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Effectiveness of Seaweed Farming Infrastructure for Advancing Sustainable Fisheries in Indonesia

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ABSTRACT

Seaweed cultivation plays a vital role in advancing the sustainable development of fisheries within the framework of the blue economy. It optimizes the use of coastal and marine resources from ecological, economic, social, and technological perspectives. This study assessed the effectiveness of government-provided seaweed cultivation facilities and infrastructure in promoting aquaculture sustainability. A mixed-methods approach—combining both qualitative and quantitative techniques—was used, including field surveys, interviews with cultivators, and analysis through Rapfish software. The research was conducted across seven provinces in Indonesia, focusing on technical, economic, environmental, and socio-institutional dimensions. The results identify Lampung, Bali, and South Sulawesi as the top-performing provinces, with Lampung achieving the highest effectiveness score of 87.09. Key leverage factors include the availability of high-quality seeds, promotion of investment, and enhancement of group dynamics, all of which significantly contribute to sustainability. These findings underscore the importance of targeted interventions and robust policy support in maximizing the benefits of seaweed farming assistance programs and advancing sustainable fisheries.

INTRODUCTION

As fishing activities continue to evolve, fish farming has experienced significant growth, particularly in marine, brackish, and freshwater aquaculture. Indonesia holds vast potential in this sector, with an estimated 17.91 million hectares of available aquaculture land. This comprises 2.8 million hectares (15.8%) suitable for freshwater aquaculture, 2.96 million hectares (16.5%) for brackish water, and 12.12 million hectares (67.7%) for

marine cultivation. However, actual utilization remains limited, averaging just 2.7% of this potential. Currently, marine aquaculture occupies 278,920 hectares, pond farming utilizes 605,909 hectares, and freshwater aquaculture spans 316,446 hectares. This underutilization presents a major opportunity to position the marine and fisheries sector as a strategic pillar of national development **(Ministry of Marine Affairs and Fisheries of the Republic of Indonesia, 2020)**.

The future development of mariculture in Indonesia is critical to the advancement of the fisheries sub-sector and is recognized as a key national priority expected to drive economic growth **(Hidayah *et al.*, 2020)**. This goal presents a strategic challenge for the Ministry of Maritime Affairs and Fisheries, which aims to elevate aquaculture as a core engine for national economic development and food security. Production targets are aligned with both domestic consumption needs and international export markets **(Ministry of Maritime Affairs and Investment of the Republic of Indonesia, 2017)**. Domestically, aquaculture supports food and nutritional security by providing safe, high-quality products for public consumption **(Dwinafiah & Hasan, 2023)**, thereby reinforcing national resilience.

Among marine commodities, seaweed stands out as one of Indonesia's most valuable aquaculture exports, owing to its high economic return and broad range of applications **(Adiguna *et al.*, 2022; Tambunan *et al.*, 2024)**. Its significance is not confined to Indonesia alone, as many countries recognize seaweed's potential across multiple industries. It is a highly versatile commodity used in diverse sectors, including pharmaceuticals, cosmetics, and food production **(Lomartire & Gonçalves, 2022)**. This versatility underscores seaweed's strategic value in both domestic and global markets, contributing to economic growth, job creation, and industrial innovation.

Seaweed cultivation also offers a sustainable livelihood alternative that empowers coastal communities. It brings several key advantages: (1) wide applicability of seaweed-based products, (2) abundant cultivation land, and (3) a cost-effective production process that requires relatively simple technology **(Marhawati *et al.*, 2020)**. Furthermore, seaweed farming promotes a shift from environmentally exploitative practices to sustainable ones, thereby supporting the preservation of coastal ecosystems and improving the economic well-being of local communities **(Annisa *et al.*, 2023)**. It also empowers fishers and their families by providing supplementary income opportunities while maintaining traditional fishing practices as part of their livelihoods **(Lein, 2018)**.

To support aquaculture development, the Government of Indonesia—through the Directorate General of Aquaculture—has distributed seaweed cultivation facilities and infrastructure annually from 2021 to 2024. These initiatives aim to facilitate the adoption of modern technologies and enhance aquaculture productivity. This study evaluated the effectiveness of these government programs in supporting seaweed cultivation and promoting sustainable aquaculture practices across Indonesia.

MATERIALS AND METHODS

Data collection

The primary objective of data collection is to obtain clear, objective information on the types of government assistance provided by the Ministry of Maritime Affairs and Fisheries (KKP). This study specifically focuses on facilities and infrastructure for seed gardens and seaweed cultivation delivered to farmer groups across seven Indonesian provinces: Lampung, East Java, Bali, West Nusa Tenggara (NTB), South Sulawesi, North Sulawesi, and Maluku.

Data were collected from both primary and secondary sources. Primary data were obtained through randomized questionnaires distributed to 10% of the seaweed farmer population in each selected province. Respondents completed the questionnaire via an online form, ensuring a systematic, efficient, and accessible data-gathering process.

Survey locations and implementation

The study focuses on provinces that are significant centers of aquaculture and have received government assistance for seed garden infrastructure and seaweed cultivation facilities. The selected provinces—Lampung, East Java, Bali, NTB, South Sulawesi, North Sulawesi, and Maluku—were chosen based on their active engagement in aquaculture and eligibility for support programs under the Ministry's initiatives.

Data analysis

Data analysis targets the evaluation of sustainability in aquaculture assistance provided to these key provinces. The analysis framework is based on the Multi-Dimensional Scaling (MDS) method, implemented using Rapfish software. This approach allows for a comprehensive sustainability assessment across four key dimensions:

- **Technical**
- **Environmental**
- **Economic**
- **Socio-institutional**

The selected attributes for evaluating the impact of aquaculture assistance across these dimensions are summarized in Table (1).

Table 1. Multidimensional sustainability attributes of aquaculture assistance impact evaluation

No	Attribute	Score (Bad-Good)	Assessment Indicators	List of Questions
A	**Technical Dimensions**			
1	Compliance with Indonesia's regional spatial plan/zoning plan	0; 1; 2;	Cultivation location: (0) Does not comply with Indonesia's regional spatial plan/zoning plan (1) Appropriate (2) Very suitable	Is the cultivation location in accordance with the Indonesia's regional spatial plan?
2	Cultivation technology	0; 1; 2;	Cultivation technologies developed: (0) Not suitable (1) Quite appropriate (2) Very suitable	Is the technology developed appropriate to existing environmental conditions?
3	Certified cultivation unit	0; 1; 2;	Increase in certified cultivation units: (0) None (1) Yes, 0-10% Units (2) Yes, > 10% Units	How many (%) certified cultivation units are available?
4	Condition of supporting infrastructure for cultivation	0; 1: 2;	Condition of supporting infrastructure for cultivation: (0) Inadequate (1) Sufficiently adequate (2) Very adequate	What is the condition of the cultivation infrastructure (transportation, electricity, Telkom network) around the cultivation location?
5	Cultivation production facilities	0; 1; 2;	Availability of cultivation production facilities: (0) None (1) Rare and hard to find (2) Easy to find	How is the availability of cultivation production facilities in the surrounding area?
6	Availability/use of quality feed	0; 1; 2	Quality of feed used: (0) Low, minimal feed (1) Medium, self-feeding (2) High, factory feed	Does the feed used meet quality requirements?

No	Attribute	Score (Bad-Good)	Assessment Indicators	List of Questions
7	Availability of quality seeds	0; 1; 2	Use of certified seeds: (0) Not using certified seeds (1) Sometimes (2) Always use certified seeds	Are certified seeds available? How often do farmer groups use certified seeds?
8	Survival rate (SR)	0; 1; 2;	(0) Low : SR<60% (1) Medium: SR 60%-75% (2) Good: > 75%	How is the survival rate of the seeds that are sown? What is the SR value produced?
9	Availability of quality fish medicine	0; 1; 2;	Availability of fish medicine for cultivation: (0) Not available (1) Available but few (2) Available in sufficient quantities	Explain how the availability of fish medicine is in the aquaculture fisheries village?
10	Management/cultivation management	0; 2;	Cultivation management is carried out: (0) Part-time Jobs (2) Main Job	Is the cultivation carried out seriously and professionally?
11	Use of appropriate technology (TG)	0; 1; 2;	Use of TG technology: (0) Do not use (1) Someone has already used it (2) Many people have used it	Does the cultivation area apply appropriate technology?
12	Production target	0; 1; 2;	Production target compliance (0) It is not in accordance with (1) Quite appropriate (2) Very suitable	Is production in accordance with the targets set per cycle?
B	**Environmental Dimensions**			
1	Condition of the quality of the aquatic environment as a source of maintenance media	0; 1; 2	Environmental quality conditions: (0) Bad (1) Good enough (2) Very good	What is the condition of the quality of the water environment used as a source of maintenance media?
2	Irrigation system in	0; 1; 2	Cultivation irrigation	Does the cultivation

No	Attribute	Score (Bad-Good)	Assessment Indicators	List of Questions
	cultivation area		system: (0) Directly from river/sea/well (1) Using a reservoir (2) Through filters and reservoirs	irrigation system use reservoir water, or directly from the source?
3	Handling of cultivation waste	0; 1; 2	Handling of cultivation waste: (0) None/bad (1) Medium (2) Good	Do you apply wastewater treatment plant in cultivation?
4	Suitability of cultivation area layout (site plan)	0; 1; 2;	Existing cultivation land layout (site plan): (0) Not suitable (1) Quite appropriate (2) Very suitable	Is the cultivation site plan in accordance with the provisions?
5	Development of space utilization (non-fisheries)	0; 1 ;2	Development of existing space utilization: (0) Height (1) Medium (2) Low	How is the development of existing (non-fishery) space utilization?
6	Intensity of disease cases	0; 1 ;2	Intensity of disease attacks: (0) Occurs frequently (1) Rarely (2) There are no cases	Is the intensity of disease attacks in cultivation common?
7	Environmental carrying capacity of cultivation	0; 1 ;2	Carrying capacity of the cultivation environment (0) Low (1) Medium (2) Height	Sir, is the cultivation carried out in accordance with the environmental carrying capacity?
8	Implementation of biosecurity	0; 1; 2;	Biosecurity Implementation: (0) There isn't any (1) There are some (2) Many apply	Does the implementation of cultivation apply biosecurity?
9	Changes in climate parameters	0; 1 ;2	The impact of climate change on environmental aspects: (0) Height	Does climate change affect environmental quality?

No	Attribute	Score (Bad-Good)	Assessment Indicators	List of Questions
			(1) Medium (2) High	
10	Rain intensity conditions (time and volume)	0; 1 ;2	The effect of rainfall intensity on the decline in the quality of cultivation water: (0) Height (1) Medium (2) Low	Does rainfall intensity affect the cultivation process and reduce water quality?
C	**Economic Dimension**			
1	Fish price	0; 1 ;2	Fish Selling Price (0) Low (1) Medium (2) Height	How much do you sell the fish (commodity) you produce?
2	Product competitiveness	0; 1 ;2	Product competitiveness towards business sustainability (0) Low (1) in progress (2) High	How does product competitiveness affect business sustainability?
3	Marketing of cultivated commodities	0; 1 ;2	Marketing of cultivated commodities: (0) Difficult (1) Quite easy (2) Very easy	Are cultivated commodities easy to market?
4	Fish feed price	0; 1 ;2	Fish feed prices: (0) Increasingly expensive and unprofitable (1) Sufficient and still profitable (2) Affordable and profitable	Are fish feed prices still affordable and profitable for farmers?
5	Cultivator income	0; 1 ;2	There is an increase in the income of farmers (0) Decreased (1) Still (2) Increase	Is the income from cultivation sufficient to increase family income/economy?
6	Marketing chain	0; 1 ;2	Marketing chain of cultivated products	How is the fish marketing chain at your

No	Attribute	Score (Bad-Good)	Assessment Indicators	List of Questions
			(0) Length (1) Medium (2) Short	location, seen from the marketing chain?
7	The use of information technology (IT) in marketing products	0; 1; 2;	Use of IT in marketing: (0) No, just conventional (1) Already started to get familiar with IT (2) Already familiar with the use of IT	Do you use information technology in marketing results?
8	Investment boost	0; 1 ;2	Activity interventions can encourage investment and the growth of new business actors: (0) Less (1) Medium (2) Height	Can activity interventions encourage the growth of interest from other investors/cultivators?
9	Encouraging access to finance	0; 1 ;2	Ease of access to financing: (0) Difficult (1) It's quite easy (2) Very easy	Is it easy to get access to financing for your cultivation business?
D	**Social and Institutional Dimensions**			
1	Multiplier effect (local community involvement)	0; 1 ;2	There is involvement of local communities (0) none (1) Enough (2) Height	Does the local community play a role/gain benefits from cultivation activities?
2	Improving human resources (HR) competence	0; 1 ;2	There is a process of transferring knowledge and technology, both training and education. (0) None (1) rarely (2) Often	What is the role of the service or extension workers in improving human resource (HR) competency?
3	Access (ease) to obtain information (technology, market)	0; 1 ;2	Access to existing information can support cultivation activities (0) None (1) Yes, less than	How is the access to information available to support improving the quality of farmers?

No	Attribute	Score (Bad-Good)	Assessment Indicators	List of Questions
			optimal (2) Yes, very optimal	
4	Involvement of women and family members	0; 1 ;2	Involvement of women and family members in cultivation activities (0) None (1) Yes, less than optimal (2) Yes, very optimal	What is the role of women and family members in the cultivation activities that you carry out?
5	Group class dynamics and improvement	0; 1 ;2	The Role of Pokdakan (0) Less important (1) Quite important (2) Very important	Does the existence of Pokdakan play a role in efforts to increase knowledge, skills and cultivation production?
6	Collaborative business climate/culture	0; 1; 2	The business culture that is carried out (0) Alone (1) There is togetherness (2) Collaboration in business has become a culture (consultation)	Is building and developing a cultivation business done collaboratively?
7	Potential conflict	0; 1 ;2	Potential conflict (0) None (1) Medium (2) Height	Does your cultivation efforts cause conflict in the community?
8	Guidance, supervision and enforcement of rules	0;1;2	The role of the apparatus in efforts to foster, supervise and enforce regulations (0) None (1) Rarely (2) Often	What is the role of the authorities in coaching, supervision and enforcement of regulations when conflicts/prohibited activities occur?

RESULTS

Contribution of each sustainability aspect (dimension) of the seaweed nursery/cultivation facilities assistance

The impact of the Seaweed Nursery and Cultivation Facilities Assistance is assessed across four key dimensions: technical, environmental, economic, and socio-

institutional. Each dimension is evaluated using specific attributes that reflect the effectiveness of the assistance in supporting sustainable aquaculture development. The evaluation covers seven provinces—Lampung, East Java, Bali, NTB, South Sulawesi, North Sulawesi, and Maluku. The results of this assessment are summarized in Table (2), which highlights the relative contribution of each aspect to the overall effectiveness of the government assistance program.

Table 2. Analysis of the contribution of sustainability aspects to seaweed nursery/cultivation facilities assistance

No	Province	Sustainability Aspects	Sustainability Values	Contribution (%)
1	Lampung	Technical	84.22	25.25
		Environment	73	21.88
		Economy	91.85	27.53
		Social Institutions	84.53	25.34
		Amount		100.00
2	East Java	Technical	53.45	18.59
		Environment	77.55	26.98
		Economy	79.83	27.77
		Social Institutions	76.64	26.66
		Amount		100.00
3	Bali	Technical	66.03	20.96
		Environment	82.63	26.23
		Economy	83.71	26.57
		Social Institutions	82.7	26.25
		Amount		100.00
4	NTB	Technical	55.61	20.97
		Environment	58.28	21.98
		Economy	70.1	26.43
		Social Institutions	81.2	30.62
		Amount		100.00
5	South Sulawesi	Technical	65	22.01
		Environment	77.56	26.26
		Economy	70.1	23.74
		Social Institutions	82.68	27.99
		Amount		100.00
6	North Sulawesi	Technical	53.73	23.16
		Environment	73.01	31.47
		Economy	53.56	23.09

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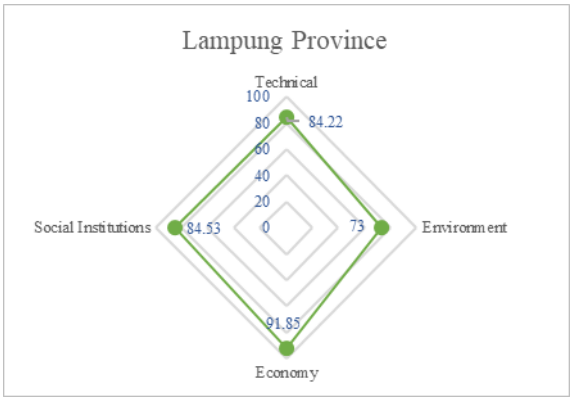
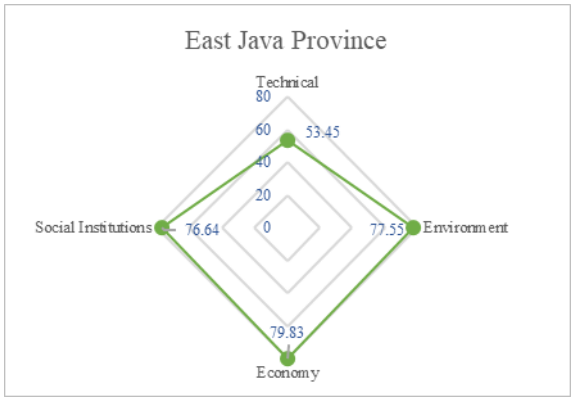
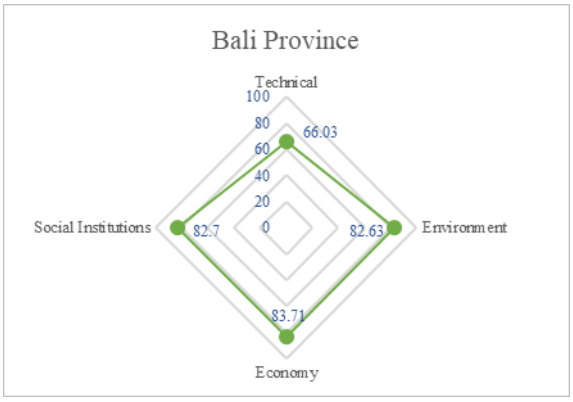
No	Province	Sustainability Aspects	Sustainability Values	Contribution (%)
		Social Institutions	51.69	22.28
		Amount		100.00
7	Maluku	Technical	62.45	23.16
		Environment	82.65	30.65
		Economy	57.43	21.30
		Social Institutions	67.13	24.89
		Amount		100.00

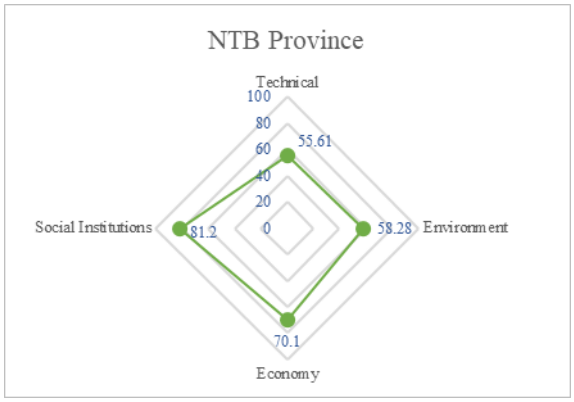
Information:

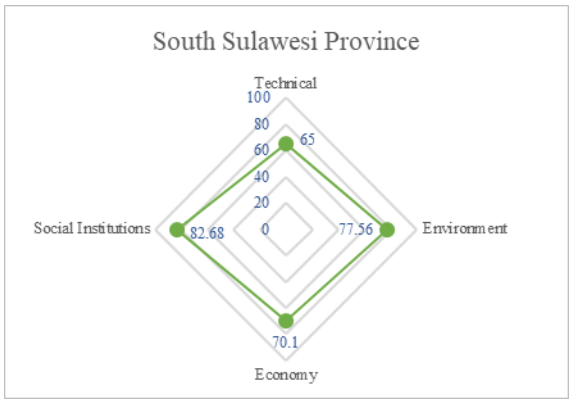
0-25	25-50	51-75	76-100
Ineffective	Less Effective	Quite Effective	Very Effective

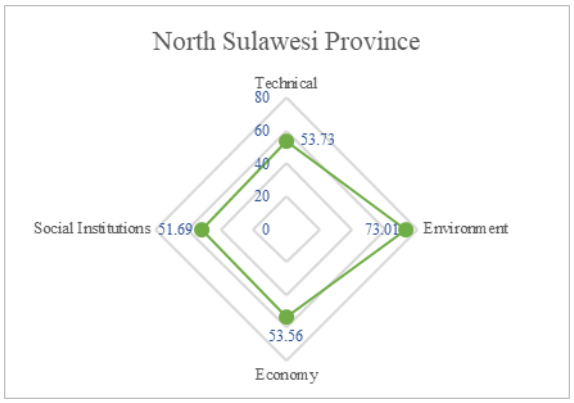












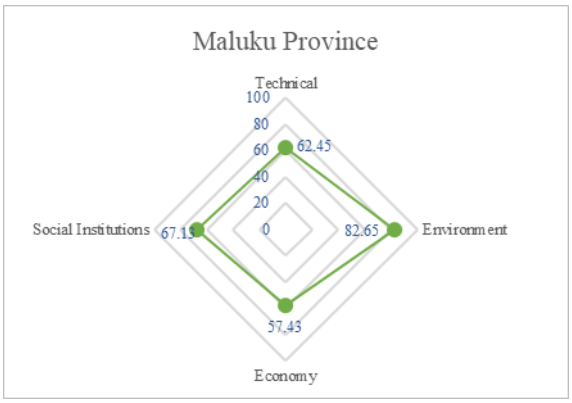


Fig. 1. Flyover diagram of the sustainability index ordination results for each province regarding assistance for seaweed seed gardens/cultivation facilities

Identification of leverage attributes (leverage analysis) of seedling/seaweed cultivation facilities assistance

Based on the results of the leverage analysis conducted using the Rapfish Evaluation Assistance method, key leverage attributes were identified within each sustainability dimension. Leverage analysis measures the sensitivity of each attribute by calculating the change in the sustainability score when the attribute is removed from the model. Specifically, leverage is determined by the difference in standard error between the sustainability score with the attribute included and the score without it. This approach provides valuable insights into the relative influence of each attribute, identifying which ones act as critical leverage factors in determining the overall impact of the seaweed nursery and cultivation facility assistance. These sensitive attributes are essential for guiding policy interventions and improving program effectiveness across the technical, environmental, economic, and socio-institutional dimensions.

Fig. 2. Sustainability ordinance and leverage attributes technical dimensions of seaweed nursery/cultivation facilities assistance

Fig. 3. Sustainability ordinance and leverage attributes of environmental dimensions of seaweed nursery/cultivation facilities assistance

Fig. 4. Sustainability ordinance and leverage attributes of economic dimension of seaweed nursery/cultivation facilities assistance

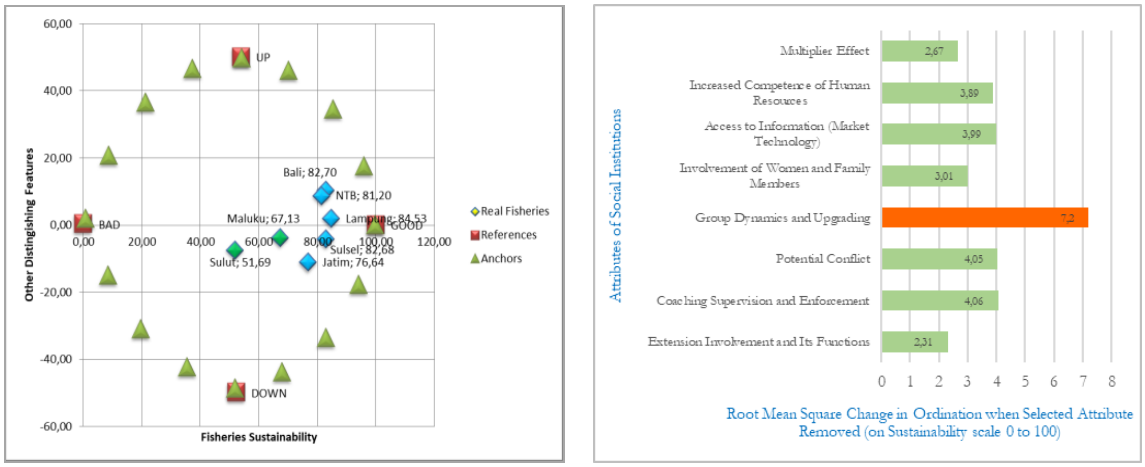


Fig. 5. Sustainability ordinance and leverage attributes of social dimension of institutional assistance for seaweed nursery/cultivation facilities

Based on Figs. (2-5), a total of eight attributes have been identified as leverage attributes in the context of seaweed nursery and cultivation facility assistance. These attributes play a critical role in influencing sustainability outcomes and are summarized in Table (3).

Comparison of seaweed cultivation facility assistance across provinces

The results of the multidimensional sustainability analysis for aquaculture assistance—specifically seaweed cultivation facility assistance—across seven provinces in Indonesia are illustrated in Fig. (6). The corresponding multidimensional sustainability scores for each province are presented in Table (4), providing a comparative overview of the effectiveness and sustainability performance of the assistance programs across regions.

Table 3. Leverage attributes of various dimensions of sustainability of seaweed nursery/cultivation facilities assistance

Dimensions	Attribute	RMS Point
Technical	Availability of Quality Seeds	4.56
	Certified Cultivation Unit	4.42
	Cultivation Production Facilities	3.84
Environment	Intensity of Disease Cases	7.76
	Climate Parameter Changes	5.37
Economy	Investment Boost	4.89
	Cultivator Income	4.85
Social Institutions	Group Class Dynamics and Improvement	7.20

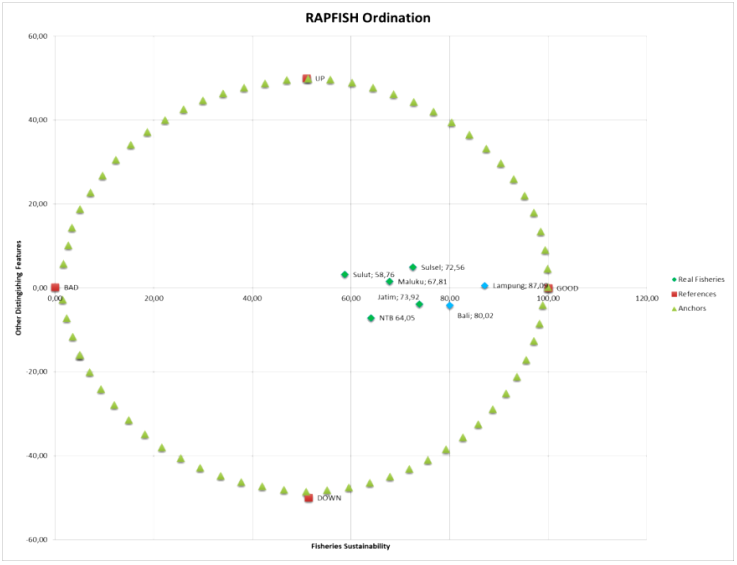


Fig. 6. Effectiveness of inter-provincial seaweed nursery/cultivation facilities assistance

Table 4. The value of ordination and effectiveness of inter-provincial seaweed nursery/cultivation facilities assistance

No	Province	Ordination Value	Effectiveness of Aid
1	Lampung	87.09	Very Effective
2	East Java	73.92	Quite Effective
3	Bali	80.02	Very Effective
4	NTB	64.05	Quite Effective
5	South Sulawesi	72.56	Quite Effective
6	North Sulawesi	58.76	Quite Effective
7	Maluku	67.81	Quite Effective

DISCUSSION

Contribution of each aspect (dimension) of sustainability of seaweed nursery/cultivation facilities assistance

The analysis of the sustainability aspects of seaweed nursery and cultivation facility assistance across seven provinces in Indonesia indicates that the effectiveness of the assistance programs ranges from moderately effective to highly effective. Lampung Province stands out with very high effectiveness in the technical, economic, and socio-institutional dimensions, while the environmental dimension is categorized as moderately effective. This moderate performance in environmental sustainability is influenced by fluctuations in climate parameters such as salinity, water clarity, high sea surface temperatures, and strong ocean currents, all of which can directly affect seaweed farming conditions. The selection of cultivation sites is crucial for maintaining sustainability. According to **Numberi *et al.* (2020)**, selecting the appropriate location is essential not only for optimizing production but also for minimizing the risk of disease and quality degradation. **Yuliana *et al.* (2015)** emphasize that variations in salinity significantly affect the growth of *Caulerpa lentillifera* (latoh seaweed), while **Zakariah *et al.* (2023)** identify water quality indicators—such as brightness, temperature, current velocity, water depth, pH, and salinity—as critical factors in determining productivity. **Indayani *et al.* (2021)** further specify that optimal seaweed cultivation occurs at water temperatures between 20–23°C, clarity of 1–5 meters, current velocity of 5–50 cm/s, and salinity ranging from 15 to 38 ppt.

East Java and Bali Provinces demonstrate a similar sustainability profile, showing high effectiveness in environmental, economic, and socio-institutional aspects, with the technical aspect rated as moderately effective. North Sulawesi, in contrast, is categorized as moderately effective across all four dimensions. Maluku Province shows a mixed pattern, achieving high effectiveness in economic and environmental aspects but only moderate effectiveness in technical and socio-institutional dimensions.

The technical dimension is significantly influenced by the availability of cultivation production facilities, quality seaweed seeds, and certified cultivation units. As noted by **Syachruddin *et al.* (2019)**, the development or procurement of cultivation facilities is essential for producing high-quality seaweed with greater market value. High-quality seed availability is a fundamental requirement for increasing productivity, as emphasized by **Suryawati and Erlina (2017)**, who identify seed quality, cultivation technology, and training as key internal strategic factors. Certification also plays a vital role by promoting proper cultivation techniques that reduce the risk of failure **(Wahyuni, 2019)**. Furthermore, production efficiency is closely linked to the availability of adequate cultivation infrastructure, as supported by **World Bank (2016)** and **Zainuddin (2023)**.

Legal and regulatory aspects also influence seaweed cultivation sustainability. **(WWF, 2014)** explains that a key legal component in this context is the requirement for a fisheries business license. According to the **Ministry of Maritime Affairs and Fisheries (2007)**, such a license is mandatory for large-scale operations but not required for small-scale activities, such as hatcheries with land areas below 0.5 hectares or grow-out farms under 5 hectares.

In West Nusa Tenggara (NTB), the socio-institutional dimension is highly effective, while the technical, economic, and environmental aspects are moderately effective. Group dynamics and the elevation of group classification are significant contributors to sustainability in this province. **Hendrawati (2016)** notes that institutional and human resource development are essential for building an ecosystem of financial and cooperative support that protects the interests of farmers and stakeholders. **Widiyanti and Nabilah (2024)** add that the number of active workers in the sector has a measurable impact on productivity, particularly in regions like East Lombok.

South Sulawesi Province is rated as moderately effective in technical and economic dimensions, while environmental and socio-institutional aspects are considered highly effective. Key leverage attributes in the economic domain include investment incentives and the resulting improvement in cultivator income. **Dinda *et al.* (2016)** explain that increased investment in seaweed cultivation leads to improved infrastructure, greater access to capital, training opportunities, and the diversification of products. **Widiyarini (2022)** confirms that domestic investment, fisheries business credit, and exports have a significant influence on the performance of the fisheries sub-sector, particularly in regions like Riau Islands Province. Cultivator income is also a crucial factor in sustainability, as efficient business practices reduce dependency on other resources and promote more stable, long-term income, as supported by **Hendrawati (2016)**.

Leverage analysis using Rapfish software identifies several key attributes that significantly influence sustainability across dimensions. In the technical dimension, the most influential attributes include the availability of quality seeds with an RMS value of 4.56, certified cultivation units with a value of 4.42, and cultivation production facilities with a value of 3.84. **Irfan *et al.* (2020)** emphasize that these factors are critical for

success in seaweed cultivation, with quality seeds having a direct impact on growth rates and resilience to disease and environmental stress, as further noted by **Irawati and Affandi (2024)**. Certification contributes to proper cultivation methods, reducing the likelihood of failure, while production facilities support increased yields and better farm management **(World Bank, 2016; Zainuddin, 2023)**.

In the environmental dimension, the most significant leverage attributes are the intensity of disease outbreaks, with an RMS value of 7.76, and changes in climate parameters, with a value of 5.37. Diseases such as "ice-ice" and stem rot can severely impact yields **(Erabley & Kelabora, 2018)**. Climate variability influences oceanographic conditions, which in turn affect seaweed growth cycles and productivity, as detailed by **Erlania and Radiarta (2014)**, **Behera *et al.* (2022)** and **Ross *et al.* (2023)**.

The economic dimension includes two prominent leverage attributes: investment encouragement (RMS: 4.89) and cultivator income (RMS: 4.85). **Sitompul *et al.* (2022)** note that both intensification and extensification of cultivation have a substantial impact on improving local economies. However, unstable farmer income, driven by non-standardized dried seaweed prices, remains a challenge, as observed by **Jaman *et al.* (2023)** and **Salim *et al.* (2023)**.

Within the socio-institutional dimension, group dynamics and organizational class improvement emerged as the single most influential leverage attribute. **Soejarwo *et al.* (2019)** argue that effective group organization facilitates the implementation of proper cultivation systems. On the other hand, **Ngabalin (2014)** highlights the role of farmer groups in marketing and collective bargaining. Group effectiveness is influenced by internal factors such as structure, unity, leadership, and goals, as discussed by **Agusanty *et al.* (2021)**.

A comparison of the overall effectiveness of seaweed cultivation assistance across the seven provinces reveals that Lampung Province achieved the highest sustainability score at 87.09, followed by Bali Province at 80.02, and South Sulawesi Province at 72.56. The high effectiveness score in Lampung reflects the strong impact of assistance programs, including infrastructure and nursery facilities, in increasing production. **Hendrawati (2016)** asserts that the success of the seaweed industry depends not only on the availability of raw materials but also on the integration of technical, marketing, environmental, financial, and institutional factors. Supporting this perspective, **Neksidin (2024)** concludes that sustainable seaweed aquaculture requires the interconnection of all sustainability dimensions. Achieving optimal sustainability in seaweed cultivation therefore depends on balanced progress across technical, environmental, economic, and socio-institutional aspects.

CONCLUSION

Government assistance distributed by the Directorate General of Aquaculture has played a significant role in advancing aquaculture development and enhancing

community welfare. However, the effectiveness of this assistance varies across regions and among recipient groups. Among the provinces evaluated, Lampung emerged as the most successful, achieving an ordination score of 87.09, which falls into the "Very Effective" category.

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