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Study of nitrogen and phosphorus nutrient dynamics in concentrated marine fish farming water environment in Long Son - Vung Tau

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ABSTRACT

The nutritional content of N and P in concentrated marine fish farming water in the Cha Va - Long Son - Vung Tau estuary area increased sharply during 2013–2016; notably, the $N\text{-}NH_4^+$ content increased in 2017–2019. The $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ content in the dry season (0.051 mg/L and 0.190 mg/L) was higher than in the rainy season (0.044 mg/L and 0.133 mg/L). In contrast, the $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$ contents in the rainy season (0.321 mg/L and 0.1 mg/L) are higher than in the dry season (0.154 mg/L and 0.093 mg/L). The N and P nutrient dynamics in water fluctuate according to the semi-diurnal tide regime; the nutrient content decreases during high water - daytime, increases during low water in the evening, and is high during high water at night and in the morning, early the next day. In dry and rainy seasons, the $N\text{-}NH_4^+$ content is always the highest (0.024–0.761 mg/L) among the nitrogen-based nutritional parameters. N and P nutrients in water are correlated: $N\text{-}NH_4^+$ parameter pairs with Total P, $N\text{-}NO_2^-$ with Total P, Total N with Total P, $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$ with Total P, and the parameter pair $N\text{-}NO_2^-$ with $P\text{-}PO_4^{3-}$ have low positive correlation coefficients (*r*), from 0.1–0.21. Conversely, the parameter pairs $N\text{-}NO_3^-$ and Total N, $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$, and $N\text{-}NO_2^-$ and $N\text{-}NH_4^+$ have low negative correlation coefficients (*r*), from -0.12 to -0.26. From 2010–2021, the number of cages increased beyond planning, causing environmental pollution in the water in the farming area. The nutritional *RQ* value of the water is high at level 4 every year (very high risk of environmental pollution).

Keywords: Nitrogen and phosphorus nutritional dynamics, concentrated marine fish farming, *RQ* index, Long Son - Vung Tau.

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INTRODUCTION

The sea area at the mouth of Cha Va River - Long Son commune - Vung Tau City has a semi-diurnal tidal regime; in the day and night tide cycle there are 2 tides; each tide has a high-water cycle and a low water cycle. This area is planned as a concentrated marine fish farming area with the largest number of cages in Ba Ria - Vung Tau Province. The number of farming cages increased sharply from 2012 (about 2,670 cages) to 2018 (8,000 cages), from 2019 to 2021, maintaining between 5,380 and 8,326 cages, of which 3,601 cages were outside the farming planning approved by the People's Committee of Ba Ria - Vung Tau Province. The main farming species are grouper fish, red snapper, seabass, pompano,... The increased spontaneous cage farming has caused environmental pollution and disease, damaging marine fish farming in Long Son.

Based on a series of monitoring and research data acquired over the years, this research aims to provide crucial information on the nitrogen (N) and phosphorus (P) nutritional dynamics in the water environment of concentrated marine fish farming areas in Long Son - Vung Tau. Doing so will significantly contribute to pollution control and water environment quality management and provide valuable recommendations for marine fish farming households.

RESEARCH MATERIALS AND METHODS

Materials, areas and research contents

The source of N and P nutritional data in the Long Son - Vung Tau area's concentrated marine fish farming water environment is the research project "Environmental monitoring task for concentrated marine fish farming areas, 2005–2021". The study of N and P fluctuations in water in the marine fish farming area at Cha Va - Long Son - Vung Tau estuary in dry and rainy seasons was collected from 2005–2021 at points VT1, VT2, VT3, VT4 (Fig. 1).

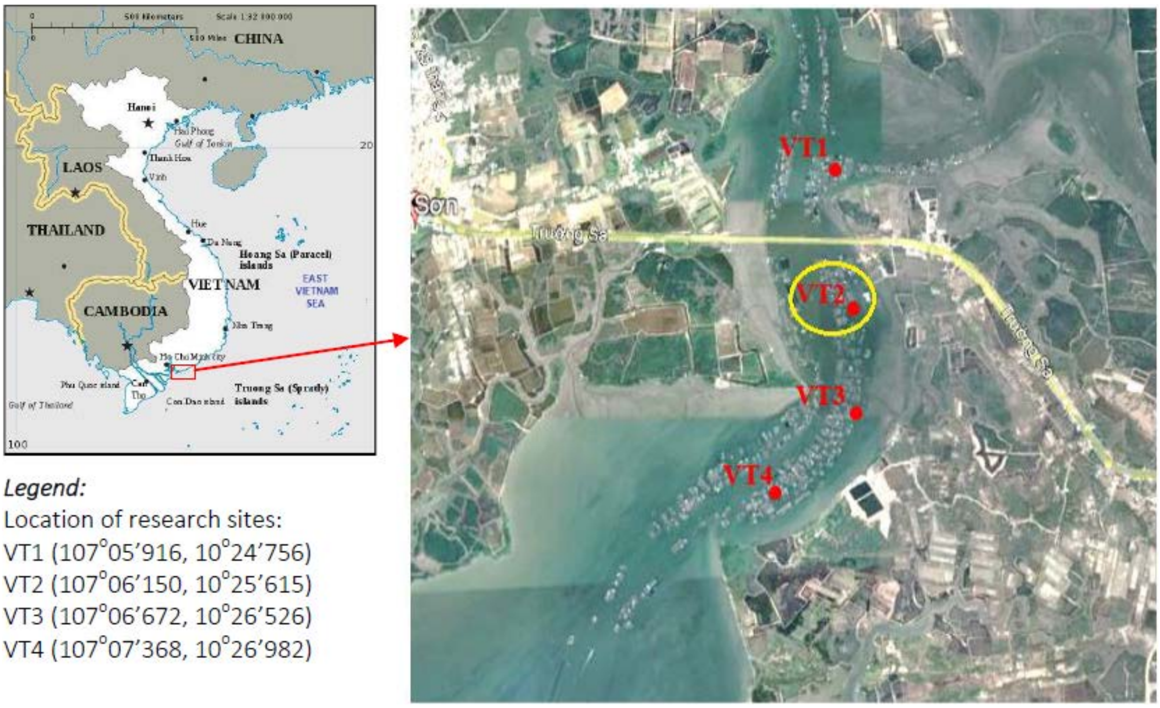


Figure 1. Location of research sites in the concentrated marine fish farming area of Long Son - Vung Tau

Research site VT2 near the foot of Long Son bridge includes surveying and analyzing fluctuations in N and P contents according to water layer (surface layer, bottom layer) and tidal cycle during day and nighttime, with a frequency of 2 hours/1 sampling.

In the dry season, the Survey started from 6:00 am on May 14, 2021, and ended at 6:00 am on May 15, 2021.

In the rainy season, the Survey started from 6:00 am on October 19, 2021, to 6:00 am on October 20, 2021.

Parameters for analyzing nutrient dynamics include N-NH_4^+, N-NO_2^-, N-NO_3^-, P-PO_4^{3-}, Total N, Total P.

Research Methods

Sampling and analytical methods

The seawater sampling method was followed according to TCVN 6663-1:2011 (ISO 5667-9:2015), and the preservation was according to TCVN 6663-3:2016.

Analytical method: N-NH_4^+ parameters were followed the APHA 4500 NH_4^+ - F, pages 4-80 to 4-81; the N-NO_2^- was after APHA-4500-NO_2^- - B, pages 4-83 to 4-84; the N-NO_3^- was after APHA-4500 NO_3^- - E pages 4-80 to 4-87; the P-PO_4^{3-} was after APHA-4500- P - E pages 4-112 to 4-113; the Total N was according to TCVN 6638:2000; and the Total P was guided in TCVN 6202:2008.

Field survey samples are preserved and transported to the Marine Science Laboratory, Seafood Research Institute, to be analyzed for N and P nutritional parameters (ISO 17025:2017 - Recognition field - Chemistry - Code VILAS 1235).

Method for assessing water environment quality

Method for assessing the possibility of environmental pollution risk (EPR) of the nutritional group through the environmental risk index (RQ) according to Circular 26/2016/TTBTNMT dated September 29, 2016 [1], specifically:

$$RQ = \frac{\sum_{j-1}^{m} W_j \left(\frac{MEC}{PNEC} \right)_j}{\sum_{j-1}^{m} W_j}$$

where: MEC: concentration of pollutants *j* (N, P) in the environment from analytical data according to current methods of Vietnam and the world; *PNEC*: limit content of pollutants *j* (N, P) in the environment according to standards of QCVN 10:2023/BTNMT [2]; *m*: total number of pollutants assessed; W_j: weight to calculate the environmental risk coefficient for pollutant *j* (N, P).

The level of pollution or environmental pollution risk is assessed through the environmental risk index *RQ* according to the classification in Table 1.

Table 1. Table of criteria for the level of environmental pollution rick according to the *RQ* environmental risk index

RQ index	Criteria	Level
RQ > 1.5	Level or very high EPR	4
1.25 < *RQ* ≤ 1.5	Level or high EPR	3
1 < *RQ* ≤ 1.25	Level or mild EPR	2
RQ ≤ 1	Level of low EPR	1

Data processing methods

This study used Excel 2010 software for statistical processing and calculating fluctuations and correlations in N and P nutritional. The correlation coefficient is calculated according to the formula in Table 2 [3].

Table 2. The formula for calculating the correlation coefficient and classifying the relationship between *x* and *y*

$r_{xy} = \dfrac{\overline{xy} - \overline{x}.\overline{y}}{\hat{s}_x . \hat{s}_y}$	Where the correlation coefficient is taken a value between -1 and 1 (-1 ≤ *r* ≤ 1). When *r* is closer to 0, the looser the relationship is; conversely when *r* is closer to 1 or -1, the closer the relationship is (*r* > 0 has a positive relationship and *r* < 0 has a negative relationship). In the case *r* = 0, there is no relationship between *x* and *y*.

RESULTS AND DISCUSSION

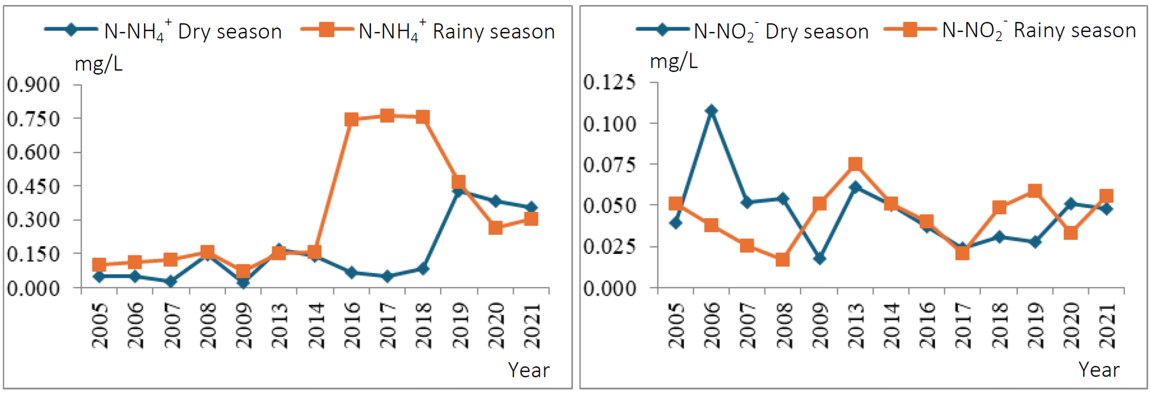
Fluctuations of N and P nutrients in marine fish farming water environment concentrated in Long Son - Vung Tau

Nitrogen nutritional content (N-NH_4^+, N-NO_2^-, N-NO_3^-):

The content of N-NH_4^+ in water in the farming area ranges from 0.024–0.761 mg/L. The average dry season is 0.154, 0.321 mg/L lower than the rainy season, and increases sharply in 2016–2021. At the same time, the N-NH_4^+ content in water is always the highest among nitrogen-based nutritional parameters. According to research by author Dang Kim Chi, the water environment is polluted when the N-NH_4^+ content is high [4]. When the environment is polluted, it will be a favorable condition that causes eutrophication [5] and diseases that harm farmed fish [6].

In the domestic Nitrogen cycle, N-NO_2^- is an intermediate product of the conversion of N-NH_4^+ to N-NO_3^- [7]. The N-NO_2^- content in water in Long Son's marine fish cage farming area over time (2005–2021) is low, ranging from 0.017–0.168 mg/L, with an average of 0.051 mg/L in the dry season. 0.044 mg/L higher than the rainy season. The N-NO_3^- content in water ranges from 0.023–0.541 mg/L. The average value in the dry season (0.199 mg/L) is higher than in the rainy season (0.133 mg/L).

Fluctuations of nitrogen nutrients over time show that the N-NH_4^+ content in water in the rainy season is higher than in the dry season (Figure 2a); this result is also similar to the study of Whitall et al., (2012) [8]. In contrast to N-NH_4^+, the content of N-NO_2^- and N-NO_3^- in the dry season is higher than in the rainy season (Figs. 2b, 3a).



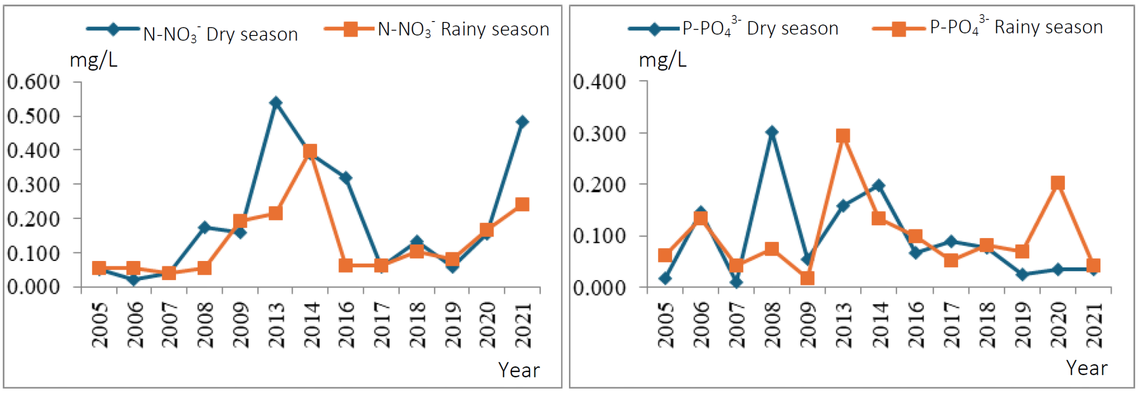
a. N-NH_4^+ b. N-NO_2^-

Figure 2. Fluctuations of N-NH_4^+, N-NO_2^- contents in Long Son - Vung Tau's water (2005–2021)

P-PO_4^{3-} content: during the research period, P-PO_4^{3-} content fluctuated between 0.011–0.303 mg/L; Like N-NH_4^+, the average P-PO_4^{3-} content value in the rainy season (0.100 mg/L) is higher than the dry season (0.093 mg/L) (Figure 3b).

The nutritional content of nitrogen and P-PO_4^{3-} in water in the marine fish farming area in cages in 2005–2009 [9] was quite stable, with low fluctuations, and increased sharply in 2013–2016. The nutritional content of N-NO_2^-, N-NO_3^-, and P-PO_4^{3-} decreased, and the fluctuation amplitude was low in 2017–2021. As for P-PO_4^{3-} parameters, the content increased the highest during 2009–2014 and decreased in 2016–2021. For the N-NH_4^+ parameter, the content increased from 2016, remained high in 2017–2019, and decreased slightly in 2020–2021 (Fig. 4).

Total N content fluctuates in the range of 0.239–1.350 mg/L, high content in 2005–2007 and decreasing in 2008–2010. From 2013 to 2016, Total N content increased, the amplitude ranged from 0.440–0.981 mg/L. From 2017 to 2021, Total N content ranges from 0.561 to 0.933 mg/L (Fig. 5).



a. $N\text{-}NO_3^-$ b. $P\text{-}PO_4^{3-}$

Figure 3. Fluctuations of $N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$ contents in Long Son - Vung Tau's water (2005–2021)

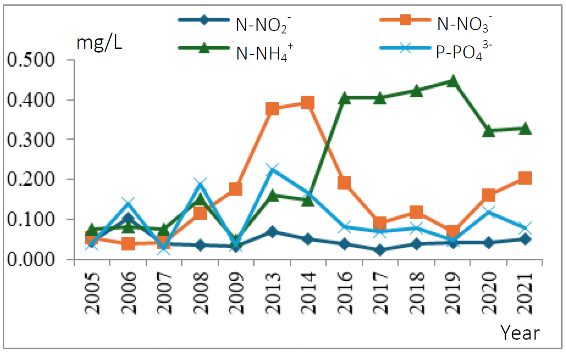


Figure 4. Fluctuations of $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$ in Long Son - Vung Tau's water

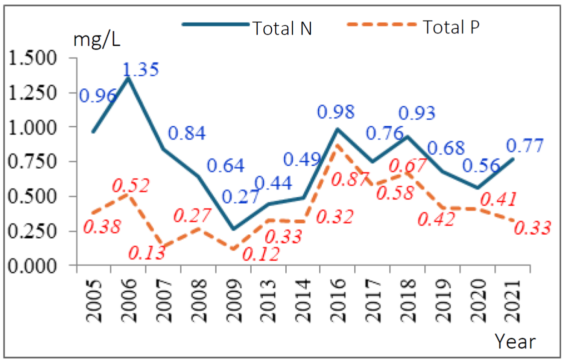


Figure 5. Fluctuations of total N and P in Long Son - Vung Tau's water

Total P content fluctuates between 0.119–0.871 mg/L and fluctuates in the same phase as Total N content; Total P content fluctuated slightly during 2005–2014, increased and fluctuated strongly in 2016–2018, then decreased during 2019–2021 (Figure 5).

Thus, from 2005 to 2021, research has always recorded that the total N content in water was higher than the total P, $N\text{-}NH_4^+$, and $P\text{-}PO_4^{3-}$ content in the rainy season, which was higher than in the dry season. This result reflects the influence of continental waste sources on the quality of the water environment in the farming area [9, 10]. This result is similar to the study of Nobuyuki Kawasaki [11]. In addition, the impact of farming activities on the environment shows that the $N\text{-}NH_4^+$ content in water increases in the farming area. This result is similar to the research of Longgen Guo and colleagues [12, 13], who also recorded high levels of $N\text{-}NH_4^+$ in the water. The $N\text{-}NH_4^+$ is high in the area where the cage is located.

N and P nutritional dynamics in concentrated marine fish farming water environment in Long Son - Vung Tau

Dynamics of N and P nutrients in water by day and night in Long Son - Vung Tau in the dry season

May 2021 at LS2 point:

May 14, 2021: Water level height at high tide (3:47 am) was 3.3 m. At low water (9:11 am), it was 2.2 m. The water level height at high water (2:04 pm) is 3.3 m. At low water (9:22 pm), it was 0.4 m. The research site depth at high water was 8.9 m, and at low water level, 6.6 m.

May 15, 2021: Water level height at high tide (4:29 am) was 3.3 m. At low water

(9:45 am), it was 2.3 m. The water level height at high water (2:23 pm) was 3.3 m. At low water (9:55 pm), it was 0.4 m. The research point depth was 9.0 m at high water.

$N-NH_4^+$ content fluctuates between 0.080–0.588 mg/L, clear stratification at the surface layer (average 0.234 mg/L) was lower than the bottom layer (0.378 mg/L). According to the tide, the $N-NH_4^+$ content in water decreased at high water (10:00 am - 2:00 pm); it increased at low water in the afternoon (4:00 pm - 10:00 pm) and reached the highest point at high water of the next tidal cycle in the next morning (0:00 am - 4:00 am); The difference in $N-NH_4^+$ content at the largest and smallest is 0.508 mg/L (Fig. 6).

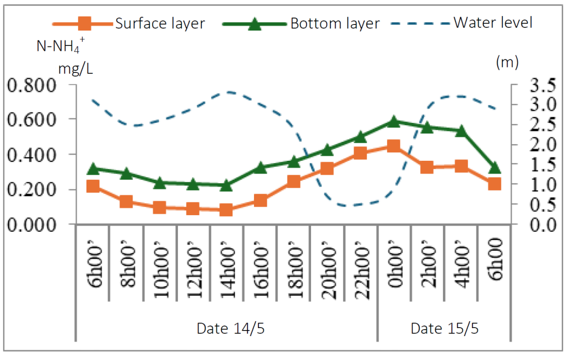


Figure 6. Fluctuations in $N-NH_4^+$ content at point LS2 - Vung Tau, on May 14–15, 2021

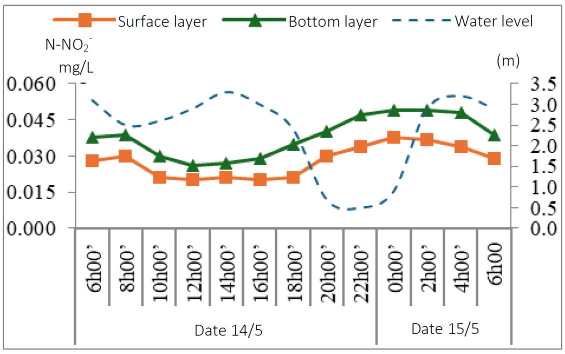


Figure 7. Fluctuations in $N-NO_2^-$ content at point LS2 - Vũng Tàu, on May 14-15, 2021

$N-NO_2^-$ content fluctuates between 0.020–0.049 mg/L, average surface layer 0.028 mg/L, bottom layer 0.038 mg/L. According to the tide, during high water during the day (8:00 am - 2:00 pm), $N-NO_2^-$ content decreases and increases when low water the night before (6:00 pm - 10:00 pm) and reaches the highest during high water the next day (2:00 am - 4:00 am). The difference between the largest and smallest $N-NO_2^-$ content in water was 0.029 mg/L (Fig. 7).

$N-NO_3^-$ content ranges from 0.268–0.612 mg/L, average surface layer 0.394 mg/L, bottom layer 0.45 mg/L; fluctuates with the tides, recording a slight decrease in $N-NO_3^-$ content during high water during the day (10:00 am - 2:00 pm) and an increase at low water at night (6:00 pm - 10:00 pm), and a high increase in $N-NO_3^-$ content at night at high water the following day (2:00 am - 4:00 am); The difference between the largest and smallest $N-NO_3^-$ content is 0.344 mg/L (Fig. 8).

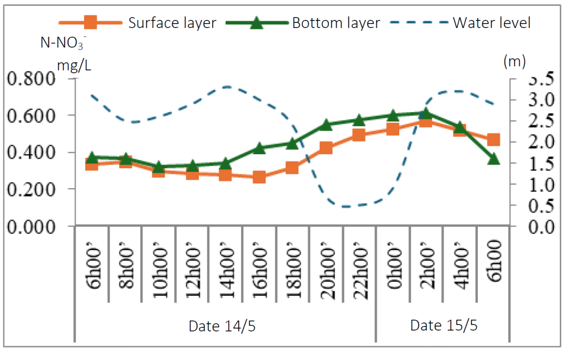


Figure 8. Fluctuations in $N-NO_3^-$ content at site LS2, Vung Tau on May 14–15, 2021

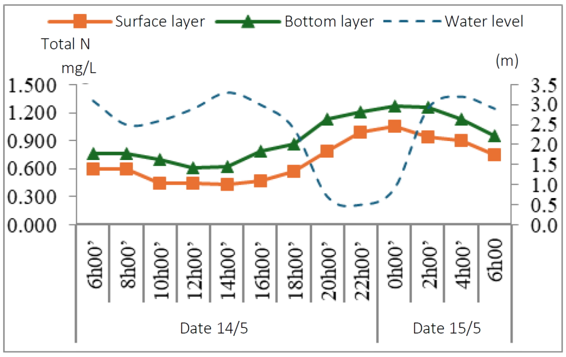


Figure 9. Fluctuations in the Total N at site LS2, Vung Tau on May 14–15, 2021

Total N content in water in the farming area ranges from 0.426–1.269 mg/L; the average surface layer is 0.629 mg/L, lower than the bottom layer of 0.659 mg/L. During the day at high water (10:00 am - 4:00 pm), it was recorded that Total N content decreased, increased during low water in the evening (6:00 pm - 10:00 pm) the previous day, and reached the highest level at high water time early the next morning (0:00 am - 2:00 am). The difference in Total N content between the largest and smallest is 0.843 mg/L (Fig. 9).

P-PO_4^{3-} content fluctuates between 0.026–0.049 mg/L, and the difference between the surface layer (0.036 mg/L) and the bottom layer (0.039 mg/L) is not much. During high water during the day (8 am - 4 pm), P-PO_4^{3-} content decreased at 2 pm. The P-PO_4^{3-} content increased at low water in the evening and night (8:00 pm - 10:00 pm), reaching the highest level at high water early the next morning (2:00 am - 4:00 am). The difference between the largest and smallest P-PO_4^{3-} content is 0.023 mg/L (Fig. 10).

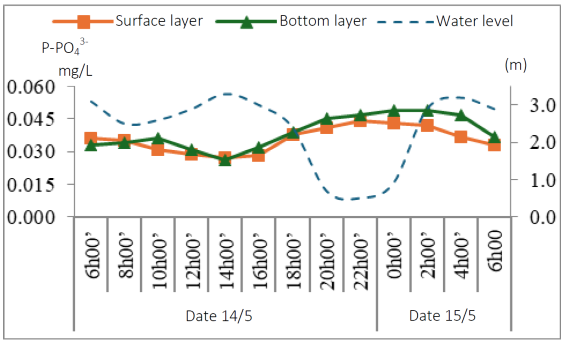


Figure 10. Fluctuations in P-PO_4^{3-} at LS2, Vung Tau, on May 14–15, 2021

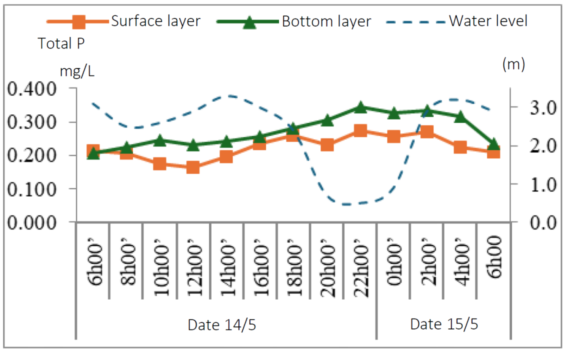


Figure 11. Fluctuations in the Total P at point LS2, Vung Tau, on May 14–15, 2021

Total P content in water in the farming area fluctuates between 0.165–0.345 mg/L; on average, the surface layer (0.224 mg/L) is lower than the bottom layer (0.345 mg/L). According to the tidal cycle, Total P content decreases during high water (10 am - 2:00 pm), increases highest during low water at night (8:00 pm - 10:00 pm), and decreases during high water (2:00 am - 6:00 am) the next day. The difference in Total P content at the maximum and the minimum is 0.180 mg/L (Fig. 11).

Dynamics of N and P nutrients in water by day and night in Long Son - Vung Tau during the rainy season

In October 2021, at LS2 point:

October 19, 2021: Water level height at high tide (0:58 am) was 3.6 m. At low water (7:08 am), it was 1.7 m. The water level height at high water (12:49 pm) was 3.4 m. At low water (5:08 pm), it is 1.3 m. The research site depth was 9.9 m at high water, and at low water was 7.5 m.

October 20, 2021: Water level height at high tide (1:19 am) is 3.6 m; At low water (7:36 am), it was 1.4 m. The water level height at high water (1:34 pm) was 3.5 m. At low water (7:42 pm), it was 1.5 m. The research site depth was 9.9 m at high water.

The N-NH_4^+ content in water fluctuates between 0.120–0.567 mg/L; the stratification was clearly shown, and the average surface layer was 0.229 mg/L lower than the bottom layer at 0.419 mg/L. Fluctuations in N-NH_4^+ content according to the tidal cycle are as follows: when the water is high (8:00 am - 2:00 pm) during the day, the N-NH_4^+ content drops low, at low water in the evening of the same day (4:00 pm - 8:00 pm), the N-NH_4^+ content increased and reached its highest level at high water of the next day's tidal cycle. The difference between the largest and smallest N-NH_4^+ content was 0.447 mg/L (Fig. 12).

N-NO_2^- content fluctuates between 0.019–0.049 mg/L, the average surface layer was 0.026 mg/L lower than the bottom layer at 0.036 mg/L. The difference in N-NO_2^- content between the largest and smallest was 0.030 mg/L. During high water during the day (10:00 am - 2:00 pm), the N-NO_2^- content in the water was low. At low water at night (6:00 pm -

8:00 pm) and at high water the next morning (0:00 am - 2:00 am), N-NO_2^- content increased and was the highest (Fig. 13).

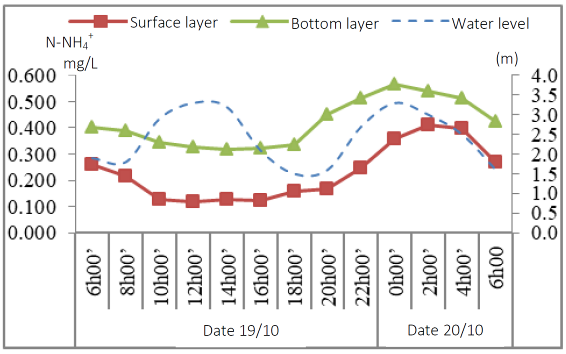


Figure 12. Fluctuations in N-NH_4^+ content at LS2, Vung Tau, on October 19–20, 2021

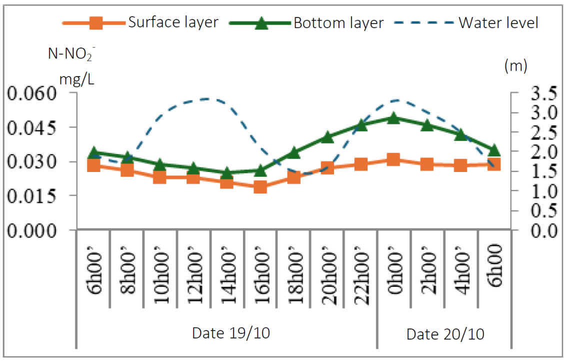


Figure 13. Fluctuations in N-NO_2^- content at site LS2, Vung Tau, on October 19–20, 2021

The N-NO_3^- content in the water in the farming area fluctuated between 0.102–0.521 mg/L. The average surface layer (0.134 mg/L) was much lower than the bottom layer (0.353 mg/L). Like N-NO_2^-, during high water periods during the day (8:00 am - 12:00 am), N-NO_3^- content decreased and increased during low water (4:00 pm - 8:00 pm), while N-NO_3^- content in water highest at high water increased sharply at the bottom in the early morning (0:00 am - 2:00 am). The difference between the largest and smallest N-NO_3^- content was 0.419 mg/L (Fig. 14).

Total N content ranged from 0.245–1.137 mg/L, distributed in the surface layer (0.389 mg/L) lower than the bottom layer (0.807 mg/L). Similar to the N-NH_4^+ parameter, the total N content was low during high tide - high water (12:00 pm - 2:00 pm), then increased during low water (6:00 pm - 8:00 pm) and reached the highest concentration at high water time at night and early the next morning (10:00 pm - 2:00 am). The difference in the total N content at the largest and smallest reached 0.892 mg/L (Fig. 15).

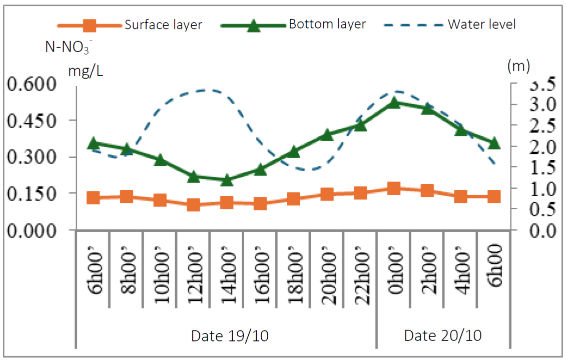


Figure 14. Fluctuations in N-NO_3^- content at site LS2, Vung Tau, on October19–20, 2021

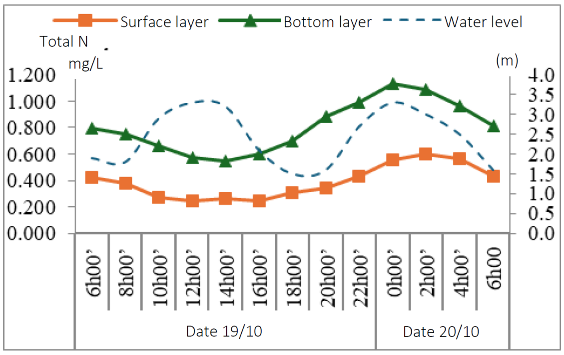


Figure 15. Fluctuations in the tota lN at site LS2, Vung Tau, on October 19–20, 2021

P-PO_4^{3-} content in water ranges from 0.028–0.054 mg/L, on average the surface layer (0.035 mg/L) was lower than the bottom layer (0.043 mg/L). The concentration slightly decreased during high water during the day (10:00 am - 2:00 pm). During low water (4:00 pm - 8:00 pm), P-PO_4^{3-} content increased and was highest during the high tide cycle - when high water enters the night before and the next morning (10:00 pm - 2:00 am) (Fig. 16). The difference in P-PO_4^{3-} content at the largest and the smallest time was 0.026 mg/L.

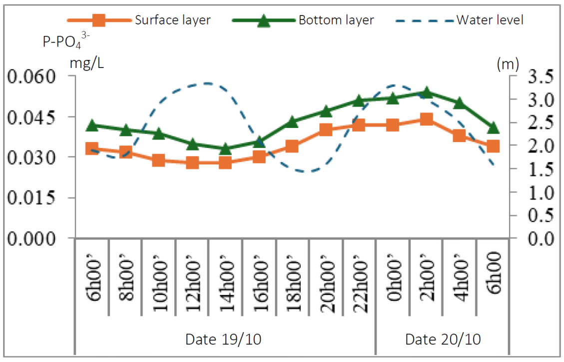


Figure 16. Fluctuations in P-PO_4^{3-} at site LS2, Vung Tau, on October 19–20, 2021

Total P content fluctuated between 0.441–0.612 mg/L in the surface layer (0.459 mg/L), which was not much lower than that in the bottom layer (0.553 mg/L) (Fig. 17). The difference in the total P content at the largest and smallest was 0.171 mg/L. According to the tidal cycle - during high water during the day (8:00 am - 2:00 pm), the total P content did not decrease. It remained stable, then increased at the bottom during low water (4:00 pm - 10:00 pm) and decreased slightly; little fluctuation was recorded in the high water cycle the following day (0:00 am - 6:00 am).

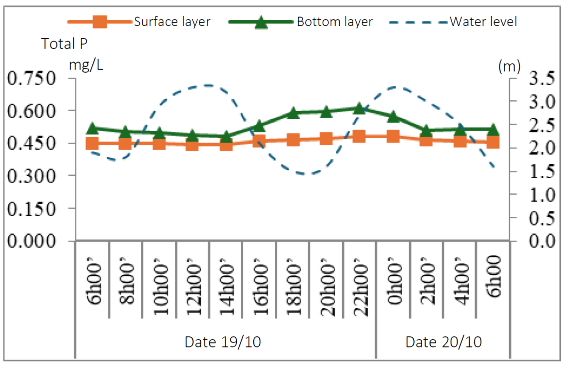


Figure 17. Fluctuations in the total P at site LS2, Vung Tau, on October 19–20, 2021

In general, in the dry and rainy seasons, most of the N and P nutrient parameters in water at Long Son 2 decreased during high water periods due to the dilution of clear water from the sea. They decreased during the day, reflecting the process of consuming nutrients through photosynthesis of phytoplankton and nutrient metabolism in water under daytime light and temperature conditions. When the N and P nutrient content in water was high, usually at the end of the low water cycle and the beginning of the next high-water cycle, it indicated the influence of pollution sources from the continent, waste from farming and processing activities. The dynamic level of the tides in the area affects the quality of the water environment where marine fish are raised in cages; this is also a characteristic of the environment of coastal estuaries.

Nutritional correlation of N and P in concentrated marine fish farming water environment in Long Son - Vung Tau

Initial calculation results (Table 3) show a weak correlation between nutritional parameters in water in the marine fish farming area using Long Son cages. In which the positive correlation coefficient (*r*) is low with the N-NH_4^+ parameter pair with Total P (*r* = 0.21); N-NO2- with Total P (*r* = 0.21); Total N vs Total P (*r* = 0.19); N-NO_2^- and N-NO_3^- (*r* = 0.16); P-PO_4^{3-} with Total P (*r* = 0.12) and parameter pair N-NO_2^- with P-PO_4^{3-} (*r* = 0.10). Low negative correlation coefficient (*r*) for the N-NO_3^- parameter pair with Total N (*r* = -0.26); N-NO_3^- with N-NH_4^+ (*r* = -0.17) and parameter pair N-NO_2^- with N-NH_4^+ (*r* = -0.12).

The correlation coefficients of N-NO_2^- and N-NO_3^- are positive with low positive values, and the correlations between N-NH_4^+ with N-NO_2^- and N-NO_3^- are negative with low negative values, proving the ability to quickly convert existing forms of nitrogen nutrients in the water environment in the farming area, high environmental self-cleaning ability, and large environmental carrying capacity. The correlation between Total N and Total P parameters is positive. It has a low positive value, proving that the area is greatly affected by nutrients provided by continental water sources. The results of this study are similar to studies of river regions [14] and concentrated marine fish farming areas of coastal rivers [15].

Table 3. The relation index (*r*) matrix among the N and P nutrition parameters in the water of concentrated marine fish farm at Long Son - Vung Tau

Parameter	$N\text{-}NO_2^-$ (*n* = 238)	$N\text{-}NO_3^-$ (*n* = 270)	$N\text{-}NH_4^+$ (*n* = 271)	Total N (*n* = 210)	$P\text{-}PO_4^{3-}$ (*n* = 266)	Total P (*n* = 223)
$N\text{-}NO_2^-$	1					
$N\text{-}NO_3^-$	0,16	1				
$N\text{-}NH_4^+$	-0,12	-0,17	1			
Total N	-0,06	-0,26	0,03	1		
$P\text{-}PO_4^{3-}$	0,10	0,07	-0,07	-0,01	1	
Total P	0,21	0,08	0,21	0,19	0,12	1

Environmental pollution rick due to N and P nutrients in water in concentrated marine fish farming areas in Long Son - Vung Tau

The nutritional environmental risk index (nutrition *RQ*) from 2005 to 2021 shows values ranging from 1.20 to 3.24. According to the environmental quality classification table (Table 1), there was no nutritional *RQ* value of water at level 1 (low environmental pollution risk) in the years of study. In 2007 and 2009, the nutritional *RQ* value was at level 2 (medium environmental pollution risk). In 2010–2021, the high nutritional *RQ* value was at level 4 (very high risk of environmental pollution) and increased by 2.5–2.7 times compared to 2005–2009. The level of nutritional pollution in water in Long Son is higher than in the Cat Ba - Hai Phong farming area [9]. Fluctuations in the nutritional *RQ* value of water in the marine fish farming area in cages in Long Son - Vung Tau during the period 2005–2021 are shown in Fig. 18.

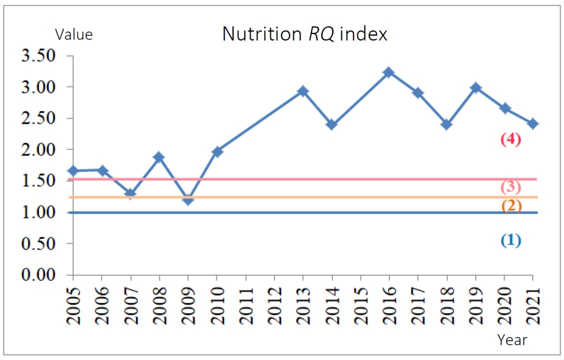


Figure 18. Fluctuations in nutrition *RQ* in water of the marine fish farm in Long Son - Vung Tau

Fluctuations in the number of marine fish cages in Long Son - Vung Tau in 2005–2021 have an impact on the quality of the water environment (Fig. 19). The result is similar to Sekar Megarajan's (2016) on marine fish farming in India [15]:

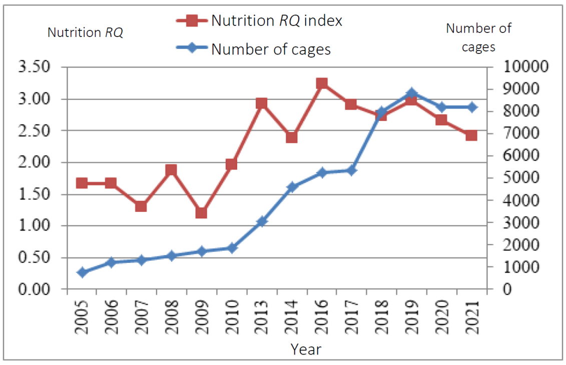


Figure 19. Fluctuation in nutrition *RQ* in water and number of marine fish farming cages in Long Son - Vung Tau

In 2005–2010, the number of cages was low (750–1,860 cages), and the nutritional *RQ* value of water in the farming area fluctuated between 1.20–1.97 at level 2, level 3, level 3, and level 4. During 2013–2019, the number of cages increased sharply between years (3,059–8,830 cages), and the nutritional *RQ* value increased from 2.39–3.24 at level 4 and was highest in 2016. During 2020–2021, the number of cages decreases, corresponding to the nutrient *RQ* value of water decreasing to 2.65 and 2.42 (Figure 19).

In addition to the impact of marine fish farming with the increasing number of cages over time, it is also related to nutritional pollution due to waste discharged from the continent into the sea, contributing to increasing the nutritional *RQ* value of water and affecting the environment field of marine fish farming in cages in Long Son - Vung Tau. Recorded signs related to waste sources from the mainland are that the content of most nutrient parameters N and P is higher during low water than during high water and higher in the rainy season than in the dry season, as described above. In recent years, the water environment has been in a state of pollution, as shown by the N-NH_4^+ content in water being consistently high and exceeding the allowable limit of 0.10 mg/L according to QCVN 10:2023/BTNMT [2].

CONCLUSIONS

During 2005 - 2009, the nutritional content of N and P in water in the concentrated marine fish farming area in Long Son was relatively stable, with low fluctuation amplitude, and then increased sharply in the years 2013–2016. The amount of nutritional salts N-NO_2^-, N-NO_3^-, and P-PO_4^{3-}decreased, and the fluctuation amplitude was low in 2017–2021. Notably, N-NH_4^+ parameters increased and remained high in 2016–2019, slightly decreasing in 2020–2021.

The average N-NO_2^- and N-NO_3^- contents in the dry season (0.051 mg/L and 0.190 mg/L) are higher than in the rainy season (0.044 mg/L and 0.133 mg/L) while the N-NH_4^+, P-PO_4^{3-} tend to change in the opposite direction in the rainy season (0.321 mg/L and 0.100 mg/L) higher than the dry season (0.154 mg/L and 0.093 mg/L) showing the influence of nutrients from the continent to the environment of the farming area. Day-night fluctuations show that most nutritional parameters in the dry and rainy seasons have decreased concentrations during high water during the day, increased during low water in the evening, and are high during high water during the morning tide cycle early the next day.

Low positive correlation coefficient (*r*) (0.10–0.21) with the N-NH_4^+ parameter pair with Total P; N-NO_2^- with Total P; Total N with Total P; N-NO_2^- and N-NO_3^-. P-PO_4^{3-} with Total P and parameter pair N-NO_2^- with P-PO_4^{3-}. In contrast, the parameter pair N-NO_3^- and Total N; N-NO_3^- and N-NH_4^+; N-NO_2^- and N-NH_4^+ have low negative correlation coefficients (*r*) from -0.12 to -0.26.

During 2010–2021, the number of farming cages increased sharply, and the water's *RQ* nutritional risk index values were high at level 4 (very high risk of environmental pollution).

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