

Financial and market analysis of seaweed cultivation in Karimunjawa National Park, Indonesia

^{1,2}Abdul-Latif M. Juma, ¹Dian Wijayanto, ¹Haeruddin, ³Aprijanto, ³Alin Fithor

¹ Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, Semarang, Central Java, Indonesia; ² Ministry of Education and Vocational Training, Pemba, Zanzibar, Tanzania; ³ Research Center of Hydrodynamic Technology, National Research and Innovation Agency-BRIN, Central Jakarta, Indonesia. Corresponding author: A. L. M. Juma, mussa.abdullatif@gmail.com; abdullatifjuma@students.undip.ac.id

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Abstract. *Kappaphycus alvarezii* and *Eucheuma denticulatum* are important seaweed species cultivated in Karimunjawa National Park, Indonesia, yet their economic viability within a protected area remains understudied. This study evaluated the profitability of seaweed cultivation using production costs, market access, value chain conditions, and three financial indicators: benefit-cost (B/C) ratio, return on investment (ROI), and net present value (NPV). Primary data were collected through questionnaires from 50 cultivators in Mrican, Telaga, and Batulawang beaches. All cultivators recorded positive ROI and NPV values and B/C ratios above 1.0, while 96% achieved a B/C ratio ≥ 2.0 . The mean B/C ratio, ROI, and NPV were 6.105, 2,459.96%, and Rp 136,028,118, respectively. These results demonstrate that seaweed cultivation is economically viable and provides an important livelihood for coastal communities in Karimunjawa National Park. However, dependence on a single market, limited bargaining power, price fluctuations, and seasonal production variability remain key constraints. Strengthening market access and production management could further improve the economic resilience of seaweed cultivation while supporting conservation objectives.

Keywords: B/C ratio, Karimunjawa, *Kappaphycus alvarezii*, net present value, return on investment.

Introduction. Seaweed cultivation has become a major livelihood and economic activity among coastal communities on Kemujan Island, Karimunjawa, Indonesia. The relatively easy process allows all family members, including women, to engage in seaweed cultivation (Zamroni et al., 2011; Wijayanto et al., 2022; Putri et al., 2026). The market demand for seaweed is also strong, particularly for the *Kappaphycus alvarezii* seaweed species. To keep up with the increasing market demand, seaweed cultivation is being developed among local fishers. Financial assessments of seaweed show strong economic feasibility, with an average annual profit of IDR 63.7 million per cultivator, a revenue cost (RC) ratio of 6.04, and a break-even point (BEP) price that is considerably lower than prevailing market prices (Wijayanto et al., 2020a). With optimized cultivation systems, production and profitability can be further enhanced (Wijayanto et al., 2021). Under ideal cultivation conditions, the total annual economic output of seaweed cultivation could reach approximately IDR 11.09 billion (Wijayanto et al., 2022). Unfortunately, seaweed cultivators face several structural constraints regarding their weak bargaining positions and dependence on collectors in the marketing chain (Wijayanto et al., 2020a).

Seaweed cultivation is also an alternative livelihood in areas where fishing is restricted, such as in Karimunjawa National Park. In Karimunjawa Islands, the cultivation of *K. alvarezii* and *Eucheuma denticulatum* seaweed is a major source of household income among the community (Wijayanto et al., 2020a). These two species are globally significant carrageenan-producing seaweeds that provide substantial economic value through export markets and downstream processing industries (Israel et al., 2010; Ferdinandus et al.,

2016). Seaweed cultivation also accommodates carbon sequestration and nutrient absorption in the environment (Israel et al., 2010). Seaweed cultivation can be performed on small islands since it requires low capital investment while resulting in steady income generation and employment opportunities. In addition, seaweed cultivation also reduces dependence on capture fisheries, which are often limited by resource constraints and conservation regulations, particularly in protected island ecosystems such as Karimunjawa National Park. Furthermore, sustainable seaweed cultivation strengthens the community acceptance of marine conservation policies (Rimmer et al., 2021; Fadilah et al., 2025).

Studies in Karimunjawa have examined production, spatial zonation, profitability, and marketing aspects of fisheries-related activities (Wijayanto et al., 2022; Trihatmoko et al., 2023). In particular, information regarding investment performance, financial returns, marketing channels, price formation, and constraints affecting cultivators' competitiveness remains limited (Raja et al., 2021; Sadimantara et al., 2025). The financial sustainability of seaweed cultivation in protected areas has never been comprehensively assessed. To address this gap, this study was performed to evaluate the economic feasibility of seaweed cultivation in Karimunjawa Islands using return on investment (ROI), net present value (NPV), and benefit-cost (B/C) ratio, based on survey data from 50 cultivators. Key constraints include ice-ice disease and potential ecological risks such as bio-invasion. This study also identified the key market constraints and opportunities to improve the economic sustainability of seaweed-based livelihoods in small island communities.

Material and Method

Design of the study and sampling technique. A structured questionnaire consisting of four sections was delivered to 50 respondents (Figure 1) who were selected using a quota sampling technique.



Figure 1. Participants responding to questionnaire.

The respondents farmed *E. denticulatum* and *K. alvarezii* in Kemujan Island at three beaches: Telaga, Mrican, and Batulawang beaches. The survey collected detailed information on production and economic variables, including infrastructure costs (boats, drying racks, floats, and ropes), labor requirements (seed preparation, planting, harvesting, and drying), seed stock expenses, and post-harvest handling costs such as processing, packaging, and storage. Additional data on financial charges, fuel for transportation, harvest yields per production cycle, selling prices, maintenance costs, and harvest frequency were also collected. The questionnaire also gathered information on investment-related aspects, including farm lifespan, initial capital requirements for establishing seaweed farms, market access conditions, and household income. All

monetary values for income, costs, and expenditures were expressed in Indonesian Rupiah (IDR).

Data collection. Primary data were collected through structured interviews using a questionnaire that covered the aspects specified in the research design.

Study location and time. The study was conducted on Kemujan Island in Karimunjawa National Park, involving seaweed cultivators in Mrican Beach, Telaga Beach, and Batulawang Beach (Figure 2). The study was conducted in April 2026 in the morning and afternoon when the cultivators were in their hamlets. The data collection sites are shown in Figure 2.

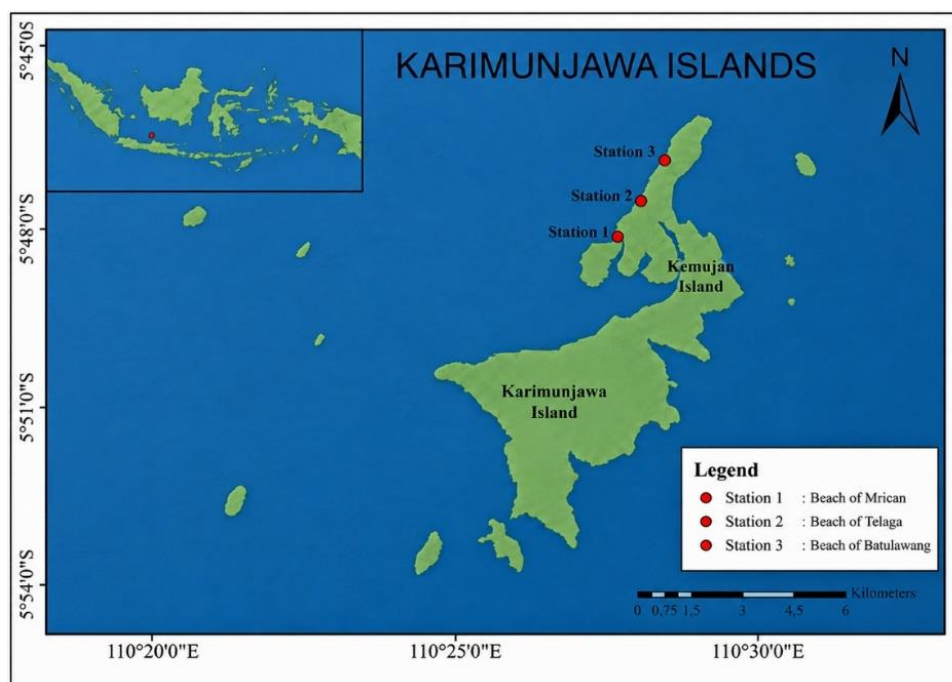


Figure 2. Location of the study.

Production cost. As explained by Rimmer et al. (2021) seaweed cultivation is a potential economic activity for small-scale cultivators since it requires small capital, simple methods, and a short period from planting to harvesting, between 30 and 45 days. The seaweed cultivation process starts with preparation, which includes the cost of procuring equipment such as boats, longlines, seeds, buoys, ballasts, ropes, and raffia. Seaweed seeds are supplied from outside of Kemujan. Seaweed seed supplies are obtained from the Centre of Marine Culture (government-owned) in Lampung and in Sulawesi. The number of longlines used by seaweed cultivators in Kemujan Village varies; at least three units of longline were used, while most use 50 units (Wijayanto et al., 2020b). Labor was used for seed preparation, planting, harvesting, and drying. Processing is an important stage to ensure maximum seaweed production by preparing post-harvest tools, packaging, and storage mechanisms. Even though seaweed cultivation is done by family members, seaweed cultivators have also established a seaweed cultivator organization where they share information and support. The government also provides assistance to seaweed cultivators through the organization. However, the revenue from the cultivation is affected by several factors such as seaweed production, seed quality, selling price, access to market, and environmental conditions. The cost incurred for the preparation, cultivation, and finally selling is unaffordable to several cultivators (Wijayanto et al., 2020b).

Profitability. Profitability is the outcome of an economic evaluation. It is necessary to measure the seaweed cultivation profitability in Karimunjawa National Park, where conservation restrictions apply.

Return on Investment (ROI). Return on investment (ROI) reflects the effectiveness of the income earned by seaweed cultivation in Karimunjawa National Park:

$$ROI = \frac{\text{Net profit}}{\text{Total investment cost}} \times 100$$

Here, Net Profit = Annual Revenue – Total Annual Costs. A lower ROI indicates that, relative to the capital invested, seaweed cultivation in Karimunjawa provides low financial returns. Likewise, a higher ROI indicates better financial returns relative to capital invested.

Net Present Value (NPV). Net Present Value (NPV) assesses the extended profitability of seaweed cultivation in Karimunjawa National Park, where revenue was obtained over multiple cultivation series. NPV accounts for the time value of money by discounting future net cash flows to their present value. The calculation used each cultivator's reported interest rate, with the Bank Indonesia reference rate of 6% applied when no loan interest rate was reported. A positive NPV indicates that seaweed cultivation in Karimunjawa National Park is economically viable, with the present value of benefits exceeding costs. NPV in this study was calculated using the following formula:

$$NPV = PV(\text{Benefits}) - PV(\text{Costs})$$

B/C ratio. B/C ratio compares the present value of benefits obtained from seaweed cultivation and the present value of total costs incurred in Karimunjawa National Park:

$$B/C \text{ ratio} = \frac{\text{Present value of benefits}}{\text{Present value of costs}}$$

A B/C ratio greater than 1.0 indicates that the economic benefits of seaweed cultivation in Karimunjawa National Park exceed its costs, demonstrating its economic viability and potential as a sustainable, environmentally compatible livelihood. A B/C ratio > 1.0 indicates viability, while a ratio ≥ 2.0 indicates high viability.

Market access. Details on the seaweed selling area following harvest, the distance traveled to the selling station, the real price, and the difficulties encountered in finding a better market were shared by the respondents. Based on the responses, seaweed cultivation is perceived as an important source of additional income, as previously mentioned by Blankenhorn (2007). However, investment in scientific research and cultivation technology can support the development of higher-value seaweed products (Mazarrasa et al., 2014). In Karimunjawa, many cultivators sell seaweed in wet form because the economic benefit from dried seaweed is lower (Wijayanto et al., 2020b). Meanwhile, seaweed-based products like carrageenan, alginate, and agar gain popularity worldwide, including in food, pharmaceuticals, cosmetics, and biofuels sectors. Indonesia is also the world's largest producer of agar, iota carrageenan, and kappa carrageenan red algae (Rhodophyta) (Hurtado et al., 2019).

Data analysis. Data were analyzed descriptively using JASP version 0.95.40 to calculate means, percentages, frequencies, and totals. Economic feasibility was assessed using NPV, ROI, and B/C ratio. Economic viability was interpreted based on standard criteria, with NPV > 0 and B/C > 1 indicating a financially feasible cultivation operation.

Results

Respondents' profiles. Based on respondents' demographic data, 29 cultivators out of 50 were females (58%). Most respondents (88%) documented seaweed cultivation as their primary occupation (Table 1). The educational background of the respondents was considered low, since 56.0% of them completed primary school, while 8.0% did not attend formal school and only 4.0% had a bachelor's degree. This situation affects market access, financial knowledge, and acceptance of better cultivation methods (Hertanto et al., 2022). Unfortunately, national statistics on rural coastal communities mostly show similar

conditions (Zamroni & Yamao, 2011). The respondents were aged between 26 and 80 years old, with a mean age score of about 49.

Table 1

Key socio-economic characteristics of surveyed seaweed cultivators (n = 50)

<i>Indicators</i>	<i>% respondent</i>	<i>Implication</i>
Female cultivators	58	Women are the dominant workforce in seaweed cultivation.
Primary occupation (seaweed cultivator)	88	Seaweed is the major livelihood source for coastal communities.
Sell to collectors only	100	Single channel dependent on collectors only.
Price set by buyer	100	No price bargaining power.
Seaweed income share $\geq 50\%$	88	Seaweed is considered strong for the family budget.

Production characteristics. Wet seaweed production ranged from 500 to 15,000 kg per cycle, with cultivators completing 3 to 12 cultivation cycles annually. Wet seaweed was sold once after each harvest at IDR 1,700 to IDR 2,000/kg, with prices set by collectors. Annual revenue ranged from IDR 3,825,000 among 39 respondents to IDR 324,000,000 among 11 respondents. Infrastructure investment ranged from IDR 3,000,000 to IDR 25,000,000, reflecting differences in farm scale and equipment. Large-scale cultivators producing up to 15 tons per cycle incurred higher absolute costs, whereas small-scale cultivators producing 0.5 to 1 ton per cycle operated with substantially lower infrastructure costs. This variation in farm scale and cost structure suggests the need for differentiated policies, particularly in the provision of technology and investment support. Differences in seaweed production are influenced by interactions among environmental, socioeconomic, and technical factors (Nurdin et al., 2025).

Financial analysis. The ROI values were positive, with a mean percentage of 2,459.96% and a median percentage of 1,921.50%. After controlling for outliers, the results showed consistently high ROI across the sample. No cultivator recorded an ROI below 100% (Table 2). Most cultivators (72%) achieved an ROI of 1,000% or higher, while 24% recorded values between 400% and 999%. The remaining 4% had ROI values ranging from 100% to 399%. Among the 50 respondents, 24 recorded the highest ROI, reaching 9,294% (Figure 3). This value was reported by 20 participants who sold seaweed at IDR 1,700/kg, produced 15,000 kg per cycle, and completed 12 cultivation cycles annually. Respondent 7 recorded the lowest ROI at 397%. This small-scale cultivator produced 500 kg per cycle while incurring relatively high infrastructure costs per unit of production. These extreme values reflect actual differences in production scale and cost structure rather than data errors.

Table 2

ROI, NPV and B/C ratio of seaweed cultivation in Karimunjawa Islands

<i>Indicators</i>	<i>Value</i>
<i>ROI</i>	
Min	397.00%
Average	2,459.96%
Max	9,294.00%
<i>NPV</i>	
Min	IDR 13,712,632
Average	IDR 136,028,118
Max	IDR 959,538,203
<i>B/C ratio</i>	
Min	1.80%
Average	6.11%
Max	18.24%

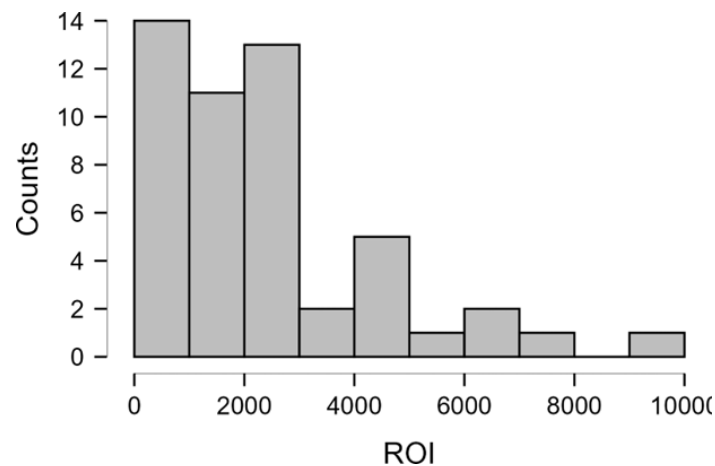


Figure 3. Distribution of return on investment (ROI) across 50 seaweed cultivators (mean = 2,459.96%, median = 1,920.50%).

All 50 participants recorded positive NPV values, indicating that the present value of expected returns exceeded discounted costs in every case. The mean and median NPV were IDR 136,538,203 and IDR 80,166,194, respectively. Respondent 38 recorded the highest NPV at IDR 959,538,203, associated with a production volume of 15,000 kg per cycle, a five-year equipment lifespan, and 12 cultivation cycles per year. Respondent 25 recorded the lowest NPV at IDR 13,712,632, reflecting the smallest farm scale.

As shown in Figure 4, Telaga Beach had the highest mean NPV at IDR 341.9 million, followed by Mrican Beach at IDR 192.1 million and Batulawang Beach at IDR 177.5 million. The analysis included 17 respondents from Mrican Beach, 19 from Telaga Beach, and 14 from Batulawang Beach. The higher mean NPV at Telaga Beach indicates greater economic returns from seaweed cultivation at this site, although NPV varied across the three locations.

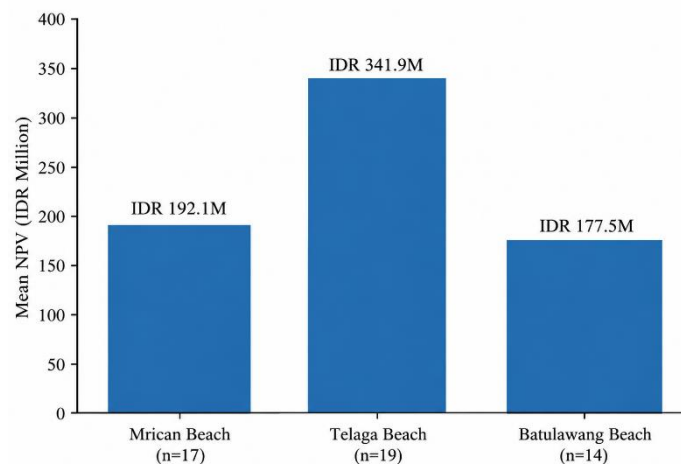


Figure 4. Mean NPV by coastal location: beach of Mrican, Telaga, and Batulawang.

A total of 48 out of 50 cultivators (96%) showed the 'Highly Viable' ranking ($B/C \geq 2.0$), and all 50 surpassed the viability limit ($B/C > 1.0$). The mean B/C ratio was 6.105, indicating that the gains of approximately Rp 6.11 were acquired for every Rp 1 paid in present value terms. Participant 5 reported a greater B/C ratio of 18.24 with relatively small documented costs relative to revenue. Respondent 8 obtained a minimum B/C ratio of 1.80, which is still within the viability threshold (Figure 5).

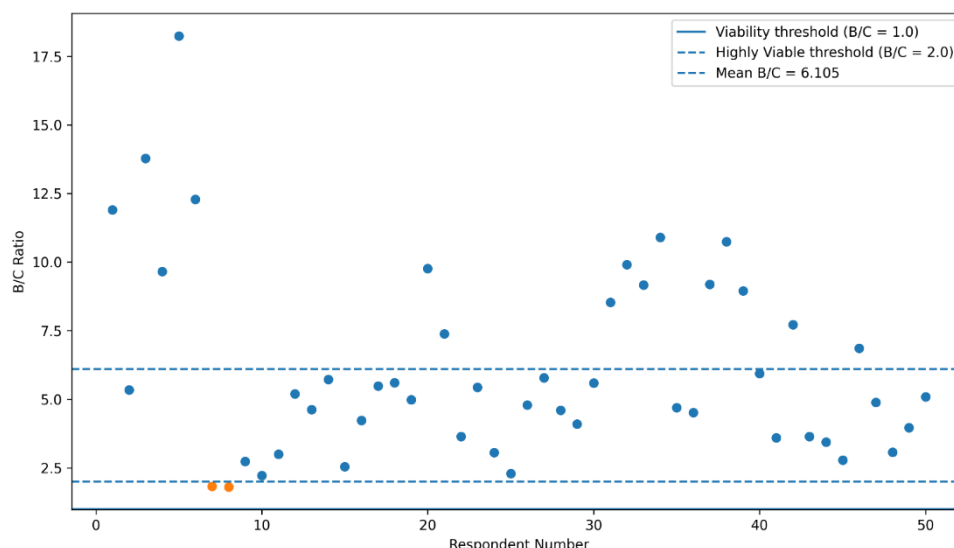


Figure 5. Benefit-cost (B/C) ratio for all 50 cultivators, red dots: $B/C < 2.0$ (viable); blue dots: $B/C \geq 2.0$ (highly viable).

Table 3 presents the factors that inhibited cultivators from accessing more promising markets. The market structure showed a major weakness: 100% of cultivators sold seaweed exclusively to collectors, with no alternative buyers, and all reported that prices were determined by buyers without negotiation. This is a single-buyer market in which cultivators are price takers and unable to benefit from potential price increases further along the value chain. Cultivators reported receiving IDR 18,000-25,000/kg for dried seaweed and IDR 1,700-2,000/kg for wet seaweed at the selling station. The approximately 10:1 price ratio indicates a substantial value gap between cultivators and downstream markets.

Table 3
Key production and market barriers reported by 50 cultivators

Barrier	% respondent	Nature of constraint
Price control by collector	100	No negotiating power, single market system
Unpredictable seasons	44	Guiding biological restrictions
Disease (ice-ice, parasites)	32	Environmental stress
Lack of market information	36	Unable to reach better markets
Transport cost	20	Geographical nature of Karimunjawa Island
Lack of government support	4	Reported mostly from Beach of Batulawang

Discussion. The results show that seaweed cultivation in Karimunjawa National Park is developing, profitable, and one of the best smallholder aquaculture systems reported in the literature, with a mean ROI of 2,459.96% and a mean B/C ratio of 6.105. No cultivator reported a deficit, B/C below 1.0, or negative NPV. The B/C ratio for small seaweed cultivators ranged from 1.5 to 4, as reported across different sites in Indonesia. In the Philippines, the cultivation of *K. alvarezii* showed positive benefits even under adverse conditions, resulting in a greater ROI (Samonte, 2017). In Southeast Asian contexts, the financial profitability of seaweed cultivation across protected areas showed a similar ROI structure and B/C ratio (Saville et al., 2025).

The coastal communities of Karimunjawa National Park have successfully shifted toward aquaculture alternatives to reduce the negative impacts of fishing. Seaweed cultivation is a viable alternative livelihood that improves welfare without endangering the marine ecosystem. Across different regions of Asia, the transition from fisheries-dependent livelihoods to seaweed cultivation is considered an important support to conservation programs and community needs (Cooke, 2004). The use of NPV and B/C ratio across six Philippine coastal waters showed that seaweed-dependent livelihoods produce the maximum economic benefits (Cuaton, 2019).

The challenges of a single market system were reported by all cultivators in the study that took place in Sub-Saharan Africa, where small cultivators were hindered by a lack of structural and proper markets (Magakwe & Olorunfemi, 2024). The occurrence of ice-ice disease is also consistent with the challenges identified by Obi et al. (2025) who linked production constraints to inadequate technical planning, limited access to quality inputs and extension services, and insufficient infrastructure for reaching higher-value markets (Claude et al., 2025). The integration of the government and other valued institutions that provide subsidies, extension, and frame better policy reduces the gap related to long-term applicability and productivity (Hasimuna et al., 2025).

Diseases such as ice-ice, moss surrounding, and frequent changes in weather were the major production threats reported by the cultivators. Ten cultivators reported ice-ice disease, a whitening of seaweed thalli due to frequent changes in salinity, low light penetration, and heat stress. Cultivators also reported stress from parasites and fish predation, which directly reduced seaweed production and the harvesting rate, eventually reducing the ROI. Ice-ice disease caused by rising sea surface temperature and falling salinity can minimize the wet biomass produced by 30 to 60% (Saraswati & Darmasetiyawana, 2016). Other contributing factors include the presence of bacteria such as *Pseudoalteromonas* spp. and *Vibrio* spp., as well as thermal abnormalities, which can reduce profitability (Kankainen et al., 2012).

Cultivators reported that seaweed cultivation enabled them to cover healthcare and education expenses for their families. Common uses of seaweed income included paying children's school fees, purchasing electronic devices and motorcycles, and maintaining homes. Seaweed income accounted for 57% of total household income, ranging from 50 to 75%, confirming its importance as a primary livelihood source for these coastal communities. These socioeconomic benefits were consistent with the financial returns observed in this study and support the need for institutional assistance to strengthen the sector. The ROI formula used in this study follows standard investment appraisal conventions commonly applied in aquaculture feasibility analyses (Samarina et al., 2021; Patrocínio et al., 2024).

The NPV formula used in this study was adjusted to the interest rate that applies, with 6% as the discount rate for cultivators who do not report formal loans, which aligns with the standard approach in economic analyses of Indonesian aquaculture (Engle, 2010). A B/C ratio greater than 1 showed profitability, whereas a value above 2 confirmed maximum viability, related to the threshold used in Indonesian aquaculture assessment (Liao & Hsu, 2003).

The B/C ratio obtained in this study exceeded the normal range of 1.5 to 3.5 (Pittman Ratterree et al., 2026). Therefore, Karimunjawa has different productive seaweed cultivation that is determined by family lifestyle, low labor cost, and effective traditional skills (Hussin & Khoso, 2017).

ROI ranged from 397 to 9,294%, NPV from IDR 13,712,632 to IDR 959,538,203, and the B/C ratio from 1.80 to 18.24. The highest values were generally recorded by cultivators who relied primarily on seaweed cultivation, such as participants 5, 37, and 38, indicating that greater concentration of labor and resources may improve financial returns. On the contrary, participants with multiple livelihoods, including 7, 8, and 10, recorded lower financial indicators, potentially because labor, time, and resources were divided across activities. Similar studies have found that focused livelihood strategies can generate higher returns than diversified activities when resources are limited (Ulukan et al., 2022; Habib et al., 2023).

Cultivators who identified seaweed cultivation as their primary occupation generally achieved higher ROI, NPV, and B/C ratios. Participants 5, 20, and 38 devoted greater effort to cultivation, whereas participants 7, 8, and 15, who treated seaweed as a secondary occupation, recorded lower returns. Similar findings from Zanzibar indicate that greater participation in seaweed cultivation increases financial benefits, while treating it as a supplementary activity produces lower returns (Mbunda et al., 2024). Profitability also depends on investment, farm scale, and cultivation intensity (Valderrama et al., 2015; Mbunda et al., 2024).

Production efficiency was linked to greater cultivation effort and lower operating costs. Participant 5 recorded a ROI of 6,862%, a B/C ratio of 18.24, and an NPV of IDR 583,201,434, demonstrating high financial performance despite weather and disease risks. Participant 7, in contrast, recorded a ROI of 397% and a B/C ratio of 1.80, indicating lower productivity and limited commitment to cultivation. Disease, poor management, limited technology, weak institutional support, and restricted market access can further reduce production efficiency and profitability (Nor et al., 2017; Sugumaran et al., 2022).

Conclusions. This study provides the first financial analysis of seaweed cultivation in Karimunjawa National Park. All 50 cultivators recorded positive NPV and ROI values, with B/C ratios above 1.0, indicating no financial losses. The mean B/C ratio of 6.105 and ROI of 2,459.96% demonstrate the importance of seaweed cultivation as a livelihood for coastal communities. However, dependence on collectors and limited bargaining power constrain cultivators' ability to capture greater value despite their production efforts. Disease and seasonal weather variation also contribute to unstable production. Strengthening market access, improving price-setting mechanisms, and adopting disease and weather management strategies could increase yields and cultivator returns. These findings support the integration of seaweed aquaculture into national park management as a community-based livelihood strategy that can contribute to both local economic welfare and conservation.

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Authors Contributions. ALMJ, DW, and H designed the study; ALMJ conducted the field survey and data analysis; ALMJ, DW, H, A, and AF contributed to manuscript preparation and writing.

Conflict of Interest. The authors declare that there is no conflict of interest.

Data Availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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Authors:

Abdul-Latif Mussa Juma (ALMJ), Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, Prof. Jacub Rais Street, Semarang, Central Java, Indonesia, e-mail: mussa.abdullatif@gmail.com; abdullatifjuma@students.undip.ac.id <https://orcid.org/0009-0008-1953-0876>

Dian Wijayanto (DW), Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, Prof. Jacub Rais Street, Semarang, Central Java, Indonesia, e-mail: undipdianwijayanto@gmail.com; dianwijayanto@gmail.com <https://orcid.org/0000-0002-1134-9748>

Haeruddin (H), Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, Prof. Jacub Rais Street, Semarang, Central Java, Indonesia, e-mail: haeruddin@lecturer.undip.ac.id <https://orcid.org/0000-0003-4014-4845>

Aprijanto (A), National Research and Innovation Agency of Indonesia, B.J. Habibie Building, M.H. Thamrin St. No. 8, Central Jakarta, Indonesia, e-mail: apri001@brin.go.id <https://orcid.org/0000-0002-7038-667X>

Alin Fithor (AF), Research Center of Hydrodynamic Technology, National Research and Innovation Agency-BRIN, B.J. Habibie Building, M.H. Thamrin St. No. 8, Central Jakarta, Indonesia, e-mail: alin005@brin.go.id <https://orcid.org/0000-0002-8890-1756>

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