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Diversity of dinoflagellates in the Northern Vietnam coastal waters

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ABSTRACT

Phytoplankton were investigated within the framework of the Vietnam's coastal water quality monitoring program. The present study analyzed phytoplankton samples collected in the northern Vietnam coastal waters (Tra Co, Cua Luc, Do Son, Ba Lat, Sam Son and Cua Lo stations) from 2019 to 2022 to characterize diversity and abundance of dinoflagellate communities. A total of 129 species belonging to 35 genera, 23 families, 8 orders, and 2 classes of dinoflagellates were recorded in this study area. The diversity of dinoflagellates varied depending on the sampling locations and times. *Tripos furca* was recorded as the most dominant and common species (accounting for approx. 93% of the samples) in the dinoflagellate communities throughout the year. The density of dinoflagellates and *Tripos furca* varied strongly by sampling locations, times, and tides. This species seems preferable and grows with high density in the study area from June to September. Among water environment factors, salinity had the strongest correlation with the density of *Tripos furca* depending on the sampling locations and the tides.

Keywords: Dinoflagellate, phytoplankton, Northern Vietnam, coastal waters, diversity.

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INTRODUCTION

The northern coastal zone of Viet Nam from Tra Co (Quang Ninh Province) to Cua Lo (Nghe An Prov.), with a coastline length of about 522 km, is an area influenced by several of rivers such as Ka Long River (Quang Ninh Prov.), Bach Dang and Van Uc Rivers (Hai Phong Prov.), Red and Thai Binh Rivers (Thai Binh Prov.), Ma river (Thanh Hoa Prov.), and Ca River (Nghe An Prov.). Hence, the characteristics of the water environment in the area change strongly in seasons due to seasonal changes in climatic factors, meteorology, river hydrology, etc. Besides, the environment of the waters is also strongly influenced by human activities such as industrial, agriculture, tourism, and service activities. Therefore, monitoring and assessment of coastal water environment quality (including plankton and benthos) has been carried out from 1995 to the present within the framework of the national environmental monitoring station system managed by the Ministry of Natural Resources and Environment (MONRE).

Dinoflagellates are unicellular or forming colony, eukaryotic, two flagella organisms, including photosynthetic (accounting for about 40–60% of the total number of approx. 4,000 modern and fossil species described as of the late 1970s) (Taylor, 1987) [1] and heterotrophic, free-living or symbiotic species. Among the earliest studies on dinoflagellates in the Viet Nam Sea, notable were the works of Hoang Quoc Truong (1963) [2], Shirota (1966) [3], studying phytoplankton communities in Nha Trang Bay and the South-East coastal waters of Vietnam, reporting 92 and 102 dinoflagellate species in these waters, respectively. However, the species lists were not updated with synonyms, and many species were still uncertain about their identification in previous studies. The studies of dinoflagellates in Vietnam had been increasing since the late 1990s, with notable publications on morphological descriptions of species such as Nguyen-Ngoc et al., (2012) on the genus *Ceratium* (*Tripos*) in the coastal waters of Vietnam [4]; Larsen and Nguyen-Ngoc (2004) on potentially harmful dinoflagellate species in coastal Viet Nam [5]; Phan Tan et al., (2016, 2017, 2024) [6–8]; Phan Tan Luom (2020) described species of the genus *Protoperidinium*[9] ; Nguyen-Ngoc et al., (2021) described species of the benthic genus *Ostreopsis* collected in Vietnam [10]; Nguyen-Ngoc et al., (2022) on seasonal variation of potentially toxic armored dinoflagellates in Nha Trang Bay [11]. Besides, dinoflagellate species have been recorded as an important component in the phytoplankton communities in some coastal areas of Viet Nam such as Nguyen Hoang Minh et al., (2012) [12]; Chu Van Thuoc et al., (1997, 2004, 2012, 2014) [13–16]; Huynh Thi Ngoc Duyen et al., (2021) [17], etc. The study on the genus *Tripos* (*T. furca* and *T. fusus*) ecology in the South-Central waters of Vietnam was recently published by Huynh Thi Ngoc Duyen et al., (2022) [18]. However, limited studies still focus on the dinoflagellates in the East Vietnam Sea and the Northern Vietnam coastal waters. This paper presents the variation of the dinoflagellate communities from 2019 to 2022 in the Northern Vietnam coastal waters.

MATERIALS AND METHODS

Study area

Table 1. Coordinates of the sampling stations

No.	Name of station	Latitude	Longitude
1	Tra Co (Quang Ninh Prov.)	21°25′50′′N	108°01′58′′E
2	Cua Luc (Quang Ninh Prov.)	20°57′00′′N	107°03′30′′E
3	Do Son (Hai Phong City)	20°43′00′′N	106°50′00′′E
4	Ba Lat (Thai Binh Prov.)	20°15′00′′N	106°36′00′′E
5	Sam Son (Thanh Hoa Prov.)	19°43′42′′N	103°53′57′′E
6	Cua Lo (Nghe An Prov.)	18°49′36′′N	105°43′00′′E

Phytoplankton samples were collected at 6 stations in the Northern Vietnam coastal waters, namely Tra Co, Cua Luc (Quang Ninh Province), Do Son (Hai Phong Prov.), Ba Lat (Thai Binh Prov.), Sam Son (Thanh Hoa Prov.), and Cua Lo (Nghe An Prov.). The sampling station coordinates are showed in Table 1 and Figure 1. The study was carried out in 4 years from 2019 to 2022. In each year, the sampling was conducted in March (hereinafter referred to as the first quarter of the year), June (referred to as the second quarter), August or September (referred to as the third quarter), and October or November (referred to as the fourth quarter).

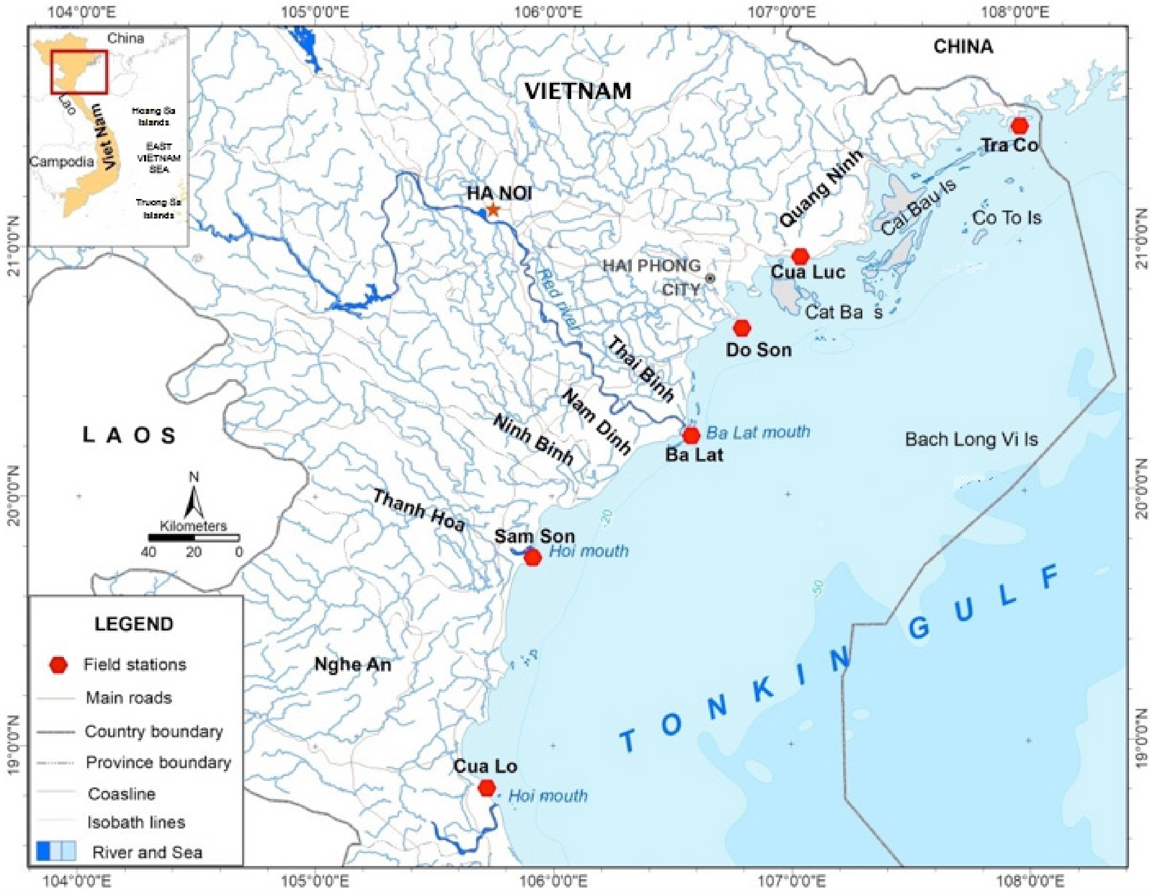

Figure 1. The locations of sampling stations

Sampling and sample analysis

The sampling of phytoplankton in the field followed Sournia (1978) [19], protocols of the Institute of Marine Environment and Resources (2014) [20], and Reguera *et al*. (2016) [21]. At each sampling station, qualitative samples were collected using a cone-shaped phytoplankton net with a mesh size of 20 µm, pulled vertically from the bottom to the surface several times at high and low tide. Quantitative samples were collected using a Niskin water sampler with a 1–2-liter volume at the surface and near bottom layers. Then, the samples were fixed immediately with Lugol solution (approx. 4 mL Lugol/L or more, depending on the concentration of the samples).

Water environment parameters, including salinity, temperature, pH, and dissolved oxygen (DO), were measured *in situ* with portable measurement meters such as Atago S/Mill-E refractometer (Japan), Exrech pH meter (USA) and YSI-55 Pro DO meter (USA) at the same time of collecting phytoplankton samples.

Sample analysis: The qualitative samples were brought to the laboratory for species composition analysis. A small sample was put it on a slide using a pipette and observed at magnification 100–1000x under the fluorescence microscope - OLYMPUS BX51 (Olympus, Japan). The specimens can be stained with Calcofluor White M2R for species that are difficult to identify under ordinary light microscope, such as *Alexandrium, Protoperidinium* genera, etc. The quantitative samples were settled for at least 24 hours in 1-liter cylinders, and the upper water of the samples was 10–20 mL. Shaking the sample vial, a pipette was used to take 1 mL of sample and put it into the Sedgewick-Rafter counting chamber (volume 1 mL), waiting about 15 minutes for sedimentation. Count each species' cell number under a LEICA DMIL (Leica, Germany) inverted microscope (at 40–400x mag.). The sample analysis was performed at the Institute of Marine Environment and Resources, Hai Phong.

The comparative morphological method has been used to identify dinoflagellate species based on the following documents: Taylor (1976) [22], Dodge (1985) [23], Tomas (1997) [24], Balech (1995) [25], Larsen and Nguyen-Ngoc (2004) [5], Nguyen-Ngoc et al., (2012) [4], Omura et al., (2012) [26].

Canonical Correspondence Analysis (PLS-CCA) on XLSTAT software has been used to evaluate the possible relationship between dinoflagellate density and environmental factors. Tables and graphs were calculated and drawn using MS Excel.

RESULTS AND DISCUSSION

Species composition of dinoflagellates in the Northern Vietnam coastal waters

A total of 129 species belonging to 35 genera, 23 families, 8 orders and 2 classes of dinoflagellates have been recorded from samples collected during 2019–2022 in the sampling area. The most diverse genera included *Protoperidinium* (42 species), *Tripos* (19 species), *Gonyaulax* (11 species), *Alexandrium* (10 species), *Dinophysis* (6 species), and *Prorocentrum* (4 species). The number of species of each remaining genera ranged from 1 to 3 (Table 2).

Table 2. Species composition of dinoflagellates in the northern Viet Nam coastal waters

No.	Scientific name	2019	2020	2021	2022
	PHYLUM DINOFLAGELLATA				
	CLASS DINOPHYCEAE				
	Order Gymnodiniales				
	Family Kareniaceae				
	Genus *Karenia* Gert Hansen & Moestrup, 2000				
1	*Karenia* cf. *brevis* (C.C. Davis) Hansen & Moestrup 2000	-	-	+	-
2	*Karenia* cf. *mikimotoi* (Miyake & Kominami ex Oda) Gert Hansen & Moestrup 2000	+	+	+	+
	Family Polykrikaceae				
	Genus *Polykrikos* Bütschli, 1873				
3	*Polykrikos schwartzii* Bütschli 1873	-	-	+	+
	Family Ceratoperidiniaceae				
	Genus *Pseliodinium* Sournia, 1972				
4	*Pseliodinium fusus* (F. Schütt) F.Gómez 2018	-	+	+	-
	Family Gyrodiniaceae				
	Genus *Gyrodinium* Kofoid & Swezy, 1921				
5	*Gyrodinium* cf. *spirale* (Bergh) Kofoid & Swezy 1921	+	+	+	+
6	*Gyrodinium* sp.	-	-	-	+
	Order Akashiwales				

No.	Scientific name	2019	2020	2021	2022
	Family Akashiwaceae				
	Genus *Akashiwo* Gert Hansen & Moestrup, 2000				
7	*Akashiwo sanguinea* (K. Hirasaka) Gert Hansen & Moestrup 2000	+	+	+	+
	Order Gonyaulacales				
	Family Gonyaulacaceae				
	Genus *Gonyaulax* Diesing, 1866				
8	*Gonyaulax* cf. *digitalis* (Pouchet) Kofoid 1911	+	+	+	+
9	*Gonyaulax* cf. *fusiformis* H.W. Graham 1942	+	+	+	+
10	*Gonyaulax polygramma* F. Stein 1883	+	+	+	+
11	*Gonyaulax* cf. *rotundata* Rampi 1952	-	-	-	+
12	*Gonyaulax scrippsiae* Kofoid 1911	+	+	+	+
13	*Gonyaulax* cf. *spinifera* (Claparède & Lachmann) Diesing 1866	+	+	+	+
14	*Gonyaulax* sp. 1	-	+	-	-
15	*Gonyaulax* sp. 2	+	+	+	+
16	*Gonyaulax* sp. 3	+	-	+	-
17	*Gonyaulax* sp. 4	+	-	-	-
18	*Gonyaulax* sp. 5	-	-	-	+
	Family Lingulodiniaceae				
	Genus *Sourniaea* H.Gu,K.N.Mertens,Zhun Li & H.H.Shin, 2020				
19	*Sourniaea diacantha* (Meunier) H. Gu., K.N. Mertens, Zhun Li & H.H. Shin 2020	+	+	+	+
	Family Ceratiaceae				
	Genus *Tripos* Bory, 1823				
20	*Tripos azoricus* (Cleve) F. Gómez 2013	+	+	-	-
21	*Tripos* cf. *brevis* (Ostenfeld & Johannes Schmidt) F. Gómez 2021	+	+	+	+
22	*Tripos candelabrum* (Ehrenberg) F. Gómez 2013	+	-	-	+
23	*Tripos gracilis* (Pavillard) F. Gómez 2013	-	-	-	+
24	*Tripos gallicus* (Kofoid) F.Gómez 2021	+	-	+	+
25	*Tripos falcatus* (Kofoid) F. Gómez 2013	-	+	+	+
26	*Tripos furca* (Ehrenberg) F. Gómez 2013	+	+	+	+
27	*Tripos fusus* (Ehrenberg) F. Gómez 2013	+	+	+	+
28	*Tripos gibberus* (Gourret) F. Gómez 2021	+	-	+	-
29	*Tripos longipes* (Bailey) F. Gómez 2021	+	+	-	-
30	*Tripos inflatus* (Kofoid) F. Gómez 2013	+	+	+	+
31	*Tripos setaceus* (Jørgensen) F. Gómez 2013	+	+	+	-
32	*Tripos lunula* (Schimper ex Karsten) F. Gómez 2013	+	-	+	-
33	*Tripos macroceros* (Ehrenberg) Hallegraeff & Huisman 2020	+	+	+	+
34	*Tripos massiliensis* (Gourret) F. Gómez 2021	+	-	+	+
35	*Tripos extensus* (Gourret) F. Gómez 2021	+	+	+	+
36	*Tripos trichoceros* (Ehrenberg) F. Gómez 2013	+	+	+	+
37	*Tripos muelleri* Bory 1826	+	+	+	+
38	*Tripos* sp.1	-	-	-	+
	Genus *Ceratium* F. Schrank, 1793				
39	*Ceratium* sp. (Freshwater species)	+	+	+	+
	Family Protoceratiaceae				
	Genus *Protoceratium* R.S. Bergh, 1881				
40	*Protoceratium* sp.	-	-	-	+

No.	Scientific name	2019	2020	2021	2022
	Family Lingulodiniaceae				
	Genus *Lingulodinium* D. Wall, 1967				
41	*Lingulodinium polyedra* (F. Stein) J.D. Dodge 1989	+	+	+	+
	Family Pyrocystaceae				
	Genus *Triadinium* J.D. Dodge, 1981				
42	*Triadinium sphaericum* (G. Murray & Whitting) J.D. Dodge 1981	+	-	-	-
43	*Triadinium polyedricum* (Pouchet) J.D. Dodge 1981	+	+	+	+
	Genus *Alexandrium* Halim, 1960				
44	*Alexandrium affine* (H. Inoue & Y. Fukuyo) Balech 1995	+	+	+	+
45	*Alexandrium leei* Balech 1985	+	+	+	+
46	*Alexandrium pseudogonyaulax* (Biecheler) Horiguchi ex K. Yuki & Y. Fukuyo 1992	+	+	+	+
47	*Alexandrium* cf. *tamarense* (Lebour) Balech 1995	-	+	-	-
48	*Alexandrium* sp. 1	+	-	-	+
49	*Alexandrium* sp. 2	+	+	+	+
50	*Alexandrium* sp. 3	+	-	-	-
51	*Alexandrium* sp. 4	+	-	-	-
52	*Alexandrium* sp. 5	-	+	+	+
53	*Alexandrium* sp. 6	-	+	-	+
	Genus *Fragilidium* Balech, 1965				
54	*Fragilidium* sp.	+	+	+	+
	Genus *Pyrophacus* F. Stein, 1883				
55	*Pyrophacus horologium* F. Stein 1883	+	+	+	+
56	*Pyrophacus steinii* (Schiller) Wall & Dale 1971	+	+	+	+
	Order Peridiniales				
	Family Peridiniaceae				
	Genus *Peridinium* Ehrenberg, 1830				
57	*Peridinium* sp. 1	+	+	-	+
58	*Peridinium* sp. 2	+	+	+	+
59	*Peridinium* sp. 3	+	-	-	+
	Family Protoperidiniaceae				
	Genus *Protoperidinium* Bergh, 1881				
60	*Protoperidinium* cf. *abei* (Paulsen) Balech 1974	+	+	+	+
61	*Protoperidinium* cf. *claudicans* (Paulsen) Balech 1974	+	+	+	+
62	*Protoperidinium conicum* (Gran) Balech 1974	+	+	+	+
63	*Protoperidinium crassipes* (Kofoid) Balech 1974	+	+	+	+
64	*Protoperidinium* cf. *curtipes* (Jørgensen) Balech 1974	+	+	+	+
65	*Protoperidinium depressum* (Bailey) Balech 1974	+	+	+	+
66	*Protoperidinium* cf. *divergens* (Ehrenberg) Balech 1974	+	+	+	+
67	*Protoperidinium* cf. *excentricum* (Paulsen) Balech 1974	+	+	+	+
68	*Protoperidinium* cf. *inflatiforme* (A.Böhm) Balech 1974	-	-	-	+
69	*Protoperidinium* cf. *larsenii* Phan-Tan, Nguyen-Ngoc & Doan-Nhu 2017	+	+	+	+
70	*Protoperidinium* cf. *latispinum* (Mangin) Balech 1974	+	+	+	-
71	*Protoperidinium latissimum* (Kofoid) Balech 1974	+	+	+	-
72	*Protoperidinium* cf. *leonis* (Pavillard) Balech 1974	+	+	+	+
73	*Protoperidinium* cf. *majus* (P.J.L. Dangeard) Balech 1974	-	-	+	-
74	*Protoperidinium* cf. *mite* (Pavillard) Balech 1974	-	-	+	-

No.	Scientific name	2019	2020	2021	2022
75	*Protoperidinium* cf. *munobis* (T.H. Abé) Balech 1974	+	-	-	-
76	*Protoperidinium oblongum* (Aurivillius) Parke & Dodge 1976	+	+	+	+
77	*Protoperidinium oceanicum* (Vanhöffen) Balech 1974	+	+	+	+
78	*Protoperidinium* cf. *ovum* (J. Schiller) Balech 1974	+	+	+	+
79	*Protoperidinium* cf. *pellucidum* Bergh 1882	+	+	+	+
80	*Protoperidinium pentagonum* (Gran) Balech 1974	+	+	+	+
81	*Protoperidinium* cf. *punctulatum* (Paulsen) Balech 1974	+	+	+	+
82	*Protoperidinium* cf. *pyriforme* (Paulsen) Balech 1974	+	+	+	+
83	*Protoperidinium* cf. *sphaericum* (G. Murray & Whitting) Balech 1974	+	-	+	-
84	*Protoperidinium* cf. *sphaeroides* (P.A. Dangeard) Balech 1974	-	-	+	+
85	*Protoperidinium* cf. *steinii* (Jørgensen) Balech 1974	+	+	+	+
86	*Protoperidinium* cf. *thorianum* (Paulsen) Balech 1973	+	+	+	+
87	*Protoperidinium* cf. *thulesense* (Balech) Balech 1974	-	-	-	+
88	*Protoperidinium* cf. *ventricum* (T.H. Abé) Balech 1974	-	+	-	-
89	*Protoperidinium* sp. 1	+	+	+	+
90	*Protoperidinium* sp. 2	+	+	+	+
91	*Protoperidinium* sp. 3	+	-	-	-
92	*Protoperidinium* sp. 4	+	+	+	+
93	*Protoperidinium* sp. 5	-	+	-	+
94	*Protoperidinium* sp. 6	-	+	+	-
95	*Protoperidinium* sp. 7	-	+	-	-
96	*Protoperidinium* sp. 8	-	+	-	-
97	*Protoperidinium* sp. 9	-	+	-	-
98	*Protoperidinium* sp. 10	-	+	-	-
99	*Protoperidinium* sp. 11	-	+	-	-
100	*Protoperidinium* sp. 12	-	-	+	-
101	*Protoperidinium* sp. 13	-	-	+	+
	Genus *Diplopelta* F. Stein ex E. Jørgensen, 1912				
102	*Diplopelta* sp.	-	-	-	+
	Genus *Diplopsalis* R.S. Bergh, 1881				
103	*Diplopsalis* sp.	+	+	+	+
	Genus *Diplopsalopsis* Meunier, 1910				
104	*Diplopsalopsis* sp.	+	+	+	+
	Genus *Oblea* Balech, 1966				
105	*Oblea* sp.	+	-	+	+
	Family Kryptoperidiniaceae				
	Genus *Blixaea* Gottschling, 2017				
106	*Blixaea quinquecornis* (T.H. Abé) Gottschling 2017	+	+	+	+
	Family Podolampadaceae				
	Genus *Podolampas* F. Stein, 1883				
107	*Podolampas palmipes* Stein 1883	+	+	+	-
108	*Podolampas bipes* F. Stein 1883	-	-	-	+
	Family Oxytoxaceae				
	Genus *Oxytoxum* Stein, 1883				
109	*Oxytoxum scolopax* F. Stein 1883	-	+	-	-
	Genus *Corythodinium* Loeblich & A.R. Loeblich, 1966				
110	*Corythodinium tesselatum* (F. Stein) Loeblich Jr. & Loeblich III 1966	+	+	+	-

No.	Scientific name	2019	2020	2021	2022
	Order Dinophysales				
	Family Dinophysaceae				
	Genus *Dinophysis* Ehrenberg, 1839				
111	*Dinophysis caudata* Kent 1881	+	+	+	+
112	*Dinophysis* cf. *infundibulum* J. Schiller 1928	+	+	+	+
113	*Dinophysis miles* Cleve 1900	+	+	+	+
114	*Dinophysis* cf. *parvula* (F. Schütt) Balech 1967	+	-	-	-
	Dinophysis rudgei (G. Murray & Whitting) T.H. Abé, nom. inval. 1967	+	+	+	+
115	*Dinophysis* sp.	-	+	+	-
	Genus *Metadinophysis* D. Nie & C.-C. Wang, 1941				
116	*Metadinophysis sinensis* Nie & Wang 1941	+	-	-	-
	Genus *Ornithocercus* Stein, 1883				
117	*Ornithocercus magnificus* F. Stein 1883	+	+	+	-
118	*Ornithocercus quadratus* Schütt 1900	-	-	-	+
	Genus *Histioneis* Stein, 1883				
119	*Histioneis costata* Kofoid & J.R. Michener 1911	+	-	-	-
	Family Dinophysiales familia incertae sedis				
	Genus *Pseudophalacroma* Jørgensen, 1923				
120	*Pseudophalacroma nasutum* (F. Stein) E. Jørgensen 1923	-	+	-	-
	Family Oxyphysaceae				
	Genus *Phalacroma* Stein, 1883				
121	*Phalacroma rotundatum* (Claparéde & Lachmann) Kofoid & J.R. Michener 1911	+	-	+	+
	Family Amphisoleniaceae				
	Genus *Amphisolenia* Stein, 1883				
122	*Amphisolenia bidentata* B. Schröder 1900	+	-	-	-
	Order Prorocentrales				
	Family Prorocentraceae				
	Genus *Prorocentrum* Ehrenberg, 1834				
123	*Prorocentrum gracile* F. Schütt 1895	+	+	+	+
124	*Prorocentrum micans* Ehrenberg 1834	+	+	+	+
125	*Prorocentrum* cf. *cordatum* (Ostenfeld) J.D.Dodge 1976	-	-	-	+
126	*Prorocentrum* cf. *rhathymum* A.R. Loeblich III, Sherley & R.J. Schmidt 1979	+	+	+	+
	Order Thoracosphaerales				
	Family Thoracosphaeraceae				
	Genus *Scrippsiella* Balech, 1965				
127	*Scrippsiella spinifera* G. Honsell & M. Cabrini 1991	+	+	+	+
128	*Scrippsiella acuminata* (Ehrenberg) Kretschmann, Elbrächter, Zinssmeister, S. Soehner, Kirsch, Kusber & Gottschling 2015	+	+	+	+
	CLASS NOCTILUCOPHYCEAE				
	Order Noctilucales				
	Family Noctilucaceae				
	Genus *Noctiluca* Suriray, 1816				
129	*Noctiluca scintillans* (Macartney) Kofoid & Swezy 1921	+	+	+	+
	Total	94	90	90	91

Notes: +: present; -: absent; systematic was followed Fensom et al., (1993) [27]; name of taxa were updated followed Guiry and Guiry (2024) [29].

Based on the synthesis of phytoplankton data from various projects that were carried out in the Gulf of Tonkin and surrounding areas from 1959 to 2009, Nguyen Hoang Minh et al., (2011) reported a total of 187 dinoflagellate species belonging to 27 genera, 20 families, 6 orders and 1 class in the study area [12]. However, no species list was provided in that publication, which makes it difficult to verify and/or compare dinoflagellate species composition. The number of species recorded in the northern Viet Nam coastal waters from 2019 to 2022 was lower. However, this species number was not much lower when compared with Chu Van Thuoc et al., (2004) (169 dinoflagellate species) study in the coastal area from Tien Yen - Ha Coi to Hai Van - Son Cha (Thua Thien Hue), the surrounding waters of the islands (Ha Mai, Thuong Mai, Ba Mun, Co To, Thanh Lan, Cat Ba - Ha Long, Hon Me), the Red River river mouth and Tam Giang - Cau Hai lagoon during period of 1990–2000 [14].

Distribution of dinoflagellates in the Northern Vietnam coastal waters

Temporal variation in diversity of species

The number of dinoflagellate species in the study area in 2019, 2020, 2021 and 2022 was 94, 90, 90, 91, respectively. The difference in the total number of species by year is not significance. Among 129 species, 64 species (approximately 50 percent) were found in all four years (Table 2). Figure 2 shows variation in species number in quarters of the year in the study area.

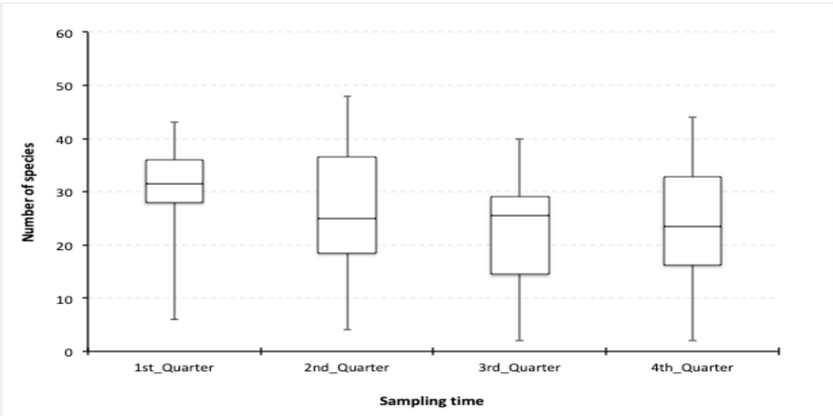

Figure 2. Number of dinoflagellate species by sampling time (*n* = 24 for each quarter from the 1st to the 3rd quarter; *n* = 18 for the 4th quarter. From top to bottom of each block showing: the highest bar - maximum value; upper quartile; median value; lower quartile; the lowest bar - minimum value)

The number of dinoflagellate species in the first quarter was the most negligible variation, ranging from 6 to 43 species, with the mean being 32 species per sample. In the second quarter, we had the strongest variation in species number, ranging from 4 to 48 species, with the mean number of 25 species per sample. The species number of the third and the fourth quarters ranged from 2 to 40 species and from 2 to 44 species, respectively, and the mean number of species was 26 and 24 species per sample, respectively. In these two quarters, the number of dinoflagellate species at estuary areas, such as Ba Lat and Do Son stations, were usually very low, only 2–3 species at the low tide. This may be caused by the strong impact of freshwater masses on the estuaries during the rainy season in North Vietnam.

Spatial variation in diversity of species

The variation of dinoflagellate species diversity in the study area is shown in Fig. 3. The results showed strong variations in the number of species among the sampling stations. Ba Lat station had the lowest number of species compared to the remaining stations and had the highest variability in species, ranging from 2 to 32 species with a mean number of 8 species per sample. Cua Luc station had the least variability in the number of species, ranging from 21 to 43 species; the mean number of species was 30 species. Do Son and Sam Son stations had several species ranging from 4 to 37 species and 4 to 48 species, and with the mean number of species of 23 and 29 species, respectively. Two stations, Tra Co and Cua Lo, had species numbers ranging from 14 to 41 species and from 12 to 47 species, and the mean number of species at these stations were 29 and 32 species, respectively.

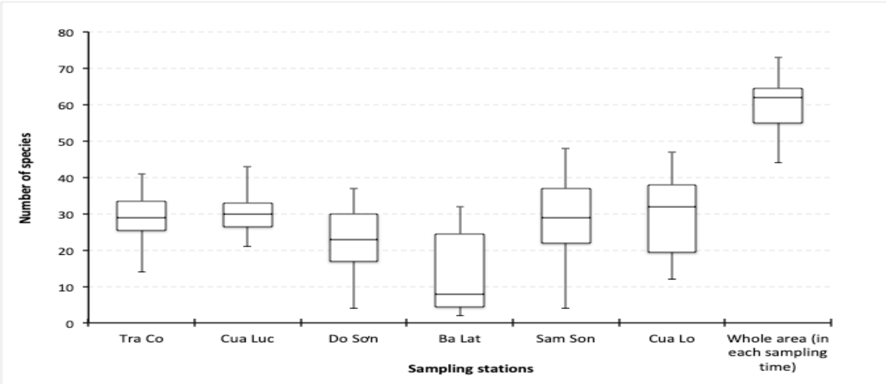

Figure 3. Number of dinoflagellate species by sampling stations (*n* = 15 for each station. From top to bottom of each block showing: the highest bar - maximum value; upper quartile; median value; lower quartile; the lowest bar - minimum value)

Our observation revealed that the dinoflagellate species in the stations near large river mouths (Ba Lat station near the Red River, Do Son station near the Van Uc and Bach Dang rivers, Sam Son station near the Ma River) were less diverse and strongly seasonal changed, especially in the rainy season, compared with the stations were less affected by the large rivers such as Tra Co, Cua Luc, and Cua Lo stations.

Temporal variation in the density of dinoflagellates

Densities of dinoflagellates in the study area in 4 quarters from 2019 to 2022 were presented in Fig. 4.

The first quarter had the highest mean density of dinoflagellates, 3.7×10^3 cells/L, followed by the second quarter, with a mean density of 1.8×10^3 cells/L; the third quarter and the fourth quarter had similar mean densities, approximate of 1.2×10^4 cells/L. Cell densities in the first quarter fluctuated the least, from 450 to 2.2×10^5 cells/L. In contrast, we had the largest density fluctuation in the third quarter, from 40 to 3×10^5 TB/L, with the highest density this quarter.

Among the dinoflagellate species presented in the study area, *Tripos furca* is the most common species. Fig. 5 showed variation of densities of *Tripos furca* in the study area ranging from 0 to more than 3×10^5 cells/L depending on the time of sampling. The mean densities of this species reached the highest value in the first quarter with approximately 10^3 cells/L, and the highest density recorded in this quarter was about 3×10^4 cells/L. In the three remaining quarters of the year, the mean densities were usually less than 5×10^2 cells/L. However, the highest density of *Tripos furca* was recorded in the third quarter (September 2019 at Do Son station) with 3×10^5 cells/L, followed by the second quarter (June 2019 at Cua Luc station) and fourth quarter (October 2020 at Do Son station) with densities of 1.7×10^5 cells/L and 1.3×10^5 cells/L, respectively. The density of *Tripos furca* in the study area changed strongly in the last three quarters of the year.

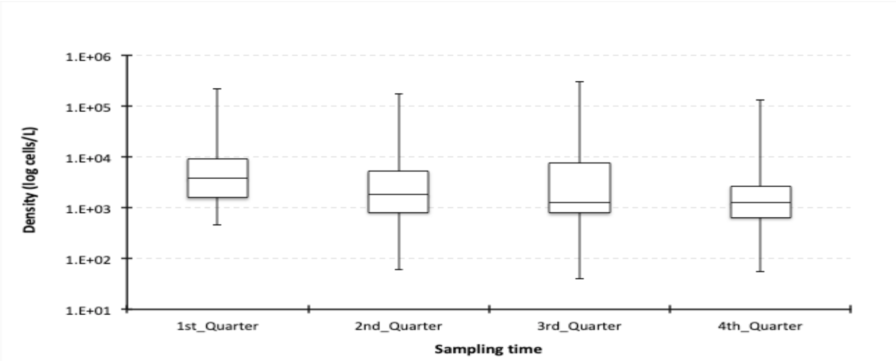

Figure 4. Total density of dinoflagellates by sampling time (n = 48 for each quarter from the 1st to the 3rd quarter; n = 36 for the 4th quarter. From top to bottom of each block showing: the highest bar - maximum value; upper quartile; median value; lower quartile; the lowest bar - minimum value)

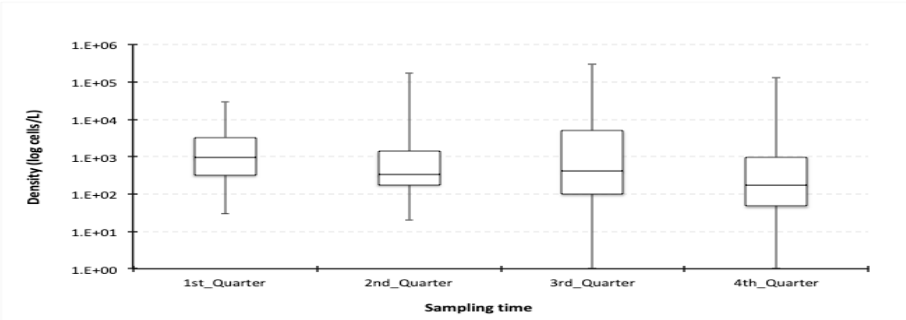

Figure 5. Density of *Tripos furca* by sampling time (n = 48 for each quarter from the 1st quarter to the 3rd quarter; n = 36 for the 4th quarter. From top to bottom of each block, the highest bar shows the maximum value, followed by the upper quartile, the median value, the lower quartile, and the lowest bar - minimum value)

Tripos furca blooms were recorded in the northern Viet Nam coastal waters. In July 2002, two blooms of *Tripos furca* were recorded in Quang Ninh and Nghe An coastal waters [30]. This species bloomed in Cat Ba Islands (Hai Phong province) in August 2008 (*Chu Van Thuoc, pers. comm.*). The blooms found from July 20th–August 4th, 2011, which coincided with the death of 11 tons of fish (cobia, snapper, grouper, and seabass) in the same area [31], and a bloom was recorded at Nghi Son (Thanh Hoa prov.) during September 8–9th, 2016 with the highest density reached to $8x10^6$ cells/L coincided caged fish mortality in the area (*Institute of Marine Environment and Resources, unpublished data*). *Tripos furca* seems preferable and grows with high density in the northern Vietnam coastal areas from June to September.

Spatial variation in the density of dinoflagellates

Total dinoflagellate density varied according to sampling stations and tide. In general, the mean cell density values of dinoflagellates in the study area ranged from 10^3 to 10^4 cells/L, except for Ba Lat station, which had a lower mean density value and usually ranges between 10^2 to 10^3 cells/L (Fig. 6). The mean cell densities at high tide were usually higher than at low tide at all sampling stations. It suggested that changes in water masses influenced the quantitative distribution of dinoflagellates in the study area.

The distribution of the cell number of *Tripos furca* among the sampling stations in the study area at high and low tide was shown in Fig. 7. Cell densities of this species varied strongly from 0 to more than 10^5 cells/L among the sampling stations. The density value at high tide was often higher than at low tide. The mean cell densities of *Tripos furca* among the sampling stations usually varied between 10^2 and 10^3 cells/L, except at two stations, Cua Luc and Sam Son, where the densities ranged from 10^3 to 10^4 cells/L. Higher mean density values of this species were recorded at Do Son and Cua Luc stations during high tide with densities of 3×10^5 cells/L and 1.7×10^5 cells/L, respectively.

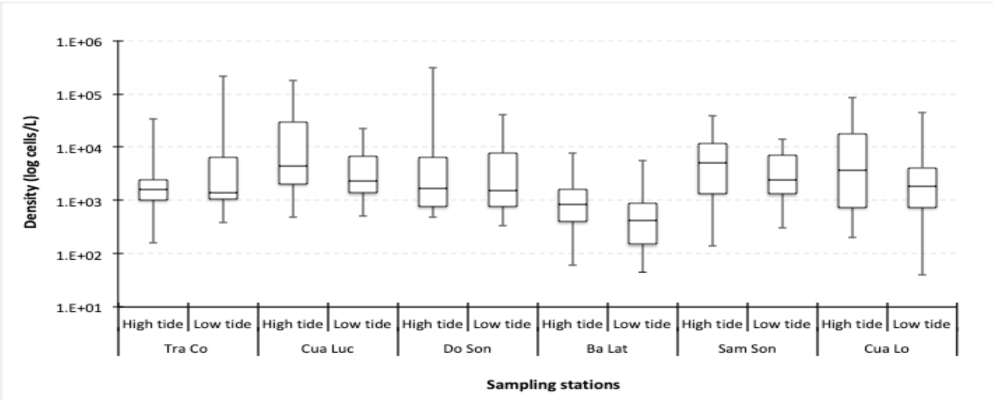

Figure 6. Total density of dinoflagellates by sampling stations (*n* = 30 for each station. From top to bottom of each block showing: the highest bar - maximum value; upper quartile; median value; lower quartile; the lowest bar - minimum value)

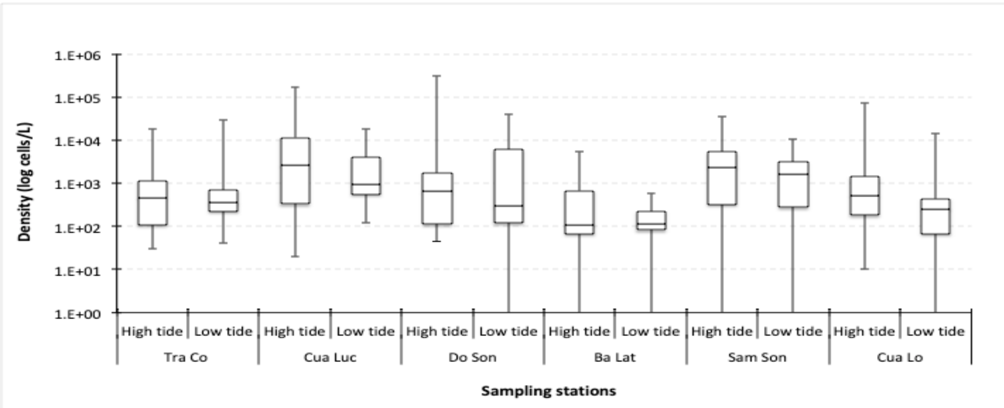

Figure 7. Th density of *Tripos furca* by sampling stations (*n* = 30 for each station. From top to bottom of each block showing: the highest bar - maximum value; upper quartile; median value; lower quartile; the lowest bar - minimum value)

The relationship between the density of Tripos furca and water environmental factors

The analysis results of the samples collected in the northern Vietnam coastal waters from 2019 to 2022 showed that *Tripos furca* was the most common species, occurring in 167 of 180 quantitative samples (accounting for approximately 93%). Therefore, this species was selected to evaluate the possible relationship between its density and some water environmental factors, such as temperature, salinity, pH, and DO.

The results of PLS-CCA analysis showed that pH and DO seem to have little correlation with *T. furca* density, especially the pH factor. This is shown in that the vectors are often short and concentrated at the origin. The salinity and seawater temperature had related to *Tripos furca* density, especially salinity. This correlation was more evident at stations near large river mouths such as Ba Lat and Do Son stations, where the wide changes in salinity by tide usually occur. At these stations, the correlation between salinity and the algal density was positive. In contrast, a negative correlation was found at stations far from giant river mouths, such as the Cua Luc and Cua Lo stations. Water temperature is also related to algal density, but not as clear as salinity (Fig. 8). Our result was also consistent with the previous publication of Huynh Thi Ngoc Duyen et al. (2022) when studying the ecology of two species, Tripos furca and Tripos fusus, in the South Central of Vietnam [18].

The blooms of *Ceratium furca* (= *Tripos furca*) were found in September 1995 and August 1996 in Chesapeake Bay (USA). This species was most abundant at or above 15 psu and at temperatures ranging from 24 to 27°C [32]. The studies in the laboratory showed that *Ceratium furca* did not cross a salinity gradient of 5 psu [33]. This species did not grow at < 10°C or > 32°C; optimum growth rates were observed at temperatures from 18 to 28°C [34]. From the above data, temperature and salinity factors have significantly influence the development of *Tripos furca* in marine environments.

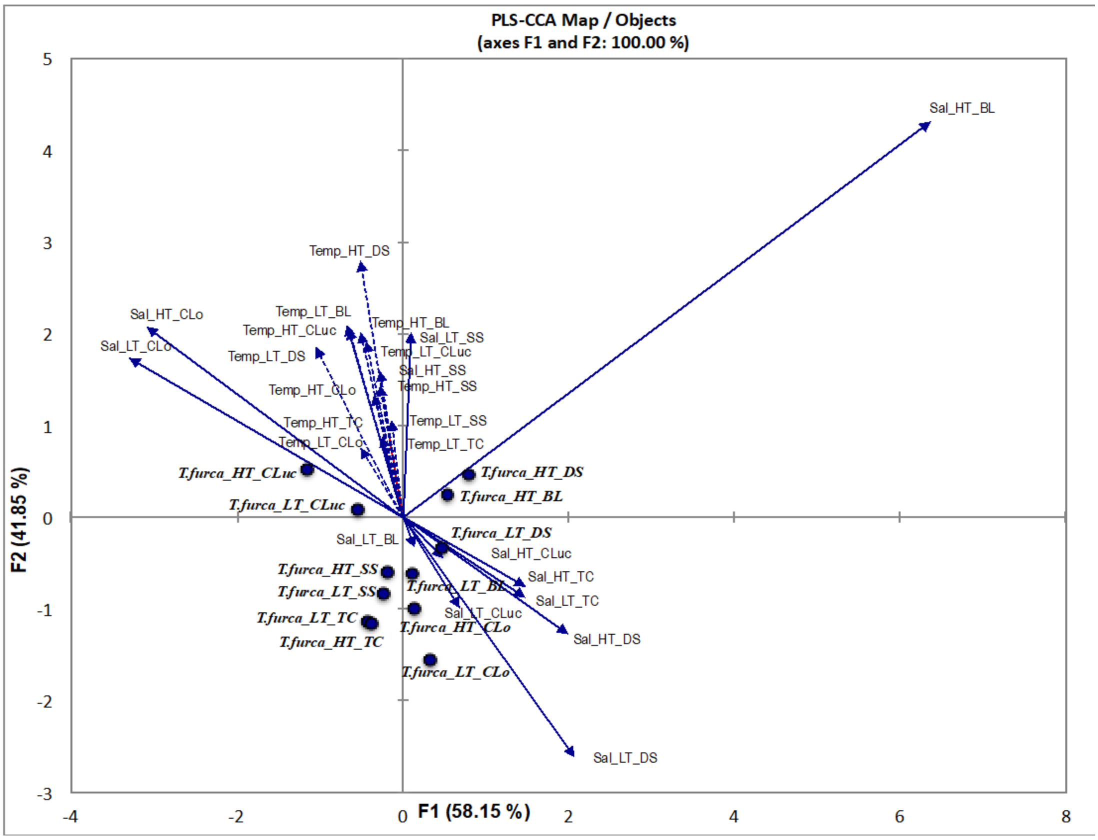

Figure 8. PLS-CCA between *Tripos furca* density and water environmental factors (salinity & temperature) (*T.furca* - *Tripos furca*; Temp - temperature ; Sal - salinity ; HT - high tide; LT - low tide ; TC - Tra Co ; CLuc - Cua Luc ; DS - Do Son ; BL - Ba Lat ; SS - Sam Son ; CLo - Cua Lo)

CONCLUSION

The composition of dinoflagellate species in the northern Viet Nam coastal waters was diverse from 2019 to 2022 with 129 species belonging to 35 genera, 23 families, 8 orders and 2 classes were recorded. Dinoflagellate species diversity varied depending on the sampling locations and time of the year. *Tripos furca* was the most common and dominant species among the dinoflagellate species recorded in the study area. The ensity of total dinoflagellates in general and density of *Tripos furca* in particular fluctuated strongly by sampling location, time and tide. Among water environment factors, salinity and temperature were related to the distribution of *Tripos furca* in the study area. The correlation of salinity and algal density was more pronounce and depending on the sampling stations and tides.

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