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# Effects of surface current patterns on spatial variations of phytoplankton community and environmental factors in Sunda shelf

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ABSTRACT

Phytoplankton community and environmental factors were investigated in the surface water from eastern Indian Ocean (EIO) to southern South China Sea (SCS) during April–May monsoon transition period both in 2010 and 2011. Our results indicated that the surface current patterns were different in the two cruises. Sea surface salinity (SSS) was lower in Java Sea (JS), but its salinity front obviously moved to the middle of Sunda Strait when surface waters flowed from JS to EIO in May of 2010. Nutrient concentrations were generally higher in Sunda Strait and JS. Silicate concentrations were significantly lower in EIO suggesting a possibility of silicate limitation for the growth of phytoplankton, which were less than 1 $\mu$mol $L^{-1}$ in the offshore stations of EIO in May of 2010. Phytoplankton abundance and biodiversity were significant higher in Sunda strait and its adjacent stations, with larger cell-size and higher diatoms proportion. More offshore species were found in Sunda Strait when surface waters flowed from EIO to JS in April of 2011. Nutrient source can be different in Sunda Strait during inflow or outflow of surface waters. The spatial variation of phytoplankton community was greatly determined by *Chaetoceros* spp., *Navicula* sp., *Pleurosigma affine*, *Thalassionema frauenfeldii* and nano-dinoflagelage. Salinity, nitrate and silicate were the most important environmental factors regulating the variation of phytoplankton community. This study suggests that spatial distribution of phytoplankton and environmental factors are significantly influenced by the surface current patterns and river discharges, and these influences should be greater in dry season.

## 1. Introduction

The marginal sea area from Java Sea (JS) to southern South China Sea (SCS) is an important pathway between SCS and Eastern India Ocean (EIO), that may be potentially important in regulating the global climate change (Qu et al., 2009; Xie et al., 2009; Du et al., 2011). This area was characterized by a complex set of surface currents that vary in strength and direction seasonally and annually. In the north of this area (southern SCS), the surface current flows from SCS into JS through Karimata Strait during northeast monsoon (November to March) and in the opposite direction during southwest monsoon (May to September) (Sofian and Kozai, 2007; Fang et al., 2012). In the south of this area (JS), the surface current flows to the east during the northwest monsoon (November to March) and to the west during the southeast monsoon (April to October) (Gingele et al., 2002). In this area, complex monsoon can drive a pronounced variability of current and precipitation, which sequentially affect the physical–chemical factors of sea water and phytoplankton community.

Many studies have indicated that seasonal changes of monsoon and current cast a vast influence on the primary productivity and phytoplankton community both in SCS and EIO (Liu et al., 2002; Dey and Singh, 2003; Vinayachandran and Mathew, 2003; Tan et al., 2006). In SCS, the Chl *a* concentration was the lowest in summer during the prevailing of southwest monsoon (Ning et al., 2004). However, an obvious pulse of primary productivity in winter can be found during the prevailing of northeast monsoon (Liu et al., 2002). In EIO, Bengal Bay generally has a relatively low productivity during southwest monsoon attributed to the strong stratification caused by freshwater influx, while large phytoplankton bloom can be usually found in its western part during northeast monsoon (Gomes et al., 2000; Vinayachandran and Mathew, 2003). In Malacca Straits, monsoon wind can cause upwelling or downwelling in its north area due to the unique topology, which significantly influences the spatial distribution and seasonal variation of the Chl *a* concentration (Tan et al., 2006). Asanuma et al. (2003) also indicated that spatial distribution of phytoplankton blooming was greatly correlated with monsoon currents along the Sunda Islands. In addition, because of higher rainfall and river

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discharges, the water of JS has significantly lower salinity and higher nutrient than surrounding seas (Sprintall et al., 2003; Hendiarti et al., 2004). The influx or outflow of JS water can greatly change the environment factors of Sunda Strait and its adjacent area (Gingele et al., 2001). Hendiarti et al. (2004) indicated that Sunda Strait is seasonally influenced by water transport from the JS or from the EIO. In this area, Chl *a* concentration and fish catch are high during the southeast monsoon when oceanic waters transport from JS to EIO and low during the northwest monsoon when oceanic waters transport from EIO to JS (Hendiarti et al., 2004). The response of marine ecosystem to the monsoon change can be different because of the topographic variation (Tan et al., 2006).

Phytoplankton community structure is important in regulating the primary productivity and carbon fixation (Han and Furuya, 2000; Marañón et al., 2001). The species composition and abundance of phytoplankton can well reflect the environmental changes (Leira and Sabater, 2005; Ke et al., 2012). Analysis of phytoplankton community is helpful to evaluate the influence of global climate change on primary productivity and fishery resource. In the area of Indonesia archipelago, many studies only focused on the physical characteristics of sea water, the salinity and thermal exchange between west Pacific and EIO, or the distribution of remotely-sensed Chl *a* (Sprintall et al., 2003; Vinayachandran and Mathew, 2003; Du et al., 2011). Little information is available on the temporal and spatial variability of phytoplankton species composition and abundance in this area, especially in the continental shelf area from JS to SCS.

In this study, we investigated the environmental factors and phytoplankton community in the surface water from EIO to southern SCS during the April–May monsoon transition period both in 2010 and 2011. The purpose of this paper is to enhance our understanding of phytoplankton distribution patterns and their relations to the environmental factors, surface current and monsoon.

## 2. Material and methods

Two cruises were performed on board R/V SHIYAN 1 during 17–23 May of 2010 and 5–11 April of 2011. A total of 35 sampling stations were selected in each cruise from EIO to southern SCS through Sunda Strait and Karimata Strait (Fig. 1). Among these stations, 6 stations (1–6) located in the EIO, 10 stations (7–16) in the JS and 19 stations (16–35) in the southern SCS.

Surface water samples were collected using a pump at the depth of about 2.5 m. Temperature and salinity were measured using a General Oceanic Sea Bird CTD. 500–1000 ml seawater was filtered through GF/F filters for the determination of chlorophyll a (Chl *a*). Then Chl *a* was extracted with 90% acetone in the dark for 24 h at 4 °C and analyzed with a Turner Design 10 fluorometer. The filtered water was collected and frozen at $-20$ °C for the nutrients analysis. Nutrients were analyzed using a flow injection analyzer (Lachat Inc., QuichChem 8500, USA) according to standard colorimetric techniques (Grasshoff et al., 1983). Nitrate was measured by reducing nitrate to nitrite using Cd column, and then identifying nitrite by means of the pink azo dye method. Nitrite was measured by the pink azo dye method and ammonia by the phonate method. Dissolved inorganic nitrogen (DIN) was calculated by the sum of nitrate, nitrite, and ammonium. Dissolved inorganic phosphate (DIP) was measured by the ascorbic acid and molybdenum blue method. Silicate was analyzed using molybdate, oxalic acid and a reducing reagent. DIN, DIP and silicate concentrations were used to calculate atomic ratios of N/P, Si/N and Si/P. Size structure of Chl *a* was examined at partial 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 filters (Osmonics Inc.), and 0.7 μm pore-size glass fiber filter (Whatman GF/F), respectively.

A 1-L sub-sample was preserved with 1% acetic Lugol's iodine solution as the phytoplankton sample. In laboratory, these phytoplankton samples were concentrated to 20 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 or genus as possible. Only the specimen with a diameter of $>5$ μm was included in the analysis of phytoplankton species composition. The group of dinoflagelate with the size of 5–10 μm was recorded as nano-dinoflagellate, mainly including some small *Gymnodinium* and cysts. The taxonomic of phytoplankton was identified according to Jin et al. (1965), Guo and Qian (2003), Tomas (1997) and Steidinger and Tangen (1997). We used species richness (*S*), Shannon–Weaver diversity index *H* (Shannon and Weaver, 1949) and Pielou's evenness index *J* (Pielou, 1966) to assess the biodiversity of phytoplankton.

The multivariate analyses of the phytoplankton communities and environmental factors were analyzed using software PRIMER 6.0. Non-normality of the data was treated by using a log $(x+1)$ transformation. Non-metric multidimensional scaling (nMDS) was applied to the similarity matrixes to determine the similarity of stations with respect to phytoplankton composition. The species that have the greatest contribution to the division of samples were determined using the similarity percentage program (SIMPER). The BIOENV procedure was used to determine which set of environmental variables best explains the biological matrices (Clarke and Gorley, 2006).

## 3. Results

### 3.1. Environmental factors

The average sea surface temperature (SST) was 30.64 °C in 2010 and 28.32 °C in 2011 at our sampling stations. SST significantly increased from SCS to JS in 2011, while there was no obvious trend in 2010 (Fig. 2). Average sea surface salinity (SSS) was 32.82 in the cruise of 2010 and 32.93 in 2011. In general, SSS was lower in JS and higher in offshore area of SCS and EIO. Sunda Strait was dominated by the low salinity water in the cruise of 2010, which showed the lowest value (31.90) in S7. While in 2011, SSS was high in Sunda Strait and suddenly declined at S8, which reached the lowest value (30.82) at S11 (Fig. 2).

The distribution of DIN, DIP and silicate concentrations in the surface water was showed in Fig. 3, which was obviously higher in 2011. DIN concentrations varied greatly among the sample stations, with an average value of 3.21 μmol $L^{-1}$ in 2010 and 4.23 μmol $L^{-1}$ in 2011. The highest DIN was found at S10 (7.08 μmol $L^{-1}$) in 2010 and at S7 (7.24 μmol $L^{-1}$) in 2011. DIP concentration gradually increased from EIO to Sunda Strait and then declined from Sunda Strait to the center of JS in the two cruises. DIP concentration showed an increasing tendency from the center of JS to Karimata Strait (from S10 to S16). In Sunda Strait, DIP concentration was relatively higher than other areas in 2010, while remained lower in 2011. The average DIP concentrations were 0.14 μmol $L^{-1}$ in 2010 and 0.23 μmol $L^{-1}$ in 2011. Silicate concentrations were significantly lower in EIO than in other areas, which were even less than 1 μmol $L^{-1}$ from S1 to S4 in 2010. The average concentrations of silicate were 2.73 μmol $L^{-1}$ in 2010 and 5.75 μmol $L^{-1}$ in 2011. Silicate concentrations were significantly higher in JS in 2011 and showed slowly declined trends from JS to SCS.