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MARINE BIOLOGY

Features of the Spatial Distribution of Phytoplankton in Nhatrang Bay of the South China Sea during the Rainy Season

L. V. Ilyash and D. N. Matorin

Biological Faculty, Moscow State University, Moscow, Russia
e-mail: ilyashl@mail.ru

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Abstract—The species composition, phytoplankton abundance, and relative yield of the variable fluorescence (F_v/F_m) were determined in the mesotrophic Nhatrang Bay in October–November of 2004. The species diversity (250 taxonomic units) and heterogeneity of the phytoplankton structure were high. With respect to the number of species and their abundance, diatoms prevailed. In selected parts of the bay, dinoflagellates dominated. The mean biomass in the water column under 1 m^2 (B_t) varied from 2.3 to 64.4 mg C/m^3 being 31.0 mg C/m^3 on average. The values of B_t were the lowest at the stations nearest to the river mouth. Seaward, B_t increased. The values of B_t increased with depth at some stations and decreased at others. In the surface sea layers, the biomass was lower than that in the underlying waters. The values of F_v/F_m ranged from 0.10 to 0.64 (at a mean value of 0.49). The lowest values of F_v/F_m were observed in the area close to the seaport. Over the greater part of the bay, the values of F_v/F_m were higher than 0.47. Such values are indicative of the relatively high potential photosynthetic activity of the phytoplankton. The abundance and species diversity were higher than those in the dry season (March–April).

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INTRODUCTION

The contribution of near-shore ecosystems to the primary production formed owing to nitrate assimilation (new production) comprises from 27 to 57% of the total new primary production of the World Ocean [7, 21]. The significance of near-shore ecosystems in the global cycling of carbon defines the necessity of studies of neritic phytoplankton communities aimed at the revelation of the principal factors that determine the seasonal dynamics, spatial distribution, and functional characteristics of planktonic algae. The South China Sea is the largest marginal sea of Southeast Asia; it extends from the equator to 23°N. The basin is characterized by a wide continental shelf with sea depths less than 100 m. At the low level of productivity in the open parts of the sea except for three upwelling regions [8, 15, 22], its near-shore areas and, in particular, Nhatrang Bay are mesotrophic [2]. The riverine runoff represents the main nutrient source for Nhatrang Bay [18] as well as for other coastal areas of the South China Sea [23]. The runoff volume increases during the season of intensive precipitation, which, in Nhatrang Bay, lasts from October to January (rainy season). From January to September, the precipitation is low (dry season); its minimums are observed in February and March and August [18].

Earlier, the species composition, abundance, and functional condition of the phytoplankton, as well as its spatial distribution, in Nhatrang Bay were estimated in the low precipitation period (March–April) [2, 3]. Then, the principal factors influencing the structure and photosynthetic activity of the phytoplankton during the dry season were outlined. Up to the present, the spatial distribution and functional characteristics of the Nhatrang Bay phytoplankton during the period of intensive precipitation have not been studied.

The objective of this study was to estimate the abundance and functional parameters of the phytoplankton at different sites in the Nhatrang Bay area during the rainy season (using the example of October–November) and to reveal the particular features of the spatial and vertical distributions of the alga abundance and their functional characteristics in this period.

MATERIALS AND METHODS

The materials for the studies were collected in Nhatrang Bay of the South China Sea on October 29–30 (cruise 1) and November 9 (cruise 2) 2004 at 15 stations (Fig. 1). The amount of precipitation in October before the cruise performance was 365 mm. A small precipitation was noted between cruises 1 and 2 (30 mm).

General Characteristic of the Region under Study

The area of Nhatrang Bay involves a region from 12°08′ to 12°24′N and from 109°10′ to 109°23′E. Together with the islands, the area of the bay is about 310 km^2. The bay is relatively shallow-water; the 50-m depth contour line runs beyond 109°20′E. The Kai River and a few smaller rivers enter the bay. In the cen-

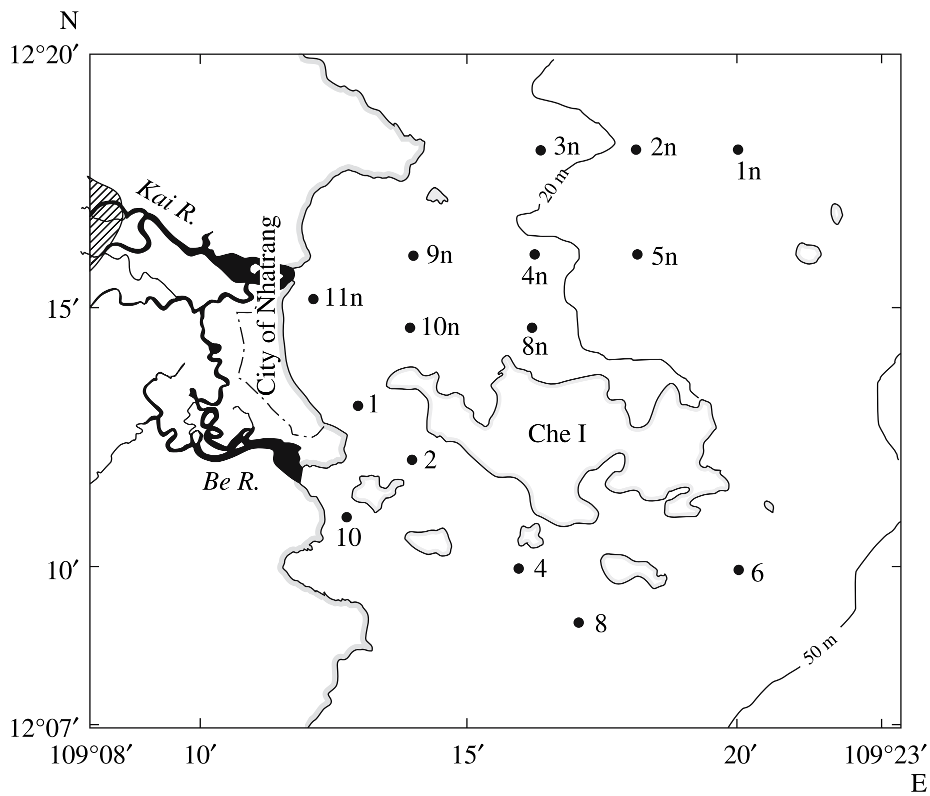

Fig. 1. Station location in Nhatrang Bay.

tral part of the area, Chemical Island, which is the largest in the bay, is located; with respect to this island, the bay area is conventionally subdivided into its northern and southern parts.

In October–November, northeastern monsoon dominates the region of the bay; the mean monthly precipitation and water discharge in the Kai River reach their annual maximums [18]. The main riverine runoff follows along the eastern edge of the Che Peninsula toward the southern part of the bay. During the rain period, the concentrations of mineral forms of phosphorus and nitrogen in the bay range within 5–50 and 0.2–1.6 μmol, respectively [18].

Sampling and Estimation of the Fluorescence Proteins of Phytoplankton

At each station, water samples 3 l in volume were collected with a 10-l bottle sampler from two or three layers (Table 1). The water salinity in the samples collected was determined using a Japan-made portable salt meter–refractometer.

The measurements of the fluorescence parameters of phytoplankton were performed after a 4-h-long sample incubation in dark with the use of an on-board fluorimeter designed at the Biological Faculty of the Moscow State University [5]. The fluorimeter helps to estimate the permanent (F_o) and maximal (F_m) lfc values and the relative yield of the variable fluorescence (F_v/F_m) of algae. The parameter F_v/F_m characterizes the efficiency of the primary photochemical transformation of the light energy in reaction centers of photosystem 2. The values of F_v/F_m for dark-adapted algae are regarded as an indicator of the potential photosynthetic activity of phytoplankton [20]. In our study, we also used the in situ data on the relative yield of the variable phytoplankton fluorescence (in situ (F'_v/F'_m)) obtained in October–November 2003 with the use of a dropped pump-and-probe fluorimeter, which registered the parameters in a virtually continuous mode [4].

Quantitative Accounting of Phytoplankton

In order to quantitatively account for phytoplankton, samples 1–2 l in volume were concentrated using the reverse filtration technique (filters with a pore diameter of 1.9 μm) and fixed with a 4% neutralized formalin; phytoplankton was counted under a light microscope in a Nageotte chamber 0.05 ml in volume. The microscopic processing of phytoplankton samples was performed in the Museum of Natural History, Paris, France. Wet biomass was determined using the geometric similarity method [12]. In order to estimate the value of biomass (B) in carbon units, the cell contents of organic carbon depending on the cell volume were calculated from allometric equations [16].

Table 1. Sea depths at the stations, the sampling depths, the saliniy (S), the phytoplankton biomass at individual levels (B), the phytoplankton biomass averaged over the water column (B_t), the phytoplankton biomass under an area of 1 m^2 (B_Σ), and the relative yield of the variable fluorescence of algae (F_v/F_m)

Station no.	Depth, m	S, ‰	B, mg C/m^3	F_v/F_m	B_t, mg C/m^3 / B_Σ, mg C/m^2
October 29, 2004					
11n, 16	2	27.5	2.97	0.50	6.4/103
	5	27.5	8.90	0.56	
	10	28.0	6.65	0.52	
9n, 16	2	31.0	1.02	0.48	2.3/37
	5	31.5	4.13	0.48	
	15	31.5	1.03	0.46	
10n, 16	5	30.5	9.00	0.50	4.6/74
	10	31.5	0.74	0.50	
8n, 19.2	5	31.5	7.97	0.50	7.1/136
	10	32.5	2.20	0.52	
	15	32.5	10.00	0.52	
1, 21.7	5	28.5	4.38	0.10	5.3/114
	10	29.0	4.80	0.15	
	15	29.0	6.69	0.21	
2, 28	5	29.5	13.97	0.10	30.5/322
	10	30.0	3.03	0.21	
	15	30.0	47.37	0.25	
October 30, 2004					
4, 22.6	5	30.0	29.74	0.61	22.0/494
	10	30.0	9.13	0.60	
	15	30.5	22.54	0.56	
8, 28.5	5	30.5	29.22	0.61	34.5/967
	10	30.5	64.40	0.60	
	15	31.0	27.44	0.62	
6, 35	5	30.5	23.45	0.49	33.7/1180
	15	31.5	18.28	0.46	
	30	32.0	50.83	0.60	
10, 10	2	30.0	36.81	0.63	30.2/302
	7	30.5	24.76	0.62	
November 9, 2004					
1n, 32	5	32.5	55.0	0.56	63.7/1911
	15	32.5	75.2	0.56	
	30	32.5	56.1	0.60	
2n, 25	5	32.5	45.4	0.57	54.4/1360
	15	32.5	56.0	0.56	
	20	32.5	64.8	0.57	
3n, 16	5	30.5	39.7	0.54	64.4/1031
	10	30.5	90.8	0.56	
	15	31.0	62.9	0.57	
4n, 18.5	5	31.5	52.3	0.56	56.6/1052
	10	31.5	45.3	0.59	
	15	32.5	72.2	0.62	
5n, 22.6	5	32.0	41.2	0.53	50.7/1141
	15	32.5	58.3	0.52	

At stations 8n, 10n, 4, 8, and 6, qualitative net plankton samples were collected. A big Juday net with an opening 0.1 m^2 in diameter and a filtering cone made of capron no. 43 was used as the sampling instrument. Fixed qualitative samples were looked through to recognize large individuals of rare species; then they were used to make permanent alga preparations.

The statistical processing of the data was performed using the PRIMER software package for analysis of ecological data, version 5.2.4). The relative contributions of algae to the total biomass (averaged over the water column under a square 1 m^2 in size) converted using the square root method were regarded as the characteristics of the phytoplankton structure. The similarity of the structure was estimated using Bray–Curtis index, which is sensible to the changes in the r4lv abundances of both rare and dominating species. Then, the communities were sorted using the multiscaling technique [10].

RESULTS

Abiotic Conditions

The temperature of the surface layer of 0–5 m was 27–28°C; in the layer of 5–15 m, it equaled 26–27°C. The salinity in the 5-m surface layer varied from 27.5 to 32.5‰ (Table 1). At stations with reduced salinity of the surface layer, the salinity grew with depth. The maximal irradiance in the subsurface layer at noon reached 800 μE/(m^2 s). At all the stations, the irradiance in the near-bottom layer exceeded 1% of the surface value; this means that the photic zone involved the entire water column. The only exception was represented by station 2, where the photic zone involved the layer from 0 to 20 m. At the levels of 5 and 15 m, the irradiance values were 13–44% and 2–17% of the subsurface value, respectively.

Phytoplankton Biomass

The mean phytoplankton biomass in the water column (B_t) varied from 2.3 to 64.4 mg C/m^3 (being 31.0 mg C/m^3 on average at a variation coefficient of 73%). The lowest B_t values were observed at the stations closest to the Kai River mouth (Table 1). The values of B_t grow toward the open sea. The higher biomass at stations 1n to 5n (cruise 2, that was performed ten days after the first cruise) may be, to a certain extent, caused by the active alga growth. This is indirectly indicated by the high values of (F_v/F_m (Table 1).

Fluorescence Parameters of the Phytoplankton

The relative yield of the variable fluorescence (Table 1) changed from 0.10 to 0.64 (at an average value of 0.49 and a variation coefficient of 29%). The lowest values of F_v/F_m were registered at stations 1 and 2 located in the region adjacent to the port of the city of Nhatrang. The low F_v/F_m values noted in this location might be caused by the impact of toxic anthropogenic compounds. At other stations, the values of F_v/F_m averaged over the water column were higher than 0.47. The values of $F_v/F_m > 0.4$ indicate the relatively high potential photosynthetic activity of the phytoplankton and its good physiological condition [4, 11]. In October–November 2003, the in situ values of F'_v/F'_m of the phytoplankton averaged over the water column (without dark adaptation) changed from 0.15 to 0.57 (at an average value over the bay of 0.44 with a variation coefficient of 21%). Low F'_v/F'_m values were noted at station 2 and over coral colonies along the southern coast of Che Island.

Phytoplankton Composition

In total, 250 taxonomic units of algae were noted, among them were 180 diatoms, 63 dinophytes, 4 cyanobacteria, and nonidentified flagellate algae; silicoflagellates and coccolithophorids were represented by a single unit each. In terms of the species number, the most diverse are the *Chaetoceros* (33 species), *Ceratium* (19 species), *Thalassiosira* (17 species), *Rhizosolenia* (14 species), *Protoperidinium* (11 species), *Coscinodiscus* (10 species), and *Amphora* (9 species) genera.

The algae that participate in the phytoplankton composition had different frequencies of occurrence in the bay area (Fig. 2). At all the stations, *Thalassionema nitzschioides* and nonidentified flagellates were encountered. About one-third (66 species) of the alga species such as, for example, *Asterolampra grevillei, Thalassiothrix spathulata, Dinophysis miles, Protoperidinium oceanicum*, and *Ceratocorys gourretii* were registered only at a single station. The *Coscinodiscus asteromphalus, C. oculus-iridis, Rhabdonema adriaticum, Rhizosolenia formosa, Ceratium carriense, C. breve, C. candelabrum, C. extensum, C. furca, C. pavillardii, C. ranipes*, and *C. vultur* algae were noted only in qualitative net samples, which seems to be related to their low abundance.

Over the greater part of the bay area, the main contribution to the B_t value is provided by diatom algae (Table 2). Dinophytes prevail at stations 8n, 9n, and 10n. The proportion of heterotrophic representatives in the total dinoflagellate abundance at individual depth levels comprised from 0% to 89%. The greatest contribution of heterotrophic dinoflagellates was registered at station 2n at the 20-m level, where *Protoperidinium depressum* was the species that dominated with respect to the biomass. The highest relative abundance of flagellate algae was noticed at station 1.

Individual regions of the bay differ in the composition of the algae that provide the greatest contribution to B_t (Table 3). The contribution of the first abundant species from the list of algae sorted with respect to the biomass varied from 11 to 78%. The best-manifested domination was observed at the stations with the lowest phytoplankton abundances. Many of the algae that made the greatest contribution to B_t in the autumn belong to mass forms that dominated in March–April as well [2, 3].

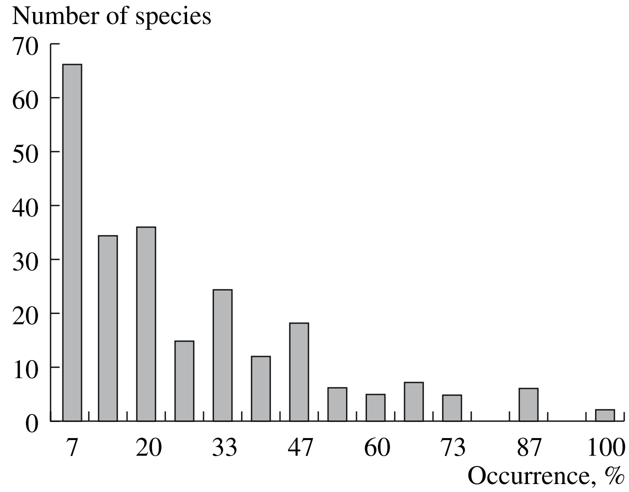

Fig. 2. Occurrence of planktonic algae in the autumn period.

About 40 species of benthic and epiphyte algae such as *Amphora* spp., *Hemidiscus cuneiformis, Diploneis*

Table 2. Contribution (B, %) of alga groups to the total phytoplankton biomass in the water column under an area of 1 m^2

Station no.	B, %				
	Bacillariophyta	Dinophyta	Cyanobacteria	Nonidentified flagellates	Silicoflagellates and coccolithophorids
11n	66.43	30.27	1.65	1.65	–
9n	38.00	50.50	7.60	3.90	–
10n	31.70	62.70	–	5.60	0.10
8n	41.45	55.93	0.27	2.11	0.23
1	6.10	40.20	–	53.70	–
2	70.40	2.00	–	27.60	–
4	30.40	17.50	0.60	15.10	–
8	78.73	20.35	0.03	0.84	0.05
6	76.50	17.40	1.30	4.80	0.10
10	76.30	22.70	1.00	1.00	0.10
1n	85.48	13.31	0.02	1.13	0.06
2n	81.21	17.45	–	1.33	0.02
3n	81.84	17.43	–	0.63	0.03
4n	88.23	10.27	0.04	0.02	0.01
5n	86.54	12.93	–	0.52	0.01

Table 3. Contribution (B, %) of the three most abundant algae to the total phytoplankton biomass in the water column under an area of 1 m^2

Station no.	B, %
11n	*Thalassiosira mala* – 23; *Coscinodiscus gigas* – 22; *Gymnodinium* spp. –15
9n	*Alexandrium affine* – 42; *Coscinodiscus gigas* – 28; *Tolypothrix* sp. – 8
10n	*Pyrocystis fusiformis* – 37; *Protoperidinium jorgensenii* – 18; *Coscinodiscus gigas* – 16
8n	*Alexandrium affine* – 42; *Coscinodiscus jonesianus* – 28; *Protoperidinium oceanicum* – 7
1	Flagellates – 54; *Alexandrium affine* – 22; *Protoperidinium incognitum* – 11
2	*Coscinodiscus concinnus* – 60; lagellates – 28; *Rhizosolenia styliformis* – 5
4	*Coscinodiscus concinnus* – 29; *Pyrocystis fusiformis* – 23; flagellates – 15
8	*Gymnodinium* spp. – 15; *Thalassiosira mala* – 14; *Odontella mobiliensis* – 9
6	O*dontella mobiliensis* – 22; *Guinardia striata* – 15; *Rhizosolenia styliformis* – 10
10	*Palmeria hardmaniana* – 11; *Odontella mobiliensis* – 11; *Gymnodinium* spp. – 10
1n	*Gymnodinium* spp. – 9; *Lauderia annulata* – 9; *Odontella mobiliensis* – 5
2n	*Protoperidinium depressum* – 11; *Bacteriastrum furcatum* – 10; *Lauderia annulata* – 9
3n	*Protoperidinium depressum* – 12; *Guinardia delicatula* – 11; *Ditylum brightwellii* – 9
4n	*Lauderia annulata* – 16; *Bacteriastrum furcatum* – 10; *Guinardia delicatula* – 8
5n	*Cerataulina pelagica* – 27; *Lauderia annulata* – 10; *Guinardia delicatula* – 7

spp., *Mastogloia* spp., *Navicula directa, Pleurosigma tahitianum, Surirella fastuosa, Trachyneis* spp., *Triceratium* sp. and others were encountered in the composition of the phytoplankton. At individual stations, the number of benthic forms ranged from 2 (station 1) to 16 (station 5n) species. *Pleurosigma angulatum* and *P. dutorium* algae were encountered at most of the stations. The total contribution of benthic forms to the B_t value was from 1% (stations 8 and 2n) to 43% (station 9n).

Phytoplankton Similarity

The similarity of phytoplankton at different stations calculated from the relative contributions of algae to B_t shows significant differences between the phytoplankton structures in individual areas of the region (Fig. 3). The greatest similarity is observed for the phytoplankton from the seaward northern part of the bay (stations 1n, 2n, 3n, 4n, and 5n). The high similarity was provided by the following algae (characteristic species): *Lauderia annulata, Guinardia striata, Chaetoceros coarctatus, Cerataulina pelagica, Bacteriastrum furcatum, Ceratium fusus, Chaetoceros affinis, Protoperidinium depressum*, and *Gymnodinium* spp. Their integrated biomass at stations 1n, 2n, 3n, 4n, and 5n comprised 34–57% of the B_t values. The group of species that defines the originality of the phytoplankton structure at the stations whose data in the “similarity field” are located on the left-hand side with respect to those of stations 1n, 2n, 3n, 4n, and 5n included *Leptocylindrus danicus, Lioloma pacificum, Coscinodiscus jonesianus, C. concinnus, C. gigas, Actinocyclus curvatulus, Alexandrium affine*, and flagellate algae. Their integrated biomass at stations 2 and 1, which are the most different in the phytoplankton structure, reached 90%–77%, while, at the stations with the highest similarity, it never exceeded 4%. The significant distinction of the phytoplankton structure at station 8, whose data are located upward from the stations with high similarity, was provided by the *Protoperidinium oceanicum, Coscinodiscus concinnus, C. jonesianus*, and *Alexandrium affine* algae (with a total contribution of 78%), while, at stations 11n, 10n, and 9n lying below them, *Coscinodiscus gigas, Actinocyclus curvatulus, Hemiaulus sinensis*, and *Pyrocystis fusiformis* dominated with an integrated contribution of 15–78%. In the 5-m surface layer, the similarity of the phytoplankton is the same as that calculated for the entire water column. In so doing, the stations subjected to the strongest freshening (11n, 9n, 10n, 1, and 2) differ from the seaward stations even more significantly. In addition to the characteristic species such as *Lauderia annulata, Cerataulina pelagica, Bacteriastrum furcatum*, and *Gymnodinium* spp., which are common both in the surface phytoplankton and in the phytoplankton in the water column, the characteristic algae of the surface layer also included *Bacteriastrum minus, Chaetoceros affinis, Ditylum sol*, and *Rhizosolenia imbricata.* The set of algae that provided the particularity of the structure of the subsurface phytoplankton consisted of *Coscinodiscus concinnus* (station 4), *C. gigas* (stations 11n and 9n), *Alexandrium affine* (station 8n), and flagellate algae (stations 1, 2, and 4).

On the seaward sides of the northern (stations 1n, 2n, 3n, 4n, and 5n) and southern (stations 6 and 8) parts of the bay, the phytoplankton is more uniform than in the inner bay areas (except for station 10). This is probably related to the more homogeneous abiotic conditions in the seaward part of the bay. In the inner part of the bay, the phytoplankton variability may be caused by the weakening of the impact of the riverine runoff in the direction from the Kai River mouth toward the open sea; it is accompanied by a decrease in the freshening of the surface waters and by an increase in the underwater irradiance owing to the reduced concentration of terrigenous particulate matter. A significant role in the variability of the phytoplankton structure in the inner part of the bay also belongs to the differences in the sea depths at the individual sites. At shallow-water stations, the number and abundance of benthic forms increases. One also cannot ignore the impact of the anthropogenic factor such as the presence of the port.

Phytoplankton Size Structure

The volumes of the cells of the algae encountered (W) differed by seven orders of magnitude: from 0.03 th. μm^3 to 19068 th. μm^3. On the logarithmic scale ($\ln W$), this range was subdivided into six size groups with a step of 2 units. At 11 stations, most of the algae referred to the size group with $\ln W$ from 9 to 11. At four stations, the most representative was the alga group with $\ln W$ from 7 to 9. In terms of their contribution to B_t, small algae ($\ln W = 3$–5) dominated only at station 1, while the largest algae ($\ln W = 13$–15) provided the greatest contribution at seven stations (Table 4). This domination of large-sized algae is probably related to the provision of the algae with nutrients and intensive mixing in the water column, which prevented large diatom algae from sinking. In March–April, virtually over the entire bay area, the major contribution to the total biomass was made by the algae of the size group with $\ln W$ from 9 to 11 [3].

Vertical Distribution of Phytoplankton

Four types of profiles were distinguished in the vertical distribution of the alga biomass (Table 1): (1) increasing with depth (stations 1, 2n), (2) decreasing with depth (stations 10n, 10), (3) the biomass at the “middle” level (10 or 15 m) being higher than those in the overlying and underlying layers (stations 11n, 9n, 8, 1n, 3n, 5n), and (4) the biomass at the “middle” level being lower than those in the overlying and underlying layers (stations 8n, 2, 4, 6, 4n). The lower values of the phytoplankton biomass in the surface layer are characteristic of the regions close to the Kai River mouth, which are subjected to a more significant freshening.

The relative yields of the variable fluorescence after the dark adaptation for the phytoplankton samples collected at different depths were virtually equal (Table 1). Similarly, no noticeable differences in the values of F_v/F_m for phytoplankton from the subsurface and underlying layers were noted at stations with a clearly manifested salinity gradient (stations 11n, 10n, 4). According to the data of 2003 (Table 5), the values of F'_v/F'_m for the in situ phytoplankton (without dark adaptation) in the subsurface layer were confidently lower than those in the underlying layers. A comparison of the vertical distributions of the F_v/F_m values of the phytoplankton adapted to the dark (2004) and the F'_v/F'_m values of the in situ phytoplankton (2003) suggests the following: (1) the salinity gradient is not responsible for the decrease in the in situ phytoplankton activity in the subsurface layer, and (2) the alga occurring in the subsurface layer are, to a certain extent, subjected to the stress caused by photoinhibition.

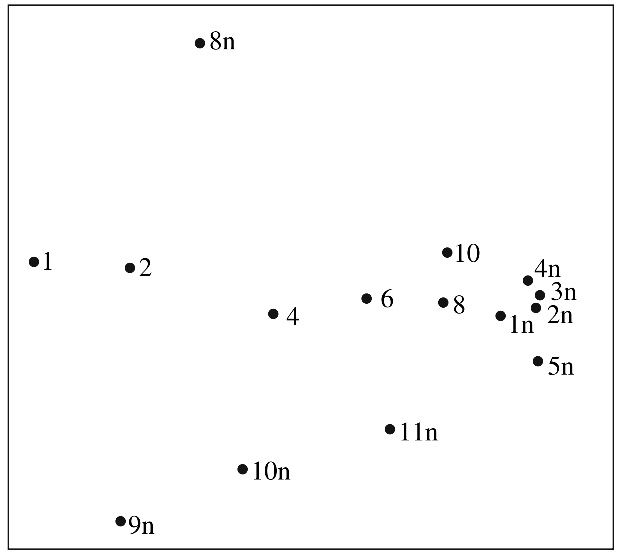

Fig. 3. Phytoplankton similarity between different stations.

Except for the *Odontella mobiliensis, Planktoniella blanda, Ceratium kofoidii, Protoperidinium depressum*, and *P. oceanicum* algae characterized by the highest abundance at the lower levels, no regular depen-

Table 4. Contribution (%) of different size groups of algae ($\ln W$) to the total phytoplankton biomass in the water column under an area of 1 m^2

Station no.	$\ln W$					
	3–5	5–7	7–9	9–11	11–13	13–15
11n	20	0	27	8	13	33
9n	4	0	11	52	4	28
10n	6	1	1	12	65	15
8n	2	0	1	54	2	43
1	57	0	2	41	0	0
3	28	0	1	3	9	60
4	16	1	2	11	13	58
8	15	7	24	18	19	17
6	5	1	11	25	33	25
10	1	5	22	14	25	34
1n	1	6	27	23	22	22
2n	1	2	21	24	20	31
3n	1	2	15	25	16	40
4n	1	3	19	31	27	18
5n	1	1	9	22	18	50

Table 5. Phytoplankton characteristics in Nhatrang Bay in the autumn and spring periods (n is the number of stations)

Parameter		October–November 2004 (this paper)	March 1998 [2]	March–April 2001 [3]
Mean biomass in the water column, B_t, mg C/m^3	Variation range	2.3–64.4	3.0–6.8	0.3–22.4
	Averaged over the bay	31.0 (n = 15)	4.7 (n = 9)	6.8 (n = 22)
	Standard deviation	22.7	1.46	5.8
	CV, %	73	31	86
Number of taxonomic units	Total	250	110	208
	Bacillariophyta	180	80	135
	Dinophyta	63	28	54
Variable in situ fluorescence F'_v/F'_m averaged over the water column	Variation range	0.15*–0.57*	0.19–0.59	0.09–0.64
	Averaged over the bay	0.44*(n = 26)	0.44 (n = 21)	0.38 (n = 18)
	Standard deviation	0.09*	0.18	0.11
	CV, %	21*	41	30
	Layer of 0–5 m			
Variable in situ fluorescence F'_v/F'_m	Averaged over the bay	0.36* (n = 15)	0.24 (n = 21)	0.37 (n = 16)
	Standard deviation	0.14*	0.09	0.14
	CV, %	40*	8	36
	Layer from 5 m to the bottom			
	Averaged over the bay	0.52* (n = 15)	0.51 (n = 21)	0.46 (n = 16)
	Standard deviation	0.06*	0.13	0.12
	CV, %	15*	26	46
Variable fluorescence after dark adaptation F_v/F_m	Variation range	0. 15–0.63	–	–
	Average	0.49 (n = 15)	–	–
	Standard deviation	0.14	–	–
	CV, %	29	–	–

Notes: * Data for October–November 2003; (–) no measurements were performed.

dence of the biomass of other species on the depth was recognized. Virtually all the algae with recurrences greater than 50% featured the same four types of vertical distribution as the distribution of the total biomass. Even large algae (with ln$W$ greater than 13) such as *Coscinodiscus gigas, C. concinnus, C. jonesianus, Thalassiosira bingensis, Palmeria hardmaniana, Rhizosolenia robusta, Pyrocystis fusiformis, Odontella mobiliensis*, and *Pseudosolenia calvar-avis* were encountered in the upper layer. Benthic and epiphyte forms were also noted at the levels of 2 and 5 m even at deep-water stations such as stations 6, 8, 1n, 2n, and 5n. The above-listed particular features of the vertical distribution of both the total phytoplankton abundance and those of individual species indirectly suggest intensive mixing in the water column.

DISCUSSION OF THE RESULTS

In the rainy season, at the end of October and the beginning of November, the average phytoplankton biomass in the water column varied in the range from 2.3 to 64.4 mg C/m^3. The lowest B_t values were noted in the area closest to the Kai River mouth, which is subjected to the influence of the riverine runoff. Toward the open sea, the alga abundance increased. The phytoplankton was characterized by relatively high photosynthetic activity and featured a good physiological condition. This, according to [4, 11], is confirmed by the values of the relative yield of the variable fluorescence, which exceeded 0.4. The only exception is represented by the phytoplankton of the area adjacent to the port of the city of Nhatrang. The low phytoplankton activity in this region of the bay is probably related to the impact of anthropogenic toxic substances.

The phytoplankton abundance was higher than in March–April (Table 5). This is in accordance with the seasonal dynamics of the nutrients; their maximal contents in the waters of the bay are observed during the period of the maximal riverine runoff at intensive precipitation [18]. In the spring period, the lower phytoplankton abundance is related to the low concentration of mineral food components (first of all, of phosphorus) and to the alga photoinhibition in the surface layers [2]. In October–November, the values of the in situ relative yield of the variable fluorescence averaged over the water column are higher than those in the spring period (Table 5). Similar to the situation in March–April, the phytoplankton in the surface layer is subjected to photoinhibition, although the degree of the suppression of the alga activity is significantly lower than in the spring period. This is caused by the lower level of incident radiation, the lower underwater irradiance owing to the high particulate matter contents, the longer residence of algae at deep levels, and the higher values of the light saturation parameter, which increases in the algae provided by the mineral nutrition [14].

With respect to the phytoplankton abundance, we regard the waters of the bay to be mesotrophic [2]. A moderate level of productivity was also noted in other ecosystems off the coasts of Vietnam [6, 17], while the open waters of the South China Sea, except for the three regions of upwelling, are oligotrophic [8, 15]. In October–November, the pool of dissolved mineral nitrogen is dominated by nitrates [18], which provides a greater proportion of new production in the total organic matter production. On the contrary, in the dry season, the phytoplankton activity in the bay is mainly provided by recycling of nutrients and the principal role in the integrated principal of organic matter belongs to regenerated production [2].

In the autumn period, the phytoplankton is characterized by a high species richness. The number of algae encountered was greater than that noted in March–April (Table 5). Many algae (134 taxonomic units) encountered in the autumn period were noticed in the spring as well. The Sorensen similarity index of the phytoplankton species composition in the autumn and spring equaled 0.60. Diatom algae dominated, as in the spring. Over the greater part of the bay area, they made the principal contribution to B_t, although regions with dinoflagellate domination were also noted. In March, diatoms prevailed over the entire aquatic area [2], while in April, as well as in the autumn, at selected stations, dinoflagellates prevailed.

In the autumn period, the variability of the species composition and the structure of the phytoplankton over the area of the bay was manifested more clearly than in the spring. In March, the phytoplankton was characterized by a high similarity; over the greater part of the area, *Guinardia striata* dominated in terms of the biomass [2]. In April, at seaward stations, other algae such as *Pseudosolenia calvar-avis, Bacillaria paxilifera, Gymnodinium* spp., and *Dinophysis* spp. started to dominate over the community [3]. In October–November, 35 species made a contribution of higher than 10% of the total biomass at least at one of the levels; in the spring, this number was 23. The mass species common for the autumn and spring were *Cerataulina pelagica, Coscinodiscus gigas, Guinardia striata, Gymnodinium* sp., *Pleurosigma angulatum, Rhizosolenia bergonii*, and *R. imbricata.* The all-year-round vegetation of most of the species of planktonic algae and the permanent presence in the plankton of the algae that become mass or dominant forms at particular stages are characteristic features of the phytoplankton of many tropical near-shore ecosystems [13, 19]. In the coastal waters of temperate and high latitudes, most of the algae referring to the dominating forms are characterized by clearly expressed seasonal dynamics of their abundance [1].

In the phytoplankton composition, oceanic species that were not encountered in the spring period were observed such as *Ceratium candelabrum, C. ranipes, C. vultur, Dinophysis miles, Asterolampra grevillei, Ceratocorys gourretii*, and others. The increase in the number of oceanic species in the waters of the bay seems to be caused by the northeasterly monsoon, which induced shoreward movement of the surface waters.

The variability of the size structure of the phytoplankton in the autumn period is manifested better than in the spring. Over the greater part of the area, the major contribution to B_t was provided by large algae ($\ln W = 13–15$); areas with a domination of small forms ($\ln W = 3–5$) and algae of moderately large sizes ($\ln W = 11–13$) were also detected. In March–April, virtually over the entire area of the bay, the principal contribution to the B_t value was made by algae of moderately large sizes with $\ln W = 9–11$ [3]. The domination of large-cell algae in October–November was probably related to the favorable nutrient regime and intensive mixing in the water column, which prevented large diatom algae from sinking.

In the autumn period, no regular changes in the alga abundance with depth were noted. There was both an increase and a decrease in the alga biomass with depth. In the regions close to the mouth of the Kai River, which were subjected to a stronger freshening, the phytoplankton biomass in the surface layer is lower than in the underlying layers. The relative yield of the variable fluorescence of the phytoplankton adapted to the dark was characterized by a uniform distribution over the water column, while the values of F'_v/F'_m for in situ phytoplankton in the subsurface layer were confidently lower than those in the underlying layers. This indicates that, in the subsurface layer, the algae are, to a certain extent, subjected to photoinhibition. In March, at the high irradiance in the subsurface layer (up to 1200 $\mu E/(m^2\ s)$ at noon) over the greater part of the bay, the algae of the surface layers were subjected to the stress of photoinhibition and the biomass of phytoplankton in the near-bottom layer was higher than that of the subsurface phytoplankton [2].

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