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Spatial variation of phytoplankton community from Malacca Strait to southern South China Sea in May of 2011

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ABSTRACT

Phytoplankton community and its relationships with environmental factors were investigated in the surface waters from Malacca Strait (MS) to the connected South China Sea (SCS) in May of 2011. Salinity was significantly lower in MS. No significant spatial variations were found for most of the nutrients (except silicate) between MS and connected SCS. Silicate gradually increased from Andaman Sea to the southern MS, and then declined from the southern MS to SCS. Phytoplankton mainly belonged to diatoms and dinoflagellates. The dominant species of diatoms were *Skeletonema*, *Pseudo-nitzschia*, *Navicula*, and *Thalassionema*. Dinoflagellates were mainly presented by *Prorocentrum*, *Scrippsiella* and nano-dinoflagellate. Diatoms contributed to most of the phytoplankton abundance in the middle and south MS. However, dinoflagellates predominated in the side of Andaman Sea or SCS. Chlorophyll *a* concentration and phytoplankton abundance were the highest in the shallowest sampling station of middle MS. CCA results suggested that salinity and silicate were the most important environmental variables influencing the phytoplankton spatial variation. The prosperity of diatoms in the middle MS may be promoted mainly by the sufficient nutrients brought by the deep-water intrusion or river inflow. Silicate can be considered as an indicator for high phytoplankton biomass, but could not be the limited factor for the phytoplankton growth in MS.

1. Introduction

The Malacca Strait (MS) is one of the most important international waterways in the world, which connects the Andaman Sea and the South China Sea (SCS). It has a tropical climate and is strongly influenced by the Asian monsoon [2]. The current was generally north-western towards the Andaman Sea throughout the year [3,21]. As a connective region of Indian Ocean and Pacific, there are high species richness and biodiversity. MS is an important fishing ground for the around country, which produced more than 50% of the fish catch for west Malaysia [2].

The spatial distribution and seasonal variation of the phytoplankton biomass were strongly influenced by the Asian monsoon in MS [17] and SCS [9,14]. During the northeast monsoon (from November to March), chlorophyll *a* (Chl *a*) was higher in MS due to the wind-driven vertical mixing and coastal upwelling [15,17]. In general, the northern part of MS had lower Chl *a* than the shallower and narrower southern area [2]. Tan et al. [17] indicated that the higher phytoplankton abundance in southern part mainly due to the stronger vertical mixing and higher nutrient input from rivers of Sumatra. Li et al. [11] thought that high silicate concentration in MS promotes the growth of phytoplankton and thus led to higher primary production. New phytoplankton species were continually identified from MS (Lim et al. 2013). Recently, a new toxic *Pseudo-nitzschia* species was found in the water of MS, which can produce domoic acid and poses a potential health threat to this region [18]. Most of the studies in MS only focused on Chl *a*. However, there were little studies conducted on the phytoplankton community and its relationship with environmental factors in this region.

Connected by MS, Andaman Sea and southern SCS were two oligotrophic, tropical marginal seas, where the nutrient concentrations usually were very low in the surface waters. Pico-phytoplankton contributed the mainly biomass of phytoplankton and phytoplankton mainly dominated by dinoflagellates in such regions [1,9]. In general, the transition region of two different ecosystems has high biodiversity and productivity. From eastern Indian Ocean to southern SCS through Sunda Strait and Karimata Strait, the phytoplankton abundance and biodiversity significantly increased in the Sunda Strait, accompanying with the larger cell-size and higher diatom proportion [10]. According to the similar geographical feature with Sunda Strait, we can suppose that the phytoplankton also showed the high diversity and abundance in MS. It should be interesting that where and why the phytoplankton reaches to the high abundance and diversity from southern SCS to MS. In this study, we investigated the spatial variations of phytoplankton community and environment factors in the surface water of MS from Andaman Sea to SCS. It could contribute to better understand the distribution pattern and controlling factors of phytoplankton species and abundance in MS.

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2. Materials and methods

This study was carried on the cruise of R/V *Shiyan I* during 6–10 May of 2011. A total of 24 sampling stations were investigated in the MS and connected southern SCS. 15 stations (1–15) are located in the MS and the rest 9 stations (16–24) are located in the southern SCS (Fig. 1). Surface water samples were collected using a pump at the depth of about 2.5 m. Temperature and salinity were measured in situ using a General Oceanic Sea Bird CTD. The water was filtered using a GF/F filter (0.7 μm) and frozen at −20 °C for the future nutrient analysis. Nutrients (nitrate, nitrite, ammonia, dissolved inorganic phosphate and reactive silicate) were analyzed using a flow injection analyzer (Lachat Inc., QuichChem 8500, USA) according to standard colorimetric techniques [5]. Dissolved inorganic nitrogen (DIN) was calculated by the sum of nitrate, nitrite and ammonia. Size-fractioned Chl *a* concentration was examined at these stations. For the size-fractioned micro- (>20 μm), nano- (3–20 μm) and pico-phytoplankton (0.7–3 μm), a subsample was sequentially filtrated onto a 20 μm, 3 μm pore-size polycarbonate filter (Osmonics Inc.), and a 0.7 μm pore-size glass fiber filter (Whatman GF/F), respectively.

A 1-L water was preserved with 1% acetic Lugol's iodine solution as the phytoplankton sample. In laboratory, these samples were concentrated to 30 ml by settling for 48 h and siphoning the supernatant. Species identification and cell count were carried out at 100× or 400× magnification using a Sedgewick-Rafter plankton counting chamber under an inverted microscope. Taxonomic identification was carried out mostly to species as possible. Only the specimen with a diameter of >5 μm was included in the analysis of phytoplankton species composition. The group of dinoflagellates with the size of 5–10 μm was recorded as nano-dinoflagellates, mainly including some small *Gymnodinium* and cysts. The taxonomic of phytoplankton was identified according to Jin et al. [7], Guo and Qian [6], and Tomas [16].

Canonical correspondence analysis (CCA) was performed using CANOCO 4.5 [19] to elucidate the relationships between phytoplankton species composition and environmental factors. All data were logarithmically transformed before the analysis. The significance of environmental factors to explain the variance of phytoplankton in CCA was tested using Monte Carlo simulations with 499 unrestricted permutations. Because the phytoplankton community often contains a number of rare species, we only included the genus with a relative abundance of >1% in the CCA analysis. The variation of phytoplankton density or Chl *a* concentration between MS and southern SCS was compared by one-way ANOVA.

3. Results

3.1. Environmental factors

The sea surface temperature (SST) showed a decline trend from MS to SCS (Fig. 2). The average SST is 30.23 °C (ranged from 29.6 °C to 30.8 °C). Sea surface salinity (SSS) was significantly higher in SCS than in MS. The average SSS was 32.91 in the stations of SCS (from S16 to S24) and 31.15 in the MS (from S1 to S15). Most of the sampling stations were shallower than 100 m, and the shallowest site was in the S9 (21 m). Nitrogen nutrients (nitrate, nitrite and ammonia) did not show a clear variation among these stations (Fig. 2). Nitrate was the primary nitrogen nutrient, ranging from 1.34 μm to 5.87 μm (average 2.68 μm). Nitrite ranged from 0.1 μm to 0.58 μm (average 0.18 μm), and ammonia ranged from 0.5 μm to 1.86 μm (average 1.2 μm). The silicate gradually increased from Andaman Sea to the southern MS, reaching the peak value (13.32 μm) at S15 in the south of MS, and declined from the southern MS to SCS. The average concentration of silicate was 5.42 μm. Phosphate was generally low in the surface water, which reached the highest value in S17 (0.33 μm).

3.2. Chl a concentration and size structure

There were two Chl *a* peaks along our sampling stations: one in the middle of MS, another in the connection area between MS and southern SCS (Fig. 3). In general, the Chl *a* concentration was significantly higher at the stations of MS than that of southern SCS (ANOVA, $P<0.01$), especially in the middle and south of MS. The average Chl *a* concentration was 0.16 μg L^{-1} in the north of MS (S1–S8), 0.61 μg L^{-1} in the south of MS (S9–S15) and 0.08 μg L^{-1} in the southern SCS (S16–S24), respectively. A significantly high Chl *a* occurred at S9 (1.81 μg L^{-1}). The cell size of phytoplankton was negatively correlated with total Chl *a* concentration (Fig. 3). At most of the stations, the contributions of pico-Chl *a* (0.7–3 μm) were more than 50%. It gradually declined from north MS to middle MS and from southern SCS to MS, even though the total Chl *a* concentration did not showed an obvious increase.

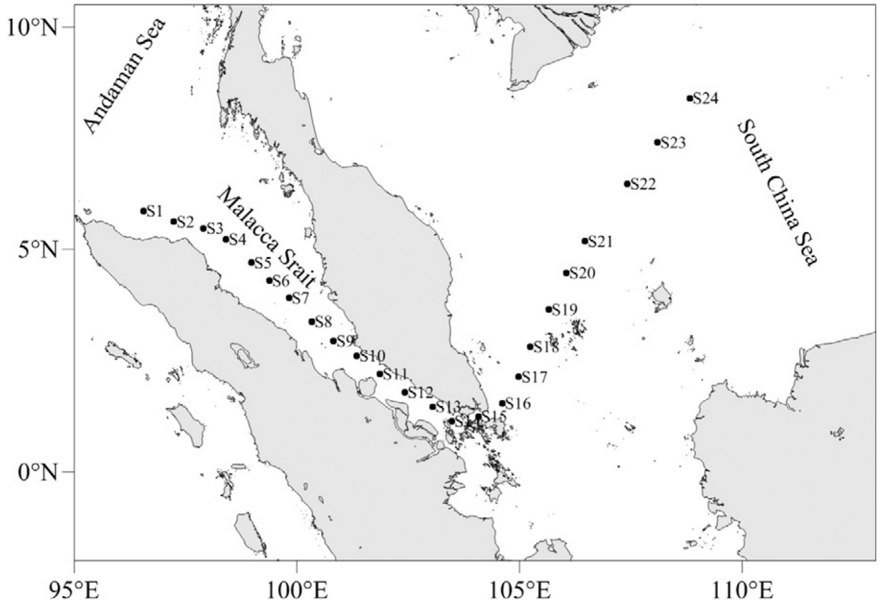

Fig. 1. Sampling stations from MS to southern SCS.