Sustainable Aquaculture within Environmental Limits: Environmental Carrying Capacity Assessment for Spatial Aquaculture Areas in Quang Ninh (Vietnam)

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Abstract

Sustainable aquaculture is vital for the aquaculture industry's development. This study focuses on calculating and evaluating the environmental carrying capacity (ECC) of six aquaculture areas within three nautical miles off the coast of Quang Ninh province, Vietnam. We employ the ECC calculation formula that needs collecting and analyzing water samples combined with in-depth interviews with aquaculture households to gather data. The results provide scientific insights for guiding sustainable aquaculture practices, environmental protection, and productivity enhancement. Our findings reveal that Quang Yen aquaculture area boasts the largest potential for aquaculture development, whereas Ha Long City has the smallest potential. To optimize carrying capacity while safeguarding environmental quality, we propose solutions for sustainable aquaculture development. Firstly, policymakers should prioritize centralized planning that considers overall district planning and assesses environmental carrying capacity to ensure sustainable aquaculture practices. Secondly, policymakers must allocate each area to a single farming zone while reserving space for other economic sectors. Thirdly, it is essential to foster collaboration between state management, local government, and coastal communities in Quang Ninh province to enhance aquaculture efficiency while maintaining environmental sustainability. Finally, policymakers should incentivize the adoption of green technologies to promote environmental sustainability in aquaculture operations.

Keywords: small scale aquaculture, environmental capacity (EC), environmental carrying Capacity (ECC), QuangNinh, Vietnam.

1. Introduction

Environmental Capacity (EC) is a measure of the environment's ability to support a specific activity or rate of activity, such as pollutant discharge, without causing unacceptable impacts. EC can be allocated to various uses *(FAO, 1986)*. Environmental Carrying Capacity (ECC) is defined as the maximum number of organisms or activities an area can sustain without exceeding its environmental capacity, within permissible limits of environmental quality standards *(Zhao et al., 2005; Rees & W,1992; Hui & C, 2006)*. Therefore, while environmental capacity refers to waste limits, environmental carrying capacity indicates activity limits (area, quantity, output). Initially applied in the mechanical field, these concepts have gained popularity in various areas including population development, livestock, tourism, and environmental factors such as water Bodies, atmosphere, and noise *(Lin et al., 2023)*. A related term frequently used, especially in environmental contexts, is 'sustainable aquaculture'. In today's context, the necessity of managing aquaculture production sustainably and responsibly is undeniable *(Engle & D'Abramo, 2016)*.

Aquaculture involves raising fish, shellfish, mollusks, aquatic plants, algae, and other organisms in controlled freshwater and saltwater populations to optimize their living conditions, growth, and development *(Tookwinas, 1999)*. In aquaculture, ECC can be expressed in terms of hectares, cage volume, or farming output on specific resource environmental limits such as rivers, bays, and lagoons *(Tookwinas, 1999)*. Numerous studies have been conducted to calculate ECC in aquaculture, significantly contributing to the industry's sustainable development by balancing economic goals with environmental protection and ecosystem preservation. Exceeding ECC, especially surpassing the environment's renewable capacity, can directly impact human life *(Peng et al., 2019)*. It is crucial to consider the far-reaching consequences of aquaculture on the ocean, including disease transmission, often underestimated in ECC estimates *(Schmittmann et al., 2023)*. Moreover, climate change factors such as rising sea levels, temperature fluctuations, altered rainfall patterns, and climate events can significantly impact aquaculture production *(FAO, 2009)*.

Based on ECC data, it is possible to calculate the maximum annual production of cage fish farms for a given area without exceeding the environmental limit *(Conides et al., 2022)*. ECC profoundly influences aquaculture efficiency *(Conides et al., 2022)*. The diverse nature of aquaculture systems has substantially contributed to the global food system since 2000 *(Verdegem et al., 2023)*. Aquaculture species diversity surpasses that of terrestrial species, with fish, mollusks, and crustaceans dominating aquaculture production *(Kültz, 2022)*. Over the past few decades, aquaculture has witnessed exponential growth in most countries due to rising consumer demand for aquatic products *(Ruiz-Zarzuela et al., 2009)*, resulting in the decline of wild fish populations due to overfishing *(FAO, 2020)*. However, marine fish farming in the European Union has declined significantly since 2000 *(APROMAR, 2019)*. Small-scale aquaculture has the potential to enhance food security and economic development in rural areas by increasing producers' incomes *(Irwin et al., 2021)*. Nevertheless, small-scale aquaculture faces challenges related to market access, technology, and environmental sustainability across different Asian regions *(Mahfudiyanto et al., 2023)*.

2. Literature review

Various models, techniques, and quantitative methods are employed to calculate ECC in aquaculture. For instance, the Norwegian MOM (Modelling - Ongrowing Fish Farms - Monitoring) evaluation standard describes a management system used to regulate the local environmental impact of marine fish farms based on site capacity *(Ervik et al., 1997)*. The MOM model integrates elements of environmental impact assessment, impact monitoring, and environmental quality standards into a single system, facilitating the evaluation of environmental impacts and site-specific conditions *(Ervik et al., 1997; Hansen et al., 2001; Stigebrandt et al., 2004)*. The MOM system's effectiveness has been demonstrated in assessing the impact of aquaculture on marine environments *(Zhang et al., 2009)*. Other methods include the Delphi study technique, which engages a group of experts to achieve consensus on ECC estimates based on baseline output and other factors *(Romero et al., 2023)*. Mathematical models, such as the Delft3D model, are also used to study the relationship between aquaculture, climate change, and ecology *(Brito et al., 2023)*. Additionally, field studies analyze physical, chemical, and biological parameters to estimate ECC and assess environmental suitability for aquaculture sites *(Tookwinas, 1998; Kurniawan et al., 2022)*. Mathematical models that consider interactions between aquaculture and the environment are valuable tools for production planning and management.

Small-scale aquaculture farmers in Southeast Asia are facing challenges stemming from globalization and neoliberal economic policies, which have disrupted economies, societies, and environments *(Szuster et al., 2021)*. Similarly, marine aquaculture in certain coastal areas of Vietnam has encountered challenges since 2018, largely due to conflicts over maritime space utilization *(IUCN, 2009)*, exacerbated by coastal urbanization, beach reclamation, and tourism activities that have degraded environmental quality. This deterioration in water quality disproportionately affects small-scale aquaculture operations, underscoring the urgency of implementing viable solutions to sustain and develop the industry. Policy recommendations derived from studies in ASEAN countries, based on Environmental Carrying Capacity (ECC) values, offer valuable insights into maintaining and enhancing aquaculture sustainability.

For instance, in the Rawa Pening Lake area of Indonesia, ensuring the overall sustainability of aquaculture activities and increasing water environmental carrying capacity necessitates disease prevention and control measures, coupled with environmental quality management and eradication programs in the event of disease outbreaks *(Putro et al., 2010)*. In the Kung Krabaen Bay area of Thailand, enhancing sustainability and environmental friendliness of aquaculture entails improving seawater pumping and wastewater treatment facilities, alongside remodeling farming areas *(Tookwinas, 1998)*.

However, calculating environmental carrying capacity in aquaculture continues to encounter challenges, primarily due to reliance on theoretical models and experimental data, resulting in estimated outcomes when applied practically *(Bohnes & Laurent, 2021)*. These methods often overlook climate change impacts and species tolerance, limiting their accuracy and applicability, especially for small-scale aquaculture areas. To address these limitations, this study aims to

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calculate Environmental Carrying Capacity (ECC) based on hydrological and hydration factors - such as flow speed, depth, temperature, pH, salinity, dissolved oxygen (DO), biochemical oxygen demand (BOD5), chemical oxygen demand (COD), ammonia nitrogen (NH_4^+-N), phosphate (PO_4^{3-}-P), and Nitrite nitrogen (NO_2^-N) - in six areas of Quang Ninh province: Mong Cai-Hai Ha, Dam Ha-Tien Yen, Van Don, Cam Pha, Ha Long, and Quang Yen. By assessing the environment's self-cleaning capacity and specific environmental parameters/pollutant sources over various timeframes and per unit volume/area, the research aims to provide crucial scientific insights to guide sustainable aquaculture practices, environmental conservation efforts, and productivity improvements.

3. Method

3.1 Study area

Quang Ninh, a coastal province nestled in the Northeast region of Vietnam, spans from the northeast to the southwest and is akin to a microcosm of Vietnam itself, boasting a diverse landscape of coastal areas, hills, plains, and midlands. Complementing its natural assets, Quang Ninh boasts a well-developed transportation network encompassing road, waterway, and air travel, making it a hub for aquatic resources.

Figure 1. 6 research areas in Quang Ninh
Source: Created by authors

Quang Ninh is selected as a case study for several reasons:

Its coastline features numerous deep, sheltered waters conducive to seaport construction and marine aquaculture development, notably in areas like Ha Long City, Cam Pha City, Tien Yen District, Mong Cai City, Hai Ha District, Van Don District, and Quang Yen District.

The coastal industry is embracing sustainability, integrating modern technologies to enhance efficiency and environmental protection, leading to increased seafood production. There is a

notable shift towards offshore aquaculture and away from nearshore exploitation, marked by the adoption of advanced technology.
Efforts to establish a production network along the value chain and develop brands for key agricultural products are underway. However, the rapid expansion of aquaculture poses significant environmental challenges, necessitating an evaluation of the marine environment's carrying capacity to inform sustainable development plans aligned with Quang Ninh's development objectives.

3.2 Calculation model for pollutant load capacity
Environmental capacity is calculated according to the following formula (Tookwinas, 1998):
$$EC = (C_{max} - C_o)(1 + R)V$$
Where: EC: Environmental capacity (averaged over a unit of day, kg); Cmax: Maximum allowable pollutant concentration, according to Vietnamese standards for aquaculture such as QCVN 08-MT:2015/BTNMT, QCVN 08:2023/BTNMT,...; Co: Pollutant concentration in the water body at the time of the study; V: Volume of water bodies in the planned area (m^3); R: Water exchange rate of water bodies in the planned area compared to other areas (%).
Environmental carrying capacity is calculated according to the formula:
$$ECC = EC / PL$$
Where: ECC: Environmental carrying capacity (km^2); PL: Pollutant load per unit area over a unit of time ($kg/m^2/day$).
The emission factor PL (pollution load) is utilized based on the findings of the study "Environmental Load Capacity AssessmentOfWater Area Surrounding Cat Ba Island For Sustainable Development." (Cao. T, Nguyen. H, 2009).
To safeguard the coastal environment, preserve natural ecosystems, and protect marine species, landscapes, and resources, the planning process for aquaculture system development must adhere to strict environmental protection criteria. This entails maintaining environmental quality and ecosystem equilibrium in bays while ensuring that pollutant levels from aquaculture activities remain within permissible limits (Tookwinas, 1998).

The results of calculating ECC will provide the maximum potential area that can be developed for aquaculture of the selected area.
(-) Survey Details:
- Survey Period: November 2023 to January 2024.
- Survey Locations: Mong Cai, Hai Ha, Dam Ha, Tien Yen, Van Don, Cam Pha, Ha Long, Quang Yen - all within Quang Ninh province.
- A total of 80 survey points are evenly distributed in the sea off Quang Ninh province. 94 water samples were collected at evenly distributed points across aquaculture areas within the aforementioned regions.
- Surveying is conducted at both nearshore and offshore locations.
- Water samples are collected and preserved according to the National Standards - TCVN 6663-3:2008 on water quality - sampling - Part 3: Guidelines for sample preservation and handling, and the standard TCVN 6663-15:2004 (ISO 5667-15:1999).
- The results of water sample analysis are evaluated and compared with the following standards and technical procedures: QCVN 10:2023/BTNMT- National technical regulation on seawater

quality, and QCVN 08-MT:2015/BTNMT-Nationaltechnicalregulation on surface water quality (Column A1 - for the purpose of conserving aquatic flora and fauna).
+ Mong Cai – Hai Ha: 17 water samples
+ Dam Ha – Tien Yen: 15 water samples
+ Van Don: 14 water samples
+ Cam Pha: 17 water samples
+ Ha Long: 16 water samples
+ Quang Yen: 15 water samples
(-) Environmental Parameters Surveyed:
- Hydrological Factors: pH, salinity.
- Hydrochemical Factors: Dissolved oxygen (DO), Biochemical oxygen demand (BOD5), Chemical oxygen demand (COD), Ammonium nitrogen (NH_4^+-N), Phosphate (PO_4^{3-}-P), Nitrite nitrogen (NO_2^--N).
- Environmental parameters are surveyed and analyzed in accordance with current standards.

Table 1. Methods for analyzing environmental parameters

No	**Content**	**Equipment/ standards**
I	**Hydrological factors**	
1	pH	Multiparameter meter: Horiba U52
2	Salinity	Multiparameter meter: Horiba U52
II	**Hydrochemical factors**	
1	Biochemical Oxygen Demand (BOD5)	TCVN 6001-1:2008
2	Chemical Oxygen Demand (COD)	TCVN 6491: 1999
3	Ammonium-Nitrogen (NH_4^+-N)	TCVN 6179-1:1996
4	Phosphate-Phosphorus (PO_4^{3-}P)	TCVN 6202:2008
5	Nitrite-Nitrogen (NO_2^-N)	TCVN 6178:1996

Source:QCVN 10:2023/BTNMT - National technical regulation on seawater quality; QCVN 08-MT:2015/BTNMT - National technical regulation on surface water quality

According to the Ministry of Natural Resources and Environment, national standards on seawater quality (QCVN 10:2023/BTNMT) and QCĐP 2:2020/QN-Aquaculture conservation aquatic ecosystems, the pH value limit for aquaculture and aquatic conservation areas is 6.5 to 8.5. As per "Decision No. 736/QD-TCTS-KHCN&HTQT: Technological process of production of golden pompano fingerlings (Trachinotus spp), General Department of Fisheries (2019)" and "Decision No. 789/QD-NN&PTNT – Decision on the issuance of technical procedures in the fisheries sector applied to 17 concentrated agricultural production planning areas of Quang Ninh

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province, Ministry of Agriculture and Rural Development," the minimum allowable salinity value is 20‰, while the maximum is 35‰.

Chemical Oxygen Demand (COD) signifies the oxygen quantity needed for chemical oxidation of inorganic and organic chemicals in wastewater, assessed using potassium permanganate ($KMnO_4$) or potassium dichromate ($K_2Cr_2O_7$). According to QCVN 08-MT:2015/BTNMT (National Technical Regulation on Industrial Wastewater), the maximum allowable value is COD < 10 mg/l.

Biochemical Oxygen Demand (BOD5) denotes the dissolved oxygen utilized for organic matter decomposition in water. It hinges on temperature, phytoplankton density, and organic matter concentration. The maximum allowable value is BOD5 < 5 mg/l (Tayel, 2003).

Nitrite (NO_2^-N) in water leads to nutrient pollution in coastal areas and is toxic to aquatic life (Basic Information about NO_2, EPA, 2023). The maximum allowable Nitrite concentration is 0.05 mg/l.

Nutrients NH_4^+-N (Ammonium) and PO_4^{3-}P (Phosphate) are vital for aquatic plant growth and development. However, excessive levels can trigger "algae blooms," adversely affecting aquaculture environments. Moreover, as NH_4^+-N increases, the toxic gas NH_3 also rises due to constant conversion between NH_4^+-N and NH_3 (A. Mahmoud, 2013). The maximum allowable levels for NH_4^+-N and PO_4^{3-}-P in seawater are 0.1 mg/l and 0.2 mg/l respectively (according to Decision No. 736/QD-TCTS-KHCN&HTQT, the appropriate NH_4^+-N concentration in seawater is ≤2 mg/l).

4. Results and Discussion

4.1Environmental Factors

Table 2 shows the average concentrations of environmental factors measured in water samples from the six aquaculture regions of Quang Ninh. These measures indicate the spread or dispersion of the data around the mean.

All six areas seem to be within the acceptable range for pH (6.5-8.5) with values ranging from 8.06 (Mong Cai - Hai Ha) to 8.21 (Quang Yen). COD (chemical oxygen demand), an indicator of organic pollution, falls within the national standard (<10 mg/l) in all six areas, with values ranging from 2.38 mg/l (Cam Pha, Quang Yen) to 2.63 mg/l (Van Don). BOD5, NO_2^--N, NH_4^+-N, and PO_4^{3-}-P in the studied areas are well within the acceptable limits.

However, salinity levels show some variation. While Mong Cai - Hai Ha and Quang Yen fall within the recommended range (20-30 ‰) with 29.45 ‰ (Mong Cai - Hai Ha, Van Don), the other three areas have slightly higher salinity readings (up to 31.02 ‰ in Cam Pha and 31.03 ‰ in Ha Long, Quang Yen).

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Table 2. Statistical summary of environmental factors by coastal region

Sequential number	Mong Cai - Hai Ha	Dam Ha - Tien Yen	Van Don	Cam Pha	Ha Long	Quang Yen	Environmental Standards
pH	**8.06±0.096**	8.07±0.098	8.07±0.098	8.2±0.10	8.18±0.10	**8.21±0.10**	**6.5 - 8.5**
Salinity (‰)	**29.45±0.334**	29.66±0.377	**29.45±0.334**	**31.02±0.397**	**31.03±0.397**	**31.03±0.397**	**20 -30**
COD (mg/l)	2.62±0.801	2.43±0.598	**2.63±0.801**	**2.38±0.589**	2.45±**0.591**	**2.38±0.589**	**<10**
BOD5 (mg/l)	1.7±0.429	**1.51±0.285**	**1.76±0.430**	1.62±0.364	1.62±0.364	1.65±0.366	< **5**
NO_2^--N (mg/l)	0.01±0.033	0.01±0.033	0.01±0.033	0.01±0.033	0.01±0.033	0.01±0.033	< **0.05**
NH_4^+-N (mg/l)	0.05±0.06	0.05±0.06	0.05±0.06	0.05±0.06	**0.04±0.06**	0.05±0.06	< **0.1**
PO_4^{3-}-P (mg/l)	0.01±0.08	0.01±0.08	0.01±0.08	0.01±0.08	0.01±0.08	0.01±0.08	< **0.2**
Sequential number	Mong Cai - Hai Ha	Dam Ha - Tien Yen	Van Don	Cam Pha	Ha Long	Quang Yen	Environmental Standards
pH	8.06±0.096	8.07±0.098	8.07±0.098	8.2±0.10	8.18±0.10	8.21±0.10	6.5 - 8.5

Salinity (‰)	29.45±0.334	29.66±0.377	29.45±0.334	31.02±0.397	31.03±0.397	31.03±0.397	20 -30
COD (mg/l)	2.62±0.801	2.43±0.598	2.63±0.801	2.38±0.589	2.45±0.591	2.38±0.589	<10
BOD5 (mg/l)	1.7±0.429	1.51±0.285	1.76±0.430	1.62±0.364	1.62±0.364	1.65±0.366	< 5
NO_2^--N (mg/l)	0.01±0.033	0.01±0.033	0.01±0.033	0.01±0.033	0.01±0.033	0.01±0.033	< 0.05
NH_4^+-N (mg/l)	0.05±0.06	0.05±0.06	0.05±0.06	0.05±0.06	0.04±0.06	0.05±0.06	< 0.1
PO_4^{3-}-P (mg/l)	0.01±0.08	0.01±0.08	0.01±0.08	0.01±0.08	0.01±0.08	0.01±0.08	< 0.2

Source: Created by authors

4.2 EnvironmentalCarrying Capacity of the Aquaculture Areas

4.2.1 Environmental Capacity in the studied areas

Table 3. Results of environmental load analysis in Mong Cai and Hai Ha areas

Parameter	**BOD5**	**COD**	**NH_4^+-N**	**PO_4^{3-}-P**	**NO_2^--N**
Cmax (mg/l)	4	10	0.1	0.2	0.05
C0 (mg/l)	1.7	2.62	0.05	0.01	0.01
V (l)	$120786x10^7$	$120786x10^7$	$120786x10^7$	$120786x10^7$	$120786x10^7$
(1+R)	1.521	1.521	1.521	1.521	1.521

(%)					
EC (mg/year)	4,225,456,638,000	13,558,204,342,800	91,857,753,000	349,059,461,400	73,486,202,400
EC (kg/day)	11577	37146	252	956	201

Source: Created by authors

Table 4. Results of environmental load analysis in Dam Ha, Tien Yen Areas

Parameter	**BOD5**	**COD**	**NH_4^+-N**	**PO_4^{3-}-P**	**NO_2^--N**
Cmax (mg/l)	4	10	0.1	0.2	0.05
C0 (mg/l)	1.51	2.43	0.05	0.01	0.01
V (l)	52662x107	52662x107	52662x107	52662x107	52662x107
(1+R) (%)	1.521	1.521	1.521	1.521	1.521
EC (mg/year)	1,994,462,659,800	6,063,486,881,400	40,049,451,000	152,187,913,800	32,039,560,800
EC (kg/day)	5464.28	16612.29	109.72	416.95	87.7796

Source: Created by authors

Table 5.Results of environmental load analysis in Van Don Areas

Parameter	**BOD5**	**COD**	**NH_4^+-N**	**PO_4^{3-}-P**	**NO_2^--N**
Cmax (mg/l)	4	10	0.1	0.2	0.05
C0 (mg/l)	1.76	2.63	0.07	0.01	0.01
V (l)	20838x107	20838x107	20838x107	20838x107	20838x107

(1+R) (%)	1.521	1.521	1.521	1.521	1.521
EC (mg/year)	709,958,995,200	2,335,891,872,600	9,508,379,400	60,219,736,200	12,677,839,200
EC (kg/day)	1945.09	6399.7	26.0504	164.99	34.7338

Source: Created by authors

Table 6.Results of environmental load analysis in Cam Pha City

Parameter	**BOD5**	**COD**	**NH_4^+-N**	**PO_4^{3-}-P**	**NO_2^--N**
Cmax (mg/l)	4	10	0.1	0.2	0.05
C0 (mg/l)	1.62	2.38	0.05	0.01	0.01
V (l)	91086x107	91086x107	91086 x107	91086 x107	91086 x107
(1+R) (%)	1.521	1.521	1.521	1.521	1.521
EC (mg/year)	3,297,294,982,800	10,556,885,617,200	69,270,903,000	263,229,431,400	55,416,722,400
EC (kg/day)	9033.68	28922.97	189.78	721.18	151.83

Source: Created by authors

Table 7.Results of environmental load analysis in Ha Long City

Parameter	**BOD5**	**COD**	**NH_4^+-N**	**PO_4^{3-}-P**	**NO_2^--N**
Cmax (mg/l)	4	10	0.1	0.2	0.05
C0 (mg/l)	1.62	2.45	0.04	0.01	0.01

V (l)	9246x107	9246x107	9246x107	9246x107	9246x107
(1+R) (%)	1.521	1.521	1.521	1.521	1.521
EC(mg/year)	334,703,350,800	1,061,769,033,000	8,437,899,600	26,720,015,400	5,625,266,400
EC(kg/day)	917	2908.96	23.1175	73.2055	15.4117

Source: Created by authors

Table 8.Results of environmental load analysis in Quang Yen Areas

Parameter	**BOD5**	**COD**	**NH_4^+-N**	**PO_4^{3-}-P**	**NO_2^--N**
Cmax (mg/l)	4	10	0.1	0.2	0.05
C0 (mg/l)	1.65	2.63	0.04	0.01	0.01
V (l)	164586 x107	164586 x107	164586 x107	164586 x107	164586 x107
(1+R) (%)	1.521	1.521	1.521	1.521	1.521
EC (mg/year)	5,882,879,691,000	18,449,712,052,200	150,201,183,600	475,637,081,400	100,134,122,400
EC (kg/day)	16117.48	50547.16	411.51	1303.12	274.34

Source: Created by authors

4.2.2 Potential for aquaculture development in the studied areas

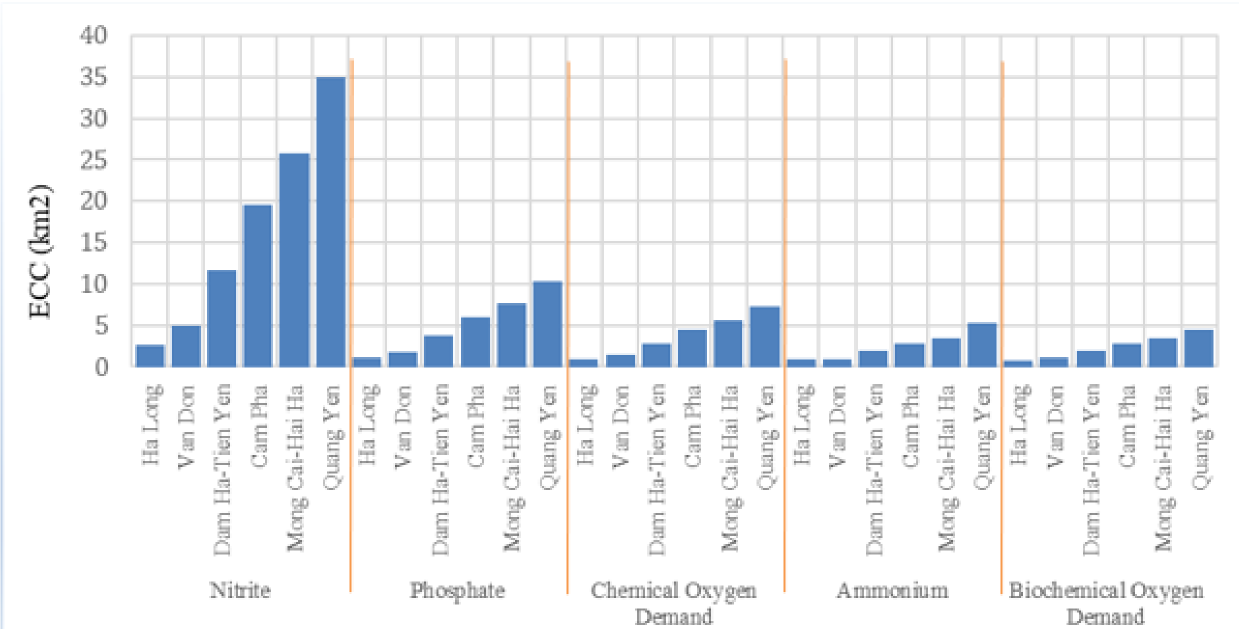

Figure 2.Potential for aquaculture development in the studied

Source: Created by authors

Table 9. Potential for aquaculture development in the studied areas

	Mong Cai – Hai Ha	Dam Ha – Tien Yen	Van Don	Cam Pha	Ha Long
(km2)	8.566	3.77	1.437	6.505	0.668

Source: Created by authors

The graph compares the ECC of different spatial aquaculture areas in Quang Ninh. Higher ECC values indicate areas with a greater capacity to support aquaculture without harming the environment.

Our estimated areas of the selected water bodies: 402.62 km2 in Mong Cai-Hai Ha, 175.54 km2 in Dam Ha-Tien Yen, 69.46 km2 in Van Don, 303.62 km2 in Cam Pha, 30.82 km2 in Ha Long, and 548.62 km2 in Quang Yen.

In all studied areas, despite Nitrite (NO2-) limitations, a significant portion remains suitable for aquaculture development. Other parameters, such as Phosphate (PO43-), Chemical Oxygen Demand (COD), Ammonium (NH4+), and Biochemical Oxygen Demand (BOD5), present even stricter limitations.

For example, in Mong Cai-Hai Ha, considering the ECC value of NO2-, there is still 25.125 km2 that can be developed for aquaculture (corresponding to 6.24%); respectively with other substances such as PO43- is 1.76%, COD is 1.23%, NH4+ is 0.711% and BOD5 is 0.7%.

4.3Discussion

In this study, we have inherited and successfully applied a formula for calculating environmental carrying capacity (ECC). Our goal was to maximize aquaculture potential while ensuring acceptable water quality standards.

Based on the results, the ECC value of NO2- in six areas is the largest while BOD5 receives the smallest value of all substances. In terms of NO2-, the ECC value of Quang Yen is the highest with 34.293 km2 and Ha Long is the lowest with 10.972 km2. This indicates Quang Yen might have better natural processes for removing Nitrite from the water than the other areas. Quang Yen also has the greatest potential for aquaculture based on other substances levels, followed by Mong Cai-Hai Ha and Van Don. This is because these areas have a relatively large area of coastal tidal land, many ponds, and lagoons. Moreover, the water BOD5 area in Quang Yen, Mong Cai-Hai Ha, and Van Don is much larger than Cam Pha and Ha Long.

In general, Quang Yen stands out as the area with the highest value of ECC. Meanwhile, the opposite trend was true for Ha Long. For areas with high ECC, we should prioritize aquaculture development based on the strengths of each area. For example, Quang Yen should be a top priority for the development of both saltwater and freshwater species. Next, based on the values of ECC, we should prioritize promoting aquaculture, especially mollusk farming (clams, oysters, mussels....) in Mong Cai-Hai Ha, marine fish and oysters in Cam Pha and shrimp farming in Dam Ha - Tien Yen. However, for areas with low ECC, aquaculture development is not recommended. Instead, we can reduce existing aquaculture or improve water quality.

Hence, our model presents several advantages. It offers a streamlined calculation method applicable to aquaculture areas in various regions and countries. This calculation method can be utilized for various environmental parameters and substances, with allowable concentration limits specified by national standards. Additionally, it can estimate the maximum area or number of cages suitable for aquaculture, providing practical insights for development.

While our approach demonstrates effectiveness, other models exist for evaluating carrying capacity. For instance, the Delphi calculation model focuses on predicting future events based on expert opinions, whereas the ECC formula assesses the load-carrying capacity of aquaculture systems. Both methods serve distinct purposes in managing water ecosystems and quality. The Norwegian MOM (Modeling - Developing Fish Farms - Monitoring) model emphasizes data accumulation from multiple monitoring sites to enhance parameter accuracy, reducing uncertainty in results.

However, our study only focused on specific water quality parameters. Future research could explore additional environmental factors such as disease, climate change, and the total cost-benefit of pollution control units. Moreover, the ECC formula used in this study has only been applied in certain provinces and cities in Vietnam and is not widely recognized in other countries. To address these limitations, we conducted in-depth interviews with experienced aquaculture households to gain insights into factors affecting aquaculture efficiency.

Estimating environmental carrying capacity is crucial for integrated environmental management, policy planning, and decision-making (Conides et al., 2022). A lack of centralized planning for aquaculture in Quang Ninh province has led to widespread unregulated practices and even illegal farming. This highlights shortcomings in management, as fragmented planning ignores environmental limitations (carrying capacity) and fails to keep pace with rapid aquaculture development.

Identifying suitable locations for aquaculture is vital for environmental sustainability (Yucel-Gier et al., 2019). Sustainable aquaculture needs careful planning. Quang Ninh province is addressing this by zoning specific areas for aquaculture, separate from tourism and transport. To ensure environmental health, policymakers need to consider not just location, but also the scale of operations. Calculating the environmental carrying capacity (ECC) will be crucial for making informed decisions about where and how much aquaculture development is sustainable.

In the project titled "Sustainable Development of Fisheries Economy in Quang Ninh Province for the period 2024 - 2030", the aquaculture areas in 2023 were as follows: 5752 hectares in Mong Cai - Hai Ha, 8083 hectares in Dam Ha - Tien Yen, 5539 hectares in Van Don, 1003 hectares in Cam Pha, 1467 hectares in Ha Long, and 7828 hectares in Quang Yen. Our results suggest a potential for expansion. For instance, in the Mong Cai-Hai Ha area, the minimum calculated ECC value is 2.815 km2 (281.5 ha), which can be improved to at least 6033.5 ha. Including ECC as a comprehensive index in the annual monitoring of aquaculture areas will enhance environmental management, as current monitoring relies on environmental indicators alone.

Sustainable economic development in coastal aquaculture requires commitment from aquaculture farmers, along with participation and guidance from local authorities at all levels and sectors. Aquaculture households must fully comply with environmental management procedures and waste treatment regulations. Strengthening the environmental management apparatus and strict enforcement of regulations are essential.

4.4 Solutions

Centralized planning and environmental assessment: Estimating environmental carrying capacity (ECC) is crucial for integrated environmental management, policy planning, and decision-making. Historically, aquaculture in Quang Ninh province lacked centralized planning, resulting in unregulated distribution across sea areas and widespread illegal farming practices. To address this, policymakers should prioritize centralized planning that considers overall district planning and assesses environmental carrying capacity to ensure sustainable aquaculture practices.

Identification of suitable locations: Identifying suitable locations for aquaculture is vital for environmental sustainability. As Quang Ninh province undertakes a project to re-plan aquaculture, policymakers must allocate each area to a single farming zone while reserving space for other economic sectors. Calculating ECC will provide policymakers with insights into geographical choices, scale, and area for aquaculture to meet environmental quality requirements.

Community commitment and regulatory enforcement: Sustainable economic development in coastal aquaculture requires commitment from aquaculture farmers, along with participation and guidance from local authorities at all levels and sectors. Aquaculture households must comply with environmental management procedures and waste treatment regulations. Using environmentally friendly materials for farming infrastructure, implementing technical measures for seaweed polyculture, and enforcing regulations are essential for mitigating environmental pollution and ensuring sustainable aquaculture practices.

Adoption of clean technologies: Embracing clean and environmentally friendly farming technologies, including reducing the use of drugs and chemicals, and exploring biological products, are crucial steps for sustainable aquaculture practices. Policymakers should incentivize the adoption of these technologies to promote environmental sustainability in aquaculture operations.

5. Conclusion

This study has calculated the environmental carrying capacity for aquaculture areas in Quang Ninh province. The research employed the mass balance theory, combining water quality analysis in water Bodies with in-depth interviews.

Analysis of water samples indicates that hydrochemical parameters in all six areas fall within allowable limits and do not pose harm to the environment. Specifically, the potential for aquaculture development based on the environmental carrying capacity in the following areas is as follows: Quang Yen, 11.854 km2; Mong Cai - Hai Ha, 8.566 km2; Cam Pha City, 6.505 km2'; Dam Ha - Tien Yen, 3.77 km2; Van Don, 1.437 km2; and Ha Long City, 0.668 km2. It is evident that the environmental carrying capacity in the Quang Yen aquaculture area is the largest, with 11.854 km2 to improve, while the environmental carrying capacity in Ha Long City is the smallest, with only 0.668 km2 to develop.

To effectively implement the re-planning of aquaculture areas in Quang Ninh province, policymakers must carefully consider the location and scale of aquaculture areas. Moreover, they should enhance management and supervision of aquaculture areas, ensuring compliance with environmental protection regulations. Collaboration with the community is also essential to ensure the successful implementation of environmental protection measures.

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