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Boosting the Economy of Mariculture in Marine Conservation Areas to Enhance the Livelihoods of Small Island Communities in the Seribu Islands

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ABSTRACT

Mariculture represents a vital component of the blue economy, offering opportunities to increase food supply, generate employment, and promote sustainable livelihoods. Its sustainability is closely linked to habitat quality and environmental conditions within marine conservation programs. Conservation areas play a pivotal role in maintaining ecosystem health, enhancing fish biomass, and supporting high production levels.

This study investigates strategies to strengthen the blue economy through mariculture practices conducted in conservation zones, with a case study in the Seribu Islands. Research was carried out in buffer and settlement zones where aquaculture activities are already established. Findings indicate that current aquaculture practices have not yet fully aligned with blue economy principles. Although conservation status improvements have contributed to moderate production gains over the 15-year observation period, the overall increase in income remains limited. Coral cover has shown minimal recovery, and substantial production growth occurs only when coral cover exceeds 30%. These results emphasize the importance of ecosystem restoration in enhancing mariculture performance and advancing the blue economy within marine conservation frameworks.

Keywords: Blue Economy, Conservation, Marine Economy, Seribu Islands, Small Islands

INTRODUCTION

The blue economy has emerged as an advanced framework for sustainable development, expanding upon the earlier concept of the green economy. Introduced in 2012, it emphasizes the responsible use of marine and aquatic resources to support economic growth while preserving ecological integrity (Rahim et al. 2024). According to Lee et al. (2020), this paradigm has gained global recognition as a pathway to protect ocean ecosystems and promote sustainable utilization of aquatic resources. Indonesia has been one of the key adopters of this concept, integrating it into national and regional marine management strategies, including the establishment of marine conservation areas.

Marine conservation areas—covering both coastal and small island ecosystems—are managed through a zoning system to ensure the sustainable use of aquatic resources (Tanto and Ilham 2023). Zoning delineates functional boundaries based on habitat potential and ecological sensitivity, prioritizing areas of high biodiversity or unique ecological function (Sambah et al. 2019). These zones are subsequently incorporated into marine spatial planning frameworks (Suraji et al. 2020).

Under the Regulation of the Minister of Marine Affairs and Fisheries No. 31 of 2020, allowable activities within conservation areas are strictly managed. Permitted non-economic uses include research, education, renewable energy development, and traditional practices. Economic activities that are conditionally permitted comprise limited fishing, ecotourism within carrying capacity limits (Bibin et al. 2017), low-impact transportation, and aquaculture practices that adhere to sustainability thresholds.

Mariculture within conservation areas requires careful consideration of environmental balance. Operations must not solely pursue economic gains but also maintain ecosystem

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resilience (Razai et al. 2021). Sound aquaculture management enables practitioners to sustain livelihoods while preserving the ecological integrity of surrounding habitats (Akmal et al. 2021).

As part of the broader "blue food" system, mariculture has the potential to significantly boost community welfare, food security, and job creation (Sarker et al. 2018). Technological innovation and improved management can increase aquaculture productivity and profitability (Prayuda and Sary 2019). In this context, conservation areas with healthy environmental conditions and well-defined zones can serve as catalysts for blue economy growth, supporting mariculture systems with high ecological carrying capacity.

MATERIALS AND METHODS

Time and Location

This research was conducted in the Seribu Islands, part of the Jakarta Province, encompassing Tidung Island, Pari Island, Panggang Island, Lancang Island, and Kelapa Island (Figure 1). Data collection took place over two months, from October to November 2024, with sampling conducted once per week.

Two data types were utilized:

1. Primary data, gathered through direct interviews with mariculture practitioners, and
2. Secondary data, obtained from previous publications and datasets from relevant institutions, particularly the Center for Coastal and Marine Resources Studies (PKSPL IPB).

These datasets provided complementary information on aquaculture operations, production, and coral reef ecosystem conditions across multiple islands.

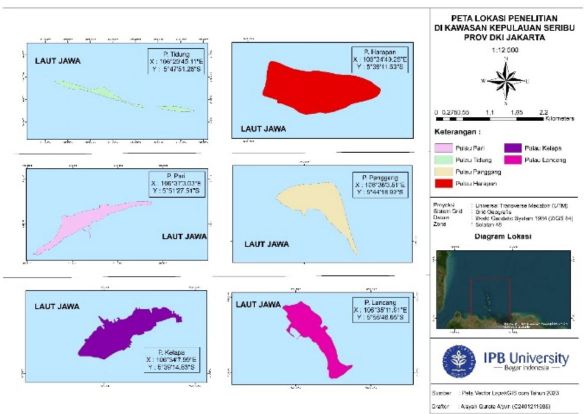

Figure 1. Research map

Data Collection

Primary data were obtained through structured and in-depth interviews with aquaculture farmers using standardized questionnaires. The survey gathered information on farming techniques, production outputs, income levels, and overall welfare indicators. Respondents also reported observed trends in productivity and operational challenges within conservation zones.

Secondary data were compiled from scientific literature and institutional reports related to marine ecosystem conditions, especially coral reef health. This included ecological indicators such as coral cover percentage, water quality parameters, and environmental carrying capacity relevant to aquaculture sustainability.

Data Analysis

The analysis focused on evaluating the efficiency and profitability of mariculture operations through a combination of biotechnical and economic indicators.

1. Feed Conversion Ratio (FCR)
   Feed efficiency was assessed using the Feed Conversion Ratio (FCR), calculated following the method of Laheng et al. (2020). The FCR value represents the ratio between the total feed provided and the total biomass produced, reflecting feed utilization effectiveness. A higher FCR indicates lower efficiency and increased waste generation in aquatic environments.
2. Income and Profitability Analysis
   The total income (π) was determined by subtracting total production costs (TC) from total revenue (TR), as described by Fahrudin (2018):

   $$\pi = TR - TC$$

   where:

   π = income (IDR),
   TR = total revenue, and
   TC = total cost.

   Total revenue was calculated using the formulation by Mulyani (2017):

   $$TR = Y \times P_y$$

   where:

   Y = total production (kg),
   P_y = price per kilogram (IDR).

Total cost was derived from both fixed costs (FC) and variable costs (VC):

TC=FC+VCTC = FC + VCTC=FC+VC

This approach enables a detailed assessment of financial performance and production sustainability across mariculture sites.

3. Revenue-Cost Ratio (R/C) Analysis
To evaluate business efficiency, the Revenue-Cost Ratio (R/C) was applied following Hudaya and Masri (2015). This metric compares total revenue and total costs to classify mariculture profitability according to three categories:
R/C > 1: Profitable business,
R/C = 1: Break-even,
R/C < 1: Loss-making operation.
R/C analysis serves as a straightforward measure of economic viability. In this study, variations in R/C among the islands were used to infer the level of economic "boosting" achieved under differing conservation and management conditions.

RESULTS AND DISCUSSIONS

Result

Feed Conversion Ratio (FCR)

The study revealed that not all feed provided in mariculture systems is consumed by fish, resulting in uneaten feed that contributes to organic waste accumulation in the aquatic environment. A higher Feed Conversion Ratio (FCR) reflects greater feed inefficiency and potential environmental pollution due to residual feed waste.

An evaluation of FCR across mariculture sites in the Seribu Islands showed considerable variation (Table 1).

Table 1. Feed conversion ratio in Seribu Island

Island	Production (Kg/cycle)	Amount of Feed (Kg/cycle)	FCR
Kelapa	110	440	4,0
Harapan	162,5	790	4,8
Panggang	103,7	500	4,8
Lancang	225	1.350	6,0
Pari	95	350	3,6
Tidung	310	1.860	6,0

The highest FCR values were recorded at Tidung Island and Lancang Island (6.0), indicating low feed utilization efficiency. These sites required approximately 6 kg of feed to produce 1 kg of fish, suggesting suboptimal feeding management and potential environmental impacts from feed residues. In contrast, Pari Island showed the lowest FCR (3.6), indicating comparatively efficient feed use. The prevalent practice of using small bycatch fish as feed remains widespread and likely contributes to the observed inefficiencies.

Income

Farmers' income serves as a key indicator of the socioeconomic contribution of mariculture to the blue economy. Income levels were calculated based on total production and prevailing market prices for key mariculture commodities such as snapper, tiger grouper, lodi grouper, mouse grouper, mackerel, and baronang.

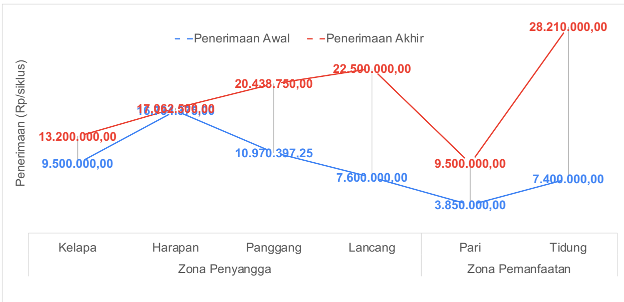

Figure 2. Total revenue in Seribu Island

Analysis of total revenue (Figure 2) demonstrates a consistent upward trend across most islands. The rise in both commodity prices and production volumes has positively influenced farmers' earnings. Interviews revealed that income growth corresponded with the progressive development of mariculture enterprises, reflecting increased production capacity and improved market access.

Costs

Total production costs were determined by aggregating fixed and variable expenses for each cultivation cycle (approximately eight months). Although mariculture systems across the Seribu Islands employed similar technology, cost variations were observed among sites (Figure 3).

Figure 3. Total cost from mariculture activities

The results indicated that Tidung Island exhibited a reduction in total costs compared to other islands, likely due to operational efficiencies and improved management practices. Meanwhile, other sites experienced moderate cost fluctuations influenced by feed prices, equipment maintenance, and transportation logistics.

Revenue and cost analyses collectively inform farmers' net income and welfare levels. The findings revealed that farmers on Tidung Island earned the highest average income, while those on Pari Island had the lowest earnings (Figure 4).

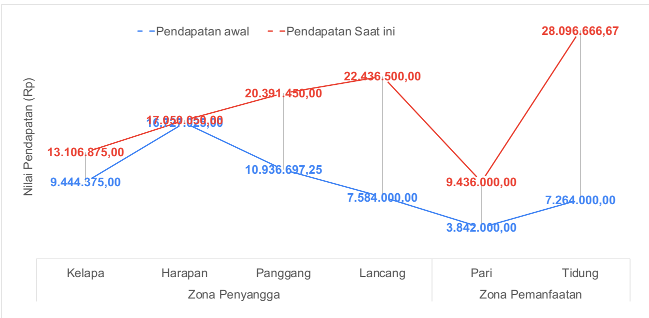

Figure 1. Graph of income analysis from mariculture activities

Average monthly incomes ranged from IDR 9,436,000 on Pari Island to IDR 28,096,666 on Tidung Island, representing an increase of approximately IDR 20,832,666 over time. Income levels were generally higher in general utilization zones compared to residential zones, suggesting that zoning type influences mariculture productivity and profitability.

Profitability (R/C Ratio)

Profitability assessments using the Revenue-Cost Ratio (R/C) indicated that all mariculture operations in the Seribu Islands were economically viable (Table 2).

Table 2. Profitability of mariculture activities in the Seribu Islands

Island	R/C	Results	Profit Margin
Kelapa	119,502	>1	Low
Harapan	871,276	>1	High
Panggang	325,242	>1	Medium
Lancang	285,291	>1	Medium
Pari	109,363	>1	Low
Tidung	232,926	>1	Medium

The mean R/C ratio was 323.93, with a standard deviation of 183.00–464.85, indicating a range of profitability from low to high. Sites exceeding 464.85 were classified as *high profit*, while those between 183.00 and 464.85 were *moderately profitable*. All R/C values greater than 1 confirmed that mariculture enterprises across the study sites were profitable and economically sustainable, albeit with varying degrees of efficiency.

Income Trends

To assess long-term economic growth, the study compared **initial** and **current income levels** among mariculture farmers, examining whether conservation and ecological factors had influenced financial outcomes. Two main drivers of mariculture growth were identified:

1. Increasing demand for fish from local residents and tourists, and
2. Improved conservation area management, particularly coral reef recovery.

Statistical analyses demonstrated significant income growth over the study period (Table 3).

Table 3. Comparison of income at the start of the business with the current situation

Island	Start Income	Current Income	Reults Comparison	Cultivation Period	Change in Annual Income	Average Annual Income per Island
Kelapa	7.959.000,00	9.885.000,00	1.926.000,00	9	214.000	963.167
Kelapa	10.869.416,67	14.294.083,34	3.424.666,67	2	1.712.333	
Harapan	3.203.666,67	3.695.666,67	492.000,00	3	164.000	370.333
Harapan	20.373.333,34	26.716.666,67	6.343.333,33	11	576.667	
Panggang	14.134.800,00	19.775.066,67	5.640.266,67	18	313.348	963.415
Panggang	19.415.900,00	59.890.066,67	40.474.166,67	18	2.248.565	
Panggang	2.959.500,00	3.944.500,00	985.000,00	3	328.333	
Lancang	13.909.666,67	69.873.000,00	55.963.333,33	9	6.218.148	2.441.197
Lancang	3.977.333,34	14.945.266,68	10.967.933,34	13	843.687	
Lancang	3.970.666,67	7.897.000,01	3.926.333,34	15	261.756	
Pari	2.576.000,01	6.889.600,01	4.313.600,00	24	179.733	334.969
Pari	5.565.333,34	11.938.000,00	6.372.666,66	13	490.205	
Tidung	15.640.000,01	59.275.000,00	43.634.999,99	11	3.966.818	759.503
Tidung	3.897.666,67	14.911.666,67	11.014.000,00	9	1.223.778	
Tidung	3.216.800,01	7.350.000,00	4.133.199,99	14	295.229	
Average	8.777.938,89	22.085.372,23	13.307.433,33	11,47	1.269.106,68	972.097,47
STDEV	6.377.379	22.126.742	17.808.046	6	1.721.266	770.929
n	15,00	15,00	15	15	15	6
SQRT N	3,87	3,87	3,87		3,87	2,45
STDEV/SQRT n	1.646.632	5.713.100	4.598.018		444.429	314.730
AVERAGE/ SQRT N(t-val)	5,33	3,87	2,89		2,86	3,09

Average annual income increased from IDR 8,777,938.89 to IDR 22,085,372.23, representing an average gain of IDR 13,307,433.33 per cultivation business and an annual growth rate of approximately IDR 1,269,106.68.

Statistical tests confirmed these increases as significant ($t_{hit} = 2.89 > t_{ta\beta} = 1.75$). Similar trends were observed across individual islands, where average annual income per island ranged between IDR 314,730 and IDR 2,441,197.

These findings demonstrate that mariculture has provided a consistent positive impact on household income, although the overall growth rate remains modest relative to living cost standards.

Discussion

This study explored the relationship between ecosystem health, particularly coral reef condition, and mariculture productivity and income among small island communities in the Seribu Islands. Two primary dimensions—ecological quality and economic performance—were analyzed to understand how conservation areas contribute to sustainable blue economy development.

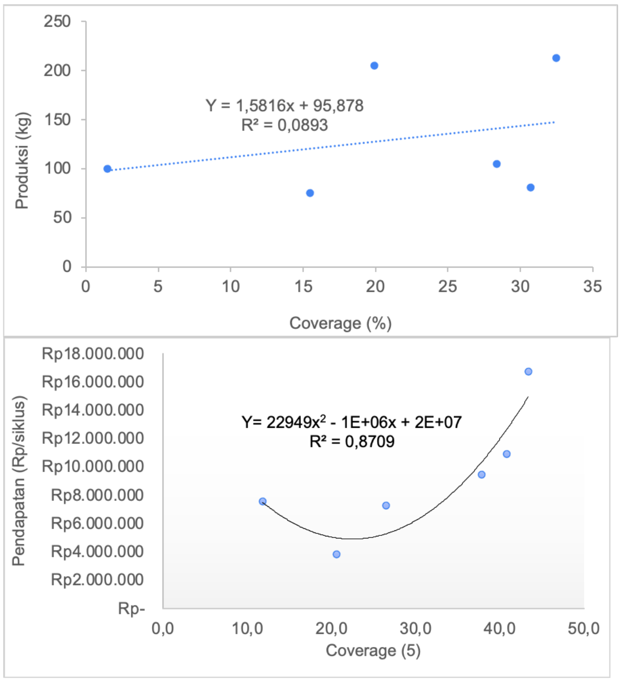

Figure 4. The relationship between coral cover and (a) income (b) from aquaculture.

Coral Cover and Aquaculture Productivity

The findings revealed a positive but weak correlation between coral cover and mariculture production. As illustrated in Figure 4, production and income levels tend to rise more noticeably once coral cover surpasses 30%, indicating a potential ecological threshold. Specifically, when coral coverage exceeds this level, mariculture production can increase by approximately 6 kg for every 1% rise in coral cover, and income increases by around IDR 434,226 per 1% increment.

This relationship underscores the indirect yet significant influence of ecosystem quality on aquaculture productivity. Coral reefs provide structural habitat complexity that supports fish biomass and stabilizes the surrounding ecological environment, both of which enhance mariculture outcomes. However, below the 30% coverage threshold, the correlation remains weak, suggesting that degraded ecosystems limit biological and economic performance.

Although these trends are promising, the relatively low correlation coefficient (8.93%) indicates that coral health alone does not fully explain variations in production. Other environmental factors—such as water quality, feed residue accumulation, and nutrient loading—likely play important roles in determining the carrying capacity of the aquaculture environment. Thus, integrated ecosystem management, including water quality monitoring and waste reduction strategies, is essential to sustain mariculture within conservation areas.

Economic Implications for Small Island Communities

The results also highlight that, while mariculture has significantly increased household income over time, the magnitude of improvement remains below the threshold for ensuring adequate livelihood standards. This finding suggests that although mariculture contributes positively to the local economy, the principles of the blue economy—particularly those concerning sustainability, efficiency, and inclusiveness—have not yet been fully realized in practice.

Income disparities between islands are partly attributed to differences in zoning status, infrastructure, and market access. Islands located within general utilization zones tend to perform better economically than those within residential zones. Moreover, the persistence of high FCR values (4–6) indicates inefficiencies in feed management that reduce profitability and exacerbate environmental stress through nutrient pollution.

Strengthening institutional support, promoting technological adoption, and enhancing ecosystem-based management are therefore critical to improving both economic returns and environmental outcomes. This aligns with earlier findings by Prayuda and Sary (2019) and Sarker et al. (2018), who noted that technological and ecological interventions can serve as major drivers for sustainable blue economy transformation in developing island systems.

CONCLUSION

Mariculture within marine conservation areas represents a strategic approach to advancing a sustainable blue economy, particularly for small island communities dependent on marine resources.

In the Seribu Islands, mariculture operations are currently characterized by low efficiency, reflected in high FCR values and limited ecological recovery. Despite measurable income growth over the past 15 years, the overall economic boost remains moderate and insufficient to meet sustainable livelihood standards.

Ecosystem health, especially coral reef cover, continues to be a determining factor for mariculture productivity. However, with coral cover averaging only 21% (poor status), ecological limitations constrain further economic expansion. The analysis indicates that mariculture becomes substantially more productive and profitable when coral cover exceeds 30%, emphasizing the need for ecosystem restoration and habitat protection as prerequisites for sustainable aquaculture growth.

To strengthen the blue economy in marine conservation areas, future strategies should focus on:

1. Enhancing feed efficiency and reducing waste generation,
2. Improving coral reef rehabilitation and water quality management,
3. Supporting technological innovation for small-scale aquaculture, and
4. Ensuring that conservation zoning aligns with both ecological carrying capacity and community welfare goals.

By integrating ecological sustainability with socioeconomic development, mariculture in conservation areas can serve as a viable model for resilient blue economy practices in small island ecosystems.

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