Mariculture development in Vietnam: Present status and prospects

Nguyen Van Quang[1*], Thai Thanh Binh[1], Ngo The Anh[2]

[1]*College of Economics, Technology and Fisheries, Ly Nhan Tong Street, Dinh Bang Ward, Tu Son City, Bac Ninh Province, Vietnam*
[2]*Department of Fisheries, Ministry of Agriculture and Rural Development, 10 Nguyen Cong Hoan Street, Ngoc Khanh Ward, Ba Dinh District, Hanoi, Vietnam*

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Abstract:

Vietnam possesses significant potential for the development of mariculture, thanks to its extensive coastline and favourable natural conditions. However, the progress of the mariculture industry has lagged behind its potential. While land-based aquaculture expansion appears limited, mariculture development holds pivotal importance for the sustainable growth of Vietnam's aquaculture sector. This study aims to review the current status of mariculture in Vietnam, offer an analytical overview of the sector's potential and challenges, and provide recommendations and policy implications for its sustainable development. Secondary data from reliable sources and existing mariculture literature inform this study. It becomes evident that Vietnam's mariculture sector remains underdeveloped, with marine aquaculture activities primarily concentrated in nearshore areas. Small-scale production dominates, while large-scale and offshore production has not gained widespread prominence. The availability of production technology and logistic services for the mariculture sector remains limited. Various sources of risk, including disease outbreaks, environmental pollution, climate change, input quality, and rising prices, pose challenges to mariculture production. The study also introduces crucial recommendations for fostering the sustainable development of the mariculture industry in Vietnam.

Keywords: **mariculture, small-scale, Vietnam.**

Classification numbers: **2.1, 2.2**

1. Introduction

Vietnam stands as one of the world's foremost aquaculture producers. In 2020, Vietnam ranked fourth globally in aquaculture production, with an output of 4.6 million tons [1]. Aquaculture represents one of the fastest-growing sectors, playing a vital role in Vietnam's socio-economic development. The industry offers employment opportunities to millions of Vietnamese, particularly in rural and coastal regions, and significantly contributes to food security and poverty alleviation. Annually, the fisheries sector, encompassing aquaculture and wild capture, accounts for 4-5% of Vietnam's GDP. Between 1995 and 2020, aquaculture production grew by a factor of 11, from 415 thousand tons to 4.6 million tons [2]. Notably, in 2022, Vietnam achieved a historic milestone, with seafood exports reaching an unprecedented 11 billion USD [3].

Aquaculture in Vietnam encompasses a variety of species, including freshwater, brackish water, and marine species. Commonly farmed species encompass fish (e.g., catfish, tilapia, carps, snakehead fish, marine finfish such as cobia, seabass, groupers), shrimp (white-leg shrimp, tiger shrimp), molluscs (oysters, clams), lobsters, seaweeds, and others. Of these, the use of sea water areas for aquaculture has been underutilised, while freshwater areas face limitations for expansion.

Vietnam, holds enormous potential for mariculture[1] development due to its 3,260-kilometer coastline spanning from North to South, a million square kilometres of Exclusive Economic Zone, over 3000 islands, and various bays, lagoons, and estuaries. Notably, land-based aquaculture

[1]Here, mariculture means the farming of organisms for food or other products in the sea, in a marine water environment.

*Corresponding author: Email: vinhquang82@gmail.com

expansion has been constrained. Furthermore, freshwater and brackish water fish farming can lead to environmental externalities such as eutrophication, disease outbreaks, antibiotic pollution, ecosystem degradation, and mangrove deforestation [4-6]. Conversely, offshore aquatic farming holds significant development potential. Mariculture has emerged as a vital industry in several countries worldwide, including Norway, China, and Australia [7, 8].

In recent years, Vietnam has enacted numerous policies, plans, and initiatives to promote mariculture development. Notably, the Central Committee of the Communist Party of Vietnam approved Resolution 36/NQ-TW on the sustainable development of the marine economy towards 2030, with a vision for 2045. This resolution identifies the development of sea-based aquaculture as one of the six economic sectors requiring substantial investment and promotion. On March 11, 2021, Decree 339/QD-TTg was issued, outlining plans for aquaculture development until 2020, with a vision extending to 2045. Additionally, on October 4, 2021, the Prime Minister introduced a Master Plan for aquaculture development at sea until 2030, with a vision extending to 2045. Despite substantial attention and support from both central and local governments and stakeholders, mariculture development remains limited compared to its potential. Production primarily remains at a small-scale level. The adoption of advanced technology across the farming, seed production, processing, and value chain stages remains constrained. The market for output and distribution networks appears unstable, while the allocation of sea water areas for farmers is time-consuming and challenging to implement in practice [9, 10].

To date, there has been a few studies that focuses on providing a thorough analysis of the mariculture sector in Vietnam, except a study done by N.V. Quang, et al. (2022) [11]. However, the study has limitations such as lacking up-to-date and detailed information as well as detailed analysis. This study, thus will overcome that limitation. The primary objectives of this study are to (i) Provide an overview of the current status of mariculture in Vietnam, (ii) Analyse the potential and challenges facing the seaculture sector in Vietnam; and (iii) Offer recommendations and policy implications for fostering the industry's sustainable development.

The subsequent sections of this article are structured as follows: Section 2 provides a global overview of mariculture. Section 3 outlines the key legal policies associated with the mariculture sector in Vietnam. Section 4 briefly presents the methodologies employed. Section 5 introduces essential information about marine aquaculture in Vietnam, while Section 6 concludes and offers recommendations.

2. Mariculture in the world

Aquaculture stands out as one of the world's fastest-growing industries in food animal production [12]. With the global population steadily on the rise, the expansion of land-based aquaculture has been constrained, while capture fisheries have exhibited stagnation over recent decades. Furthermore, the demand for seafood is on the upswing in tandem with increasing income levels. Therefore, the imperative of "farming at sea," or mariculture, becomes paramount in fulfilling the global human food demand [5].

Mariculture undeniably assumes a pivotal role in supporting coastal communities by providing protein-rich sustenance, elevating the incomes of coastal residents, generating livelihood opportunities for fish farmers, fostering regional economic development, and enhancing tourism in localities [13]. Over the past few decades, mariculture has been actively promoted and has experienced rapid growth, particularly in countries such as China, Norway, Chile, Canada, and the USA [5, 14-16]. Presently, a total of 112 countries and territories engage in seafood production within marine environments [17].

Since 1970, the production and economic worth of mariculture, encompassing marine and brackish areas, have witnessed a substantial surge [18]. In 2018, the combined output of mariculture and coastal aquaculture reached approximately 30.8 million tons, with a total value of USD 106.5 billion [15]. Over the past few decades, mariculture's contribution to global aquaculture production has significantly escalated, ascending from 14% in 2000 to 35.9% in 2016 [19].

The spectrum of organisms cultivated in mariculture encompasses fish, crustaceans, molluscs, seaweed, and various other marine aquatic species. As marine resources face depletion due to overexploitation, mariculture development emerges as an inexorable trend [20].

3. Legal policies for mariculture in Vietnam

This section delineates the legal framework and policies associated with mariculture development in Vietnam. While numerous legal documents exist, this section highlights several key documents profoundly relevant to marine aquaculture (Table 1).

Table 1. Main legal documents associated with the mariculture sector.

No.	Legal documents	Policies/directions
1	The Fisheries Law 2017, the National Assembly Law approved Law No 18/2017/QH14	- The People's Committee at the District level has the rights to allocate the use right of sea areas within 3 nautical miles to farmers whose livelihoods mainly depend on aquaculture. - The People's Committee at the Provincial level has rights to issue the use right of sea areas within 6 nautical miles for Vietnamese, organizations engaged in scientific and technological activities in aquaculture. - The Ministry of Natural Resources and Environment has the rights to issue the use right of sea areas beyond 6 nautical miles for Vietnamese, organizations conducting scientific and technological activities in aquaculture. - Mariculture activities must have an approved project by authorities, except for farmers whose livelihoods mainly come from aquaculture or farmers transitioning from marine capture to sea-based aquaculture.
2	Decision 339/QD-TTg issued on 11 March 2021 by the Prime Minister about approving the master plan for aquaculture development strategy until 2020 and a vision to 2045	- This plan encompasses the aquaculture industry, including mariculture. - Mariculture is promoted to evolve into a commercial industry. Large-scale production and offshore farming are encouraged to provide substantial output for exportation and domestic consumption.
3	Decision 1664/QD-TTg issued on 04 October 2021 by the Prime Minister about approving the plan for mariculture development until 2020 with a vision to 2045	- This plan specifically addresses the development of the mariculture industry. - The plan outlines both general and specific objectives for mariculture development until 2030, with a vision for 2045. - It also presents duties, actions, and solutions for mariculture development up to 2030, with a vision for 2045.
4	Resolution 36/NQ-TW by the Central Committee of the Communist Party on the sustainable development of the marine economy toward 2030 and with a vision to 2045	- The Resolution identifies sea-based aquaculture as one of the six economic sectors requiring promotion for rapid development.
5	Decree 11/2021/ND-CP issued on 10 February 2021 about regulating the assignment of certain sea areas to organizations and individuals for marine resource exploitation and utilisation	- This Decree governs the allocation of sea areas to individuals and organizations. Specifically, the People's Committee of each coastal district has the authority to allocate sea areas within 3 nautical miles to Vietnamese individuals for aquaculture purposes, with a limitation of 01 hectare for sea areas allocated to aquaculture farmers. The People's Committee of each coastal province has the authority to allocate sea areas within 6 nautical miles for individuals and organizations. The Ministry of Natural Resources and Environment has the authority to allocate sea areas beyond 6 nautical miles for marine users. - The maximum sea areas (within 3 nautical miles) allocated for individuals for aquaculture activities are limited to one hectare. - The maximum duration for the right to utilize the allocated sea areas is 30 years. However, the utilization right can be renewed for a total renewal period of less than 20 years.

4. Research methods

In this research, several methods were employed, including summary analysis, statistical analysis, literature review, and SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats). The study primarily relied on secondary data collected from reputable sources, such as the General Statistical Office (GSO), Directorate of Fisheries - Ministry of Agriculture and Rural Development (MARD), Vietnam Seaculture Association (VSA), Department of Fisheries in coastal provinces in Vietnam, as well as existing literature and prior research [11].

5. Present status of mariculture in Vietnam

5.1. The production of main marine species

Vietnam's seas and islands boast an array of biological resources, housing approximately 12,000 species of living organisms, and are acknowledged as one of the ten hubs of marine biodiversity regions [21].

Evidently, there has been a significant increase in both the farming areas and production output within the mariculture sector during the period spanning from 2010 to 2022. This upswing in both parameters suggests the expanding scope of the mariculture industry in Vietnam.

Mariculture species can be categorised into five groups, encompassing fish, lobster, crab, molluscs (oysters, clams, snails, and blood cockles), and seaweed. A detailed discussion of each species follows.

Marine fish species: This group is widely cultivated in nearly all coastal provinces in Vietnam. Common

Table 2. Farming areas and production volume of main farmed species.

No.	Main farmed species	2010	2012	2015	2017	2018	2019	2020	2021	2022
I	**Production areas**									
1	Marine fish cage culture (1000 m^3)	-	-	-	-	2.980	3.425	3.390	3.375	3.372
2	Crab (1000 ha)	-	-	-	179	166	355	369	387	379
3	Lobster									
	- No of cage (1000 cages)	50	50	43	86	149	192	144	161	186
	- Measured in cubic (1000 m^3)	1.395	1.667	1.343	2.652	3.389	4.724	3.730	4.160	4.468
4	Molluscs (1000 ha)	26	31	41	41	54	54	53	51	61
5	Seaweed (1000 ha)	4	22	25	25	4	10	11	11	12
II	**Production quantity (1000 tons)**	157	200	309	377	561	598	484	516	589
1	Marine fish (1000 tons)	-	-	-	-	16	19	26	24	30
2	Crab (1000 tons)	-	-	-	-	47	49	56	61	62
3	Lobster (1000 tons)	2	2	1	2	2	3	3	3	3
4	Molluscs (1000 tons)	135	197	265	273	354	372	367	396	457
5	Seaweed (1000 tons)	19	18	63	102	110	120	135	138	145

Source: Directorate of fisheries (2023) [22].

species include grouper, cobia, pompano, seabass, and red drum. Both the production area and quantity have experienced significant growth between 2010 and 2022. However, marine fish farming technology in Vietnam appears somewhat outdated, with many farmers relying on traditional technologies and materials for fish cages, such as wood and bamboo. Consequently, fish farming primarily takes place in nearshore areas, as cages constructed from traditional materials (wood and bamboo) are ill-equipped to withstand strong winds and waves in offshore locations. The adoption of advanced technologies in mariculture, such as the use of High-Density Polyethylene (HDPE) cages and Internet of Things (IoT) applications, remains limited. The feed for marine fish farming heavily relies on marine capture, particularly trash fish. Although industrial feed has been employed for certain fish species, such as pompano, cobia, and seabass, the number of fish farmers utilising industrial feed for their operations remains restricted.

Lobster: Lobster holds significant importance within Vietnam's mariculture sector, given its relatively high market value. The demand for this species is also substantial, both in local and international markets. Lobster farming predominantly thrives in several central provinces, such as Quang Ngai, Phu Yen, Binh Dinh, Khanh Hoa, and Ninh Thuan. Particularly, Khanh Hoa and Phu Yen provinces collectively account for over 90% of the total production areas and the value of lobster production in Vietnam. This is attributed to the presence of favourable natural resources conducive to lobster farming in these provinces.

As depicted in Table 2, the number of lobster cages witnessed a rapid increase between 2010 and 2022. In 2010, there were 50 thousand lobster cages (equating to approximately 1.4 million m^3); this figure quadrupled over nine years, escalating from 50 thousand cages to 186 thousand cages (approximately 4.5 million m^3). However, the quantity of lobster production only increased by 1.5 times during this period, implying a decrease in productivity between 2010 and 2022. The decline in production can be attributed to factors such as disease outbreaks, notably milky disease, which occurred during those years [23].

Molluscs: Mollusc species find cultivation in numerous coastal provinces across Vietnam, encompassing around 28 provinces [24]. Common species include oysters, clams, snails, mussels, blood cockles, shells, geoduck clams, and others. Each province possesses its unique potential and favourable conditions for these species. In 2019, the total production areas for molluscs spanned about 61 thousand hectares, yielding a production volume of 457 thousand tons. Notably, oyster and clam farming areas accounted for approximately 30% of the total mollusc farming areas, while the production volume of oysters and clams contributed to 67% of the total mollusc production volume.

Clam farming has been established in several provinces, including Hai Phong, Thai Binh, Nam Dinh, Ninh Binh, Thanh Hoa, and a selection of southern provinces such as Tien Giang, Ben Tre, and Tra Vinh. Conversely, oyster cultivation has flourished in regions such as Quang Ninh, Hai Phong, Nghe An, Thua Thien Hue, Khanh Hoa, Ba Ria - Vung Tau, and Ca Mau. Other mollusc species, including abalone, blood cockle, geoduck clam, and snail, have found cultivation in coastal areas with favourable natural conditions. For instance, abalone and geoduck clams are cultivated in Quang Ninh, Khanh Hoa, and Kien Giang, while snail species are commonly farmed in Quang Ninh, Quang Ngai, Binh Dinh, Phu Yen, Khanh Hoa, and Ninh Thuan.

Seaweed: Vietnam boasts more than 800 types of seaweeds, with over 90 species of significant value. Some seaweeds, such as sea grape, Gracilaria verrucosa, and cartilage seaweed [25], hold high economic value. Between 2010 and 2022, seaweed production volumes experienced remarkable growth. Specifically, seaweed production surged from 19 thousand tons in 2010 to 145,000 tons in 2022, marking a sevenfold increase [26].

5.2. Mariculture areas

Marine aquaculture is prevalent across all 28 coastal provinces spanning from the northern to the southern regions of Vietnam. Nonetheless, the mariculture sector exhibits concentration in specific areas and provinces. For instance, northern provinces like Quang Ninh, Hai Phong, Thai Binh, and Nam Dinh engage in mariculture, as do central provinces including Thanh Hoa, Nghe An, Phu Yen, and Khanh Hoa, alongside several southern provinces such as Ba Ria-Vung Tau, Tien Giang, Ben Tre, Ca Mau, and Kien Giang. Each province possesses distinct advantages and favourable conditions for mariculture development. Certain provinces excel in marine fish farming, such as Quang Ninh and Ba Ria-Vung Tau, while others, like Tra Vinh and Ca Mau, shine in crab farming. Similarly, Phu Yen and Khanh Hoa have gained recognition for lobster farming, whereas mollusc farming thrives in Quang Ninh and Kien Giang.

Concerning sea-based farming areas, mariculture activities are categorised into three area groups: within 3 nautical miles, between 3 and 6 nautical miles, and beyond 6 nautical miles. Nevertheless, the majority of mariculture activities are conducted in nearshore areas (within <3 nautical miles) utilising traditional technology, such as wooden cages and frames. Conversely, mariculture in offshore areas (>6 nautical miles) remains relatively limited. For instance, in 2019, there were 6,506 mariculture producers (encompassing marine fish, lobster, and other marine species) operating within 3 nautical miles, while 914 fish mariculture producers operated between 3 and 6 nautical miles. However, only 27 fish seaculture producers managed farms in offshore areas (beyond 6 nautical miles) [27].

The concentration of mariculture cages in coastal regions has led to a high density of farming activities, giving rise to growing concerns about pollution stemming from aquaculture operations. Accumulation of discarded nutrients from uneaten feed, faeces, and waste from farming activities can pose a threat to the seabed and benthic ecosystems [28]. This accumulation may result in damage to benthic ecosystems and, at times, lead to algal blooms [29], subsequently impacting farming activities, including disease outbreaks and oxygen shortages in farming areas. Furthermore, aquaculture in nearshore areas may encounter various challenges and risks, such as environmental pollution from other economic activities (e.g., mining, construction, tourism, industrial and residential water discharge), and potential conflicts with other sea-based economic activities (tourism, transportation, mining, marine capture, wind power, etc.). A notable example of coastal environmental pollution due to industrial activities occurred in 2016 when the Formosa Ha Tinh Steel Corporation illegally discharged wastewater into the sea, causing extensive adverse effects on the natural environment, socioeconomic development, livelihoods, and other economic activities (including marine aquaculture) in the surrounding areas [30].

Offshore mariculture offers the potential for increased seafood production while mitigating pressure on coastal ecosystems [31]. Fish farming in offshore areas can help mitigate the impact of onshore economic activities on farming, reducing negative environmental repercussions [32]. However, offshore fish farming also presents challenges, including substantial investment costs, the necessity for advanced technology and skilled labour, and risks associated with safety at sea, adverse weather conditions, waves, currents, and security [32, 33]. Consequently, only a limited number of seaculture producers have ventured into offshore farming, with a mere 27 farmers and organisations operating mariculture in offshore areas [22].

To stimulate offshore fish farming activities, the government must institute appropriate policies and provide support mechanisms, such as financial and technological assistance, to incentivise farmers, organisations, and enterprises to invest in offshore seaculture. Moreover, marine spatial planning and marine aquaculture planning are imperative to foster the development of mariculture in Vietnam.

Table 3 presents the farming area and production output in coastal provinces in Vietnam.

Table 3. Production areas and production output of some main marine species in 28 provinces/cities in 2022.

No	Province	Farming areas of main species					Production output volume (tons)				
		Total production areas (ha)	*Marine fish cage (m^3)*	*Crab (ha)*	*Lobster (m^3)*	*Molluscs (ha)*	*Total production*	*Marine fish cage*	*Crab*	*Lobster*	*Molluscs*
1	Quang Ninh	27.794	391.554	7.000	0	9.500	54.192	8.747	1.034	0	38.393
2	Hai Phong	5.130	51.000	260	0	2.400	46.935	0	250	0	46.500
3	Thai Binh	6.726	0	2.296	0	3.169	124.245	0	1.307	0	120.902
4	Nam Dinh	5.580	0	1.365	0	2.350	57.490	0	1.240	0	45.300
5	Ninh Binh	3.330	0	2.000	0	1.300	26.210	0	740	0	24.500
6	Thanh Hoa	5.290	41.000	3.450	0	1.140	20.950	800	750	0	18.000
7	Nghe An	278	10.000	25	0	163	5.042	0	0	0	4.588
8	Ha Tinh	610	8.256	36	0	422	3.566	29	0	0	3.213
9	Quang Binh	301	23.227	241	0	16	480	195	172	0	68
10	Quang Tri	71	313	0	0	27	499	89	0	0	337
11	Thua Thien Hue	5.081	75.336	693	0	0	4.456	1.256	0	0	1.145
12	Da Nang	-	-	-	-	-	-	-	-	-	-
13	Quang Nam	107	252.000	27	0	25	3.510	3.300	15	0	60
14	Quang Ngai	108	155.000	10	0	75	2.624	556	7	0	1.921
15	Binh Dinh	2.765	42.270	1.368	14.700	29	1.367	187	55	30	616
16	Phu Yen	873	2.085	286	1.488.767	68	4.484	990	0	1.750	0
17	Khanh Hoa	1.372	495.424	297	2.795.844	629	16.031	8.173	34	1.376	4.405
18	Ninh Thuan	89	32.400	0	79.200	31	2.448	532	0	140	1.307
19	Binh Thuan	11	104.479	0	5.058	10	808	504	0	12	280
20	Ba Ria-Vung Tau	992	1.383.840	0	84.000	568	6.712	1.112	0	140	4.912
21	Ho Chi Minh city	985	2.000	0	0	985	22.441	120	0	0	22.321
22	Tien Giang	2.375	0	0	0	2.320	19.920	0	0	0	18.570
23	Ben Tre	5.200	0	0	0	5.200	18.357	0	0	0	14.900
24	Tra Vinh	24.280	0	23.700	0	580	9.662	0	6.603	0	3.059
25	Soc Trang	1.851	0	1.728	0	0	2.593	0	1.425	0	0
26	Bac Lieu	950	0	0	0	950	6.270	0	0	0	6.270
27	Ca Mau	259.410	10.000	252.000	0	7.410	25.202	250	24.000	0	952
28	Kien Giang	104.178	292.300	82.081	0	22.097	102.432	3.372	24.444	0	74.616
Total		**465.735**	**3.372.484**	**378.863**	**4.467.569**	**61.464**	**588.925**	**30.212**	**62.076**	**3.448**	**457.134**

Source: Directorate of Fisheries (2023) [22].

5.3. Technology and supporting logistics services in mariculture

The technology employed in mariculture in Vietnam is generally underdeveloped and outdated, with limited utilisation of advanced technology and industrial-scale production. Traditional technology remains prevalent among most farmers. For instance, bamboo, wood materials, and foam floats are commonly used to construct fish cages, whereas the use of HDPE cages is infrequent. Farming operations predominantly occur on a small scale at the household level. The vulnerability of bamboo, wood, and foam float cages to natural disasters and environmental challenges, such as strong waves, wind, and storms, is evident. An illustrative example is the devastating impact of typhoon Damrey in 2017 on the Central region of Vietnam, resulting in extensive damage to nearly all seaculture cages and significant losses for fish farmers. Furthermore, farmers' attitudes and compliance with instructions and regulations regarding fish density, environmental protection, and cage placement have been limited. The density of fish cages in some coastal areas has been overcrowded and exceeded its carrying capacity, leading to environmental pollution, disease outbreaks, and ecosystem disturbances [10, 34].

Seed production and supply: In 2022, Vietnam held 71 marine fish hatcheries, primarily concentrated in the northern and central regions of the country. Successful artificial seed production has been achieved for various marine-farmed fish species in Vietnam, including grouper, cobia, pompano, red drum, and seabass. Additionally, there were 706 hatcheries for molluscs and 325 hatcheries for crabs [22]. However, lobster seed is entirely reliant on wild sources, either harvested from Vietnam's sea areas or imported from foreign countries. While seed crab was previously sourced from the wild, it is now available to farmers through artificial production.

Despite recent advancements in breeding technology and artificial production in mariculture, some limitations persist. During peak seasons, the supply of seed often falls short of fish farmers' demand, necessitating imports. However, these imports largely occur outside official quotas, posing challenges in terms of quality, disease control, biosecurity, and quantity regulation. Furthermore, concerns linger over the quality of seed for marine aquaculture due to limitations in broodstock sources and breeding technology within the mariculture sector.

Feed for the mariculture industry: Two primary types of feed are utilised in the seaculture industry: industrial feed and natural feed, such as trash fish. Trash fish is more commonly used than industrial feed, particularly in lobster farming (where 100% of the feed consists of trash fish). Relying on captured trash fish for mariculture contributes to the depletion of marine resources and overexploitation of fish stocks, culminating in unsustainable development and environmental issues. Additionally, fish farmers encounter difficulties in managing their feeding operations when heavily dependent on trash fish. This dependence becomes apparent when adverse weather conditions, such as typhoons, strong currents, or high winds, impede fishing, resulting in a shortage of trash fish. While industrial feed has been adopted by farmers for several marine fish species, such as pompano, seabass, and red drum, challenges persist in this domain.

Regarding industrial feed, Vietnam houses 23 aquafeed mills offering 150 products [22]. Most of these mills are foreign direct investment (FDI) or joint venture companies, importing feed ingredients, primarily soybeans and fishmeal, from international markets. This heavy reliance on imported inputs for the aquafeed industry poses various concerns and challenges for the mariculture sector, including quality control, escalating input prices, traceability issues, market monopolies, and price fluctuations. Given that feed costs constitute a substantial portion of the total production expenses in the mariculture [35], the industry faces multiple risks when heavily relying on imported feed or feed ingredients.

Workforce in the mariculture sector: The fisheries industry, inclusive of the mariculture sector, employs over 4 million individuals (VASEP, 2020). In this context, most farmers rely on their personal experience and knowledge for farming operations. The workforce in the sector exhibits limitations in terms of education level, farming management, environmental consciousness, and technology adoption [36]. Skilled labour is imperative for mariculture, especially in offshore farming; however, a shortage of skilled labour exists in this domain [37].

Several universities, colleges, and institutes offer courses and programmes related to aquaculture. Regrettably, none of these institutions provide educational programmes specifically tailored to industrial mariculture [38].

5.4. Output market

The market for mariculture output exhibits diversity, encompassing both international and domestic markets. The demand for mariculture products is often influenced by the product type (e.g., processed or live fish) and the specific marine species. For instance, live and fresh fish species enjoy popularity in the domestic market and are also exported to China through unofficial channels. Marine fish species, on the other hand, are exported to the EU and the USA as frozen products.

For mollusc species: Vietnamese mollusc products are exported to 42 countries, as reported by the Vietnam Association of Seafood Exporters and Producers in 2022 [39]. Notably, the export value of molluscs has shown steady growth over recent years. The primary markets for Vietnamese molluscs include the EU, which accounts for approximately 62% of the total export value, followed by the USA at 12%, as well as Korea, China, and ASEAN countries. Specifically, in 2021, the total export value of molluscs reached US$ 141.6 million [39].

Lobster: Lobsters are traded in both domestic and international markets. Live lobsters are frequently exported to various countries. However, the largest market for live lobsters is China, where it constitutes 90% of the total quantity of Vietnamese lobster exports. A smaller proportion of lobsters is sold within Vietnam, primarily targeting high-end hotels and restaurants in major cities. Annually, the quantity of lobster exported amounts to approximately 2-3

thousand tons, with the total production value of lobster farming reaching about US$ 120 million per year [40].

Crab and sentinel crab: Crab and sentinel crab primarily find their main markets in domestic and Chinese markets. A small quantity of crab and sentinel crab is processed into crab meat and exported to international markets.

Seaweed species: Seaweed species have a versatile range of uses. Several Vietnamese seaweed species serve as food and feed for humans and animals, as well as materials for other industries such as cosmetics and traditional medicine production. Vietnamese seaweed species are sold both in domestic and international markets.

While the export value of seaculture products has shown growth in recent years, it remains relatively modest. China's market continues to be the primary destination, particularly for fish and lobster exports, with seaculture products primarily reaching China through unofficial quotas. Although other markets such as the EU, Japan, and the US are important, the export value to these regions remains limited. Additionally, these markets often demand high-quality products meeting stringent standards, including traceability, safety and hygiene, responsible farming practices, and eco-labelling. Therefore, expanding international markets for mariculture products necessitates the adoption of international standards within the mariculture industry.

5.5. Value chain of mariculture sector

There has been limited collaboration among various stakeholders within the mariculture industry's value chain. This lack of cooperation stems from the fact that seaculture production is predominantly household-based and small-scale. Moreover, many marine species are mostly exported through unofficial quotas, and the distribution network relies heavily on intermediaries. In the processing sector, there has been limited application of cutting-edge technologies. Although various products, including fish oil, oyster oil, dietary supplements, cosmetics, and pharmaceuticals, have been produced, advancements in processing technology and value addition in manufacturing have been relatively limited. Transitioning from small-scale to large-scale and industrial production is imperative to foster greater cooperation among participants along the mariculture value chain.

5.6. Opportunities and challenges for the mariculture industry in Vietnam

The development of mariculture in Vietnam is associated with both opportunities and challenges, as outlined in Table 4. Notably, the favourable environmental conditions present one of mariculture's significant advantages. Conversely, challenges can be categorised into several groups, including outdated technology across mariculture stages (from breeding and seed production to farming, processing, and distribution), the supporting industry, and logistical services for mariculture. The allocation of marine area usage rights to fish farmers under existing legal frameworks also presents a barrier to the industry's growth [11].

Table 4. Main opportunities and challenges of mariculture sector.

Opportunities	Challenges and obstacles
- Abundant natural resources and favourable conditions for mariculture development, including extensive sea areas, islands, and bays.	- Lack of comprehensive sea aquaculture planning and spatial marine planning at the local government level, leading to conflicts and overlapping among sea area users.
- A lengthy coastline spanning 3,260 km, encompassing 28 coastal provinces. These provinces collectively account for over 50% of Vietnam's population, offering potential markets and a source of labour for various aquaculture activities, including farming, processing, and logistical services.	- Complex and time-consuming allocation of usage rights for marine areas to fish farmers.
	- Concentration of mariculture activities in coastal areas.
	- Limited mariculture technologies, with small-scale production prevailing. The adoption of advanced technology and large-scale production remains limited.
- Increasing demand for seafood, driven by rising incomes in both global and domestic markets.	- Shortage of skilled labour in the mariculture sector.
	- Scarce, weak, and underdeveloped supporting and logistical services in the mariculture industry.
- Access to the high-demand seafood market in China, one of the largest seafood consumers globally.	- Growing environmental concerns, including issues such as plastic pollution, disease outbreaks, and ecosystem imbalances, associated with mariculture.
- Growing global recognition of mariculture's importance, with significant support and attention from both central and local governments. The sector is identified as a crucial component of Vietnam's ocean economy.	- High investment costs, particularly for offshore mariculture. Additionally, mariculture at sea is exposed to significant risks, including those related to climate change, storms, diseases, and price volatility for inputs and outputs. Supportive policies from authorities have been limited in addressing these challenges.

6. Conclusions

Vietnam, with its extensive coastline spanning over 3,260 kilometres and numerous islands and bays, possesses the ideal conditions for the development of mariculture. While the mariculture sector has shown substantial growth in recent years and has made significant contributions to the national economy, its potential remains largely untapped. The mariculture industry in Vietnam is still in its infancy and emerging stages, primarily concentrated in coastal regions, with limited offshore operations and predominantly small-scale, unorganized production.

Despite its potential, the mariculture sector faces several challenges that hinder its sustainable development. The adoption of advanced technology and cutting-edge practices in mariculture remains limited. Insufficient development of logistical services and supporting industries further impedes the sector's progress. Mariculture farmers contend with multiple risks, including climate change, disease outbreaks, volatile markets, environmental degradation, credit constraints, and various complexities.

To achieve sustainable development in mariculture, a range of policies and strategies must be promoted and implemented. Mariculture zoning and maritime spatial planning are crucial to prevent conflicts between sea activities, and the allocation of sea areas to fish farmers or organizations is a key challenge that needs to be addressed. Removing these constraints will provide partial encouragement and support for the industry's development.

Investment in high-tech solutions and scientific research for the mariculture sector should be encouraged and prioritized, given the limited adoption of advanced technologies. Workforce training is essential, particularly as the transition from small-scale to industrial-scale aquaculture models necessitates a highly skilled and experienced workforce. Collaboration in production, such as value chain-based production models, cooperatives, and groups, should be promoted and government-supported.

Furthermore, investment and credit programs should be established to incentivize farmers and businesses to invest in the mariculture sector, particularly in offshore areas. Investments should encompass breeding and hatchery operations, mariculture technology, processing and distribution, logistical and support services, and infrastructure development for mariculture activities, including seaports, markets, security, weather monitoring, and environmental observation stations. These measures, when implemented effectively, will help unlock the full potential of Vietnam's mariculture industry and contribute significantly to its sustainable growth and economic development.

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COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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