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The abundance of *Spirulina platensis* in an intensive shrimp pond based on *causal loop* model analysis

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ABSTRACT

Spirulina platensis is a type of plankton commonly found in tropical waters. This study aims to analyze the fluctuations in its abundance in intensive shrimp ponds using dynamic system modelling. The research employed a causal ex-post facto design, with data collected through purposive sampling prior to dynamic analysis. The findings indicate that water quality parameters were generally very good. Several plankton genera were identified, including *Chlamydomonas* spp., *Chlorella* spp., *Oocystis* spp., *Chroococcus* spp., *Microcystis* spp., *Oschillatoria* spp., *Spirulina* spp., *Cyclotella* spp., and *Prorocentrum* spp. Regarding abundance, chlorophyceae reached 5.40E+05 cells/ml, cyanophyceae 3.30E+05 cells/ml, chrysophyceae 1.85E+05 cells/ml, dinophyceae 3.50E+05 cells/ml, and oligohymenophorea 2.50E+03 cells/ml. Specifically, *Spirulina platensis* abundance was 2.00E+04 cells/ml in pond A and 1.00E+04 cells/ml in pond B. Dynamic modelling results show that a 1:10 decrease in nutrient ratio leads to a reduction in plankton biomass by approximately 10.00E+03 cells/ml. Additionally, the model indicates that at N:P ratios of 1:30 and 1:40, plankton abundance reached saturation points, effectively ceasing growth (0 cells/ml). Factors influencing its abundance include temperature, pH, water flow, and nutrient availability. In conclusion, *Spirulina platensis* exhibits oscillatory fluctuations in abundance over a twenty-week shrimp cultivation period, with optimal growth occurring at N:P ratios of ≤1:20. Moreover, its abundance trends are inversely related to the N:P ratio in pond waters.

Keywords: chlorophyll, feed, *L. vannamei*, nutrient, water quality

INTRODUCTION

Spirulina sp. is one of the plankton genera that offers various benefits. Based on its utilization, *Spirulina* sp. is widely used in cosmetics, pharmacology, food, and as natural feed for aquaculture activities (Napolitano et al., 2022). *Spirulina* sp. can be found in both marine and freshwater environments with abundant species diversity (Kunwong et al., 2024). It is noteworthy that *Spirulina* sp. exhibits a very high vulnerability to the abundance of nutrient elements in water conditions, yet this plankton is commonly found in various water conditions (Salgado et al., 2024). This condition allows for effective utilization efforts of *Spirulina* sp.

One of the uses of *Spirulina* sp. is in the intensive cultivation of *L. vannamei* shrimp, with *Spirulina platensis* being a commonly found species (Siringi et al., 2021). *Spirulina platensis* is used as natural shrimp feed during the larval stage (Tibbetts et al., 2023). Additionally, *Spirulina platensis* can also be cultivated in shrimp pond ecosystems as supplementary feed besides artificial feed (Napolitano et al., 2022). According to research findings, *Spirulina platensis* has a high protein content beneficial for shrimp growth (Dmytryk et al., 2022). *Spirulina platensis* contains 30.4% crude protein, 0.8% essential amino acids, and 12% chlorophyll, which significantly support the growth of cultivated shrimp (Siringi et al., 2021).

In intensive shrimp pond ecosystems, the abundance of *Spirulina platensis* is found to be highly dynamic. This is due to the high nutrient solubility dynamics and intensity of nutrient cycles in pond ecosystems (Zulfahmi et al., 2023). *Spirulina platensis* in pond ecosystems is a plankton genus that tends to have a low existence (Jiang et al., 2023). Moreover, its abundance tends to be moderate compared to other plankton genera such as green algae or blue-green algae (Ariadi et al., 2023a). However, the abundance of *Spirulina* sp. will always be found in shrimp pond ecosystems due to the high input of protein elements in ponds (Tayag et al., 2010).

The protein elements in ponds will periodically affect the dynamics of the N:P ratio and the abundance of the *Spirulina* sp. genus directly (Soeprapto et al., 2023). Based on this background overview, the purpose of this research is to analyze the fluctuation of *Spirulina platensis* abundance in intensive shrimp ponds based on dynamic modelling system analysis. The results of this study are expected to contribute to the development of analytical theories that can be used to predict the dynamic patterns of *Spirulina platensis* abundance in intensive shrimp pond ecosystems, serving as an alternative natural feed for shrimp and supporting the advancement of green aquaculture systems.

MATERIALS AND METHODS

This research was conducted in the shrimp pond area of Berkah Company, Pekalongan Regency, in March-April 2024. The ponds used for this research amounted to two ponds with the same treatments and observation techniques. The research parameters observed were plankton abundance, *Spirulina platensis* abundance, pond water quality parameters, daily shrimp feed intake, and cultivated shrimp biomass. This research was conducted using the causal ex-post facto design concept method, as well as purposive sampling data collection. Data sampling points were taken at the edge and middle sides of the ponds every three days. Subsequently, sample data were collected according to the specified time and parameter variables to be studied. The causal model analysis was used with Stella software version 9.02.

To validate the model, a correction factor test is conducted on the formula in the Stella software version 9.02. This correction factor test is performed to minimize errors in formula input or mistakes in creating the causal loop model. Once the model validation results are accurate, the conceptual model we have developed can be used as an analytical tool.

Plankton abundance

Plankton and *Spirulina* sp. abundance analysis was performed using an Olympus CX22 microscope and a NEUBEUR haemocytometer. Furthermore, plankton and *Spirulina platensis* abundance were calculated using the formula from APHA (1998).

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

where *N* is the individual abundance of plankton (ind/lt), Z is the individual number of plankton, *X* is the volume of the filtered water sample (40 ml), *Y* is the volume of 1 water drop (0.06 ml), and *V* is the volume of water filtered (100 L).

Water quality

The water quality parameters observed in this study included pH measured using a pH EcoTestr®; salinity, measured with a Hand ATAGO Refractometer; dissolved oxygen and temperature measured using a YSI550i DO meter; nitrite and Total Ammonia Nitrogen (TAN) analyzed by spectrophotometric methods; and organic matter determined by titrimetric methods. Water quality parameters are measured daily at 11.00 am.

RESULTS AND DISCUSSION

Water quality

The water quality parameters in the research ponds are still in good condition and comply with the standard water quality requirements for shrimp cultivation. The description of the pond water quality profile can be presented in Table 1. The water quality parameter that may be quite risky is the organic matter, which is 92.62 mg/L (pond A) and 90.03 mg/L (pond B). Organic matter concentrations >90 mg/L are highly detrimental to water stability. The high concentration of organic matter is caused by the diverse inputs from cultivation entering the ponds (Chen et al., 2022).

Other parameters such as pH (8.2-8.2), salinity (16-17 g/l), dissolved oxygen (5.82-6.00 mg/l), temperature (28.36-28.38 °C), nitrite (0.107-0.164 mg/l), and total ammonia nitrogen (0.033-0.041 mg/l) are considered to be quite good. The stability of water quality parameters in the ponds is influenced by good management practices (Vione et al., 2021). Additionally, the use of paddle aerators also significantly supports the stability of water quality conditions in pond ecosystems (Ariadi et al., 2023b). *Spirulina platensis* tends to thrive in warm waters with temperatures ranging from 27-31°C (Napolitano et al., 2022).

Plankton abundance

Plankton abundance at the research pond site is dominated by the classes Chlorophyceae, Chyanophyceae, Chrysophyceae, and Dinophyceae (Pond A). For Pond B, it is dominated by the classes Chlorophyceae, Chyanophyceae, Chrysophyceae, Dinophyceae, and Oligohymenophorea. The plankton genera from each class can be seen in Table 2. The application of uniform shrimp farming practices also influences the dominance of classes in pond waters (Qiu et al., 2024). Additionally, seasonal stability also affects the existence of plankton in pond aquatic ecosystems (Gao et al., 2024).

When viewed at the genus level, several plankton genera that frequently appear include *Chlamydomonas* spp., *Chlorella* spp., *Oocystis* spp., *Chroococcus* spp., *Microcystis* spp., *Oschillatoria* spp., *Spirulina* spp., *Cyclotella* spp., and *Prorocentrum* spp. Judging from the abundance of genera, it can be said that the plankton in pond waters is relatively stable, with moderate dominance. The stability of plankton genus dominance is influenced by the balance of nutrients present in pond waters (Ariadi et al., 2023c). Intensive *L. vannamei* shrimp ponds have high nutrient inputs and good water quality management practices, thus affecting the abundance level of plankton genera (Kajgrova et al., 2024).

The most dominant class in the pond aquatic ecosystem is Chlorophyceae with a total abundance of 5.40E+05 cells/ml, followed by Chyanophyceae at 3.30E+05 cells/ml, Chrysophyceae at 1.85E+05 cells/ml, Dinophyceae at 3.50E+05 cells/ml, and lastly Oligohymenophorea at 2.50E+03 cells/ml (Figure 1). The dominance of the Chlorophyceae class is due to the tendency of shrimp pond waters to be fertile (Winner and Owen, 1991). Chlorophyceae is also solitary and responsive to warm water temperatures, hence its abundance is quite dominant (Soeprapto et al., 2023).

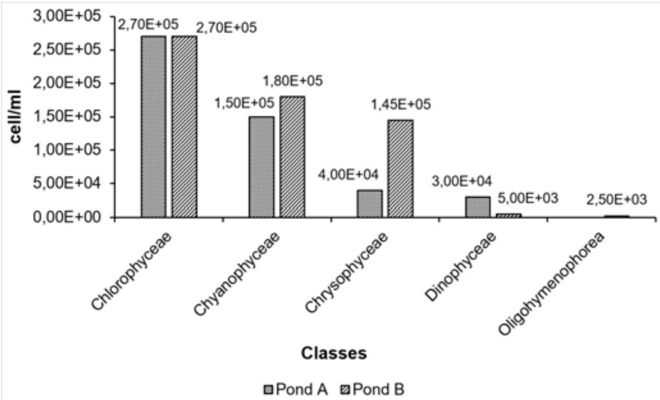

Figure 1. Plankton abundance in shrimp ponds

Table 1. Shrimp pond water quality parameters

Ponds	Water Quality						
	pH	Salinity (g/l)	Dissolved oxygen (mg/l)	Temperature (°C)	Nitrite (mg/l)	Total ammonia nitrogen (mg/l)	Organic matter (mg/l)
Pond A	8.2 ± 0.14 (7.6 - 8.3)	17 ± 0.30 (5 - 27)	5.82 ± 0.63 (3.85 - 6.93)	28.36 ± 0.98 (25.50 - 29.60)	0.164 ± 0.13 (0.013 - 0.101)	0.033 ± 0.05 (0.009 - 0.101)	92.62 ± 1.15 (51.82 - 115.02)
Pond B	8.2 ± 0.15 (7.6 - 8.4)	16 ± 0.95 (5 - 27)	6.00 ± 0.58 (4.14 - 6.78)	28.38 ± 0.93 (25.50 - 29.50)	0.107 ± 0.07 (0.001 - 0.200)	0.041 ± 0.06 (0.002 - 0.110)	90.03 ± 2.56 (42.98 - 128.93)

Table 2. Plankton abundance based on identified class and genus

Class	Genus
	Pond A
Chlorophyceae	*Chlamydomonas* spp., *Chlorella* spp., *Westella* spp., *Oocystis* spp.
Chyanophyceae	*Chroococcus* spp., *Microcystis* spp., *Oschillatoria* spp., *Spirulina* spp.
Chrysophyceae	*Amphora* spp., *Cyclotella* spp.
Dinophyceae	*Peridinium* spp., *Prorocentrum* spp.
	Pond B
Chlorophyceae	*Chlamydomonas* spp., *Chlorella* spp., *Oocystis* spp., *Gleocystis* spp.
Chyanophyceae	*Chroococcus* spp., *Microcystis* spp., *Oschillatoria* spp., *Spirulina* spp.
Chrysophyceae	*Streptoteca* spp., *Cyclotella* spp.
Dinophyceae	*Prorocentrum* spp.
Oligohymenophorea	*Vorticella* spp.

Plankton from the Chyanophyceae class, such as *Chroococcus* spp., *Microcystis* spp., *Oschillatoria* spp., and *Spirulina* spp., are found slightly more abundant compared to plankton from the Chrysophyceae class. The Chrysophyceae class is highly sensitive to changes in nutrient solubility within pond ecosystems, causing its abundance to be relatively unstable. Especially *Spirulina* spp., its presence indicates that the pond waters are sufficiently fertile. The presence of *Spirulina* spp. in pond ecosystems is highly anticipated to support the availability of natural feed for shrimp (Xue et al., 2020). Meanwhile, other plankton species such as *Chroococcus* spp., *Microcystis* spp., and *Oschillatoria* spp. are blue-green algae genera that easily bloom in pond waters (Lemonnier et al., 2016).

Based on the available data, it can be described that the abundance of plankton classes and genera in the ponds is quite diverse and stable, with no prominent dominance from any one class. The stability of water quality parameters greatly influences the level of plankton dominance stability (Ariadi et al., 2023a). Furthermore, the presence of fluctuating but stable pH and warm water temperatures also impacts the composition of plankton abundance in the ponds (Gao et al., 2024). The abundance of plankton in the ponds is also influenced by the speed of currents and good water circulation patterns (Ariadi et al., 2023b).

An abundance of Spirulina platensis

The dominant genus of *Spirulina* spp. (Figure 2) at the research pond site is the *Spirulina platensis* species (Figure 3). *Spirulina platensis* is one of the green algae species that can be utilized as natural shrimp feed (Sirikulrat et al., 2021).

Figure 2. *Spirulina platensis* view from the microscope (research document)

The protein and mineral content in *Spirulina platensis* greatly aid in the shrimp biomass growth process (Nieto et al., 2015). *Spirulina platensis* can also be utilized as an environmental bioindicator (Dmytryk et al., 2022). The presence of *Spirulina platensis* indicates moderately clean water conditions with low pollution (Abdel-Latif et al., 2022).

The abundance of *Spirulina platensis* in the research ponds is 2.00E+04 cells/ml (pond A) and 1.00E+04 cells/ml (pond B) (Figure 3). This means that there is no significant difference in the abundance pattern of *Spirulina platensis* between ponds A and B. Similar concentrations of nitrite and total ammonia nitrogen parameters in the two ponds significantly affect the abundance level of *Spirulina platensis* (Janke et al., 2022). *Spirulina platensis* is a plankton species resistant to fluctuations in abundance dynamics if there are changes in nutrient elements in aquatic ecosystems (Griffiths and Mitsch, 2020). The salinity level of the water also influences the existence of *Spirulina platensis* in the ponds (Jimenez et al., 2003).

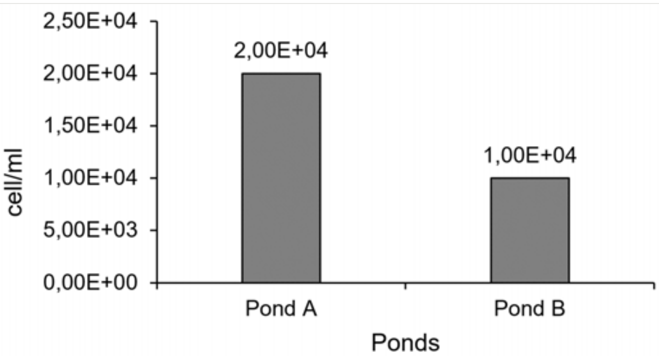

Figure 3. *Spirulina platensis* abundance in the shrimp pond

Dynamic Causal Loop Model

To analyze the correlation among research parameters, a dynamic causal loop model is constructed. The causal loop model is structured based on the correlation relationships between variables according to theory and scientific studies (Dong and Vogel-Heuser, 2021). The correlational relationships between parameters in the causal loop model will then be run to generate analysis data. In the construction of the causal loop model, a multicorrelation assessment process is conducted between variables to determine if the model created is appropriate (Agnew et al., 2018).

The determination of model variables is based on the research objectives. In this study, the parameters tested in the causal loop model are the abundance of *Spirulina platensis* and nutrient abundance. Theoretically, the abundance of *Spirulina platensis* is influenced by temperature, sunlight intensity, and nutrient levels in the water (Almeida et al., 2021). Meanwhile, the nutrient abundance in pond waters is influenced by fertilization intensity and the presence of residual shrimp feed waste (Ray et al., 2023). From these theorems, causal relationships are then established in the form of a model as shown in Figure 4.

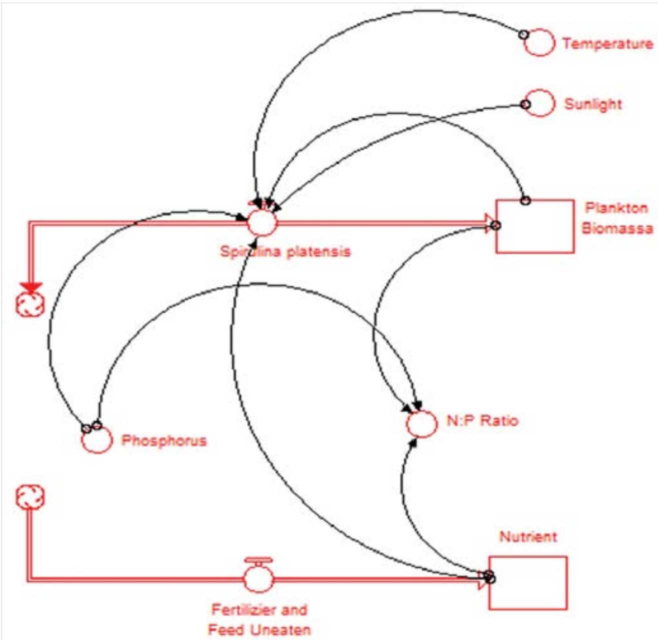

Figure 4. Causal loop model analysis

The relationship between Spirulina platensis and nutrients in the pond

The correlational relationship between the abundance of *Spirulina platensis* and nutrients in the pond can be presented in the results of dynamic modelling analysis in Figure 5. From the analysis results, it is described that plankton abundance in pond waters is influenced by fluctuations in the N:P Ratio (Figure 5). The N:P ratio acts as a limiting factor in controlling both the abundance of plankton and the species dominance index in a correlative manner. For every decrease of 1:10, it affects a decrease in plankton biomass by 10.00E+03 cells/ml (Figure 5). The N:P ratio is a limiting factor that affects the level of plankton abundance in aquatic ecosystems (Adomako and Yu, 2023).

From Figure 5, it is also described that the fluctuation of *Spirulina platensis* abundance correlates negatively with the N:P ratio. If the N:P ratio value is low, then the abundance of *Spirulina platensis* will decrease, and vice versa. *Spirulina platensis* is a plankton species sensitive to changes in the N:P ratio in ponds (Li et al., 2013). *Spirulina platensis* has a low N:P ratio (<1:20), life level similar to other chyanophyceae species (Ariadi et al., 2021).

The level of nutrient abundance in the pond is also depicted to continually increase from the first week to the 20th week of shrimp cultivation (Figure 5). The increase in nutrients is caused by the increasing amount of feed waste in the pond water. The increasing biomass weight of shrimp correlates with the amount of feed input given and the waste runoff produced (Araidi et al., 2022). Additionally, the fertilization process and liming treatment also contribute to the increase in nutrients in shrimp ponds aggregatively (Han et al., 2014).

The relationship between the abundance of Spirulina platensis and N:P ratio

Based on the results of dynamic modelling analysis, it is illustrated that different N:P ratios affect the pattern of fluctuation in the abundance of *Spirulina platensis* in pond waters (Figure 6). At N:P ratios of 1:10 (A), 1.20 (B), 1:30 (C), and 1:40 (D), *Spirulina platensis* experiences dynamic abundance (Figure 6). Inappropriate N:P levels will cause plankton to experience blooming (Adomako and Yu, 2023). *Spirulina platensis* at N:P ratios of 1:30 (C) and 1:40 (D) reach the saturation point of abundance (00.00E+03 cells/ml), meaning there is no growth at these N:P ratios. This is due to the presence of excessive nutrients (eutrophication) in the pond, leading to blooming and nutrient competition (Zhang et al., 2024). Excessive nutrients in the water will be utilized by plankton for cell regeneration processes (Liu et al., 2023).

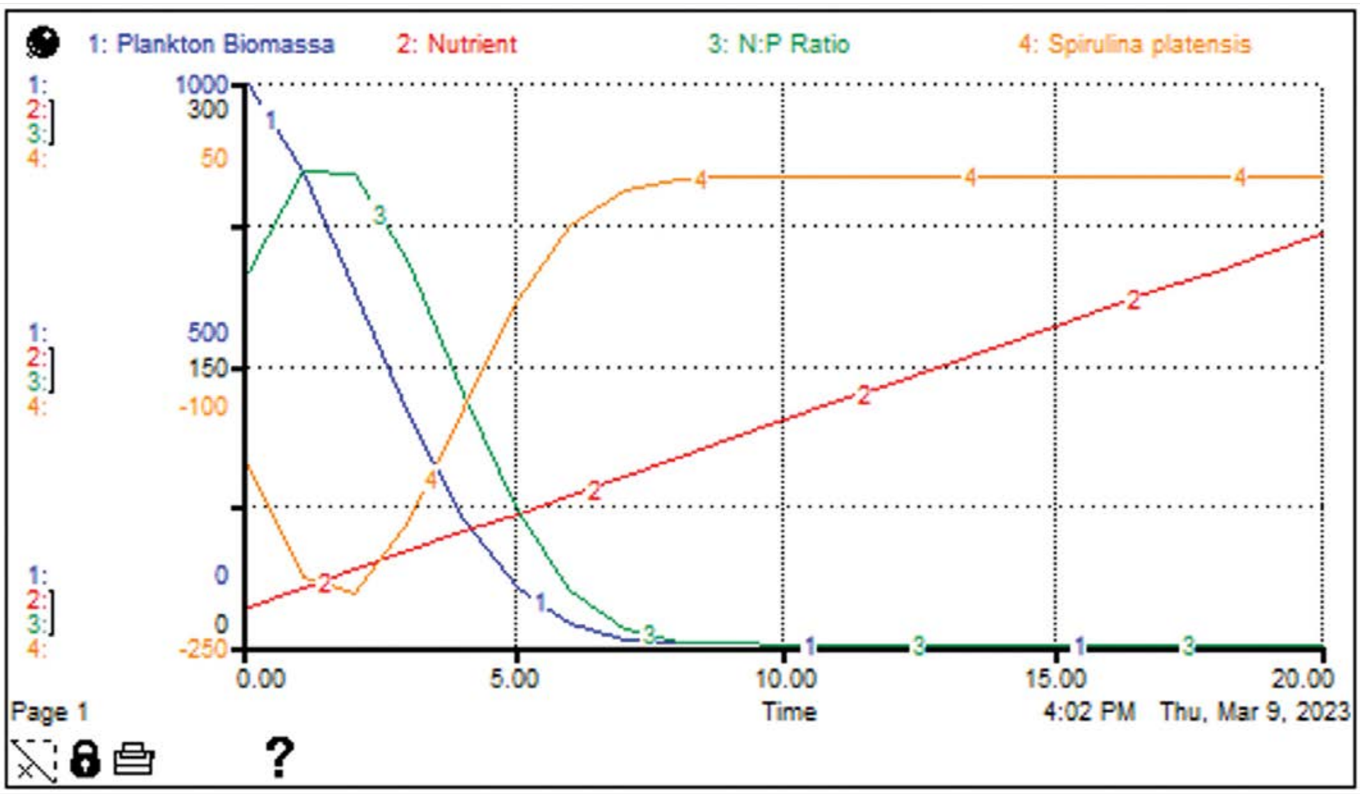

Figure 5. *Causal loop* results about the relationship between *Spirulina platensis* and nutrients in the pond

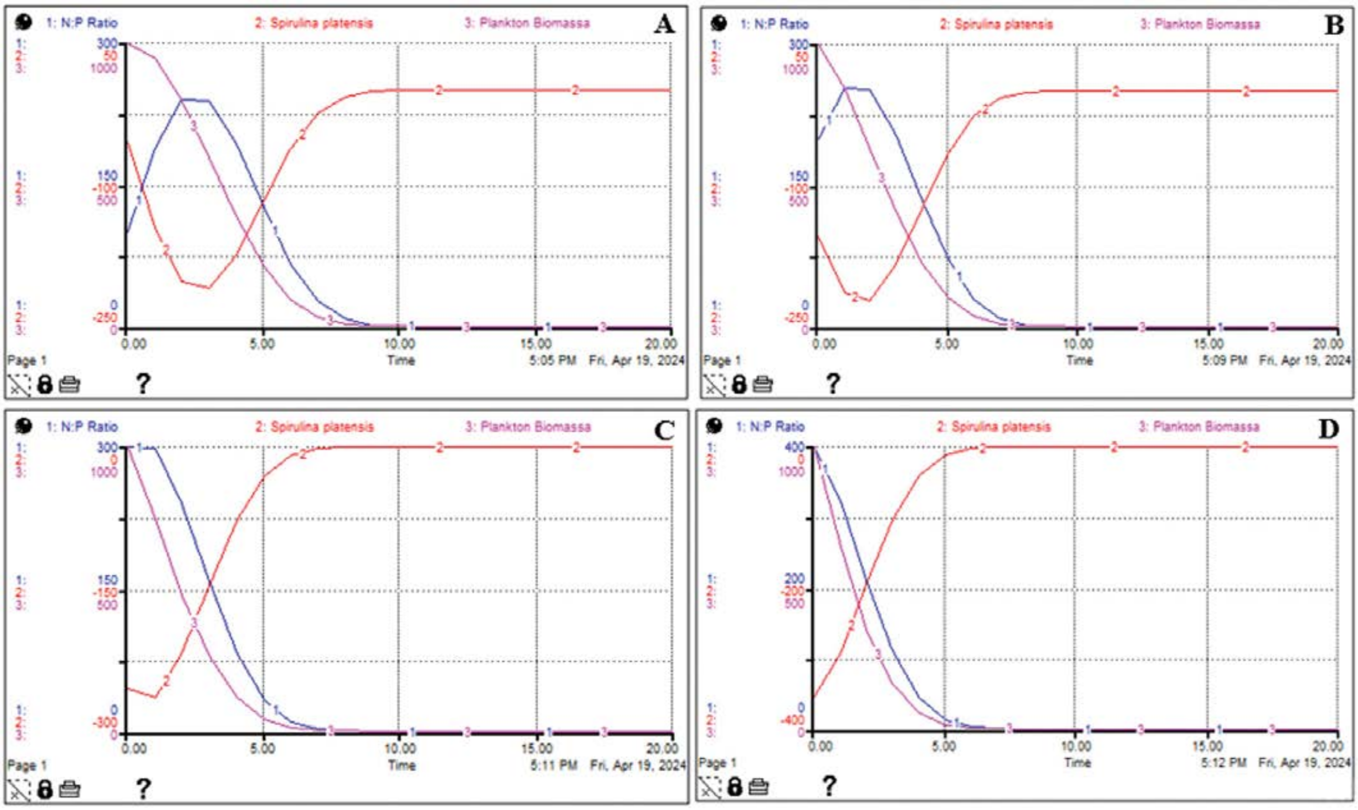

Figure 6. *Causal loop* result about the relationship between the abundance of *Spirulina platensis* and N:P ratio in shrimp pond with proportion of N:P ratio 1:10 (A); N:P ratio 1:20 (B); N:P ratio 1:30 (C); and N:P ratio 1:40 (D)

At N:P ratios of 1:10 and 1.20, the abundance level of *Spirulina platensis* ranges from 00.00E+03 cells/ml to 25.00E+03 cells/ml. This justifies that *Spirulina platensis* will grow optimally within the N:P ratio range of 1:10-1:20. An N:P ratio of ≤1:20 is the optimal proportion for the growth of plankton from the chyanophyceae and chrysophyceae classes (Adomako and Yu, 2023). N:P ratios that are too high (>1:20) are usually dominated by chlorophyceae class plankton (Ariadi et al., 2021).

Spirulina platensis is a type of plankton that does not thrive in just any aquatic conditions. The proportion of N:P ratio and water quality stability are crucial in determining the existence of *Spirulina platensis* in pond ecosystems (Zhou et al., 2018). Several parameters that influence the existence of *Spirulina platensis* include temperature, pH, currents, and the presence of suitable nutrients (Satanwat et al., 2023). *Spirulina platensis* has a short growth phase, making it susceptible to decline (Zulfahmi et al., 2023). Moreover, *Spirulina platensis* is also a plankton species that does not readily bloom, resulting in its relatively low dominance in pond waters (Pestana et al., 2020).

The presence of *Spirulina platensis* in pond waters indicates a balance of biotic and abiotic factors in the ponds (Zhang et al., 2023). *Spirulina platensis* can serve as a bioindicator of water balance levels (Mredul et al., 2022). Its presence also signifies a fairly even dominance cycle of plankton in the water (Pestana et al., 2020). In the food chain, *Spirulina platensis* is at the first level (Tibbetts et al., 2023).

Overall, the abundance of plankton in pond aquatic ecosystems tends to be moderate, with evenly distributed class dominance. The dominant plankton classes are chlorophyceae and chyanophyceae with a low dominance range. *Spirulina platensis* is one of the plankton species found stably in the research pond locations. High nutrient levels in shrimp ponds, originating from feed waste, feces, and cumulative fertilization, will influence the existence of *Spirulina platensis* (Ariadi et al., 2025). The presence of *Spirulina platensis* species reflects a relatively good pond ecosystem condition (Mredul et al., 2022). Additionally, *Spirulina platensis* can be utilized as a natural food source for shrimp in ponds (Jimenez et al., 2003). Implicitly, the existence of *Spirulina platensis* is influenced by the presence of suitable nutrients in the water (Fernandez-Rios et al., 2023).

The *Spirulina platensis* dominance in the pond ecosystem during the research period was also closely influenced by seasonal conditions. The research implementation conducted in the transition season from rainy to dry had quite an impact on water temperature. Pond water in the transition season tends to be warm, but not so hot. The transition season also marks a decrease in rainfall, which results in wind gusts (Kim et al., 2022). This is quite influential because of the impact of the correlation between life in the aquatic ecosystem and the atmosphere (Yang et al., 2022).

Spirulina platensis is a highly beneficial plankton. The main functions of *Spirulina platensis* as a live feed and bioindicator of aquatic environments are essential for aquaculture farmers. *Spirulina platensis* can stabilize the aquatic environment due to nutrient stabilization and the balance of water quality parameters, which tend to be favorable when this plankton is dominant (Raji et al., 2018). Therefore, standardization of nutrient abundance in ponds and the minimum usage of paddle wheel aerators are necessary. Nutrients are a limiting factor in the growth of *Spirulina platensis* in shrimp pond ecosystems (Ariadi et al., 2024; Mardiana et al., 2024). Paddle wheel aerators serve to distribute nutrients evenly throughout the pond water, allowing *Spirulina platensis* to utilize them (Zouhir et al., 2017; Maharani et al., 2024). Paddle wheel aerators also play a role in stirring the water, ensuring that plankton distribution in the pond ecosystem is relatively uniform (Ramesh et al., 2024).

CONCLUSION

The conclusion from this research is that *Spirulina platensis*, based on the analysis of the causal loop model in dynamic modeling systems, is depicted to undergo oscillating abundance fluctuations during the twenty-week shrimp farming period, with an optimal N:P ratio for the growth of this plankton species being ≤1:20. *Spirulina platensis* is also depicted to exhibit a contradictory abundance fluctuation pattern with the N:P ratio in pond waters. Therefore, shrimp farmers in tropical waters should always maintain a low N:P ratio of ≤1:20 to maintain of the aquatic ecosystem stability and also so that *Spirulina platensis* can grow optimally as a natural shrimp feed. The use of consistent paddle aerators according to carrying capacity is also highly recommended to stimulate the growth of *Spirulina platensis*, because the plankton really likes homogeneous water conditions due to stirring by pond currents.

The results of this study are also expected to have future research implications that model several shrimp farming practices in tropical waters, which support the development of green aquaculture through the utilization of phytoplankton as a natural feed for cultured shrimp. Furthermore, as a recommendation for future research, it is hoped that there will be research concepts examining the dynamics of ecological engineering to optimize the growth of *Spirulina platensis* in pond ecosystems, while considering various environmental factors, such as water quality parameters, fertilizer availability, the intensity of farming waste pollution, and weather conditions.

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