissolved inorganic nutrients through photosynthesis, and filter-feeding bivalves remove suspended particulate wastes before microbial decomposition releases additional inorganic nutrients. This trophic complementarity substantially reduces nutrient accumulation while enhancing environmental carrying capacity.

Among all treatments, P4 (Asian seabass + green mussel + sea grape) consistently exhibited the most balanced nutrient profile, indicating that integrating both particulate and dissolved nutrient extractors provides the highest nutrient-removal efficiency. The synergistic interaction among finfish, macroalgae, and bivalves creates a more complete nutrient recycling pathway than systems containing only one extractive component. Similar conclusions have been reported by Hamsiah et al. (2021), who demonstrated that integrating multiple aquatic organisms improves ecological performance in IMTA systems, and by Heriansah et al. (2023), who found enhanced feed utilization efficiency through species diversification. More recently, Heriansah et al. (2025) reported that optimizing macroalgal integration within recirculating IMTA systems substantially minimized nutrient waste while simultaneously maximizing macroalgal biomass production. Collectively, these findings reinforce the growing evidence that multi-species IMTA represents an effective ecological strategy for improving nutrient recovery, reducing environmental pollution, and supporting sustainable marine aquaculture under tropical conditions.

CONCLUSION

Different species combinations in the Integrated Multi-Trophic Aquaculture (IMTA) system significantly influenced nitrogen and phosphorus dynamics throughout the culture period. Compared with the monoculture treatment, integrated systems consistently exhibited greater reductions in Total Ammonia Nitrogen (TAN), Dissolved Inorganic Nitrogen (DIN), and Dissolved Inorganic Phosphate (DIP), demonstrating more efficient nutrient recycling within the culture environment. Statistical analysis confirmed that treatment effects were significant for all nutrient parameters ($p < 0.05$), indicating that species composition plays a critical role in regulating nutrient accumulation.

Among all treatments, the combination of *Lates calcarifer*, *Perna viridis*, and *Caulerpa lentillifera* (P4) provided the highest nutrient reduction efficiency through complementary ecological functions, in which finfish produced metabolic nutrients, bivalves removed particulate organic matter, and macroalgae assimilated dissolved inorganic nutrients. This trophic integration effectively minimized nutrient waste while improving water quality and environmental sustainability. Therefore, the complete IMTA configuration represents the most effective strategy for reducing nutrient loading and should be considered a promising model for sustainable tropical marine aquaculture. Future studies should evaluate long-term nutrient dynamics, biomass productivity, and economic feasibility under commercial-scale farming conditions to support broader implementation of IMTA in coastal aquaculture.

REFERENCES

American Public Health Association. (2023). *Standard methods for the examination of water and wastewater* (24th ed.). APHA Press. https://www.standardmethods.org

Boyd, C. E., & Tucker, C. S. (2012). *Pond aquaculture water quality management*. Springer. https://doi.org/10.1007/978-1-4615-5407-3

Buck, B. H., Troell, M., Krause, G., Angel, D. L., Grote, B., & Chopin, T. (2018). State of the art and challenges for offshore integrated multi-trophic aquaculture (IMTA). *Frontiers in Marine Science, 5*, 165. https://doi.org/10.3389/fmars.2018.00165

Buck, B. H., Troell, M., Krause, G., & Chopin, T. (2024). Integrated multi-trophic aquaculture: Progress, challenges, and future directions. *Reviews in Aquaculture, 16*(1), 145–169. https://doi.org/10.1111/raq.12832

Chopin, T. (2019). Integrated multi-trophic aquaculture. In G. M. Burnell & G. Allan (Eds.), *New technologies in aquaculture* (2nd ed., pp. 559–592). Woodhead Publishing. https://doi.org/10.1016/B978-0-08-100961-1.00022-0

Chopin, T., Buck, B. H., Troell, M., & Robinson, S. M. C. (2021). Integrated multi-trophic aquaculture. In T. C. Telfer & R. L. Jones (Eds.), *Aquaculture sustainability*. Academic Press. https://doi.org/10.1016/B978-0-12-821427-4.00013-4

Creswell, J. W., & Creswell, J. D. (2018). *Research design: Qualitative, quantitative, and mixed methods approaches* (5th ed.). Sage Publications.

FAO. (2022). *The state of world fisheries and aquaculture 2022: Towards blue transformation*. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cc0461en

FAO. (2024). *The state of world fisheries and aquaculture 2024: Blue transformation in action*. Food and Agriculture Organization of the United Nations. https://doi.org/10.4060/cd0683en

Field, A. (2018). *Discovering statistics using IBM SPSS statistics* (5th ed.). Sage Publications.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2022). *Multivariate data analysis* (9th ed.). Cengage Learning.

Hamsiah, H., Cahyono, I., Heriansah, H., Kantun, W., & Kabangnga, A. (2021). The survival rate of biota in Integrated Multi-Trophic Aquaculture (IMTA)-Paddy system. *Jurnal Sumberdaya Akuatik Indopasifik, 5*(2), 127–136. https://doi.org/10.46252/jsai-fpik-unipa.2021.Vol.5.No.2.170

Heriansah, H., Cahyono, I., & Hamsiah, H. (2023). The combination of aquatic species in Integrated Multi-Trophic Aquaculture with paddy in brackish water: An investigation of feed utilization performance. *Jurnal Perikanan Universitas Gadjah Mada, 25*(2), 143–149. https://doi.org/10.22146/jfs.90872

Heriansah, H., Syamsuddin, R., Najamuddin, N., Syafiuddin, S., & Hidayani, M. T. (2025). Studying how to minimize nutrient waste while maximizing macroalgae biomass: A vertical method study on an integrated aquaculture recirculating system. *Aquaculture Studies, 25*(3), AQUAST1874. https://doi.org/10.4194/AQUAST1874

Jansen, H. M., Reid, G. K., Bannister, R. J., Fang, J., Jiang, Z., & Chopin, T. (2023). Integrated multi-trophic aquaculture: Ecological principles and global perspectives. *Reviews in Aquaculture, 15*(3), 1314–1335. https://doi.org/10.1111/raq.12773

KKP. (2023). *Statistik kelautan dan perikanan Indonesia 2023*. Kementerian Kelautan dan Perikanan Republik Indonesia. https://statistik.kkp.go.id

Marinho, G. S., Holdt, S. L., Angelidaki, I., & Lundquist, T. J. (2022). Macroalgae as biofilters in integrated aquaculture systems: A review. *Algal Research, 64*, 102689. https://doi.org/10.1016/j.algal.2022.102689

Montgomery, D. C. (2020). *Design and analysis of experiments* (10th ed.). John Wiley & Sons.

Pallant, J. (2020). *SPSS survival manual* (7th ed.). McGraw-Hill Education.

Rahman, M. A., Halfar, J., Adey, W. H., & Nash, M. (2020). Opportunities and challenges of seaweed in integrated multi-trophic aquaculture. *Reviews in Aquaculture, 12*(2), 869–889. https://doi.org/10.1111/raq.12340

Smaal, A. C., Ferreira, J. G., Grant, J., Petersen, J. K., & Strand, Ø. (2021). *Goods and services of* *marine bivalves*. Springer. https://doi.org/10.1007/978-3-319-96776-9

Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A. H., Fang, J., & Buck, B. H. (2022). Ecological engineering in aquaculture—Potential for integrated multi-trophic aquaculture (IMTA). *Reviews in Aquaculture, 14*(2), 879–904. https://doi.org/10.1111/raq.12646.