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Dynamic Modelling Analysis of *Vibrio* sp. and Plankton Abundance in Intensive Shrimp Pond

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Abstract. *Vibrio* sp. and plankton are important microorganisms in shrimp pond ecosystems. The research aims to predict the dynamics of *Vibrio* sp. and plankton abundance in intensive shrimp pond ecosystems based on causal model analysis. The research method used is an *ex-pose facto* causal design concept with quantitative descriptive data analysis using causal dynamic modeling. The results showed the water quality in the pond has a high correlation, except *Vibrio* sp. and alkalinity. In the pond ecosystem 24 genus of plankton from 6 classes. *Chlorella* sp. is the dominant plankton genus with an abundance of 1.00E+05-4.00E+05 cells/ml. *Vibrio* sp. abundance in ponds ranged from 1.38E+03 - 1.31E+05 CFU/ml. Based on the results of dynamic modelling, the growth pattern of *Vibrio* sp. lasted for 30 weeks which was divided into 4 growth phases. The conclusion of this study is that *Vibrio* sp. will dynamically experience a pure growth rate for 30 weeks with details of the initial growth phase (1-7 weeks), logarithmic growth phase (8-14 weeks), exponential phase (15-21 weeks), and growth declination phase (22-30 weeks). The growth phase of *Vibrio* sp. has a high degree of similarity to the growth pattern of plankton in the pond water ecosystem correlatively. The novelty of this research lies in the discovery of an estimation model for the abundance of *Vibrio* sp. and plankton during the shrimp farming cycle. This finding can serve as a fundamental reference for farmers to optimize feeding processes and conduct regular siphoning during the peak abundance of *Vibrio* sp. and plankton.

Keywords: microorganisms; nutrient; oxygen; pond; waste

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INTRODUCTION

Vibrio sp. is a pathogenic microorganism commonly found in shrimp pond ecosystems (Purgar et al., 2023; Prakash et al., 2023). *Vibrio* sp. bacteria are toxic because they can cause stress in shrimp and lead to disease (Imtiyaz et al., 2023). Several diseases in shrimp associated with high abundance of *Vibrio* sp. include AHPND (*Acute Hepatopancreatic Necrosis Disease*), EMS (*Early Mortality Syndrome*), and WFD (*White Feces Disease*) (Wechprasit et al., 2019; Chandran et al., 2023; Kangze et al., 2024). Based on their characteristics, some of these diseases are preceded by co-infection between *Vibrio* sp. and other pathogenic organisms (Zhu et al., 2022; Saha et al., 2023). These diseases also exhibit similar symptoms in infected shrimp, including damaged hepatopancreas, stunted growth, abnormal feces, physical fragility, and a drastic decrease in appetite (Ariadi et al., 2023; Kangze et al., 2024).

The abundance of *Vibrio* sp. bacteria is also correlated with the presence of plankton communities. Intense plankton blooms will impact the increased abundance of *Vibrio* sp. after the bloom (Xu et al., 2022). This occurs because post-bloom, there is an accumulation of lysis waste from plankton (klekap) in the pond ecosystem (Soeprapto et al., 2023). This waste triggers an increase in organic matter and suspended materials in the pond water (That and Hoang, 2024). Intense accumulation of organic waste correlates with an aggregated increase in the population of *Vibrio* sp. (Mardiana et al., 2024).

This means that effective management of plankton is necessary to maintain stable water conditions.

The research conducted by Ariadi et al., (2019) indicates that *Oscillatoria* sp. abundance affects the intensity of *Vibrio* sp. population growth in shrimp ponds. A similar finding was reported by Linayati et al., (2024), stating that the *blooming* of *Chlamydomonas* sp. correlates with the *Vibrio* sp. toxicity in fish ponds. Plankton blooms impact changes in the pond ecosystems and the dynamics of aquatic microorganism abundance. Both plankton and *Vibrio* sp. are aquatic microorganisms that are highly resistant to changes in nutrient availability in pond ecosystems (Dien et al., 2018).

Ecologically, the plankton community in the pond also affects the growth patterns of shrimp (Soeprapto et al., 2023). This is closely related to the availability of natural feed for shrimp in the pond. We can control plankton dominance if we can consistently stabilize the N:P ratio in the pond (Lemonnier et al., 2010). *Vibrio* sp. can be controlled by consistently managing the C: N ratio in the pond water (Zhao et al., 2023). Some studies have examined the correlative relationship between the plankton abundance and the toxicity levels of *Vibrio* sp., however, research related to the simulation analysis of *Vibrio* sp. and plankton growth in shrimp ponds is still rare. The aim of this study is to predict the dynamics of *Vibrio* sp. and plankton abundance in intensive shrimp pond ecosystems based on causal model analysis.

METHODS

This research was conducted in the intensive shrimp ponds of Krapyak Village, Pekalongan, from June to August 2024. A total of 3 pond plots were used, each with a stocking density of 110 shrimp/m². The research method employed was a causal ex-post facto design, with data analysis conducted descriptively and quantitatively. To predict the dynamics of *Vibrio* sp. and plankton abundance, a dynamic modeling analysis was performed.

Research Parameters

The parameters observed in this study included water quality parameters such as pH, salinity, dissolved oxygen, turbidity, temperature, alkalinity, phosphate, nitrite, Total Ammonia Nitrogen, and Total Organic Matter. Additionally, the abundance of *Vibrio* sp. bacteria and plankton was also measured. The parameters of pH, salinity, dissolved oxygen, turbidity, temperature, and alkalinity were measured periodically every day in the morning and afternoon. Alkalinity, phosphate, nitrite, Total Ammonia Nitrogen, Total Organic Matter, and the abundance of *Vibrio* sp. and plankton were measured every seven days.

Data Analysis

The pH was analyzed using a pH ecotest, salinity was measured with an ATAGO AT311 refractometer, dissolved oxygen, and temperature were measured using a YSI550i DO Meter, and turbidity was assessed using a Secchi disk. Phosphate, nitrite, and Total Ammonia Nitrogen were analyzed using spectrophotometry. Alkalinity and Total Organic Matter were determined using titrimetry. To count the abundance of *Vibrio* sp. the Total Plate Count method was used on TCBS agar media. The abundance of plankton was counted using a Neubauer hemocytometer under an Olympus CX23 microscope. The plankton population abundance was calculated by the formula:

$$\mathbf{N = Z\ x\ \frac{\mathit{x}}{\mathit{y}}\ x\ \frac{1}{\mathit{v}}}$$

Note:
N : plankton abundance in a haemocytometer (ind/lt)
Z : plankton individual number
x : water sample filtered (40 ml)
y : water drop volume (0.06 ml)
v : water filtered (100 l)

Dynamic Modeling Analysis

The dynamic modeling analysis in this study was conducted using the software Stella ver. 9.02. The data used in the dynamic modeling analysis includes water quality data, *Vibrio* sp. abundance, and plankton, which are presented in a causal loop model. To determine the correlation between parameters, a correlation test was conducted using IBM SPSS software ver. 23.

RESULTS AND DISCUSSION

The results of the pond water quality parameter measurements over the 60-day study period are described on average in Table 1. The average concentration of water quality parameters in the ponds is quite good and meets the quality standards for shrimp farming. There are no significant differences in each parameter across the different ponds. This indicates that the ecosystem conditions in the ponds tend to be uniform and stable. The uniformity of water quality is attributed to the same standard operating procedures in aquaculture, which influence the water quality profile.

The turbidity value in the research ponds is categorized as relatively clear (51-55 cm). This is influenced by weather conditions, the abundance of organic materials, and the dynamic fluctuations in plankton abundance. Unstable weather can affect the intensity of sunlight exposure in the water (Chirdchoo et al., 2024). The plankton abundance and the solubility of organic materials will impact the turbidity level of the water (Setiabudi et al., 2016; Guo et al., 2022). Shrimp tend to prefer turbidity, as such conditions can accelerate the development of chromatophores in shrimp (Fitri et al., 2017; Best et al., 2023).

The Correlation of Water Quality Parameters

The results of the multi-parameter correlation test in this study are presented in Table 2. Based on the description in Table 2, it can be explained that only the alkalinity parameter and *Vibrio* sp. abundance do not show a correlation with the other parameters (parameter lines that are not bold). The other physicochemical parameters exhibit varying degrees of correlation. This finding aligns with the opinion of Ariadi et al. (2023), which states that water quality parameters in shrimp ponds have dynamic causal relationships among them. This causal relationship is related to trends in fluctuations and the dynamics of changes in the physicochemical conditions of water in the pond ecosystem (Linayati et al., 2024).

The lack of correlation between alkalinity and *Vibrio* sp. is attributed to the dynamic variance and fluctuations in the data. The concentration of alkalinity in the ponds is influenced by the solubility of CO_3, HCO_3, and OH^- (Ayini et al., 2014; Li et al., 2024). The population of *Vibrio* sp. in the ponds is triggered by an increase in waste load and a high C:N ratio occurring correlatively (Panigrahi et al., 2018). Some of these parameters were not measured in this study, which is why alkalinity and the abundance of *Vibrio* sp. do not correlate with the other parameters.

The dynamics of water quality parameters in the pond ecosystem will affect the performance of shrimp life. Shrimp biologically have an osmoregulation system related to the level of salt solubility in water (Anand et al, 2023). In addition, excessive solubility of oxygen and carbon dioxide will also cause hypoxia and hypercapnia conditions in the physiological functions of the shrimp body (Cruz-Moreno, 2024). The shrimp immune system is also influenced by dynamic pH fluctuations (Zhang et al, 2006). Likewise, other water quality parameters will indirectly provide a stimulus effect on the shrimp life cycle in ponds (Mardiana et al, 2023).

Table 1. Pond water quality parameters

Parameters	Ponds		
	A	B	C
pH	8.1±0.31 (7.5-8.9)	8.0±0.27 (7.5-8.7)	8.0±0.26 (7.4-8.8)
Salinity (gr/L)	28±2.15 (23-30)	28±1.85 (24-31)	27±2.30 (23-31)
Dissolved Oxygen (mg/L)	5.36±0.41 (4.18-6.28)	5.40±0.46 (4.18-7.15)	5.39±0.41 (4.25-6.24)
Brightness (cm)	55±24.59 (30-120)	51±21.46 (30-120)	54±23.85 (30-120)
Temperature (°C)	30.10±0.72 (28.00-31.80)	30.20±0.75 (28.30-32.00)	30.00±0.69 (28.20-31.60)
Alkalinity (mg/L)	109±5.55 (100-116)	106±6.39 (100-116)	109±6.21 (104-116)
Nitrite (mg/L)	0.259±0.24 (0.000-0.682)	0.072±0.07 (0.004-0.199)	0.054±0.04 (0.005-0.127)
TAN (mg/L)	0.063±0.04 (0.000-0.123)	0.057±0.07 (0.000-0.214)	0.055±0.06 (0.000-0.182)
Organic Matter (mg/L)	75.18±32.19 (0.000-98.14)	84.78±12.54 (68.26-101.12)	82.15±14.02 (63.94-101.12)
Vibrio Count (CFU/mL)	1.45E+05 ± 2.0E+05 (5.00E+03 – 6.81E+05)	1.38E+03 ± 1.31E+06 (4.00E+01 - 4.12E+03)	1.86E+03 ± 2.45E+05 (5.00E+01 – 7.71E+03)

Table 2. The correlation tests of water quality parameters in pond ecosystems

Variable	pH	Salinity	DO	Temperature	Brightness	Alkalinity	Nitrite	TAN	TOM	TVC
pH	1	**-.577****	**.297***	**.429****	-.058	-.296	-.083	-.167	-.476	.239
Salinity	**-.577****	1	**-.282***	**-.514****	**-.398****	.346	.396	**.803***	.557	.018
Dissolved Oxygen	**.297***	**-.282***	1	**.306***	-.191	-.409	-.314	**-.895****	-.609	.152
Temperature	**.429****	**-.514****	**.306***	1	.067	-.284	-.408	-.594	**-.742***	-.274
Brightness	-.058	**-.398****	-.191	.067	1	-.373	**-.715***	-.602	-.646	-.357
Alkalinity	-.296	.346	-.409	-.284	-.409	1	.040	-.101	.290	.195
Nitrite	-.083	.396	-.314	-.408	**-.715***	.040	1	.355	.066	.568
TAN	-.167	**.803***	**-.895****	-.594	-.602	-.101	.355	1	.485	-.067
TOM	-.476	.557	-.609	**-.742***	-.646	.290	.066	.485	1	-.063
TVC	.239	.018	.152	-.274	-.357	.195	.568	-.067	-.063	1

Note: *correlation is significant at 0.05 confidence level; **correlation is significant at 0.01 confidence level; TVC (Total Vibrio Count); TAN (Total Ammonia Nitrogen); TOM (Total Organic Matter)

Table 3. The plankton genus in the shrimp pond ecosystem during the research period

Plankton genus	Abundance (cell/ml)		
	A1	A2	A3
Chlamydomonas sp.	2.00E+04	5.00E+04	2.00E+04
Chlorella sp.	1.00E+05	3.60E+05	4.00E+05
Chodatela sp.	1.00E+04	1.00E+04	1.00E+04
Oocystis sp.	2.00E+04	1.00E+04	
Gleocystis sp.			1.00E+04
Anabaena sp.			1.00E+04
Chroococcus sp.			1.00E+04
Gomphosphaeria sp.			1.00E+04
Microcystis sp.	1.00E+04		
Oschillatoria sp.	3.00E+04	3.00E+04	9.00E+04
Amphora sp.	1.00E+04		
Cerataulina sp.			3.00E+04
Chaetoceros sp.			1.00E+04
Coscinodiscus sp.		5.00E+03	
Cyclotella sp.		2.50E+03	1.00E+04
Nitzchia sp.			1.00E+04
Streptoteca sp.	1.25E+04		
Euglena sp.	1.00E+04		
Alexandrium sp.		2.50E+03	
Chryptomonas sp.		1.00E+04	
Gymnodinium sp.		5.00E+03	
Noctilluca sp.	1.00E+04	2.00E+04	
Prorocentrum sp.	9.00E+04	1.00E+04	
Actinophrys sp.		1.00E+04	

The Plankton Abundance

The average abundance of plankton in the research ponds is presented in Table 3. The study identified 24 genera of plankton present in the pond water ecosystem. The most dominant genera in the pond ecosystem are *Chlamydomonas* sp., *Chlorella* sp., and *Chodatela* sp. These three genera were found in each pond (Table 3.) The highest abundance of plankton is observed in the genus *Chlorella* sp., with values ranging from 1.00E+05 to 4.00E+05 cells/ml. The dominance of *Chlorella* sp. indicates that the water conditions in the ponds are highly fertile.

In the pond ecosystem, the presence of plankton is crucial as a source of live feed and for oxygen production through photosynthesis (Seto et al., 2013; Tulsankar et al., 2021). The presence of certain plankton genera, such as *Chlamydomonas* sp. and *Chlorella* sp., plays an important role in photosynthesis (Soeprapto et al., 2023; Soeprapto et al., 2023). Plankton also serve as environmental biomonitoring agents (Aryawati et al., 2016). The dominance of plankton in the pond waters reflects the conditions of that water in relation to nutrient load status (Lu et al., 2023).

The Plankton Dominance

The results of the plankton dominance index analysis from shrimp pond water samples at the research site are presented in Figure 1. The results of the study indicate that the class Chlorophyceae has a very high percentage of dominance compared to other classes (Figure 1). This suggests that in the pond ecosystem, green algae are significantly more dominant than other types. The dominance of green algae is attributed to the cultivation cycle occurring during the dry season, as they tend to grow massively in warm water conditions (Binet et al., 2022).

Additionally, the high solubility of nutrients also greatly influences the dominance of certain plankton species (Luthfi et al., 2019; Zabbey et al., 2024). High nutrient levels enable several genera of plankton, such as Chlorophyceae and Cyanophyceae, to grow optimally (Narayana et al., 2020; Soeprapto et al., 2023). Some genera of plankton are also dependent on the salinity levels of the ponds (Pimentel et al., 2023). Stable salinity will affect the growth patterns and grazing cycles of plankton (Yang and Fan, 2023). The short shrimp cultivation cycle also impacts the dominance of plankton genera because the life cycles of plankton are relatively short (Soccodato, 2016).

***Vibrio* sp. Abundance**

The results of the average *Vibrio* sp. abundance from each pond during the study period are presented in Figure 2. Based on the illustration in Figure 2, shows that the abundance of *Vibrio* sp. in the ponds ranges from 1.38E+03 to 1.31E+05 CFU/ml. The highest abundance is found in Pond A, while Ponds B and C have relatively low levels. The high abundance of *Vibrio* sp. in Pond A correlates with the elevated concentrations of nitrite and Total Ammonia Nitrogen (TAN) in that pond. This indicates an excess of toxic nutrient levels in the pond. *Vibrio* sp. thrives in poor ecosystems, such as those with high solubility of toxic compounds (Kalvaitienė et al., 2023).

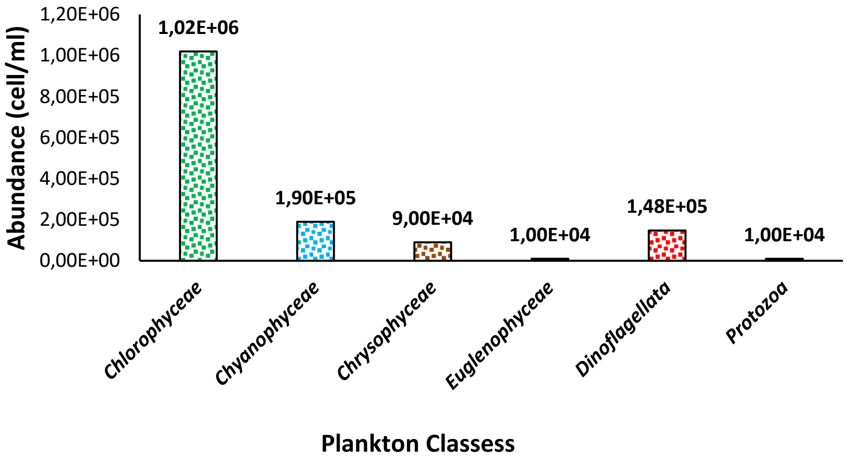


Figure 1. Dominance of plankton classes in pond ecosystems

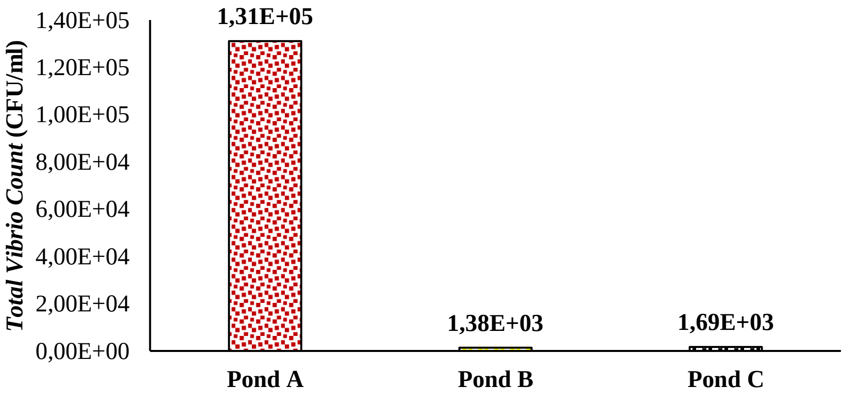


Figure 2. Vibrio sp. abundance in pond aquatic ecosystem

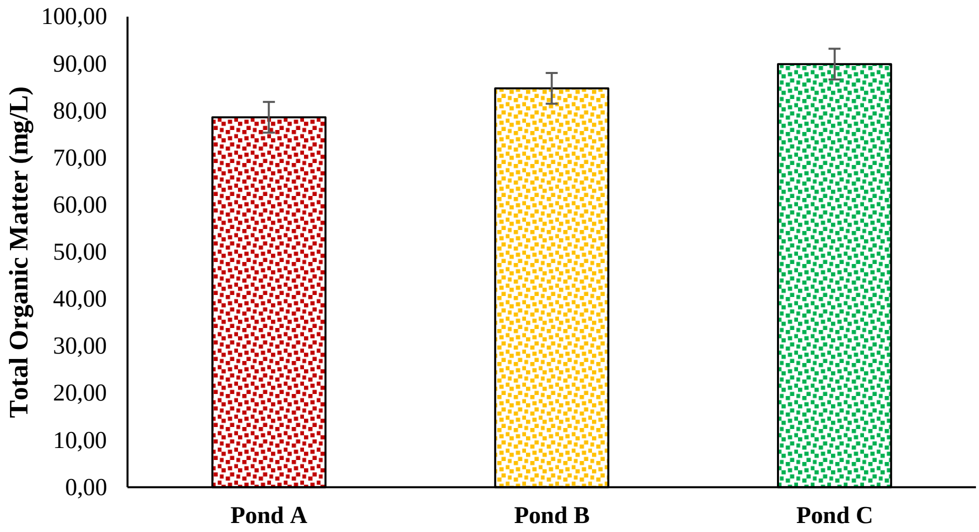


Figure 3. The organic matter solubility level in aquatic ecosystems

The high nutrient concentration in Pond A not only affects the abundance of *Vibrio sp.* but also correlates with the plankton population (Ljubesic et al., 2024). The plankton population in Pond A is denser compared to Ponds B and C. Aquatic microorganisms utilize the abundance of nutrients as single-cell proteins (Jones et al., 2023). This suggests a positive correlation: when the water has high nutrient levels, it impacts the abundance of diverse aquatic microorganisms.

The Organic Matter Concentrations

The average organic matter solubility level in shrimp ponds during the research period is presented in Figure 3. The concentration of organic matter solubility in the pond water tends to be relatively the same across the observed cultivation ponds. The concentration ranges from 75.18 to 84.78 mg/L (Figure 3). The short shrimp cultivation cycle and the regular implementation of siphoning significantly affect the solubility levels of organic matter. The flushing water from siphoning activities contributes to a significant decrease in the solubility of organic matter (Mardiana et al., 2023).

The solubility of organic matter also influences the abundance of *Vibrio* sp. The *Vibrio* sp. bacteria tend to grow massively in turbid pond ecosystems (Prakash et al., 2023). This can be observed from the high levels of dissolved organic matter and suspended particles in the pond ecosystem. Intensive cultivation ponds are very susceptible to increases in organic matter, which impacts the fertility of the water (Satanwat et al., 2023). One way to manage organic matter levels in the pond environment is through siphoning and the application of efficient feeding management (That and Hoang, 2024).

The primary sources of organic matter in pond water come from feed waste and shrimp feces (Islam et al., 2024). Additionally, there is shrimp shell waste, plankton lysis, and the carcasses of dead shrimp. Cumulatively, the dissolved and non-dissolved waste forms an abundance of organic material in the water (Ariadi et al., 2019; Yamsomphong, 2025). Good pond water is characterized by a concentration of dissolved organic matter <90 mg/L (Ariadi et al., 2019).

Shrimp Biomass Harvest

The results of the shrimp harvest biomass over the 60-day shrimp farming period in the research ponds are shown in Figure 4. The shrimp biomass resulting from the cultivation activities over 60 days ranges from 2,108 to 2,792 kg per pond. The highest production was observed in Pond C (Figure 4). The difference in shrimp biomass is not very significant due to the similar stocking density and cultivation duration. Ponds with longer cultivation periods tend to have higher tonnage. Under normal conditions, shrimp can convert feed biomass at a rate of 1.5 g/day (Nunes et al., 2022).

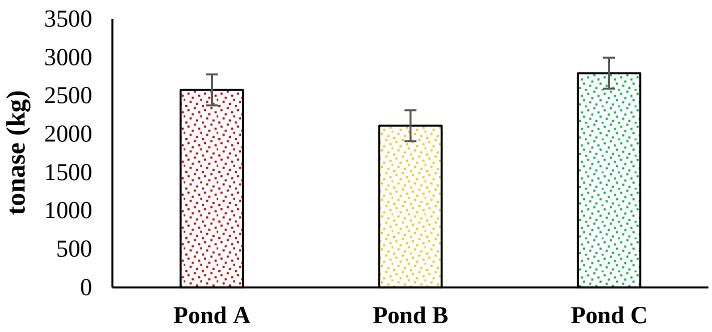


Figure 4. Total shrimp biomass harvest in research ponds

Additionally, the differences in shrimp biomass are influenced by the metabolic conditions of the shrimp being raised (Alam et al., 2021). Shrimp have an effective feed conversion capability when their physiological digestive conditions are good (Pazmino et al., 2024). This condition is also affected by environmental factors and the quality of the feed provided. The ideal proportion of feed formulation and appropriate feeding amounts will result in better biomass conversion efficiency (Nunes et al., 2022). This condition is often referred to as demand feeding.

The effectiveness of feed provision for biomass growth can be assessed through feed conversion ratios and consumption rates in the ancho (Ariadi et al., 2023). Hungry shrimp will readily consume feed in all areas of the pond. This result can be represented by the ancho media installed in the pond (Madusari et al., 2022). The amount of feed in the ancho represents the quantity that should be consumed by the shrimp (Ariadi and Wafi, 2020). The ancho also serves as a medium for monitoring the health conditions of the shrimp in the pond (Ariadi et al., 2023). Collapsed (abnormal) shrimp will rise to the top of the ancho as a physiological response (Best et al., 2023).

The Causal Loop of Vibrio sp. and Plankton Abundance in Ponds

The conceptual model illustrating the relationship between the abundance of *Vibrio* sp. in the pond water ecosystem is described in Figure 5. It shows that the population of *Vibrio* sp. is influenced by salinity levels and the dominance of *Vibrio* sp. itself. A high abundance of *Vibrio* sp. will impact the oxygen consumption levels in the pond ecosystem (Purgar et al., 2023).

The abundance of *Vibrio* sp. also affects the existence of plankton abundance in the ponds. This plankton dominance is attributed to the stability of water quality parameters and nutrient solubility levels (Saha et al., 2023). Thus, the causal loop model indicates a connection between the abundance of *Vibrio* sp. and plankton.

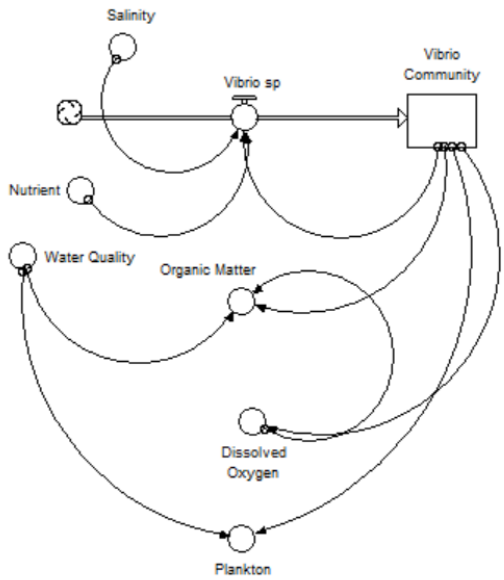
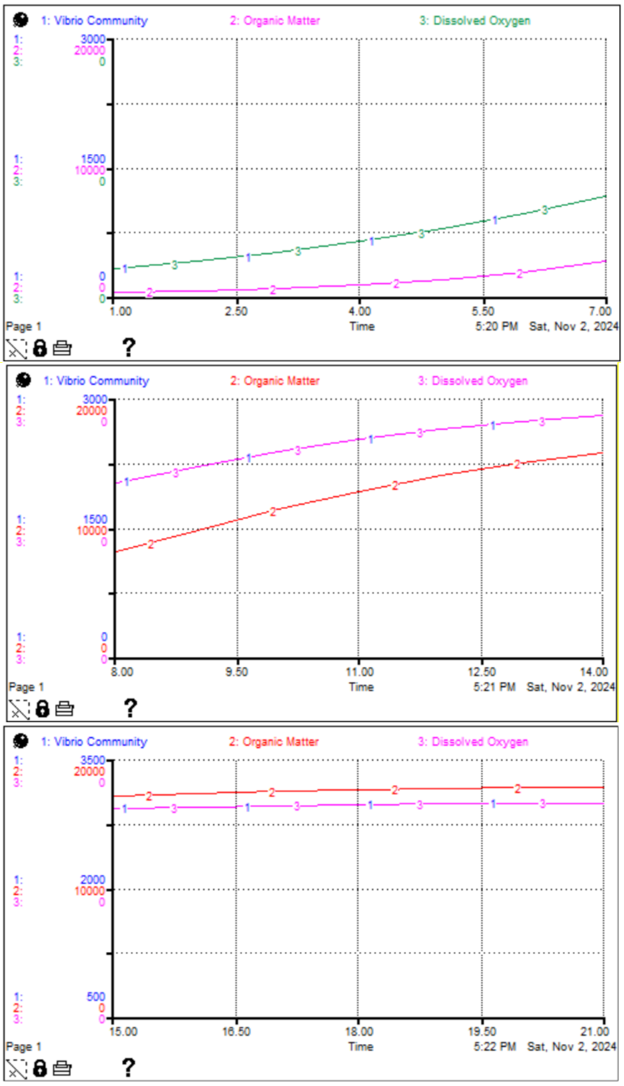


Figure 5. The Causal loop model of the abundance of Vibrio sp and plankton

The Abundance of *Vibrio* sp. Relative to Dissolved Oxygen Concentration

The results of the dynamic modeling simulation can be mapped to the predicted abundance levels of *Vibrio* sp., as described in Figure 6. From weeks 1 to 7, the abundance of *Vibrio* sp. in the pond is shown to continuously increase in an aggregate manner (Figure 6.). This condition is closely correlated with the oxygen consumption levels in the pond water (Ariadi et al., 2023). The increase in *Vibrio* sp. is similarly related to the increase in organic matter. By weeks 1 to 7, the abundance of *Vibrio* sp. is predicted to reach 1.50E+03 CFU/ml. The abundance will continue to rise during weeks 8 to 14, reaching 3.00E+03 CFU/ml. It will continue to increase gradually during weeks 15 to 21, with an abundance of 3.50E+03 CFU/ml. However, the abundance of *Vibrio* sp. will decrease during the shrimp cultivation cycle from weeks 22 to 30.

This indicates four phases of *Vibrio* sp. population spread in the pond ecosystem: week 1-7 (phase 1), week 8-14 (phase 2), week 15-21 (phase 3), and week 22-30 (phase 4). Phase 1 represents the early growth of *Vibrio* sp. in the pond ecosystem. Phase 2 marks the logarithmic growth stage of *Vibrio* sp. Phase 3 is the peak (exponential) growth stage of the *Vibrio* sp. population spread in the pond. Phase 4 is the decline phase of the *Vibrio* sp. distribution cycle in the shrimp pond ecosystem. The optimum growth phases are found in phases 2 and 3, or between weeks 8 and 21. This occurs because the bacteria have a stable growth cycle that progresses through the logarithmic, exponential, stationary, and decline phases in sequence (Jarvio et al., 2021).



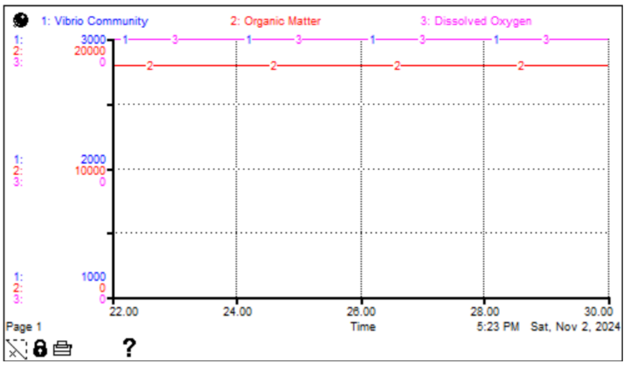


Figure 6. The modeling results of Vibrio sp. abundance in the shrimp pond during weeks 1-7 (top left image), weeks 8-14 (top right image), weeks 15-21 (bottom left image), and weeks 22-30 (bottom right image).

The analysis of this modeling also reveals that the normal growth cycle of *Vibrio* sp. in the pond ecosystem lasts a considerable length of time (30 weeks). *Vibrio* sp. are gram-negative bacteria whose life cycle is influenced by both biotic and abiotic environmental factors. The maximal growth pattern of *Vibrio* sp. during weeks 8 to 21 (phases 2 & 3) is also affected by high waste loads in the pond during that period. High levels of organic waste in the water significantly impact the massive growth of *Vibrio* sp. (Ariadi et al., 2019). Additionally, stable temperature and salinity levels in the water also influence the abundance of *Vibrio* sp. throughout the cultivation cycle (Zhu et al., 2022).

From the predictions generated by the dynamic modeling system, methods can be developed to suppress the *Vibrio* sp. population when the shrimp cultivation reaches 8 weeks. This allows for effective control of the logarithmic growth cycle of *Vibrio* sp. Increased siphoning activity can also be performed intensively during the cultivation period of 8 to 21 weeks (Vinasyiam et al., 2024). Techniques for suppressing the *Vibrio* sp. population may include introducing beneficial bacterial communities into the pond ecosystem during weeks 8 to 21 (Intriago et al., 2024). Partial harvesting and effective feed management also impact the accumulation of waste compounds in the pond ecosystem, which triggers the growth of *Vibrio* sp. (Dumont et al., 2023).

The Prediction of Plankton Abundance

The abundance of plankton populations in the ponds is influenced by nutrients and biotic factors in the water (Soeprapto et al., 2023). In terms of trends, the predicted abundance of plankton in the ponds follows a cycle similar to that of *Vibrio* sp. Plankton abundance exhibits a higher biomass growth ratio compared to *Vibrio* sp. This study indicates that plankton abundance is significantly greater than that of *Vibrio* sp.

The similarity between plankton and organic matter is due to the habitat shared by both organisms. Here, competition for oxygen and nutrients will also occur, as plankton have a faster capacity to absorb nutrients (Soeprapto et al., 2023). Both *Vibrio* sp. and plankton have long life cycles that heavily depend on the biotic and abiotic conditions of their environment (Ariadi et al., 2019).

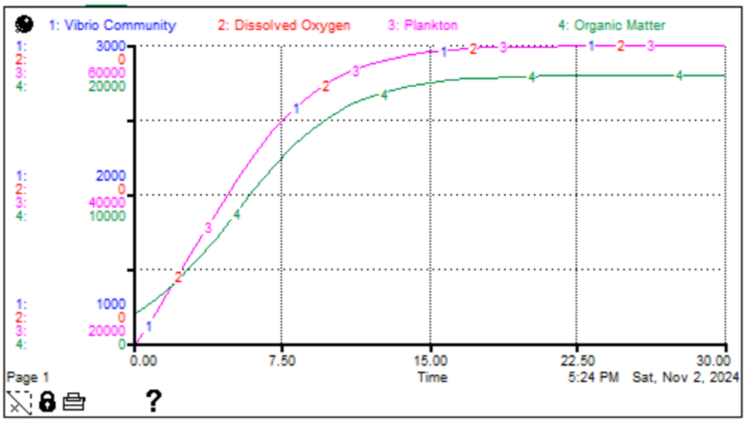


Figure 7. The results of the correlation modeling of the Vibrio sp. abundance with plankton

Stable water conditions and the addition of fertilizers or accumulated feed waste will positively impact the enrichment of the water (Islam et al., 2024). Such conditions will significantly affect the increase in populations of both *Vibrio* sp. and plankton. Effective feed management is necessary, such as using auto-feeders and adjusting feeding programs (Madusari et al., 2022). The presence of *Vibrio* sp. that can infect shrimp may lead to vibriosis. Additionally, *Vibrio* sp. can co-infect with other toxic bacteria that have similar life cycles (Chandran et al., 2023).

Intensive shrimp farming ponds with high waste output will correlate with the growth patterns of both *Vibrio* sp. and plankton (Ariadi et al., 2019). Technical efforts must be made in managing pond water to prevent plankton blooms. *Vibrio* sp. has a deadly impact on the shrimp life cycle (Chandran et al., 2023). Modeling results also indicate that the growth patterns of *Vibrio* sp. and plankton will affect the increasing levels of dissolved oxygen consumption. In aquatic ecosystems, dissolved oxygen acts as a limiting factor for microorganisms (Wafi et al., 2021). Oxygen is utilized for the decomposition and breakdown of nutrients present in pond ecosystems (Panigrahi et al., 2018). The processes of oxygen consumption and distribution will involve both bacteria and plankton in the pond water (Pimentel et al., 2023).

The intensive abundance of *Vibrio* sp. beyond 8 weeks in the shrimp farming cycle poses significant risks to shrimp growth rates. At this age, shrimp will rapidly consume feed as they are in the peak growth phase (Ariadi et al., 2019). During this stage, shrimp are also more susceptible to stress due to fluctuations in water quality (Qu et al., 2024). As shrimp age, they become increasingly vulnerable to environmental stress. Moreover, shrimp are highly sensitive to changes in environmental conditions (Zhang et al., 2024).

The novelty of this research lies in providing information related to the life cycle of *Vibrio* sp. bacteria and plankton in the intensive shrimp pond ecosystem through dynamic modeling analysis. Currently, there are no studies in the fields of microbiology or aquaculture that present detailed information on the life cycle of *Vibrio* sp. bacteria and plankton in pond ecosystems. The results of this study could serve as valuable information for aquaculturists in managing pond environments. *Vibrio* sp. bacteria and plankton blooms are primary issues that contribute to the emergence of various diseases in pond ecosystems. Additionally, the findings of this study provide the foundation for future research ideas related to developing a model for estimating shrimp farm environmental management based on a collaborative approach involving pathology and modeling.

CONCLUSION

Based on the results of this study, it can be concluded that the bacteria *Vibrio* sp. exhibits a dynamic growth cycle over a period of 30 weeks. Throughout these 30 weeks, the growth rate of *Vibrio* sp. can be divided into four phases: the early growth phase (Phase 1), the logarithmic growth phase (Phase 2), the exponential growth phase (Phase 3), and the decline phase (Phase 4). The growth patterns of *Vibrio* sp. show a high level of similarity to the growth patterns of plankton in the aquaculture ecosystem in a correlational manner. Based on the results of this study, the information that can be developed for future research is the need for the development of causal relationship analysis between *Vibrio* sp. abundance and specific plankton species at the species level in shrimp pond ecosystems, as a foundation for the development of dynamic system modeling analysis applications in the field of aquaculture.

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