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Dynamic modelling and SWOT approach for developing strengthening strategies for the shrimp industry in the coastal area

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Abstract: Today, Indonesia's food security and coastal economy are sustained by the vita sector of shrimp aquaculture. This study aims to formulate strategies for developing sustainable shrimp farming in the coastal region of Pekalongan, Indonesia, one of the country's major aquaculture centres. The research employed a case study and exploratory approach, integrating dynamic system modelling and SWOT (strengths, weaknesses, opportunities, and threats) analysis. Data were collected through field observations, interviews, and literature reviews. The process involved shrimp farmers, fisheries agencies, and local stakeholders. Dynamic model outputs indicated that rising shrimp harvest yields are linked with greater organic waste loads, potentially diminishing the ecological carrying capacity of surrounding coastal ecosystems. The modelling results indicate that shrimp pond operations have strong prospects for future development, provided that appropriate aquaculture methods are effectively adapted. The SWOT analysis positioned the development of shrimp aquaculture in quadrant I, indicating the need for an aggressive strategy to capitalise on existing strengths and opportunities. Priority strategies focus on optimising land use based on accessibility and stabilising water sources through advanced technologies. They also emphasise leveraging government support for aquaculture innovation, strengthening research collaborations, and digitalising export product marketing. Implementing these strategies is expected to enhance production efficiency, maintain environmental sustainability, and strengthen the competitiveness of Pekalongan's shrimp industry in the global market. These findings provide a conceptual foundation for developing an adaptive aquaculture sector in Indonesia that aligns with climate change resilience and the principles of a sustainable blue economy. This finding is highly important considering the rising global demand for food security.

Keywords: aquaculture, modelling, shrimp harvest, shrimp industry, SWOT (strengths, weaknesses, opportunities, and threats) analysis

INTRODUCTION

Indonesia has been one of the world's largest shrimp exporters over the past few decades (Asmild *et al.*, 2024). Shrimp production in Indonesia in 2023 reached 1.74 mln Mg, representing an average increase of 6.57% over the past five years (Satrio, Irfani and Lasut, 2023; Suhana, Sapanli and Fauzi, 2023). Its extensive coastline and tropical climate make year round shrimp aquaculture possible across coastal regions (Toiba *et al.*, 2024). One of the regions with significant potential for shrimp farming in Indonesia is the Pekalongan coastal area. The main shrimp species cultivated in this region is whiteleg shrimp (*Litopenaeus vannamei*). Pekalongan shrimp production ranks among the highest along the northern coast of Central Java Province, Indonesia (Ariadi *et al*., 2025b).

Shrimp aquaculture in the Pekalongan coastal region has generated substantial socio-economic benefits for local communities (Ariadi *et al*., 2024a). Intensification of shrimp farming has contributed to increased employment and the creation of new job opportunities (Setyawan *et al*., 2022). Moreover, shrimp farming activities in coastal Pekalongan provide regional economic benefits of approximately USD1.05 per year (KKP, 2023). Shrimp farming in the coastal region of Pekalongan achieves productivity of 21 $Mg{\cdot}ha^{-1}$ under an intensive cultivation system (Madusari, Ariadi and Mardhiyana, 2024). This industry provides an alternative livelihood alongside the region's batik and culinary industries. Such diversification plays a vital role in fostering the development of creative industry hubs within Indonesia's coastal zones.

However, the increasing intensity of shrimp aquaculture in the Pekalongan coastal area poses a potential risk of organic waste pollution to surrounding aquatic environments. Intensive shrimp farming practices are closely linked to heavy feed use and other input materials (Satanwat *et al*., 2023). In shrimp feeding management, approximately 15% of feed remains uneaten, while a further 20% is released as faecal waste (Mayekar *et al*., 2025; Ariadi, Azril and Mujtahidah, 2023). These waste loads tend to accumulate over time as shrimp biomass increases and culture periods extend (Cao, Le and Eppe, 2025). Ultimately, this leads to the accumulation of waste discharged into the coastal waters of Pekalongan, which may reduce the area's carrying capacity to support future shrimp farming activities. The presence of the textile industry and agricultural activities in the upstream area also contributes to increase of pollutant loads in the Pekalongan coastal region. Waste from these activities accounts for a major share (60–70%) of pollution in the Pekalongan coastal area (Ariadi, Maghfiroh and Murty, 2024).

Shrimp aquaculture in Indonesia, including in coastal Pekalongan, has a long-standing history dating back to the giant tiger prawn (*Penaeus monodon*) culture era. Numerous technologies and farming methods have since been developed, supported by continuous technical innovation. For decades, shrimp farming has served as an important pillar of Indonesia's food security (Asmild *et al*., 2024). The decline in environmental carrying capacity has emerged as a critical concern, alongside the widespread issue of shrimp disease outbreaks (Satanwat *et al*., 2023). Several regions along the northern coast of Java such as Pekalongan, Tegal, Situbondo, Tuban, Indramayu, and Lamongan are key shrimp production centres that contribute significantly to Indonesia's national shrimp supply (Yi, Reardon and Stringer, 2018; Hukom *et al*., 2020; Belland *et al*., 2025; Soegianto *et al*., 2025). The sustainability of shrimp aquaculture in these areas is therefore essential to supporting national food security programmes.

Despite the positive and negative aspects of intensive shrimp farming in Indonesia's coastal waters, the past decade has seen a significant expansion of aquaculture areas (Wafi and Ariadi, 2024). This indicates the high economic potential of shrimp farming as a profitable business. However, the expansion of aquaculture areas also necessitates careful consideration of its social impacts and outcomes. In this context, the government plays a crucial role in promoting environmentally responsible shrimp aquaculture development (Taiyebi, Welden and Hossain, 2025).

This study aims to formulate a comprehensive strategy for developing shrimp aquaculture in the coastal region of Pekalongan. The findings are expected to serve as a conceptual framework for advancing sustainable shrimp farming in Pekalongan as an adaptive strategy for addressing broader challenges in the sustainable development of coastal shrimp aquaculture across the country. The outcomes of this strategic mapping process are also expected to address food security challenges and support the improvement of productive agribusiness activities in coastal areas, thereby helping to respond to the impacts of global climate change.

MATERIALS AND METHODS

GENERAL INFORMATION

This study was conducted in the coastal areas of Pekalongan Regency and Pekalongan City, Indonesia, from February to May 2025 (Fig. 1). The research employed a case study and exploratory method. Aquaculture production data were obtained from the Marine and Fisheries Office of Pekalongan Regency and the Marine and Fisheries Office of Pekalongan City. Meanwhile, social and economic data used for formulating shrimp aquaculture development strategies in the Pekalongan coastal area were collected through observations, interviews, and literature reviews. Respondents included shrimp farmers, representatives from both regional marine and fisheries offices, middlemen buyers, and farm workers. Data collection was conducted at nine shrimp ponds located at different points along the coastal area of Pekalongan. The respondents surveyed included nine shrimp farmers, four government officials, five middlemen buyers, and 20 farm workers.

To assess the feasibility for developing shrimp aquaculture in the Pekalongan coastal region, a dynamic system modelling analysis was applied. Additionally, a SWOT analysis was employed to formulate strategic development plans for shrimp aquaculture in the area. The internal and external factors were derived from various aspects that influence the operational cycle of shrimp farming. Internal factors include water and soil quality, shrimp performance, and harvest tonnage. External factors refer to influences originating outside the farm operations, such as government policies, the presence of investors, market access, and price fluctuations. Based on these internal and external factors, the elements were then grouped into SWOT categories to facilitate the sampling process. The collected sampling data were subsequently processed by assigning scores and weights to each parameter within its respective factor. Dynamic system modelling was used to evaluate the long-term feasibility and projected outcomes of the aquaculture enterprise, while the SWOT analysis served to develop practical strategic plans based on the study findings.

RESEARCH DESIGN

The research was structured into three stages. The first stage involved collecting data on shrimp aquaculture production and the number of people actively engaged in shrimp farming

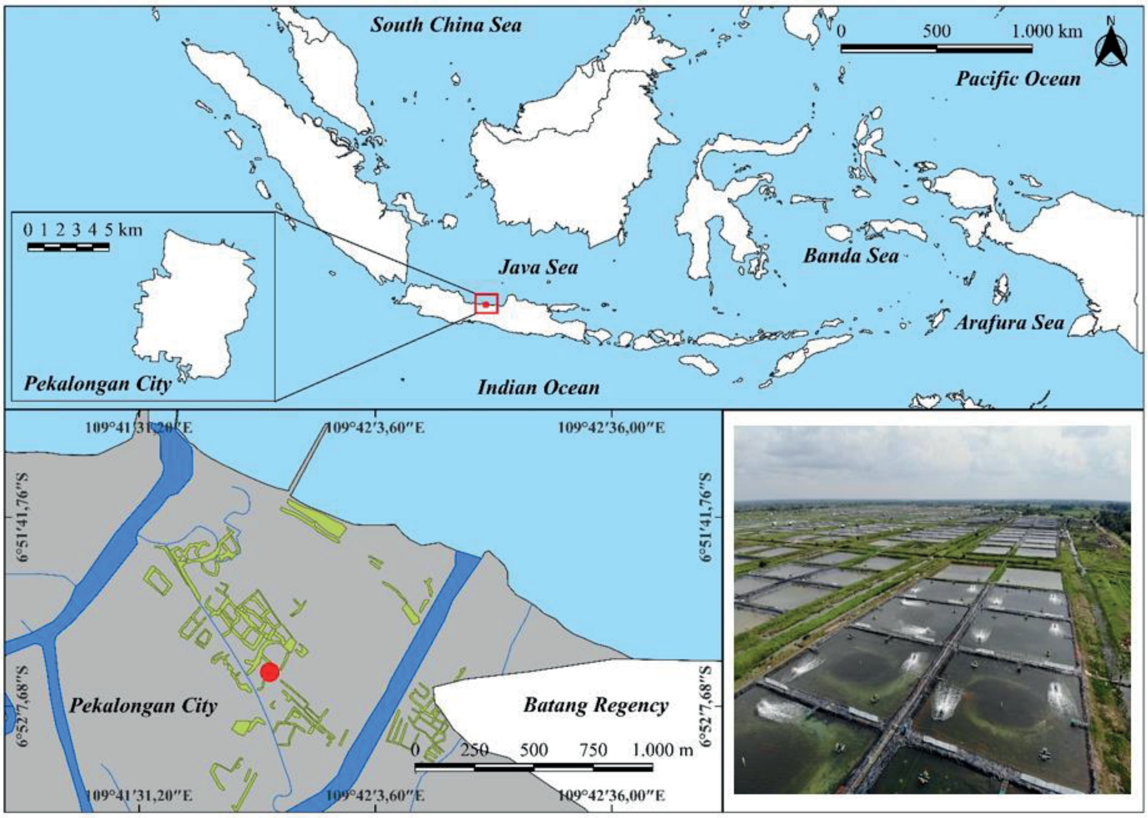

Fig. 1. Research location in Pekalongan coastal; source: own elaboration

businesses in the Pekalongan coastal area. These data were analysed descriptively using quantitative methods to assess production levels and their corresponding socio-economic impacts. Subsequently, qualitative exploration was conducted to examine the characteristics and implications of shrimp aquaculture activities in the region.

The second stage focused on forecasting the feasibility of shrimp aquaculture using dynamic system modelling analysis. This stage examined the potential impacts and economic benefits of sustained shrimp farming activities over several years. This process identified various supporting factors for the comprehensive development of shrimp aquaculture in the Pekalongan coastal area.

The third stage involved formulating strategic plans for developing shrimp aquaculture in Pekalongan coastal region. This phase identified internal and external factors influencing strategy formulation. The analysis considered strengths, weaknesses, opportunities, and threats (SWOT) to determine appropriate development strategies. Each factor was weighted on a scale from 1.0 (crucial) to 0.0 (not important) and ranked from 1 (low) to 4 (high). Weighted scores were then calculated to determine the overall rating, which was used to identify the SWOT quadrant position and define the optimal strategic orientation.

DATA ANALYSIS

The collected data were systematically analysed according to the established research framework. Quantitative data analysis was performed using Microsoft Excel 2021. The dynamic system modelling for forecasting shrimp aquaculture feasibility was conducted with Stella software version 9.02. The comprehensive strategy development analysis for shrimp aquaculture in the Pekalongan coastal area employed SWOT analysis, supported by thematic data processing using Microsoft Excel 2021.

RESULTS AND DISCUSSION

SHRIMP POND PRODUCTION

Shrimp production from pond aquaculture activities in the coastal areas of Pekalongan has shown a consistent increase over the past three years (Fig. 2). The production level in the regency's coastal area is higher than that in the city's coastal area. This difference is primarily due to the larger pond area and the larger number of shrimp farmers in the regency. The coastal region of Pekalongan is designated as a minapolitan zone in Central Java Province, making it well-suited to the development of shrimp aquaculture.

Shrimp production levels in coastal regions reflect the vitality of productive fisheries enterprises in the area. Shrimp farming is classified as a seasonal agribusiness activity (Li K. *et al.*, 2025). Weather and environmental factors remain major challenges for achieving optimal aquaculture practices in the field (Ariadi *et al.*, 2025a). However, exceptions occur in tropical waters, where countries benefit from consistent sunlight exposure that maintains relatively stable water temperatures throughout the year (Cao *et al.*, 2025; Oliveira, Barreto and Henry-Silva, 2025).

The steadily rising shrimp production in the coastal areas of Pekalongan highlights a promising opportunity for aquaculture development. The stability of shrimp production is largely

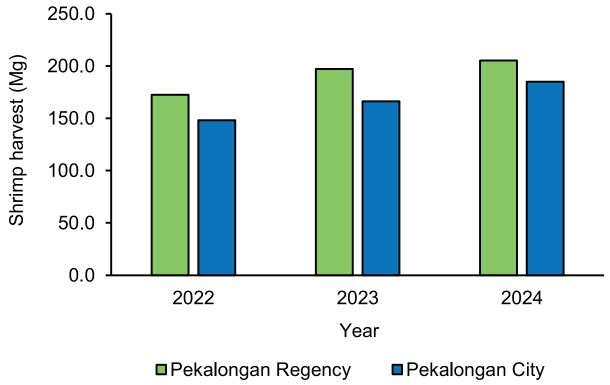

Fig. 2. Shrimp production in Pekalongan Regency and Pekalongan City during the 2022–2024 periods; own study

attributed to the high number of active farming ponds, which allows for rotational operational cycles throughout the year. This pattern is also consistent with global shrimp production trends, which tend to remain steady in several tropical countries such as Vietnam and Thailand. In addition to technical farm management, the timing and frequency of cultivation cycles are crucial for shrimp farmers to secure favourable market prices (Dorber *et al.*, 2020). The continuity of shrimp farming activities is also influenced by the carrying capacity of the waters, which remains sufficient to support ongoing aquaculture operations (Taiyebi, Welden and Hossain, 2025). Shrimp farming has the potential to become a distinctive economic symbol of Pekalongan, complementing its well-known batik industry. However, the development of region-based aquaculture enterprises requires a well-conceptualised strategy aligned with the socio-cultural characteristics of local communities (Siemens and Islam, 2025).

DYNAMIC SYSTEM MODELLING

The dynamic system modelling developed in this study consists of two sub-models: the harvest productivity model and the waste loading model (Fig. 3). The harvest productivity model represents the total shrimp yield produced within a single culture cycle, while the waste loading model illustrates the volume of waste generated during the same period. By combining these two models, it is possible to forecast both the projected shrimp harvest and the amount of waste produced from aquaculture activities.

The development of the causal loop model began by reviewing theories related to the technical operational cycle of shrimp farming. These theoretical foundations were then translated into interconnected causal loops r each representing identified technical parameters of the culture system. Once the causal loop structure was established, correlation formulas between parameters were constructed to enable data simulation. During the simulation process, the model can be used as an analytical tool if no data stagnation occurs. However, if data stagnation is detected, further refinement of the formulas is required. The model can be fully executed once the research data have been collected and subsequently processed through simulation according to the analytical needs of the study.

The developed dynamic system model represents the existing operational cycle of shrimp aquaculture in the coastal area of Pekalongan. Based on the forecasting results, the model is then qualitatively described to interpret its functional dynamics. Dynamic modelling can be effectively used to forecast production levels in aquaculture systems (Knowler *et al.*, 2009; Das *et al.*, 2025).

DYNAMIC MODELLING RESULTS

The results of the dynamic modelling indicate that the total waste generated from shrimp farming continues to increase in line with higher productivity (Fig. 4, upper). Meanwhile, in the Pekalongan coastal area, shrimp biomass exhibits dynamic fluctuations during the cultivation period (Fig. 4, lower). This condition contributes to a gradual decline in the carrying capacity of the aquaculture environment.

The increase in harvest yield directly correlates with the accumulation of waste runoff. This waste primarily originates from uneaten feed, faeces, and organic particulates (Reis *et al.*, 2022; Naderlof, Kaushik and Schrama, 2023; Ariadi *et al.*, 2025c).

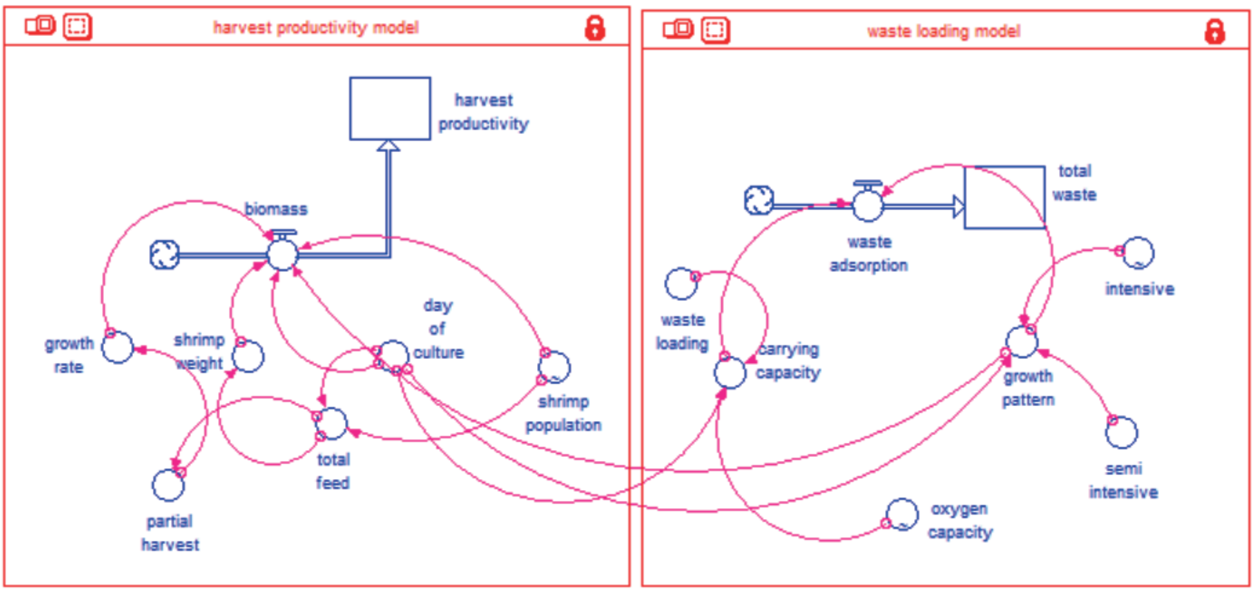

Fig. 3. Simulation model of shrimp harvest productivity and pond waste load in the coastal area of Pekalongan; source: own study

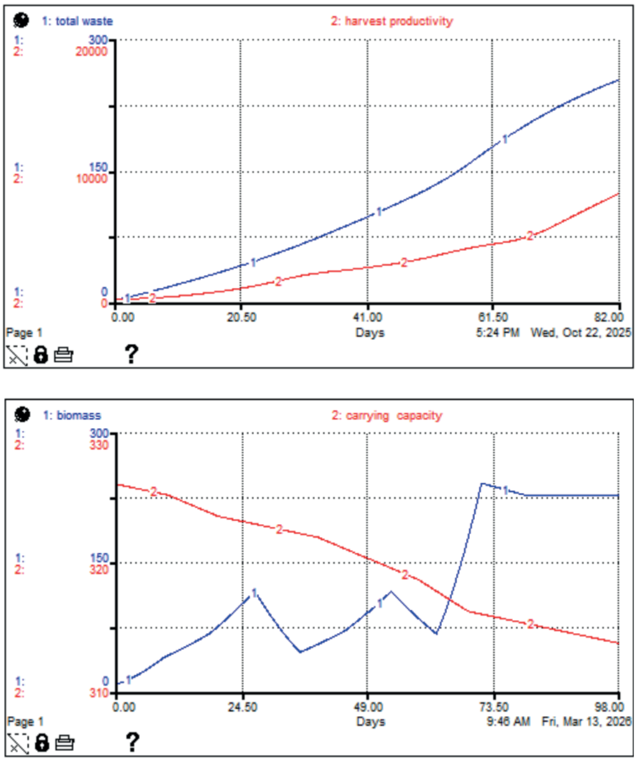

Fig. 4. Model analysis of shrimp production characteristics in the Pekalongan coastal zone: estimated shrimp yield and total waste generation (upper), shrimp biomass productivity and waste pond capacity (lower); source: own study

The waste load tends to rise as the shrimp culture period progresses. This growing waste burden is strongly associated with deteriorating water quality and higher prevalence of disease outbreaks within pond ecosystems (Satanwat *et al.*, 2023; Mayekar *et al.*, 2025).

Implementing proper feed management practices can significantly minimise the amount of waste generated from aquaculture operations (Rahardjo *et al.*, 2026). Aquaculture waste in pond ecosystems acts as a pollutant that contaminates surrounding environments. As waste load increases, the water's oxygen-carrying capacity declines, limiting its ability to absorb and decompose organic matter (Tarunamulia and Sammut, 2023; Ariadi *et al.*, 2025c). Oxygen-carrying capacity, in turn, influences shrimp farming management practices and the overall stability of water quality in coastal environments (Araujo *et al.*, 2025).

A decline in the carrying capacity of coastal waters also has physiological impacts on shrimp. When water quality parameters deteriorate due to reduced environmental carrying capacity, shrimp become more susceptible to stress and mortality (Satanwat *et al.*, 2023). More broadly, a decline in the carrying capacity of an aquatic environment impairs its function as a suitable medium for shrimp culture. Although cultivation remains possible under such conditions, ecological engineering measures are required to ensure that available water sources are suitable and safe for supporting shrimp habitats (Cao *et al.*, 2025). The accumulation of waste in coastal areas does not arise solely from aquaculture; household activities and wastewater runoff from various social sectors contribute an even greater proportion to pollution threats in coastal waters (Huvet *et al.*, 2025).

Shrimp aquaculture in coastal areas plays a critical role in food security initiatives, particularly in many developing countries (Taiyebi, Welden and Hossain, 2025). The coastal region of Pekalongan, which is characteristic of tropical coastal ecosystems, has strong potential to be designated as a minapolitan zone (Ariadi *et al.*, 2025b). A minapolitan zone represents an integrated fisheries area that aligns aquaculture with environmental conservation. In Pekalongan coastal region, mangrove forests cover approximately 20% of the total coastal area (Ariadi *et al.*, 2024b). This finding provides an important basic for the future development of environmentally friendly shrimp aquaculture initiatives in the region.

SHRIMP FARMING BUSINESS PROFILE IN PEKALONGAN

In general, shrimp aquaculture activities in the coastal areas of Pekalongan show strong potential to be developed into a large-scale agribusiness industry. The availability of extensive active farming areas, together with well-developed road access that supports operational activities, makes this sector highly suitable for expansion along the northern coast of Java Island. The vast area of cultivable land is directly proportional to the number of active shrimp farmers in coastal Pekalongan. These conditions represent a significant asset for potential investors interested in developing integrated aquaculture operations in Indonesia.

The regions strategic road connectivity to major cities such as Jakarta, Semarang, Surabaya, and Yogyakarta facilitates efficient distribution and marketing of shrimp products from Pekalongan coastal area. Moreover, the governments ongoing national food self-sufficiency programme further strengthens the bargaining position of shrimp aquaculture development in Pekalongan, making it a strong candidate for inclusion in national food security projects (Puspitawati *et al.*, 2022). The availability of adequate infrastructure and solid government support also plays a vital role in driving the downstream processing and productivity of the fisheries sector (Xu *et al.*, 2025).

INTERNAL FACTORS ANALYSIS STRATEGY

In this study, the internal factors analysis strategy (IFAS) was applied to determine strategies for developing shrimp aquaculture in the coastal area of Pekalongan based on internal environmental conditions, specifically assessing strengths and weaknesses. The internal factor values were derived from direct interviews and field observations, involving shrimp farmers and aquaculture stakeholders in Pekalongan coastal region. The IFAS scores were calculated by multiplying the weight and rating of each indicator. The internal factor scores for the development of an integrated shrimp aquaculture concept in coastal Pekalongan are presented in Table 1.

Based on Table 1, the total score for strengths is 3.25, while the total score for weaknesses is 1.73. The cumulative internal factor score, obtained by subtracting the weakness score from the strength score, is 1.52. This value serves as the basis for positioning the strategy within the SWOT analysis framework.

EXTERNAL FACTORS ANALYSIS STRATEGY

The external factors analysis strategy (EFAS) was applied to identify strategies for developing shrimp aquaculture in the coastal region of Pekalongan based on external environmental

Table 1. Internal factors analysis (IFAS)

Factor	Weight	Rating	Score
Strengths			
S1. Availability of aquaculture land	0.20	3.00	0.60
S2. Easy access to pond locations	0.20	3.00	0.60
S3. Stable water supply availability	0.15	3.00	0.45
S4. Support from local government authorities	0.25	4.00	1.00
S5. Presence of active shrimp farmers	0.20	3.00	0.60
Total strength factors	**1.00**	**–**	**3.25**
Weaknesses			
W1. Constraints in the application of practical technology	0.20	2.00	0.41
W2. Inadequate infrastructure	0.31	2.00	0.63
W3. Disease infection in shrimp	0.16	1.00	0.16
W4. Dependence on seed and feed supplies from other regions	0.22	2.00	0.43
W5. Absence of wastewater treatment units	0.11	1.00	0.11
Total weakness factors	**1.00**	**–**	**1.73**

Source: own study.

Table 2. External factors analysis (EFAS)

Factor	Weight	Rating	Score
Opportunities			
O1. High market demand	0.19	3.00	0.57
O2. Active cultivation period	0.19	3.00	0.57
O3. Adoption of various modern aquaculture technologies	0.19	3.00	0.57
O4. Relevant government programs (food security)	0.19	3.00	0.57
O5. Cross-sector collaboration opportunities	0.24	4.00	0.95
Total opportunity factors	**1.00**	**–**	**3.24**
Threats			
T1. Risk of tidal flooding	0.16	1.00	0.16
T2. Threat of waste pollution	0.16	1.00	0.16
T3. Dynamic shrimp price fluctuations	0.25	2.00	0.50
T4. Impact of climate change	0.16	1.00	0.16
T5. Coastal land-use conversion	0.25	2.00	0.50
Total threat factors	**1.00**	**–**	**1.48**

Source: own study.

conditions, with particular emphasis on opportunities and threats. The external factor values were obtained through direct interviews and field observations involving shrimp farmers and other aquaculture stakeholders in the Pekalongan coastal area. EFAS scores were calculated by multiplying the assigned weight by the rating for each indicator. The resulting external factor scores for shrimp aquaculture development in the Pekalongan coastal region are presented in Table 2.

According to Table 2, the total score for opportunities is 3.24, while the total score for threats is 1.48. The accumulated difference between the opportunity and threat scores is 1.76. This value is then combined with the cumulative internal factor score (strength–weakness difference) to determine the strategic position on the SWOT analysis matrix.

In terms of comparative ratio values, there is no significant fluctuation between the scores obtained from internal and external factors. This indicates that the factors influencing the planned development of an integrated shrimp aquaculture model in the coastal area of Pekalongan still exhibit a balanced impact. However, this condition does not necessarily apply when these values are later used to determine the strategic quadrant in the SWOT analysis.

STRATEGY FOR DEVELOPING SHRIMP AQUACULTURE IN THE PEKALONGAN COASTAL AREA

The formulation of sustainable shrimp aquaculture development strategies was carried out by integrating the factors identified in the strengths, weaknesses, opportunities, and threats aspects derived from the EFAS and IFAS analyses. In this process, strategy formulation was conducted using the SWOT matrix approach. The SWOT analysis serves as an analytical tool for formulating strategies based on existing business conditions and identifying alternative solutions (Abidin *et al.*, 2025). Within this framework, several alternative combinations are examined, including S–O (strength–opportunity) strategies, S–T (strength–threat) strategies, W–O (weakness–opportunity) strategies, and W–T (weakness–threat) strategies. The mapping results of the SWOT strategy for the development of shrimp aquaculture in the coastal region of Pekalongan are presented in Tables 3 and 4.

Based on the mapping of strengths, weaknesses, opportunities, and threats, the factor values were first curated and reduced. For the internal factors, the weakness score was subtracted from the strength score, resulting in a value of 1.52, which represents the X-coordinate. Similarly, for the external factors, the threat score was subtracted from the opportunity score, yielding a value of 1.76, which represents the y-coordinate. The combined values of these coordinates determine the strategic pattern to be applied in the SWOT analysis diagram. Accordingly, the coordinate pair (x = 1.52; y = 1.76) was plotted on the SWOT diagram, as presented in Figure 5. The comparison of scores along the OX and OY axes determines the type of strategy to be implemented. The curation of these values is a key step in defining the position of the intersection point on the SWOT diagram.

The intersection point of these coordinates on the SWOT diagram lies in quadrant I, indicating that an aggressive support strategy should be adopted. This position suggests that shrimp aquaculture development in the coastal area of Pekalongan is supported by substantial opportunities and strong resource advantages, making it highly suitable for expansion into a large-scale aquaculture industry (Madusari, Ariadi and Mardhiyana, 2024). Therefore, a set of alternative aggressive support strategies should be formulated based on the region's resource strengths and development opportunities. The recommended strategic alternatives are as follows.

Table 3. SWOT (strengths, weaknesses, opportunities, and threats) analysis of shrimp aquaculture in the coastal region of Pekalongan

Factor	Positive	Negative
Internal	**Strength** S1. Availability of aquaculture land S2. Easy access to pond locations S3. Stable water supply availability S4. Support from local government authorities S5. Presence of active shrimp farmers	**Weaknesses** W1. Limited practical technology application W2. Inadequate infrastructure W3. Disease infection in shrimp culture W4. Dependence on external seed and feed supply W5. Absence of waste management unit
External	**Opportunities** O1. High market demand O2. Active cultivation period O3. Adoption of various modern aquaculture technologies O4. Relevant government programs (food security) O5. Cross-sector collaboration opportunities	**Threats** T1. Risk of tidal flooding T2. Threat of waste pollution T3. Dynamic shrimp price fluctuations T4. Climate change impacts T5. Coastal land conversion

Source: own study.

development of an integrated and sustainable aquaculture zone, reducing logistics costs while enhancing product competitiveness. This strategy may also improve the efficiency of the shrimp product marketing chain. Through this strategy, shrimp farmers will benefit not only from production cycle efficiency, but also from the accelerated delivery and the expansion of market networks due to improved accessibility across the coastal areas of Java Island. Accessibility-based land optimisation represents a key strategy for adaptive coastal management in response to environmental and economic dynamics (Knowler *et al.*, 2009; Jamilah *et al.*, 2025; Li Y. *et al.*, 2025).

2. Water source stabilisation through technology

Stabilising water sources through technological applications in the Pekalongan coastal area is a strategic step to ensure water continuity and quality for the shrimp farming industry. Water management technologies, such as recirculating aquaculture systems (RAS), biofiltration, and geomembrane-lined reservoirs, help maintaining stable physico-chemical water quality parameters (Suantika *et al.*, 2018; Mayekar *et al.*, 2025; Rana and Ray, 2025; Rong *et al.*, 2025). These innovations not only reduce dependence on direct seawater intake but also minimise pollution risks caused by saline intrusion and organic waste. The application of digital sensors for real-time water quality monitoring further strengthens adaptive and efficient water management systems (Izharuddin, 2025). In shrimp pond operations, technological stabilisation of water sources is a critical factor in building a sustainable culture system resilient to environmental fluctuations (Jayraj *et al.*, 2025).

Table 4. Matrix of strategies based on SWOT (strengths, weaknesses, opportunities, and threats) analysis of shrimp aquaculture in the coastal region of Pekalongan

Item	Strengths	Weaknesses
Opportunities	**S-O strategy** 1. Optimisation of pond land based on accessibility (S1, S2, O1, O2) 2. Stabilisation of water sources through technological application (S3, O3) 3. Utilisation of government support for innovation (S4, O4) 4. Strengthening collaboration between farmers and research institutions (S5, O5) 5. Digitalisation of premium export product marketing (S2, O3)	**W-O strategy** 1. Practical technology training for shrimp farmers (W1, O3) 2. Development of integrated and sustainable aquaculture infrastructure (W2, O4) 3. Establishment of local hatcheries and feed production (W4, O5) 4. Integration of modern technology with waste management systems (W5, O4) 5. Digital monitoring for water quality and biosecurity (W3, O3)
Threats	**S-T strategy** 1. Coastal mitigation through adaptive spatial planning (S1, S2, T1, T5) 2. Optimisation of sustainable pond water management (S3, T2) 3. Formation of shrimp farmers' marketing cooperatives (S5, T3) 4. Designation of sustainable pond zoning areas (S4, T5) 5. Climate adaptation through resilient shrimp varieties and farming calendar management (S4, T4)	**W-T strategy** 1. Rehabilitation of climate-adaptive pond infrastructure (W2, T1, T4) 2. Collective waste management based on closed-loop systems (W5, T2) 3. Development of local seed and feed self-sufficiency (W4, T3) 4. Implementation of integrated and sustainable shrimp health management (W3, T4) 5. Human resource capacity building for market adaptation and shrimp product competitiveness (W1, T5)

Source: own study.

1. Pond land optimisation based on accessibility

The optimisation of shrimp pond areas based on accessibility in the coastal region of Pekalongan aims to maximise the potential of productive aquaculture land by considering access to supporting facilities and infrastructure. Key accessibility factors, such as proximity to seawater sources, transportation routes, markets, and production input facilities, determine the operational efficiency of shrimp farming in the region. This approach enables the

3. Leveraging government support for innovation

Government support is a critical factor in accelerating shrimp farming development in the Pekalongan coastal region. Assistance programmes such as pond rehabilitation, the provision

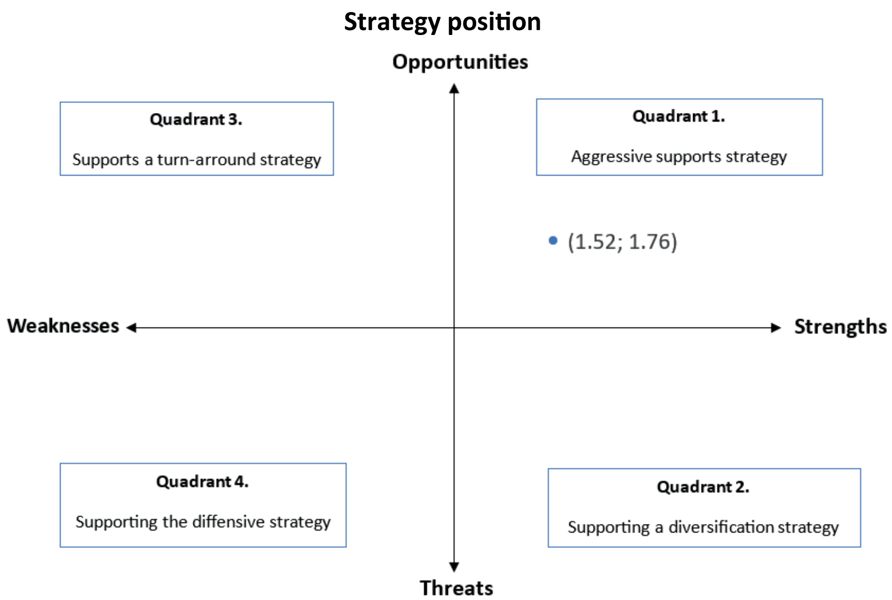

Fig. 5. SWOT (strengths, weaknesses, opportunities, and threats) strategy analysis diagram; source: own study

of high-quality seed, technical training, and access to financing serve as key instruments to enhance productivity and efficiency. Additionally, coastal spatial planning policies and the development of supporting infrastructure, including improved road access to pond sites and irrigation systems, significantly strengthen aquaculture connectivity (Lien *et al*., 2021; Chhotray, 2022). The government also promotes sustainable aquaculture practices through certification schemes and environmental quality monitoring implemented by extension officers. In addition, the Fisheries Department has periodically provided high quality shrimp fry to small-scale farmers and has consistently organised several technical training programmes on shrimp diseases control.

The synergy between policy, technology, and enterprise may contribute to sustainable development of the Pekalongan aquaculture economy and strengthen its competitiveness.

4. Strengthening collaboration between farmers and research institutions

Enhancing collaboration between shrimp farmers and research institutions is a strategic factor in the development of the aquaculture industry in the Pekalongan coastal region. This synergy facilitates the transfer of modern farming technologies such as biofloc systems, RAS, and data-based water quality management to improve production efficiency and sustainability (Suantika *et al*., 2018; Estante-Superio *et al*., 2025; Rana and Ray, 2025). Through applied research, these innovations can be adapted to local ecological and socio-economic conditions, resulting in inclusive and sustainable farming models. In addition, such collaboration enhances farmers' capacity through training, technical assistance, and the formulation of scientifically based farming protocols (Liu, 2007; Ariadi, Fahrurrozi and Al Ramadhani, 2024). With continued research support, the Pekalongan shrimp aquaculture industry can evolve into a resilient, productive, and export-oriented sector.

5. Digitalisation of export-oriented product marketing

Implementing digitalisation in the marketing of export-oriented shrimp products from Pekalongan coastal aquaculture is an innovative step toward expanding market reach and improving global competitiveness. Through digital platforms such as e-commerce, online marketplaces, and blockchain-based traceability systems, producers can promote their products transparently and efficiently (Tran *et al*., 2013; Errickson and Zemeckis, 2021; Kruk Kloppenburg and Lovita, 2025). Digitalisation also enables real-time market data collection, allowing sales strategies to adapt to international demand trends. Furthermore, digital certification and technology-based quality labelling strengthen consumer trust in product safety and quality (Rowan, 2023; Kruk, Kloppenburg and Lovita, 2025). The advancement of digital infrastructure and technological literacy supports the modernisation of marketing systems for shrimp aquaculture products in coastal regions (Izharuddin, 2025).

The shrimp aquaculture industry in the Pekalongan coastal region represents a highly promising agribusiness sector, as shown by potential assessments and forecasting analyses. Recent trends in shrimp harvest productivity across Pekalongan Regency and City, along with dynamic modelling simulations, suggest that the future development of the shrimp industry will require an integrated approach encompassing land optimisation, water stabilisation, policy support, research collaboration, and marketing digitalisation.

Accessibility-based land optimisation ensures spatial and logistical efficiency, while water management technologies sustain environmental stability. Government support through regulation, infrastructure, and financing further accelerates innovation in the aquaculture sector (Puspitawati *et al*., 2022). Collaboration between farmers and research institutions enhances adaptive capacity to environmental and technological changes, whereas marketing digitalisation broadens global market reach, making the Pekalongan shrimp industry more competitive and sustainable (Errickson and Zemeckis, 2021; Rowan, 2023; Kruk, Kloppenburg and Lovita, 2025). Integrated shrimp farming systems are considered more efficient and synergistic compared to partial approaches (Gangnery *et al*., 2021; Salminen *et al*., 2025), both in terms of management performance and their socio-economic impact (Rahman *et al*., 2021).

The results of the dynamic modelling system, which combines the harvest productivity model and the waste loading model, indicate a linear relationship between the increase in harvest productivity and the accumulation of waste loads generated within a single cultivation cycle. This finding provides an important signal that the development of the shrimp industry in the coastal area of Pekalongan should not only focus on increasing production output but also on mitigating the potential ecological impacts that may arise. In this context, the eco-efficiency approach becomes crucial, where production growth must be accompanied by input efficiency and waste minimisation (Knowler *et al.*, 2009; Das *et al.*, 2025). The implementation of modern aquaculture technologies such as recirculating aquaculture systems (RAS), biofloc technology, and the adoption of circular economy principles can serve as effective solutions to maintain a balance between productivity and environmental sustainability. Based on this analysis, the dynamic model serves not only as a quantitative predictive tool but also as a scientific justification for developing management strategies oriented toward ecosystem efficiency and long-term adaptation to coastal environmental changes.

The integration of system dynamics modelling and the SWOT approach suggests that efforts to strengthen the shrimp industry in the coastal area of Pekalongan should focus on the implementation of an aggressive support strategy. This strategy reflects the region's strong natural resource base, institutional support, and vast market opportunities, while still facing external challenges such as climate change and global price fluctuations. Therefore, policy direction and strategic implementation should emphasise strengthening institutional capacity, developing adaptive infrastructure, and adopting low-emission aquaculture innovations. The development of green aquaculture is highly important to ensure that the carrying capacity of coastal environments remains stable over the long term (Mardiana *et al.*, 2023). This approach aligns with the blue economy framework, which promotes resource efficiency, food security, and social inclusiveness in the fisheries sector. Furthermore, collaborative research involving local government, academia, and the private sector plays a decisive role in driving digital transformation, expanding export markets, and enhancing the competitiveness of the national shrimp industry in the future. Technology practices implemented through multi stakeholder empowerment programmes are considered highly effective for shrimp farmers, as they enable them to understand both theoretical concepts and practical applications simultaneously (Ariadi, Fahrurrozi and Al Ramadhani, 2024).

Through the implementation of science-based and well targeted strategies, shrimp aquaculture in the coastal area of Pekalongan has the potential to become a model for sustainable aquaculture industry practices across Indonesia's coastal regions in the coming years. This model will greatly support coastal communities that experience low employment levels. This strategic analysis is also valuable for local governments in optimising the potential of natural and human resources in coastal areas to support the development of priority commodities (Abdel-Hady *et al.*, 2024). However, its successful implementation depends on strong and integrated collaboration among communities, government, and other relevant stakeholders (Fong *et al.*, 2024).

CONCLUSIONS

The findings of this study indicate that shrimp farming in the coastal area of Pekalongan is feasible for development through an integrated strategy that strengthens local resource potential. The results from dynamic modelling indicate that the increase in shrimp harvest productivity is directly associated with higher waste loads, thereby highlighting the need for adaptive management based on technology and sustainable spatial planning. These aspects are translated into the implementation of an aggressive support strategy encompassing land optimisation, water source stabilisation, policy support, research collaboration, and market digitalisation. The application of these strategies is crucial for maintaining the environmental carrying capacity of Pekalongan's coastal ecosystem while enhancing the efficiency and global competitiveness of the shrimp industry. Ultimately, these findings provide a conceptual foundation for strengthening the national aquaculture sector toward a sustainable blue economy framework.

CONFLICT OF INTERESTS

All authors declare that they have no conflict of interest

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