Phytoplankton bioindicators as a measure of productivity for Pacific white shrimp (*Penaeus vannamei*) pond farming in Indonesia

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Abstract. Shrimp is a commodity that has considerable economic prospects and drives the economy from urban to rural areas. Plankton affects the quality of water media, the environment, and shrimp feed. This study aimed to analyze phytoplankton as a bioindicator of the productivity of Pacific white shrimp (*Penaeus vannamei*) in ponds. The research was conducted in the vaname shrimp farming industry pond, Banten Province, Indonesia, in 2023. The method used is descriptive, with a field survey. The study used six ponds with the same treatment. Independent variables consist of plankton abundance, diversity index, uniformity and dominance. The dependent variable is the pond productivity. The results showed the value of plankton abundance in plots 2,669-14,987 ind L^{-1}. Plankton diversity index value is 0.218-2.774, the plankton uniformity index value is 0.038-0.873, and the plankton dominance index value is 0.074-1.28. Shrimp ponds are moderately stable. Water quality parameters are suitable for shrimp growth. Plot B has a diversity index of 2.774, uniformity of 0.873 and dominance of 0.871, resulting in the highest shrimp production compared to other plots. The influence of diversity, uniformity and plankton dominance on shrimp production was 53.6%. The higher the diversity, uniformity and dominance index values, the better the water quality and the higher the shrimp cultivation production in the pond.
Key Words: fisheries aquaculture, plankton, diversity, uniformity, dominance.

Introduction. Shrimp, a highly valued commodity with promising economic potential, plays a significant role in the economy across various industries. The Pacific white shrimp (*Penaeus vannamei* Boone 1931), commonly known as vaname shrimp, thrives in the culture media water, a critical factor for successful shrimp farming. The presence of phytoplankton in these water bodies, with their profound influence on water quality, underscores their significance in the ecosystem. Plankton, a biological indicator, can be used to analyse its relationship with pond productivity (Pirzan & Utojo 2012; Xu et al 2016) and water fertility (Cahyaningtyas et al 2013; Pramesthi et al 2019; Samadan et al 2020).

Plankton is a natural food for shrimp and encourages the growth of bacteria that decompose organic matter (Zhang et al 2022). For that, phytoplankton utilize organic compounds and nutrients and produce oxygen in the aquatic ecosystem (Yusuf et al 2021). Nutrients in ponds come primarily from the organic matter resulting from residual artificial feed that is not consumed (Venkateswarlu et al 2019). For this reason, phytoplankton production in intensive shrimp farming is influenced by the nutrients nitrogen (N) and phosphate (P) (Putri et al 2019). Phytoplankton, serving as bioindicators, play a pivotal role in assessing the quality and fertility of a water body. Their photosynthesis process, vital for oxygen production in water, is a fascinating aspect of their existence. Furthermore, they serve as a nutrient source for fish and shrimp and help maintain the water quality by absorbing compounds that can be toxic to cultured shrimp. This multifaceted role of phytoplankton makes them an intriguing subject of study in the context of vaname shrimp ponds.

The productivity of vaname shrimp ponds in Banten Village, coastal Banten Bay, is a significant indicator of the success of shrimp farming. With a yearly production rate of about 12,000 kg ha^{-1}, the past five years have shown a stable and prosperous trend. However, the decline in water quality and the technology applied are crucial factors that can significantly impact shrimp productivity in ponds. Considering these factors, this study aims at analysing phytoplankton bioindicators, a key element in the productivity of vaname shrimp ponds.

Material and Method

Description of the study sites. This research was conducted from February 2023 to November 2023. The research location of shrimp farming was in Coastal Banten Bay, Banten village, Serang, Banten Province, Indonesia. The ponds used in the study were six plots measuring 900 m^2. The rearing technique was an intensive system. Shrimp larvae Post larvae (PL) 10 or 14 days old. The stocking density is 100 post larvae m^{-2}. Shrimp culture includes preparing and maintaining ponds, managing water quantity and quality, managing feed, pest and disease control, and harvesting. Plankton is an indicator of the quality of the aquatic environment. Failure of shrimp cultivation in ponds most often occurs due to poor water quality during the rearing time, between day 20 and day 35, or in stable conditions after 65 days of age, when the plankton quality indices (diversity, uniformity, dominance and plankton abundance) cease fluctuating significantly (Akbarurrasyid et al 2023; Cahyaningtyas et al 2013; Samadan et al 2020; Supriatna 2018). Phytoplankton monitoring was carried out from day 20 to day 70. The research location map is shown in Figure 1.

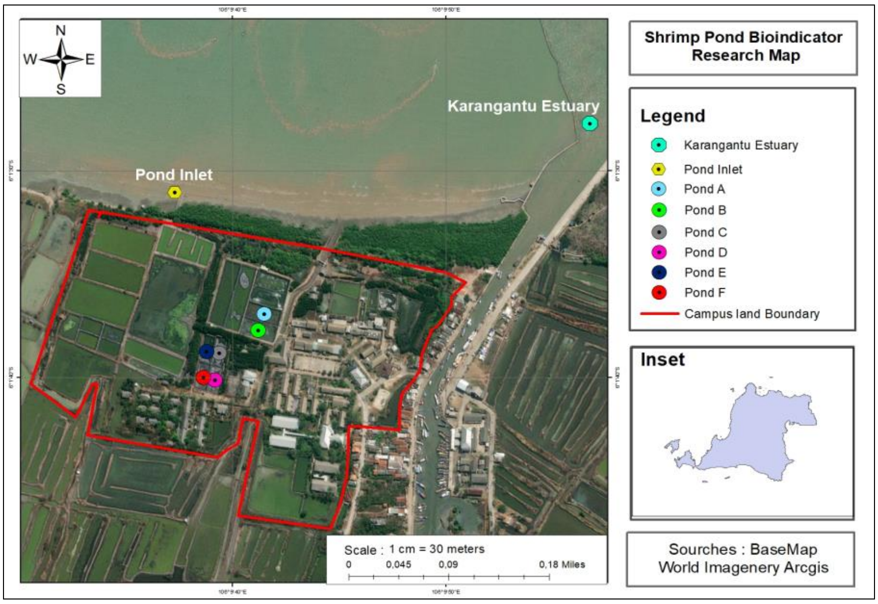

Figure 1. Map of the research location.

Data collection. Plankton sampling equipment used is plankton net number 25 with a mesh size of 23 µm to collect phytoplankton. Materials used include 4% formalin, a water quality test kit, filter paper, a counter, and a phytoplankton identification book. Sampling used purposive random sampling and survey methods (Wirabumi 2017; Campbel et al; 2020). Sampling time was performed at 08.00-10.00 WIB or morning (Maresi et al 2015; Winarsih & Susanto 2023). Plankton samples were collected by filtering 50 L of water into 30 mL, then preserved with four drops of formalin (Umami et al 2018) and identified at the species level using a phytoplankton identification book (Bellinger & Sigee 2010) and the illustrations of The Marine Plankton of Japan (Yamaji 1984).

Data analysis

Diversity index. Diversity analysis aims to determine the presence of plankton species in the community. The diversity index (H') of plankton is calculated by using the Shannon-Weaver equation (Odum 1971):

$$H' = -\sum Pi \ln Pi$$

Where:
H' - Shannon-Weaver diversity index;
Pi - ni/N;
ni - total number of individuals in species i;
N - total number of individuals in the community.
Discrimination criteria:
H'<1: community is unstable, or water quality is heavily polluted;
H'=1-3: community in moderate condition;
H'>3: community in stable condition.

Uniformity index. The species uniformity index (E) is intended to analyze the distribution of individuals/cells of each species in the community. If the uniformity index value is relatively high, the presence of each type of biota in the waters is evenly distributed. The uniformity index uses the following formula (Odum 1971):

$$E = \frac{H'}{H\,max}$$

Where:
E - uniformity index;
H' - Shannon-Weaver diversity index;
H max - ln S;
S - number of species.
Discrimination criteria:
e< 0.4: small population uniformity;
0.4 <e<0.6: moderate population uniformity;
e>0.6: high population uniformity.

Dominance index. The dominance index shows the species' population abundance in the community. The dominance index is calculated as follows (Odum 1971):

$$C = \sum (Pi)^2 = \sum (\frac{ni^2}{N})$$

Where:
C - dominance index;
Pi - ni/N;
ni - number of individuals of type i;
N - total number of individuals.
Result criteria:
C<0.5: no dominating species.

Plankton abundance. Calculation of phytoplankton abundance per liter was done using the APHA (1992) formulation, namely:

$$N = \frac{T}{L}\,x\,\frac{P}{p}\,x\,\frac{V}{v}\,x\,\frac{1}{W}$$

Where:
N - number of plankton per liter;
T - total area of Sedgwick-rafter plot (1,000 mm^2);

L - microscope field of view (mm^2);
P - number of plankton counted;
p - number of fields of view observed;
V - volume of filtered plankton sample (mL);
v - volume of plankton sample in Sedgwick-rafter (mL);
W - volume of filtered water samples (L).
Data is processed using Excel and the Statistical Program for Social Science (SPSS).

Results. Enumeration in the pond was carried out twice during one cycle, namely at 20 and 70 days. The type and number of plankton identified are in Tables 1 and 2 below.

Table 1
Results of enumeration (ind L^{-1}) of phytoplankton in plots A, B and C at 20 and 70 days

No	*Class / Species*	*Plot A Age (days)*		*Plot B Age (days)*		*Plot C Age (days)*	
		20	70	20	70	20	70
	Phytoplankton						
	Bacillariophyceae						
1.	*Chaetoceros* sp.	735	762	854	1,472	598	831
2.	*Rhizosolenia* sp.	675	0	458	765	549	641
3.	*Nitzschia* sp.	1,003	976	1,546	1,654	1,198	1,781
4.	*Asterionella* sp.	199	199	438	438	265	265
5.	*Pleurogsigma* sp.	8	431	45	0	0	876
6.	*Melosira* sp.	227	276	45	542	79	431
7.	*Thalassiosira* sp.	290	461	1	319	0	413
8.	*Skeletonema*	996	1,763	1,076	1,874	789	789
9.	*Hemialus* sp.	9	0	0	48	0	0
10.	*Navicula* sp.	288	341	675	765	474	842
11.	*Hemiaulus* sp.	67	87	0	0	0	42
12.	*Thallassiotrix* sp.	0	54	7	134	0	0
13.	*Bacilaria* sp.	0	444	0	47	75	0
14.	*Bacteriastrum*	0	59	0	0	0	0
15.	*Synedra* sp.	0	0	0	652	89	0
	Cyanophyceae						
1.	*Spirulina* sp.	1,190	1,761	1,231	1,721	1,432	1,523
2.	*Tolypothrix* sp.	456	0	658	0	438	987
3.	*Anabaenopsis* sp.	56	142	0	176	0	10
4.	*Oscillatoria* sp.	43	0	45	76	65	167
5.	*Microcystus* sp.	0	0	0	761	0	0
6.	*Meriospedia* sp.	0	46	0	0	0	0
	Chlorophyceae						
1.	*Polyedrium* sp.	987	0	765	564	431	987
2.	*Scedesmus* sp.	0	657	0	345	38	0
3.	*Chlorrella* sp.	320	672	145	871	321	341
4.	*Schroederia* sp.	39	0	65	365	132	0
	Dinophyacea						
1.	*Ceratium* sp.	35	372	42	143	0	67
2.	*Pyrocystis* sp.	0	0	0	45	98	77
3.	*Noctiluca* sp.	43	12	32	9	12	42
4.	*Peridinium* sp.	53	42	76	1201	0	32
	Total	7,719	9,557	8,204	14,987	7,083	11,144

While the results of phytoplankton identification and abundance counts in pond plots D, E, F are shown in Table 2 below.

Table 2

Plankton enumeration (ind L^{-1}) results in plots D, E and F at 20 and 70 days

No	Class / Species	*Plot D Age (days)*		*Plot E Age (days)*		*Plot F Age (days)*	
		20	70	20	70	20	70
	Phytoplankton						
	Bacillariophyceae						
1.	*Chaetoceros* sp.	75	762	84	987	523	931
2.	*Rhizosolenia* sp.	334	21	15	272	321	440
3.	*Nitzschia* sp.	102	21	89	987	876	987
4.	*Asterionella* sp.	12	0	48	87	165	531
5.	*Pleurogsigma* sp.	0	4	0	95	4	67
6.	*Melosira* sp.	0	43	0	92	2	321
7.	*Thalassiosira* sp.	213	131	1	319	9	421
8.	*Skeletonema* sp.	134	976	64	988	765	871
9.	*Asterionella* sp.	0	23	0	0	0	0
10.	*Navicula* sp.	271	0	95	532	432	437
11.	*Hemiaulus* sp.	53	0	0	0	7	42
12.	*Thallassiotrix* sp.	0	98	7	99	0	0
13.	*Bacilaria* sp.	3	76	5	65	57	411
14	*Bacteriastrum*	0	251	0	500	0	101
15	*Synedra* sp.	211	0	0	211	0	0
	Cyanophyceae						
1.	*Spirulina* sp.	587	542	789	743	653	987
2.	*Tolypothrix*	5	0	45	0	54	654
3.	*Anabaenopsis* sp.	5	54	2	77	0	0
4.	*Oscillatoria* sp.	67	0	46	101	32	111
5.	*Microcystis* sp.	0	0	0	0	2	9
6.	*Meriospedia* sp.	0	99	0	85	0	0
	Chlorophyceae						
1.	*Polyedrium* sp.	32	76	1	98	34	422
2.	*Scedesmus* sp.	2	0	8	654	36	0
3.	*Chlorrella* sp.	431	751	543	679	433	654
4.	*Schroederia* sp.	4	0	42	87	13	0
	Dinophyacea						
1.	*Ceratium* sp.	2	42	45	987	3	0
2.	*Pyrocystis* sp.	0	0		78	3	0
3.	*Noctiluca* sp.	57	78	98	69	54	78
4.	*Peridinium* sp.	71	7	56	133	8	89
	Total	2,678	4,055	2,091	9,025	3,858	8,564

Plankton index and shrimp pond production. For comparison, another parameter that is also an indicator of production and plankton index is the survival rate (SR). The higher the SR value, the better the cultivation result. The Feed Conversion Ratio (FCR) is used to calculate the amount of feed needed. FCR=1 means that to produce 1 kg of shrimp requires 1 kg of feed, and feed costs require between 60-70% of total costs. The relationship between plankton index and shrimp pond productivity is shown in Table 3.

Table 3 shows that the best SR is plot B with SR 86 and good FCR on plots D and E. Plot B has the highest production, SR and abundance of phytoplankton, as in Figure 2. However, the difference is only 0.1. To facilitate analysis, the relationship between the plankton index (diversity, uniformity and dominance) is depicted in Figure 3.

From Figure 3, it can be seen that there is no relationship between the three indices.

Table 3

Recapitulation of the results of the calculation of index diversity, uniformity, dominance and production in pond plots.

Plot/age (days)	*Diversity (H')*	*Uniformity (E)*	*Dominance (D)*	*Production (Ton)*	*SR*	*FCR*
A20	2.495	0.819	0.100	1.240	81.3	1.6
A70	2.506	0.837	0.105			
B20	2.264	0.722	1.114	1.385	86.2	1.5
B70	2.774	0.873	0.871			
C20	2.430	0.027	0.111	1.170	80.7	1.5
C70	2.571	0.024	0.090			
D10	2.220	0.729	0.140	0.942	75.4	1.4
D70	2.509	0.837	0.105			
E20	1.605	0.512	1.284	1.136	72.0	1.4
E70	2.774	0.873	0.074			
F20	0.218	0.038	0.130	0. 973	70.3	1.5
F70	2.571	0.024	0.090			

FCR-Food Conversion Ratio; SR-Survival rate; Category: All moderate with differences in index values.

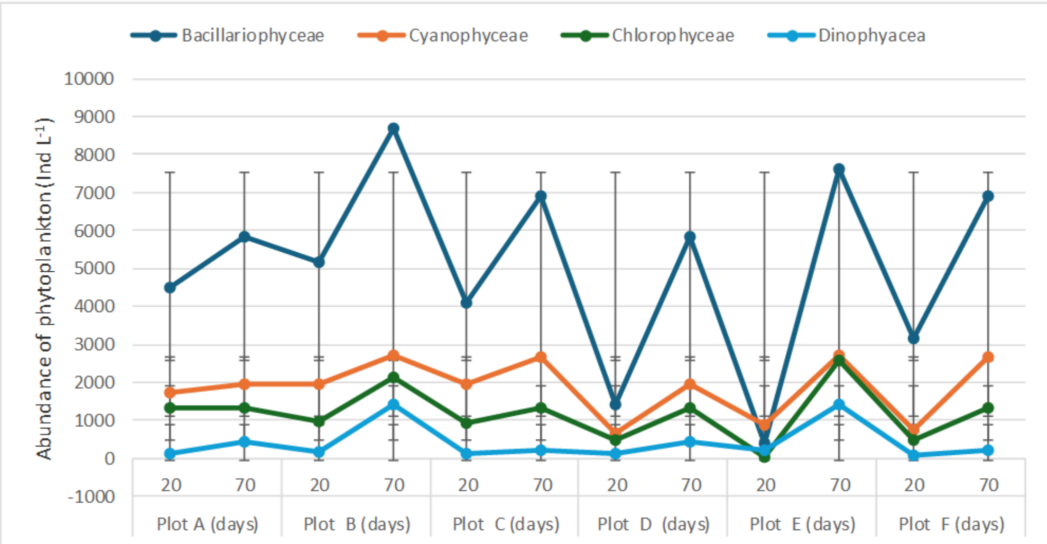

Figure 2. Abundance of phytoplankton on each pond plot (ind L^{-1}).

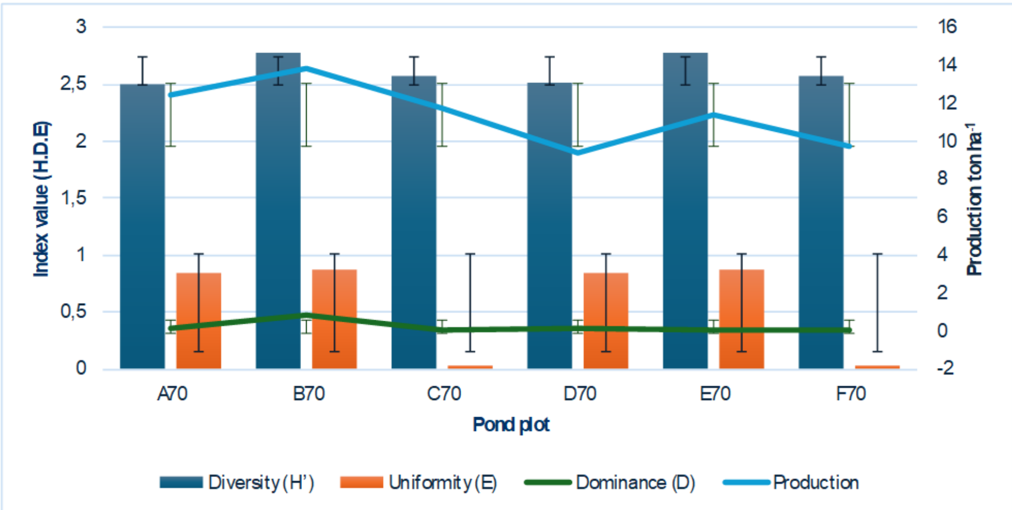

Figure 3. Relationship between index and production.

Figure 3 shows that the diversity and production fluctuations are almost identical. The diversity, uniformity and dominance indices support shrimp production. Figure 4 shows the number of each class.

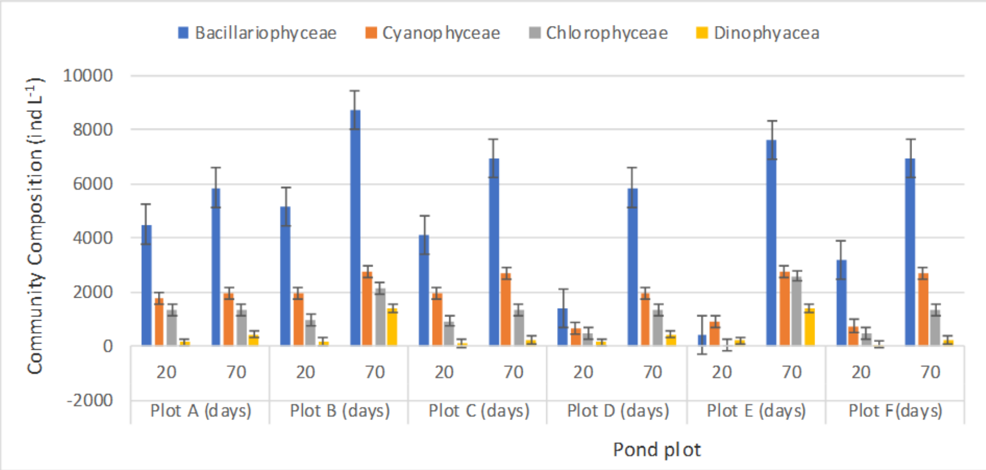

Figure 4. Several individuals from each class identified in the community.

For all species, each plot A, B, C, D, E and F display two groups; the right group shows the age of 70 days, and the left group shows 20 days. Plot B had greater plankton abundance and a more optimum index balance.

Water quality parameters. The pond plots' temperature measurements are shown in Table 4.

Table 4

Water quality measurement results in pond plots

Parameters	*Pond mapping*				*Optimum level*	*Reference source*
	Unit	*A and B*	*C and D*	*E and F*		
Water temperature	°C	28.8 ±1.6	29.5±2	28.9±1.4	30±2	Yunarty et al (2022)
Brightness	cm	35.5± 4.5	38.5±6.5	39±6	35±5	Anjaini et al (2024)
Suspended solids total	mg L^{-1}	30±5	30±5	34±6	50±25	Venkateswarlu et al (2019)
Depth	cm	123	120	120	140±20	Zhang et al (2022)
Salinity	mg L^{-1}	24±4	27±1.5	28±2	20.5±5.5	Utojo (2015)
pH		7.8±0.5	7.8±0.4	7.8±0.4	7.7±0.5	Utojo (2015)
Dissolved oxygen (DO)	mg L^{-1}	6.7±0.7	5.9±0.6	6,3±0.5	6.5± 0.7	Yunarty et al (2022)
Phosphate (PO_4)	mg L^{-1}	0.96±0.06	0,76±0.06	0.72±0.05	0.2±0.02	Muaddama & Jayadi (2018)
Nitrate (NO_3) total	mg L^{-1}	0.09±0.4	0.28±0.2	0.09± 0.25	<1.5	Anjaini et al (2024)
Organic matter (TOM)	mg L^{-1}	125.7±21	141.8±48.1	115.6±22	< 90	Zhang et al (2022)

Discussion. The results of the enumeration of plankton abundance in plot B are 8,204 to 14,987 ind L^{-1}, which is the most considerable abundance compared to other plots. Plankton abundance can be used as an aquatic bioindicator to evaluate the fertility level of a body of water (Yunandar et al 2020). Plankton abundance increased over time after ten days of shrimp rearing. Some genera dominate for a relatively long time, while others dominate for a relatively short time. Several factors influence such fluctuations, including pH, temperature, nutrient concentration, light, weather, disease, fish predation, zooplankton, interspecies competition, algal toxins, and opportunity (Venkateswarlu et al 2019). The increasing amount of nutrients can cause algae to bloom in the waters, thus indicating the waters are poor (Apriadi et al 2021). According to Herawati et al (2023), phytoplankton are said to be blooming when their abundance is >5,000 cells L^{-1}. This condition can occur in ponds at 30-40 cm water brightness. For this reason, the plankton balance must be considered in the context of the entire community of organisms, namely the number of species/genera and their composition (Flach & DeBruin 1999). To maintain the balance of plankton, it is necessary to manage the water quantity and quality through managing facilities and infrastructure and regular monitoring. Phytoplankton abundance per class is discussed below.

Bacillariophyceae. The data shows that the Bacillariophyceae class is the most abundant. Samudra et al (2024) research showed similar results. The Bacillariophyceae class has a relatively fast growth, even under hostile conditions. It can indicate water quality (Haryoko et al 2018; Kamilah et al 2014; Aryawati 2021). Species in Bacillariophyceae are used as bioindicators of water pollution because they have strong cell walls, made of silica, and their analysis reveals which pollutants have accumulated in a body of water (Apriadi et al 2021). In addition, Bacillariophyceae have an essential role in mineralizing and recycling organic materials from water and land (Rines & Hargraves 1988; Taurozzi et al 2024). Bacilliariophyceae is a type of phytoplankton containing nutrients, such as omega-3 fatty acids, that support healthy shrimp growth (Fortuna 2023). Some species of Class Bacillariophyceae that are expected to grow in shrimp ponds are Navicula sp., *Chaetoceros* sp., *Skeletonema* sp., *Nitzschia* sp., and *Spirogyra* sp. Waters where this type is dominant are usually greenish brown.

Chlorophyceae. The results of the Chlorophyceae study showed that it was the second most abundant class. This class is a natural food and can perform photosynthesis, which increases the amount of oxygen in the water. Its members include *Tetraselmis, Chlamydomonas, Oocytis*, and *Chlorella*. *Tetraselmis* and *Chlorella* are widely used as zooplankton feed (Fortuna 2023).

Cyanophyceae. Types of beneficial cyanophyceae *Spirulina* sp. Cyanophyceae species that are harmful include *Microcrystis aeruginosa* and *Nodularia* sp., which produce neurotoxins, hepatotoxins, cytotoxins, and endotoxins, which are toxic and can affect shrimp growth, development, histology, reproduction and survival (Svircev et al 2015; Masithah 2021).

Dinophyceae. The results of the study showed that this class was not dominant. Toxic dinoflagellates can produce toxins (derived from their flagella) that can harm shrimp (Herawati et al 2023). Some species belonging to this class, *Ceratium*, *Noctiluca* sp., *Gyrodinium*, *Alexandrium* and others, can change the color of pond water to brown, tending to reddish. The presence of dinoflagellates in ponds should not exceed 5% (Fortuna 2023). Some protozoa, such as Vorticella and Zoothamnium, also harm to shrimp ponds. These species are ectoparasites, therefore they must be controlled in shrimp farming (Khalik et al 2021).

Diversity index (H'). The diversity index was between 0.218 in plot F, day 20, and the highest was 2,779 in plot B, day 70 (Table 3). These values have practical implications, indicating that the community is in a moderate condition (except plot F, day 20, which showed an unstable community). The stability of shrimp farming water, a crucial factor for successful aquaculture, is characterized by a high plankton diversity, high and evenly distributed populations of each species, and water quality suitable for shrimp growth (Khalik et al 2021). The more species there are, the higher the diversity index. A high diversity index indicates that the location is suitable for phytoplankton growth, a vital aspect of aquaculture (Akbarurrasyid 2022).

Uniformity index (E). The uniformity index in plots C and F day 70, was the lowest 0.024 while the highest was found in plots B and E at 70 days 0.873. Plots C and F showed an unevenly distributed population, while plots B and E showed a high population uniformity. According to Odum (1998), a value of E>0.5 indicates that populations are evenly distributed due to the lack of competition for food or space.

Dominance index (D). The smallest dominance index (0.074) was found in the pond plot E day 70. D<0.5 means no dominating species. The highest dominance index, 1.284, was found in plots E and B 1.114 day 20 (Table 3). Plots B and E have dominant species due to the initial inoculation of the preferred shrimp species at the beginning of stocking post-larval shrimp. However, at 70 days, the dominance index value is close to zero, meaning that the community species' structure is homogenous, due to optimal environmental conditions, without ecological pressure on the habitat and biota. According to Evita et al (2021), the dominance index (D) value close to 0 indicates that there are no dominating species, and the D value close to 1 indicates that there is a dominating species.

Water quality. Overall, water quality meets the standards required for shrimp culture (Table 4). Vanname shrimp production is determined by the plankton community's relationships and the water quality fluctuations (Hemraj et al 2017; Liu et al 2022). Basmi (2000) explained that changes in pH values affect the metabolism and respiration of some types of phytoplankton. Phosphate nutrient content in all pond plots is in accordance with the needs of plankton. Phosphate is one of the important elements for plankton and periphyton life (Arsad et al 2019; Apriadi et al 2021). For this reason, it is necessary to maintain the quality and nutrients in water media.

Shrimp farming productivity. Based on the T and F tests of the simple and multiple linear regression analysis results, there is no significant effect of diversity, uniformity and dominance of plankton on the shrimp pond production either separately or simultaneously. This means that the productivity of shrimp ponds is not negatively impacted by the obtained value ranges of diversity, uniformity, and dominance indices. From the multiple regression analysis, the coefficient of determination (R_2) obtained, of 0.536 indicates that the effect of independent variables X_1 (plankton diversity), X_2 (plankton uniformity), X_3 (plankton dominance) on the dependent variable Y (shrimp production) is 53.6% while other variables outside the model influence the remaining 46.4%.

Shrimp production in ponds can be increased by managed growth of the plankton by the needs of shrimp, focusing on the Bacillariophycea and Chloropyiceae classes, and by monitoring the state of the environment, including physical and chemical factors of water. Physical factors include current speed, brightness, temperature, color, smell and taste. Chemical factors include pH, dissolved oxygen, CO_2, phosphate, nitrate, ammonia, mineral salts, and salinity (Sachlan 1982). These factors determine the type, fertility and nature of the waters. Besides the appropriate water quality, the addition of nutrients is adjusted to the needs of each plankton. The use of organic and inorganic fertilizers will complement each other in growing plankton. Generally, fertilizing ponds using organic and inorganic fertilizers depends on soil conditions, soil fertility, level of cultivation technology, and stocking season (Aryawati et al 2021).

Conclusions. Bacillariophyceae and Chlorophyceae dominate the plankton abundance. Species of these two classes are the types that suit the needs of shrimp in the pond. The plankton's diversity, uniformity, dominance, and abundance indices in the cultivation pond plots show a moderate state, but plot B has a higher productivity. Plot B had higher diversity and dominance indices and was dominated by species required for shrimp culture. There is no significant influence of the diversity, uniformity, and dominance of plankton species and populations on shrimp pond production, either separately or simultaneously. The effect of variables diversity, uniformity, and domination on the dependent variable shrimp production is 53.6%. In comparison, other variables outside the model influence the remaining 46.4%.

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Conflict of interest. The authors declare no conflict of interest.

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