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Marine mollusk biodiversity in Northeastern Islands of Vietnam, impact factors and proposing conservation solutions

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ABSTRACT

A biodiversity and water-quality monitoring campaign was conducted in the Northeastern Archipelago of Vietnam, including Quang Ninh Province and Hai Phong, in 2017–2018. Mollusks are selected as the critical proxy indicator, and water-quality parameters are tested against National acceptability standards. The study revealed that, despite declining trends over the past two decades, mollusks are still highly diverse, with 647 species belonging to 227 genera, 95 families, and five classes (76% of all the species identified in the Tonkin Gulf). Of these, 253 species of 39 families (39% of the whole stock) are of high economic value, supporting an active trade in the region and thousands of livelihoods. Several species (abalone, blood cockle, green mussel, pearl oysters, Pacific oysters, double-headed clams, Asian hard clams, white clams, and squids) are intensively farmed. However, aquaculture still needs to be derdeveloped as capture from the wild is preferred. Water quality is unexpectedly high despite impacting factors such as urban development, industry, mass tourism, and demographic increase, mainly within the limits of acceptability set by the Government. Salinity, pH, and temperature are compatible with marine life, and a limited impact is represented by dissolved nitrates and suspended hydrocarbons in suspension. Despite favorable conditions of the aquatic environment, biodiversity decline has been a steady trend over the past decade. The causes are the urban encroachment over the coastal tract, the intertidal spawning grounds, breeding grounds, and nurseries, overexploitation, IUU fishing, lack of management, and failed establishment of conservation areas and MPAs. Spawning and breeding grounds identification and demarcation, their participated co-management, investments in environmental protection, technologies, and capacity building, and promotion of aquafarming of marketable species are among the measures recommended to be implemented with priority, to relieve the pressure over the wild stock and promote regeneration. The role of science in monitoring and detecting environmental changes guiding the adoption of proactive measures to prevent depletion and stock collapse, is the pathway to the sustainability of resource use and human well-being.

Keywords: Biodiversity, mollusks, Northeastern Archipelago Vietnam, marine resources exploitation.

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INTRODUCTION

Most managers and decision-makers do not consider marine biodiversity conservation a vital issue by. It is a concept that escapes comprehension to most because its detection is not often apparent; it implies decadal monitoring, and their outcomes, except for a few éclatan exceptions, are effectively disseminated outside academia's perimeter.

Preserving the wealth and the variety of species is fundamental to maintaining the integrity of habitats, ecosystems, and the environment. Healthy ecosystems provide human communities' for food security, health, wealth, and fuel services.

An ecosystem's effectiveness in providing services relies on biological diversity and equilibria among species; when altered, ecosystems become unstable, and straightforward functions such as fertilizing the soil, recycling nutrients, regulating pests and disease, controlling erosion, and pollinating crops and trees are disrupted.

A USAID development agency report lists the four main contributions of biodiversity conservation to balanced and sustainable development.

Biodiversity conservation protects plant, animal, microbial, and genetic resources for food production and security; it is vital for economic growth and poverty reduction (most impoverished communities live in rural areas and rely on natural resources for subsistence); it can help to address climate changes (greenhouse gases segregation) and may contribute in minimizing social conflicts (resource scarcity are often the root of conflicts).

Modern Vietnam faces challenges rooted in the developmental pressure on the environment (mainly marine) resulting from the past decade's vigorous economic growth. Overusing natural resources increased maritime traffic, urbanization, and industrialization have imposed an unprecedented threat on marine communities. While undeveloped tracts of the coastline are relatively preserved from impacts, more tangible effects are detectable in the proximity of urbanized and industrialized areas. However, these are yet to be objectively and verifiably documented.

Hot human impact and developmental pressure spots are the Tonkin sub-region, the central provinces, and the Ho Chi Minh area, including the Mekong Delta. The Tonkin sub-region, including the provinces Hai Phong, Quang Ninh, and the Northeastern Archipelago, has been monitored for over two decades, and a suite of species has been selected for distribution and abundance, revealing impacts on biodiversity. Because of their ubiquitous distribution, abundance, and diversity, mollusks proved to be effective indicators of long-range changes in the habitat, and results are herewith reported along with a discussion on the impact on the economy and human activities.

An archipelago of approximately two thousand limestone islands is located within the Quang Ninh and Hai Phong provinces' territory along the Western coast of the Gulf of Tonkin. The area has critical economic importance for the northern regions, being a historic mining district, a maritime commercial hub, a fishery of international relevance, and lately, an international tourist attraction: the Ha Long Bay archipelago was designated an UNESCO World Heritage site in 1996 and the Cat Ba Island, next to the Hai Phong harbor, a UNESCO Biosphere Reserve in 2003, triggering aggressive urbanization ever since.

The archipelago and its surrounding marine habitat have great natural-resource potential and are a primary National economic driver due to tourism. Despite severe threats impounding the area, the clusters of islands lingering off Ha Long-Cat Ba, the Co To-Thanh Lan, Ba Mun, and Tran Island, and the vicinities of Thuong Mai, Ha Mai, and Bach Long Vi have been assessed as sites of great conservation potential.

Because of the lack of a comprehensive and integrated management plan regulating the use of the resources, the development of the area, illegal and unregulated access, and overexploitation lead to a severe imbalance of species distribution and density and the decline of the biological diversity once existing in the marine environment.

Marine mollusks are a broadly distributed and diversified group of creatures in the shallow marine realm. Vietnam records at least 2,500 species [1], accounting for about one-fifth of all marine organisms identified along the coast of the Eastern Sea. The North-Eastern archipelago of Quang Ninh and Hai Phong alone account for 647 identified species, contributing significantly to Vietnam's marine biodiversity [2].

Even with their potential in biodiversity assessments, this taxonomic group's importance as an indicator of habitat health has been overlooked, such that the outcomes of long-term monitoring, species counts, and related statistics still need to be published. Decadal variations of species composition, density, and distributions over large sea tracts are primarily unreported in the literature.

This paper summarizes mollusk biodiversity data recorded over 15 years in the North-Eastern Archipelago of Vietnam. It is intended to document environmental changes in an area of remarkable environmental significance during the country's rapid economic growth and vigorous development, causing unprecedented threats to the marine realm and its biota.

The disclosure of long-term data series on the mollusk population of this marine tract aims to build a factual scientific basis supporting the formulation of conservation strategies for the future, the sustainable use of biological resources, and the delineation of management criteria for use by local administrators and decision-makers.

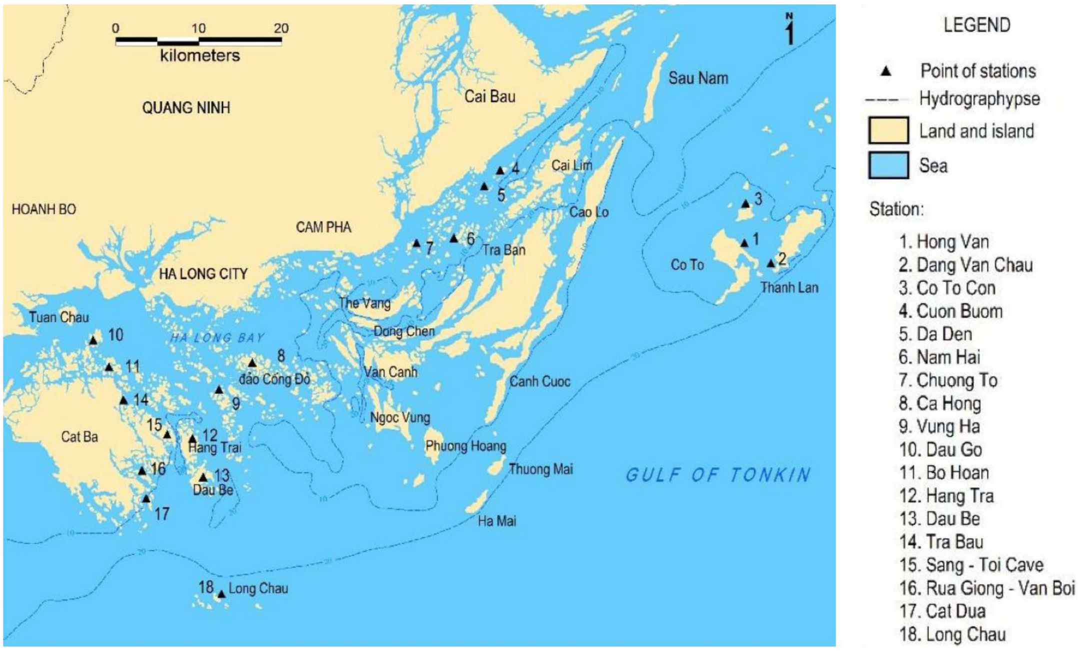

Figure 1. Location map of surveys and sampling stations in the Northeast Vietnam Archipelago

MATERIAL AND METHODOLOGY

The samples were collected during the dry season 2017–2018 (extending from November through April) and the rainy season 2018 (July through October). Surveys were carried out in December 2017 and August 2018).

Sampling stations were located in the Ha Long - Bai Tu Long Bays (Van Ha, Cong Do, Dau Go, Hon Da Den, Hang Te, Cat Chuong To, Dau Be, Bo Nau, Hang Trai, Bu Xam, Hon Tay Hoi, and Con Buom sites), and the Cat Ba-Long Chau area (Hang Sang, Van Boi, Gio Cung, Cat Dua, Long Chau Islands) (Fig. 1). Two hundred mollusk samples were collected during the December 2017 survey and 250 samples in August 2018.

Mollusk sampling techniques, preservation method, and mollusk classification

In the littoral area, where patchy unconsolidated sediment and hard coral substrate prevail, samples were collected in the upper to lower intertidal zone, following a transect perpendicular to the shoreline, using the method of [3–5].

Reconnaissance samples of bulk sediment intended for qualitative mollusk-specimen analysis were collected manually from the shallow seafloor; those selected for quantitative counts were collected from standard 40 × 50 × 15-cm plots using a frame and a sampling shovel. Deeper-water samples were collected using a Ponar dredge with an open mouth of 0.05 m^2, a 300 × 600 mm mesh, and a 50 × 80 cm skateboard.

On coral patch reefs and nearby peri-reefal areas, mollusk specimens for quantitative counts were picked up manually by SCUBA divers from the surface of a 1-square-meter-wide plot. The sampling spot and plot selection were guided by visual observation [3, 4].

Mollusk specimens were fixed in a 4%-concentration formalin solution and, after 24 hours, transferred to alcohol (70^o).

Mollusk classification was based on morphological and comparative anatomical characteristics, according to [6–8].

Analytical methodology for physico-chemical water parameters

Physico-chemical water parameters (temperature, pH, dissolved oxygen, salinity, and turbidity) were measured in situ with hand-held portable probes. BOD_5, COD, inorganic dissolved nutrients of nitrogen and phosphorus, total suspended solids, oil, and grease, and heavy metals, such as Cu, Pb, Zn, Cd, Hg, and As, and organochlorinated pesticides were measured in the laboratory, after storage at 4^oC.

In the water samples tested for inorganic nitrogen and phosphorus, chloroform and H_2SO_4 (1 mL/L) were added to dissolve nutrients before the analysis. Phosphates (P-$[PO_4]^{3-}$), nitrites (N-NO_2^-), ammonium (NH_3, NH_4^+), total nitrogen, and total phosphorus were determined by the colorimetric method.

The biochemical oxygen demand (BOD_5) was determined by the difference in dissolved oxygen concentration (DO) in the samples in the time interval of five days starting from sample collection. The dissolved oxygen was determined by the Winkler method [9]. The chemical oxygen demand (COD) was determined by the potassium permanganate ($KMnO_4$) method in an alkaline environment.

The total suspended solids were determined by filtering through filter paper with a pore size of 1mm, followed by drying and weighing the residue. The oil and grease in the water were determined by the colorimetric method after extraction with n-hexane. Heavy metals, such as Cu, Pb, Cd, Zn, Hg, As in water, were determined by ICP-MS equipment (Model ELAN DRC-e): the method's detection limit was 0.01 µg/L for each element [9].

Organochlorinated pesticides, including lindane, aldrin, dieldrin, endrin, 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT, were determined using an Electronic Capture Detector GC/ECD-HP 6890 gas chromatographer. External calibration was performed using lindane, aldrin, endrin, dieldrin, 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT standards. The method's recovery for individual standards ranges between 70.6% and 97.8%. The method's detection limit is 0.15 ηg/L for lindane and 4,4'-DDT and 0.10 ηg/L for the remaining compounds.

The seawater sampling and preservation methodology complied with APHA (2002) guidelines and Vietnamese standards[1].

Analyses of water-quality parameters were followed by the Vietnamese Government [10–12], based on APHA (2002).

RESULTS

Mollusk assemblages in the Northeastern archipelago of Vietnam

Overall, 647 species and 227 genera of mollusks were identified, belonging to 95 families and five classes (Table 1). Of the identified 647 species, 329 belong to Bivalvia,

[1]Document 5998-1995 (ISO 5667-9:1992) - Water-quality sampling - Guidance on seawater sampling. Document 6663-3-2016 (ISO 5667-3:2012) -Water-quality sampling- Preservation and handling of water samples.

followed by Gastropoda (284), Cephalopoda (19), Scaphopoda with eight species, and Polyplacophora with seven species.

The Northeastern archipelago of Vietnam is still among the areas with the highest mollusk diversity in the region. It records approximately 76% of all species identified in the Tonkin Gulf, based on the inventory by Hyllerberg [1], with taxonomic group counts summarized in Table 1.

Table 1. Taxonomic categories recorded in the Northeastern archipelago of Vietnam

Class name	Number of families	Number of genuses	Number of species
Polyplacophora	3	7	7
Scaphopoda	2	3	8
Gastropoda	48	91	284
Bivalvia	38	117	329
Cephalopoda	4	7	19
Total	95	225	647
Total number of species in the west of Tonkin Gulf, according to [2]		225	856

Statistics document that there is an average of 7 species per family. Based on species richness disaggregated per family, families can be subdivided into five categories.

Out of the 95 total, four families display an exceptionally high number of species (31–72) belonging to Veneridae (72 species), Muricidae (35 species of the Murex genus), Mitilidae (31 species of mussels), and Arcidae (31 species).

Eight families are represented with a few species ranging from 15 to 31, with the Tellinidae family leading the group (27 species), followed by Nassariidae (21 species of Nasa snails), Trochidae (20 species), Cardiidae (19 species of the cockle group), Naticidae (18 species), Cerithiidae (16 species), and Neritidae (15 species of nerite snails).

Fourteen families displayed a number of species ranging between 7 and 14. These are in descending order: Cypraeidae (14 species, including the cowries snails), Psammobiidae (sunset clams, 13 species), Conidae and Ostreidae, (13 species each); Pectinidae (12 species); Strombidae (true conchs) and Mitridae (11 species each), Solenidae and Pholadidae (10 species), Littorinidae, (intertidal periwinkle snails), Pteriidae (pearl oysters), and Pinnidae (9 species), Sepiidae (8 species) and Turbinidae (7 species of turban shells).

The remaining 69 families represented in the Northern archipelago record a species number ranging from 1 to 6.

The statistics show that only 26 families out of 95 account for 90% of the total species living in this sea. The high convergence of species in this group of families makes it possible to regenerate the resources when they are in decline.

Habitat definition and mollusk distribution per habitat types

Regarding species diversity, a distinctive mollusk distribution characterizes each habitat type and substrate compositional and textural attributes [10–13]. The diversity of benthic assemblages in this area determines the high convergence of most of the Tonkin Gulf mollusks.

Three habitat types have been identified in the Northeastern archipelago:

The reefal and peri-reefal coral patches;

The subtidal soft, muddy substrate;

The high-energy intertidal littoral environment (sand and muddy sand).

Mollusk counts reveal that reefal habitats record the highest species diversity while sandy beaches have the lowest.

In the reefal and peri-reefal habitats, over 400 species have been identified, with predominant *Ostrea* spp., *Cerithium* sp., *Nerita albicilla*, *Lunella coronata*, *Septifer bilocularis*, *Brachidontes senchousei*, *Tectorius granularis*, *Thais echinata*, *Trochus* spp., *Morula* *foniculus*, *Cellana toreuma*, *Planaxis sulcatus*, *Spondylus nicobaricus*, *Ostrea mordax*, and *Ostea glomerata*. Most species of the Mytilidae family live in reefal and peri-reefal habitats.

On a soft, muddy substrate, about 300 species were sampled, prevailing in the lower intertidal zone. The most representative groups belong to the Bivalvia families of Pinnidae, Arcidae, Cardiidae, Spondylidae, Veneridae, to the Gastropoda families of Muricidae and Trochidae, and Scaphopods Cephalopoda.

High-energy sandy beaches host a limited number of specialized species (25–50), with prevailing, in order of abundance, *Meretrix meretrix*, *Meretrix lusoria*, *Sanguinolaria diphos*, *Paphia literata*, *Strombus* spp., *Heliacus variegatus*, *Cerithidea cingulata*, *Anadara granosa*, and *Meretrix lyrata*.

Hydro-chemical and physical properties of the seawater in the Northeastern Archipelago

The seawater temperature within the archipelago ranged from an average of 20.6°C at the climax of the dry season (December) to an average of 31.8°C during the rainy (summer) season (August). The northern Bai Tu Long Sea tracts recorded the most extensive excursion of over 10°C.

The pH value ranged from 7.85 to 8.07 units, with no variability recorded among areas and between seasons.

Water salinity in Bai Tu Long Bay recorded the lowest value (23.7‰) during the rainy season due to the freshwater runoff from inland, while around Cat Ba island, where continental runoff is minimal, maximum values of 30.1‰ were recorded during the dry season. At all stations during the dry season, the salinity was high and stable, with an average value of 29.3‰. During the rainy season, the salinity systematically decreased, fluctuating values depending upon the intensity of the continental runoff (average values of 24.9‰).

Table 2. Average value of water-quality parameters in the three main sectors of the Northeastern Archipelago of Vietnam (Ha Long, Bai Tu Long, and Cat Ba) during the dry season 2017 (December) and rainy season 2018 (August)

Parameters	Dry season (December 2017)			Rainy season (August 2018)		
	Ha Long Bay (*n* = 11)	Bai Tu Long bay (*n* = 4)	Cat Ba Island (*n* = 8)	Ha Long bay (*n* = 12)	Bai Tu Long bay (*n* = 10)	Cat Ba Island (*n* = 8)
Temperature, °C	21.15 ± 0.69	20.63 ± 0.25	21.2 ± 0.35	31.83 ± 0.68	31.25 ± 0.43	31.0 ± 0.37
pH	7.96 ± 0.15	7.92 ± 0.06	8.07 ± 0.10	7.85 ± 0.25	7.99 ± 0.07	8.00 ± 0.09
Salinity (‰)	28.5 ± 5.5	29.3 ± 0.58	30.1 ± 0.35	23.8 ± 5.9	23.7 ± 1.75	27.3.1 ± 1.52
Turbidity (NTU)	2.8 ± 2.0	2.3 ± 3.7	2.5 ± 1.6	2.9 ± 1.7	3.3 ± 1.7	2.4 ± 0.6
DO, mg/L	6.65 ± 0.21	6.51 ± 0.08	6.54 ± 0.35	6.47 ± 0.47	6.10 ± 0.55	6.29 ± 0.66
BOD5, mg/L	1.96 ± 0.42	2.25 ± 0.41	1.73 ± 0.19	1.66 ± 0.09	1.62 ± 0.10	1.69 ± 0.09
COD, mg/L	2.64 ± 0.64	2.92 ± 0.36	2.40 ± 0.18	2.53 ± 0.21	2.33 ± 0.19	2.32 ± 0.14
N-NO_2^-, µg/L	27.89 ± 10.55	8.33 ± 1.26	38.03 ± 8.49	23.19 ± 5.94	10.85 ± 1.66	15.22 ± 7.78
N-NO_3^-, µg/L	43.28 ± 12.96	39.20 ± 2.73	44.67 ± 7.14	35.70 ± 7.56	52.63 ± 13.68	54.09 ± 7.03
N-NH_4^+, µg/L	37.61 ± 19.27	22.83 ± 2.37	38.15 ± 14.48	49.69 ± 5.36	33.81 ± 8.25	41.69 ± 6.85
P-PO_4^{3-}, µg/L	38.07 ± 7.73	36.14 ± 4.40	129.75 ± 10.94	18.70 ± 3.21	20.83 ± 3.58	21.89 ± 5.55
N-T (mg/L)	0.76 ± 0.17	0.70 ± 0.15	1.92 ± 0.11	1.03 ± 0.32	0.81 ± 0.24	1.93 ± 0.36
P-T (mg/L)	0.37 ± 0.33	0.60 ± 0.03	0.64 ± 0.33	0.11 ± 0.03	0.07 ± 0.02	0.61 ± 0.18
Oil and grease, mg/L	0.19 ± 0.06	0.26 ± 0.05	0.23 ± 0.03	0.19 ± 0.05	0.16 ± 0.07	0.19 ± 0.03
Cu, µg/L	59.50 ± 21.65	73.63 ± 5.48	74.77 ± 9.28	25.38 ± 9.82	25.04 ± 7.08	22.95 ± 2.49
Pb, µg/L	1.56 ± 1.47	0.27 ± 0.06	0.31 ± 0.23	0.89 ± 0.39	4.73 ± 5.38	0.61 ± 0.61
Zn, µg/L	18.35 ± 8.43	15.24 ± 2.89	11.35 ± 0.56	29.51 ± 5.48	25.86 ± 6.37	22.59 ± 9.86
Hg, µg/L	0.34 ± 0.17	0.25 ± 0.06	0.19 ± 0.05	0.23 ± 0.17	0.16 ± 0.12	0.12 ± 0.03
Total OCP, ng/L	4.33 ± 4.74	2.68 ± 4.64	4.69 ± 4.43	1.75 ± 2.05	0.35 ± 0.68	2.56 ± 1.72

Notes: OCP, Organo-Chlorinated Pesticides; n, number of samples.

Seawater turbidity is, in general, relatively low, ranging from 2.3 to 3.3 Nephelometric Turbidity Units (NTU). Turbidity systematically increased during the rainy season due to increased suspended load from continental runoff and storm impact on the shallow seafloor.

Dissolved oxygen in the water and related organic content

Dissolved oxygen (DO) concentration in the archipelago's seawater was relatively high, ranging between 6.10 and 6.65 mg/L, with an average value of 6.56 mg/L during the dry season and 6.26 mg/L in the rainy season. Biochemical Oxygen Demand (BOD) was in the range of 1.62–2.25 mg/L, and the Chemical Oxygen Demand (COD) was in the range of 2.32–2.92 mg/L. Comparing COD values in the different areas of the archipelago revealed that Cat Ba waters, showing the lowest values, have lesser amounts of oxidizable pollutants than anywhere else.

The highest recorded values are in the Bai Tu Long Bay during the dry season and the Ha Long Bay during the rainy season, showing effluents' effects from the urbanized and industrialized areas.

Nutrients content in the seawater in the Northeastern archipelago

The nitrite concentration ranged from 8.33–38.03µg/L, with the highest average value in Cat Ba Island. The nitrates ranged from 35.70–54.09 µg/L, with extreme values in the polluted waters of Cong Do (in Ha Long Bay), Cat Chuong To (in Bai Tu Long Bay), Cat Dua (Cat Ba area).

The ammonium concentration varied strongly from 22.83–49.69 µg/L, and the phosphates ranged from 18.70–129.75 µg/L. The total nitrogen concentration ranged from 0.70–1.93 mg/L, the highest values detected in the Cat Ba area, both in the rainy and dry seasons.

The total phosphorous concentration ranged from 0.07–0.64 mg/L, remarkably higher in the dry season (December 2017) in Ha Long Bay and Bai Tu Long Bay.

Pollutants

The seawater's oil and grease content in the archipelagos ranged from 0.19–0.26 mg/L at most sampling points.

Four heavy metals, such as Cu, Pb, Zn, and Hg, were measured, and absolute values were relatively low: Cu ranged from 22.95–74.77 µg/L; Pb, from 0.27–4.73 µg/L; Zn, from 11.35–29.51 µg/L), and Hg, from 0.12–0.34 µg/L. No systematic variations were noted in the three investigated areas and sampling stations.

The total residue of organochlorinated pesticides (OCPs) showed extremely low values, ranging from 0.35–4.69 ng/L, denoting negligible contamination of the archipelago seawater from agricultural effluents.

Economic implications of mollusk biodiversity assessment and conservation issue

The mollusk is one of Earth's most widely distributed taxonomic groups, inhabiting virtually all aquatic, terrestrial, marine, and freshwater environments. Mollusks are a highly diversified group of creatures; they are essential ecosystem engineers in shaping their habitats, providing a structure to the seafloor, and representing a food source for various other taxa.

Not only critical climatic indicators and proxies to environmental changes, but mollusks have also been vital to humans for millennia and economically important as food. When farmed, mollusks may provide subsistence for a range of small-scale artisanal fishers and become primary drivers of coastal regions' economies.

Mollusk species of remarkable economic value

In the Northeastern archipelago of Vietnam, mollusks are essential commodity, supporting local coastal communities' livelihoods and economy. They are exploited for human consumption, feed for cattle and poultry, shrimps, crabs, and farmed fish.

Based on local market analysis, our research has reckoned that 253 mollusks belonging to 39 families are of high economic value, traded nationally on most coastal markets, and sold for export. These represent 39% of the total number of known species in this area (Table 3).

Table 3. Mollusk's families with economic value in the Northeastern archipelago of Vietnam (sorted in descending order of abundance)

No.	Scientific name	Vietnamese vulgar name	English vulgar name	Number of species with economic value
1	Veneridae	Họ ngao	Venus clams	56
2	Trochidae	Họ ốc đụn	Top shells	20
3	Neritidae	Ốc đĩa	Nerites	15
4	Psammobiidae	Họ phi	Sunset clams	13
5	Naticidae	Ốc mỡ	Moon snails	12
6	Strombidae	Ốc nhảy	True conchs	11
7	Arcidae	Họ sò	Ark clam	9
8	Pectinidae	Sò pecten	Scallops	9
9	Pinnidae	Bàn mai	Pen shells	8
10	Sepiidae	Mực nang	Cuttlefish	8
11	Solenidae	Móng tay	Razor shells	7
12	Turbinidae	Ốc Tu bô	Turban snails	7
13	Muricidae	Ốc gai	Murex shells	6
14	Pteriidae	Trai ngọc	Pearl Oyster	6
15	Cardiidae	Sò nứa	Cockles	6
16	Mactridae	Họ vọp	Duck clams, Mactras	6
17	Tellinidae	Họ den	Tellins	5
18	Ostreidae	Họ hàu	Osters	5
19	Patellidae	Ốc vú nàng	True limpets	4
20	Cerithiidae	Ốc mút	Ceriths	4
21	Octopodidae	Bạch tuộc	Octopus	4
22	Cassididae	Ốc tù và	Helmet shells	3
23	Nuculanidae	Nghêu cánh dài	Yoldias clams	3
24	Loliginidae	Mực ống	Pencil squids	3
25	Sepiolidae	Mực xim	Bobtail squid	3
26	Lucinidae	Ngó	Lucina clams	3
27	Placunidae	Điệp giấy	Windowpane oysters	2
28	Nuculidae	Nghêu thân cao	Nut clams	2
29	Mytilidae	Vẹm	Sea Mussels	2
30	Corbulidae	Don	Corbulas clams	2
31	Cymatiidae	Ốc cymat	Tritons	1
32	Personidae	Ốc nhảy vùng triều	Distorsio shells	1
33	Charoniidae	Ốc tù và	Triton's trumpet	1
34	Melongenidae	Ốc melo	Crown conch	1
35	Solecurtidae	Họ phi	Solecurtus clams	1
36	Carditidae	Sò trái tim	Carditas clams	1
37	Laternulidae	Ngao đèn lồng	Lantern clams	1
38	Semelidae	Ngao nhọn	Semele clams	1
39	Glaucomyidae	Dắt	Glaucomyids clams	1
	Total species			253 species

Of the 253 species, 87 are Gastropoda, 150 are Bivalvia, and 18 are Cephalopoda. All edible species are generally threatened by overexploitation if conservation policies are not implemented and enforced. Those of higher market value (*Venus* clams, Top shells, *Nerites*, sunset clams, moon snails, true conchs, oysters, clams of the Ark family, and green mussels) are particularly vulnerable so that population density and signs of decline should be monitored. The duck clam (Mactridae) family has a few species, but these are highly valued; therefore, the natural populations are overexploited. The high production of duck clams comes from aquaculture.

Mollusks are not only targeted for human consumption; their shells are used as raw material to produce traditional handicrafts, delicate art objects, and pearls, posing an additional threat to natural populations. In the local markets of coastal provinces, these objects are from the shell material of 54 distinctive species that might soon become endangered because of high demand. Among them, some species of exceptionally high economic value, such as *Haliotis diversicolor* (abalone), nowadays almost exhausted in the wild but being cultured in Bach Long Vi and Co To with high yields.

Moreover, natural populations of juvenile mollusks are depleted to support aquaculture. Blood cockle (*Anadara granosa*) is widely distributed in the wild but actively captured as broodstock in aquaculture. Similarly, are the Asian green mussel (*Perna virdis*), the pearl of Marten (*Pinctada martensii*), pearl oyster (*Pinctada margaritifera*), Pacific oysters (*Crassostrea gigas*), double-headed clam (*Tapes dorsatus*), poker chip clam (*Meretrix meretrix*), white clam (*Meretrix lyrata*), snout otter clam (*Lutraria rhychaena*), and squid (*Loligo beka*).

Mollusk fishing capacity in the Northeastern Archipelago and production data

Because of flaws in monitoring and objective difficulties in acquiring data from an insular population of small-scale artisanal fishers, there have not been any accurate statistics on fishery resources and mollusk catch. Therefore, managing activities sustainably and controlling overexploitation needs to be improved. Neither our consultation with critical informants nor data from the Provincial Department of Fisheries proved to be a reliable assessment.

The Quang Ninh and Hai Phong produce over 10,000 and 4,000 tons of clams from the Northeastern archipelago, respectively. Moreover, another 6,000 tons of unspecified shellfish are added from the two provinces, plus 390 tons of scallops and 300 tons of oysters.

Cephalopoda, primarily squids and cuttlefish, represent another substantial item of the total production, with a catch from Bach Long Vi and Co To fishing grounds totaling approximately 14,000 tons.

Production statistics from aquaculture are virtually lacking, being activities escaping any attempt at monitoring and control. Aquaculture impacts, to a large extent, also the natural populations that are the source of fingerling and broodstock.

Species that can be farmed in the Ha Long and Cat Ba areas include blood cockles, oysters, clams, and boring clams. Pearl oysters are reared in Co To, Thanh Lan, Ha Long, and Cat Ba, while abalone is farmed in Bach Long Vi, Co To, Thanh Lan, and snout otter clams are raised in Cat Ba and Ha Long Bay.

Nowadays, the Pacific oyster and double-headed clam are the primary cultured species in the insular communes of Quang Ninh, following market demand.

DISCUSSION

Threat assessment: significance and methodology

Immediate use of biodiversity data relates to the support of the local economy from the sustainable use of biological resources in the long term. Mollusk biodiversity in the Northeastern Archipelago is a sensitive issue because mollusk trade is one of the primary livelihoods and source of income, and mollusk biodiversity data provide indicators for overall environmental degradation. Moreover, the Northeastern archipelago has undergone unprecedented developmental pressure changes, urbanization, vigorous industrialization, and mass tourism in the last two decades, inevitably causing stress in the marine environment.

To quantify the relevance of mollusk trade in the Quang Ninh and Hai Phong area to serve the whole country and the export, we visited major local mollusk trading hubs in Tien Yen, Cam Pha, Ha Long City and Cat Ba, Hai Phong, and the volumes marketed are startling if compared to the limited acreage of the fishery (*cfr. supra*). We also collected data on mollusk exploitation and production data from farming enterprises from the provincial Departments of Agriculture and Rural Development of Quang Ninh Province and Hai Phong.

To assess the stress on the biological stock and threats to its sustainable use in the long term, we tested the quality of seawater around the islands of the archipelagos against the specifications provided by the National Technical Regulations on Marine Water Quality for the protection of aquaculture and aquatic life [11], and the Vietnam Standard for Surface Water Quality [12]. The results are summarized in Thung D. C. et al., (2018) [14].

Also, ASEAN criteria [15] were used to evaluate the potential impacts of water quality parameters not listed in the National Technical Regulation documents.

Within these regulatory frameworks' perimeter, the water-quality risk quotient (RQ) was calculated following Jheng Jie Jiang et al., (2015) [13].

The risk quotient RQ_i relating to pollutant "*i*" equals the concentration of pollutant "*i*" divided by its upper limit allowed concentration as per norms. If the *RQ* value is less than 0.75, the water is considered by convention not contaminated; for values comprised between 0.75 and 1, the water is at risk of contamination, and for values of *RQ* above 1, the water is contaminated. The *RQ* value is calculated for every potential pollutant revealed by the analysis.

Risk Quotient (*RQ*) based on water quality in the Northeastern Archipelago

Despite the number of anthropic hazards affecting the Northeastern archipelago's enclosed sea tract, water quality is maintained well within the range of National safety parameters for all the pollutant species.

Data from the dry season samples (December 2017) display an average value of 0.32 for the whole area. The *RQ* values range between 0.29 recorded in the Bai Tu Long Bay and 0.36, in the platform around Cat Ba Island, with a value of 0.31 in the area in between (within Ha Long Bay).

The *RQ* values are relatively constant in the rainy season due to adequate mixing by storm waves and wind, with 0.27 in Bai Tu Long Bay and 0.28 in the Cat Ba Island Sea tract.

More specifically, concerning dissolved organics, Bai Tu Long Bay and Cat Ba Island waters are at risk of nitrate pollution during the rainy season.

The *RQ* average for all the archipelago areas and all pollutant species in the season 2017–2018 was 0.278.

With such low *QR* values, pollutants dispersed in the Northeastern archipelago waters from industrial hubs and urban centers will not significantly affect marine organisms' lives. Therefore, the reasons for biodiversity loss in the bays must be sought into other, more subtle, and fundamental reasons.

Causes of biodiversity loss in mollusk populations

Due to the province's economic development, aggressive tourism demand for accommodation, and the encroachment of people's settlements along the coast of the bays, the floodplain is rapidly shrinking, and so is the platform surrounding the limestone islands of the archipelago. Economic activities along the shore have reclaimed land, pushing breeding grounds offshore. For these reasons, for instance, the dense populations of blood cockles thriving offshore Bai Chay and Cai Dam along the coast of Cam Pha (Quang Ninh) have almost entirely vanished.

The overuse of chemical fertilizers and pesticides in agriculture has been causing past episodes of mass mortality and even some rare species' disappearance in the region. Effective control by authorities over effluents, demonstrated by the survey's suitable water-quality parameter, limits the negative impacts on the biota, that has been badly depleted over the years.

Mangrove deforestation to make space for aquaculture ponds altered the shallow shoreface. As a result, ecological niches and local nurseries have disappeared, causing habitat degradation where most benthic species live. It is a general phenomenon characteristic of the past decades of aggressive aquaculture development. It affects not only Quang Ninh and Hai Phong but also large tracts of the country's coastline, causing a generalized decline of habitat and marine livestock.

Finally, the destructive methods still used to catch fish from the wild (e.g., electro-fishing) and IUU fishing ultimately affect a vast range of marine creatures indiscriminately, killing juveniles and disrupting the food chain. Consequences are severe for the whole ecosystem, and mollusks are the taxonomic groups that are impacted the most. Electro-fishing and overexploitation have emblematic consequences in the shallow shoreface of Con Hai sand beach, where locals' pervasive uncontrolled capture depletes seed sources, causing the virtual disappearance of once extensive mollusk colonies.

Biodiversity conservation: Management strategies and objectives for sustainable resource utilization

The analysis of biodiversity data and water quality invariably demonstrated that pollutants are not responsible for biodiversity loss recorded in the mollusk taxonomic group in the last decade. Other than mere effluent discharge, a range of other human activities has impacted marine life, with a remarkable decrement in species and a severe threat to economic activities relying on food production and biological resources trade.

Stricter control of these human activities is recommended to revert the decline trends, which might manifest adverse economic effects in the short term. Herewith are listed some management measures to be undertaken with priority to reveal their beneficial effects over the biota composition, the food security of the region, and the fisherfolks' livelihoods.

Developing management plans for mollusk spawning grounds: Currently, six unmanaged mollusks breeding grounds are of primary importance along the shores and around the islands of the Quang Ninh Province and Hai Phong [14]. These seed yards have not been under the management responsibility of any agencies, resulting in the illegal, unregulated, and unreported exploitation of juveniles. This practice, persisting for years, has depleted the populations of adults of market size for some species now at risk of extinction, such as blood cockles (*Anadara granosa*), oysters, and Lucina clams (*Austriella corrugata*).

The responsible authorities should develop and implement a management plan for breeding ground, envisioning demarcation, regulated access, monitoring, surveillance, and control to prevent IUU fishing and further depletion. A co-management system should be considered, with a clear definition of resource-users rights and responsibilities and sanctions for violators prescribed by law. Where necessary, a moratorium, either limited to spawning and breeding seasons or extended for extended periods, should be established to promote the dispersal of juveniles and natural repopulation.

Particular attention should be paid to the protection and reforestation/afforestation of mangrove swamps and intertidal flats, typical sanctuaries of most marine species.

The study of technological solutions for protecting sensitive habitats and the designation of conservation areas for specific cultivars and broodstock survival should be a task of research institutions. The same entities should be assigned monitoring responsibilities closely with local public administrations and decision-makers for proactive interventions whenever needed.

Increasing investments for natural resources protection: The biota protection measures should be framed into a broader-scope development plan for the Northeastern archipelago that puts nature conservation, landscape (including urban) valorization, ecosystem, and habitat enhancement for the objective of the well-being of residents and visitors. This overall plan, particularly appropriate for a UNESCO World Heritage site hosting millions of tourists yearly, should consider more substantial investments in ecosystem-compatible infrastructures and capacity-building for personnel. Strengthening public administrators' and decision-makers' management capacity through the empowerment of Management Boards is of utmost importance for a location of international appeals, such as the Ha Long Bay Heritage, the Cat Ba Biosphere Reserve, and the Cat Ba - Bai Tu Long National Park (Cat Ba, Bai Tu Long).

The Government has approved the list of marine protected areas (MPAs) in the Northeaster archipelago (e.g., Bach Long Vi, Cat Ba, Co To, and Dao Tran waters). It should be implemented soonest with appropriate finance and personnel.

Developing and piloting a co-management scheme: Adopting a co-management scheme is recommended considering the severe depletion of the mollusk stock in the archipelago and the latent need for a regulatory framework to access it sustainably. Co-management and shared responsibilities comply with two complementary principles, according to which resource management should be realized according to a uniform code of conduct governed by state laws, and fishers' communities should have the opportunity to self-regulate their access to the common-pool resources. That means a mechanism that envisions a partnership between local authorities and the professional associations of citizens (i.e., the fishers' association), ensuring that these are granted legal rights to exploit and duties to protect their assigned area. This mechanism will create enhanced resource stocks and, ultimately, higher user economic benefits. A prerequisite for successfully implementing a co-management scheme is law compliance, effective monitoring, and sanctioning violations.

Promoting aquaculture by expanding areas of mollusk farming: Collecting mollusks from the wild is a preferred practice rather than farming, generating unnecessary stress on the stock. A more labor-intensive activity, raising high economic value species such as abalone, snout otter clam, Pacific oyster, blood cockle, and double-headed clam, once set up and running, would instead be able to generate higher income for fishery entrepreneurs. Not requiring substantial investments and the deployment of sophisticated technology, with appropriate credit-access policies, could be accessible to most, significantly reducing the pressure on the wild stock and promote rapid regeneration of the resource.

SUMMARY AND CONCLUSIONS

A monitoring campaign in 2017–2018 aimed to document the distribution, abundance, and species diversification of one of the critical taxa - the mollusk - an indicator of environmental quality revealed that the Northeastern Archipelago of Quang Ninh and Hai Phong is a sanctuary for biodiversity counting over the 76% of all species in the Tonkin Gulf. Biodiversity remains relatively high, with 647 species, 227 genera belonging to 95 families, and five classes.

Water quality parameters, notwithstanding the past two decades the vigorous economic development of the coastal region, in terms of industrialization, expansion of the urban areas, and mass tourism, revealed levels of pollutants well below the threshold of acceptability set by the Government and international standards, and overall safety conditions for humans and marine living creatures.

Despite these favorable conditions, there has been a biodiversity decline over recent years, indicating that environmental stress impacts marine life, probably not only the mollusks used as a proxy.

Hazards have been identified in the urban encroachment over the coastal tract and the intertidal spawning and nursing grounds, mangrove deforestation, lack of management responsibilities over the marine realm within the archipelago, and the program of MPA establishment still need to be fully implemented.

There is a latent need for the coastal sea tract where marine life regenerates, envisioning a share of responsibilities between the authority and the resource users to prevent resource overexploitation, IUU fishing, and promote and ban destructive fishing methods.

A few urgent interventions are recommended to revert declining trends, which might jeopardize thousands of livelihoods and a traditional fishery economy based on mollusk production. Notably, 253 species among 39 families (39% of all species present) are economically valuable and support the most profitable fishery trade in the region.

Recommended priority measures are:

Developing management plans for mollusk spawning and nursing grounds, with clear objectives and set goals;

Establishing the approved MPAs in the archipelago;

Deploying investments in environmental protection, technologies, and capacity of local managers within the frame of an overall integrated master plan for the archipelago, subject to an increasing impact of mass tourism and hospitality demand;

Set up a co-management scheme for biodiversity conservation areas and MPAs;

Promote aquaculture to relieve pressure on the wild stock.

Given the impending impacts of a deteriorating climate, there is a need to implement further routine monitoring to detect changes and trends against past datasets timely. The project, which this paper is a synthesis of, established an environmental, water quality, and biodiversity database for the Northeastern Archipelago, which, if used as a prescriptive tool, may guide future decisions toward resource use and human-life sustainability.

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