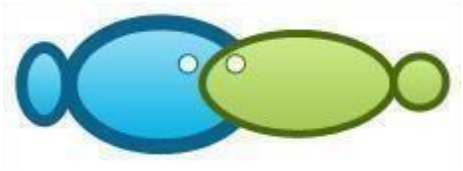

Advancing sustainability in coastal smallholder salt production: a Rapfish and Monte Carlo assessment from Eastern Indonesia

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Abstract. Indonesia, as a maritime country, holds considerable potential for coastal-based salt production. However, smallholder salt farmers in regions like Pangkajene and Islands Regency (Pangkep) still rely on traditional and inefficient methods, resulting in low productivity and challenges in meeting domestic demand. Additionally, salt production systems face pressure from climate change, environmental degradation, and limited technological modernization. This study aims to assess the sustainability and resilience of smallholder salt production systems in Pangkep across five dimensions: technological, ecological, economic, social, and institutional. Research was conducted in three key salt-producing districts: Marang, Labakkang, and Bungoro. Data were obtained through focus group discussions, direct observation, structured interviews, and literature review. A Rapfish-based analysis was used, employing multidimensional scaling (MDS) and Monte Carlo simulation to evaluate sustainability status. Findings show varying sustainability scores: technological (71.01, moderately sustainable), ecological (80.70, highly sustainable), economic (73.09, moderately sustainable), institutional (32.24, less sustainable), and social (92.32, highly sustainable). Key influencing factors include equipment availability, salt quality, technology experience, salinity, market access, education, and stakeholder involvement. The study concludes that improving smallholder salt production sustainability requires addressing technological gaps, boosting institutional support, and enhancing social and economic systems. Recommended actions include adopting modern technologies (e.g., geomembranes, 3D rope evaporators), improving market infrastructure, strengthening cooperatives and extension services, and promoting farmer education.
Key Words: climate change, environmental degradation, multidimensionality, salt farmer.

Introduction. As a maritime nation, Indonesia possesses significant potential to become a leading global salt producer through the utilization of coastal lands for salt farming. Smallholder salt farming not only contributes to the supply of salt for food and industrial needs but also plays an important role in employment generation and increasing household incomes. However, smallholder salt production is still managed using traditional and inefficient methods, which negatively affect productivity and hinder the ability to meet the growing domestic demand (Henriksson et al 2017; Prihantini et al 2024a). One of the salt-producing regions in Indonesia is Pangkajene and Islands Regency (Pangkep), which offers extensive land resources and favorable climatic conditions. The salt produced in this region contributes not only to domestic needs but also plays a crucial role in national industrial supply chains. Nevertheless, smallholder salt production in Pangkep faces major sustainability challenges, including climate change, environmental degradation, and a lack of technological modernization. These challenges require serious attention to ensure the long-term sustainability of smallholder salt farming in Pangkep.

Most salt farmers in Pangkep still rely on traditional methods, using open ponds to evaporate seawater - a process highly dependent on weather and climate conditions

(Prihantini et al 2024a, b). This results in fluctuations in both the quantity and quality of salt production, directly affecting farmers' incomes. To improve efficiency and productivity, the adoption of new technologies is essential, such as the use of geo-isolators and 3D rope evaporator technology in smallholder salt production (Ariyani et al 2020; Novitasari & Suryawan 2024). Research by Wanta et al (2023) in East Nusa Tenggara demonstrates that the application of 3D rope evaporator technology can increase production efficiency. This technology accelerates seawater evaporation and produces finer and whiter salt. Such innovations are crucial for enhancing the competitiveness of smallholder salt products in increasingly competitive markets. Furthermore, appropriate technologies can help salt farmers address climate-related challenges, such as unpredictable temperature fluctuations and rainfall (Sudaryana & Pramesti 2018). Technological modernization, therefore, offers a potential solution to enhance productivity, salt quality, and market competitiveness on a global scale (Novitasari & Suryawan 2024).

Climate change and weather conditions have significant impacts on salt production (Dono et al 2014; Roland et al 2019). Research in Rembang Regency by Ashilah et al (2022) indicates that weather variability affects both the quality and quantity of salt produced. Thus, it is important for salt farmers to have reliable weather monitoring systems to support effective decision-making in salt farm management. Installing weather monitoring devices at farming sites can assist farmers in planning production activities more efficiently (Walker 2021; Kushwaha et al 2024). The success of smallholder salt farming is also influenced by environmental conditions and site characteristics. Research conducted in Jeneponto Regency shows that the potential and size of salt farm areas are greatly affected by environmental factors and seawater supply (Ramly et al 2022). Therefore, proper site selection and a thorough understanding of biophysical characteristics are essential for effective salt farm management (Chanpiwat & Damrongsiri 2024; Maurya et al 2024).

Research on the sustainability of smallholder salt farming in Pangkep Regency is necessary to identify factors affecting sustainability and to develop appropriate strategies to address management challenges. The Rapfish approach provides a suitable method for addressing these issues by offering a comprehensive evaluation of technological, ecological, economic, social, and institutional aspects, as seen in Figure 1 (Li et al 2023; Zhang et al 2023). This method enables multidimensional analysis to identify strengths and weaknesses in the management of smallholder salt farming in Pangkep Regency. Through this approach, strategies that comprehensively support salt farming sustainability can be formulated.

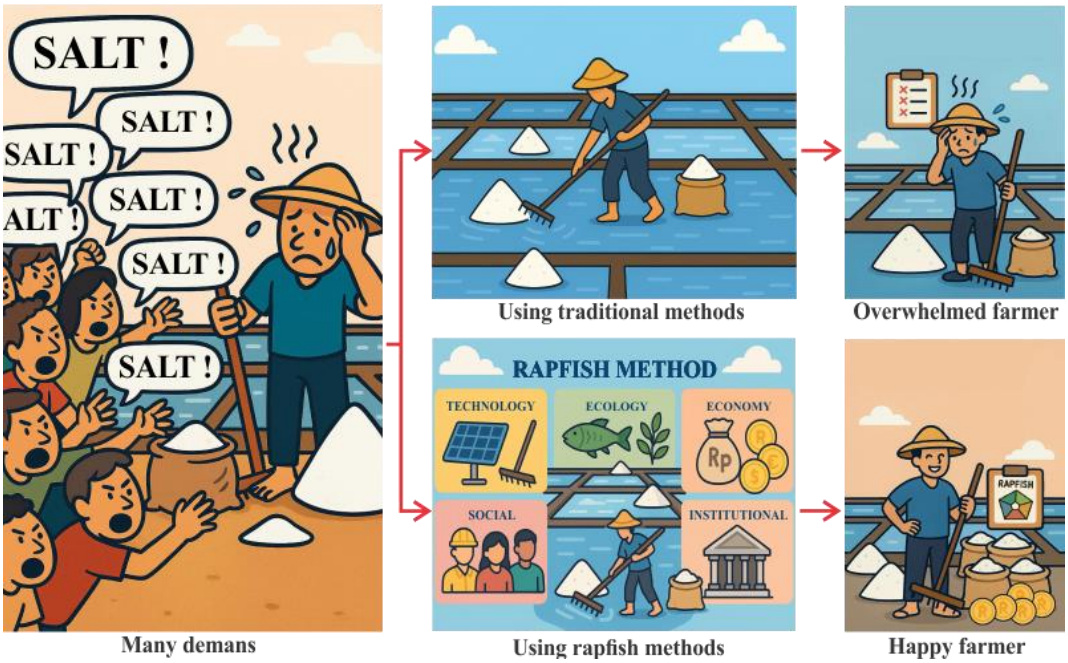

Figure 1. Comparison of traditional and RAPFISH methods in salt production.

Research gaps (novelties). This study reveals that while the ecological and social dimensions of smallholder salt production in Pangkep Regency are highly sustainable, the technological, economic, and particularly institutional dimensions still require significant improvement. The institutional aspect remains a major challenge due to limited access to cooperatives, inadequate extension services, and weak organizational support for salt farmers. Although several studies have examined salt farming sustainability, few data comprehensively integrate all five sustainability dimensions - technological, ecological, economic, social, and institutional - using the Rapfish approach in smallholder salt production systems. Moreover, the effectiveness of institutional interventions and market-based solutions in enhancing sustainability remains not well understood, especially in the context of Eastern Indonesia. Rarely have previous studies combined multidimensional scaling with Monte Carlo simulation to validate sustainability indices in this sector. Therefore, this study contributes by identifying key leverage attributes and proposing a replicable assessment model for other salt-producing regions, with the potential to inform adaptive governance and technology transfer in community-based salt production systems.

The objective of the study. Several previous studies have applied the Rapfish approach to assess sustainability in fisheries management, including: sustainability analysis of fisheries resource management in Madura Strait, East Java, Indonesia (Adiga et al 2015; Hidayah et al 2020). sustainability status of the ecological dimension in Bali sardine (*Sardinella lemuru* Bleeker 1853) fisheries management in Bali Strait (Satyawan et al 2023); sustainability analysis of mangrove ecosystems and their impact on fisheries resource management in Bekasi Regency, West Java Province (Haris et al 2021); sustainability status analysis and strategy development for carp (*Cyprinus carpio* L.) hatchery industry in Ciparay Regency, West Java Province (Rizkita et al 2023); and sustainability analysis of integrated salt farming in Pati Regency, Central Java Province (Sriwati et al 2022). Sustainability assessments using the Rapfish approach can identify the most influential attributes, ultimately supporting the formulation of more effective management strategies. This study aims to assess the sustainability of smallholder salt farm management in Pangkep Regency from technological, ecological, and economic perspectives using the Rapfish approach. Through Rapfish, this study can identify areas requiring intervention across these dimensions. This approach not only supports strategic planning for Pangkep Regency but may also serve as a model applicable to other salt-producing regions in Indonesia and other countries.

Material and Method

The equipments. The field research utilized basic field survey instruments including:

- GPS devices for mapping and site localization;
- questionnaires for structured interviews;
- laptops with statistical software for data processing and analysis using Multidimensional Scaling (MDS) and Monte Carlo simulation.

The materials. The primary materials included:

- primary data collected through Focus Group Discussions (FGDs), direct observation, and structured interviews involving key stakeholders such as salt farmers, landowners, salt traders, and local authorities;
- secondary data from relevant literature and previous studies.

Ethical approval. This study did not require ethical approval from a formal ethics committee, as it did not involve experiments on humans or animals, nor did it pose any ethical risks. Nevertheless, all participants involved in interviews and FGDs provided informed consent prior to data collection. The researchers ensured that the confidentiality and privacy of respondents were maintained in accordance with ethical principles of social research.

Time and location. The research was conducted in three districts with potential for smallholder salt production development in Pangkajene and Islands Regency: Marang District, Labakkang District, and Bungoro District. The study was carried out over a period of eight months, from April to November 2023.

Method of collecting data. Data for this study were collected using a combination of qualitative and quantitative methods. First, FGDs were conducted by the research team involving various stakeholders such as representatives from relevant government agencies, salt farmers, land and financial capital owners, salt traders and marketers, fisheries extension officers, village heads, and other key actors in the salt production system. These discussions provided a platform to explore perceptions, challenges, and institutional dynamics within the industry. In addition, direct field observations were carried out to assess the actual management practices employed by smallholder salt farmers. This allowed the research team to validate and contextualize the information obtained during the discussions and interviews. Furthermore, structured interviews were administered using standardized questionnaires to key respondents, including salt farmers, capital owners, and salt traders, to gather consistent and measurable data across different stakeholder groups. Finally, a comprehensive literature review was undertaken to support the empirical findings with theoretical frameworks and previous research related to the development and management of the smallholder salt industry.

Population and sample. The subject of this study includes all individuals involved in managing smallholder salt businesses in Pangkep Regency, namely salt farmers, landowners, and salt collectors or traders. The research samples or respondents were selected using a key informant approach, meaning that individuals who have in-depth knowledge and direct involvement in the smallholder salt business were specifically chosen to provide relevant and detailed information.The key informants selected in this study include representatives of salt farmers, representatives of land/capital owners (bosses), representatives of salt collectors/marketers. The selection of these key informants based on the assumption that they are people who know and have in-depth experience related to the management of people's salt businesses.

Data analysis. The sustainability status of salt farming is expressed in the form of a sustainability index based on the Rap-Fish approach (Rapid Assessment Techniques for Fisheries), developed by the Fisheries Center, University of British Columbia (Arief et al 2025). The determination of the sustainability index and status of salt farming using the Rap-Fish approach follows a systematic procedure consisting of several stages (Nababan et al 2007), as follows:

- examining the attributes of each sustainability dimension and defining these attributes through field observations and literature review. In this study, a total of 32 attributes were analyzed, consisting of 6 attributes for the Technological dimension, 6 attributes for the Ecological dimension, 8 attributes for the Economic dimension, 5 attributes for the Socio-cultural dimension, and 7 attributes for the Institutional dimension;
- scoring was conducted based on field observations and expert opinions. The scores ranged from 1 to 5, representing conditions from poor to good, depending on each attribute's condition. The criteria for "good" and "poor" in each dimension followed the concept developed by Kavanagh and Pitcher (Fauzi 2019), as well as the opinions of experts and stakeholders involved in salt farming;
- the scores were analyzed using the Multidimensional Scaling (MDS) method to determine the sustainability status position of salt farming in Pangkep Regency for each dimension, expressed as a sustainability index scale ranging from 0 to 100. The sustainability index scale was categorized as follows: 0-25 indicating poor status, 25.01-50.00 indicating less sustainable status, 50.01-75.00 indicating moderately sustainable status, and 75.01-100 indicating good sustainability status;
- another result obtained through the Rap-Fish analysis was the identification of leverage factors, which are strategic factors for the future development of salt farming (Pitcher & Preikshot 2001). These leverage factors help in identifying critical environmental

management factors. Sensitivity analysis (leverage analysis) was conducted to determine the variables that dominantly influence sustainability. The analysis identifies sensitive or dominant attributes and potential interventions for improving the sustainability status of salt farming in Pangkep. Leverage analysis determines which attributes have the most significant influence relative to others, indicated by the highest leverage index. The greater the leverage index, the more sensitive the attribute is compared to others. The determination of sensitive attributes was prioritized based on the results of the leverage analysis by observing changes in the Root Mean Square (RMS) of the X-axis ordination. The higher the RMS change value, the greater the role of that attribute in improving the sustainability status of salt farming in Pangkep Regency.

Result and Discussion

Sustainability status of smallholder salt farm management in Pangkep Regency. The results of the sustainability analysis of smallholder salt farm management in Pangkep Regency across five dimensions - technological, ecological, economic, social, and institutional - using the MDS method with the Rapfish approach and Monte Carlo validation are presented in Tables 1 and 2.

Table 1

Sustainability analysis results of smallholder salt farming in Pangkep by dimension

Dimensions	*Analysis results*			
	Number of attributes	*Rap-Fish*	*Leverage atributes*	*Status*
Technology	6	71.01	4	Quite sustainable
Ecology	6	80.70	2	Very sustainable
Economy	8	73.09	4	Quite sustainable
Institutional	7	32.24	3	Less sustainable
Social	5	92.32	1	Very sustainable

Table 2

Statistical values and Monte Carlo validation

Dimensions	*Statistical values*		*MDS Rap-Fish*	*Monte Carlo*	*Difference*
	Stress	R^2			
Technology	14%	0.94	71.01	70.06	0.95
Ecology	14%	0.95	80.70	79.24	1.46
Economy	13%	0.94	73.09	71.88	1.21
Institutional	14%	0.93	32.24	33.93	1.69
Social	14%	0.95	92.32	90.13	2.19

Based on Table 2, the Stress values obtained across the five dimensions ranged between 13 and 14%. A good Rapfish model is indicated by a Stress value of less than 25%, as lower Stress values reflect a good fit. The R^2 values across all dimensions ranged between 0.93 and 0.95, indicating that 93 to 95% of the system variability is explained by the variables included in the study.

The Monte Carlo analysis serves as a model validation technique to assess the effect of error levels on the model generated from the MDS analysis (Zhou et al 2020; Lin & Su 2021). The Monte Carlo analysis was conducted at a 95% confidence interval. As shown in Table 2, the differences between the Rapfish MDS and Monte Carlo results for each dimension were less than 5%, suggesting a very low risk of error and demonstrating that the iterative analysis process was stable (Arief et al 2025). Model validation using the Monte Carlo approach can also be observed through the scatter plot output (Mao & Xin 2013), which indicates that the technological, ecological, economic, socio-cultural, and institutional dimensions of salt farming sustainability in Pangkep Regency were not affected by disturbances (perturbations), as shown by the Monte Carlo simulation plots closely

aligning with the Rapfish MDS sustainability points. Based on the Monte Carlo simulation validation results across all analyzed sustainability dimensions, it can be concluded that the Rapfish MDS ordination analysis possesses high accuracy.

Sustainability of salt business management in the technological aspect. The analysis of the technological aspect in the sustainability of smallholder salt farm management is crucial, as it is closely related to production efficiency, product quality, and market competitiveness (Drejeris & Oželienė 2019; Kong et al 2025). The application of appropriate technology can enhance productivity by optimizing the crystallization process, reducing impurities, and improving energy and water use efficiency. In addition, innovations in processing and storage technologies contribute to improved product quality, allowing products to meet industrial and consumer standards (Ravishankar et al 2021; Saturnino et al 2024). With stronger competitiveness, smallholder salt farms have greater opportunities to survive and grow amidst increasingly competitive markets, both locally and globally. Therefore, the technological aspect represents one of the key factors that must be assessed in analyzing the sustainability of smallholder salt production in Pangkep Regency. The results of the sustainability leverage analysis and sustainability index for the technological dimension of smallholder salt farm management in Pangkep Regency are presented in Figure 2.

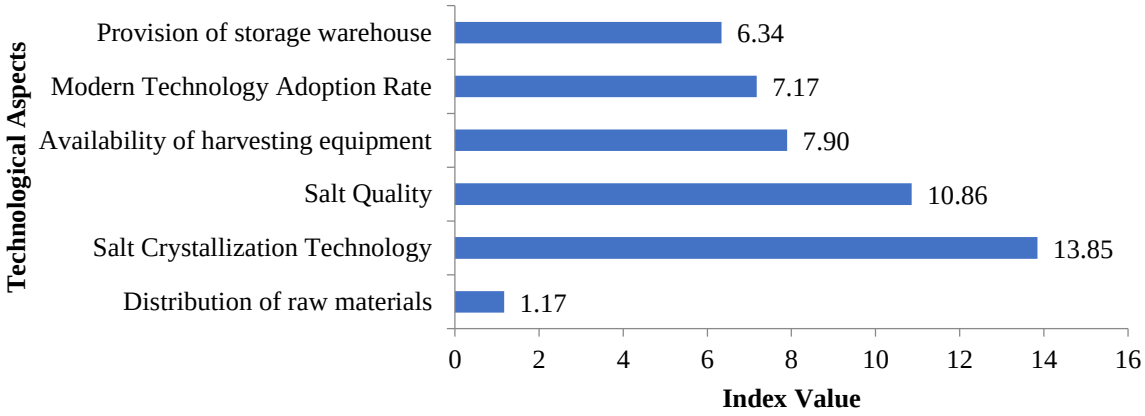

Figure 2. Sustainability index and leverage of attributes of the technological dimension of community salt business management in Pangkep Regency.

Based on the Rapfish ordination results, the management of smallholder salt farms in Pangkep Regency in the technological dimension is categorized as moderately sustainable, with an ordination score of 71.01% (Table 1). The leverage analysis identified three dominant attributes that should be prioritized to enhance technological sustainability: availability of harvesting equipment, salt quality, and experience in utilizing crystallization technology. Among these, the crystallization technology is the most influential attribute affecting the sustainability of smallholder salt farm management in Pangkep Regency. This is because the crystallization process plays a critical role in salt production. One of the technologies adopted by salt farmers to accelerate the crystallization process is the use of geomembranes (Prastiwi 2019) .

Research conducted by Hoiriyah (2019) reported that the use of geomembranes significantly improves the quality of smallholder salt production. This method allows better control over the crystallization process and ensures the cleanliness of the resulting salt. Similarly, Muslimah et al (2024) reported that geomembranes produce high-quality salt that meets consumption standards while also accelerating the crystallization process.

The technological aspect is also closely linked to environmental sustainability. Innovations in salt production technology, such as the use of geomembranes, can help reduce negative environmental impacts and improve resource use efficiency (Plaiphum & Tansuchat 2023). Thus, the application of environmentally friendly technologies not only supports the sustainability of salt farming but also contributes to ecosystem conservation (Bhattasali & Savarimuthu).

Most salt farmers in Pangkep Regency employ geomembrane technology for salt crystallization, as this technology eliminates the need to halt production while waiting for the ponds to dry. Moreover, this technology enhances salt quality because it prevents direct contact with the soil, resulting in cleaner and larger salt crystals (Jumaeri et al 2018). Then Tansil et al (2016) stated that the use of geomembrane ponds can significantly increase salt production. His study on the salt fields owned by PT. Garam Madura showed that the use of geomembranes can increase salt production by up to 460% compared to non-geomembrane salt fields.

Appropriate technology can assist salt farmers in addressing various challenges, such as climate change and price fluctuations. One proven technology is the use of Ulir Filter Technology and Geoisolators, which have been shown to enhance salt production in Indramayu Regency. Research indicates that the application of these technologies produces salt that meets national standards while improving both the quality and quantity of production (Salsabiela & Prayitno 2022).

Efficient production technologies can not only boost productivity but also minimize environmental impacts. Research by Kocks et al (2020) demonstrated that the use of separation technologies such as electrochemical crystallization can reduce salt waste generation and increase product recovery efficiency. Furthermore, the implementation of integrated drainage management systems in agricultural lands allows for the production of more marketable salt while mitigating negative environmental impacts (Euh 2017). Thus, the application of appropriate technology can contribute significantly to the sustainability of smallholder salt farming (Gaj & Madramootoo 2020; Kovach et al 2020).

A study conducted in Pati, Central Java, using the Rapfish method, showed that integrating salt farming with sustainable practices can enhance overall sustainability. The findings suggest that by adopting appropriate technologies and actively involving local communities, smallholder salt production can contribute to both food security and environmental sustainability (Sriwati et al 2022).

Sustainability of salt business management in the ecological aspects. The ecological dimension is a key factor determining the productivity of smallholder salt farming, particularly concerning environmental quality, the availability of natural resources, and climatic conditions (Xue et al 2021; Yang et al 2022; Zhang et al 2022; Anjum et al 2025). The sustainability of salt production heavily depends on the quality of seawater used in the crystallization process, where pollution from industrial waste, sedimentation, or changes in ocean currents can reduce the purity of the salt produced (Prabawa & Bramawanto 2021; Song et al 2021; Santoso et al 2023; Ditia 2024). In addition, land degradation caused by excessive exploitation without proper conservation efforts can diminish the environmental carrying capacity of salt ponds, leading to long-term declines in production (Dharumarajan et al 2019). Climatic factors, such as high rainfall, humidity, and shifts in seasonal patterns due to climate change, also influence the rate of seawater evaporation, directly affecting the speed and efficiency of the salt crystallization process (Weeraratna 2022). Therefore, sound ecological management - including coastal zone protection, pollution control, and the implementation of climate change adaptation systems - is essential for maintaining the stability and productivity of smallholder salt farming on a sustainable basis (Sun et al 2020; Blok 2021). The results of the sustainability index analysis and leverage of attributes for the ecological dimension of smallholder salt farming in Pangkep Regency are presented in Figure 3.

Based on the Rap-Fish ordination results for the ecological dimension, the sustainability index of smallholder salt farming management in Pangkep Regency was 80.70 (positioned within the ordination scale of 75.01-100.00). This indicates that the ecological dimension of smallholder salt farming in Pangkep Regency is classified as highly sustainable. The leverage of attribute analysis identified three dominant attributes influencing ecological sustainability: salinity, soil condition, and distance from the coastline. According to Zhang et al (2024) proximity to seawater sources improves salt quality, while clay-sandy soils with high permeability prevent seawater from seeping into the ground and minimize cracking, allowing optimal water retention for salt crystallization.

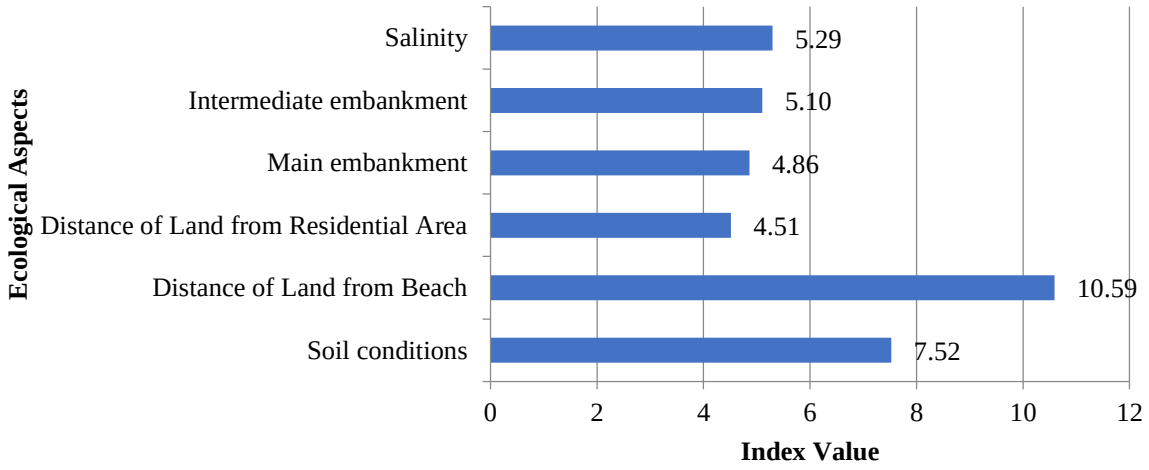

Figure 3. Sustainability index and leverage of attributes of the ecological dimension of community salt business management in Pangkep Regency.

Soil condition - including soil type, permeability, and chemical quality - significantly affects both the productivity and quality of salt production in salt ponds (Rachman 2019; Mahasin et al 2020; Prabawa & Bramawanto 2021). Suitable soil types enhance production efficiency, whereas unsuitable soils may lead to contamination and decreased salt quality (Zeng et al 2013; Fu et al 2024).

In addition to soil condition, the salinity level of seawater used as raw material is a key factor in the crystallization process and salt quality. High and stable salinity levels improve production efficiency and ensure salt quality meets food-grade standards (Tansuchat 2023; Oelviani et al 2024). Salinity is closely associated with farmers' production performance, where areas with higher salinity tend to yield higher quality and more profitable salt (Khan & Kurunc 2023; Radityo & Pratomo 2024). Variations in salinity, along with other parameters such as pH and temperature, are critical in determining the suitability of seawater for food-grade salt production (Su et al 2020). In this context, the use of DNA barcoding techniques, such as those applied in identifying *Aeromonas hydrophila* in the Ternate Island Sea (Rozi et al 2018), demonstrates the relevance of molecular approaches in monitoring seawater microbial quality, which is essential not only for food safety but also for maintaining ecological balance in salt-producing coastal environments.

Sustainability of salt business management in the economics aspects. The economic dimension plays a significant role in determining the productivity and sustainability of smallholder salt farming, particularly in terms of production costs, access to capital, selling prices, marketing chains, and market competitiveness (Nowfal et al 2025a). Limited capital often hinders salt farmers from adopting modern technologies that could enhance production efficiency and product quality. In addition, price fluctuations - driven by market demand, import policies, and distribution mechanisms - also affect farmers' income stability (Fatihudin et al 2022; Akbar et al 2025; Ratnaningtyas et al 2025). When salt prices are too low, farmers struggle to earn reasonable profits, ultimately hampering their ability to invest in production infrastructure and threatening the long-term sustainability of their operations. Competition with imported salt, which often offers lower prices and more stable quality, presents further challenges for local smallholder salt producers to remain competitive in the market (Nwafor 2020; Muhandhis et al 2021). Therefore, policy support in the form of stable pricing, easier access to capital, and improved competitiveness through innovation and product diversification are strategic measures to maintain the productivity and sustainability of smallholder salt farming amidst constantly changing economic dynamics.

Based on the Rap-Fish ordination results for the economic dimension, the sustainability index of smallholder salt farming management in Pangkep Regency was

73.09 (positioned within the ordination scale of 50.1-75.00). This indicates that the economic dimension of smallholder salt farming in Pangkep Regency is classified as moderately sustainable. The Stress value was 0.13, which is below 0.25, indicating that the analysis results are well-fitted to actual field conditions. The R^2 value was 0.94, indicating that the model, using the selected indicators, explains 94% of the variation in the system, demonstrating the strong suitability of the indicators applied.

Leverage analysis (Figure 4) identified four dominant attributes influencing the economic sustainability dimension: selling price of salt (RMS = 5.51), market rejection (RMS = 5.53), market absorption rate (RMS = 5.62), and marketing through collectors (RMS = 9.93). These four attributes exhibit relatively high root mean square (RMS) values compared to other attributes. According to Kavanagh & Pitcher (2004), the RMS value indicates the degree of each attribute's contribution as a leverage factor, with dominant attributes generally having RMS values greater than half of the highest observed value.

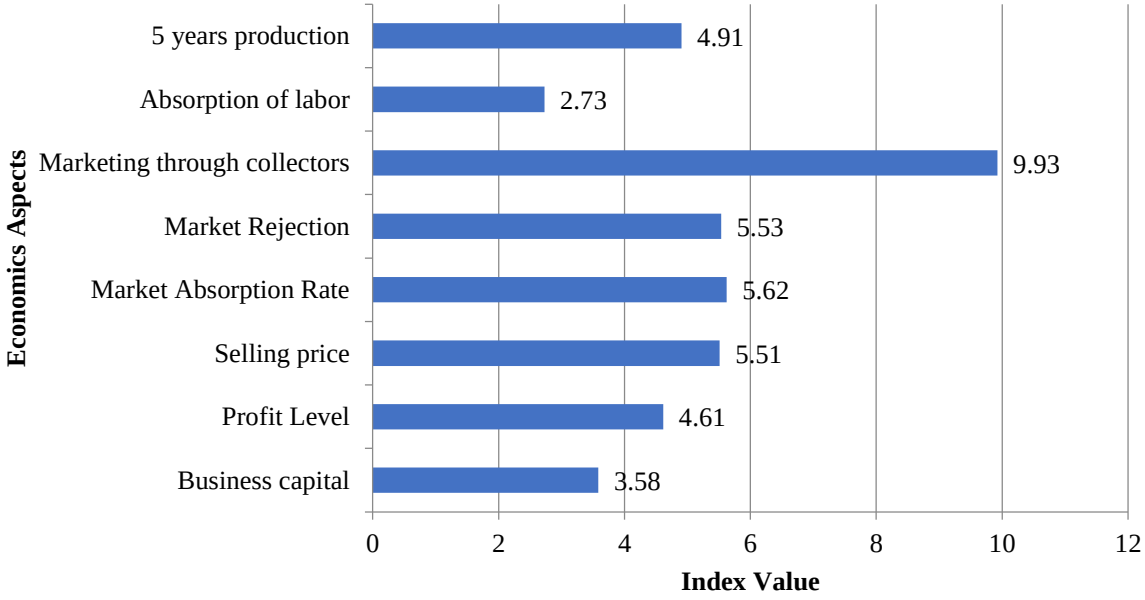

Figure 4. Sustainability index and leverage of attributes of the economic dimension of community salt business management in Pangkep Regency.

The most dominant attribute influencing the sustainability of smallholder salt farming in the economic dimension is marketing through collectors. Collectors play a critical role in the entire salt farming value chain in Pangkep, as they purchase farmers' harvests, process the salt into iodized salt, and subsequently market or distribute the product to processing industries or large-scale traders. In addition, collectors store the ready-to-sell salt and sell it when prices rise. Therefore, monitoring and regulating the role of collectors should be conducted periodically to prevent significant disadvantages for salt farmers. According to Jamil & Tinaprilla (2015), the upstream sector of the salt industry is largely dominated by small-scale, fragmented farmers with weak institutional organization, resulting in low bargaining power within the marketing chain. In contrast, the downstream sector is dominated by large-scale industries with strong networks, leading to an imbalance where most of the profit in the marketing chain is captured by downstream industries.

The imbalance in bargaining power between salt farmers and traders significantly affects industry behavior, as reflected in the salt marketing process. In this process, farmers primarily act as producers without any substantial influence over product quality or pricing, largely due to their limited access to market information. This situation is further exacerbated by inadequate infrastructure and facilities, as well as the remote coastal locations of many salt farms, which result in higher post-harvest (after farm gate) marketing costs. In Madura, East Java Province, Indonesia, the salt marketing system reflects farmers' dependence on middlemen due to their limited access to direct markets. As a result, farmers have little control over pricing and often suffer financial losses during

peak harvest periods when salt prices drop significantly (Giannoccaro et al 2017). A similar case was observed in Klungkung, Bali, where the market structure for smallholder salt production is oligopsonistic. In this system, prices are largely determined by intermediary traders, while farmers receive only a small portion of the final market value (Riyanti et al 2019).

Sustainability of salt business management in the institutional aspects. The institutional dimension plays a crucial role in determining the productivity and sustainability of smallholder salt farming through regulation, policy support, access to technical assistance, and the involvement of salt farmer organizations (Pereira 2024; Zheng et al 2024; Nowfal et al 2025b). Strong institutional frameworks can help farmers receive technical guidance in adopting technological innovations to improve production efficiency and salt quality. In addition, the existence of cooperatives or salt farmer associations strengthens farmers' bargaining power against middlemen and the market, thus stabilizing and increasing salt prices to more profitable levels. Government regulations related to trade arrangements, price protection, and subsidy policies also affect business sustainability, particularly in facing competition from imported salt (Malak-Rawlikowska et al 2019; Chen 2024).

When institutions do not function optimally, salt farmers face difficulties in accessing capital, technology, and fair markets, making their businesses vulnerable to economic and environmental uncertainties. Therefore, strengthening institutions through synergy between the government, academia, and farmer associations is key to supporting the long-term productivity and sustainability of smallholder salt farming (Anthony et al 2019; Riza & Wijaya 2022; Mathis et al 2023).

Based on the Rap-Fish ordination results for the institutional dimension, the management of smallholder salt farming in Pangkep Regency falls into the less sustainable category (Table 1). The leverage of attributes analysis for the institutional dimension was conducted to identify the dominant attributes that require improvement to maintain the sustainability of smallholder salt farming management in Pangkep Regency. This analysis helps determine which attributes have significant influence on the management of the salt farming sector in Pangkep Regency. The analysis results are presented in Figure 5.

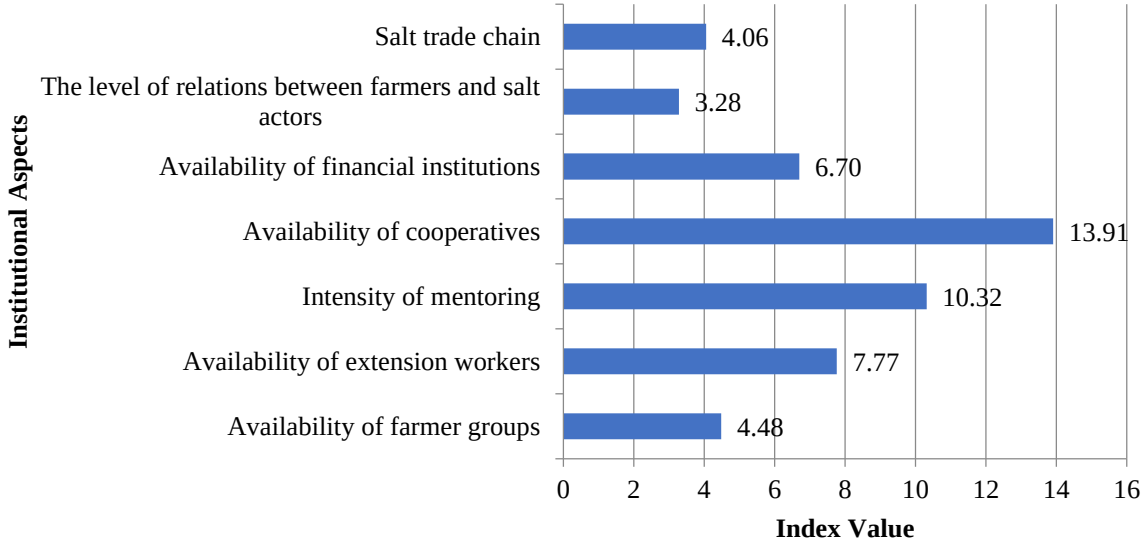

Figure 5. Sustainability index and leverage of attributes of the institutional dimension of community salt business management in Pangkep Regency.

Institutional sustainability reflects the sustainability aspect of organizations involved in the management of smallholder salt farming in Pangkep Regency. The leverage of attributes analysis identified three dominant attributes influencing the sustainability of the institutional dimension: the availability of extension workers (RMS = 7.77), the intensity

of technical assistance (RMS = 10.32), and the availability of cooperatives (RMS = 13.91). The presence of cooperatives is particularly crucial for sustaining smallholder salt farming in Pangkep Regency. Salt cooperatives serve as key partners for farmers in managing salt trade and marketing. Therefore, the establishment of cooperatives in salt-producing centers is essential to facilitate farmers' access to markets.

Ideally, agricultural cooperatives can enhance both production and farmers' welfare. Cooperatives provide economic and social benefits for their members, most importantly by strengthening farmers' bargaining power in determining the prices of their agricultural products (Woldie & Nuppenau 2010). According to Wang et al (2019), cooperatives that succeed in improving their members' welfare enable them to overcome the economic and social challenges they face.

Government support also plays an important role in the development of smallholder salt farming. Research indicates that government assistance can improve the competitiveness of small and medium enterprises in the salt sector (Sunoko et al 2023). Policies that encourage eco-manufacturing and the use of environmentally friendly packaging materials can further enhance the sustainability of salt businesses (Utami & Novianti 2021). With such support, salt producers can adopt more sustainable and environmentally responsible practices.

The availability of extension workers and the intensity of the assistance provided are strongly and positively associated with the improvement of farmers' productivity. Active and competent extension agents foster technology adoption, increase farmer satisfaction, and strengthen the sustainability of smallholder farming operations (Alam et al 2024; Mburu et al 2024).

Sustainability of salt business management in the social aspects. The social dimension has a significant influence on the productivity and sustainability of smallholder salt farming, particularly in aspects such as community participation, work patterns, and intergenerational knowledge transfer. Solidarity and cooperation among salt farmers, through farmer groups or cooperatives, can improve production efficiency by sharing resources, information, and technology (Holis et al 2019). Furthermore, the education level and skills of salt farmers determine their capacity to adopt innovations, enhance product quality, and respond to increasingly competitive market challenges. However, social changes - such as the declining interest of younger generations in salt farming due to perceptions of low profitability and labor-intensive work - pose a long-term threat to the sustainability of the industry (Wulandari et al 2021).

Additionally, social support from both government and community, in the form of policies, training, and local product promotion, is essential to ensure the continued development of smallholder salt farming. Therefore, strengthening social capacity through education, farmer regeneration, and community empowerment becomes a strategic approach to maintain sustainability and competitiveness in the smallholder salt farming sector (Kurniadi et al 2024; Asrum & Morkoyunlu 2025).

Based on the Rap-Fish ordination results for the social dimension, the sustainability index of smallholder salt farming management in Pangkep Regency was found to be 92.32 (within the ordination scale range of 75.01-100.00). This indicates that the social dimension of smallholder salt farming management in Pangkep Regency is classified as highly sustainable. The Stress value was 0.14, which is < 0.25, suggesting that the analysis results adequately reflect field conditions. The coefficient of determination (R^2) was 0.95, indicating that the model, using the selected indicators, explains 95 percent of the variability in the system. This demonstrates that the indicators employed are highly reliable.

Leverage of attributes analysis was used to identify the most influential attributes within the social dimension that significantly affect smallholder salt farming management in Pangkep Regency. The analysis results are presented in Figure 6.

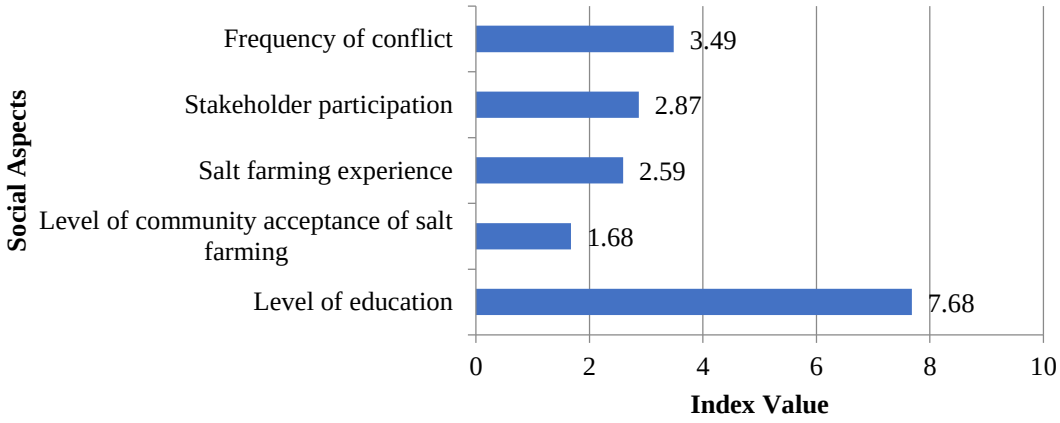

Figure 6. Sustainability index and leverage of attributes of the social dimension of community salt business management in Pangkep Regency.

There are three dominant attributes influencing the sustainability of the social dimension, namely stakeholder participation (RMS = 2.87), conflict frequency (RMS = 3.49), and education level (RMS = 7.68) (Figure 6). The education level of salt farmers indirectly affects their business management practices. Generally, salt farmers manage their farms using relatively simple management systems. However, the demands of a more advanced business environment require a more professional and modern management approach. Therefore, it is necessary to conduct socialization programs targeted at communities with at least secondary education to prepare them to become entrepreneurs or salt farmers.

In Pangkep Regency, the majority of salt farmers still have relatively low levels of education, which correlates with lower income levels. The education level of salt farmers is considered one of the factors influencing income generation. Farmers with higher education levels tend to have broader perspectives and better strategies for optimizing income, whereas those with lower education levels tend to have more limited views on income opportunities. Family economic education has been shown to have a significant positive influence on farmers' income levels (Sahrir 2016).

The success of salt farming enterprises is determined not only by the technology employed but also by community support and government policies that promote salt industry development (Chen et al 2024). Therefore, fostering partnerships among salt farmers, government agencies, and research institutions is essential for creating a holistic ecosystem that supports the sustainability of the salt industry.

The formation of social organizations among salt farmers can enhance both the economic and social welfare of local communities (Plaiphum & Tansuchat 2023). Such organizations can facilitate resource management and provide support for implementing sustainable salt farming practices. Thus, the sustainability of smallholder salt farming depends not only on technology and government support but also on active community involvement.

Formulation of sustainable strategy for management of people's salt business in Pangkep Regency. Based on the sustainability analysis of smallholder salt farming management in Pangkep Regency, several strategic recommendations can be proposed for relevant stakeholders, particularly the local government of Pangkep Regency through its related agencies.

The location of salt tables close to the coastline offers better raw material characteristics. Therefore, the selection of land for salt tables is recommended to use sandy clay soil, which has low permeability. The porosity of the soil influences the rate of seawater seepage or leakage into the storage ponds or salt tables. If the seepage rate exceeds the evaporation rate, high-quality salt cannot be produced. The role of collectors (middlemen) in smallholder salt farming management is highly significant for the market absorption of salt produced by farmers. The level of market absorption is crucial for the sustainability of

salt farming in Pangkep Regency, as market demand for salt continues to increase. This must be balanced by increasing both production volume and product quality to meet market needs. However, control and monitoring of the trading chain created by collectors must be implemented to prevent the exploitation of salt farmers.

Extension agents play a crucial role in the development of smallholder salt farming by providing technical assistance before, during, and after production, as well as in management and marketing activities. Therefore, it is recommended that the frequency and active role of extension agents in supporting salt farmers be further enhanced. Salt cooperatives serve as important partners for farmers in managing salt trade and marketing. Their role in absorbing the farmers' production is essential. Through their established marketing networks, cooperatives can collect salt harvests from members and sell them to various buyers. This ensures that farmers do not have to worry about where to sell their products, which often becomes a major issue during peak production periods. Furthermore, cooperatives are expected to actively support farmers in providing production and post-production equipment for smallholder salt farming. Cooperatives can supply essential equipment to improve production efficiency and quality, such as geomembrane plastic sheets, water pumps, and salt content measurement tools. They can also provide packaging and post-processing equipment for salt products (Pllashniku 2015; Hao 2018; Luo et al 2022).

Salt farming management should be directed toward professional business management to attract younger generations to engage in this sector. A professional approach can offer more stable and higher income opportunities. With professional management, salt farming operations can be more efficient and produce higher-quality products with better market value, ultimately improving the economic welfare of not only the farmers but also their families and surrounding communities.

Conclusions. This study reveals that while ecological and social aspects of salt production in Pangkep Regency are highly sustainable, technological, economic, and institutional dimensions need improvement. Adopting modern technologies and strengthening institutional support through extension services, cooperatives, and market access are essential. Enhancing education and reducing conflicts can further boost social resilience. A multidimensional strategy is crucial for long-term sustainability and can serve as a model for other regions. Future research should explore policy development and the practical implementation of these recommendations.

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