International Journal of Agriculture and Biosciences 2024 13(4): 610-616.
https://doi.org/10.47278/journal.ijab/2024.166

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

Implementation of Integrated Multi-Trophic Aquaculture in the Cultivation of Giant Trevally (*Caranx ignobilis*), Seaweed (*Kappaphycus alvarezii*) and Sea Cucumber (*Holothuria atra*) in the Aquaculture Sub-Zone of the Banda Marine Conservation Area

Aditya Putra Basir [1]*, Sri Rejeki [2], Frida Purwanti [3] and Pujiono Wahyu Purnomo [3]

[1]Doctoral Program in Marine Science, Faculty of Fisheries and Marine Science, Diponegoro University, Jl. Prof. Jacub Rais, Tembalang, District Tembalang, Semarang City, Central Java 50275, Indonesia
[2]Department of Aquaculture, Faculty of Fisheries and Marine Science, Diponegoro University, Jl. Prof. Jacub Rais, Tembalang, District Tembalang, Semarang City, Central Java 50275, Indonesia
[3]Department of Aquatic Resources, Faculty of Fisheries and Marine Science, Diponegoro University, Jl. Prof. Jacub Rais, Tembalang, District Tembalang, Semarang City, Central Java 50275, Indonesia
*Corresponding author: adityabasir88@gmail.com

ABSTRACT

Integrated Multi-Trophic Aquaculture (IMTA) research was conducted in the Banda Marine Conservation Area to develop a sustainable farming system and preserve the environment. Fish were cultured in three floating net cages (3m x 3m x 3m), with 300 fish per cage, totalling 900. Sea cucumbers were cultivated in three square net cages (3m x 3m, 50cm height) with 150 sea cucumbers per unit, totalling 450. Seaweed was grown using vertical long lines around the KJA area, with horizontal distance treatments (5, 15, 2, 35, 45m) and vertical distance between nodes at 2m. Over 180 days, *Caranx ignobilis* had a Relative Growth Rate (RGR) of 0.42 g/day, while *Holothuria atra* had 0.005 g/day. *Kappaphycus alvarezii* had an average RGR of 0.11 g/day over four 45-day cycles. Specific Growth Rates (SGR) were 6.45%/day for *C. ignobilis*, 2.91%/day for *H. atra*, and 6.29%/day for *K. alvarezii*. *H. atra* had the highest survival rate (97.60%), while *C. ignobilis* had the lowest (96.17%). The NO3-N and PO4-P content in *K. alvarezii* at the end of the cycle was highest on the northern raft, with NO3-N=4.62gN/m^2 and PO4-P=1.06gN/m^2.

Keywords: IMTA, *C. ignobilis, K. alvarezii, H. atra*

Article History
Article # 24-693
Received: 03-Jul-24
Revised: 13-Sep-24
Accepted: 23-Sep-24
Online First: 05-Oct-24

INTRODUCTION

Fish and shellfish production from aquaculture activities in 2020 was reported to have contributed 49% of the total production for human consumption (Chambers et al., 2024). Fish and shellfish production from aquaculture activities in 2020 was reported to have contributed 49% of the total production for human consumption (Chambers et al., 2024). Additionally, the importance of diverse aquatic ecosystems, including mangrove areas, has been highlighted in several studies. For instance, checklists of mangrove snails have been documented along the South Coast of Pamekasan, Madura Island, and Lamongan District in East Java, indicating the significance of mollusk biodiversity in these regions (Islamy & Hasan, 2020; Isroni et al., 2023). Furthermore, the presence of non-native aquatic plants in freshwater ecosystems such as the Brantas River has been recorded, underscoring the ecological challenges posed by these species (Islamy et al., 2024).

Aquaculture is still recognized as the fastest-growing sector in animal food production, driven by the global consumption of fish increasing almost twice as fast as the growth of the world's population each year (FAO, 2022). Asian countries have been noted as the largest producers of aquaculture, contributing 89% of the total fish production volume over the last 20 years. The global capture fisheries production was observed to have declined from a peak of 96.5 million tons in 2018 to 90.3 million tons in 2020. Overall, capture fisheries production has stagnated since 1986, with a decrease in the number of wild-caught species (FAO, 2022).

Cite this Article as: Basir AP, Rejeki S, Purwanti F and Purnomo PW, 2024. Implementation of integrated multi-trophic aquaculture in the cultivation of giant trevally (*Caranx ignobilis*), seaweed (*Kappaphycus alvarezii*) and sea cucumber (*Holothuria atra*) in the aquaculture sub-zone of the Banda marine conservation area. International Journal of Agriculture and Biosciences 13(4): 610-616. https://doi.org/10.47278/journal.ijab/2024.166

A Publication of Unique Scientific Publishers

Fishermen worldwide have been facing numerous challenges, such as rising fuel costs, price fluctuations, stock depletion, and the impacts of climate change (Chambers et al., 2024). In the Banda Neira waters of Indonesia, where this study was conducted, fishermen are unable to fish during the early east and west wind seasons due to large waves in the Banda Sea. Consequently, many fishermen are required to seek alternative employment during these seasons.

Some fishermen have shifted to aquaculture to supplement their income. The skills and equipment needed for fishing have been easily transferable to aquaculture. The primary obstacles in aquaculture activities are high production costs and the environmental impact of aquaculture waste (Young et al., 2019). Unutilized nutrients in aquaculture that are released into the aquatic environment have been known to cause hypernitrification. The negative impacts of aquaculture have mainly originated from particulate and dissolved nutrients from animal waste and uneaten food (Quimpo et al., 2020).

The goal of IMTA has been to integrate the production of species from different trophic levels within the same system. In this system, fed fish are placed at the top level, cultured alongside seaweed as a low-level filter to extract inorganic and organic biological waste. Larger organic waste, which typically sinks and accumulates at the bottom, can be utilized by sea cucumbers (Qiu et al., 2022). According to Widowati et al. (2020), IMTA can be developed to increase the efficiency and productivity of an area by utilizing local organisms such as fish, sea cucumbers, shellfish, and seaweed, and can serve as an alternative livelihood for the community.

This research on IMTA implementation was conducted in the aquaculture subzone of the Banda Marine Conservation Area with the aim of providing a sustainable cultivation system for the Banda community while preserving the surrounding environment at the cultivation site. Three organisms were utilized in the implementation of IMTA: giant trevally, sea cucumbers, and seaweed. These organisms were selected because they are easily obtained in the Banda Islands waters. The application of the IMTA cultivation model is expected to be adopted by the Banda Naira community.

MATERIALS & METHODS

The study was conducted from July to December 2023 in the Aquaculture Sub-Zone of the Banda Marine Conservation Area (Fig. 1). The samples used in this research included giant trevally, seaweed, and sea cucumbers (Fig. 2). The giant trevally fry was sourced from wild catches with an average initial weight of 8.34g/individual. The seaweed seedlings of the *Kappaphycus alvarezii* species were purchased from local farmers in Langgur Village, Southeast Maluku Regency. The average initial weight used for each seaweed node was 100g. The sea cucumber seedlings of the *H. atra* species were obtained from wild catches by local communities in the Banda Islands. The average initial weight used was 9.23g/individual.

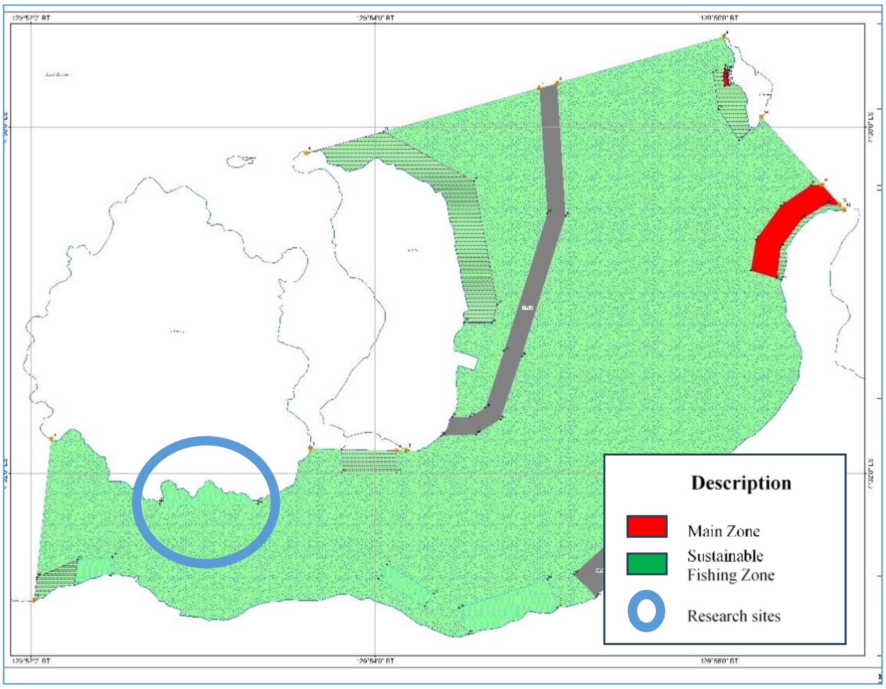

Fig. 1: Research Location (Banda Marine Conservation Area)

Fig. 2: (A). *Charanx ignobilis*; (B). *Kappaphycus alvarezii*; (C). *Holothuria atra*

Giant trevally was cultivated in floating net cages (KJA) which serve as the central component of the IMTA system. The KJA measured 3m x 3m, with a height of 3m, and a total of three cages were used (Putro et al., 2015). The stocking density for each KJA was 300 fish, totalling 900 fish for the three cages. Sea cucumbers were cultivated at the bottom trophic level directly beneath the KJA locations. The containers for sea cucumber cultivation were staked net cages (KJT) in a square shape, measuring 3m x 3m with a height of 50cm from the seabed, and a total of three units were used. The stocking density for each KJT was 150 sea cucumbers, totalling 450 sea cucumbers for the three units.

Seaweed was cultivated using a vertical long-line floating raft model placed around the KJA area. The horizontal distance treatments were A = 5m, B = 15m, C = 25m, D = 35m, and E = 45m. Seaweed was cultivated at each trophic level, from the seabed to the water surface. The vertical distance between seaweed nodes was 2m, with 5 nodes per line on each floating raft, while the horizontal distance between nodes was 25cm, with 10 nodes on each floating raft. This treatment aimed to measure the ability of seaweed to absorb organic waste at each water trophic level (Fig. 3).

The growth of fish, sea cucumbers, and seaweed was measured using relative growth rate (RGR), specific growth rate (SGR), length growth (GR), and survival rate (SR). The growth measurements for giant trevally and sea cucumbers were taken from the initial weight at the start of the cultivation period (W0) to the final weight at the end of the cultivation period (Wt), which lasted 6 months or 180 days (W180). Seaweed was cultivated for 4 cycles, with each cycle lasting 45 days, and harvested at the end of each cycle. Growth measurements were taken biweekly over the six-month period. Growth data were collected by weighing the fish using a digital scale with an accuracy of 0.01g and measuring fish length using a ruler or measuring tape.

The RGR was calculated using the formula by Vidakovic (2015):

$$\mathrm{RGR}(\%) = \left(\frac{W_t - W_0}{W_0}\right) \times \frac{100}{t}$$

where:

- *W0* is the initial weight,
- *Wt* is the final weight,
- *t* is the time in days.

The SGR was calculated using the formula by Busacker et al. (1990):

$$\mathrm{SGR}\,(\%/\mathrm{day}) = \left(\frac{\ln W_t - \ln W_0}{t}\right) \times 100$$

where:

- *W0* is the initial weight,
- *Wt* is the final weight,
- *t* is the time in days.

This formula calculates the daily percentage increase in weight.

The GR was calculated using the formula by Busacker et al. (1990):

$$\mathrm{GR} = \frac{L_t - L_0}{t}$$

where:

- *L0* is the initial length,
- *Lt* is the final length,
- *t* is the time in days.

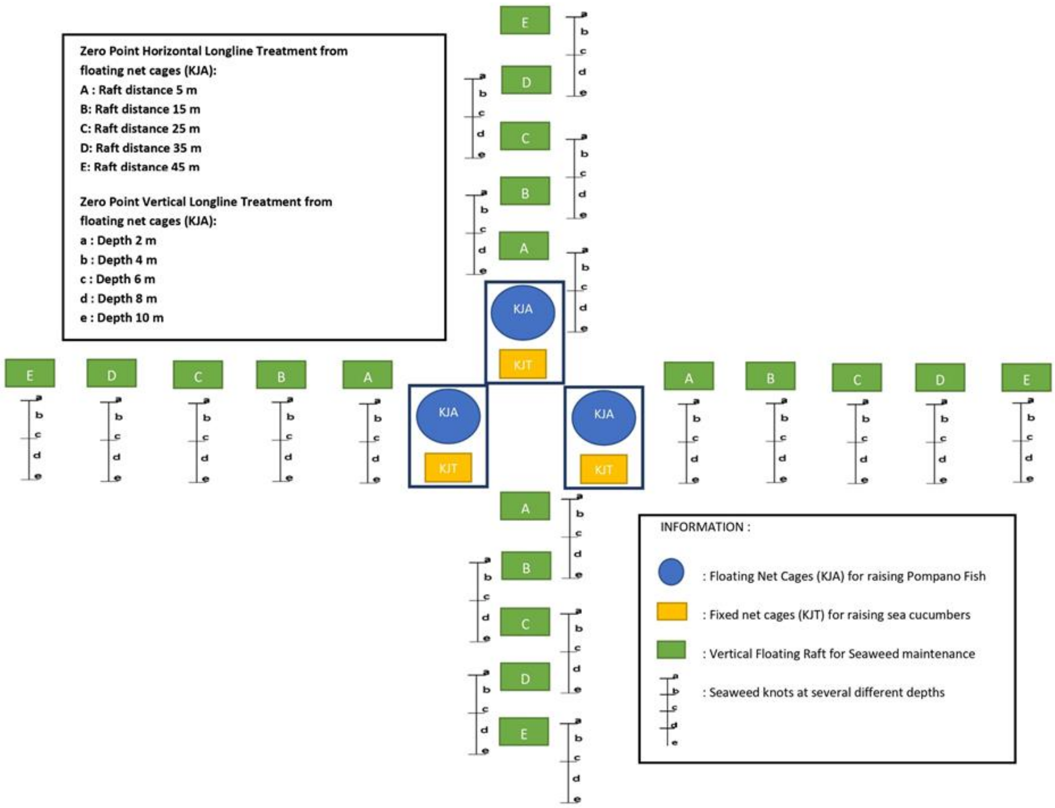

Fig. 3: IMTA Design

The SR was calculated using the formula by Busacker et al. (1990):

$$\mathrm{SR}(\%) = \left(\frac{N_t}{N_0}\right) \times 100$$

where:

- $N0$ is the initial number of individuals,
- Nt is the number of individuals at the end of the period.

This formula calculates the percentage of individuals that survive from the beginning to the end of the study period.

The uptake rate of nitrogen (N) and phosphorus (P) by seaweed was calculated using the equation as follows (Kitadai and Kadowaki 2007):

$$P_{\mathrm{ob}} = \frac{(C_t - C_0)\times \alpha}{t}$$

where:

- Pob is the uptake rate of phosphorus (P) or nitrogen (N) by seaweed (gN or P/m^2 / day),
- Ct is the concentration of nitrogen (N) or phosphorus (P) at time tt (gN or P/m^2),
- $C0$ is the initial concentration of nitrogen (N) or phosphorus (P) (gN or P/m^2),
- α is the coefficient reflecting the increase in concentration per unit increase in weight (gN or P/g DW),
- t is the duration of the experiment (days).

The water quality parameters measured include salinity, temperature, pH, dissolved oxygen (DO), water flow velocity, water clarity, nitrate, and phosphate in the water, as well as total nitrogen (N) and phosphate (P) in the seaweed.

Data Analyses

The data on RGR, SGR, GR, and SR for *C. ignobilis*, *K. alvarezii*, and *H. atra*, as well as the nitrogen (N) and phosphorus (P) uptake by seaweed, were obtained. Subsequently, they were analyzed using descriptive analysis.

RESULTS

Results of the analysis of relative growth rate (RGR), specific growth rate (SGR), length growth (GR), and survival rate (SR) of *C. ignobilis*, *K. alvarezii*, and *H. atra* cultivated using the IMTA system in the aquaculture sub-zone of the Banda Marine Conservation Area are presented in Table 1.

Table 1: Value of SGR, SGR, GR and SR analysis results of *Charanx ignobilis*, *Kappaphycus alvarezii* and *Holothuria atra* cultivated with the IMTA system.

Organism	Observed Variable			
	RGR (g/day)	SGR (%/day)	GR (cm)	SR (%)
Charanx ignobilis	0.42±0.01^c	6.45±0.24^c	20.14±0.05^b	96.17±0.37^a
Kappaphycus alvarezii	0.11±0.02^b	6.29±0.08^b	-	97.11±0.83^b
Holothuria atra	0.005±0.002^a	2.91±0.05^a	8.03±0.26^a	97.60±0.89^c

Note: The superscript letters (a, b, c) following the values in the table indicate statistically significant differences among the organisms for each observed variable. When different superscript letters are present, it suggests that the means of the respective organisms are significantly different from each other based on a statistical test.

The research results indicate that the average RGR values obtained over 180 days of cultivation were 0.42 g/day for *C. ignobilis* and 0.005g/day for *H. atra*. The average RGR value for *K. alvarezii* per cycle (45 days of cultivation) over 4 cycles was 0.11 g/day. The SGR values were as follows: *C. ignobilis* 6.45%/day, *H. atra* 2.91%/day, and *K. alvarezii* 6.29%/day. The highest survival rate was observed in *H. atra* with SR value of 97.60%, while the lowest SR was recorded for *C. ignobilis* at 96.17%.

Based on the SGR, SGR, GR values of *C. ignobilis*, *K. alvarezii* and *H. atra* cultivated using the IMTA system, a graph was made (Fig. 4). The results of water quality monitoring at the cultivation subzone of the Banda Marine Conservation Area are presented in Table 2.

Table 2: Descriptive statistics of water quality in the cultivation subzone of the Banda Marine Conservation Area

Parameters	Unit	Minimum	Maximum	Average	Standard Guidelines
Salinity	g/L	32	34	33	28-34 ***
Temperature	°C	26	29	27.5	25-30 ***
Water Clarity	m	8.2	10	9.1	>5 ***
pH		7.4	7.6	7.5	7-8.5 ***
Dissolved Oxygen	mg/L	7.13	7.56	7.35	>5 *
Water Flow Rate	m/s	0.21	1.03	0.62	0.20-0.40 ***
NO3-N	mg/L	0.001	0.08	0.04	0.06 ***
PO4-P	mg/L	0.002	0.013	0.007	0.015 ***

Standard guidelines based on regulations: *Ministry of Environment No. 51 of 2004; **Yuniarsih et al. (2014); ***Government Regulation of the Republic of Indonesia No. 22 of 2021 concerning the Implementation of Environmental Protection and Management.

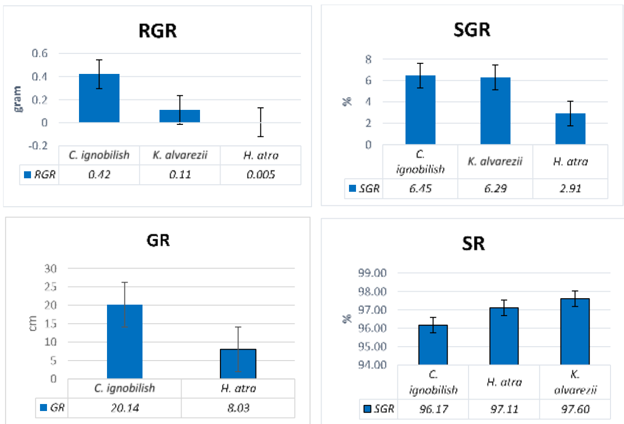

Fig. 4: Graphs of relative growth rate (RGR), specific growth rate (SGR), length growth (GR), and survival rate (SR).

The water quality condition is an important factor to consider in aquaculture activities using the IMTA system because water directly affects cultivation activities (Yuniarsih et al., 2014). Based on observations of water quality during the research, it is evident that the water quality in the aquaculture sub-zone of the Banda Marine Conservation Area is still highly supportive of cultivation activities (Table 2). The measurement results of NO3-N and PO4-P data in the IMTA area waters are presented in Fig. 4.

The results of the measurement of nitrogen (N) and phosphorus (P) uptake rates by seaweed are presented in Fig. 5 and Fig. 6.

DISCUSSION

The growth, as one of the biological aspects of fish, is a good indicator to assess the health of individuals, populations, and the environment. Rapid growth can indicate abundance of food and suitable environmental

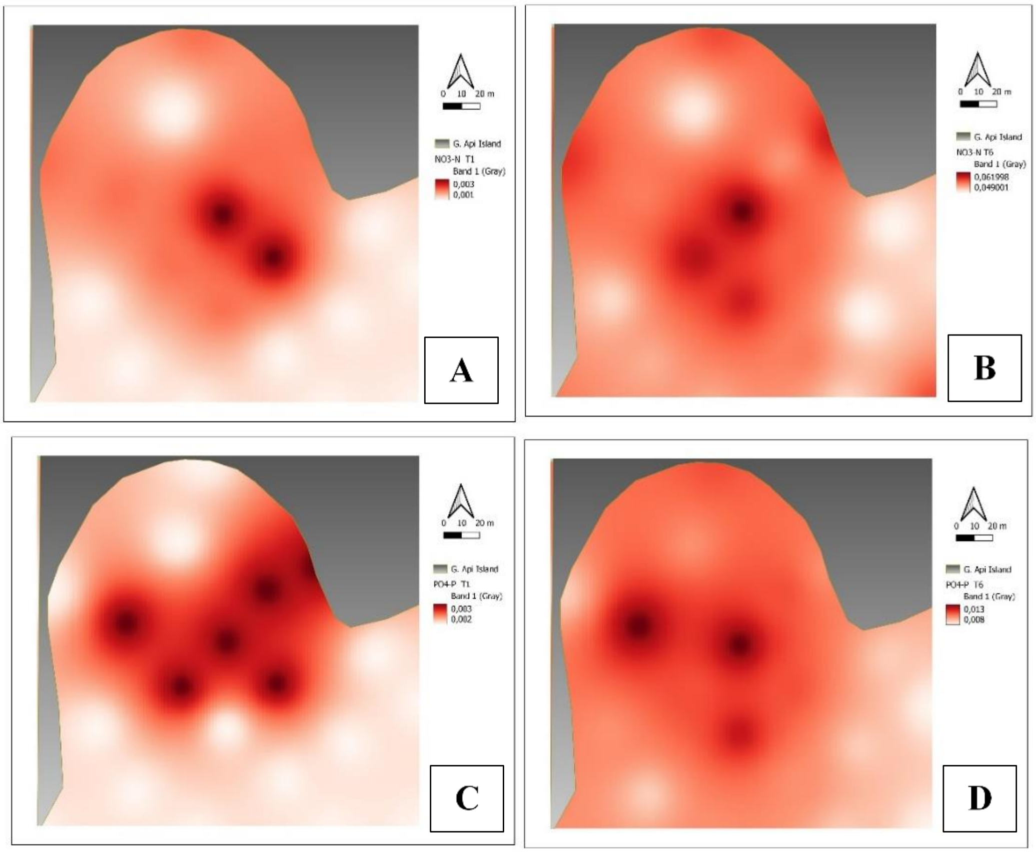

Fig. 1: NO3-N and PO4-P levels in the waters of the IMTA location: A. NO3-N on day 30 (T1); B. NO3-N on day 180 (T6); C. PO4-P on day 30 (T1); D. PO4-P on day 180 (T6).

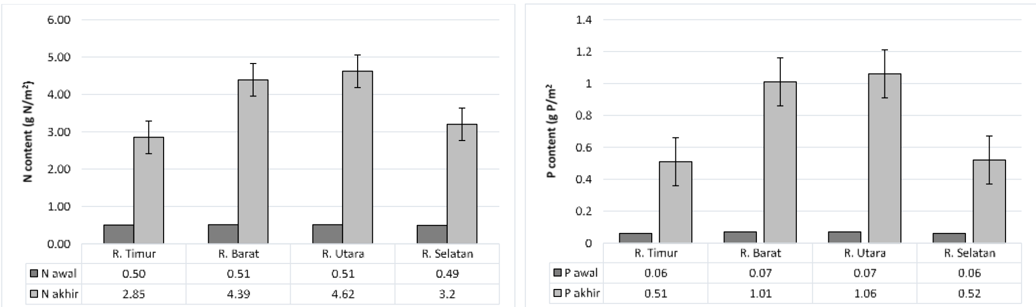

Fig. 6: Nitrogen and phosphorus content in *Kappaphycus alvarezii* seaweed.

conditions (Muhammad, 2022). Mulkan et al. (2017) explained that factors influencing growth include age and water quality. The research results of *C. ignobilis* growth showed a relative growth rate reaching 0.42%, while the specific growth rate reached 6.45% per day. The specific growth rate values from the research were much higher compared to the specific growth rate values from Darfin et al. (2022) research, which was conducted for 90 days with treatments (snails) reaching a percentage of 1.9%, followed by treatments (sea worms) reaching an average percentage of 1.2%, and treatments (oysters) reaching 1.06%.

The growth of sea cucumbers is greatly influenced by the nutrients available as a growth source for the sea cucumbers. The research results showed that the RGR value of the cultivated sea cucumbers reached 0.11%, while the SGR value reached 2.91% per day. This growth rate is better compared to the research by Padang et al. (2015), which cultured sandfish sea cucumbers in pens with a growth result of 0.069% over two months. Padang et al. (2015) explained that sandfish sea cucumbers experience nutrient deficiencies due to limited cultivation facilities, resulting in limited availability of benthic diatoms as food for the sandfish sea cucumbers. In the IMTA system, uneaten feed from *C. ignobilis* will settle on the seabed and become additional feed for the cultivated sea cucumbers.

For seaweed growth, there are internal factors affecting seaweed growth, such as species, thallus part, and age, while external factors include environmental factors, initial seed weight, planting techniques, and cultivation methods (Fikri et al., 2015). Pande et al. (2021) explained that the success of seaweed cultivation can be determined by the appropriate cultivation method, good environmental quality, and the use of initial seed weights used in seaweed cultivation. The specific growth rate in seaweed is determined by weighing the wet weight of seaweed at the end of the cultivation period minus the initial weight of seaweed at the beginning of the cultivation period divided by the duration of cultivation and multiplied by 100% (Maulana et al., 2023). The SGR value of seaweed from the research reached 6.29%. Halimah et al. (2021) explained that in their research, the specific growth of seaweed on the long-line method averaged 3.5%, while on the bottom release method, the specific growth averaged 2.9%. Anggadiredja et al. (2010) suggested that the good daily growth rate for seaweed is not less than 3%.

Survival rate is a key parameter that can indicate success in aquaculture biota production (Dangmeka et al., 2018). The highest survival rate was observed in *K. alvarezii* at 97.60%, followed by *H. atra* at 97.11% and *C. ignobilis* at 96.17%. Fish mortality occurs during the adaptation period of the cultivated fish in the cultivation containers used. Fish seeds obtained from nature must be able to adapt to the cultivation containers prepared. The research results from Suyatno et al. (2022) showed that the survival rate of barramundi fish seeds cultivated for 28 days with different feed reached 100%. Sea cucumber survival is influenced by biotic factors such as competition, parasites, predators, age, density, and human handling, as well as abiotic factors such as physical and chemical properties in the water (Kabelen et al., 2023).

The main impact of the presence of fish farming activities using artificial feed on water quality in the surrounding area is the accumulation of particles and dissolved nutrients in the water column (Nordvarg & Johansson, 2002). Nutrients play a significant role in seaweed growth, especially nitrogen and phosphorus content (Parenrengi et al., 2011; Isroni et al., 2019; Masithah & Islamy, 2023). In the water, nitrogen exists in the form of nitrate, nitrite, ammonium, and ammonia, as well as organic nitrogen compounds such as urea and amino acids. Dissolved Inorganic Nutrient (including NH4, NO3, and NO2) is a limiting factor that determines seaweed productivity in various marine environments (Troell et al., 2009). The analysis results of NO3-N and PO4-P in the water of the IMTA cultivation location showed that on day 30, the concentration distribution of NO3-N accumulated most at the center of the IMTA KJA up to the northern part of the research site. On day 180, the distribution of NO3-N spread almost throughout the research location, ranging between 0.001-0.8 mg/L. The highest distribution of PO4-P concentration was found on the northern side of the IMTA KJA with a range of values reaching 0.013mg/L (Fig. 5C). At the end of the research period (day 180), the distribution of dissolved nutrients, both NO3-N and PO4-P, accumulated most on the northern side of the IMTA KJA. The differences in nutrient distribution observed during the research were caused by the current patterns at the research location. Yuniarsih et al. (2014) explained that the nutrient distribution pattern caused by the movement of currents directly affects the cultivated.

Further research should be directed towards analyzing the nutritional composition of various organisms cultured within IMTA systems, as has been previously conducted on inland aquatic species (Pratama et al., 2020; Islamy et al., 2024). Additionally, investigations into optimized husbandry techniques are required to enhance the growth performance of IMTA species, following the approaches outlined in existing studies (Safir et al., 2024; Serdiati et al., 2024).

Conclusion

In this study, the growth of yellowtail fish (*C. ignobilis*), sea cucumbers (*H. atra*), and seaweed (*K. alvarezii*) in the IMTA cultivation system in the Banda Sea Conservation Area has been observed. The results show positive growth for all three organisms, with sea cucumber and seaweed growth outperforming that of yellowtail fish. Water quality at the cultivation site is also well maintained, supporting aquaculture activities. Additionally, the absorption of nitrogen and phosphorus by seaweed also shows promising results. Thus, the IMTA system has the potential to be a sustainable aquaculture solution in the area, providing alternative livelihoods for local communities and reducing pressure on the marine environment.

Acknowledgment: The authors would like to thank the Indonesia Endowment Fund for Education (LPDP) from the Ministry of Finance, Republic of Indonesia, for granting the scholarship and supporting this research. The authors also acknowledge the Integrated Research Laboratory (IRL) Brawijaya University, and the SATU JRS 647/UN3/3023 funding for all support and facilities.

Conflict of Interest: Authors declare there is no conflict of interest.

Author's Contribution: A.P. Basir contributed to the conceptualization and design of the research, as well as the data analysis and interpretation. S. Rejeki was responsible for the methodology, overseeing the experimental procedures, and ensuring the accuracy of the results. F. Purwanti participated in the data collection and provided expertise in statistical analysis, while P.W. Purnomo contributed to the review of the manuscript, offering critical insights and revisions to enhance the overall quality of the research. All authors reviewed and approved the final version of the manuscript.

REFERENCES

Anggadiredja, J.T., Zatnika, A., Purwoto, H., & Istini, S. (2010). Rumput laut: Pembudidayaan, pengolahan, dan pemasaran komoditas perikanan potensial. Jakarta: Penebar Swadaya.

Busacker, G.P., Adelman, T.R., & Goolish, E.M. (1990). Busgrowth. In C.B. Schreck & P.B. Moyle (Eds.), Method for fish biology (pp. 11-22). Bethesda, MD: American Fisheries Society. https://doi.org/10.47886/9780913235584.ch11

Chambers, M., Coogan, M., Doherty, M., & Howell, H. (2024). Integrated multi-trophic aquaculture of steelhead trout, blue mussel and sugar kelp from a floating ocean platform. *Aquaculture*, 582, 740540. https://doi.org/10.1016/j.aquaculture.2023.740540

Dangmeka, K., Dahoklory, N., & Santoso, P. (2018). Pengaruh pemberian detritus dari bahan organik berupa limbah hewan sebagai pakan terhadap pertumbuhan dan kelangsungan hidup teripang pasir (holothuria scabra) yang dipelihara dengan sistem kurungan. *Jurnal Aquatik*, 1(1), 98-103. https://doi.org/10.35508/aquatik.v1i1.2443

Darfin, Patadjai, R.S., & Balubi, A.M. (2022). Studi pertumbuhan ikan kuwe (Caranx sp) yang diberi pakan kepiting hermit, cacing laut dan tiram. *Media Akuatika: Jurnal Ilmiah Jurusan Budidaya Perairan*, 7(3), 132-136. http://dx.doi.org/10.33772/jma.v7i3.24832

Fikri, M., Rejeki, S., & Widowati, L. L. (2015). Produksi dan kualitas rumput laut (*Eucheuma cottonii*) dengan kedalaman berbeda di perairan bulu kabupaten jepara. *Journal of Aquaculture Management and Technology*, 4(2), 67-74. Retrieved from https://ejournal3.undip.ac.id/index.php/jamt/article/view/8544

Food and Agriculture Organization [FAO], (2022). The state of world fisheries and aquaculture 2022: Sustainability in action. Rome. Retrieved from https://www.fao.org/3/cc0461en/cc0461en.pdf

Halimah, N., Usman, H., & Kasnir, M. (2021). Laju pertumbuhan dan produksi rumput laut (Kappaphycus alvarezii) dengan metode budidaya yang berbeda di pesisir pantai Kecamatan Mare Kabupaten Bone. In Seminar Ilmiah Nasional Fakultas Perikanan dan Ilmu Kelautan Universitas Muslim Indonesia (pp. 61-75). https://jurnal.fpik.umi.ac.id/index.php/SemINasFPIKUMI/article/view/182

Islamy, N.R.A., Senas, N.P., Isroni, N.W., Mamat, N.N.B., & Kilawati, N.Y. (2024). Sea moss flour (E. cottonii) as an ingredient of pasta: the analysis of organoleptic, proximate and antioxidant. *Iraqi Journal of Agricultural Sciences*, *55*(4), 1521–1533. https://doi.org/10.36103/kzmmxc09

Islamy, N.R., Hasan, N.V., Mamat, N.N., Kilawati, N.Y., & Maimunah, N.Y. (2024). immunostimulant evaluation of neem leaves againts non-specific immune of tilapia infected by A. hydrophila. *Iraqi Journal of Agricultural Sciences*, *55*(3), 1194–1208. https://doi.org/10.36103/dywdqs57

Islamy, R.A., & Hasan, V. (2020). Checklist of mangrove snails (Mollusca: Gastropoda) in South Coast of Pamekasan, Madura Island, East Java, Indonesia. *Biodiversitas Journal of Biological Diversity*, *21*(7). https://doi.org/10.13057/biodiv/d210733

Islamy, R.A., Hasan, V., & Mamat, N.B. (2024). Checklist of Non-Native aquatic plants in up, middle and downstream of Brantas River, East Java, Indonesia. *Egyptian Journal of Aquatic Biology and Fisheries*, *28*(4), 415–435. https://doi.org/10.21608/ejabf.2024.368384

Isroni, W., Islamy, R.A., Musa, M., & Wijanarko, P. (2019). Short Communication: Species composition and density of mangrove forest in Kedawang Village, Pasuruan, East Java, Indonesia. *Biodiversitas Journal of Biological Diversity*, *20*(6). https://doi.org/10.13057/biodiv/d200626

Isroni, W., Sari, P.D., Sari, L.A., Daniel, K., South, J., Islamy, R.A., Wirabuana, P.Y., & Hasan, V. (2023). Checklist of mangrove snails (Gastropoda: Mollusca) on the coast of Lamongan District, East Java, Indonesia. *Biodiversitas Journal of Biological Diversity*, *24*(3). https://doi.org/10.13057/biodiv/d240341

Kabelen, A.S., Oedjoe, M.D.R., & Yulianus, L. (2023). Pertumbuhan teripang pasir (Holothuria scabra) yang dipelihara pada substrat yang berbeda. *Jurnal Vokasi Ilmu-Ilmu Perikanan* , 4(1), 36-41.

Kitadai, Y., & Kadowaki, S. (2007). The growth, N, P uptake rates and photosynthetic rate of seaweeds cultured in coastal fish farm. Kagoshima University.

Masithah, E., & Islamy, R.A. (2023). Checklist of freshwater periphytic diatoms in the midstream of Brantas River, East Java, Indonesia. *Biodiversitas Journal of Biological Diversity*, *24*(6). https://doi.org/10.13057/biodiv/d240621

Maulana, F.W., Minsas, S., & Safitri, I. (2023). Laju pertumbuhan rumput laut Eucheuma cottonii berdasarkan perbedaan kedalaman dengan metode keramba jaring apung di perairan Pulau Lemukutan. *Jurnal Laut Khatulistiwa*, 6(2), 58-70. https://dx.doi.org/10.26418/lkuntan.v6i2.58126

Muhammad S.R. (2022). Kajian pertumbuhan beberapa jenis ikan di perairan pesisir Kabupaten Kutai Timur (Growth study of several fish species in coastal of East Kutai Regency). *Jurnal Ilmu Perikanan Tropis Nusantara*, 1(2), 101-106. https://doi.org/10.30872/jipt.v1i2.428

Mulkan, M., Rahmi, E., Afdhal, S., & Duwiyanti, I. (2017). Pertumbuhan dan kelangsungan hidup benih ikan nila gesit (O. niloticus) pada sistem aquaponik dengan jenis tanaman berbeda. *Jurnal Ilmiah Mahasiswa Kelautan Unsyiah*, 2(1), 183-193.

Nordvarg, L., & Johansson, T. (2002). The effect of fish farm effluents on the water quality in the Aland archipelago, Baltic Sea. *Aquaculture Engineering*, 25, 253-279.

Padang, A., Lukman, E., & Sangadji, M. (2015). Pertumbuhan dan kelulusan hidup teripang pasir (Holothuria scabra) yang dipelihara di kurungan tancap (pen-culture). *Jurnal Bimafika*, 7(1), 782-786.

Pande, N., Suji, P., Antari, D., Watiniasih, N.L., Putu, A., & Krisna, W. (2021). Pertumbuhan rumput laut (Eucheuma cottonii) dengan berat bibit awal berbeda di Pantai Pandawa, Bali. *Jurnal Biologi Udayana*, 25, 122-129.

Parenrengi, A., Rachmansyah, & Suryati, E. (2011). Budidaya rumput laut penghasil karaginan (karaginofit). Edisi Revisi. Jakarta: Balai Riset Perikanan Budidaya Air Payau, Badan Penelitian dan Pengembangan Kelautan dan Perikanan, Kementerian Kelautan dan Perikanan.

Pratama, W.W., Nursyam, H., Hariati, A.M., Islamy, R.A., & Hasan, N.V. (2020). Short Communication: Proximate analysis, amino acid profile and albumin concentration of various weights of Giant Snakehead (Channa micropeltes) from Kapuas Hulu, West Kalimantan, Indonesia. *Biodiversitas Journal of Biological Diversity*, *21*(3). https://doi.org/10.13057/biodiv/d210346

Putro, S.P., Widowati, S., Suhartana, & Muhammad, F. (2015). The application of integrated multi trophic aquaculture (IMTA) using stratified double net rounded cage (SDFNC) for aquaculture sustainability. *International Journal of Science and Engineering*, 9(2), 85-89. https://doi.org/10.12777/ijse.9.2.85-89

Qiu, X., Carter, C.G., Hilder, P.E., & Hadley, S. (2022). A dynamic nutrient mass balance model for optimizing waste treatment in RAS and associated IMTA system. *Aquaculture*, 555, 738216. https://doi.org/10.1016/j.aquaculture.2022.738216

Quimpo, T.J.R., Ligson, C.A., Manogan, D.P., Requilme, J.N.C., Albelda, R.L., Conaco, C., & Cabaitan, P.C. (2020). Fish farm effluents alter reef benthic assemblages and reduce coral settlement. *Marine Pollution Bulletin*, 153, 111025. https://doi.org/10.1016/j.marpolbul.2020.111025

Safir, M., Maasily, I.S., Serdiati, N., & Islamy, R.A. (2024). Growth of Bamboo Lobster (Panulirus versicolor; Latreille, 1804) Fed with Feed Made from Sosodek Fish Meal (Atherinomorus lacunosus). *Jurnal Penelitian Pendidikan IPA*, *10*(SpecialIssue), 100–106. https://doi.org/10.29303/jppipa.v10ispecialissue.7884

Serdiati, N., Islamy, R.A., Mamat, N.B., Hasan, V., & Valen, F.S. (2024). Nutritional value of alligator weed (Alternanthera philoxeroides) and its application for herbivorous aquaculture feed. *International Journal of Agriculture and Biosciences*, *13*(3), 318-324. https://doi.org/10.47278/journal.ijab/2024.124

Suyatno, S., Khartiono, L.D., & Tasruddin, T. (2022). Pemberian jenis pakan rucah terhadap pertumbuhan ikan kuwe gerong (Caranx inbobilis). *Jurnal ZAB: Zona Akuatik Banggai*, 3(1), 39-45.

Troell, M., Joyce, A., Chopin, T., Neori, A., Buschmann, A.H., & Fang, J.G. (2009). Ecological engineering in aquaculture - potential for integrated multi-trophic aquaculture (IMTA) in marine offshore systems. *Aquaculture*, 297, 1-9.

Vidakovic, A. (2015). Fungal and mussel protein sources in fish feed. Doctoral Thesis. Swedish University of Agricultural Sciences Uppsala.

Widowati, L.L., Ariyati, R.W., & Rejeki, S. (2020). Ecological and economical analysis for implementing integrated multi trophic aquaculture (IMTA) in an abraded area to recover aquaculture production in Kaliwlingi, Brebes, Indonesia. *Geo Eco Marina*, 25, 161-170. https://doi.org/10.5281/zenodo.3609841

Young, N., Brattland, C., Digiovanni, C., Hersoug, B., Johnsen, J.P., Karlsen, K.M., & Thoraransen, H. (2019). Limitations to growth: Social-ecological challenges to aquaculture development in five wealthy nations. *Marine Policy*, 104, 216–224. https://doi.org/10.1016/j.marpol.2019.03.012

Yuniarsih, E., Nirmala, K., & Radiarta, I.N. (2014). Tingkat penyerapan nitrogen dan fosfor pada budidaya rumput laut berbasis IMTA (integrated multi-trophic aquaculture) di Teluk Gerupuk, Lombok Tengah, Nusa Tenggara Barat. *Jurnal Riset Akuakultur*, 9(3), 487-500.