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ORGANIC MATERIAL SOLUBILITY AND DYNAMIC MODELLING ANALYSIS OF INTENSIVE SHRIMP FARMING ACTIVITIES IN THE COASTAL AREA OF PEKALONGAN, INDONESIA

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ABSTRACT

The interaction between water and soil quality in intensive shrimp farming significantly influences the success of aquaculture operations. This study aims to examine the correlation between fluctuations in water and soil quality in intensive shrimp ponds and analyze the solubility level of organic matter using a dynamic system modelling approach. The research method used a causal *ex post facto* design, collecting data systematically from intensive shrimp ponds. The findings indicate that increased shrimp growth stimulates higher feeding activity, which subsequently raises waste production and organic matter solubility within the pond ecosystem. Over time, this process reaches a saturation point. By the fifteenth week of the operational cycle, the pond's waste carrying capacity decreases, ultimately affecting shrimp farming productivity patterns. Throughout the farming cycle, fluctuations in water and soil quality parameters demonstrate this dynamic interaction. The study identifies a strong correlation between these factors, with patterns following an oscillatory trend in the model. The ecosystem's carrying capacity primarily depends on waste load levels, oxygen availability for organic matter absorption, and the overall condition of the aquatic environment. Organic matter solubility exhibits an accumulative pattern throughout the operational cycle, highlighting its crucial role in ecosystem dynamics. The study concludes that water and soil quality are inherently linked to the stability of the pond ecosystem. Additionally, the presence and distribution of organic matter, as revealed through dynamic modeling, serve as critical factors influencing the ecological balance in shrimp farming systems.

How to Cite

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INTRODUCTION

Intensive shrimp farming is an aquaculture activity developed in the coastal areas of Pekalongan City, Indonesia. This method offers several advantages, including higher production, extended farming cycles, faster shrimp growth, and relatively quicker returns on investment (Junda, 2018; Ngoc et al., 2021; Ulhaq et al., 2022). Intensive shrimp farming has been developed as a form of revitalization to enhance the productivity of idle land in Indonesia's coastal regions (Mustafa et al., 2023; Wafi and Ariadi, 2024). This initiative aims to improve the utilization of coastal resources.

The production rate of intensive shrimp farming ranges from 15 to 25 tons per hectare, with a stocking density of 100–150 shrimp per square meter (Khanjani et al., 2023). In Ecuador and Brazil, shrimp harvest productivity reaches 104,030 – 916,836 tons (FAO, 2024). In Southeast Asia, including Thailand, Indonesia, and Vietnam, shrimp aquaculture production ranges from 101,860 to 215,690 tons (FAO, 2024). Other studies also indicate that intensive shrimp farming can be developed in low-salinity areas, achieving a harvest productivity of 4,205–4,816 kg/m^3 (Suantika et al., 2018). The key characteristics of the intensive shrimp farming system include the use of aerators, commercial feed, selectively bred shrimp seeds, and fully integrated farming facilities (Boyd, 1998; Nguyen and Matsuhashi, 2019; Emerenciano et al., 2022).

The high productivity of intensive shrimp farming has provided significant economic benefits to farmers (Wu et al., 2023). However, this high production also leads to substantial waste output from farming activities (Wu et al., 2023). Waste in shrimp ponds is categorized into organic and inorganic waste. Inorganic waste, such as ammonia and nitrite at high concentrations, is toxic to shrimp (Zhou et al., 2024). Meanwhile, organic waste can become a pollutant in both the pond ecosystem and surrounding environment when pond water is discharged (Salawu et al., 2022). One mitigation strategy to reduce organic waste in ponds is regular siphoning (Huang et al., 2022). Additionally, the use of aerators and the application of decomposer bacteria effectively reduce organic waste through decomposition processes (Ramesh et al., 2024).

The solubility of organic matter in intensive shrimp pond ecosystems is measured by analyzing the concentration of Total Organic Matter (TOM). TOM concentration represents the total solubility level of dissolved particles, suspended matter, and other organic materials (Nimptsch et al., 2015). The recommended standard for organic matter solubility in intensive shrimp ponds is less than 90 mg/L (Li and Boyd, 2016; Ariadi et al., 2023). Excessively high organic matter levels can cause pond water to become turbid, reducing sunlight penetration into the water column (Fossmark et al., 2020). If this condition occurs, oxygen levels in the water will decrease due to limited photosynthesis. Furthermore, high organic matter levels trigger fluctuations in pond water quality parameters (Ariadi et al., 2023).

The primary sources of organic matter in intensive shrimp ponds include uneaten feed waste, feces, plankton lysis, and other dissolved particles (de Almeida et al., 2024; Huang et al., 2024; Ariadi et al., 2019). Farmers frequently perform regular siphoning and adjust aerator positions to remove organic matter from the pond (Prasetyaningsari et al., 2013; Delphino et al., 2022). Since organic matter solubility plays a vital role in the dynamics of pond ecosystems, it is a critical topic for further research. Based on this hypothesis, this study aims: (1) to analyze the correlation between fluctuations in water and soil quality in intensive shrimp ponds, and (2) to examine the dynamics of organic matter solubility fluctuations in intensive shrimp farming using a dynamic system modeling approach. The results of this study are expected to provide important insights into the management of waste carrying capacity in ponds for sustainable shrimp farming.

MATERIALS AND METHODS

This study was conducted in an intensive shrimp pond located in the coastal area of Pekalongan, Indonesia (Figure 1) from November 2024 to January 2025. The research method used was a causal *ex post facto* design with structured data collection. The study area included three different pond locations: Degayu, Krapyak, and Slamaran. The selection of research sites was based on ease of access and their representativeness of local pond conditions. Three ponds were selected from each location as research observation objects.

The observed research parameters included water quality, soil quality, shrimp weight, harvest production from each pond area, and the abundance of organic matter throughout the shrimp farming period. The observed water quality parameters were pH, measured using a pH meter (EcoTestr); temperature and dissolved oxygen, measured using a YSI 550i DO meter; salinity, measured using a refractometer; and water clarity, measured using a Secchi disk. All parameters were analysed *in situ*.

The observed soil quality parameters included soil pH, redox potential, and cation exchange capacity (CEC), which were analyzed using the compulsive analysis method (FAO, 1980). Pond soil texture was measured using the hydrometer method. Meanwhile, nitrite, orthophosphate, ammonia, and nitrate levels were analyzed using spectrophotometry, following APHA (2005) guidelines. Organic matter parameters in this study were analyzed *ex situ* using the titrimetry method (APHA, 2005). All soil and organic matter parameters were analyzed *ex situ*.

Shrimp harvest production data were obtained from the harvest records of each studied pond. Meanwhile, the shrimp growth rate was calculated using the formula (APHA, 2005):

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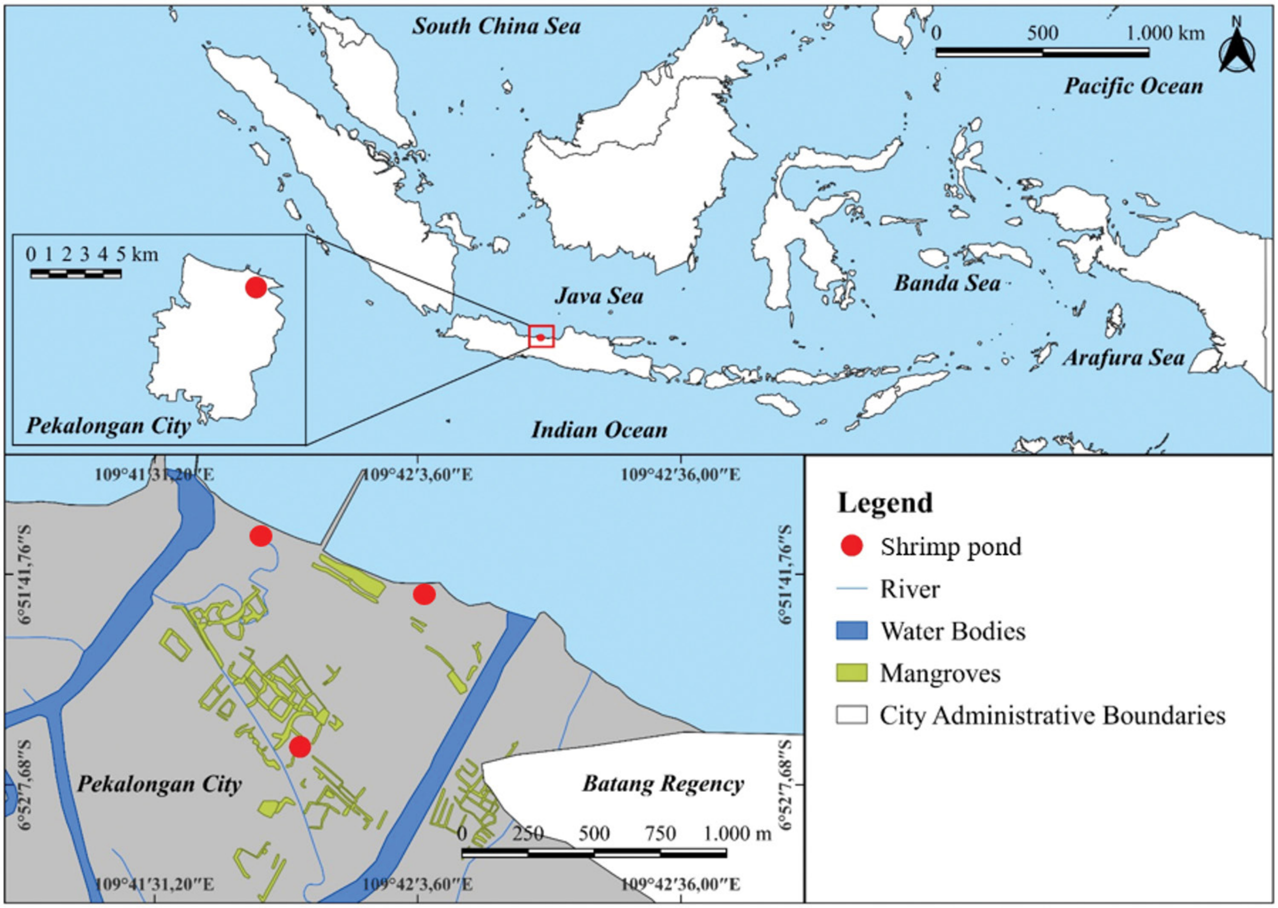

Fig 1. Map of research location

$$W = W_t - W_o$$

where:

- W − shrimp weight
- W_t − current (final) weight
- W_o − previous (initial) weight.

Shrimp farming waste data were obtained based on waste conversion calculations according to Primavera (2006), which states that 100% of feed breaks down into 15% uneaten feed and 20% feces. The research data were further analyzed mathematically using Microsoft Office Excel 2013 and SPSS 19.0. Additionally, to assess the dynamic fluctuations in organic matter solubility in the ponds, a dynamic system modeling analysis was conducted using Stella 9.02.

RESULTS AND DISCUSSION

Shrimp harvest

Shrimp harvest productivity varied across the research pond locations. The highest productivity was recorded in Slamaran, with a total harvest of 10.206 kg from three ponds, while the lowest was in Degayu, with 9.204 kg. Several factors influence these differences in productivity. In the coastal region of Pekalongan, a key factor affecting shrimp harvest productivity is the quality of the aquatic environment. Good environmental biophysical conditions will support increased shrimp farming productivity (Uddin et al., 2013).

The aquatic ecosystem plays a crucial role in maintaining pond water quality. Variations in water quality can cause stress in shrimp, making them more susceptible to diseases (Ariadi et al., 2023). Under poor water conditions, disease prevalence and spread intensify, further weakening stressed shrimp and increasing their risk of infection. As a result, shrimp mortality rates rise, ultimately impacting the overall shrimp biomass in the pond.

Additionally, shrimp post-larvae (PL) performance and farm management play a crucial role in determining shrimp harvest productivity (Wu et al., 2024). In intensive shrimp farming, adherence to proper standard operating procedures (SOP) significantly impacts overall farming performance. Feed quality and management also frequently influence shrimp harvest outcomes (Alam et al., 2021). Furthermore, abiotic and biotic factors within the pond ecosystem serve as additional parameters that affect shrimp harvest quality (Ariadi et al., 2023).

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Table 1. Shrimp harvest productivity in Degayu, Krapyak, and Slamaran ponds

Location	**Harvest Periods**			
	Partial 1	**Partial 2**	**Final Harvest**	**Total Harvest**
Degayu				
Pond 1.	204	257	2.420	2.881
Pond 2.	217	261	2.725	3.203
Pond 3.	214	265	2.641	3.120
Krapyak				
Pond 1.	208	260	2.681	3.149
Pond 2.	225	251	2.755	3.231
Pond 3.	219	264	2.810	3.293
Slamaran				
Pond 1.	211	282	3.027	3.520
Pond 2.	230	250	2.933	3.413
Pond 3.	223	250	2.800	3.273

Feed waste

Feed waste is generated from uneaten feed accumulated during the shrimp farming operational cycle. The quantification of feed waste is illustrated in Figure 2, showing a consistent increase in feed waste as the amount of feed provided rises. However, a different trend was observed in Degayu ponds, where feed waste decreased after 90 days of culture. This decline resulted from mass shrimp mortality, which significantly reduced the amount of feed administered.

The feed waste load in pond ecosystems is highly dependent on the amount of feed given to the shrimp. Feed provision is aggregated in accordance with the increasing shrimp biomass (Ariadi et al., 2019). During specific periods, such as the moulting phase, shrimp experience a decrease in appetite (Peixoto et al., 2025). This is due to physiological changes, particularly an increase in hemolymph levels, which facilitate the moulting process (Liou et al., 2023). During moulting, shrimp farmers significantly reduce feed amounts to prevent excessive waste.

An increase in waste will affect the oxygen-carrying capacity in the pond. Oxygen will be competed for by decomposition, shrimp respiration, and biochemical reactions (Satanwat et al., 2023; Araujo et al., 2025). A decrease in oxygen levels can lead to hypoxic conditions in the pond, which in turn causes shrimp stress (Li and Brouwer, 2013). To mitigate the increased waste load, regular siphoning and water replacement are carried out (Burford et al., 2003; Zhang et al., 2022).

Organic matter

The solubility of organic matter is described in Figure 3. The concentration of organic matter in each pond location tends to fluctuate and increase over time. The solubility of organic matter predominantly shows a significant increase after reaching 60 days of culture. The ideal concentration of organic matter for intensive shrimp farming is <90 mg/l (Ariadi et al., 2020). Excessive organic matter can trigger dynamics in water quality within the pond ecosystem (Wafi et al., 2021). High concentrations of organic matter influence water quality dynamics and affect the physical properties of feed and chemical particles within the pond ecosystem (Wu et al., 2024).

High organic matter levels can lead to aphotic conditions in the water. This occurs because the penetration of sunlight into the water column is disrupted (Xu et al., 2023). Elevated organic matter concentrations also encourage the growth of *Vibrio* sp. (Ariadi and Mujtahidah, 2022). Additionally, high organic matter content intensifies the decomposition process in the pond, which causes fluctuations in water quality (Hill et al., 2022).

Shrimp are organisms that thrive in dark waters. Dark water conditions promote the proper growth of shrimp chromatophores. Shrimp chromatophores function for environmental adaptation, avoiding predators, and physiological responses to light (Siegenthaler et al., 2022). Chromatophores influence the shrimp's coloration patterns and physiological adaptation to varying light intensity levels. Shrimp that have dark chromatophores

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tend to be healthier. However, in pond ecosystems, excessive darkness due to organic matter accumulation is ecologically unfavorable. When organic matter levels are too high, it can lead to increased oxygen consumption and eutrophication (Herbeck et al., 2013; Aguilera-Rivera et al., 2019).

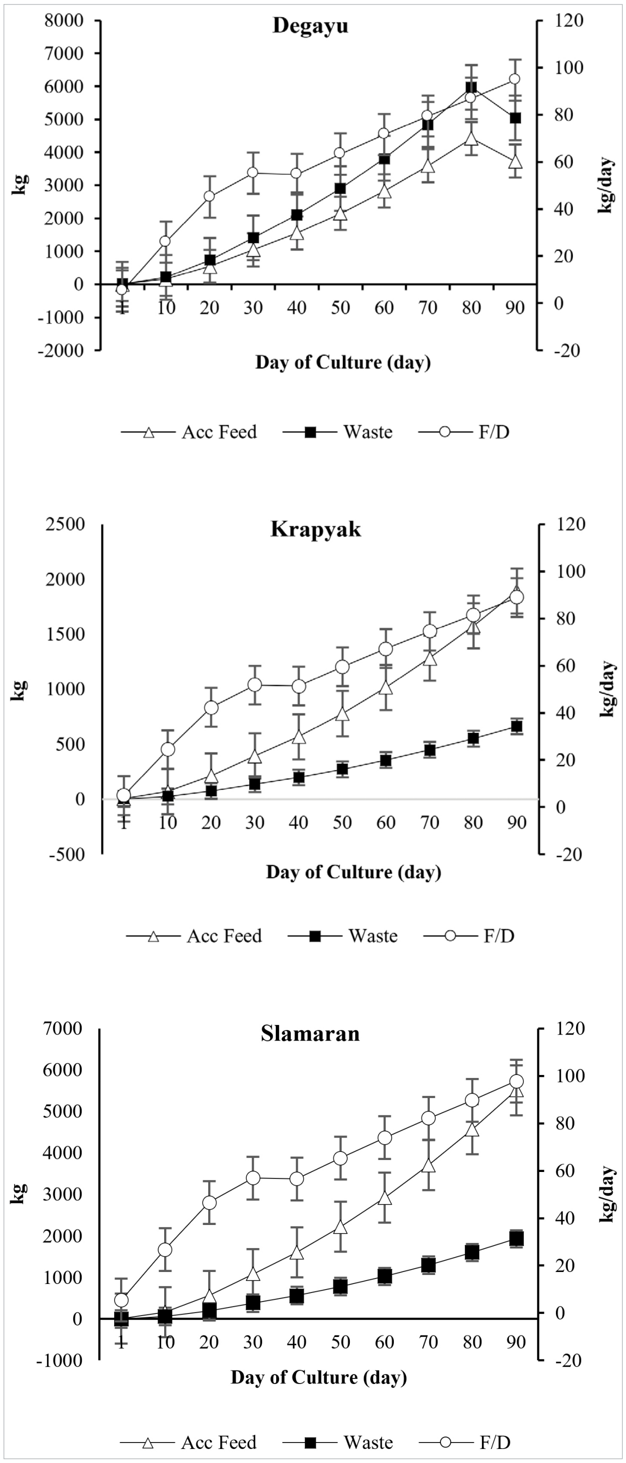

Fig 2. Feeding data and waste loads in Degayu, Krapyak, and Slamaran ponds

Therefore, based on the recommendation of Ariadi et al. (2023), it is advised that the solubility of organic matter in shrimp ponds should not exceed 90 mg/l (Ariadi et al., 2023).

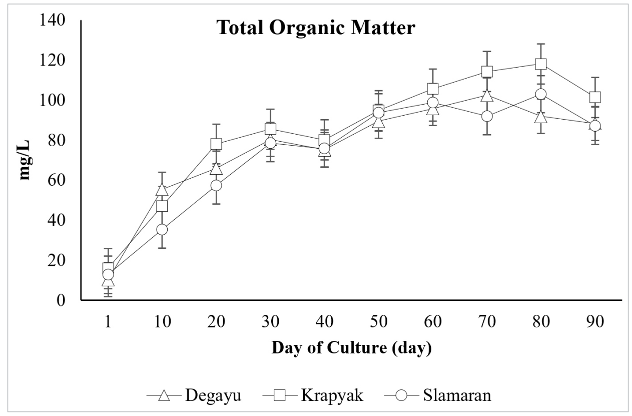

Fig 3. The abundance of organic matter in Degayu, Krapyak, and Slamaran ponds

Shrimp growth

The growth rate of shrimp in each pond exhibits different trends (Figure 4). Degayu pond shows a slow growth rate in the early period, but accelerates in the later stages. Krapyak pond experiences rapid growth at the beginning, followed by slower growth towards the end. Slamaran pond displays a steadily increasing growth trend. Different farming techniques influence the growth performance of the shrimp being cultured. Variations in cultivation management practices have an ethnocultural influence on the stability of the pond ecosystem, which in turn affects shrimp life performance (Khanjani et al., 2023).

The best growth rate was observed in Krapyak pond. The significant increase in shrimp growth at Krapyak correlates with the intensive feeding regimen. The performance of shrimp juveniles (post-larvae) also affects the stability of growth (Okura et al., 2025). Furthermore, the pond size and the number of aerators used also impact shrimp growth. This is related to the availability of space for the shrimp to move around in the pond and sufficient oxygen consumption (Ruiz-Velazco et al., 2010; Zhao et al., 2025). The feeding timing also plays a crucial role in shrimp growth performance in the pond. The feed provided must be administered in the correct dosage and at the appropriate times (Reis et al., 2021). Proper feeding timing stimulates the shrimp's feeding behavior in response to daily feed offerings (Borges et al., 2024; Sanchez-Gendriz et al., 2025). Additionally, the shrimp must be in optimal health to efficiently convert feed into biomass (Ariadi et al., 2019).

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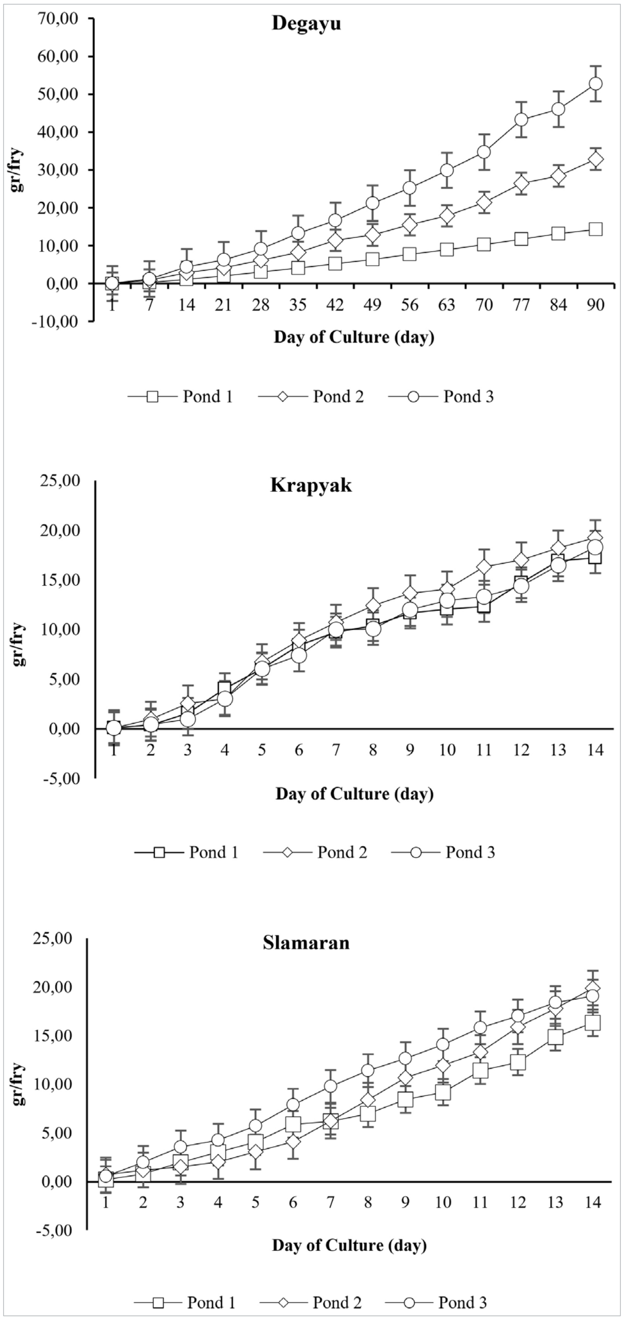

Fig 4. Shrimp growth rate in Degayu, Krapyak, and Slamaran ponds

Water quality

Water quality parameters in intensive shrimp ponds tend to vary. Overall, the water quality conditions still meet the standards for shrimp farming, except for the phosphate and ammonia parameters. The ammonia concentration in the shrimp ponds ranges from 0.297 to 0.611 mg/l, and the phosphate concentration ranges from 0.725 to 0.965 mg/l (Table 2). The high levels of ammonia and phosphate are attributed to feed waste, fertilization, and liming.

Water quality parameters play a crucial role in forming a healthy pond ecosystem. The dynamics of water quality in the pond ecosystem are influenced by feed waste and chemical treatments (Primavera, 2006; Nyberg et al., 2024). Good and stable water quality conditions have a positive impact on shrimp health (Chumpol et al., 2019). Shrimp tend to be healthier in stable water conditions with minimal fluctuations. Fluctuating water quality conditions, on the other hand, can cause stress to shrimp and slow down their growth process (Li et al., 2025).

Water quality also affects the presence of microorganisms in the pond ecosystem. The dominance of plankton and the abundance of pathogenic bacteria in pond waters are partly due to the dynamic water quality conditions (Chowdhury et al., 2024; Ariadi et al., 2024). Parameters such as pH, dissolved oxygen, salinity, and temperature have simultaneous effects on both shrimp and microorganisms in the pond ecosystem (Ma et al., 2013). Pathogenic bacteria and plankton will grow optimally if the water conditions support their life processes, so this can be controlled technically.

Correlation analysis results show that phosphate parameters do not have a significant relationship with other parameters (Table 3). This indicates that all water quality parameters in the intensive shrimp pond ecosystem are interrelated. The dynamics of water quality parameters in the ecosystem will influence each other due to the hydrological cycle (Braaten and Flaherty, 2000). Fluctuations in water quality parameters will affect other parameters that are hydrodynamically correlated.

The correlative relationship and stability of water quality in the pond ecosystem greatly affect the life patterns of the cultured shrimp. The sensitivity of shrimp to environmental conditions in the water will impact their growth patterns and harvest productivity (Trang et al., 2022). The water quality profile in shrimp ponds changes dynamically as the shrimp culture progresses. Older culture systems tend to have a more fluctuating and dynamic water quality profile (Ariadi et al., 2023).

Soil quality

The soil quality parameters in the shrimp pond ecosystem are described in Table 4. The soil quality at the pond sites tends to be quite good and meets the standard soil quality for shrimp pond ecosystems, except for the oxidation-reduction potential. The oxidation-reduction potential values in the ponds are generally quite low, ranging from -12.8 to -25.2 mV. The low redox levels are influenced by the concentration of oxidants and reductants in the soil. The intensity of nutrient abundance in the soil has a significant effect on soil productivity to support shrimp farming activities (Das et al., 2022).

The decrease in reduction and oxidation values in the soil is also influenced by microorganism activity (Chen et al., 2024).

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Table 2. Concentration of water quality in Degayu, Krapyak, and Slamaran ponds

Pond	Water Quality Parameters									
	pH	Temperature (°C)	Dissolved Oxygen (mg/l)	Salinity (gr/l)	Brightness (cm)	NO_2 (mg/l)	NH_3 (mg/l)	PO_4 (mg/l)	NO_3 (mg/l)	OM (mg/l)
Degayu Ponds										
1	8.2 ± 0.56	31 ± 1.63	5.48 ± 1.90	25 ±1.72	30 ± 3.80	0.171 ± 2.19	0.590 ± 2.91	0.810 ± 2.99	0.195 ± 2.05	78.39 ± 5.06
2	8.4 ± 0.44	32 ± 1.03	5.81 ± 1.49	25 ±1.69	35 ± 3.21	0.081 ± 2.42	0.429 ± 2.88	0.758 ± 3.19	0.169 ± 2.37	77.42 ± 5.91
3	8.2 ± 0.49	31 ± 1.28	6.05 ± 1.21	25 ±1.80	30 ± 4.08	0.181 ± 2.80	0.486 ± 2.08	0.833 ± 2.80	0.153 ± 2.493	75.99 ± 4.90
Krapyak Ponds										
1	8.0 ± 0.66	30 ± 1.03	6.05 ± 0.93	26 ±1.48	28 ± 3.20	0.119 ± 3.28	0.521 ± 2.77	0.914 ± 3.22	0.220 ± 2.36	84.93 ± 5.80
2	8.2 ± 0.61	30 ± 0.99	5.87 ± 0.87	26 ±1.62	30 ± 3.00	0.153 ± 2.85	0.538 ± 2.08	0.899 ± 3.05	0.192 ± 2.94	83.92 ± 4.75
3	8.2 ± 0.59	31 ± 1.26	6.17 ± 1.07	26 ±1.80	25 ± 3.81	0.180 ± 3.11	0.611 ± 3.11	0.965 ± 3.19	0.213 ± 2.46	84.26 ± 4.26
Slamaran Ponds										
1	8.3 ± 0.66	31 ± 0.89	5.62 ± 0.90	25 ± 1.90	35 ± 4.17	0.099 ± 3.68	0.320 ± 2.94	0.763 ± 3.29	0.172 ± 2.84	75.91 ± 4.37
2	8.1 ± 0.43	31 ± 0.94	5.83 ± 1.14	25 ± 1.82	35 ± 4.26	0.110 ± 3.52	0.392 ± 2.55	0.770 ± 3.82	0.163 ± 2.31	74.83 ± 4.00
3	8.4 ± 0.50	31 ± 1.26	6.00 ± 1.39	25 ± 1.99	33 ± 4.27	0.139 ± 2.91	0.297 ± 2.71	0.725 ± 3.36	0.188 ± 2.45	76.29 ± 4.72

Table 3. Results of water quality parameter correlation analysis

	pH	Temperature	DO	Salinity	Brightness	NO_2	NH_3	PO_4	NO_3	OM
pH	1									
Suhu	**.245***	1								
DO	.107*	**.381***	1							
Sal	.318*	**.117****	**.105****	1						
Brig	.444*	**.201***	**.379***	.424*	1					
NO_2	**.109****	.417*	**.707***	**.213***	.008*	1				
NH_3	**.529****	**.638***	.052*	.019*	.337*	.228*	1			
PO_4	.420*	.590*	.381*	.721*	.491*	.910*	.728*	1		
NO_3	.572*	**.588***	**.009***	.359*	.082*	**.005***	.620*	.008*	1	
OM	.229*	.005*	**.901****	.093*	**.106***	.102*	**.197***	.104*	.216*	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

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Table 4. Concentration of soil quality in Degayu, Krapyak, and Slamaran ponds

Pond	Soil Quality Parameters					
	pH	Redoks	CEC	% Sand	% Silt	% Clay
Degayu Ponds						
1	7.9 ± 0.45	-16.4 ± 0.15	21.55 ± 7.18	34 ± 7.11	58 ± 9.41	12 ± 5.90
2	7.9 ± 0.51	-12.8 ± 0.25	22.50 ± 7.36	38 ± 8.31	63 ± 9.19	18 ± 5.21
3	7.8 ± 0.60	-15.8 ± 0.17	21.28 ± 7.21	43 ± 8.90	65 ± 9.36	24 ± 6.05
Krapyak Ponds						
1	7.8 ± 0.62	-22.6 ± 0.12	25.61 ± 6.82	46 ± 8.31	52 ± 8.12	15 ± 6.01
2	7.7 ± 0.39	-25.2 ± 0.24	25.10 ± 6.26	43 ± 8.25	59 ± 9.22	19 ± 5.83
3	7.8 ± 0.99	-20.5 ± 0.20	23.91 ± 6.36	49 ± 7.99	57 ± 8.96	17 ± 5.86
Slamaran Ponds						
1	7.9 ± 0.75	-19.4 ± 0.12	24.71 ± 5.72	52 ± 8.50	49 ± 9.01	21 ± 7.74
2	7.8 ± 0.63	-18.5 ± 0.32	25.11 ± 5.43	57 ± 8.26	57 ± 8.68	19 ± 6.93
3	7.8 ± 0.76	-20.0 ± 0.28	25.27 ± 5.45	48 ± 7.27	59 ± 9.33	23 ± 7.32

In some coastal areas with clay soil texture, the reduction and oxidation capacity tends to be low. This is due to the low oxidizing capacity of the soil and the thermodynamic conditions of the soil (Qian et al., 2024). To address this, plastic is often used as an aquaculture medium in regions with clay soil texture.

Soil parameters play a vital role in the biophysical conditions of shrimp ponds. Ideal soil physicochemical parameters will affect soil conductivity, making the soil fertile (Banerjee et al., 2009). In intensive ponds with tarps as the cultivation medium, soil quality is often neglected. In general, soil parameters in shrimp ponds affect the concentration of water pH and organic matter (Hasibuan et al., 2023).

Correlation analysis shows that the %sand and %silt parameters do not correlate with other soil quality parameters (Table 5). The majority of quality parameters exhibit multi-parameter correlations. The diverse soil conditions at pond locations result in different characteristics. The majority of soil profiles for shrimp ponds in coastal areas are clay.

The profile and quality of the soil will impact the physical condition of the shrimp pond (Berlanga-Robles et al., 2024). The ideal soil for shrimp farming is compact in texture and rich in mineral elements. The dissolved mineral content of the soil will affect the dynamics of water quality and the stability of lime proportions (Lemonnier et al., 2010; Wu et al., 2023).

Table 5. Results of correlation analysis of shrimp pond soil quality parameters

	pH	Redox	CEC	% Sand	% Silt	% Clay
pH	1					
Redox	.317**	1				
CEC	.195*	.921*	1			
% Sand	.204*	.319*	.519*	1		
% Silt	.401*	.095*	.210*	.105*	1	
% Clay	.049*	.194*	.098*	.493*	.694*	1

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

Causal loop model of intensive shrimp farming

The causal loop model developed is based on the presence of water quality, soil quality, and biological parameters of shrimp, which influence the farming patterns (Figure 5). Each of these sub-parameters creates a causal impact that affects the productivity patterns of intensive shrimp farming. Intensive shrimp farming will also exert feedback (feed impact) on each of the sub-parameters. As a result, the causal model will reveal the combination of parameters that have the most significant influence on intensive shrimp farming.

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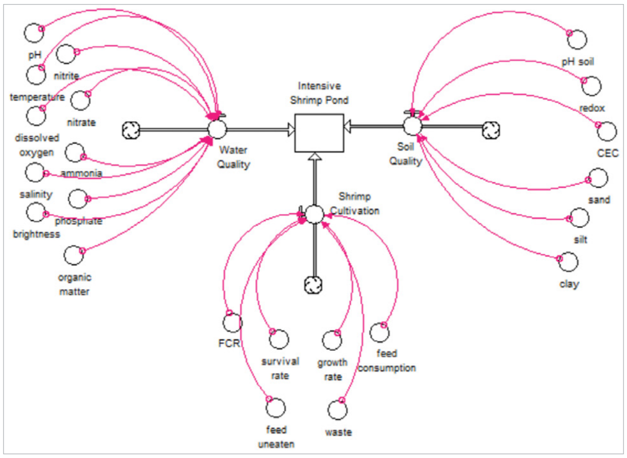

Fig 5. Causal loop model between water quality, soil quality, and shrimp farming operations

In the causal loop system concept, it can be used as a tool to examine the cause-and-effect relationships from multi-parameter interactions (Ram and Irfan, 2021; Dong and Vogel-Heuser, 2021). From the causal loop system, we can determine the influencing factors that can impact the sustainability of intensive shrimp farming operations. The results of the causal loop analysis will make it easier for farmers to determine the appropriate shrimp farming practices in their ponds.

This causal loop model illustrates the symbiotic relationship between water quality parameters, soil quality parameters, and technical farming indicators in relation to shrimp production levels in intensive ponds. Key water quality parameters that significantly impact the operational cycle of shrimp farming include pH, temperature, dissolved oxygen, salinity, brightness, nitrite, nitrate, ammonia, phosphate, and organic matter. Meanwhile, crucial soil quality parameters in the shrimp farming cycle include soil pH, redox potential, cation exchange capacity (CEC), and soil texture (sand, silt, and clay). Additionally, shrimp harvest productivity in intensive ponds is also influenced by biological factors such as shrimp growth rate, survival rate, feed conversion ratio, feed consumption, waste production, and uneaten feed. Correlatively, all these parameters interact with each other, impacting the stability of shrimp farming operations in intensive ponds.

The results of the causal loop model analysis are described in Figure 6. The dynamic modeling analysis shows that water quality and soil quality have the same fluctuation trend during the shrimp farming process. From post-stocking to week 15, there is an increase in the concentration load of each parameter by 5% per week, after which it decreases from week 15 to week 20. The shrimp farming cycle is described as showing an increase in shrimp growth from post-stocking to week eight, ranging from 500 to 2,500 kg/week per pond, after which it declines. The results of intensive shrimp farming show that the harvest productivity continuously increases from post-stocking to week 15, reaching 20,000 kg/ha, after which it decreases. This means that all sub-parameters in intensive shrimp farming operations exhibit an oscillatory pattern.

The results of the causal loop system analysis show that the operational pattern of intensive shrimp farming exhibits an oscillatory trend throughout the shrimp cultivation period. The majority of the trends indicate a decrease in performance during week 15 of the aquaculture period. Therefore, it can be stated that the peak performance of the operational cycle lasts only until week 15. This finding serves as a suggestion for farmers to intensify aquaculture management after week 15. Intensive shrimp farming has an optimal carrying capacity that must be considered, particularly in relation to the ecological conditions and shrimp production (Zhao et al., 2025).

Overall, it is shown that the water quality and soil quality parameters in intensive shrimp farms have similar concentrations. This is likely due to the farms being located in tropical aquatic areas that are geographically close. Both water quality and soil quality parameters have a high correlation and follow the same trend in modeling. Temperature fluctuations in tropical regions, which tend to be uniform and stable, contribute to the geochemical characteristics of water and soil quality parameters throughout the shrimp farming cycle (Perez et al., 2025). Based on physical, biological, and chemical characteristics, the water and soil quality parameters in tropical regions tend to be fluctuating and uniform (Lemonnier et al., 2016). This affects the biological performance of the cultivated shrimp.

The intensive farming pattern with high feed usage intensity will trigger dynamic fluctuations in water quality. The high feed intensity influences the solubility of organic matter, which continuously increases. Organic matter is crucial as it is closely related to the amount of oxygen consumed in the pond for decomposition processes. Oxygen consumption levels are related to the oxygen-carrying capacity in the pond ecosystem for aquaculture activities (Araujo et al., 2025; Zhao et al., 2025). Shrimp are organisms that do not tolerate living in hypoxic waters (Li and Brouwer, 2013; Nguyen et al., 2022).

In intensive shrimp farms, the harvest productivity tends to be more stable compared to other farming patterns. An increase in harvest productivity will affect the economic benefits gained by the farmers. Shrimp harvest productivity is influenced by both biotic and abiotic factors. Stable water and soil quality are essential prerequisites in shrimp farming (Rocha et al., 2022; Satanwat et al., 2023). Additionally, farming management practices, such as feed provision, use of chemicals, and the use of paddle aerators, will impact the success rate of shrimp farming (Araujo et al., 2025; Ariadi et al., 2023; Ngoc et al., 2021).

In tropical regions of Southeast Asia, such as Indonesia, Thailand, Vietnam, and the Philippines, the most ideal shrimp farming system is intensive pond farming.

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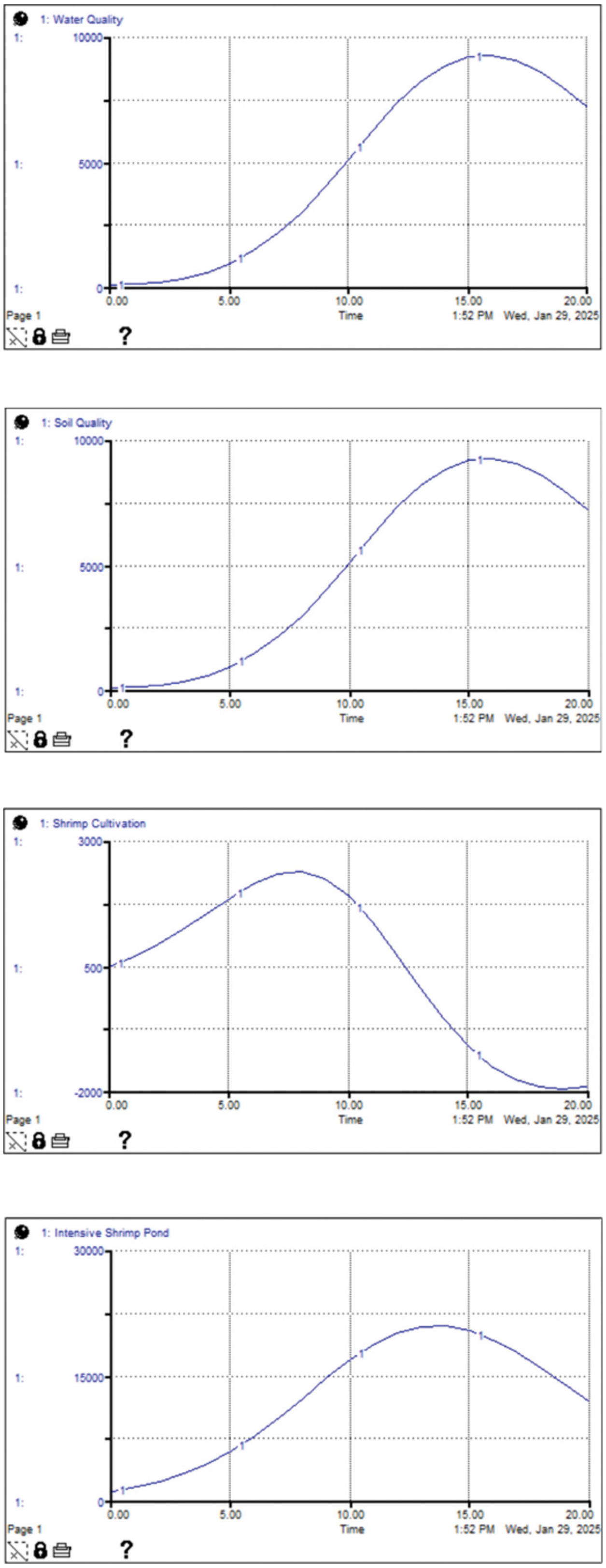

Fig 6. The results of the dynamic model analysis of water quality conditions, soil quality, shrimp growth, and shrimp harvest productivity in ponds

These countries have consistently warm weather and stable sunlight exposure throughout the year, with relatively low rainfall levels (Akber et al., 2020; Luo et al., 2022). Indonesia, as an archipelagic country, has extensive coastal areas that can be utilized for shrimp farming zones. This is highly beneficial in meeting the growing global per capita demand for shrimp protein each year. Utilizing coastal areas for shrimp farming while considering the sustainable carrying capacity of organic waste will help establish a standard for sustainable aquaculture. Additionally, this approach can serve as an innovation in optimizing coastal resources amidst the ongoing impacts of climate change.

CONCLUSION

The results of this study indicate that dynamic fluctuations in water and soil quality parameters within intensive shrimp farming ecosystems are strongly interrelated. This condition is closely associated with the causal relationships among the parameters, where each factor influences and is influenced by others. These interactions impact shrimp performance and are shaped by the management practices throughout the shrimp farming cycle. Another key conclusion from this study is that the high and continuously increasing feeding rates in intensive shrimp farms affect the solubility of organic matter in the ecosystem. This is demonstrated by the rising concentration of organic matter in shrimp ponds as the farming period progresses and feeding intensity increases. These findings highlight the importance of effective management strategies in intensive shrimp farming systems.

TOPLJIVOST ORGANSKOG MATERIJALA I ANALIZA DINAMIČKOG MODELIRANJA INTENZIVNOG UZGOJA RAČIĆA U OBALNOM PODRUČJU PEKALONGANA, INDONEZIJA

SAŽETAK

Interakcija između kvalitete vode i tla u intenzivnom uzgoju račića značajno utječe na uspjeh akvakulture. Ova studija imala je za cilj ispitati korelaciju između fluktuacija u kvaliteti vode i tla u ribnjacima s intenzivnim uzgojem račića i analizirati razinu topljivosti organske tvari korištenjem pristupa modeliranja dinamičkog sustava. Kao metoda istraživanja koristio se kauzalni *ex post facto* dizajn, sustavno prikupljajući podatke iz intenzivnih ribnjaka s račićima. Rezultati ukazuju da povećani rast račića potiče veću aktivnost hranjenja, što posljedično povećava proizvodnju otpada i topljivost organske tvari unutar ekosustava ribnjaka. S vremenom ovaj proces doseže točku zasićenja. Do petnaestog tjedna radnog ciklusa, kapacitet podržavanja otpada u ribnjaku se

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smanjuje, što u konačnici utječe na obrasce produktivnosti uzgoja račića. Tijekom uzgojnog ciklusa, fluktuacije u parametrima kvalitete vode i tla pokazuju ovu dinamičku interakciju. Studija identificira snažnu korelaciju između ovih čimbenika, s obrascima koji slijede oscilatorni trend u modelu. Kapacitet ekosustava prvenstveno ovisi o količini otpada, dostupnosti kisika za apsorpciju organske tvari i ukupnom stanju vodenog okoliša. Topljivost organske tvari pokazuje akumulativni obrazac tijekom radnog ciklusa, naglašavajući njenu ključnu ulogu u dinamici ekosustava. Studija zaključuje da su kvaliteta vode i tla inherentno povezani sa stabilnošću ekosustava ribnjaka. Osim toga, prisutnost i distribucija organske tvari, kako je utvrđeno kroz dinamičko modeliranje, služe kao ključni čimbenici koji utječu na ekološku ravnotežu u sustavima uzgoja račića.

Ključne riječi: uzročnost, hranidba, rast, modeliranje, otpad

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