Phytoplankton performance in supporting primary productivity in the intensive culture system of vannamei shrimp

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Abstract. Plankton is an important element in supporting successful shrimp production, including in intensive ponds with high stocking densities and high frequency of feed application. This influences phytoplankton dynamics due to changes in water conditions. This study aims to analyze the dynamics of primary production related to the performance of the phytoplankton community and water quality in the intensive pond system. Observations were made on primary productivity, phytoplankton community structure, and water quality. The results showed that Chaetoceros and Rhizosolenia appeared in all observation with high densities, followed by Nitzschia, Straurastrum, Oscillatoria, and Peridinium with less densities. The diversity and dominance indices of plankton were relatively low with moderate to relatively high evenness index. There was increasing primary productivity over time and fluctuated characteristics of water quality. A strong correlation shown between nutrient (nitrate, nitrite and ammonium, and orthophosphate) and the abundance of phytoplankton that tend to increase due to the nutrients resulting from the decomposition. Diatoms mostly constructed the primary productivity of shrimp pond, which was supported by synchronous condition between organic matter and nutrients through the value of C/N and N/P, as well as the composition of plankton.

Keyword: nutrients; organic matter; shrimp pond; water quality

1. Introduction
In a shrimp pond ecosystem, plankton is an important element in supporting successful shrimp production, especially through the production of oxygen required for shrimp respiration [1] and also the biomass. Besides, the biomass of phytoplankton bends the light penetration and roe as shelter for the shrimps in the pond.

The intensive system ponds have high stocking densities and high frequency of feed application. The system receives material input, especially from the rest of the feed which results in a considerable increase in nutrients into the water [2]. In general, the increase in nutrient content will be followed by an increase in the plankton population [3]. As a result, in this system, there are phytoplankton dynamics due to changes in water conditions in the ponds.

Excessive increase in nutrients can cause changes in the composition and density of phytoplankton which can disrupt the life of vannamei shrimp in the pond. This condition can potentially lead to a lack
of oxygen at night and the emergence of dominance of the noxious species. On the other hand, the
condition of phytoplankton can also be indicated from the primary production or organic carbon
formation through photosynthesis process. The level of primary productivity reflects the dynamic of
phytoplankton community.
Both composition and density of phytoplankton depend on the environmental conditions in which
they live [4]. Therefore, changes in environmental conditions trigger changes in both of these.
Conversely, the existence of composition and density can also describe the environmental conditions in
which phytoplankton live. The dynamic or changes in water quality will cause differences in the
components of life requirements for microalgae, which are species specific [5]. This study aims to
analyze the dynamics of primary production related to the performance of the phytoplankton community
and water quality in the intensive pond system.

2. Materials and methods
The study was carried out on shrimp ponds at Sumur District, Pandeglang, Province of Banten (figure
1) in one production cycle (Sept-Dec 2018), for about 84 DOC; before the hit of tsunami, there. The
pond is constructed with central drainage, and the dense stocking of shrimp was 125 ind/m². The
observations were made on primary productivity (PP), phytoplankton community structure, and various
water quality parameters in twice a day (temperature, pH, and DO) and weekly (transparency, salinity,
nutrients: NH₃, NO₂, NO₃, and orthophosphate (PO₄), and COD) [6].

![Figure 1](image1.jpg)

Figure 1. Observation location of shrimp pond at Sumur, Pandeglang, Banten.

There was analysis of the phytoplankton community structure performs, such as diversity of
Shannon-Wiener, evenness, and dominance of Simpson [7, 8]. The C/P and N/P ratio [9, 10] was
determined as a database and was used in statistical regression [11] between C/N and PP, C/N and N/P, PO$_4$ and PP, and also between TAN and PP.

3. Results
There were found 30 genera of phytoplankton belongs to six classes. Those were Amphiphora, Bacteriastrum, Chaetoceros, Coscinodiscus, Cyclotella, Diploeci, Gyrogiga, Homidiscus, Lauderia, Melosira, Nitzschia, Rhizosolenia, Skeletonema, Oscillatoria, Pleurosigma (Bacillariophyceae), Stauroastrum, Trichodesmium, Closterium, Oocystis, Scenedesmus, Pediastrum (Chlorophyceae), Alexandrium, Gymnodinium, Peridinium, Ceratium (Dinophyceae), Chrococcus, Coelosphaerium, Microcystis (Cyanophyceae), Cosmocladium (Chrisophyceae), and Euglena (Euglenophyceae).

![Figure 2](image)

**Figure 2.** Phytoplankton of *vannamei* shrimp pond in 14 times of observation.

![Figure 3](image)

**Figure 3.** The performers of phytoplankton density, phosphate, and nitrogen in the shrimp ponds.

Some of the phytoplankton were always found along 14 times of observation, such as Chaetoceros and Rhizosolenia. The phytoplankton that appeared about 10 times or more were Coscinodiscus, Nitzschia, Stauroastrum, Oocystis, Peridinium, Oscillatoria, and Euglena. Some of them with high density, and vice versa (figure 2). Chaetoceros appeared in all observation with high densities, and Rhizosolenia with less density; followed by Coscinodiscus, Nitzschia, Stauroastrum, Oocystis, Peridinium, and Euglena with less densities; and then Oscillatoria with quite high density.
The number of genera and abundance of phytoplankton found tended to fluctuate during the observation. Apart from always being found throughout the observation, several genera were only found once during the observation, i.e. Bacteriastrum, Diploneis, Gyrogsima, Homidiscus, Lauderia, Melosira, Pleurosigma, Trichodesmium, Closterium, and Alexandrium.

There was dominance performance of phytoplankton community structure, which was shown by the group of Bacillariophyceae or Diatom. Even though, the dominance of Diatom in the shrimp pond indicates good water quality that will supporting shrimp life.

The total density combined with the condition of phosphate and total inorganic nitrogen along the observation is shown in Figure 3. Both nutrients tend to raise at the end of the observation, with the highest concentration at DOC 56 and 70 for phosphate and nitrogen. It indicated the raise of organic substances as nutrients source that came from the accumulation of the remaining shrimp feed. The increase of nutrients was followed by the raise of phytoplankton density in total.

Furthermore, the condition of phytoplankton community structure is presented in Table 1. The diversity and dominance ranged in low category, while the evenness showed moderate to relatively high category. A high level of diversity and evenness were found in the middle of the observation (DOC 49 and 56). There was a change in the composition of phytoplankton, but with a quite similar proportion of abundance, while the quantity continues to increase to the end of the observation.

Table 1. Community structure of phytoplankton in the shrimp pond.

| Index        | Value         |
|--------------|---------------|
| H'(diversity)| 1.0897–2.1068|
| E (evenness) | 0.4024–0.7436|
| D (dominance)| 0.1590–0.4977|

Figure 3 shows the dynamic of organic materials (represented by COD), the C/N ratio as representative of decomposition process, N/P ratio that indicated the result of decomposition process, and primary productivity that showed the utilization of nutrients by phytoplankton. The decrease of COD is followed by the decrease of C/N ratio. This shows that the decomposition process continues to progress more intensively along with the observation. The high protein content of feed produced high nitrogen from the decomposition process. With such of N/P ratio and adequate concentration, the primary productivity took place properly.

Figure 4. The performers of COD, C/N, PP, and N/P in the shrimp ponds.

The performance of phytoplankton that was supported by the water quality was also showed a good relationship towards the primary production (PP) of the pond. It was shown by the good relationship between C/N and PP, C/N and N/P, PO₄ and PP, and also TN and PP (Figure 5-8). The least R-value was shown by the relationship between C/N and N/P.
Figure 5. Relationship between primary productivity (PP) and C/N of the shrimp pond.

\[ y = -90.15\ln(x) + 488.19 \]
\[ R^2 = 0.9374 \]

Figure 6. Relationship between C/N and N/P of the shrimp pond.

\[ y = -2.125\ln(x) + 6.7864 \]
\[ R^2 = 0.5288 \]

Figure 7. Relationship between orthophosphate (PO$_4$) and primary productivity (PP) of the shrimp pond.

\[ y = -43.95x^2 + 250.12x + 6.4277 \]
\[ R^2 = 0.7934 \]
4. Discussion

To reduce the environmental impact of waste disposal and to prevent the entry of hazardous components into the water supply, a management change was made from an open system with frequent water disposal to a closed system with limited water disposal. However, a major problem with implementing closed systems is rapid eutrophication, which can raise nutrient concentrations to levels unsuitable for shrimp culture [12]. Therefore, pond productivity which has a great opportunity to be increased through the application of a semi-intensive system must be accompanied by a good design, layout, construction, and drainage network [13].

This is related to providing the environment required by shrimp during the production period. Water quality, such as temperature, salinity, and pH during the production period plays an important role in supporting shrimp life and growth because it affects the growth rate, mortality, molting frequency, and the appearance of harmful bacteria [14]. Good water change regulation as well as choosing the right type of feed and feeding management greatly affect the quality of pond water [15, 16]. The application of replacing water and feed changes along with the increase in DOC that lead to different ecological conditions, both physical, chemical, and biological conditions sequentially.

Good environmental conditions in pond waters allow for good ecological processes. This can be indicated by the emergence of phytoplankton types which provide an initial response to ongoing environmental changes or water quality. In addition, the abundance of phytoplankton which is also reflected through primary production can indicate the eutrophication level of pond.

There were sequence processes from organic material as remaining shrimp feed to nutrients and organic material as biomass of phytoplankton. The catabolism process in decomposition disintegrated organic fractions into less complex compounds, which eventually form minerals or inorganic compounds. The higher organic contents in the water, the higher nutrients will produce, potentially [17].

The decreasing C/N value indicated reducing organic materials and increasing mineral along the decomposition process (figure 5). The results showed that the C/N ratio had decreased. Several studies have shown that the C-organic content decreases as a result of the release of carbon dioxide due to the decomposition of organic matter; meanwhile, the total N content has increased due to the mineralization process. Thus, the higher the total N content formed, the lower the C/N [18, 19].

The high relationship between C/N ratio and primary productivity in the pond shows that phytoplankton utilized nutrients intensively. This is also shown in Figure 3 that the density of phytoplankton tends to increase to the end of observation. The density supports the oxygen and phytoplankton biomass production as the result of photosynthesis process. This was strengthened by the high relationship between primary productivity and nutrients (figure 7 and 8). The composition and absolute nutrients content could support the appearance of phytoplankton. The dynamics of nutrient
uptake and plankton production are related to changes in water change periods and feeding patterns [20]. Furthermore, primary production is affected by radiation and temperature [21]. This study shows that the level of primary productivity was relatively moderate as categorized in other studies [22].

Several types of phytoplankton that were found during the observation were also found in other studies [23], those were Oocystis, Chlorella, Nannochloropsis, Chaetoceros, Stephanodiscus, Nitzschia, Coscinodiscus, Cyclotella, and Ulothrix, and dominated by diatom groups. As was found in this study, the high density of phytoplankton is mostly supported by the group of diatom. The emergence of such phytoplankton composition indicates that the pond waters provide natural food and good environmental conditions for shrimp. Diatom is one of useful phytoplankton, directly or indirectly to the shrimp life. Directly, it sources biomass, because diatom is one of benefcial phytoplankton or nutritious feed for the shrimp. As source of oxygen, with other phytoplankton, diatom maintain s good water condition. On the other hand, diatom and other phytoplankton also a shelter for the shrimp in the pond [24]. Indirectly, it indicates. Supporting by the high N/P ratio (figure 4), the diatoms were able to grow well, both in composition variation and the density [4].

Figure 6 shows that the protein in the remaining feed did not only consist of nitrogen, but also another mineral, such as phosphorus. The release of both nutrients depends on the type of organic material and environmental condition [24]. The organic material sources from the remaining feed and rest of metabolic process, with a composition that depends on the nutritional needs of the shrimp following the DOC [25-27].

As a whole, the primary productivity that relatively moderate was supported by a good composition of phytoplankton. Even though the diversity was relatively low, the evenness level that relatively moderate to high indicated that the phytoplankton community was relatively in good condition. The high density of diatom was also indicated that the water quality was in a good condition. These were supported by the ecological process that was shown by the good decomposition process expressed by the pattern of C/N ratio, the level of nutrients, and the N/P ratio along with the observation. It means that good pond water quality indicates that proper management and the potential to produce low-impact shrimp pond waste is beneficial to the environmentally conditions surrounding the pond [20].

5. Conclusion
The high density and high frequency of occurrence of Diatom support the primary productivity of shrimp pond that supported by synchronous condition between the presence of organic matter and nutrients through the value of C/N and N/P, as well as the composition of plankton, which supports primary productivity during shrimp rearing in the pond

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