Oceanological and Hydrobiological Studies

International Journal of Oceanography and Hydrobiology

Volume 44, Issue 4, December 2015
pages (530-538)

ISSN 1730-413X
eISSN 1897-3191

Netz-Phytoplankton Diversity in the western and southern regions of the South China Sea

by

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DOI: **10.1515/ohs-2015-0050**
Category: **Original research paper**
Received: **March 16, 2015**
Accepted: **May 11, 2015**

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Abstract

Based on the survey records on netz-phytoplankton (>76 μm) collected in the South China Sea (SCS) during the cruise from the 21st August to the 18th October, 2012, the species composition, biodiversity and its spatial distribution were studied. The identified 326 phytoplankton species belonged to 75 genera and 4 phyla. *Thalassionema nitzschioides* was the most dominant species accounting for 33.24% of the total cell abundance, followed by *Bacteriastrum furcatum* – 8.69%. Whereas the phytoplankton cell abundance (cells l^{-1}) was the highest in the Zhubi Reef (1106.45 ± 2475.38), the southern SCS (396.84 ± 969.87), the western SCS (90.82 ± 144.66) and the northern SCS (66.48 ± 70.89) in order. The distribution of phytoplankton appears to be affected by the Mekong river discharge and particles derived in Sumatra and Kalimantan from biomass burning, nutrient concentrations, the South China Sea Warm Current (SCSWC). The evaluation of biodiversity indices indicated the high level of species richness, evenness and biodiversity in the survey area.

Key words: phytoplankton, South China Sea, diatoms, biodiversity, remote sensing data

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Introduction

It has long been believed that marine phytoplankton is one of the largest primary producers in the world. Variable-sized phytoplankton communities act as mediators for carbon partition between the atmospheric and oceanic content (Falkowski, Oliver 2007). Typically, they are governed by many sophisticated factors, including the top-down and bottom-up controls.

As the largest semi-closed marginal sea, the South China Sea (SCS) is exposed to strong monsoons affecting the biogeochemical patterns. The mesoscale eddy is a prominent phenomenon in the SCS related to the hydrodynamic variations. The eddy flux can potentially change the biota composition and location. In the east of Vietnam and west of Taiwan, the mesoscale activity center and eddy kinetic energy were observed (Chen et al. 2011). In addition, the South China Sea Warm Current (SCSWC) is a northeasterly current originating in the Guangdong coastal waters and in the offshore area (Guan 1998). The SCSWC is powerful enough to exist in all seasons. These water masses coupled with nutrients, temperature and salinity, defined as integrated growth environment, co-determine the phytoplankton propagation (Behrenfeld et al. 2008).

Researches on phytoplankton in the SCS can be traced back to the 1970s. Yujie Guo and Jiasong Ye (Guo et al. 1978, Guo et al. 1983, Ye et al. 1983) has pioneered the research to unravel the phytoplankton pattern in the SCS. Particularly, Guo has made prominent contributions to relative studies on planktonic diatoms (Guo 1976, Guo et al. 1979, Guo 1981). Consequently, more than 90% of phytoplankton are represented by diatoms, particularly abundant in summer. The ecotypes of phytoplankton in the SCS are mainly represented by those eurytopic and warm-temperate groups. Recently, some studies of phytoplankton community structure and primary producers have been reported (Song et al. 2002; Zhu et al. 2003; Le et al. 2006; Sun et al. 2007; Liu et al. 2007; Ma et al. 2011; Li et al. 2012; Gong et al. 2012). Whereas most large-scale surveys were carried out focusing mainly on the southern SCS. In our present study, we analyzed the composition and distribution of the phytoplankton community at a large spatial scale, thereby providing a better understanding of the phytoplankton population and its relation to the environment.

Materials and methods

Study site and field sampling

We carried out the cruise (1°29.98´S-21°29.95´N, 102°00.11´E-115°00.11´E) in the SCS from August to October, 2012. Typical 110 net tow stations were selected to present the microphytoplankton diversity in SCS (Fig. 1). At each station, phytoplankton samples were taken by a vertical trawl from a water depth of 0 - 200 m using a net with the mesh size of 76 μm and the mouth area of 0.1 m^2. Next, the samples were quickly preserved in formalin solution with the final concentration of 2%. The samples had been stored in a dark and cold place until they were analyzed in a laboratory.

In situ temperature and salinity were recorded with a SeaBird SBE25 CTD, mounted in a Rossette system. Remote sensing data were used in our study. The surface chlorophyll *a* (Chl *a*) content and surface sea temperature (SST) were derived from standard monthly Level-3 products of a moderate resolution imaging spectroradiometer on aqua (MODIS-Aqua) provided by the NASA Ocean Color Working Group (http://oceancolor.gsfc.nasa.gov/). The spatial resolution is 4 km in three months (August, September and October).

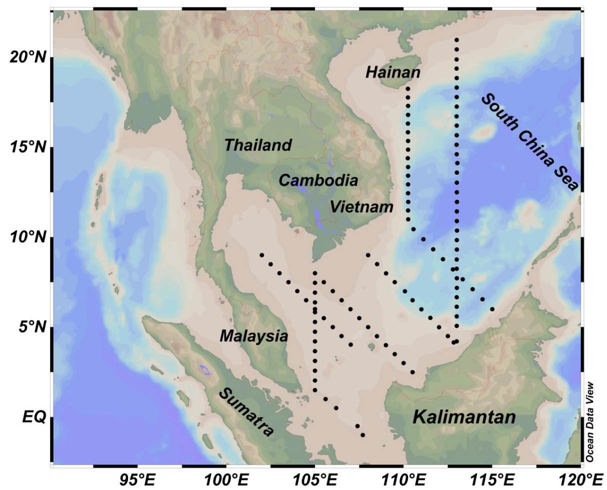

Figure 1

Sampling stations in the SCS (black dot indicates a sampling station)

Microscopic analyses and Data processing

The entire slide (0.25 ml) was examined to identify and count all cells under a light microscope (Motic AE2000) at magnifications of 200× or 400×. For a given total volume settled, we could calculate phytoplankton cell abundance. Unknown species were identified based on morphological descriptions. The biodiversity level was evaluated using the Shannon-Wiener index and Pielou's index. The specific calculations are saved (Sun, Liu 2004). The nomenclature modification is followed after Sun Jun (Sun, Liu 2002). Remote sensing data were processed using the MATLAB software.

Results

Hydrographic settings

During the study period, temperature and salinity measurements were read from CTD deployment tied to the rosette samplers. A high temperature integral value occurred in Qiongdong coastal water and in the southwestern part of the study area, and the salinity integral showed the maximum value in the northeastern part of the study area. Remote sensing data were used in the spatial pattern expression (SST, Chl *a*). The distributions of SST and Chl *a* were presented in Fig. 2 and Fig. 3, respectively. In general,

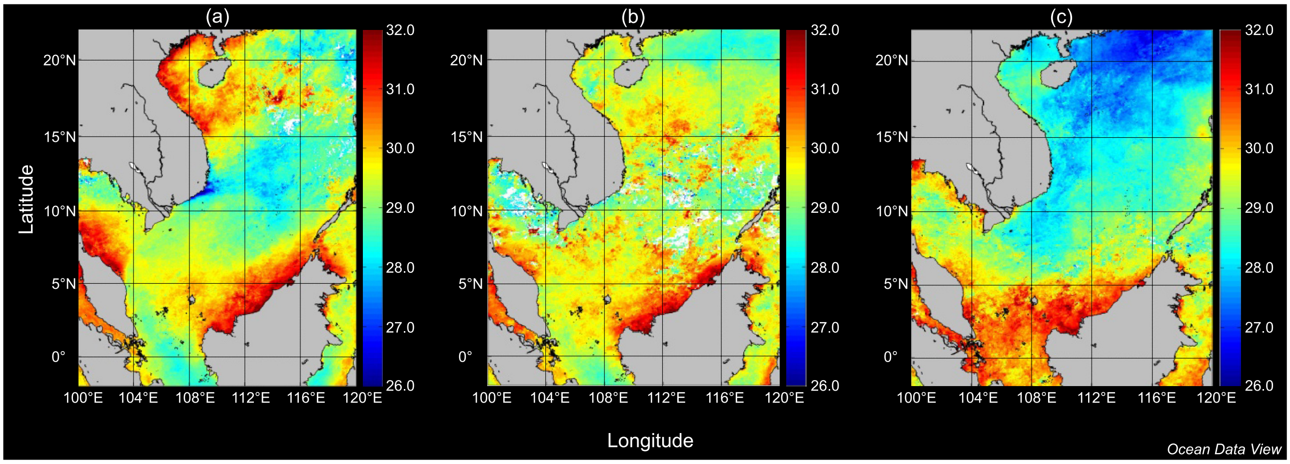

Figure 2

Spatial distribution of monthly averaged SST. (a) August; (b) September; (c) October

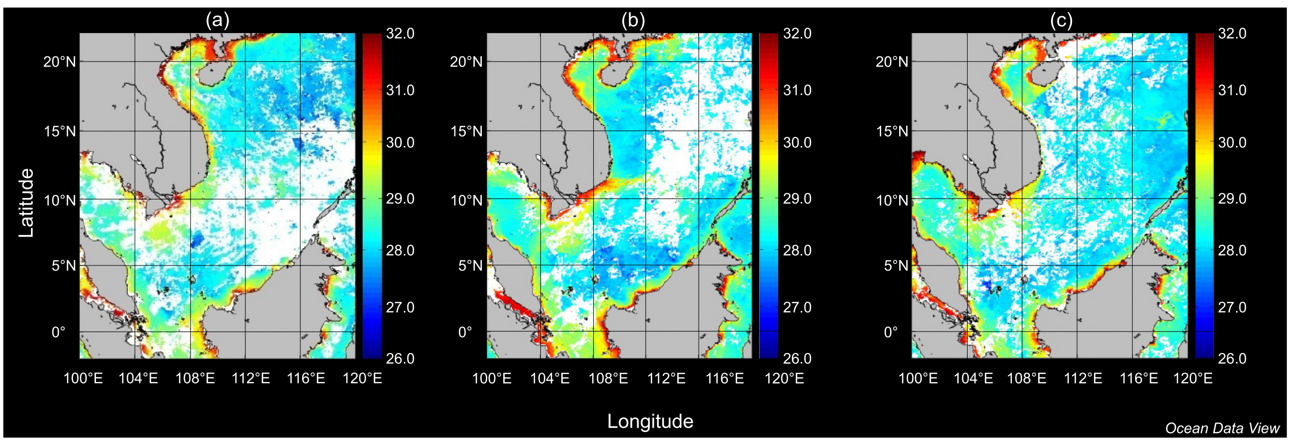

Figure 3

Spatial distribution of monthly averaged Chlorophyll *a* in surface water (unit: mg m^{-3}). (a) August; (b) September; (c) October temperature in the coastal area was higher than in the offshore area (Fig. 2). The southernmost sea area exhibited the highest temperature in October (Fig. 2c) compared to August and September (Fig. 2a, b). Chl *a* concentration decreased gradually from the inshore to offshore area sharing a similar tread with temperature pattern (Figs. 2, 3). Besides most coastal area, Chl *a* levels were consistently low in open waters.

Species composition and abundance of phytoplankton

A total of 326 taxa, including 188 taxa in 53 genera of diatoms, 130 taxa in 17 genera of dinoflagellates, 4 taxa in 2 genera of cyanobacteria and 4 taxa in 3 genera of chrysophytes were identified during the phytoplankton analysis in the study area. The dominant species are eurytopic and warm-water groups. Due to the inaccuracy of the cyanobacteria cell count, the dominance was calculated separately. The community composition was characterized by diatoms, followed by dinoflagellates. The common dominant diatoms were *Thalassionema nitzschioides*, *Bacteriastrum furcatum*, *Chaetoceros* sp., *Chaetoceros lorenzianus* and *Pseudonitzschia delicatissima*, while *Ceratium trichoceros* and *Ceratium fusus* were dominant dinoflagellates. A total of 108 samples were statistically processed. The phytoplankton abundance ranged from 3.33 cells l^{-1} to 7042.43 cells l^{-1} with an average of 328.94 ± 950.47 cells l^{-1}, including diatoms 319.09 ± 942.80 cells l^{-1} accounting for 97.01%, dinoflagellates and cyanobacteria 9.62 ± 9.88, 10077.30 ± 25 416.15 cells l^{-1}, respectively. *T. nitzschioides* was the dominant species whose Y value was 0.30473. The dominant species and their values were listed in Table 1.

Abundance and biodiversity distribution of phytoplankton

Peaks of phytoplankton and diatoms were observed in south of Vietnam and in the waters between Sumatra and Kalimantan Island. *Trichodesmium* sp. concentrated in the southern Vietnam waters and in the Malacca Strait (Fig. 4). The distribution patterns of dominant species were consistent with that of diatoms (Fig. 5a-d), peaks occurred at offshore stations. Biodiversity of microalgae in the SCS plays a critical role in global climatology and macro-economy. Sun (Sun, Liu 2004) listed several diversity indices applied in marine phytoplankton studies and gave fuzzy evaluation on phytoplankton groups (Sun et al. 2001). Finally, the Shannon-Wiener diversity index (*H'*) and Pielou evenness index (*J*) were calculated. *H'* and *J* showed reverse patterns whose low value emerged in the northwest coastal area (Fig. 6). The mean values were 4.17 ± 0.59 and 0.76 ± 0.11, respectively. According to the biodiversity index, the survey area was at level V. This can be well explained by the highest phytoplankton cell abundance occurred in the southernmost part of Vietnam with 7042.43 cells l^{-1}.

Table 1

The top ten dominant species observed at the survey stations

No.	Latin	Y	fi
1	*Thalassionema nitzschioides*	0.30473	0.916667
2	*Bacteriastrum furcatum*	0.07078	0.814815
3	*Chaetoceros* sp.	0.05889	0.953704
4	*Chaetoceros lorenzianus*	0.02599	0.712963
5	*Pseudo-nitzschia delicatissima*	0.01682	0.648148
6	*Climacodium biconcavum*	0.01559	0.824074
7	*Thalassionema frauenfeldii*	0.01494	0.777778
8	*Thalassiosira* sp.	0.01133	0.648148
9	*Chaetoceros messanensis*	0.00996	0.712963
10	*Proboscia alata* f. *gracillima*	0.00972	0.935185

Discussion

Ecophysiological descriptions characterized by dominant floras

Dominant species of diatoms and dinoflagellates were listed in Fig. 5. The dominant diatoms observed in the study area were controlled by chain-forming populations. They represent the causative bloom species and aggregate by physiological stickiness. The star-like chain-forming *T. nitzschioides* dominated and was characterized by a large effective size and morphological stickiness (Riebesell 1991). Its structured marginal areolae are suggested as

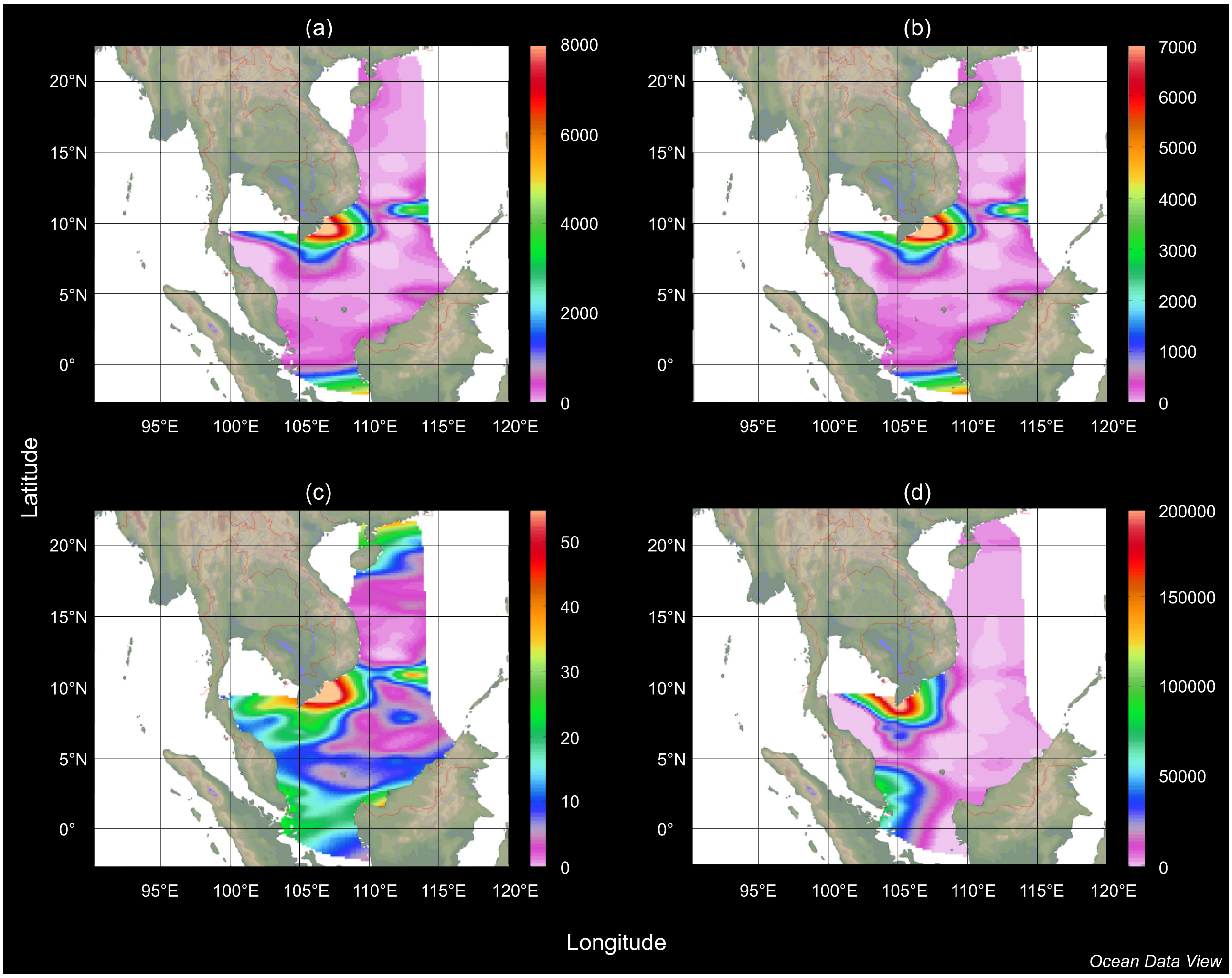

Figure 4

General horizontal distribution of (a) phytoplankton; (b) diatom; (c) dinoflagellate; (d) *Trichodesmium*

Table 2

Comparison of phytoplankton abundance with historical survey data in the South China Sea

Time	Range	Method	Mean (cells l^{-1})	Richness	Reference
1979.06-07	17-23°N, 113-120°E	Net sample (0-75 m)	50	204	Ye et al. 1983
		0-200 m	20,000	287	
1997-2002	Northern SCS	----	872	----	Zhao et al. 2011
1997.11	5°59′-10°25′N,110°-116°48′E	Net sample	23.1	121	Li et al. 2005
1998.06-07	5°-25°N, 105-120°E	Water sample	830	63	Zhu et al. 2003
1999.08	18°-22°N, 102-117°E	Water sample	181,000	58	
1998.12	5°-25°N, 105-120°E	Water sample	8460	89	
1999.04	5.58°-9.96°N,108.68°-113.75°E	Net sample	24.9	109	Song et al. 2002
2004.02	18°-23°N, 111°-117°E	Water sample	206,400	198	Sun et al. 2007
2004.08-09	18°-22°N, 110°-117°E	Water sample	115,050	----	Le et al. 2006
2007.08	18°-23°N, 110°-120°E	Net sample	14,090	216	Ke et al. 2011
2009.08	18°-22°N, 110°-117°E	Water sample	8197	109	Li et al. 2012
2009.07-08	18°-22.5°N,109.5°-120.5°E	Net sample	60.2	180	Gong et al. 2012
2010.01	18°-22.5°N,109.5°-120.5°E	Net sample	360.46	155	Ma et al. 2011
2012.08-10	Large scale	Net sample	328.94	326	Present study

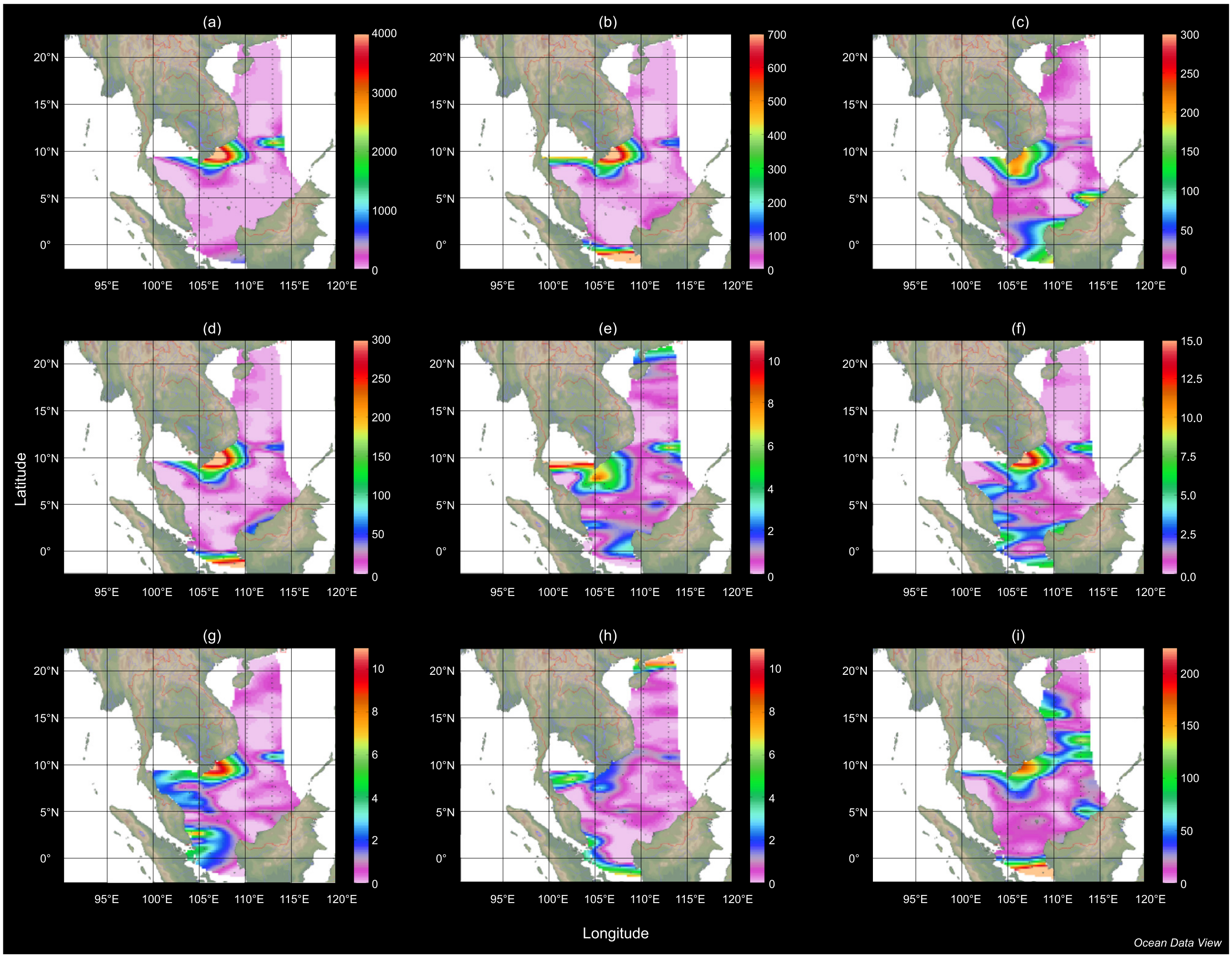

Figure 5

Horizontal distribution of the dominant diatoms and dinoflagellates in the survey area. (a)-(d) are diatoms: (a) *Thalassionema nitzschioides*; (b) *Bacteriastrum furcatum*; (c) *Chaetoceros* sp.; (d) *Chaetoceros lorenzianus*; (e)-(i) are dinoflagellates: (e) *Ceratium trichoceros*; (f) *Ceratium fusus*; (g) *Amphisolenia rectangulata*; (h) *Ceratium pulchellum*; (i) the ratio of diatoms/dinoflagellates.

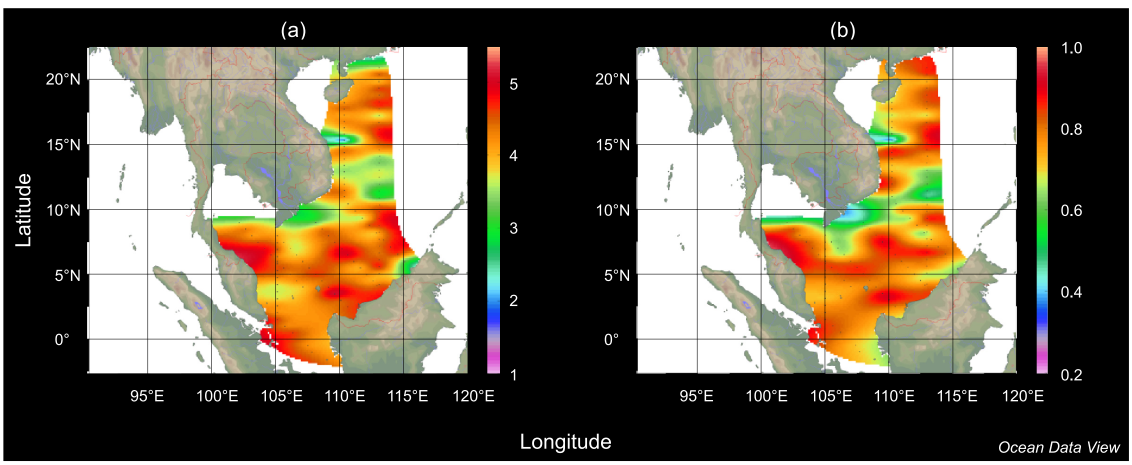

Figure 6

Horizontal distributions of biodiversity indices in the SCS. (a) Shannon-Wiener index; (b) Pielou's index a diagnostic trait (Hallegraeff 1986). *B. furcatum* and *C. lorenzianus* are fitted with long setae characterized by a high rate of aggregation. The dominant dinoflagellate floras exhibit intricate morphologies, especially with wing-like extensions (*Ornithocercus steinii*) or enlarged and flattened theca (*Ceratium cephalotum*). Numerical symbionts were detected extracellularly in the dinoflagellate girdle. *Amphisolenia* sp. was found with a specialized endocytic relationship (Hallegraeff, Jeffrey 1984).

Comparison with previous studies

The result of comparative analysis between historic and present data was shown in Table 2. We could easily discrminate the variability among phytoplankton due to their spatial heterogeneity in the survey area. In general, the total abundance was relatively low in our present investigation, however, the species biodiversity was higher and the *H'* value was at level V. The observed richness reached the highest value. In the light of previous studies, dinoflagellates favored high temperatures and contributed nearly 20% of the total abundance. Yet, our results did not reveal a high abundance of dinoflagellates. The ratio of diatoms to dinoflagellates showed a decreasing trend from inshore to offshore stations, which was consistent with previous analysis (Fig. 5i). The distribution and cell density appear to be associated with environmental conditions, nutrient availability and grazing impact of predators.

The links between microalgae and surrounding environments

Understanding the relationships between biological populations and physical parameters has profound implications for the management of the SCS water ecosystems. The whole survey area was subdivided into four parts. Each part was defined as Northern SCS (N-SCS, 18°-22°N), Zhubi Reef (10°-11°N, 114°E), Western SCS (W-SCS, 10°-18°N) and Southern SCS (S-SCS, 0°-10°N), respectively. Phytoplankton was negatively correlated with temperature and salinity in the northern SCS (Le et al. 2006). The Eastward Jet and Kuroshio intrusions may be associated with a series of biological processes. The mean abundance was 66.48 cells l^{-1}. Due to the specific biological and topographic significance of water in the vicinity water of Zhubi Reef and relatively few microalgae studies, the emphasis was also put on the identification of local phytoplankton assemblages. The highest abundance occurred in waters surrounding the Zhubi Reef (1106.45 cells l^{-1}). Besides the dominant species, *Trichodesmium thiebaultii* occurred with high abundance in the coral reef region. The W-SCS was characterized by the mesoscale eddy and the upwelling current occurring throughout east Vietnam. Furthermore, many rivers drained into the W-SCS, particularly the Mekong inflow significantly facilitates phytoplankton blooming growth. Under the influence of combined intricate elements, the average count of phytoplankton was expected to be 90.82 cells l^{-1}. There is plenty of rainfall in the equatorial areas in September (Zheng et al. 2013). And the cell density in S-SCS was up to 396.84 cells l^{-1} affected by aerosol and particles derived in Sumatra and Kalimantan from biomass burning (Wong 2007). Consequently, the general pattern of phytoplankton emerged as in Fig. 5. The distribution of the total phytoplankton abundance matched well with that of Chl *a*. The high values of Chl *a* were recorded in the southern part of the survey area near Vietnam, around the southernmost stations (Fig. 3 and Fig. 4a).

Above all, monsoons and water masses can never be ignored when to examine the interactive relations between biological and environmental variables.

Acknowledgements

This study was supported by the Ocean Public Welfare Scientific Research Project (No. 201105021-03), the National Basic Research Program (2015CB954002), the Program for New Century Excellent Talents in University (No. NCET-12-1065), and National Natural Science Foundation of China (Nos. 41176136, 41276124, 40776093 and 40676089) to Jun Sun. The authors are grateful to Qibiao Zhao, Xiaoyao Gu and Shan Zhang for their diligent field work. We also express thanks to the crews of R/V *Dongfanghong II*.

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