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Dynamic Model Analysis of Waste Absorption Carrying Capacity Values in Semi-Intensive Shrimp Ponds

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Abstract. The stable availability of dissolved oxygen in semi-intensive shrimp ponds plays a crucial role in the sustainability of the aquaculture system. The objective of this study is to determine the trend of the dissolved oxygen carrying capacity for waste absorption during shrimp farming in a semi-intensive system. The method used in this research is causal-ex-post facto research with data analysis using dynamic modeling systems. The results show that the water quality parameters tend to be stable, except for organic matter (51.82–115.02 mg/L). The semi-intensive shrimp farming system demonstrates relatively high harvest production, attributed to rapid shrimp growth despite limited feed management, resulting in profitable outcomes. Dynamic modeling reveals that increased biomass correlates with higher waste output, affecting the dissolved oxygen (DO) carrying capacity. Modeling also shows a moderate and fluctuating waste runoff pattern, indicating variable DO consumption. An important finding from this research is that we can control the water's carrying capacity for waste adsorption by determining the ideal cultivation system. The study concludes that DO carrying capacity follows a linear relationship with waste load; as waste increases, oxygen demand rises accordingly to support organic matter decomposition and ecosystem balance. These findings highlight the importance of managing waste to maintain optimal oxygen levels in semi-intensive systems. The conclusions of this research are important to be used as a source for coastal area management studies based on carrying capacity.

Keywords: growth; oxygen; pond; shrimp; waste

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INTRODUCTION

Semi-intensive shrimp farming is the most popular farming system among small-scale farmers in Situbondo. The limited use of farming facilities makes the application of this farming system highly feasible. This farming pattern also tends to have minimal risks for development within the available farming area (Araujo et al., 2015). From existing case studies, the most common problem encountered in semi-intensive shrimp farming is waste (Valencia-Castaneda et al., 2022). A semi-intensive shrimp farming system that does not implement waste management and has a limited number of paddle aerators will affect the solubility of waste in the pond (Junior et al., 2025; Araujo et al., 2015).

Waste in shrimp farming is a significant issue that needs to be addressed. The presence of waste will trigger the growth of pathogenic microorganisms in the pond ecosystem (Mohamad et al., 2019). An increase in waste load will also impact the decline of dissolved oxygen carrying capacity for the decomposition process (Satanwat et al., 2023). This condition will be extremely dangerous for the survival of the shrimp being farmed (Wafi et al., 2021). Several studies mention that a high level of waste will affect the prevalence of vibriosis infections (Lemonnier et al., 2006). A high waste load will worsen the water quality as the medium for shrimp farming (Ariadi et al., 2023). Waste in semi-intensive shrimp farming comes from uneaten feed and shrimp feces (Dong et al., 2024). To manage the rate of waste accumulation in the pond, it is necessary to evaluate the dissolved oxygen carrying capacity for waste absorption. If dissolved oxygen availability is insufficient, it will lead to hypoxic conditions in the pond ecosystem (Wafi et al., 2021).

Waste and oxygen solubility are inseparable parts of shrimp farming. A high waste load will increase the competition for dissolved oxygen in the pond ecosystem (Li et al., 2019). This competition for dissolved oxygen will result in hypoxic water conditions (Wafi et al., 2021). These conditions will cause the shrimp to become stressed. When shrimp are stressed, their growth rate and immune system will decrease in correlation (Maiti et al., 2024). The impact is that shrimp will become more susceptible to diseases and death (Ariadi et al., 2024). Low oxygen solubility in the pond will trigger mass mortality of shrimp due to poor respiration (Nguyen et al., 2022; Araujo et al., 2015).

Several studies that have been conducted only focus on how to calculate the estimated carrying capacity and its short-term analysis. In addition, the results of existing research related to the carrying capacity of waste are still limited to static analysis. Therefore, a simulation analysis using modeling is very necessary to see in the long term how the carrying capacity of oxygen in waste absorption can last. Based on the background, the aim of this study is to determine the trend of dissolved oxygen carrying capacity for waste absorption during semi-intensive shrimp farming activities. The results of this study are expected to provide an overview of the dynamics of oxygen solubility levels in the pond and their relationship to the intensity of the existing waste load.

METHODS

Research Location

This research was conducted from June to August 2024 in an intensive shrimp pond area in Sukorejo Village, Situbondo Regency (Figure 1.). The study location was selected based on the highest intensity of shrimp farming activities in Situbondo Regency. Additionally, factors such as site accessibility and the stability of operational farming cycles were considered in determining the research location. It is necessary to explain the sampling technique, how many ponds were surveyed, whether only one pond or all ponds at the location.

Research Parameters

This study employed a causal *ex-post facto* design with data collection conducted through purposive sampling. The *ex-post facto* design is a research method that observes natural conditions in the field without manipulating variables. The considerations for purposive data collection included the duration of the shrimp pond's operational cycle, stocking density, farming patterns, and the total pond area.

The observed indicators in this study were water quality parameters and shrimp production parameters. Water quality parameters included pH measured using a pH Ecotestr™, salinity measured with a hand refractometer ATAGO M131, dissolved oxygen and temperature measured with a DO meter YSI 550i, organic matter analyzed using the titrimetry method, water color, and Brightness observed using a Secchi disk.

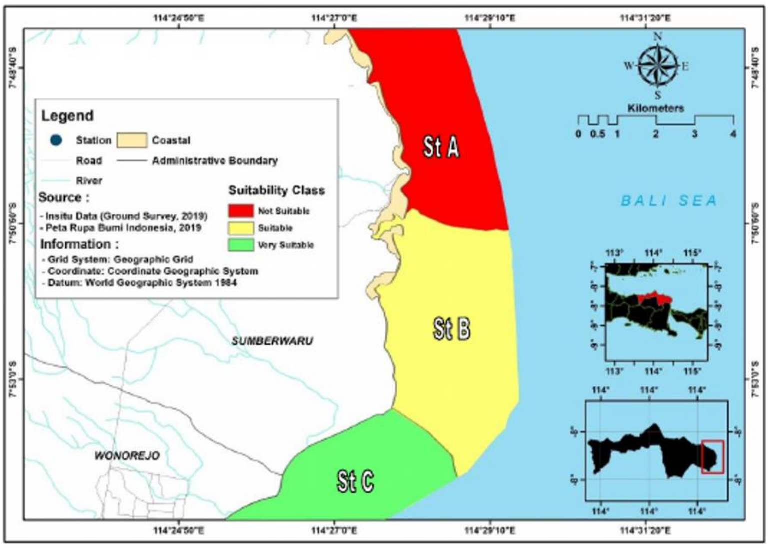


Figure 1. Sampling location

Water quality data were collected every seven days from the initial stocking of shrimp larvae until harvest. Shrimp production data were recorded weekly from stocking to harvest. The observed production parameters included final harvest tonnage collected during the total harvest, daily feed data, and shrimp growth rate, which was analyzed using the following formula (Ariadi et al., 2025):

$$ABW = \frac{W}{N}$$

$$ADG = \frac{W2-W1}{d}$$

Explain: ABW = Average Body Weight (gr/fry); ADG = Average Daily Gain (gr/day); W = Shrimp biomassa sampling (gr); N = Shrimp amount sampling (fry); W_2 = Shrimp body weight sampling (gr/fry); W_1 = Shrimp body weight sampling last periods (gr/fry); d = Time distance of sampling (day)

To calculate the daily feed allocation, the amount of feed consumed is determined using the following formula (Ariadi et al., 2025):

$$F/D = ABW*\%FR*100\%$$

Explain : F/D = Feed of the day (kg); ABW = Average Body Weight (gr/fry); %FR = feeding rate percent from feeding table; 100% = absolute shrimp survival rate

Data Analysis

Water quality parameters, such as pH, salinity, dissolved oxygen, temperature, brightness, and water color, were monitored *in situ* twice daily in the morning and evening. Organic matter was analyzed *ex situ*, while shrimp growth rate and feed consumption were assessed through in situ sampling. The harvest biomass was determined based on the total tonnage recorded during the final harvest. All collected research data were classified according to variables and data types before being analyzed using quantitative methods in Microsoft Excel 2021. Additionally, a dynamic system modeling analysis was conducted using Stella™ software version 9.02.

RESULTS AND DISCUSSION

Water Quality

The water quality parameters at the pond site are described in Table 1. In general, the water quality conditions in the pond ecosystem are still within the standards required for shrimp farming activities. The water quality parameter that is slightly critical is organic matter (51.82–115.02 mg/L). The salinity parameter is also relatively low, but still meets the water quality standards for shrimp farming. *Litopenaeus vannamei* are euryhaline, meaning they can live in a wide range of salinity (Asaro et al., 2023).

The high concentration of organic matter is caused by uneaten feed and shrimp feces (Dong et al., 2024). In addition, plankton lysis and the solubility of suspended particles also affect the organic matter solubility levels in the pond (Ni et al., 2018). In this study, the excessive solubility of organic matter was first observed at 21 days of age. High organic matter levels will cause the solubility of ammonia and hydrogen sulfide compounds (Torun et al., 2020).

The water quality parameters in the shrimp pond will fluctuate dynamically (Ariadi et al., 2023). The dynamics of water quality fluctuations will affect the biochemical processes within the pond ecosystem. Shrimp are sensitive organisms to fluctuations in water quality (Araujo et al., 2015). Extreme fluctuations in water quality will affect the growth rate of shrimp, causing it to slow down (Cheng et al., 2025). Furthermore, shrimp are also prone to stress when the pond water conditions are turbulent (Islam et al., 2024).

Table 1. Pond water quality parameters

Day Of Culture	Water Quality						
	pH	Salinity (ppt)	DO (mg/L)	Water Colour	Temperature (^{0}C)	Organic Matter (mg/L)	Brightness (cm)
1	8.3	17	5.72	brown	30.50	74.58	80
7	8.0	16	5.89	brown	29.20	51.82	100
14	8.2	12	7.18	brown	26.20	73.31	60
21	8.1	10	6.42	green	28.00	91.04	25
28	7.9	9	5.54	green	29.65	99.00	30
35	8.1	10	6.42	green	28.35	87.21	15
42	8.0	10	5.52	brown	27.80	98.59	10
49	8.4	11	6.29	green	29.40	106.18	26
56	8.3	20	5.63	green	27.45	101.91	25
63	8.3	22	5.62	green	28.15	105.38	25
70	8.2	27	5.28	green	29.60	107.44	30
77	8.2	25	5.72	green	29.75	115.02	30
84	8.0	25	5.89	green	27.50	112.49	25
91	8.4	21	5.41	green	27.55	92.27	25
98	8.2	22	5.53	green	29.70	85.95	30

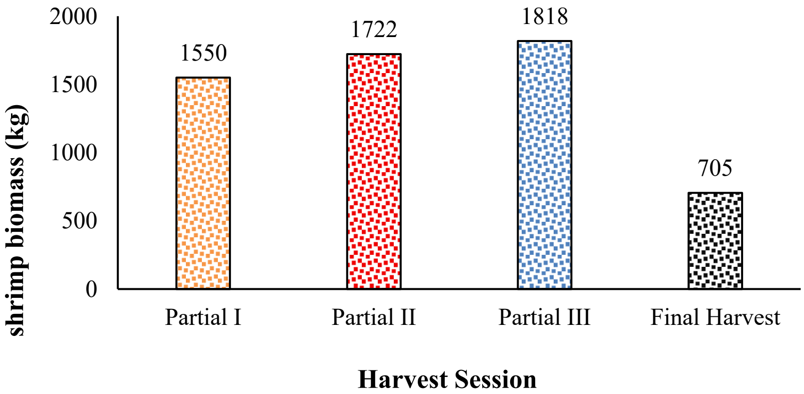


Figure 2. Shrimp harvest season records (primary research data)

Shrimp Harvest Production

The shrimp harvest production data during the study period are depicted in Figure 2. Throughout the study, three partial harvests were conducted before the total harvest. The biomass from the partial harvests was 1,550 kg (partial 1), 1,722 kg (partial 2), and 1,818 kg (partial 3) (Figure 2.). The total harvested shrimp tonnage was 5,795 kg. This amount is considered high for a semi-intensive pond

The frequent partial harvests were a precautionary measure to prevent overcrowding of shrimp populations in the pond. Partial harvests were also aimed at avoiding oxygen competition among the shrimp in the pond (Yu et al., 2009). Another benefit of partial harvesting is the reduction of waste load, minimizing the occurrence of loss mortality, and the effective use of paddle wheels (Estrada-Perez et al., 2016; Zahrina et al., 2024). Through partial harvests, at least the farmers were able to save tonnage to prevent harvest loss (Reis and Brites, 2025).

The partial harvesting system is considered effective in avoiding ecosystem damage in the pond caused by waste load (Ariadi et al., 2023). The use of partial harvesting is also deemed more effective for disease management (Yu et al., 2009; Reis and Brites, 2025). From the partial harvests, the pond was able to save dissolved oxygen by 1.0-1.7 mg/L/pond, which is consumed by the shrimp (Da Silveira, 2022). The reduction in waste load also affects the decrease in oxygen consumption for the decomposition process by detritus.

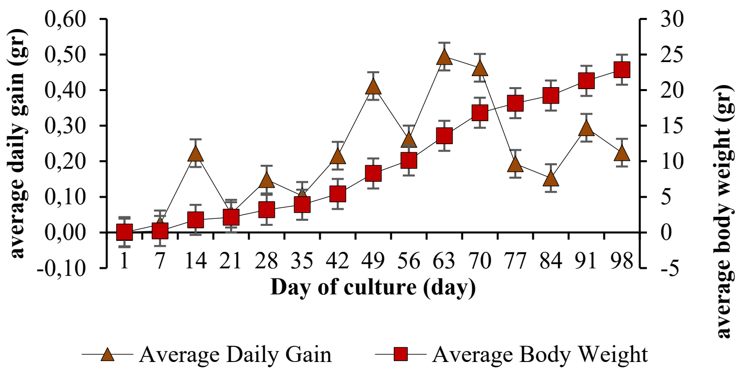


Figure 3. Shrimp growth rate and average body weight during cultivation periods

Shrimp Growth Rate

The shrimp growth rate during the farming period is presented in Figure 3. The weight of the shrimp is described as continuously increasing, while the average daily gain fluctuates. The fluctuations in shrimp daily gain are due to environmental conditions and the biological state of the shrimp. Under certain conditions, such as during moulting, the shrimp will experience a decrease in appetite, which impacts their growth rate (Li et al., 2023).

The physiological condition of the shrimp also consistently affects their growth rate. Stressed shrimp will experience a decrease in their growth rate (Li et al., 2024). Additionally, the quality of the feed and the inappropriate amount of feed provided will also affect the shrimp's growth rate, leading to suboptimal growth (Strebel et al., 2023). Preventive measures must be taken to maintain the biological health of the shrimp, ensuring their growth rate remains optimal (Reis and Brites, 2025).

As an aquatic organism, the growth performance of shrimp is also influenced by abiotic factors (Millard et al., 2021). Fluctuations in temperature and pH will impact the shrimp's appetite (Ponce-Palafox et al., 2019). Additionally, low salinity conditions will affect the shrimp's performance during moulting (Spencer et al., 2023). The vital role of water quality teaches us how important it is to consistently manage water quality with great care.

Feed Management

The average amount of feed given to each pond during the farming period is depicted in Figure 4. The daily feed amount shows fluctuations. The decrease in feed amount is due to partial harvests. Additionally, when the shrimp undergo moulting, the feed amount is reduced proportionally (Ullman et al., 2019; Strebel et al., 2023).

The feed amount continuously increases in line with the shrimp's growth rate. As the shrimp grow larger, their basal energy requirements also increase (Carvalho and Phan, 1998). This correlates with the increasing feed requirements (Strebel et al., 2023). Insufficient feed will impact the growth rate, leading to suboptimal growth during the shrimp's growth period (Junior et al., 2025). As a consequence, the increased feed amount will result in a higher waste load (Madusari et al., 2024).

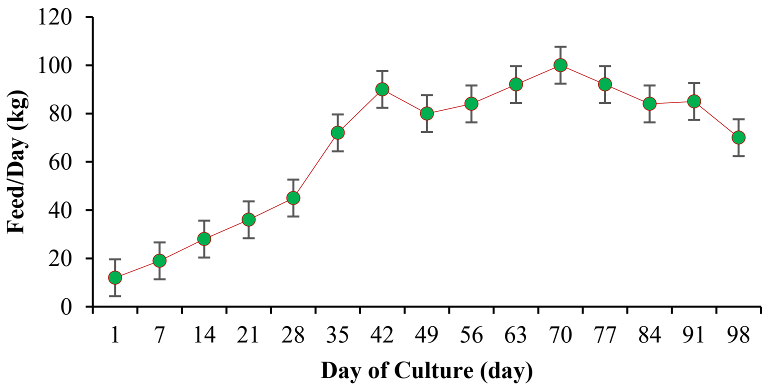


Figure 4. Feed management in the shrimp culture cycle

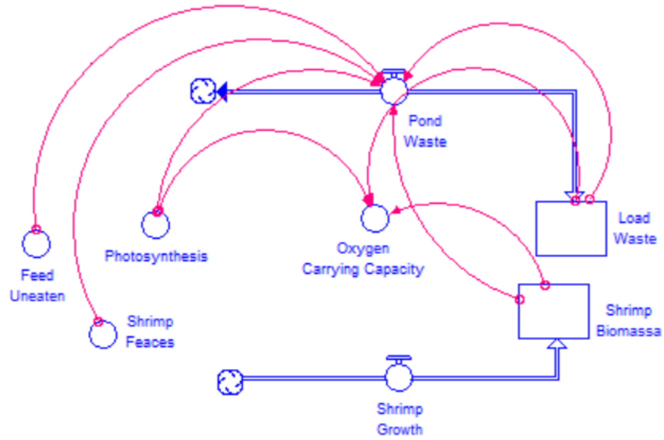


Figure 5. Causal loop model of waste production and oxygen-carrying capacity in shrimp pond ecosystems

Causal Loop Model

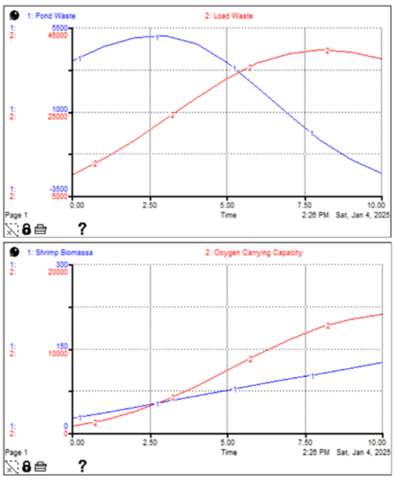
The concept of the causal loop model for oxygen carrying capacity and waste load is illustrated in Figure 5. To determine the carrying capacity and the trend of waste absorption by dissolved oxygen in the semi-intensive pond ecosystem, two subsystem models were created. The first subsystem is the conceptual model of waste in the pond. The second subsystem is the shrimp biomass in the pond.

The waste load in the shrimp pond comes from uneaten feed and shrimp feces (Dong et al., 2024). The shrimp biomass in the pond results from the accumulation of the shrimp's growth rate (Islam et al., 2024). The increase in shrimp biomass will affect the growing feed requirements (Satanwat et al., 2023). The increase in feed amount will impact the aggregate waste load (Naidu et al., 2025). This correlation will influence the carrying capacity status in the shrimp pond.

Pond Waste Load Model

The waste in semi-intensive ponds is shown to experience a fluctuating trend and has a negative correlation with the total waste load resulting from the farming activities (Figure 6.). When the waste in the shrimp pond decreases, the total waste load in the farming environment will increase. This indicates the sustainability effect of the waste production dynamics in the semi-intensive shrimp pond. The waste trend also shows a decrease on the one-hundredth day of the farming period. This is because, at that stage, the shrimp biomass has significantly decreased and is approaching the final harvest period (Reis et al., 2020).

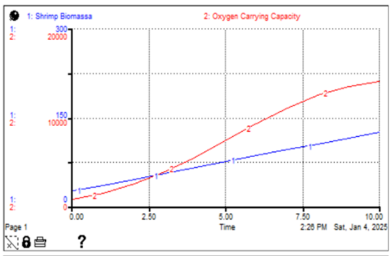
Waste in aquatic ecosystems will fluctuate oscillatively. The oscillation of the waste trend in the water is caused by the availability of dissolved oxygen as an oxidation compound (Dien et al., 2019; Jasmin et al., 2022). The waste will also decrease in quantity if there is an intense flushing rate (Ahmed et al., 2023). In semi-intensive ponds, the flushing rate tends to be minimal, so the dissolution of organic waste can remain consistent over a long period.



Time	Pond Waste	Load Waste
1	3.600	15.000
2	4.000	17.500
3	4.750	22.000
4	3.500	27.000
5	3.000	31.000
6	2.500	35.750
7	1.950	40.000
8	900	42.500
9	750	41.000
10	600	39.550

Time	Shrimp Biomass	Oxygen Carrying Capacity
1	1	10
2	5	125
3	15	475
4	22	970
5	28	2.000
6	34	4.050
7	44	7.755
8	58	10.100
9	70	13.750
10	86	15.000

Figure 6. Model results about waste production and oxygen-carrying capacity



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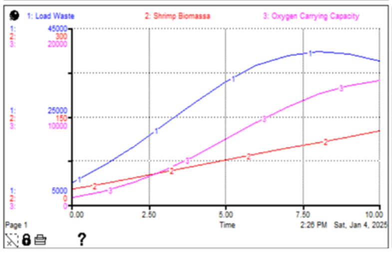
2	5	125
3	15	475
4	22	970
5	28	2.000
6	34	4.050
7	44	7.755
8	58	10.100
9	70	13.750
10	86	15.000



Time	Load Waste	Shrimp Biomass	Oxygen Carrying Capacity
1	15.000	1	10
2	17.500	5	125
3	22.000	15	475
4	27.000	22	970
5	31.000	28	2.000
6	35.750	34	4.050
7	40.000	44	7.755
8	42.500	58	10.100
9	41.000	70	13.750
10	39.550	86	15.000

Figure 7. Model results about oxygen-carrying capacity in the shrimp pond

Dissolved Oxygen Carrying Capacity Model

The carrying capacity of oxygen for waste absorption in a semi-intensive pond is shown in Figure 7. The dissolved oxygen carrying capacity in the semi-intensive pond follows a similar trend to the waste load dissolution rate in the pond ecosystem. The growth analysis results are described as continuously increasing in an aggregate manner. This means that the graph showing the increase in waste load, resulting from the accumulation of uneaten feed and feces, will gradually affect the oxygen-carrying capacity graph in the pond.

The dissolved oxygen carrying capacity for waste absorption impacts the suitability status of the water for aquaculture (Mardiana et al., 2023). Suitable water has an adequate level of dissolved oxygen for waste absorption processes at all times (Colette et al., 2022; Wu et al., 2022). According to several studies, a dissolved oxygen capacity of >4 kg/L/ha is required for the waste absorption process (McGraw et al., 2001). Furthermore, water is required to have a volume of 100 times the total volume of aquaculture water for the flushing process of organic waste (Green and Ward, 2011).

In general, the farming system applied in semi-intensive ponds affects harvest productivity. The semi-intensive farming system, which relies on limited artificial feed and minimal use of technology, tends to be more beneficial for increasing carrying capacity. The relatively low waste load in semi-intensive ponds positively impacts the stability of water quality conditions (Cooney et al., 2023; Araujo et al., 2015). This can be observed from the trend in oxygen solubility during the cultivation period, which consistently remains above 4.00 mg/L.

The dissolved oxygen carrying capacity for waste degradation from the modeling results is shown to have a positive correlation. This means that any increase in waste load in the pond will affect the carrying capacity value in an accelerated manner. In the semi-intensive farming system, the carrying capacity is influenced by the stocking density of shrimp and the amount of feed provided (Rocha et al., 2022; Mahapatra et al., 2022; Pai et al., 2022). Additionally, the effectiveness of the siphon also impacts the oxygen-carrying capacity for the waste decomposition process (Ariadi et al., 2023). The sources of oxygen in semi-intensive ponds come from photosynthesis, water exchange, and the use of paddle aerators (Yang et al., 2022; Wafi et al., 2021; Maharani et al., 2024).

This study highlights the accelerated response of dissolved oxygen carrying capacity to incremental waste loads in semi-intensive shrimp ponds. It uniquely correlates stocking density, feed input, and siphon effectiveness with oxygen dynamics under minimal technological intervention. The integration of multiple oxygen sources in modeling oxygen capacity offers a novel framework for optimizing semi-intensive aquaculture systems. So the novelty and important information obtained from this research are expected to become a scientific study that can be elaborated in developing research on carrying capacity in coastal areas.

CONCLUSION

The carrying capacity of dissolved oxygen in the semi-intensive shrimp pond is depicted to have a linear graph in relation to the pond's waste load. This means that the higher the waste load produced in the pond, the greater the oxygen demand for the absorption of organic matter and the oxygen consumption dynamics within the pond ecosystem. The relatively low feed input in the semi-intensive shrimp farming ecosystem significantly impacts the stability of the carrying capacity, which is adequate for waste degradation processes.

Future research should explore how varying shrimp farming models influence oxygen demand and waste decomposition efficiency in semi-intensive systems. Further investigation is also needed to assess the role of natural oxygen sources, such as photosynthesis and water exchange, under different environmental conditions. Additionally, integrating real-time monitoring technologies could enhance predictive models for dissolved oxygen dynamics and improve overall pond management strategies.

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AUTHOR CONTRIBUTION STATEMENT

All authors contributed significantly to the work reported in this manuscript. AW conceived and designed the study, conducted the data analysis. HA was responsible for data collection, conducted the data analysis, and supported data visualization. Author TM assisted in the literature review and provided substantial feedback during the manuscript drafting process. All authors read and approved the final manuscript and agreed to be accountable for all aspects of the work.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this paper

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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