

Effects of salinity variation on species composition of dinoflagellates on Hau River, Mekong Delta

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Abstract. Dinoflagellates are considered a phytoplankton group which negatively affects the aquaculture. The study aimed to assess the effects of salinity variation on species composition of dinoflagellates on the Hau River estuary area in order to provide a baseline for proposing measures for managing water quality to enhance the sustainability of shrimp farming in saline intrusion areas in the Mekong Delta. Samples of phytoplankton were collected monthly at 3 sites of the Hau River. Dinoflagellates were determined qualitatively by their morphology and quantitatively by counting them in a Sedgewick-Rafter chamber. A total of 16 species of dinoflagellates were recorded with cell densities ranging from 10,300 to 25,500 cells L⁻¹, depending on the location, date of sampling and tidal conditions. Both number of species and cell density increased linearly with an increasing salinity. Toxic dinoflagellates like *Ceratium* spp., *Glenodinium* spp., *Peridinium* spp., and *Gymnodinium* spp. were absent from sites with a salinity of 0‰, but appeared when salinity rose by as little as 1-3‰ as a result of saline intrusion in the drier months. The increase in toxic dinoflagellate populations during periods of saline intrusion could have serious adverse impacts on aquaculture and natural aquatic resources in and along the lower reaches of the Hau River in the Mekong Delta of Vietnam.

Key Words: algae structure, Hau river, Mekong delta, saline intrusion, toxic algae.

Introduction. Dinoflagellates belonging to the Dinophyta phylum are considered toxic to aquaculture (Matsuyama 1999; Camacho et al 2007; Zhou et al 2017). Many studies have shown that dinoflagellates contain a variety of toxins, including saxitoxins, brevetoxins, ciguatoxins, dinophysistoxins, okadaic acid, and these toxins can harm or kill aquatic animals (Glasgow et al 1995; Ibrahim 2007; Linares et al 2009; Nabb et al 2012; Moestrup et al 2014; Nielsen et al 2016). In fact, more than 75% of dinoflagellates are harmful to farmed aquatic animals (Smayda & Reynolds 2003). In Vietnam, 70 species of dinoflagellates are reported to be potentially harmful in coastal areas, including estuaries of the Mekong River (Larsen & Nguyen 2004). Furthermore, many studies have identified salinity as the main factor influencing the distribution of algae in estuarine areas (Nielsen et al 2003; Zorina-Sakharova et al 2014). When salinity increases, dinoflagellates will thrive and impose negative impact on aquatic ecosystems and aquaculture (Lueangthuwapranit et al 2011; Zina et al 2012; Angles et al 2015).

In the Mekong Delta, the Hau River plays an important role in providing water for agriculture and aquaculture. The lower part of Hau River in Soc Trang province is the main water source for freshwater fish culture and brackish water shrimp farming. However, this part of the river is tidally influenced and especially vulnerable to saline intrusion, which tends to be exacerbated by sea level rise and decreased freshwater flow from upstream (IPCC 2007). In the latter case, the utilization of water for agriculture and the construction of hydro-power dams upstream in the Mekong River has resulted in a decline in water flow, causing freshwater shortages and saline intrusion downstream in the dry season (Hoanh et al 2003; Sunada et al 2009). In the near future, the lower section of the Hau River is likely to experience more severe saline intrusion in the dry season (Tuan et al 2007; Nhan et al 2007), which is expected to shift the composition of

algal communities to dominance by dinoflagellates, with potentially negative impacts on aquaculture in the surrounding areas. This study on the effects of salinity variation on changes in composition of algae, especially dinoflagellates in the lower part of the Hau River, was carried out to provide important baseline data for proposing measures to avoid or minimize the negative effects of rising dinoflagellate populations on water quality, especially for aquaculture, in saline intrusion areas in the Mekong Delta.

Material and Method

Study time and study sites. The study was carried out from July of 2017 to June of 2018. Samples were collected monthly at three sites in the lower part of the Hau River in Soc Trang province: I-upstream site of Hau River - Cai Con ($9^{\circ}55'48.9''-105^{\circ}54'02.6''$), approximately 60 km from the river mouth and considered the farthest point of saline intrusion upstream from the river mouth during the dry season; II-midstream site of Hau River - Dai Ngai ($9^{\circ}43'47.2''-106^{\circ}04'52.4''$), midway between Cai Con and the river mouth; and III-downstream site of Hau River - Tran De ($9^{\circ}28'0.90''-106^{\circ}14'35.5''$) at the river mouth (Figure 1).

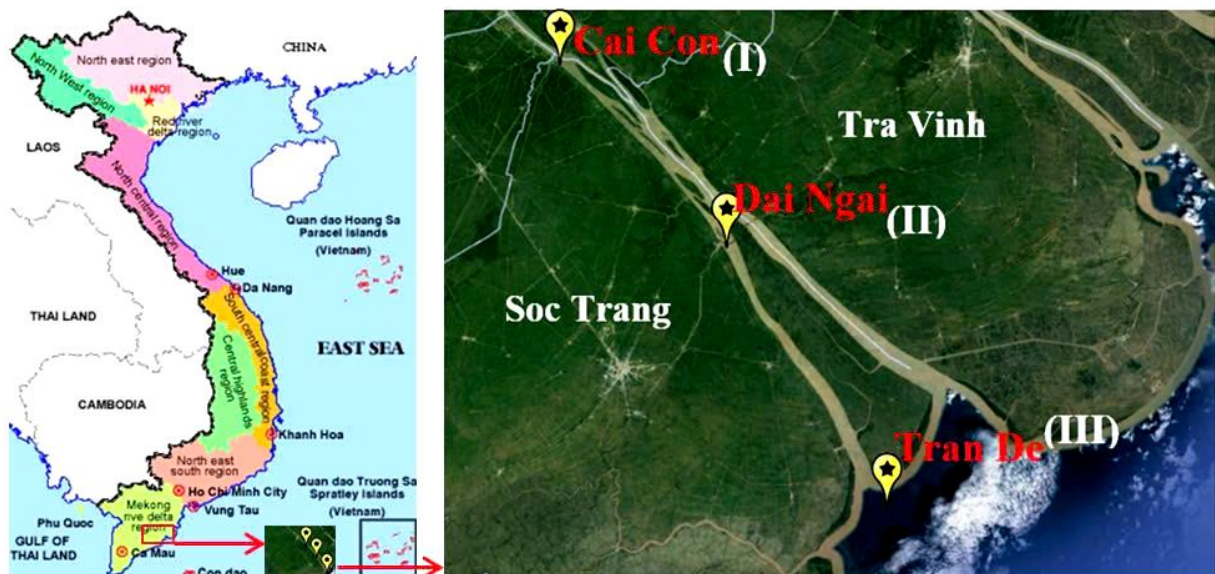


Figure 1. Location of the three sampling sites (I-upstream site, II-midstream site, III-downstream site) on the lower part of the Hau River.

Sampling and sample analysis. Water samples for qualitative and quantitative analysis of phytoplankton populations (notably dinoflagellates) were collected at a depth of 30 cm at high tide and low tide at each site. Qualitative samples were collected by dragging a phytoplankton net (with a mesh size of 30 μm) along the sampling site for about 10 minutes. For the quantitative samples, 400 L samples were collected at a depth of 0.5 cm at different places in the sampling area, mixed, and then it was filled and preserved in 110 mL plastic jars with 4% formalin (38%) and transported to the laboratory for further analysis in the College of Aquaculture and Fisheries, Can Tho University.

At the same time, temperature and salinity were directly recorded using a thermometer and refractometer (ATAGO, Japan), respectively. Total nitrogen (TN), total phosphorus (TP) and turbidity (NTU) were also sampled by collecting one liter of water in a plastic bottle and further analysed in the laboratory using standard methods (APHA 2012). In the field, all water samples were stored in an ice chest, and then transferred to a refrigerator for storage until analyzed.

Dinoflagellates were identified qualitatively based on their morphology using published taxonomic keys (Shirota 1966; Truong 1993; Duong & Vo 1997; Dang 2005; Bellinger & Sigee 2010). Quantitative samples were analyzed by counting cells in a

Sedgewick-Rafter counting chamber. Densities of the algae were determined based on the following formula (Boyd & Tucker 1992):

$$X = \frac{T \times 1000 \times V_{cd} \times 10^3}{A \times N \times V_M}$$

Where:

X-density of algae (cells L⁻¹);

T-number of cells counted;

A-area of a counting square (1 mm²);

N-number of squares counted=180;

V_{cd}-concentrated volume which was measured before counting (mL);

V_M-total volume sampled in the field (mL).

Data analysis. Data were analyzed using a range of specialized software, including SPSS 20.0, R 3.6 and R-studio. In order to fully assess the impact of salinity on the structure of the dinoflagellates' community, analysis and assessment were implemented in two ways. Firstly, (i) the dinoflagellate composition was assessed at different salinity ranges based on the number of species, population density (cells L⁻¹) of each dinoflagellate species. Secondly, (ii) the distribution of species and community density of dinoflagellates was assessed at different salinities by Cluster analysis (using SPSS 20.0), Canonical Correlation Analysis-CCA (using R 3.6 + R-studio), Principal Component Analysis-PCA (using R 3.6 + R-studio) and linear regression analysis (using SPSS 20.0). Cluster (using SPSS 20.0) and PCA analysis were used to assess the similarity of distribution of dinoflagellates species under the effects of salinity. CCA analysis was used to assess the similarities of distribution and correlation of dinoflagellate species with salinity and the main water parameters. The purpose of linear regression analysis was to determine the relationship between salinity and the abundance of dinoflagellates in the Hau River. A positive or negative correlation between salinity and dinoflagellates populations was expected. The result of the output from regression analysis was used to predict number of species and abundance of dinoflagellates in the river. The model is expressed by the equation:

$$Y = aX+b$$

Where:

Y-the number of species or density of dinoflagellates (cells L⁻¹);

X-the water salinity (‰);

a-the slope of the relationship between Y and X;

b-the intercept.

Results

Fluctuation of salinity on Hau River estuary area. Salinity recorded at all three sites on the lower part of the Hau River ranged from 0 to 20‰, with the highest at the downstream site of Tran De and the lowest at the upstream site of Cai Con. Salinity at high tide was higher than that at low tide. The salinity on both high and low tides was 0‰ at all three sites during the rainy season (August to October), but then began to rise in November at the beginning of the dry season as a result of saline intrusion. This was most evident at the downstream site of Tran De, where the salinity had risen to 2‰ by late November. Strong saline intrusion occurred from December 2017 to April 2018, with salinities peaking at about 20‰ in March at the downstream site of Tran De and 6‰ at the midstream site of Dai Ngai (Figure 2). The upstream site of Cai Con experienced only a brief pulse of elevated salinity between December and February, peaking at 1‰ at low tide and 2‰ at high tide (Figure 2). Salinities began to drop sharply at Dai Ngai and Tran De in April and fell to zero by June in the rainy season of 2018 (Figure 2).

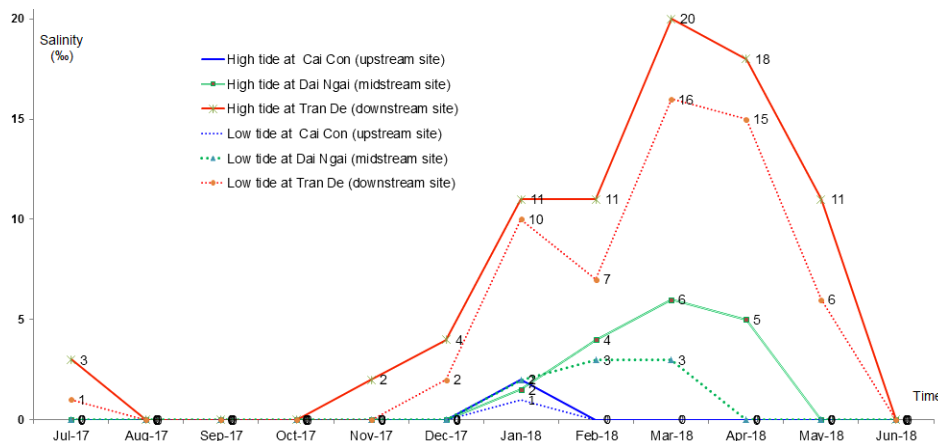


Figure 2. Variation of salinity (‰) on the lower part of the Hau River during the sampling periods.

Composition of dinoflagellates on Hau River, species composition and abundance. A total of 16 species of dinoflagellates belonging to 8 families of 7 orders were recorded (Table 1). The number of species at high tide (15 species) was higher than that at low tide (12 species) (Table 2). The number of dinoflagellate species at both low and high tide decreased from the river mouth (Tran De) to the upstream site (Cai Con) to Tran De (Table 1), indicating clearly that the species composition of dinoflagellate populations was influenced by salinity. Toxic or harmful dinoflagellates such as *Ceratium* spp., *Glenodinium* spp., *Dinophysis homunculus*, and *Gymnodinium neglectum* were recorded at all sampling sites.

Table 1
Species composition of dinoflagellates recorded on the lower part of the Hau River

No	Species name	Low tide			High tide		
		Cai Con (U)	Dai Ngai (M)	Tran De (D)	Cai Con (U)	Dai Ngai (M)	Tran De (D)
Order: Gonyaulacales, family: Ceratiaceae							
1	<i>Ceratium candelabrum</i>	+	+	+	+	+	+
2	<i>Ceratium candelabrum f. commune</i>	+	+	+			
3	<i>Ceratium furca</i>				+	+	+
4	<i>Ceratium pennatum var. scapiforme</i>		+	+		+	+
Order: Dictyochales, family: Dictyochaceae							
5	<i>Dictyocha fibula</i>	+	+	+	+	+	+
6	<i>Dictyocha fibula var. longispina</i>	+		+		+	+
Order: Dinophysiales, family: Dinophysiaceae							
7	<i>Dinophysis homunculus</i>				+	+	+
Order: Peridinales, family: Peridinales incertae sedis							
8	<i>Glenodinium berolinense</i>	+	+	+	+		+
9	<i>Glenodinium kulczynskii</i>	+	+	+	+	+	+
10	<i>Glenodinium uliginosum</i>		+		+	+	
Order: Peridinales, family: Peridiniaceae							
11	<i>Peridinium breve</i>				+	+	+
12	<i>Peridinium sp.</i>	+	+	+	+	+	+
13	<i>Peridinium umbonatum</i>	+	+	+	+	+	+
Order: Thoracosphaerales, family: Thoracosphaeraceae							
14	<i>Goniodoma sphaericum</i>	+	+	+			
Order: Gymnodiniales, family: Gymnodiniaceae							
15	<i>Gymnodinium neglectum</i>	+	+	+	+		+
Order: Suessiales, family: Sphaerodiniaceae							
16	<i>Sphaerodinium cinctum</i>				+	+	+
Total number of species present		10	11	11	12	13	14

(+) indicate presence of these species; U-upstream site of river, M-midstream site of river, D-downstream site of river.

The density of dinoflagellates varied with salinity, both in terms of the large differences in salinity between sites, and the relatively small differences in salinity between low and high tide. The density of dinoflagellates at Tran De (6,098 cells L⁻¹) was highest and significantly different to that at Cai Con (2,284 cells L⁻¹) (Table 2). Likewise, the density of dinoflagellates at high tide (5,028 cells L⁻¹) was considerably higher than that at low tide (3,270 cells L⁻¹) (Table 2).

Table 2
Number of species and density of dinoflagellates in different sampling sites and tides

Sites and tides		Number of species	Density (Mean±SE; cells L ⁻¹)
Sites	Cai Con (U)	15	2,284±401 ^a
	Dai Ngai (M)	16	4,080±747 ^{ab}
	Tran De (D)	15	6,098±1,068 ^b
Tides	Low tide	12	3,280±409 ^a
	High tide	15	5,028±862 ^b

Different superscript letters indicate a significant difference in density (P<0.05), U-upstream site of river, M-midstream site of river, D-downstream site of river.

Composition of dinoflagellates on Hau River, similarity of distribution. Similarity of distribution of dinoflagellates community on the lower part of the Hau River was assessed through Cluster analysis which are presented in Table 3 and Figure 3. There were 5 clusters and the diversity of the distribution of dinoflagellates within the distance 1-25 (Euclidean distance) ranged 4.397-6.074 (Table 3 and Figure 3).

Table 3
Cluster analysis of dinoflagellates diversity in different sampling sites and tides

Cluster	Distance (Euclidean)	Distance [1-25]	Samples (Site combined tide)
1	4.397	1.00	1,2,3,(4,5),6
2	4.570	3.00	(1,3),2,(4,5),6
3	5.073	11.00	(1,2,3),(4,5),6
4	5.199	12.00	(1,2,3),(4,5,6)
5	6.074	25.00	(1,2,3,4,5,6)

1-indicates low tide in Cai Con, 2-indicates low tide in Dai Ngai, 3-indicates low tide in Tran De, 4-indicates high tide in Cai Con, 5-indicates high tide in Dai Ngai, 6-indicates high tide in Tran De.

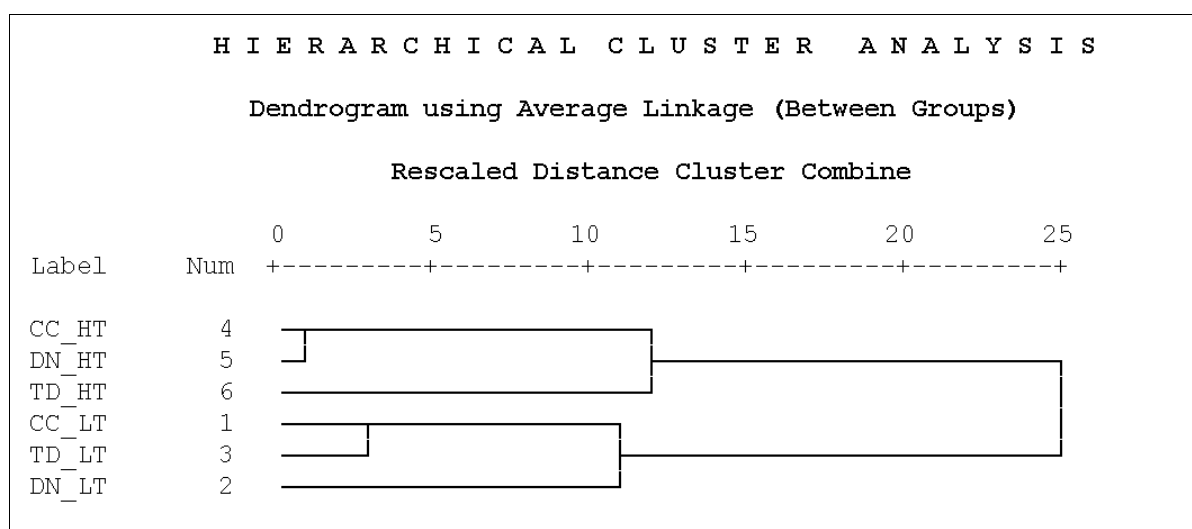


Figure 3. The cluster results of diversity for dinoflagellates densities at 3 sites and tides (CC: Cai Con-upstream site, DN: Dai Ngai-midstream site, TD: Tran De-downstream site; HT: high tide, LT: low tide).

When the distance was less than 5.00, there were 2 clusters including 1-3 and 4-5 (Figure 3) indicating the diversity of dinoflagellates in Cai Con (upstream site of river) at low tide was similar to that in Tran De (downstream site of river) at low tide. Within the distance 5-15, there were 2 big clusters, 1-2-3, and 4-5-6 (Table 3). This indicated that tides and sites had an impact on composition and distribution of dinoflagellates on the lower part of the Hau River.

Dinoflagellates with salinity changes, species composition structure and abundance. The number of dinoflagellates species at different sampling periods fluctuated widely, without any consistent trend or apparent pattern related to salinity (Figure 4a). Especially, in the salinity range of 15-20‰ (in Tran De, downstream site), the number of species increased gradually with the increase of salinity (Figure 4a). According to Figure 4b, the density of dinoflagellates fluctuated when salinity increased with a trend of density which increased with an increasing salinity. The lowest density was 1,156 cells L⁻¹ at 1‰ (in Cai Con at low tide in January). Highest density was recorded at 20‰ at high tide in Tran De in March with 17,500 cells L⁻¹. Similar to number of species, density of dinoflagellates was also high at 11‰ and reached 13,639 cells L⁻¹ (Figure 4b). This indicates that a salinity of 11‰, coinciding with warm water in the dry season (from January to February), was the optimal condition for dinoflagellate growth. In addition, Figure 4b also shows that when salinity increased gradually from 16‰ to 20‰ (in Tran De), the density of dinoflagellates also increased.

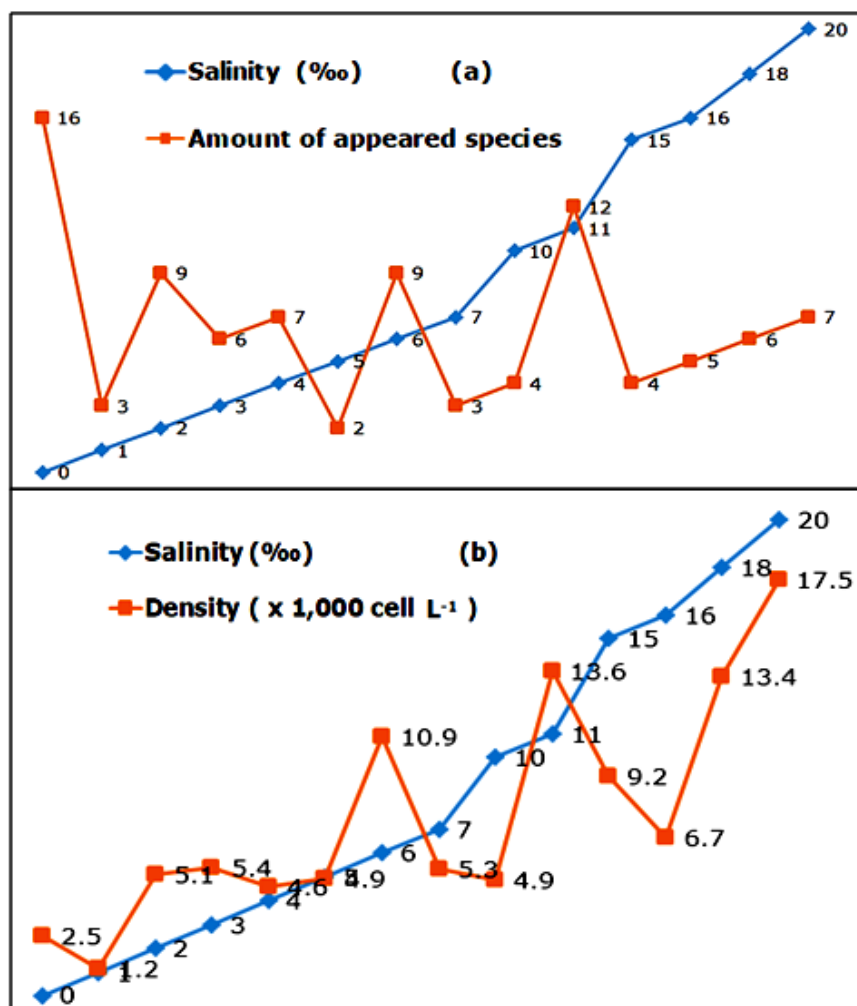


Figure 4. Number of species (a) and density (b) of dinoflagellates at different salinities on the lower part of Hau River.

Dinoflagellates with salinity changes, species composition at different salinities and sampling sites.

The species composition of dinoflagellates at different salinity and sampling sites was analyzed to assess their possible relationship with saline intrusion. At the upstream site of Cai Con, where salinity only ranged from 0, 1 and 2‰, the highest number of species (15 species) was recorded at a salinity of 0‰, and most of them were freshwater or euryhaline dinoflagellates; the toxic dinoflagellates *Ceratium candelabrum*, *Peridinium breve*, *P. umbonatum* were absent at 0‰, only appearing at salinities of 2‰ and 3‰ (Table 4). When salinity increased from 1‰ to 2‰, the mean density of dinoflagellates also increased from 1,200 cells L⁻¹ to 1,800 cells L⁻¹ (Table 4). Thus, saline intrusion into a typically freshwater environment triggered the appearance of toxic dinoflagellates, and their density increased with an increasing salinity. At the midstream site of Dai Ngai, where salinity ranged from 0 to 6‰, the number of dinoflagellate species (12 species) was the highest at 0‰ as at the upstream site of Cai Con. Species such as *Dictyocha fibula* var. *longispina*, *Glenodinium berolinense*, *Goniodoma sphaericum* and toxic *Peridinium* sp. were not recorded at a salinity of 0‰, but all appeared at salinities of 2-3‰ and above (Table 4). Cell densities also increased from 1,700 cells L⁻¹ to 3,000 cells L⁻¹ with an increasing salinity from 4‰ to 6‰ (Table 4).

Table 4
Dinoflagellates species composition in the sampling sites on the lower part of Hau River

(I)	Cai Con (upstream site)	Salinity (‰)					
		0	1	2			
1	<i>Ceratium candelabrum</i>	+		+			
2	<i>Ceratium candelabrum</i> f. <i>commune</i>	+					
3	<i>Ceratium furca</i>	+					
4	<i>Dictyocha fibula</i>	+					
5	<i>Dictyocha fibula</i> var. <i>longispina</i>	+					
6	<i>Dinophysis homunculus</i>	+					
7	<i>Glenodinium berolinense</i>	+					
8	<i>Glenodinium kulczynskii</i>	+					
9	<i>Glenodinium uliginosum</i>	+					
10	<i>Goniodoma sphaericum</i>	+					
11	<i>Gymnodinium neglectum</i>	+					
12	<i>Peridinium breve</i>	+		+			
13	<i>Peridinium</i> sp.	+					
14	<i>Peridinium umbonatum</i>	+	+				
15	<i>Sphaerodinium cinctum</i>	+					
Total	Number of species	15	1	2			
	Mean density (x 1,000 cells L ⁻¹)	1.2	1.2	1.8			
(II)	Dai Ngai (midstream site)	Salinities (‰)					
		0	2	3	4	5	6
1	<i>Ceratium candelabrum</i>	+	+	+			
2	<i>Ceratium candelabrum</i> f. <i>commune</i>	+					+
3	<i>Ceratium furca</i>	+				+	+
4	<i>Ceratium pennatum</i> var. <i>scapiforme</i>	+			+	+	
5	<i>Dictyocha fibula</i>	+	+				+
6	<i>Dictyocha fibula</i> var. <i>longispina</i>		+		+		
7	<i>Dinophysis homunculus</i>	+					
8	<i>Glenodinium berolinense</i>		+	+			
9	<i>Glenodinium kulczynskii</i>	+					
10	<i>Glenodinium uliginosum</i>	+					+
11	<i>Goniodoma sphaericum</i>			+			
12	<i>Gymnodinium neglectum</i>	+					
13	<i>Peridinium breve</i>	+	+		+		
14	<i>Peridinium</i> sp.			+	+		+
15	<i>Peridinium umbonatum</i>	+	+				
16	<i>Sphaerodinium cinctum</i>	+	+		+		
Total	Number of species	12	7	4	5	2	5
	Mean density (x 1,000 cells L ⁻¹)	1.0	2.2	2.0	1.7	2.3	3.0

(III)	Tran De (downstream site)	Salinities (‰)													
		0	1	2	3	4	6	7	10	11	15	16	18	20	
1	<i>Ceratium candelabrum</i>	+			+					+				+	
2	<i>Ceratium candelabrum f. commune</i>	+									+	+	+	+	
3	<i>Ceratium furca</i>	+		+							+				
4	<i>Ceratium pennatum var. scapiforme</i>	+					+			+			+	+	
5	<i>Dictyocha fibula</i>	+		+	+	+				+	+				
6	<i>Dictyocha fibula var. longispina</i>	+		+	+	+	+		+	+		+			
7	<i>Dinophysis homunculus</i>	+		+		+							+	+	
8	<i>Glenodinium berolinense</i>	+							+			+		+	
9	<i>Glenodinium kulczynskii</i>	+								+	+		+		
10	<i>Goniodoma sphaericum</i>	+	+				+		+			+			
11	<i>Gymnodinium neglectum</i>	+								+	+			+	
12	<i>Peridinium breve</i>	+		+		+				+			+		
13	<i>Peridinium sp.</i>		+		+			+	+	+		+	+	+	
14	<i>Peridinium umbonatum</i>	+						+	+		+				
15	<i>Sphaerodinium cinctum</i>	+		+						+			+	+	
	Number of species	14	2	6	4	4	5	3	4	12	4	5	6	7	
Total	Mean density (x 1,000 cells L ⁻¹)	1.0	0.5	0.5	1.4	0.2	1.3	1.7	1.2	1.8	2.3	1.3	2.2	2.5	

Salinity at the downstream site of Tran De varied widely from 0 to 20‰. The highest number of species were observed at 0‰ (14 species) and 11‰ (12 species). The species *C. candelabrum f. commune* was not present at 1-10‰ but were present at 11-18‰. Similarly, *G. neglectum* was not recorded until salinity increased to more than 11‰. Notably, *Peridinium sp.* was only found at all salinities higher than 1‰. As at Cai Con and Dai Ngai, the mean density of dinoflagellates at this site also increased with increasing salinity, from 1,300 cells L⁻¹ at 16‰ to 2,500 cells L⁻¹ at 20‰ (Table 4).

Correlation between water quality and distribution of dinoflagellates. The CCA analysis was applied to assess the correlation between the main water parameters including temperature, salinity, turbidity (NTU), total nitrogen (TN) and total phosphorus (TP), and species composition and distribution of the dinoflagellates. The results are illustrated in Figure 5 and show that all water parameters were significantly correlated with the composition of dinoflagellate populations on the lower part of Hau River. The eigenvalue of the model explained 69.4% of all the variability in the data, and salinity, TN and NTU were all strongly correlated with dinoflagellate composition. The presence and abundance of the toxic species *D. homunculus*, *Ceratium pennatum var. scapiforme*, *Sphaerodinium cinctum*, *Peridinium sp.* and *Glenodinium* were all positively and strongly correlated with salinity. In addition, *Ceratium candelabrum f. commune* and *Peridinium sp.* were closely correlated with TN. *G. berolinense* and *C. candelabrum* were closely correlated with turbidity. *Dictyocha fibula var. longispina* and *G. uliginosum* were significantly correlated with TP rather than with other water parameters (Figure 5).

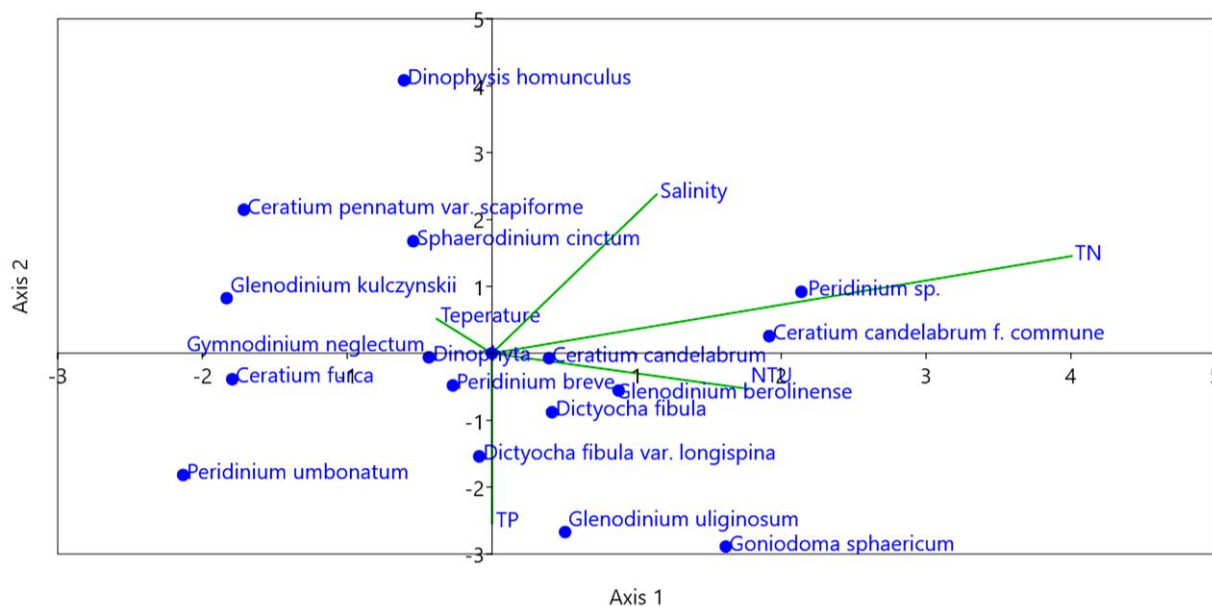


Figure 5. Results of CCA analysis between water parameters and composition of dinoflagellates (Eigenvalue: 69.4%).

Correlation between salinity and distribution of dinoflagellates. Principal Component Analysis (PCA) indicates the composition of dinoflagellate communities was significantly correlated with salinity, and when added together, PC1 and PC2 explained 76.7% of all the variability in the data, indicating that salinity was the main factor influencing the distribution of dinoflagellates (Figure 6). The majority of dinoflagellates species were distributed tightly at locations with salinities of 0, 2, 6, 11 and 18‰ (Figure 6). In particular, the distributions of *Peridinium breve*, *P. umbonatum*, *S. cinctum*, *Glenodinium uliginosum*, *Dinophysis homunculus*, *Dictyocha fibula*, *Ceratium furca* and *C. candelabrum f. commune* were significantly correlated with salinity, while the distribution of *Dictyocha fibula var. longispina*, *Glenodinium kulczynskii*, *G. sphaericum*, *G. neglectum* and *Peridinium sp.* were less strongly correlated with salinity, and the distribution of *Ceratium candelabrum*, *C. pennatum var. scapiforme* and *G. berolinense* was poorly correlated with salinity (Figure 6). Moreover, this figure also indicates that the species *Peridinium sp.* distributed closely with salinity of 10, 15 and 16‰. *G. uliginosum* and *C. candelabrum f. commune* thrived more at 6‰. Whereas, *C. furca*, *P. umbonatum* and *G. neglectum* were closely distributed to salinity of 0‰, 11‰, and *G. kulczynskii*, *P. breve*, *C. candelabrum* and *S. cinctum* were distributed at all sites with 2‰ (Figure 6). The strong correlation between the composition dinoflagellate communities and salinity, indicated by PCA, was confirmed by a simple linear regression model, which showed a statistically significant linear relationship between salinity and both the number of species and total population density (Table 5).

Table 5
Model of regression between salinity and composition of dinoflagellates under salinity variation

Criteria	Output	Value	Sig. value (p)
Number of appeared species (Y ₁)	Constants (b ₁)	2.3	0.000
	Coefficient (a ₁)	0.25	0.000
	Regression equation: Y ₁ = 0.25 x X + 2.3 (R ² =0.423)		0.000
	Constants (b ₂)	2,671	0.000
Densities (Y ₂)	Coefficient (a ₂)	647	0.000
	Regression equation: Y ₂ = 647 x X + 2,671 (R ² =0.529)		0.000

X indicates salinities on Hau River (‰).

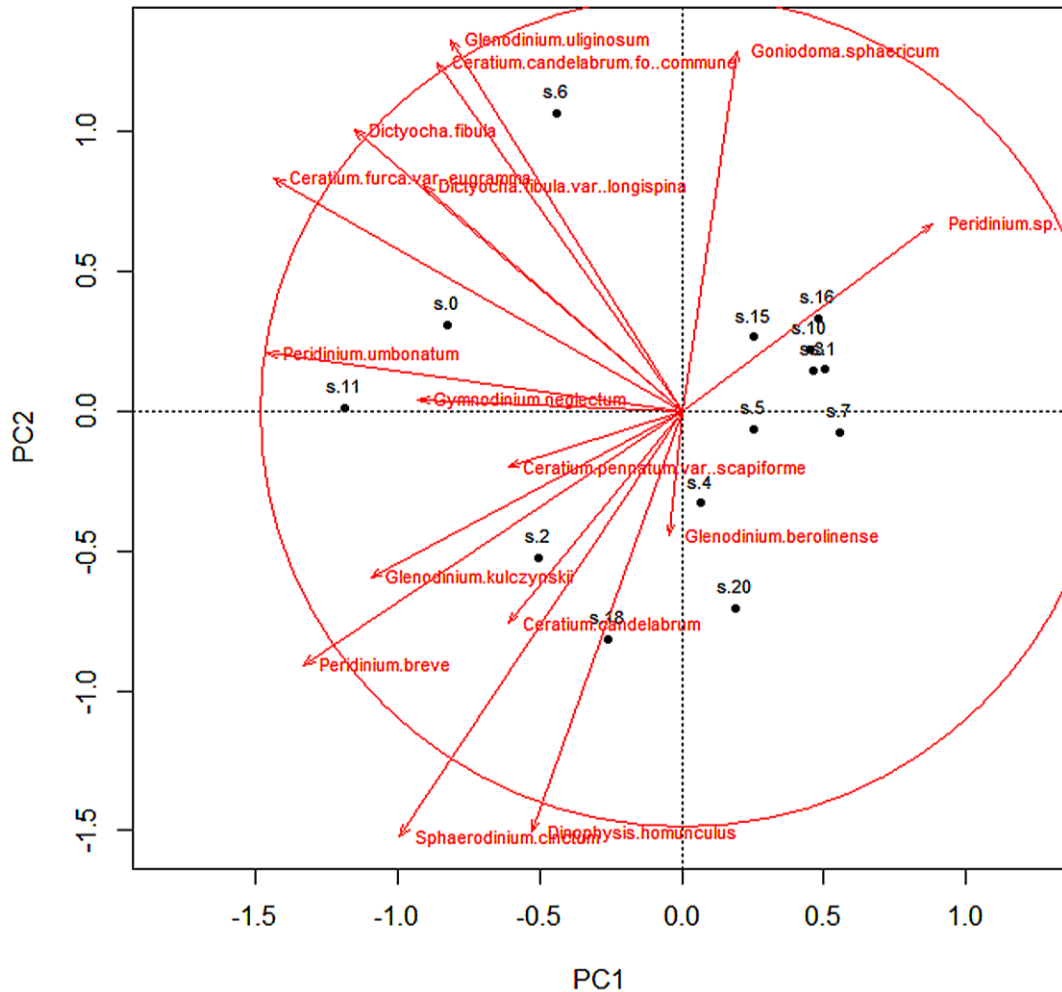


Figure 6. PCA biplot of the Hellinger-transformed 16 dinoflagellates species under different salinities on the lower part of Hau River (PC1 explained 27.7% var., PC2 explained 48.9% var.).

Discussion

Fluctuation of salinity on Hau River. The results obtained in the current study for changes in salinity with distance upstream from the mouth of the Hau River, and their seasonal and tidally driven patterns are qualitatively similar to those observed in previous studies of the Hau River (Binh et al 2018) and the Tien River, another branch of the Mekong (Hung et al 2018). Normally, strong river flow during the rainy season pushes freshwater well downstream and reduces salinity, even at the river mouth. However, as the flood season passes, tidally driven sea water propagates further upstream, leading to rising river salinities from saline intrusion, with higher salinities on the high tide than the low tide. Salinization from salt intrusion is becoming an increasingly serious problem in the Mekong Delta (Dat & Likitdecharote 2010; Anh et al 2018), and severe events such as that which occurred in 2018 impact adversely on agriculture, aquaculture and access to freshwater supplies (Anh et al 2018). This problem is likely to be exacerbated by rising sea levels and the construction of dams upstream on the Mekong River, which will change the fresh water flow regime in the lower Hau and Tien Rivers. Although water flow and hydrological regimes are dependent upon many factors and complicated to predict (Dat & Likitdecharote 2010), the flow can be described mathematically and modelled using computer simulation (MRC 2009) which has been shown to be a useful tool to predict saline intrusion for different river flows and rising sea level scenarios (Long et al 2016; Li et al 2017).

Effects of salinity on composition structure of Dinophyta on Hau River. The increase in species number and population density of dinoflagellates in the lower Hau River follow the same trends observed in other studies in the Mekong Delta (Au et al 2019), and in other geographical locations (Armi et al 2008; Muylaert et al 2009; Lueangthuwapranit et al 2011; Zina et al 2012; Angles et al 2015). Our results show that even small rise in salinity of 1-3‰ resulting from saline intrusion can lead to the presence of toxic dinoflagellates, as shown by the appearance of *C. furca*, *G. berolinense* and *P. umbonatum* in Cai Con (upstream site of river) and Dai Ngai (midstream site of river). This was particularly obvious in the midstream Dai Ngai area, where the toxic dinoflagellates *Dictyocha fibula* var. *longispina*, *G. berolinense*, *G. sphaericum* and *Peridinium* sp., which were not present at 0‰ salinity, were detected when the salinity rose to only 1-2‰ as a result of saline water intrusion from downstream. These dinoflagellate species have been shown to be toxic or harmful to aquatic animals or ecosystems (Hallegraeff 1987; Smayda 2002; Hallegraeff et al 2004; Khokhar et al 2022). In our investigation, in addition, the toxic dinoflagellates *C. furca*, *P. umbonatum*, *G. neglectum*, *G. kulczynskii*, *P. breve* and *C. candelabrum* all had a similar distribution and thrived at low salinity (<2‰). This could be a risk to aquaculture activities in downstream areas of the Hau River that are subject to slight saline intrusion, especially the culture of freshwater fish, white leg shrimp and black tiger shrimp. The dinoflagellate *C. furca* is one of the 70 toxic microalgae found in the coastal areas of Vietnam (Larsen & Nguyen 2004), and is responsible for creating red tide, a harmful algal bloom or HAB (Nguyen & Doan 1996). The presence of *C. furca* at all three sampling sites during periods of slight saline intrusion poses a significant potential risk to aquaculture activities in the lower Hau River and neighboring coastal estuaries. Consequently, consideration must be given to the potential for outbreaks of toxic dinoflagellate blooms when using the water for aquaculture in areas between Cai Con and Dai Ngai during periods of saline intrusion. Furthermore, the optimal salinity for the culture of white leg shrimp is 15-25‰ (Boyd 1989), so high densities of dinoflagellates, notably *G. uliginosum*, *C. candelabrum* f. *wage*, *C. furca*, *P. umbonatum* and *G. neglectum*, also need to be considered when white leg shrimp is cultured at sites like Tran De close to the river mouth. In addition, the presence of toxic dinoflagellates due to saline intrusion could also have adverse effects on natural food webs and wild aquatic animals in the lower Hau River.

Conclusions. The species composition of dinoflagellates 60 km upstream from the mouth of the Hau River during the rainy season was less diverse and typical of freshwater or oligohaline dinoflagellate communities. However, during the dry season, saline intrusion caused a shift in the composition of dinoflagellate communities, with the appearance of number of harmful dinoflagellate species. Only a small increase in salinity could be sufficient to cause adverse impacts in aquaculture and other aquatic systems from toxic dinoflagellates in the Mekong Delta.

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References

- Angles S., Jordi A., Campbell L., 2015 Responses of the coastal phytoplankton community to tropical cyclones revealed by high-frequency imaging flow cytometry. *Limnology and Oceanography* 60:1562-1576.
- Anh D. T., Long H. P., Duc B. M., Rutschmann P., 2018 Simulating future flows and salinity intrusion using combined one and two-dimensional hydrodynamic modelling - The case of Hau River, Vietnamese Mekong Delta. *Water* 10(897):1-21.

- Armi Z., Turki S., Trabelsi E., Maiz N. B., 2008 Nutrient loading and occurrence of potentially harmful phytoplankton species in the North Lake of Tunis (Tunisia). *Cahiers de Biologie Marine* 49:311-321.
- Au V. H., Lien N. T. K., Phuong N. T., Giang H. T., Ut V. N., 2019 [Correlation between salinity changes and species composition of dinophyta on My Thanh estuary area, Soc Trang]. *Journal of Fisheries Science and Technology, Nha Trang university* 4:41-49. [In Vietnamese].
- Bellinger E. G., Sigeo D. C., 2010 *Fresh water algae: Identification and use as Bio-indicator*. Wiley-Blackwell Publishing House, 271 p.
- Binh V. D., Kantoush S., Sumi T., Nguyen P. M., La V. T., 2018 Field investigations on river bed changes and salinity intrusion along Tien and Hau Rivers in Vietnamese Mekong Delta considering upstream dam's impacts. *Disaster Prevention Research Institute Annuals* 61(B):770-783.
- Boyd C. E., Tucker S. C., 1992 *Water quality and pond soil analyses for aquaculture*. Auburn University, Alabama 36849:139-148.
- Boyd C. E., 1989 *Water quality management and aeration in shrimp farming*. 2nd ed. Alabama Fisheries and Allied Aquacultures Department, Agricultural Experiment Station, Auburn University, Alabama, USA, 83 p.
- Camacho G. F., Rodriguez G. J., Miron A. S., Garcia M. C. C., Belarbi E. H., Chisti Y., Grima E. M., 2007 Biotechnological significance of toxic marine dinoflagellates. *Biotechnology Advances* 25:176-194.
- Dang T. S., 2005 [Sciences of algae]. Ha Noi National University Publishing House, 191 p. [In Vietnamese].
- Dat T. Q., Likitdecharote K., 2010 Effect of sea level rise and low flow on salinity intrusion in Mekong Delta. *GMSTEC 2010: International Conference for a Sustainable Greater Mekong Subregion*, Bangkok, Thailand, pp 26-27.
- Duong D. T., Vo H., 1997 [Freshwater algae of Vietnam]. Vietnam Agricultural Publishing House, 503 p. [In Vietnamese].
- Glasgow H. B. J., Burkholder J. M., Schmechel P. A., Tester P. A., Rublee P. A., 1995 Insidious effects of a toxic estuarine dinoflagellate on fish survival and human health. *Journal of Toxicology and Environmental Health* 45:501-522.
- Hallegraeff G. M., 1987 *Red tide in the Australasian Region*. CSIRO Marine Laboratories Report 187, 19 p.
- Hallegraeff G. M., Anderson D. M., Cembella A. D., Enevoldsen H. O., 2004 *Manual on harmful marine microalgae*. 2nd revised edition. Paris, France, UNESCO, Monographs on Oceanographic Methodology 11, 793 p.
- Hoanh C. T., Guttuman H., Droogers P., Aerts J., 2003 *Water, climate, food, and environment in the Mekong basin in South Asia*. Final report, contribution to the adaption strategies to changing environment ADAPT project. International Water Management Institute, 57 p.
- Hung N. D., Ngot P. V., Toan E. Q. V., Thuy V. T. B., 2018 [Survey of salinity of surface water and pore water in some mangrove vegetation along Tien River, Tien Giang province]. *Journal of Natural Science and Technology, Ho Chi Minh City University of Education of Vietnam* 15(6):156-169. [In Vietnamese].
- Ibrahim A. M. M., 2007 Review of the impact of harmful algae blooms and toxins on the world economy and human health. *Egyptian Journal of Aquatic Research* 33(1):210-223.
- Khokhar F. N., Ahmedb N., Alia A., Gabolc K., Khooharoa A. R., Faheemc M., Hussainc A., Burhana Z. N., Siddiquia P. J. A., 2022 Distribution and abundance of dinoflagellates from the coastal waters of Karachi, Pakistan, northern part of the Arabian Sea. *Brazilian Journal of Biology* 82:1-14.
- Larsen J., Nguyen N. L., 2004 Potentially toxic microalgae of Vietnamese waters. *Opera Botanica* 140:5-216.
- Li D., Long D., Zhao J., Lu H., Hong Y., 2017 Observed changes in flow regimes in the Mekong River basin. *Journal of Hydrology* 551:217-232.

- Linares J. P., Ochoa J. L., Martinez A. G., 2009 Retention and tissue damage of PSP and NSP toxins in shrimp: Is shrimp a potential vector of toxins to human population? *Toxicon* 53:185-195.
- Long P. H., Lauri H., Kumm M., Koponen J., Van V. M., Supit I., Leemans R., Kabat P., Ludwig F., 2016 Mekong River flow and hydrological extremes under climate change. *Hydrology and Earth System Sciences* 20:3027-3041.
- Lueangthuwapranit C., Sampantarak U., Wongsai S., 2011 Distribution and abundance of phytoplankton: influence of salinity and turbidity gradients in the Na Thap River, Songkhla Province, Thailand. *Journal of Coastal Research* 27:585-594.
- Matsuyama Y., 1999 Harmful effect of dinoflagellate *Heterocapsa circularisquama* on shellfish aquaculture in Japan. *Japan Agricultural Research Quarterly* 33:283-293.
- Moestrup O., Hansen G., Daugbjerg N., Lundholm N., Overton J., Vesterg M., Jorgen S., Antonio S., Calado J., Hansen P. J., 2014 The dinoflagellates *Pfiesteria shumwayae* and *Luciella masanensis* cause fish kills in recirculation fish farms in Denmark. *Harmful Algae* 32:33-39.
- Muylaert K., Koen S., Vyverman W., 2009 Changes in phytoplankton diversity and community composition along the salinity gradient of the Schelde estuary (Belgium/The Netherlands). *Estuarine, Coastal and Shelf Science* 82:335-340.
- Nabb F. S., Rhodes L., Holland P., Webb S., Adamson J., Immers A., Gooneratne R., Holland J., 2012 The toxic effects of three dinoflagellate species from the genus *Karenia* on invertebrate larvae and finfish. *New Zealand Journal of Marine and Freshwater Research* 46(2):149-165.
- Nguyen N. L., Doan N. H., 1996 Harmful marine phytoplankton in Vietnam water. *Proceeding of International Conference on Toxic Phytoplankton* 7:45-48.
- Nhan D. K., Be N. V., Trung N. H., 2007 Water use and competition in the Mekong Delta, Vietnam. *Challenges to Sustainable Development in the Mekong Delta: Regional and National Policy Issues and research Needs. The Sustainable Mekong Research Network*, pp. 143-188.
- Nielsen D. L., Brock M. A., Rees G. N., Baldwin D. S., 2003 The effect of increasing salinity on freshwater ecosystem in Australia. *Australian Journal of Botany* 51:655-665.
- Nielsen L. T., Hansen P. J., Krock B., Vismann B., 2016 Accumulation, transformation and breakdown of DSP toxins from the toxic dinoflagellate *Dinophysis acuta* in blue mussels *Mytilus edulis*. *Toxicon* 117:84-93.
- Shirota A., 1966 The plankton of South Vietnam-Freshwater and marine plankton. Overseas Technical Cooperation Agency, Japan, 179 p.
- Smayda T. J., 2002 Turbulence, watermass stratification and harmful algal blooms: an alternative view and frontal zones as "pelagic seed banks. *Harmful Algae* 1:95-112.
- Smayda T. T., Reynolds C. S., 2003 Strategies of marine dinoflagellate survival and some rules of assembly. *Journal of Sea Research* 49:95-106.
- Sunada K., 2009 Study on Asian River Basin. CREST Asian River Basins: Water Policy Study Team, 258 p.
- Truong N. A., 1993 [Taxonomy of marine silic-phytoplankton of Vietnam]. Publishing House of Science and Technology of Vietnam, 315 p. [In Vietnamese].
- Tuan L. A., Hoanh C. T., Miller F., Sinh B. T., 2007 Flood and salinity management in the Mekong Delta, Vietnam. *Challenges to sustainable development in the Mekong delta: Regional and national policy issues and research needs: Literature analysis. Bangkok, Thailand: The Sustainable Mekong Research Network (Sumernet)*, pp. 15-68.
- Zhou Z. X., Yu R. C., Zhou M. J., 2017 Seasonal succession of microalgal blooms from diatoms to dinoflagellates in the East China Sea: A numerical simulation study. *Ecological Modelling* 360(C):150-162.
- Zina A., Elbahri T., Souad T., Naceur B. M., Ezzeddine M., 2012 Composition and dynamics of potentially toxic dinoflagellates in a shallow Mediterranean lagoon. *Oceanological and Hydrobiological Studies* 41:25-35.

- Zorina-Sakharova K., Liashenko A., Marchenko I., 2014 Effects of salinity on the zooplankton communities in the Fore-Delta of Kyliya Branch of the Danube River. *Acta Zoologica Bulgarica* 7:129-133.
- *** APHA, American Water Works Assn, 2012 Standard methods examination water wastewater. 22th edition. American Water Works Assn, 1496 p.
- *** IPCC, 2007 Fourth assessment report: Climate change 2007. Working Group I Report "The Physical Science Basis", 1007 p.
- *** MRC, Mekong River Council, 2009 The flow of the Mekong. MRC Management Information booklet series No. 2, 12 p.

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