MINISTRY OF EDUCATION AND TRAINING

VIETNAM ACADEMY OF SIENCE AND TECHNOLOGY

GRADUATE UNIVERSITY OF SIENCE AND TECHNOLOGY

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STUDY OF NITROGEN AND PHOSPHORUS NUTRIENT DYNAMICS IN CONCENTRATED MARINE FISH FARMING WATER ENVIRONMENT IN VIETNAM COASTAL

SUMMARY OF DOCTORAL THESIS ENVIRONMENTAL AND RESOURCE MANAGEMENT

Major: Environmental and Resource Management

Code: 9850101

Hai Phong - 2024

The dissertation is completed at: Graduate University of Science and Technology, Vietnam Academy of Science and Technology

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INTRODUCITON

1. The urgency of the thesis

The development of marine cage fish farming has made an important contribution to creating jobs and increasing the fisheries economy in many coastal localities such as Quang Ninh, Hai Phong, Thanh Hoa, Nghe An, Khanh Hoa, Binh Thuan, Phu Yen, Ba Ria - Vung Tau, Ca Mau, Kien Giang. There are quite a variety of farmed marine fish, including: Serranidae, Blood Snapper, Cobia, Starfish, Sprus latus, Pomfret.

The increase in the number and density of marine fish cages has put pressure on the environmental quality of water in the farming area. When water quality is reduced or polluted, high levels of pollutants are always recorded. It contains high levels of water-soluble nutrients nitrogen (N) and phosphorus (P).

For fish cage farming in coastal areas, along with the seeds, water quality is the decisive factor for effectiveness. Among those factors, the N and P content in water fluctuates according to the characteristics of each water body. When the N and P content in water is high, it facilitates disease development and eutrophication occurs, causing great damage to farmers. Therefore, studying the content and fluctuations of N and P in caged fish farming water in coastal waters is very necessary for production practices in marine fish farming areas in Vietnam.

To solve the above reality, the implementation of the thesis: *"Study of Nitrogen and Phosphorus nutrient dynamics in concentrated marine fish farming water environment in Vietnam coastal"* has scientific and practical significance, helping for monitoring and adjusting the water environment in marine fish farming areas, contributing to directing production and sustainable development of coastal marine fish farming in Vietnam.

2. Research objectives

1) Determine the nutritional dynamics of N and P in sea cage fish farming water in coastal waters of Vietnam in three representative research areas (Cat Ba - Hai Phong, Vinh Tan - Binh Thuan, Long Son - Vung Tau);

2) Propose management solutions, minimize pollution, and optimize effective farming environment.

3. Research contents

- Research on discharge and fluctuations of N and P nutrients in the water environment of caged fish farming areas in coastal.

- Research on the dynamics and relationships of nutritional parameters N (including: $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Total N) and P (including: $P\text{-}PO_4^{3-}$, Total P) in the environment water environment in cage fish farming areas in coastal waters of Vietnam.

- Propose solutions to protect the environment for sustainable development of cage fish farming in Vietnam's coastal.

CHAPTER 1. OVERVIEW

1.1. Research on N and P nutrient dynamics in the water environment of fish cages in coastal

1.1.1. Nutritional balance of N in seawater

The N cycle in the seawater environment starts from the process of decomposing organic N from material sources in the water, converting it into soluble forms of $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$. In natural seawater and offshore seawater, with the nutritional parameter N, the total N content is highest (0.5mg/l), followed by the parameter $N\text{-}NO_3^-$ (0.4 - 0.5mg/l). l), $N\text{-}NH_4^+$ parameter (0.02 - 0.025mg/l) and lowest $N\text{-}NO_2^-$ content (0.01 - 0.02mg/l).

1.1.2. Nutritional balance of P in seawater

The P content in seawater is due to the oxidation of organic compounds from many different sources. In tropical waters and open ocean waters, $P\text{-}PO_4^{3-}$ content is as low as 0.0002mg/l and Total P content ranges from 0.03 - 0.07mg/l.

1.1.3. Discharge of N and P nutrients into the water environment for fish cages in coastal waters on the world

1.1.3.1. Discharge of N nutrients into the water environment of fish cage farming areas in coastal waters

The trend of increasing N content in coastal waters is of worldwide concern, as it contributes to nutrient enrichment or causes eutrophication. Coastal marine cage fish farming is a source of N generation through particulate matter (uneaten food and fish feces) and dissolved metabolic wastes including ammonia and urea

1.1.3.2. Discharge of P nutrients in water from caged fish farming areas in coastal waters

In China, research by Wu (1999) suggested that 82% of P in fish food was released into the environment; Author Longgen Guo (2009) research shows that a lower percentage, about 34 - 41% of P in food is released in soluble form.

According to FAO (2020), research in Greece showed that the total amount of P released from sea cage fish farming into the environment was 71.4%. Calculated annual P emissions at the 4 fish farms studied are 0.6 - 6.5 tons of dissolved P/100 - 700 tons of farmed fish; About 27% of P is emitted from salmon digestion and from feed in dissolved form; 40% is released as particulates, while only 33% is controlled.

1.1.4. Nutrient dynamics of N and P in the water environment of fish cages in coastal on the world

On the world, research on N and P nutrient emissions into the water environment in marine fish farming areas is being carried out. When increasing N and P nutrient sources, the natural balance of the water area will change (the N:P ratio in the water environment in marine fish farming areas is higher than in other marine areas), causing risks to marine fish farming. with cage fish farming in coastal waters, due to declining water quality in most regions of the world. High levels of N and P nutrients in water reduce DO, which is directly harmful to livestock; At the same time, it is the cause

of eutrophication (red tide) in the aquatic environment, causing mass deaths of livestock (sea fish).

1.1.5. Nutrient dynamics of N and P in the water environment of caged fish farming in coastal of Vietnam

N and P nutritional dynamics in coastal marine fish farming water environments have not been studied much, especially in very limited concentrated farming areas. Mainly the results of the current status, but also fluctuate according to time (year, season, month, day, hour), location, afternoon cycle, water layer, N:P ratio in water synchronously in each farming area. marine fish to increase productivity and environmental sustainability has not been researched.

Research on the Total N/Total P ratio in water in coastal fish cage farming areas in Vietnam: Farming activities have caused an increase in N and P nutrients in the water environment of marine fish farming areas. According to the natural conditions of the sea, the fish cage farming area in the sea has increased nutrient content and is much higher than the nutrient content in open sea water.

Table 1. Summary table of domestic studies on Total N: Total P ratio in water bodies (research water areas)

Area	Total N: Total P ratio	Location
Offshore	1.7 - 7.1 and average 4.9	Bach Long Vi MPA
	2.6 - 7.8 and average 5.6	Cat Ba MPA
	7.0	Ocean
Coastal sea	4.3 - 12.9 and average 7.8	Coastal estuary of Ba Lat - Thai Binh
	dry season: 4.4 and rainy season: 6.6	Binh Dinh coastal area
	7.2	Coastal area
Fish cage farming area in coastal areas	Not researched yet	

1.2. Overview of solutions to control N and P nutrients in caged fish farming water in coastal on the world and in Vietnam

On the world, research on solutions to control N and P nutrients from fish cage farming in coastal waters focuses on the following issues: - Surveying the characteristics of natural conditions in the farming area; - Assess the carrying capacity of the farming area; - Select target species and farming density; - How to care for and choose food; - Raising animals alternately; - Stop farming and rotate by region; -Regular and early monitoring to control environmental quality in the farming area.

In Vietnam, solutions to control N and P nutrients for sea cage fish farming activities are generally regulated on management and environmental protection in the Law on Environmental Protection 2020 and the Law on Fisheries 2017 but have not been specifically stated. Research on environmental control solutions for marine fish farming is still limited. Actions on nutritional mechanisms to control food and waste entering marine cage fish farming areas to manage and protect the environment in farming areas are still lacking. been researched specifically.

CHAPTER 2. SUBJECTS AND METHODS

2.1. Research subjects and locations

- Research on nutrition of N ($N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Total N) and P ($P\text{-}PO_4^{3-}$, Total P) in the water environment of fish cages in coastal waters of Vietnam.
- Research locations for cage fish farming areas in Vietnam's coastal waters include: 1) Cat Ba gulf region - Hai Phong; 2) Vinh Tan coastal area - Binh Thuan and 3) Long Son estuary area - Vung Tau.

2.2. Synthesize information, documents and data

- Collect information and data on fish cage farming activities in coastal waters around the world, domestically and in the study area.
- Collect data and information about natural conditions, weather and climate, and tidal regime in the study area.
- Collect information about water environment parameters in the study area.

- Collect and synthesize data on N and P nutritional parameters in the study area, neighboring areas, and other sea areas.
- Summary of legal documents on environmental protection.

2.3. Methods of sampling, preservation and analysis of samples

- *Sampling method:* Collect and sample sea water according to the instructions of Circular 10/2021/TTBTNMT regulating environmental monitoring techniques and management of environmental monitoring information and data.
- *Sample preservation method:* Sample preservation according to TCVN 6663-3:2016. Preserving and processing water samples.
- *Method of analyzing soluble nutrient parameters N (N-NO_2^-, N-NO_3^-, N-NH_4^+, Total N) and P (P-PO_4^{3-}, Total P) in water* according to Vietnam's prescribed method and the world.

Table 2. Summary table of N and P nutritional data in water in cage fish farming areas in coastal by year, season, month and sampling time by hour of the day

Time	Year	Season (dry, rainy)	Month (February - November)	Day (sampling by panel: once every 2 hours in 1 day)
2005 - 2016	x	x		
2017 - 2018	x	x	x	
2019 - 2022	x	x	x	x

2.4. Methods of comparing and assessing the risk and nutritional dynamics of N and P in the water environment of caged fish farming in coastal

- Assess the level of pollution or risk of environmental pollution through the environmental risk index (RQ). The formula to calculate the RQ index is as follows:

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

- Research on N/P ratio: Determine the limiting factor for eutrophication (Redfield index) in water environment: Redfield index is calculated based on the ratio Total N/Total P according to the instructions in Redfield's document (1963) and WHO (2002).

2.5. Method to determine nutritional relationships in water

- Method for calculating correlation coefficient.
- Linear regression equation.
- Determination coefficient R^2

2.6. Data processing method

Analytical data are processed using statistical methods (on Excel software) to evaluate the current status and fluctuations in water quality over time and space; Analyzing correlation between N and P nutritional parameters in water environment.

CHAPTER 3. RESULTS AND DISCUSSION

3.1. Emission of N and P nutrients from fish cage farming activities in coastal of Vietnam

Nutrient discharge from the cage fish farming area in Long Son - Vung Tau is highest, followed by Cat Ba - Hai Phong, lowest in Vinh Tan - Binh Thuan; Specific amounts of each nutritional parameter N and P are shown in Table 3.

Table 3. Calculating N and P nutrient emissions from cage fish farming activities at Cat Ba, Vinh Tan, Long Son

Parameters	N and P nutrient emissions (tons/year)					
	Year 2020			Year 2021		
	Cat Ba	Vinh Tan	Long Son	Cat Ba	Vinh Tan	Long Son
Total N	427.9	17.4	458.8	405.0	20.7	440.2

$N\text{-}NO_3^- + N\text{-}NO_2^-$	4.4	0.2	110.7	4.2	0.2	106.3
$N\text{-}NH_4^+$	103.3	4.2	4.7	97.8	5.0	4.6
Total P	383.7	15.6	411.3	363.1	18.5	394.7
$P\text{-}PO_4^{3-}$	172.6	7.0	185.1	163.4	8.3	177.6

3.2. Changes in environmental quality of caged fish farming water in coastal of Vietnam

3.2.1. Changes in the quality of water environment for fish cage farming at Cat Ba - Hai Phong, Vinh Tan - Binh Thuan, Long Son - Vung Tau

Fluctuations in RQtb values of water in marine fish farming areas are shown in Table 4; reflects reduced water quality and signs of pollution; The level of environmental risks in the rainy season is higher than in the dry season; The water environment in Long Son farming area is the worst, followed by Cat Ba and Vinh Tan.

Table 4. Fluctuations in RQtb value (calculated according to TCVN) of sea cage fish farming water at Cat Ba, Vinh Tan, Long Son

Time	Cat Ba - Hai Phong		Vinh Tan - Binh Thuan		Long Son - Vung Tau	
	May	October	May	October	May	October
2018	2.60	2.33	-	-	1.56	3.83
2019	1.24	3.54	0.91	1.13	2.16	2.97
2020	1.28	1.57	0.87	1.31	2.54	2.47
2021	1.14	1.57	1.09	1.03	2.41	2.11
2022	1.40	0.99	0.68	0.74	1.11	1.88
Medium years	***1.55***	***2.10***	***0.88***	***1.05***	***1.94***	***2.64***

Note: RQtt ≤ 1 | 1 < RQ ≤ 1.25 | 1.25 < RQ ≤ 1.5 | RQ > 1.5

3.2.2. Changes in nutritional RQ index of caged fish farming water in coastal of Vietnam

- *Cat Ba gulf region - Hai Phong:* Fluctuations in $RQN\text{-}NH_4^+$, $RQP\text{-}PO_4^{3-}$ values of water in the farming area fluctuate between 1.25 - 6.0, 100% of RQ values exceed the threshold of 1.0 and tend to decrease during 2018. - 2022; 40% of water $RQN\text{-}NO_2^-$ values are higher than the threshold value of 1.0.

- *Vinh Tan coastal area - Binh Thuan:* During the period 2019 - 2022, the rate of 87.5% of the RQN-NH_4^+ value and the rate of 75% of the RQP-PO_4^{3-} value of the water in the farming area are higher than the threshold value of 1.0 and tend to decrease; Opposite, RQN-NO_2^- and RQN-NO_3^- values are lower than 1.0 but tend to increase.

- *Long Son estuary area - Vung Tau:* All four parameters have high RQ values, including 100% RQN-NO_2^- value, 90% RQN-NH_4^+ value and 50% RQN-NO_3^-, RQP-PO_4^{3-} value ratio of water farming area is higher than the threshold value of 1.0. During 2018 - 2020, nutritional RQ values were high and decreased during 2021 - 2022.

3.3. Nutrient dynamics of N and P in the water environment of caged fish farming in coastal of Vietnam

3.3.1. Nutritional dynamics of N (N-NO_2^-, N-NO_3^-, N-NH_4^+, Total N) and P (P-PO_4^{3-}, Total P) in cage fish farming water in Cat Ba gulf region - Hai Phong

The difference in N and P nutrients according to time of day and tidal cycle in the farming area was determined to be higher at the end of the rainy season than at the end of the dry season, the surface layer is higher than the bottom layer (Table 5, Table 6); N and P fluctuations depend on the tidal cycle according to day and night, surface and bottom layers; When the water is low at night, the nutrient content of N and P increases; When water is low during the day, nutrients N and P decrease due to photosynthesis consumption; When the water is high during the day, the N and P content is reduced compared to when the water is high at night due to the process of decomposing pollutants and supplementing N and P nutrients.

Table 5. Fluctuations of N-NH_4^+, N-NO_2^-, N-NO_3^- and Total N in caged fish culture water over time at Cat Ba gulf region - Hai Phong

Value	N-NH_4^+ (mg/l)		N-NO_2^- (mg/l)		N-NO_3^- (mg/l)		Total N (mg/l)	
	surface n=14	bottom n=14	surface n=14	bottom n=14	surface n=14	bottom n=14	surface n=14	bottom n=14
Time: From 7:00 a.m on May 16 to 9:00 a.m on May 17, 2021 during the dry season								
Min	0.166	0.151	0.013	0.018	0.029	0.033	0.220	0.216

Max	0.323	0.384	0.017	0.024	0.038	0.043	0.383	0.423
Average	0.236	0.269	0.016	0.021	0.034	0.037	0.287	0.335
Max - Min	0.157	0.233	0.004	0.006	0.009	0.010	0.163	0.207
Time: From 6:00 a.m on September 6 to 8:00 a.m on September 7, 2021 during the rainy season								
Min	0.125	0.156	0.008	0.010	0.022	0.039	0.437	0.517
Max	0.312	0.361	0.016	0.018	0.135	0.165	0.694	0.819
Average	0.223	0.250	0.012	0.014	0.065	0.078	0.532	0.652
Max - Min	0.187	0.205	0.008	0.008	0.113	0.126	0.257	0.302

Table 6. P nutritional fluctuations in caged fish farming water environment over time at Cat Ba gulf region - Hai Phong

Time/Value	From 7:00 a.m on May 16 to 9:00 a.m on May 17, 2021 in the dry season				From 6:00 a.m on September 6 to 8:00 a.m on September 7, 2021 during the rainy season			
	$P\text{-}PO_4^{3-}$(mg/l)		Total P (mg/l)		$P\text{-}PO_4^{3-}$ (mg/l)		Total P (mg/l)	
	surface n=14	bottom n=14	surface n=14	bottom n=14	surface n=14	bottom n=14	surface n=14	bottom n=14
Min	0.022	0.021	0.283	0.278	0.021	0.024	0.204	0.222
Max	0.041	0.043	0.410	0.445	0.046	0.052	0.332	0.352
Average	0.033	0.034	0.320	0.339	0.032	0.037	0.270	0.314
Max - Min	0.019	0.022	0.127	0.167	0.025	0.028	0.128	0.130

3.3.2. Nutritional dynamics of N ($N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Total N) and P ($P\text{-}PO_4^{3-}$, Total P) in caged fish culture water at Vinh Tan coastal area - Binh Thuan

For the semi-diurnal tide regime in the Vinh Tan coastal area, fluctuations in N and P content often lag behind the tide (increasing in the second low tide cycle - at low water). The difference in N and P nutrients over time and tidal cycle clearly shows that N and P nutrients increase depending on the tidal cycle according to day and night, surface and bottom layers (Table 7, Table 8); When water is low at night, N and P content increases and when water is low during the day, N and P content decreases due to consumption by photosynthesis; When the water is high during the

day, the N and P content is reduced compared to when the water is high at night.

Table 7. Fluctuation of N content in marine fish farming water environment over time at Vinh Tan coastal area - BinhThuan

Value	$N\text{-}NH_4^+$ (mg/l)		$N\text{-}NO_2^-$ (mg/l)		$N\text{-}NO_3^-$ (mg/l)		Total N (mg/l)	
	surface n=13	bottom n=13	surface n=13	bottom n=13	surface n=13	bottom n=13	surface n=13	bottom n=13
Time: From 6:00 a.m. on May 10 to 6:00 a.m. on May 11, 2021 during the dry season								
Min	0.050	0.079	0.005	0.007	0.008	0.010	0.089	0.111
Max	0.245	0.310	0.010	0.012	0.027	0.033	0.294	0.363
Average	0.146	0.206	0.007	0.009	0.016	0.020	0.180	0.250
Max - Min	0.195	0.231	0.005	0.005	0.019	0.023	0.205	0.252
Time: From 6:00 a.m. on October 14 to 6:00 a.m. on October 15, 2021 during the rainy								
Min	0.021	0.028	0.006	0.007	0.024	0.030	0.078	0.095
Max	0.056	0.088	0.010	0.012	0.053	0.085	0.121	0.165
Average	0.032	0.049	0.008	0.010	0.035	0.049	0.095	0.125
Max - Min	0.035	0.060	0.004	0.005	0.030	0.055	0.043	0.070

Table 8. Fluctuation of P content in water in marine fish farming area over time at Vinh Tan coastal area - Binh Thuan

Time/Value	From 6:00 a.m on May 10 to 6:00 a.m on May 11, 2021 in the dry season				From 6:00 a.m on October 14 to 6:00 a.m on October 15, 2021 during the rainy season			
	$P\text{-}PO_4^{3-}$ (mg/l)		Total P (mg/l)		$P\text{-}PO_4^{3-}$ (mg/l)		Total P (mg/l)	
	surface n=13	bottom n=13	surface n=13	bottom n=13	surface n=13	bottom n=13	surface n=13	bottom n=13
Min	0.003	0.006	0.018	0.021	0.004	0.033	0.012	0.040
Max	0.026	0.039	0.068	0.094	0.018	0.063	0.056	0.080
Average	0.024	0.032	0.038	0.048	0.027	0.047	0.035	0.055
Max - Min	0.023	0.033	0.050	0.073	0.014	0.030	0.035	0.040

3.3.3. Nutritional dynamics of N ($N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Total N) and P ($P\text{-}PO_4^{3-}$, Total P) in water in cage fish farming at Long Son estuary area - Vung Tau

Regarding the semi-diurnal tide regime in Long Son area: fluctuations in N and P content often lag behind the tide (nutrients in water increase in the second low tide cycle - at low water). Differences in N and P content according to time and tidal cycle in the farming area; N and P nutrients increase depending on the tidal cycle of day and night; When water is low at night, N and P content increases; When water is low during the day, N and P content decreases due to consumption by photosynthesis; When the water is high during the day, the N and P content is reduced compared to when the water is high at night.

Table 9. Fluctuations of $N\text{-}NH_4^+$, $N\text{-}NO_2^-$, $N\text{-}NO_3^-$ and Total N content in water marine fish farming area over time at Long Son estuary area - Vung Tau

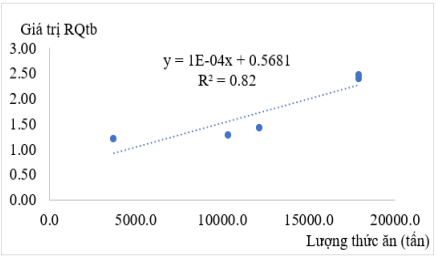
Value	$N\text{-}NH_4^+$ (mg/l)		$N\text{-}NO_2^-$ (mg/l)		$N\text{-}NO_3^-$ (mg/l)		Total N (mg/l)	
	surface n=13	bottom n=13	surface n=13	bottom n=13	surface n=13	bottom n=13	surface n=13	bottom n=13
Time: From 6:00 a.m on May 14 to 6:00 a.m on May 15, 2021 during the dry season								
Min	0.080	0.227	0.020	0.026	0.268	0.325	0.426	0.610
Max	0.450	0.588	0.038	0.049	0.567	0.612	1.055	1.269
Average	0.234	0.378	0.028	0.038	0.395	0.450	0.690	0.925
Max - Min	0.370	0.361	0.018	0.023	0.299	0.287	0.629	0.659
Time: From 6:00 a.m on October 19 to 6:00 a.m on October 20, 2021 during the rainy season								
Min	0.120	0.319	0.019	0.025	0.102	0.207	0.245	0.551
Max	0.413	0.567	0.031	0.049	0.169	0.521	0.603	1.137
Average	0.229	0.419	0.026	0.036	0.134	0.353	0.389	0.807
Max - Min	0.293	0.248	0.012	0.024	0.067	0.314	0.358	0.586

Table 10. Fluctuation of P content in water marine fish farming area over time at Long Son estuary area - Vung Tau

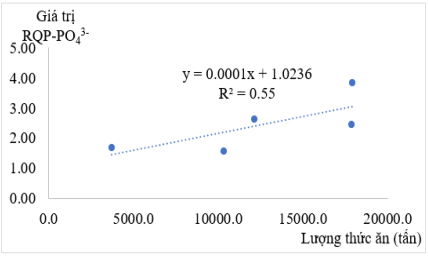
Time/Value	From 6:00 a.m on May 14 to 6:00 a.m on May 15, 2021 in the dry season				From 6:00 a.m on October 19 to 6:00 a.m on October 20, 2021 during the rainy season			
	$P\text{-}PO_4^{3-}$ (mg/l)		Total P (mg/l)		$P\text{-}PO_4^{3-}$ (mg/l)		Total P (mg/l)	
	surface n=13	bottom n=13	surface n=13	bottom n=13	surface n=13	bottom n=13	surface n=13	bottom n=13
Min	0.027	0.026	0.165	0.205	0.028	0.033	0.441	0.481
Max	0.044	0.049	0.275	0.345	0.044	0.054	0.481	0.612
Average	0.036	0.039	0.224	0.272	0.035	0.043	0.459	0.533
Max - Min	0.017	0.023	0.110	0.140	0.016	0.021	0.040	0.131

3.3.4. Assessing fluctuations in the correlation between the amount of food and the N and P nutritional environmental risk coefficient in caged fish farming water in coastal

- *Cat Ba gulf region - Hai Phong:* The study shows that there is a correlation between the amount of trash fish feed used for sea cage fish farming and the RQtb index value of water in the Cat Ba - Hai Phong farming area shown in Figure 1.a. The correlation coefficient $R^2 = 0.82$ shows a positive correlation between the amount of food affecting water quality in the farming area. The positive correlation between food intake and RQ $P\text{-}PO_4^{3-}$ value in water is also clearly shown with $R^2 = 0.55$ (Figure 1.b). For the nutritional parameter N, a positive correlation with $R^2 = 0.39$ was recorded between food intake and RQN-NH_4^+ value.



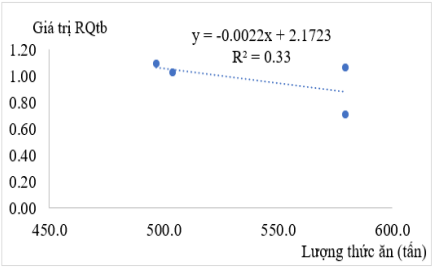
a. Food intake with RQtb



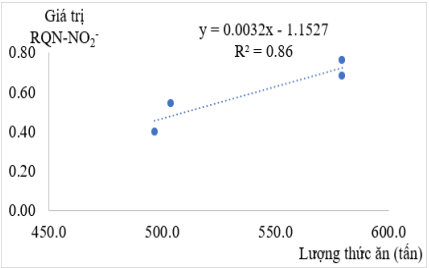
b. Food intake with RQP-PO_4^{3-}

Figure 1. Correlation of food intake with environmental risk coefficient in Cat Ba marine cage fish farming area

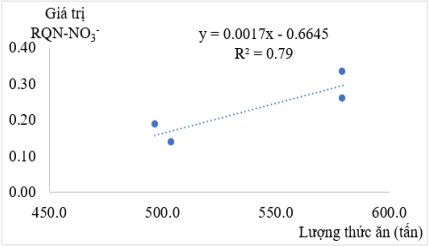
- *Vinh Tan coastal area - Binh Thuan:* Research on the correlation between food intake and RQtb value of water in the sea cage fish farming area of Vinh Tan - Binh Thuan showed a low coefficient of determination $R^2 = 0.33$, showing a weak correlation (Figure 2.a). In terms of each parameter, all three N nutritional parameters have a positive correlation with food intake, in which the RQN-NO_2^- value has the highest coefficient $R^2 = 0.86$ (Figure 2.b); with RQN-NO_3^- value, coefficient $R^2 = 0.79$ (Figure 2.c) and with RQN-NH_4^+ value, coefficient $R^2 = 0.59$ (Figure 2.d). This result reflects the direct impact of excess food in high temperature conditions (characteristics of the Central region) that will immediately decompose, affecting the water in the sea cage fish farming area in Vinh Tan - Binh Thuan.



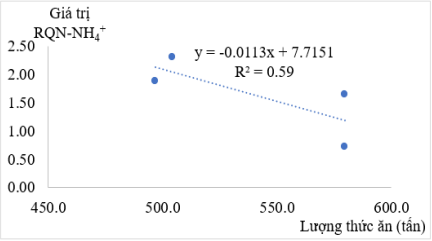
a. Food intake with RQtb



b. Food intake with RQN-NO_2^-



c. Food intake with RQN-NO_3^-

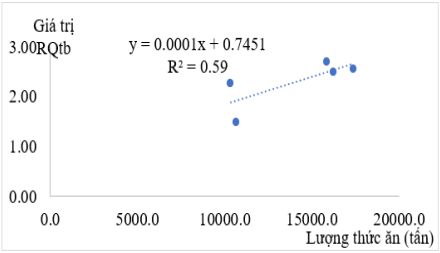


d. Food intake with RQN-NH_4^+

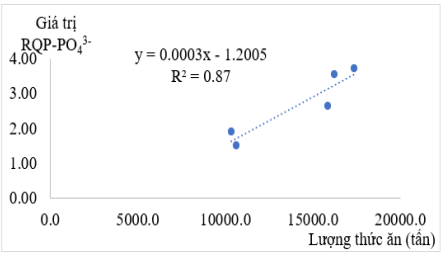
Figure 2. Correlation of food intake with environmental risk coefficient in Vinh Tan marine fish farming area

- *Long Son estuary area - Vung Tau*: Research on the correlation between the amount of trash fish food and the RQtb value of water shows $R^2 = 0.59$, showing a not high positive correlation (Figure 3.a). Considering the correlation of food intake with nutritional parameters N, P: recorded a

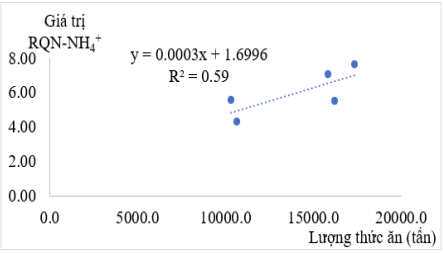
positive correlation with the value of RQP-PO_4^{3-} with a quite high determination coefficient R^2 = 0.87 (Figure 3.b); positively correlated with the RQN-NH_4^+ value with R^2 = 0.59 (Figure 3.c). This research result reflects the location of the estuary farming area, the semi-diurnal tidal regime during the day has changed. diffuse and transport diluted pollutants over a large area, contributing to reducing pollution in estuarine and coastal areas; in addition, the high R^2 value between food intake and RQP-PO_4^{3-} value shows the source waste from continental sources (large amounts of P-PO_4^{3-}) contributes to affecting the environmental quality of water for fish farming in sea cages in the Long Son estuary - Vung Tau.



a. Food intake with RQtb



b. Food intake with RQP-PO_4^{3-}



c. Food intake with RQN-NH_4^+

Figure 3. Correlation of food intake with environmental risk coefficient at Long Son marine fish farming area

3.4. Fluctuations of N/P ratio in caged fish farming water environment in coastal of Vietnam

3.4.1. N:P ratio in water in cage fish farming areas in coastal waters of Vietnam

Research on N/P ratio in water environment includes ratio N-NH_4^+: N-NO_3^-: N-NO_2^- (ratio A), ratio N-NH_4^+ : P-PO_4^{3-} (ratio B), ratio ratio Total N : Total P (ratio C).

The results of studying the N/P ratio of water in the sea cage fish farming area show that: The water environment in the 3 farming areas is in a P-limited state due to the high C ratio. The ratio of A in water tends to increase for the parameter N-NH_4^+. The B rate in water has fluctuated strongly in recent years and shifted the nutritional status in water from N-NH_4^+ to P-PO_4^{3-} in Cat Ba - Hai Phong and Vinh Tan - Binh Thuan; Particularly in the Long Son - Vung Tau, the nutritional shifts of N- NH_4^+ and P-PO_4^{3-} were mixed during the years of research.

Table 11. Fluctuations in Total N/Total P ratio of water in marine fish farming areas in Cat Ba, Vinh Tan, Long Son

Time/Area		Cat Ba - Hai Phong	Vinh Tan - Binh Thuan	Long Son - Vung Tau
2018	May	26.2	-	7,1
	October	23.3	-	22,0
2019	May	20.2	8.5	25,3
	October	14.6	12.2	11,4
2020	May	14.8	7.8	16,6
	October	14.6	5.2	16,8
2021	May	22.4	7.4	40,9
	October	24.1	4.7	20,1
2022	May	19.4	5.7	14,8
	October	14.7	3.7	25,4
Average dry season		*20,6*	*7.2*	*20.9*
Average rainy season		*16,2*	*6.2*	*17.1*
Average of all years		18,7	7.2	19.0

In the water environment of the farming area, the N nutrient content is more than the P nutrient content, so the water Total N/Total P ratio is high. When the N and P content in the water is high, it leads to a high RQtb value and also reflects the pollution level of the water in the farming area; When the ratio of Total N/Total P in water is high, the RQtb value of water is also recorded as high.

Table 12. Summary of Total N/Total P ratio values and RQtb values of water in marine fish farming areas in Cat Ba - Hai Phong, Vinh Tan - Binh Thuan, Long Son - Vung Tau

Value	Cat Ba		Vinh Tan		Long Son	
	Total N:Total P	Index RQtb	Total N:Total P	Index RQtb	Total N:Total P	Index RQtb
Min	2.05	0.58	1.56	0.42	1.21	0.77
Max	86.96	8.26	19.18	3.79	65.78	6.51
Average	18.65	1.87	7.23	0.99	19.03	2.33

3.4.2. Research on the correlation between N and P nutritional parameters of water in cage fish farming areas in coastal

a. At the marine fish farming area in Cat Ba gulf region - Hai Phong

Summary and analysis of N and P nutritional data series in water in cage fish farming area in Cat Ba - Hai Phong from 2005 - 2021: Correlation between $N\text{-}NO_2^-$ and Total N; $N\text{-}NO_3^-$ with Total N; $N\text{-}NH_4^+$ with Total N; Total N with Total P and $P\text{-}PO_4^{3-}$ with Total P are positively correlated (Table 13). The correlation between parameters $N\text{-}NH_4^+$ and Total N has r = 0.50; The correlation between parameters $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ has a correlation coefficient r = 0.45.

Table 13. Matrix table of correlation coefficient (r) between parameters $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, $P\text{-}PO_4^{3-}$, Total N, Total P in water in marine fish farming area at Cat Ba - Hai Phong

Parameters	$N\text{-}NO_2^-$ (n=455)	$N\text{-}NO_3^-$ (n=511)	$N\text{-}NH_4^+$ (n=509)	$P\text{-}PO_4^{3-}$ (n=509)	Total N (n=512)	Total P (n=511)
$N\text{-}NO_2^-$	1					
$N\text{-}NO_3^-$	0.45	1				
$N\text{-}NH_4^+$	0.14	0.11	1			
$P\text{-}PO_4^{3-}$	0.17	0.20	0.01	1		
Total N	0.12	0.20	0.50	0.10	1	
Total P	0.07	0.17	0.27	0.26	0.25	1

The correlation coefficient of pairs of nutritional parameters has low values and is consistent, proving that the sea cage fish farming area has a

process of self-cleaning the environment of high N and P organic nutrients due to photosynthesis and oxidation. Strongly metabolizes nutrients according to the N metabolism cycle to $N\text{-}NO_3^-$ form. The correlation between Total N and Total P has a low co-variation value, proving that the P supply from alluvium is largely dominated by coastal estuaries.

b. At the marine fish farming area in Vinh Tan coastal - Binh Thuan

Vinh Tan - Binh Thuan farming area is in open sea so the water exchange process is more favorable than other sea areas. The results of the correlation study between nutritional parameters N and P clearly show a strong positive correlation with the $N\text{-}NH_4^+$ parameter pair with Total N having coefficient r = 0.99; Parameter pair $P\text{-}PO_4^{3-}$ with Total P has coefficient r = 0.98; The parameter pair $N\text{-}NO_2^-$ with $N\text{-}NO_3^-$ has r = 0.82. Negative correlation with the parameter pair $N\text{-}NH_4^+$ with $N\text{-}NO_2^-$ has r = - 0.32 and the parameter pair $N\text{-}NH_4^+$ with $N\text{-}NO_3^-$ has r = - 0.033.

Table 14. Matrix table of correlation coefficient (r) between nutritional parameters $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Total N, $P\text{-}PO_4^{3-}$, Total P in water in cage fish farming area at Vinh Tan - Binh Thuan

Parameters	$N\text{-}NO_2^-$ (n=96)	$N\text{-}NO_3^-$ (n=96)	$N\text{-}NH_4^+$ (n=96)	Total N (n=96)	$P\text{-}PO_4^{3-}$ (n=96)	Total P (n=96)
$N\text{-}NO_2^-$	1					
$N\text{-}NO_3^-$	0,82	1				
$N\text{-}NH_4^+$	-0,32	-0,33	1			
Total N	-0,18	-0,17	0,99	1		
$P\text{-}PO_4^{3-}$	0,22	0,24	0,19	0,25	1	
Total P	0,21	0,24	0,29	0,34	0,98	1

This correlation shows that the ability to decompose pollutants in water is strong, releasing pollutants in the form of nutrients N and P. The decomposition process takes place combined with the ability to dilute and diffuse strong substances. Pollution limits sedimentation to the bottom of the farming area. These reasons make the water environment in Vinh Tan farming area still good compared to TCVN and natural ocean water.

c. At the marine fish farming area in Long Son estuary - Vung Tau

The marine fish farming area is located at the mouth of the Cha Va - Long Son river. The tide follows the semi-diurnal regime in the area, affecting the disturbance of nutrients in the water. This is also a common characteristic of the river's area.

The correlation coefficients of $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ are positive correlations with low positive values, and the correlations between $N\text{-}NH_4^+$ with $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ are negative correlations with low negative values. This proves the ability to quickly convert existing forms of N 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 and has a low positive value, proving that the area is greatly affected by nutrients from continental water sources.

Table 15. Matrix table of correlation coefficient (r) between nutritional parameters $N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, Total N, $P\text{-}PO_4^{3-}$, Total P in water in marine fish farming area at Long Son - Vung Tau

Parameters	$N\text{-}NO_2^-$ (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

3.5. Proposing a model for environmental management in cage fish farming areas in Vietnam's coastal

a. Environmental management process for fish cage farming in coastal waters

It is necessary to uniformly implement the environmental management process of sea cage fish farming from the national and local levels to the owner of the sea cage fish farming facility. The work contents of each level are according to the diagram in Figure 4.

b. Environmental management activities in cage fish farming area in coastal

- Organization and management:

+ ***Nation:*** Develop a national marine farming project based on the natural conditions of each region and coastal area. Develop marine cage fish farming on the basis of national development orientation along with environmental protection plans for sustainable development of marine fish farming activities.

+ *Local:* For provinces/cities, it is implemented by the Department of Agriculture and Rural Development on the basis of establishing a local cage aquaculture project in accordance with the development orientation of marine cage fish farming based on the environmental carrying capacity of the water body. It is planned to develop marine cage fish farming. Develop environmental protection activities for local sea lion fish farming areas.

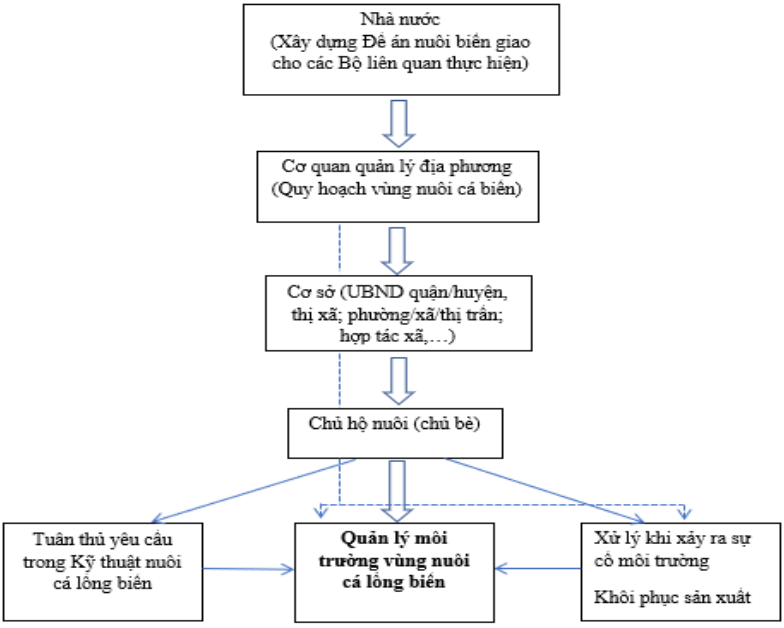


Figure 4. Water environment management for fish cage farming in coastal waters

+ *Farming location:* General management by the People's Committee of the commune/ward, assigned to the officer in charge of fisheries, environmental management and marine fish farming activities in the commune/ward.

+ *Farming:* Carry out marine cage fish farming activities by each farming household owner; Raising awareness and implementing environmental protection work for marine cage fish farming areas at the farming site, for each household's cages.

- Technical measures:

+ *Minimize pollutants:*

Feed enough and at the right time according to biological characteristics (age, type of food, amount of food). Intercropping farming species (fish that feed on the bottom, middle layer, and surface layer) to minimize suspended pollutants in the water of the farming area. Comply with farming techniques for each farmed marine fish to minimize the amount of leftover food and excretion from the farmed fish.

Manage waste generated during the farming process (collect all types of waste generated from farming activities).

Choose a location with good water circulation, safe for rafts (farming activities), or periodically move the cage location to limit the accumulation of pollutants at the bottom of the farming area. Farming households need to clean the cages 1-2 times/month to ensure the mesh surface is clear, have better water exchange and avoid pollution on the cage mesh.

Develop local marine fish farming in accordance with local farming planning (correct areas licensed for farming, number of cages, and farming density for each type of marine fish).

+ *Respond to pollution:*

Owners of sea cage fish farming facilities must regularly monitor the water environment in the cages and around the farming area; Monitor environmental quality, detect the earliest signs of environmental change and change. When the water is standing and the water environment is still, it is necessary to increase aeration to supply oxygen to the farmed fish.

Handle immediately when detecting environmental changes (narrow scope); Report to the Commune People's Committee (aquaculture monitoring officer) when there are signs of abnormal environment;

Commune People's Committee reports to district and provincial levels for timely handling.

+ Pollution treatment:

Delineate the water environment in polluted areas to have timely response plans; Collect polluting waste and carcasses of farmed marine fish that died due to environmental incidents.

Treatment: Measures to treat household waste from sea cage fish farming. Collect, store, and process dead bodies of farmed marine fish. Handling cages and farming tools when the farming environment is polluted.

CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

- N and P nutrition in the Cat Ba and Long Son marine fish farming areas tends to increase from 2018 - 2020, decreasing in 2021 - 2022. The RQtb value is at a high risk of pollution in Cat Ba and Long Son. Son and at low risk in Vinh Tan. The RQN-NH_4^+, RQP-PO_4^{3-} values of coastal fish farming water are higher than those of open sea water.

- Research on N and P nutritional dynamics in marine fish farming water; Determine the correlation between N and P nutritional parameters; N and P ratio in marine fish farming water at Cat Ba gulf region, Vinh Tan coastal area and Long Son estuary area.

+ Determine the difference in N and P nutrients according to time of day and tidal cycle in the farming area; N and P nutrients increase depending on the tidal cycle of day and night; When water is low at night, N and P content increases; When water is low during the day, N and P content decreases due to consumption by photosynthesis; When the water is high during the day, the amount of N and P nutrients is reduced compared to when the water is high at night (due to the decomposition of pollutants supplementing N and P nutrients). For the semi-diurnal tide regime in Long Son and Vinh Tan areas: fluctuations in N and P content often lag behind the tide (second low tide cycle - low water, increased nutrients in the water).

+ N/P ratio in water in marine fish farming area: The water environment in three farming areas is in a P-limited state due to high C ratio. The ratio of A in water tends to increase for the parameter N-NH_4^+. The B

ratio in water has fluctuated strongly in recent years and shifted the nutrient status in water from $N\text{-}NH_4^+$ to $P\text{-}PO_4^{3-}$ in Cat Ba and Vinh Tan; Particularly in Long Son farming area, the state of $N\text{-}NH_4^+$ and $P\text{-}PO_4^{3-}$ nutrient shifts was mixed during the years of research. Changes in nutritional status in water depend on the farming activities themselves and the natural conditions of the farming area.

+ At Cat Ba gulf region, the correlation coefficient of pairs of nutritional parameters has low values and is consistent, proving that the sea cage fish farming area has a process of self-cleaning the environment of high N and P nutrients due to the process of self-cleaning the environment. photosynthesis and strong metabolism of nutrients according to the metabolic cycle of N to $N\text{-}NO_3^-$ form. The T-N and T-P correlations have low co-variation values, proving that P supply from alluvium is largely dominated by coastal estuaries.

+ At Vinh Tan coastal area, the correlation coefficient between parameters N and P clearly shows a strong positive correlation with the pair of parameters $N\text{-}NH_4^+$ and Total N; Parameter pair $P\text{-}PO_4^{3-}$ with Total P; The parameter pair $N\text{-}NO_2^-$ with $N\text{-}NO_3^-$ has r = 0.82. Negatively correlated with the pair of parameters $N\text{-}NH_4^+$ with $N\text{-}NO_2^-$ and the pair of parameters $N\text{-}NH_4^+$ with $N\text{-}NO_3^-$. This correlation shows the strong ability to decompose pollutants in water, releasing pollutants in the form of nutrients N and P. The decomposition process takes place combined with the ability to dilute and diffuse pollutants strongly. Limit sedimentation to the bottom of the farming area.

+ At Long Son estuary area, the correlation coefficients of $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ are positive correlations with low positive values and the correlations between $N\text{-}NH_4^+$ with $N\text{-}NO_2^-$ and $N\text{-}NO_3^-$ are negative with high values. low negative value. This proves the ability to quickly convert existing forms of N nutrients in the water 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 and has a low positive value, proving that the area is greatly affected by nutrients from continental sources.

- Propose general solutions and specific solutions for each cage fish farming area in coastal waters; Propose an environmental management model for cage fish farming in Vietnam's coastal waters.

2. Recommendations

Study of the relationship between N and P nutritional parameters when water is polluted with N and P, causing harm to the environment in marine fish farming areas.

Research solutions to control and handle on-site when the water environment for fish farming in sea cages is polluted and treat waste generated from sea fish farming activities in cages.

NEW CONTRIBUTIONS OF THE THESIS

1. Determining the nutritional dynamics of N and P in the water environment of caged fish farming in coastal waters over time (day, month, season, year) in 3 research areas (Cat Ba gulf region - Hai Phong, Vinh Tan coastal areas - Binh Thuan, Long Son estuary area - Vung Tau) including:

- Determine fluctuations in nutrient content N ($N\text{-}NO_2^-$, $N\text{-}NO_3^-$, $N\text{-}NH_4^+$, T-N) and P ($P\text{-}PO_4^{3-}$, T-P) in the water environment in Cat Ba gulf region, Vinh Tan coastal areas and Long Son estuary area.
- Determine the N/P ratio (ratio A is $N\text{-}NH_4^+/N\text{-}NO_3^-/N\text{-}NO_2^-$; ratio B is $N\text{-}NH_4^+/P\text{-}PO_4^{3-}$ and ratio C is T-N/T-P) in the water environment of caged fish farming areas in coastal waters in Cat Ba gulf region (11.4 : 5.1 : 1; 2.1 : 1 and 18.7 : 1); Vinh Tan coastal areas (13.7 : 3.9 : 1; 5.6 : 1 and 7.2 : 1); Long Son estuary area (17.1 : 4.8 : 1; 4.1 : 1 and 19.0 : 1).
- The first time to determine the correlation between N and P nutritional parameters in the water environment of caged fish farming in coastal waters. The results show the nutritional characteristics in the water of each farming area, reflecting the decomposition process and sources of N and P nutrient emissions that impact the water environment in marine cage fish farming areas.

2. Propose a comprehensive solution to adjust the amount of N and P nutrients in caged fish farming water in Vietnam's coastal based on the results of research on 3 concentrated marine fish farming areas in the thesis.

LIST OF PUBLISHED WORKS RELATED TO THE THESIS

1. Trần Quang Thư, Nguyễn Đức Cự (2019), *Biến động môi trường nước khu vực nuôi cá lồng biển vùng ven bờ tại Cát Bà - Hải Phòng*, Tuyển tập báo cáo khoa học - Diễn đàn khoa học toàn quốc năm 2019 - Sinh học biển và phát triển bền vững, Nhà xuất bản Khoa học Tự nhiện và Công nghệ, ISBN: 978-604-913-874-4, Hà Nội, tr. 636 - 645.
2. Trần Quang Thư, Nguyễn Đức Cự, Dương Thanh Nghị, Nguyễn Xuân Sang (2023), *Một số vấn đề môi trường tại khu vực nuôi cá lồng biển vùng ven bờ Cát Bà - Hải Phòng và Long Sơn - Vũng Tàu,* Tạp chí Khoa học Công nghệ Hàng hải, số 76 (11-2023), Mã tạp chí ISSN: 1859 - 316X, tr. 90 - 96.
3. Trần Quang Thư, Nguyễn Đức Cự, Dương Thanh Nghị (2023), *Nghiên cứu động thái dinh dưỡng Nitơ và Phốt pho trong nước khu vực nuôi cá lồng biển vùng ven bờ tại Cát Bà - Hải Phòng*, Tạp chí Nông nghiệp và Phát triển nông thôn, số 23/2023, Mã tạp chí ISSN 1859 - 4581, tr. 77 - 89.
4. Tran Quang Thu, Nguyen Duc Cu (2024), *Study of nitrogen and phosphorus nutrient dynamics in concentrated marine fish farming water environment in Long Son - Vung Tau*, Vietnam Journal of Marine Science and Technology 2024, 23 (4) 1 - 12 https://doi.org/10.15625/1859-3097/21111 , ISSN 1859-3097; e-ISSN 2815-5904