



Relationship of Plankton Abundance to Hemocyte Profile and Phagocytic Activity of Whiteleg Shrimp (*Litopenaeus Vannamei*) in Different Pond Management, East Java, Indonesia

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Abstract

Plankton is an important component of aquatic ecosystems that acts as natural food and water quality indicators, with distribution influenced by environmental factors such as nutrients, temperature, and dissolved oxygen. This study evaluated the spatial and temporal dynamics of plankton in supra-intensive, intensive, and traditional ponds, and their relationship to water quality and the health of whiteleg shrimp (*Litopenaeus vannamei*). The results showed that supra-intensive ponds had the highest plankton abundance reflecting better ecosystem stability. Canonical Correspondence Analysis (CCA) analysis by comparing three whiteleg shrimp (*Litopenaeus vannamei*) pond cultivation systems, namely supra-intensive, intensive, and traditional, based on plankton abundance, water quality, and shrimp productivity. Supra-intensive ponds showed the highest plankton abundance (25,290–49,967 ind/L), this system produced the highest shrimp Total Hemocyte Count (THC) (12,000 cells/ μ L) and a phagocytosis rate of 85%, but high water quality fluctuations and high concentrations of phosphate, nitrate, and ammonia require strict waste management. Intensive ponds showed moderate plankton abundance (1,540–14,996 ind/L). This system achieved a balance between productivity (THC: 10,500 cells/ μ L; phagocytosis: 78%) and ecosystem stability through good water quality management. Traditional ponds had low abundance values due to low nutrient inputs and less intensive water management, reflecting a more naturally stable ecosystem. This system produced the lowest THC (9,000 cells/ μ L) and phagocytosis rate of 70%, with stable water quality but lower productivity (plankton abundance: 264–9,781 ind/L). These results indicate that supra-intensive ponds are superior in productivity but require intensive management, while traditional ponds are more environmentally friendly but less efficient. Intensive ponds offer a balance between productivity and sustainability. Thus, it can be said that there is a significant relationship between environmental parameters such as temperature, nitrate, and dissolved oxygen with shrimp growth and health, as measured by the total number of hemocytes and phagocytosis activity.

Keywords: Plankton dynamics, *Litopenaeus vannamei*, Shrimp health, different pond management.



Introduction

Plankton are small unicellular organisms that drift with the movement of water and are divided into phytoplankton and zooplankton. As an important component of the ecosystem, plankton contribute to the global biogeochemical cycle, carbon dioxide accumulation, and the basic food chain for aquatic biota. In shrimp ponds, plankton function as natural food, especially in the early stages of maintenance, and help inhibit the growth of moss and improve water quality by providing oxygen and maintaining water clarity (Abubakar et al., 2021).

The distribution of plankton in waters is uneven and tends to be in groups, influenced by environmental factors such as water quality, nutrients, temperature, brightness, dissolved oxygen, and pH. Plankton is an indicator of water conditions, with horizontal distribution influenced by the movement of water masses and vertical distribution by temperature and light intensity (Witariningsih et al., 2020).

Plankton in ponds act as natural food and water quality indicators. Plankton distribution is influenced by aeration, biotic interactions, water column stratification, and pond management. Light affects plankton vertical migration, with zooplankton moving according to light intensity to avoid predators (Ishak, 2017).

The temporal distribution of plankton is influenced by seasons, daily changes, and episodic events such as phytoplankton blooms. Observations of distribution were conducted by sampling at various depths and times, as well as analyzing environmental parameters. Daily vertical migration of plankton shows patterns of adaptation to light and predators (Hertika et al., 2021).

Plankton can also be an environmental bioindicator because it is sensitive to changes in water quality. The diversity and abundance of plankton indicate the stability of the pond environment, but some types such as *Dinoflagellates*, *Protozoa*, and *Blue Green Algae* can be detrimental. producing toxins, becoming parasites, or causing changes in water color that have a negative impact on shrimp. Therefore, monitoring the distribution of plankton abundance is important to maintain the quality of the pond environment as seen from the quality of the hemocyte cells of vaname shrimp (Zulfikar, 2023).

Research Methodology

Research area

The research was conducted in June - September 2024 in a vaname shrimp pond located in Kandang Semangkon, Paciran District, Lamongan Regency, East Java (Figure 1.) precisely in 6 pond plots with details of supra-intensive ponds (2 plots), intensive ponds (2 plots) and traditional ponds (2 plots) with different management management.



Figure 1. Sampling locations at Station 1 supra-intensive ponds, Station 2 intensive ponds and Station 3 traditional ponds.



Sample Preparation

Shrimp sampling in ponds with 3 replications at (DOC 20, 35 and 50), plankton samples were then identified using a microscope to determine the type and abundance of plankton in the pond. Shrimp samples were taken for hemocytes using a 1 ml injection that had previously been given 10% sodium citrate and added with 0.05 ml of Trypan Blue (ratio 1: 1), then the mixture was homogenized using an 8-shaped hand (Estrada et al., 2022). To observe phagocytic activity, a challenge test was carried out using *Vibrio* sp. bacteria. after that it was homogenized using a stirrer and given a diluted Giemsa solution (ratio 100 ml: 1 gr).

Data analysis

This research analysis uses Canonical Correspondence Analysis (CCA) is a multivariate method used in aquatic ecology and biology to assess the relationship between organism communities and environmental variables (Legendre & Legendre, 2012). In the context of whiteleg shrimp (*Litopenaeus vannamei*) research, CCA is used to evaluate how various environmental factors affect the growth, health, and distribution of shrimp in ponds. In the context of research on the influence of spatial and temporal dynamics of plankton on different pond management, CCA can provide information on how these environmental variables affect water quality, shrimp growth, and shrimp health as assessed through various parameters, such as shrimp health as reviewed from total shrimp hemocytes, granular cells, semi-granular cells and hyaline cells and phagocytosis activity.

Analysis and Result

Composition and structure of plankton communities

The composition and structure of the plankton community are influenced by the type of pond management. Intensive management increases plankton abundance but decreases the diversity and stability of its community, so pond management must balance productivity and ecosystem health (Putri & Rahardjo, 2020). According to Rahmawati & Wahyudi (2021), plankton abundance is influenced by water quality, nutrients (nitrate, phosphate, silicate), light intensity, temperature, and management systems. Intensive ponds tend to have high plankton abundance due to nutrient inputs from feed and fertilizers. Physical factors such as temperature, salinity, pH, and dissolved oxygen also affect plankton growth, making plankton abundance and diversity important indicators of pond ecosystems.

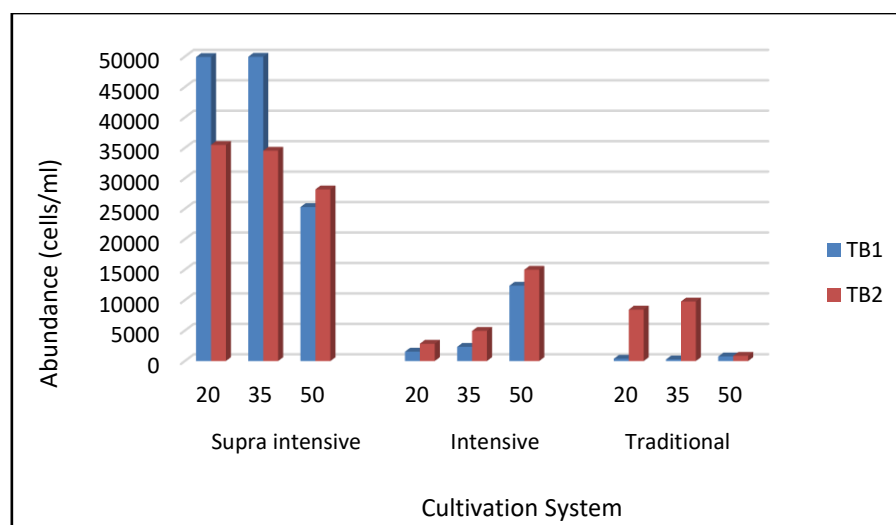


Figure 2. Results of plankton abundance (cells/ml) in different pond management systems.

Results were in supra intensive ponds DOC-20 (TB1: 49941.12 cells/ml; TB2: 35493.36 cells/ml).
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cells/ml), plankton abundance decreased in DOC-50 (TB1: 25290.24 cells/ml; TB2: 28185.12 cells/ml). Plankton abundance in supra intensive ponds was higher than in intensive and traditional systems, this was due to more intensive feeding, resulting in more nutrients to support plankton growth. However, the decrease in plankton abundance in DOC-50 was due to increased environmental pressure, such as waste accumulation or competition between plankton.

The high abundance of plankton in supra-intensive ponds (DOC-20 and DOC-35) has the potential to provide an abundant supply of natural food, such as *phytoplankton* and *zooplankton*, which are important for shrimp growth. However, in DOC-50, the low abundance of plankton is caused by the accumulation of organic waste or an increase in dead plankton biomass, which can cause oxidative stress and poor water quality. So that it can affect the proportion of hemocytes in whiteleg shrimp, such as: 1.) Granular cells (SG): Increased environmental stress can trigger the activation of SG which plays a role in shrimp immune defense. 2.) Semi-granular cells (SSG): SSG will be involved in the secondary immune response, especially for phagocytosis. 3.) Hyaline cells (SH): The number of SH can decrease because it is involved in the mechanism of shrimp blood coagulation which increases due to stress conditions. Based on these results, it can be said that the high abundance of plankton as shrimp nutrition, but if uncontrolled, can cause oxidative stress that triggers hemocyte responses, such as increased SG and SSG. A decrease in SH can also be observed due to intensive use to maintain immune function.

Plankton abundance increased in intensive ponds from DOC-20 to DOC-35, then the highest in DOC-50 (TB1: 12376.5 cells/ml; TB2: 14996.1 cells/ml). The increase in plankton abundance in DOC-35 and DOC-50 indicates an ecosystem adjustment to the available nutrients. The increasing abundance of plankton with increasing shrimp DOC in intensive systems can provide an optimal balance between natural food supply and environmental health, so as to maintain the normal proportion of SG, SSG, and SH.

TB1 in traditional ponds, it is known that plankton abundance is low during the observation period (DOC-20: 379.62 cells/ml, DOC-35: 264.18 cells/ml, DOC-50: 752.58 cells/ml), while in TB2 it shows higher abundance results compared to TB1 ranging from (9781.32 cells/ml) in DOC-35. It is known that plankton abundance is lower, especially in TB1 due to less nutrient input and less intensive water management. In the traditional system (TB1), low plankton abundance (DOC-20 and DOC-50) can be caused by low natural nutrients in the pond, which can reduce the quality of natural shrimp feed, and have an impact on the weak immune system, characterized by 1.) Decreased SG and SSG: Shrimp are more susceptible to infection because immune cells are not optimally activated, 2.) Increased SH: Shrimp that lack nutrition tend to show increased blood coagulation activity in response to environmental stress. In accordance with the research results of Effendi et al. (2022) stated that shrimp raised in ponds with poor water quality due to decreased plankton abundance showed a decrease in the number of hyaline cells (SH) and an increase in SG, which indicates an immune response to environmental stress. According to Widanarni et al. (2023) that low plankton abundance in traditional ponds is associated with natural nutritional deficiencies, causing a weak shrimp immune system, especially in SSG, so that shrimp are more susceptible to infection.

The highest plankton abundance was found in supra-intensive ponds (DOC-20 and DOC-35), while traditional ponds showed much lower plankton abundance, especially in TB1. In addition, the decrease in plankton abundance in DOC-50 in supra-intensive ponds indicates potential changes in water quality due to the accumulation of organic waste or dead plankton explosions. Based on the results of Navianda's research (2020), it shows that pond water quality, which is influenced by plankton and nutrients, affects the *Total Haemocyte Count* (THC) and *Differential Haemocyte Count* (DHC) in shrimp. Decreased water quality due to waste



accumulation or dead plankton explosions can trigger stress in shrimp, causing changes in the number of hemocytes, especially granular cells (SG) and semi-granular cells (SSG). According to Ningsih et al. (2021), optimal plankton abundance contributes to shrimp health, but uncontrolled plankton explosions can cause oxidative stress, increase hemocyte activity, and reduce shrimp resistance to disease.

Characteristics of plankton communities

Different pond management will result in variations in the distribution of plankton communities. Intensive and supra-intensive systems tend to have plankton dominated by stress-resistant species, while traditional ponds tend to support higher plankton diversity. During the research activities, 19 beneficial plankton species from 8 *phyla* were found in ponds with different management. The details of the distribution of these species are Class *Bacillariophyceae* (diatoms) 8 species, Class *Coscinodiscophyceae* (diatoms) 2 species, Class *Chlorophyceae* (Chlorophyceae (Green Algae) 3 species, Class *Trebouxiophyceae* (Chlorophyceae (Green Algae) 1 species, Class *Cyanophyceae* (Cyanobacteria) 2 species, Class *Euglenophyceae* (Euglenoid) 1 species, Class *Monogononta* (Rotifera) 1 species, Class *Branchiopoda* (Crustacea) 1 species.

Meanwhile, 32 species of harmful plankton were found from 10 *phyla* with details of the distribution of these species, namely Class *Bacillariophyceae* (diatoms) 5 species, Class *Coscinodiscophyceae* (diatoms) 4 species, Class *Dinophyceae* (Dinoflagellata) 7 species, Class *Zygnematophyceae* (Chlorophyceae (Green Algae) 2 species, Class *Xanthophyceae* (Yellow-green algae) 1 species, Class *Cyanophyceae* (Cyanobacteria) 3 species, Class *Monogononta* (Rotifera) 1 species, Class *Ciliophora* (Protozoa) 6 species, Class *Maxillopoda* (Crustacea) 2 species, Class *Tubulinea* (Amoebozoa) 1 species. The distribution of plankton in 3 parts of the pond water column (surface, middle and bottom) the diversity of the largest number of species on the surface with a total of 42,232 cells/L, the bottom column of the waters is 38,561 cells/L, while the middle column of water is around 37,520 cells/L.

The spatial distribution of plankton is influenced by pond management. Ponds with mechanical aeration technology increase dissolved oxygen, support plankton densities such as diatoms, but the accumulation of organic matter often triggers the dominance of Cyanobacteria that are tolerant to eutrophication. In contrast, traditional ponds with minimal technological intervention tend to have higher plankton diversity due to stable environmental conditions.

The vertical distribution of plankton is influenced by environmental factors such as light and nutrients. The surface layer has the highest abundance because the light is optimal for photosynthesis, supporting phytoplankton such as diatoms and green algae. The bottom layer, with nutrient accumulation and hypoxic conditions, supports plankton such as Cyanobacteria and Dinophyceae that are tolerant to extreme conditions.

Diatoms dominate with 8 species, acting as the main primary producers. Chlorophyceae contribute to primary productivity, although their abundance is lower. Dinophyceae and Cyanobacteria often cause ecosystem disturbances such as algal blooms. Ciliophora and Tubulinea are found as indicators of declining water quality due to the accumulation of organic matter.

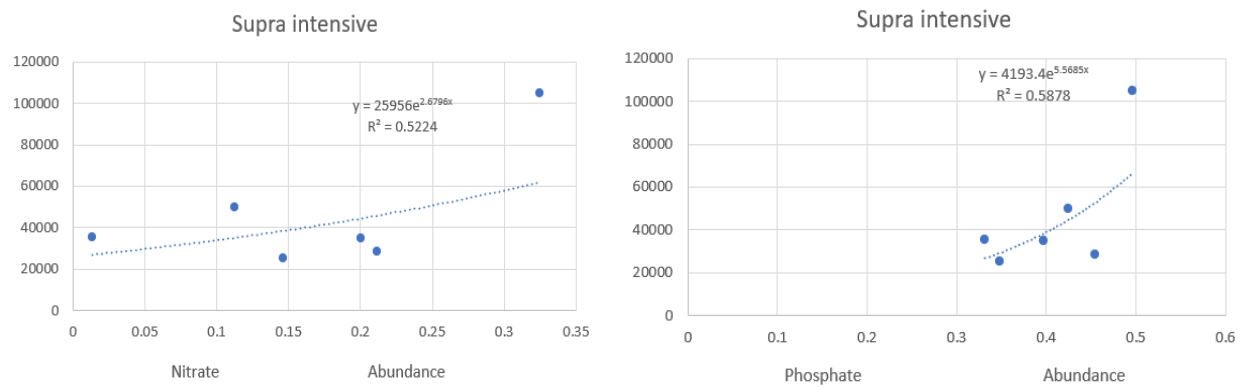


Figure 6. Correlation results of water quality (N/P) with plankton abundance in intensive Supra ponds

The correlation between nitrate and phosphate concentrations with plankton abundance showed different results. The coefficient of determination (R^2) of 0.5224 showed a moderate correlation, with 52.24% of the variation in plankton abundance explained by variations in nitrate concentration. Increasing nitrate concentrations tended to increase plankton abundance, especially Bacillariophyceae and Chlorophyceae, although other factors such as phosphate, light, and temperature also influenced.

The coefficient of determination (R^2) of 0.5878 shows a stronger correlation than nitrate, with 58.78% of the variation in plankton abundance explained by variations in phosphate concentration. Phosphate plays an important role in supporting primary productivity, especially in supra-intensive ponds, but excess phosphate can cause the dominance of certain species or algal blooms. Phosphate has a greater influence than nitrate on plankton abundance in supra-intensive ponds. However, a balanced combination of nitrate and phosphate is needed to maintain productivity without triggering ecosystem imbalance. Optimal nutrient management is essential to prevent the dominance of species such as Cyanobacteria which can damage water quality and pond production Suryadi et al. (2018).

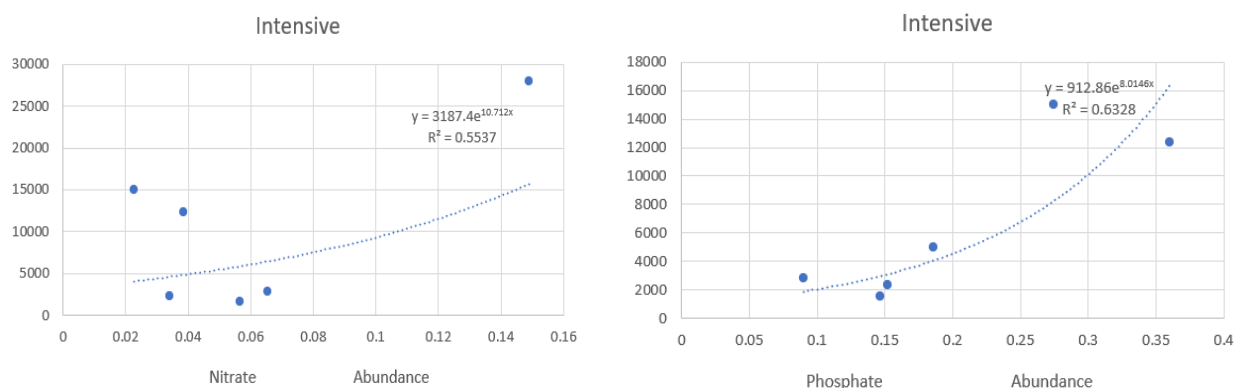


Figure 7. Correlation results of water quality (N/P) with plankton abundance in intensive ponds

The concentration of nitrate and phosphate with the abundance of plankton showed a difference in the level of influence of the coefficient of determination (R^2) of 0.5537 indicating a moderate correlation, with 55.37% of the variation in plankton abundance explained by nitrate concentration. Increased nitrate supports the growth of plankton, especially Bacillariophyceae (diatoms), but other factors such as phosphate, temperature, and light also play a role.



The coefficient of determination (R^2) of 0.6328 indicates a stronger correlation, with 63.28% of the variation in plankton abundance explained by phosphate concentration. Phosphate is an essential nutrient and the main limitation in primary productivity, especially in intensive ponds. Phosphate has a greater effect than nitrate on plankton abundance. High phosphate availability increases plankton productivity but can cause the dominance of certain species, such as Cyanobacteria, which reduces water quality. Balanced nutrient management is essential to maintain pond productivity without damaging the ecosystem (Smith et al., 2019).

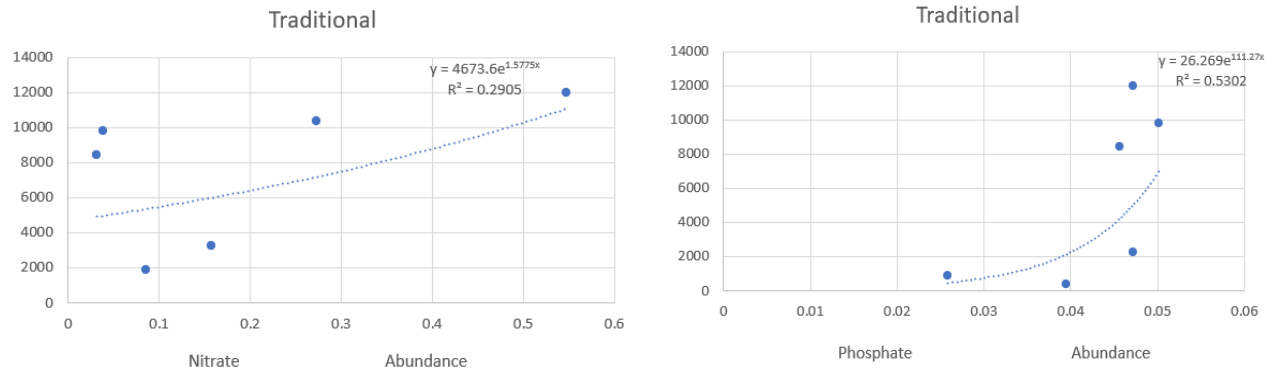


Figure 8. Correlation results of water quality (N/P) with plankton abundance in traditional ponds

The relationship between nitrate and phosphate concentrations with plankton abundance in traditional ponds showed a coefficient of determination (R^2) of 0.2905 indicating a low correlation, with only 29.05% of the variation in plankton abundance influenced by nitrate concentration. Nitrate is not the main factor influencing plankton abundance in traditional ponds, because nutrients are more natural and are not greatly influenced by the provision of nitrogen-rich fertilizers or feed.

The coefficient of determination (R^2) of 0.5302 indicates a moderate correlation, with 53.02% of the variation in plankton abundance influenced by phosphate concentration. Phosphate has a more significant effect than nitrate, supporting plankton productivity, especially phytoplankton. Phosphate comes from the decomposition of organic matter at the bottom of the pond. In traditional ponds, phosphate plays a greater role in supporting plankton abundance than nitrate. Traditional pond systems have a more stable source of natural nutrients, but do not always support optimal plankton productivity. Other environmental factors such as temperature, light, and water depth also affect plankton abundance.

The relationship between plankton dynamics and the health of whiteleg shrimp

Plankton as the main producer in the food chain, in addition, can trigger an immune response in shrimp when exposed to pathogens. Phytoplankton containing bioactive or potentially toxic compounds can cause stress in shrimp, which then triggers increased immune system activity and can produce more hemocytes. However, if shrimp stress continues in the long term, in unbalanced plankton conditions, shrimp will experience a decrease in immune system capacity, increasing their susceptibility to disease (Cakmak et al., 2011). Pond waters with plankton distribution, both phytoplankton and zooplankton, have a significant effect on the health of whiteleg shrimp (*Penaeus vannamei*), especially in the context of the immune response represented by the total number of hemocytes (THC). Hemocytes are blood cells in shrimp that function in the body's defense, both in the process of pathogen phagocytosis and in the immune response to environmental stress.

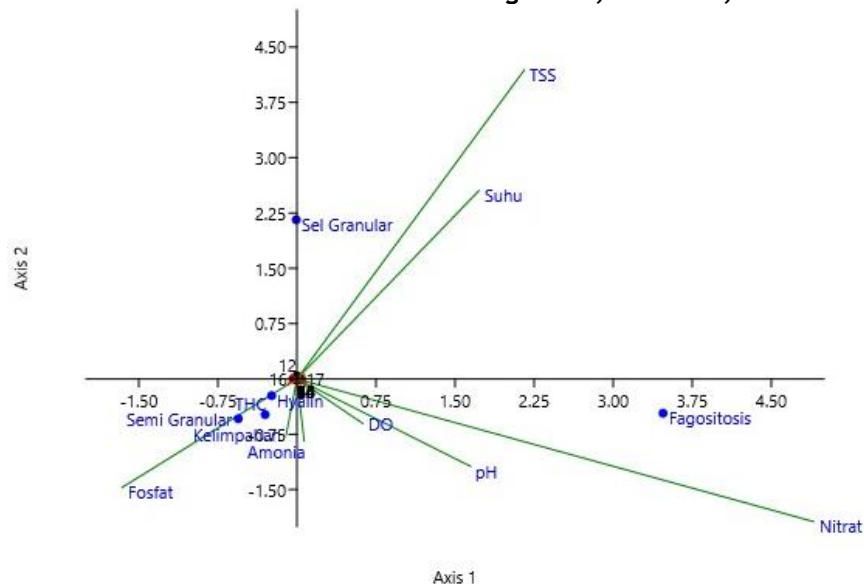


Figure 9. Relationship between the influence of water quality (physics, chemistry and biology) on the health of vaname shrimp (hemocytes) (research results)

The results of the study showed that healthy and diverse plankton distribution can increase the amount of THC in whiteleg shrimp, with different variations in influence on supra-intensive, intensive, and traditional ponds. Based on the graph, the levels of phosphate, ammonia, and plankton abundance in different pond management are closely related to the amount of THC, the number of semi-granular cells, and Hyaline cells in shrimp hemocytes, so it can be said that the higher the levels of phosphate, ammonia, and plankton abundance in the pond, the more hemocytes will produce and trigger an immune response and significantly affect the health of whiteleg shrimp.

While the TSS parameter, temperature in different pond management is closely related to the number of granular cells while the nitrate, pH and dissolved oxygen (DO) parameters are closely related to the ability of hemocytes in phagocytosis activity when exposed to *Vibrio sp.* bacteria. It is said that stable TSS and temperature values will increase the production of granular cells in shrimp hemocytes. Granular cells have a major role in the production of enzymes and proteins involved in phagocytosis and the formation of melanin capsules. The stability of these parameters supports shrimp health by increasing immune ability. If the nitrate, pH and dissolved oxygen (DO) parameters remain stable with routine control, it will increase the granular cells that are active in capturing pathogenic bacteria in shrimp phagocytosis activity. The stability of nitrate, pH and DO is very important to support the phagocytosis activity of hemocytes. Balanced nitrate prevents the accumulation of toxic nitrogen compounds, while optimal pH and DO support hemocyte metabolism and phagocytosis efficiency in capturing pathogenic bacteria such as *Vibrio sp.*

The results of the study showed that healthy and diverse plankton distribution has a significant effect on the health of whiteleg shrimp (*Litopenaeus vannamei*), especially through increasing the number of *Total Hemocyte Count* (THC) and hemocyte activity. Hemocytes are important components in the shrimp immune system, which play a role in the process of phagocytosis, melanin production, and immune response to pathogens. Water quality parameters such as phosphate, ammonia, nitrate, pH, dissolved oxygen (DO), Total Suspended Solid (TSS), and temperature are closely related to plankton dynamics and shrimp health.

Plankton Dynamics and Its Relationship to Shrimp Health, both phytoplankton and zooplankton, act as primary producers and nutrient providers in the pond ecosystem. Phytoplankton provide oxygen through photosynthesis and are a food source for zooplankton,

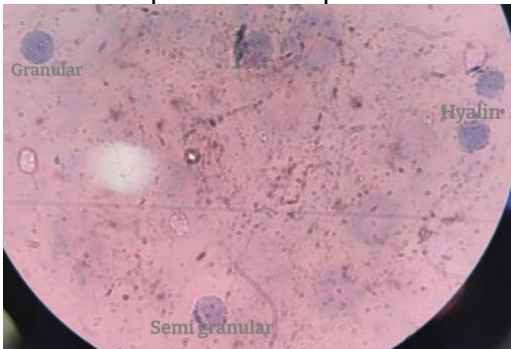
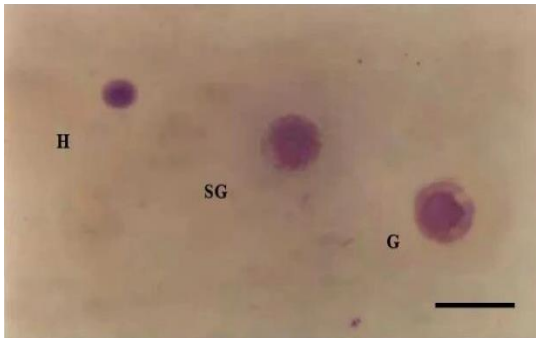
which in turn support the food chain in the pond. Pond conditions with different management (supra-intensive, intensive, and traditional) result in variations in plankton abundance and water quality. Healthy plankton distribution can increase the abundance of THC in shrimp, including semi-granular cells and hyaline cells, which play a role in the immune response.

Shrimp immune response mechanism to environmental dynamics, Shrimp hemocytes consist of three main types: granular, semi-granular, and hyaline cells. These three types of cells have different roles in the immune response: 1) Granular cells play a role in phagocytosis and the release of lysozyme enzymes; 2) Semi-granular cells are involved in the formation of melanin to fight infection; 3) Hyaline cells are responsible for the initial immune response to pathogens.

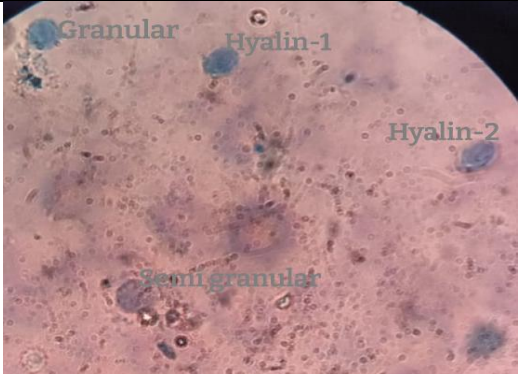
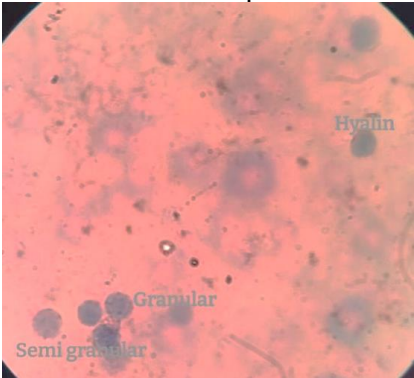
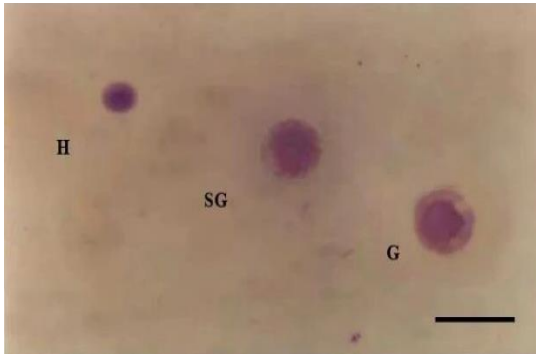
Diverse plankton distribution supports shrimp health by increasing hemocyte abundance and phagocytosis activity. Previous studies have shown that good water quality management can prevent stress in shrimp and improve immune function. So it can be said that healthy plankton dynamics and stable water quality parameters are very important in supporting the health of whiteleg shrimp. Parameters such as phosphate, ammonia, TSS, temperature, nitrate, pH, and DO must be monitored routinely to ensure optimal plankton abundance and support THC production and hemocyte activity. In addition, good pond management can improve the immune response of shrimp to pathogens, thus supporting the success of sustainable shrimp farming.

Based on their morphology and function, hemocytes in shrimp are classified into three main types: granular, semi-granular, and hyaline cells. Visualization and identification of the morphology of these three types of cells are often used to assess the immunological condition of shrimp, especially in the context of health and response to pathogens. The following (Table 1.) are the forms of semi-granular cells, granular cells and hyaline cells in shrimp hemocytes and the stages of shrimp phagocytosis activity:

Table 1. Granular cell shape, semi-granular cells and hyaline cells in shrimp hemocytes

No.	Types of hemocyte cells	Previous research
1	Supra intensive ponds  100x magnification (research result)	 (Jasmanindar 2009)
2	Intensive ponds	 (Jasmanindar 2009)



	 100x magnification (research result)	
3	Traditional ponds  100x magnification (research result)	 (Jasmanindar 2009)

Shrimp hemocytes are divided into three main types: hyaline, semigranular, and granular, each with specific functions. Detecting only granular cells can provide unique insights into the immunological status and physiological conditions of shrimp. Granular cells are known to play a major role in the immune response of shrimp, especially in the processes of phagocytosis, nodule formation, and encapsulation. These cells also contain lysozyme enzymes, antimicrobial proteins, and other compounds that help fight pathogens. In addition, the granules in these cells contain active ingredients such as prophenoloxidase (ProPO) which plays a role in the melanization cascade system to fight infection.

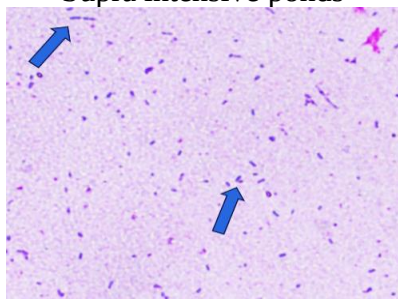
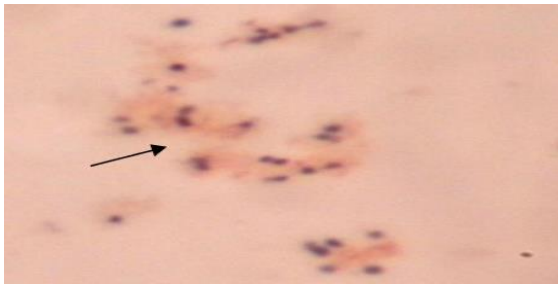
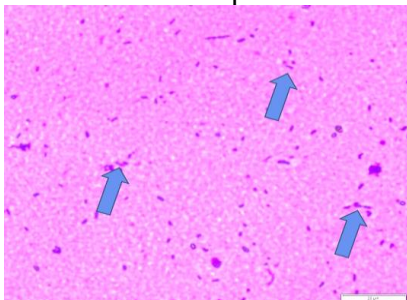
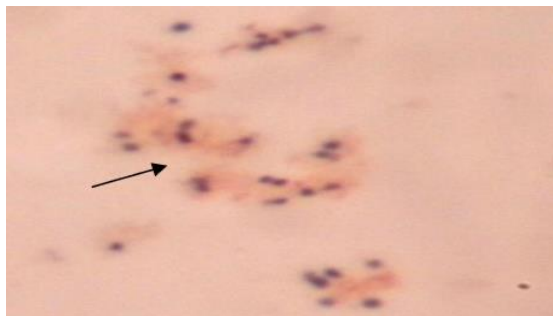
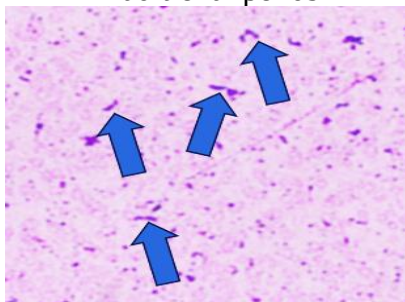
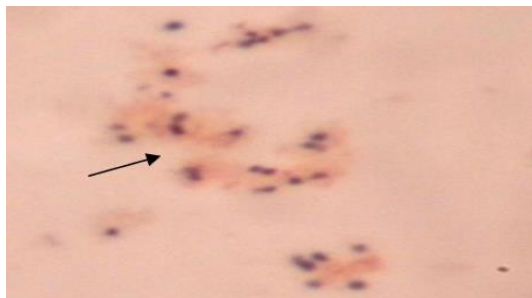
The presence of only granular cells may indicate that the shrimp is in an active phase of fighting pathogens or environmental stress. Granular cells usually increase when there is a bacterial, viral, or parasitic infection. The absence or low number of hyaline and semigranular cells may indicate an imbalance in the immune system, possibly due to exposure to environmental stressors such as poor water quality (extreme pH, high ammonia, or high nitrite). Poor pond environments may stimulate the dominance of granular cells as a form of immune adaptation in shrimp. Parameters such as high temperature, low oxygen (DO) levels, and ammonia can increase oxidative stress, triggering a granular cell-based immune response. The dominance of harmful plankton, such as blue-green algae, can produce toxins that trigger granular immune reactions.

Phagocytosis is one of the innate immune defense mechanisms in aquatic animals, including whiteleg shrimp (*Litopenaeus vannamei*). This process is carried out by hemocytes, which are blood cells in crustaceans, which function as the main component in fighting pathogens such as bacteria, viruses, and fungi. Hemocytes play an important role in recognizing, internalizing, and destroying pathogens through a series of biochemical mechanisms. The following are the



results of the whiteleg shrimp hemocyte phagocytosis challenge test.

Table 2. Results of phagocytosis activity tests on vaname shrimp hemocytes

No.	Phagocytic activity (research result)	Previous research
1	Supra intensive ponds  20x magnification	 (Juharni & Muchdar, 2011)
2	Intensive ponds  20x magnification	 (Juharni & Muchdar, 2011)
3	Traditional ponds  20x magnification	 (Juharni & Muchdar, 2011)

Hemocytes recognize pathogens such as *Vibrio* through pathogen-associated molecular patterns (PAMPs), such as lipopolysaccharide (LPS) on the bacterial cell wall. After recognizing the pathogen, hemocytes will internalize the bacteria through endocytosis. The captured bacteria will be inserted into the phagolysosome, where proteolytic enzymes and oxygen radicals destroy the pathogen.

Challenge test to determine the immune response of whiteleg shrimp hemocyte phagocytosis to *Vibrio bacterial challenge* showed that after exposure, the level of phagocytosis by hemocytes increased significantly. This reflects the activation of the innate immune response, higher doses of bacteria usually increase the phagocytic response, but too high doses can cause immune stress and shrimp death.

Findings and Conclusion

Supra-intensive ponds have the highest plankton abundance with optimal shrimp productivity, but the dominance of certain species and fluctuations in water quality indicate ecosystem



imbalance due to high nutrient content. This system requires advanced waste management and technology to maintain sustainability.

Intensive ponds demonstrate a balance between productivity and ecosystem stability, with better managed water quality and moderate plankton abundance. These systems are more efficient than traditional ponds, although they still face challenges in maintaining long-term sustainability.

Traditional ponds have naturally more stable plankton diversity and water quality, supporting an environmentally friendly ecosystem. However, their productivity and land use efficiency are lower than other ponds, making them suitable for cultivation with minimal technological intervention.

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