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Seasonal variability of sea surface chlorophyll-*a* and abundance of pelagic fish in Lampung Bay, Southern Coastal Area of Sumatra, Indonesia

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Abstract — An observation of sea surface chlorophyll-*a* in relation to the abundance of pelagic fish was conducted in Lampung Bay, Southern Coastal Area of Sumatra using MODIS satellite data of 2003–2004. The observation result shows the variability of sea surface chlorophyll-*a* in Lampung Bay seems to be correlated with the monsoonal system that influences on the variability of the meteorological and oceanographic situation. In the wet season (northwest monsoon), the concentration of chlorophyll-*a* is high. It was suspected due to high precipitation during this season in which the coastal area was enriched by the nutrient load from the upper land area through the rivers and coastal discharge. While in the dry season (southeast monsoon), high concentration of the chlorophyll-*a* is stimulated by increasing nutrient concentration due to the upwelling. During these seasons, the abundance of the pelagic fish was high within this region.

Key words: Seasonal variability, chlorophyll-*a*, pelagic fish, Lampung Bay

Introduction

Lampung Bay is a semi enclosed water ecosystem estuary. This area is situated in the southern coastal area of Sumatra and faces to the Sunda Strait (Fig. 1). Geographically, Lampung Bay is located at 5°26′S to 5°50′S and 105°10′E to 105°35′E and has an area of about 847 km^2, a mean depth of 17.3 m and coast-length of around 160 km (Wiryawan et al., 1999). The environment within this area seems to be strongly influenced by monsoonal wind system that affects on the variability of the meteorological and oceanographic conditions of Lampung Bay (Damar, 2003). There are two dominant monsoonal seasons, which drive the climate cycle in the study area (as in all other Indonesian areas) named the wet and dry seasons that occur during December to March and June to September, respectively. The rainy season is related to the northwest (NW) monsoon, while the dry season is related to the southeast (SE) monsoon. Among these seasons, there are two transition periods that also influence on the circulation of the water mass within the study area, that is, the transition period from wet to dry season (Trans. W-D) occurs between April–May and the transition period from dry to wet season (Trans. D-W) occurs in October to November. During the wet season, high air pressure over Asia and low air pressure over Australia are observed, allowing wet air transport (northwesterly wind) from the South China Sea to the Pacific Ocean across the Indonesian archipelago. Inversely, low air pressure over Asia and high air pressure over Australia drive the wind blowing from the southeast to the northwest (southeasterly wind) carrying the dry air from Australia and resulting in the dry season (Tomascik et al., 1997). As consequently, on the regional scale, the oceanic condition of Lampung Bay is highly influenced by water masses from the South China Sea, the Java Sea and the Indian Ocean that intrude through the Sunda Strait and spread into Lampung Bay (Sachoemar et al., 2006; Damar, 2003; Wiryawan et al., 1999).

Lampung Bay is one of the productive water areas in the western part of Indonesia. Various fisheries activities of both aquaculture and marine fishing exist within this area. However the information of seasonal marine productivities is still limited and necessary to be investigated to understand their characteristics particularly in relation to the oceanographycal phenomena. Recently the investigation of global and local marine productivity by using satellite has been widely popular among the scientists to understand various phenomena occurred within the marine environment through the ocean color detection (e.g. Legaard and Thomas, 2006). The concentration of chlorophyll pigments (the photosynthetic pig-

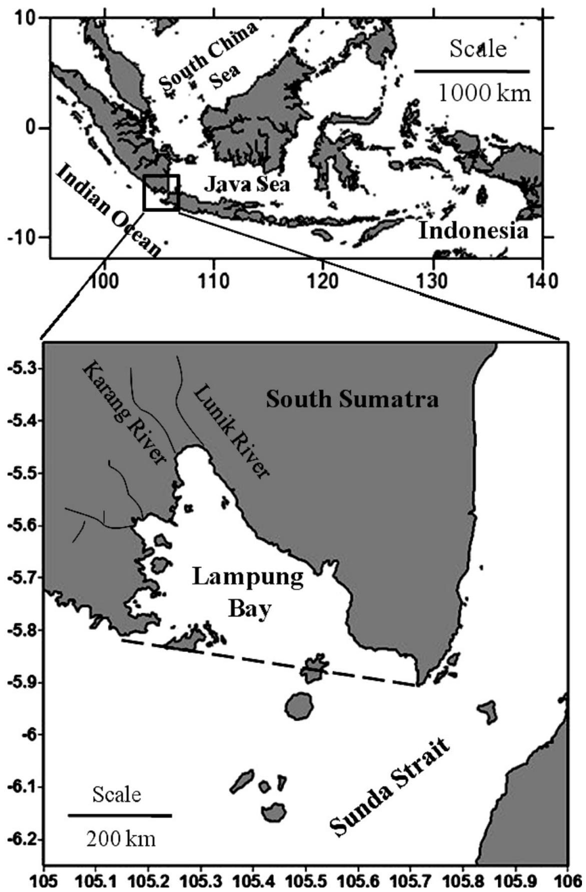

Fig 1. The situation of Lampung Bay. Broken line shows the boundary of Lampung Bay.

ments of phytoplankton) is often considered as an index of biological productivity, and in an oceanic environment, it can be related to fish production. Chlorophyll concentrations above 0.2 mg/cu.m indicate the presence of sufficient planktonic life to sustain a viable commercial fishery (Butler at al, 1988). Chlorophyll pigments have a specific and distinctive spectral signature since they absorb blue (and red) light and reflect strongly the green, thus affecting ocean color.

Since the Coastal Zone Color Scanner (CZCS) sensor was terminated in 1987, new generation of ocean color sensors were appeared and widely used to observe marine environment change, i.e. Advance Very High Resolution Radiometer (AVHRR) sensor of National Oceanic and Atmospheric Administration (NOAA), Ocean Colour and Thermal Scanner (OCTS) sensor of Advanced Earth Observing Satellite (ADEOS) and Sea-viewing Wide Field-of-view Sensor (SeaWiFS). Recently, MODIS (Moderate Resolution Imaging Spectroradiometer) sensor aboard the Terra and Aqua satellites has been common to be used for marine environment observation, for both global (GAC) and local area coverage (LAC) due to a high spatial resolution (Level 1 data) and frequency of their data acquisition. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths. These data will improve understanding of global dynamics and processes occurring in the oceans (NASA, 2007). Some observations of sea surface chlorophyll-*a* in relation to the fish abundance and ocean circulation by using the CZCS (Banse and English, 2000), AVHRR (Tameishi and Shinomiya, 1989), OCTS (Ishizaka, 1998) and MODIS data (Legaard and Thomas, 2006) have conducted successfully in the temperate area, but in the Indonesian tropical area, such studies were still limited due to the limited data. Hence in this study we attempt the observation of seasonal variability of sea surface chlorophyll-*a* in relation to the abundance of small pelagic fish in Lampung Bay, southern coastal area of Sumatra by using sea surface chlorophyll-*a* (SSC) and sea surface temperature (SST) derived from MODIS satellite data.

Method

A series of monthly mean SSC and SST data of Lampung Bay (Fig. 1) derived from the Aqua MODIS Level 3 Standard Map Image (SMI) obtained from NASA (http://oceancolor. gsfc.nasa.gov) was collected from the period of 2003 to 2004. The spatial resolution of this data is about 4 km. The data was downloaded in hdf format and then cropped by using SeaDAS 4.7 software. The ascii data of SSC and SST was extracted from the similar source by using the same software and converted into Excel format. While monthly pelagic fish catch data was collected from fish landing area of Lampung Bay for the period of 2003 to 2004. To support this study, the meteorological data (precipitation and wind) and oceanographic data (water temperature and nutrient) were also collected to understand the influence of monsoonal system and the ocean phenomena on fish productivity within the study area. The meteorological data of Lampung region were obtained from the Indonesian Meteorological Agency and temporal water temperature data from buoy (Hayami et al., 2003). The nutrient data (DIN: nitrate and DIP: phosphate) were obtained by sampling of sea surface water (depth of 0 to 1.5 m) using PVC Van Dorn bottle (Damar, 2003). The sample water was then filtered through MFS nucleopore (diameter 47 mm and pore size of 0.2 μm) and analyzed at the main laboratory in Bogor by using spectrophotometric according to Grasshoff et al. (1983). To understand seasonal variability of SSC and its impact on the pelagic fish productivity in Lampung Bay, a simple regression analysis was then employed to understand the correlation between MODIS satellite data (SSC and SST) and fish abundance.

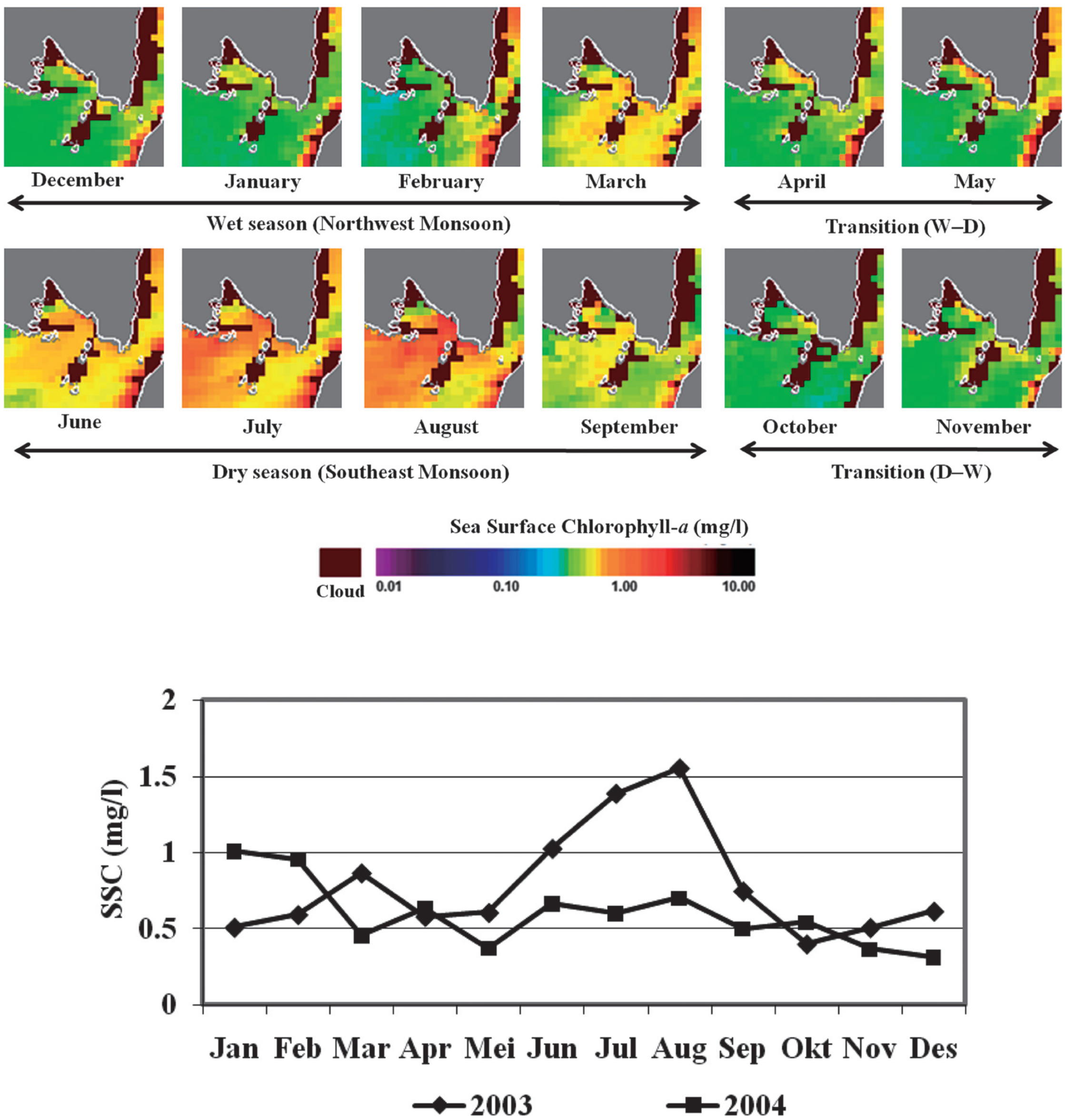

Fig. 2. Seasonal spatial (above) and temporal variability (below) of sea surface chlorophyll-*a* (SSC) in Lampung Bay.

Result and Discussion

Seasonal spatial and temporal variability of SSC in Lampung Bay where averaged value is obtained in the broken line of Fig.1 was shown in Fig. 2. In the northwest monsoon (wet season) occurred during December to March, high concentration of SSC was seen in the upper part of the bay. High precipitation during these periods (Fig. 3) seems to have enriched the marine environment within this region by nutrient load transported through the rivers around the bay. There are two main rivers near Bandar Lampung, the biggest city of Lampung, which are Karang and Lunik rivers (see Fig. 1). These rivers pass through human settlements and small industrial area, along the eastern border of the city. The others are 6 major rivers, transported the untreated organic waste water of the city directly into the bay. In the wet sea-

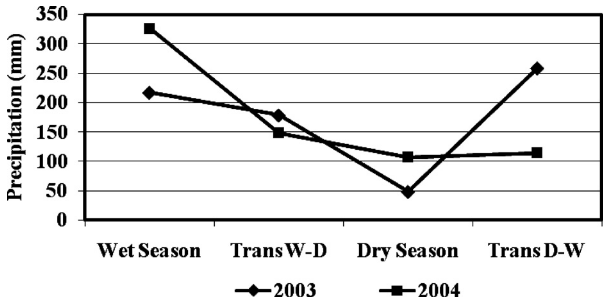

Fig. 3. Seasonal variability of precipitation in Lampung Bay.

son, high river discharge has brought a large amount of the organic matter into the bay and might cause the phytoplankton bloom in the area near of the estuary. However, those rivers are not the only source of nutrients for the bay (Damar 2003). Other sources of nutrients are scattered along the coast, such as a trading harbour, an industrial area, agricultural rice fields and shrimp pond areas, altogether contributing to the nutrient dynamics of the bay. Both of the rivers and sources exhibit similar patterns in nutrient loads, showing that DIN (nitrate) and DIP (phosphate) as the most important nutrients discharged by the city. Temporal and spatial distributions of the nutrients concentrations in the bay were high in the river mouths and surrounding areas, then decreased in the inner, middle and outer parts of the bay (Fig. 4 and 5). The strong influence occurred only in the limited area close

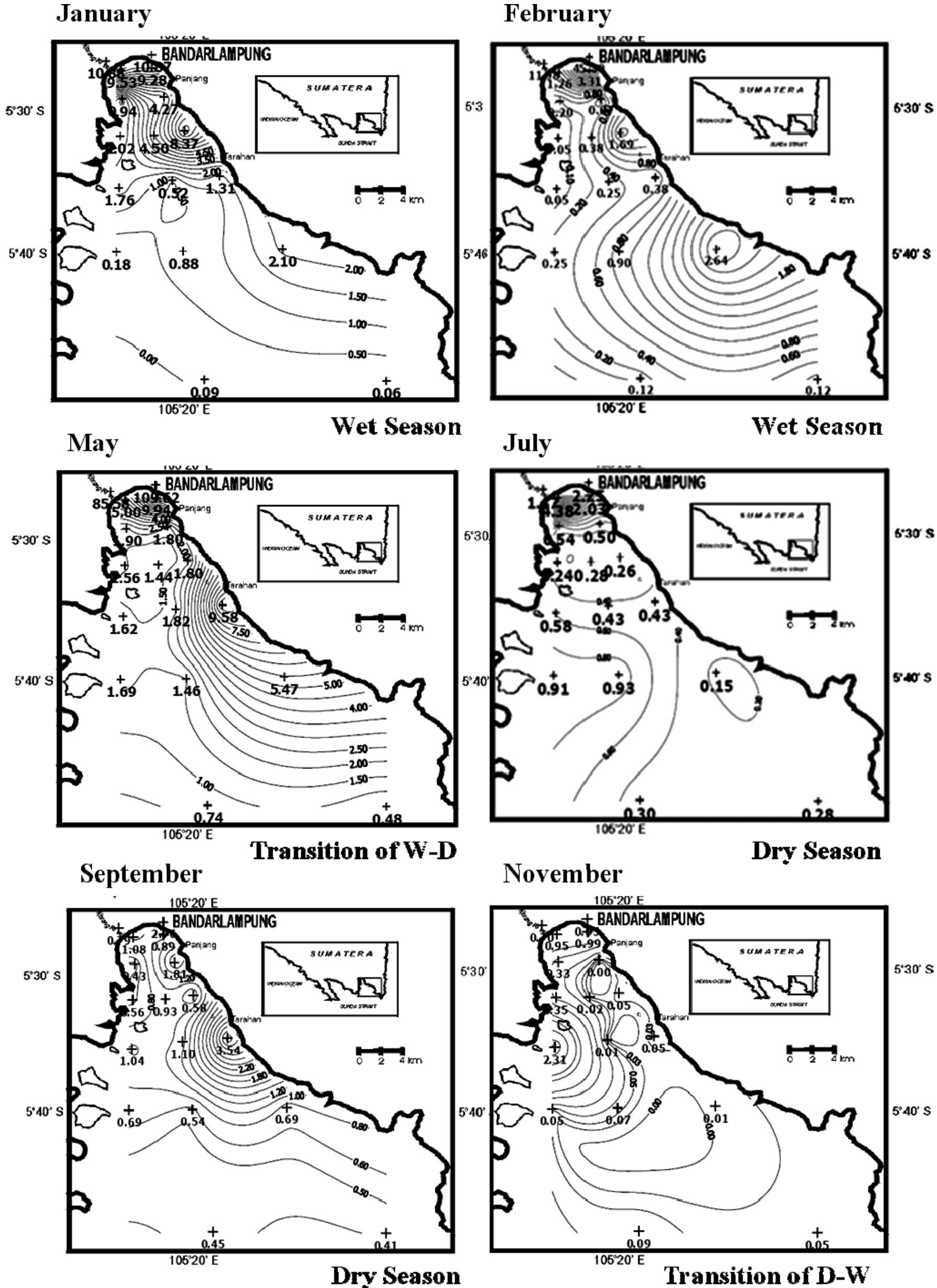

Fig. 4. Temporal and spatial distribution of sea surface DIN (μM NO_3-N) in Lampung Bay (Damar, 2003).

to the incoming rivers and in the inner part of the bay. In the middle part of the bay, nutrient concentrations might be also governed by other sources of nutrients scattered along the bay's coastline, such as shrimp pond and rice field culture activities. Damar (2003) denotes that high values of phytoplankton biomass occurred in the river mouths and surrounding areas, while in the more offshore waters, phytoplankton biomass remained low. This situation shows that the phytoplankton bloom at Lampung Bay during the wet season is regulated by the availability of nutrients from both rivers and coastal discharges that scattered within this region. While in the transition period of wet to dry season occurred in April to

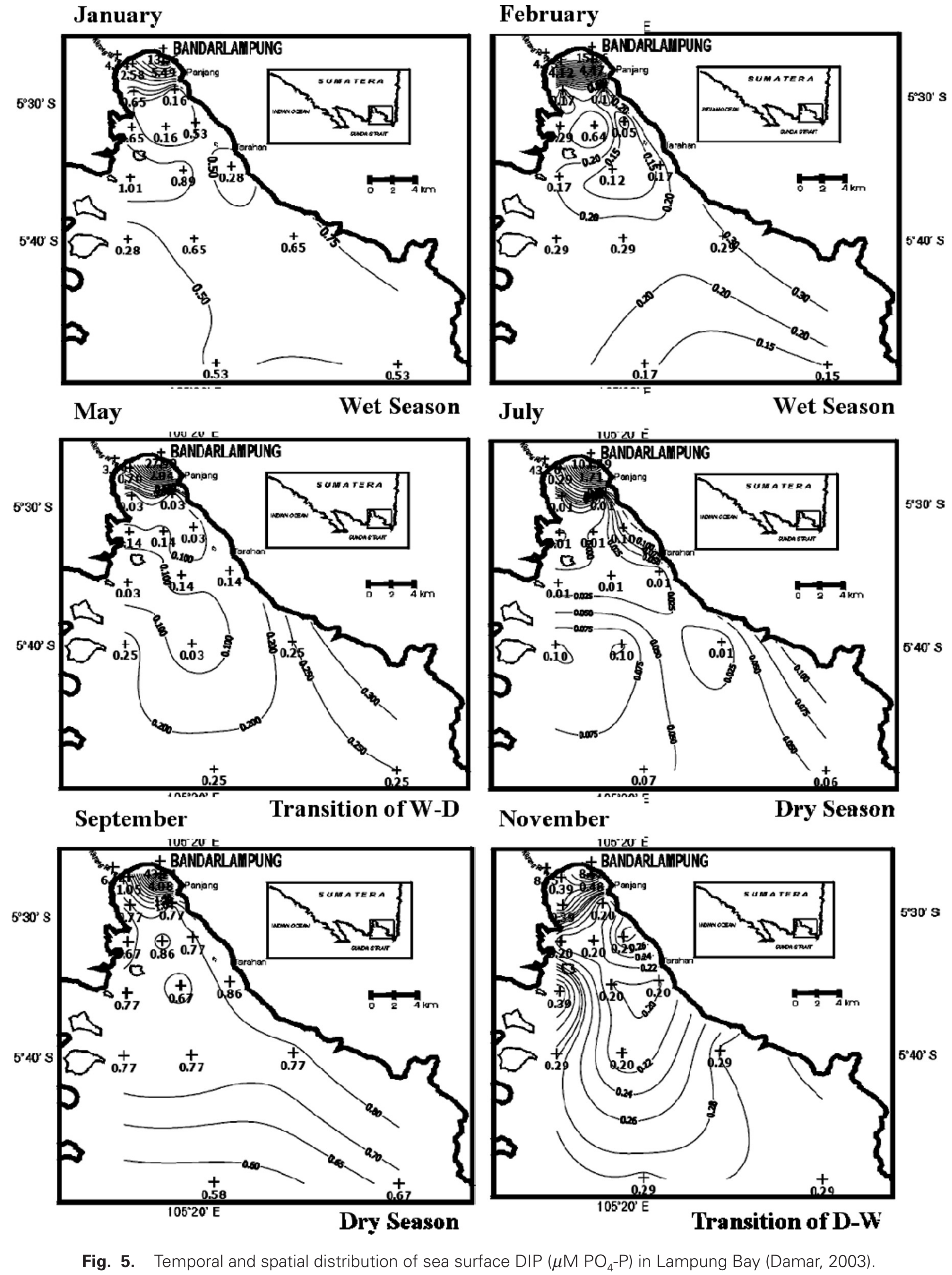

Fig. 5. Temporal and spatial distribution of sea surface DIP (μM PO_4-P) in Lampung Bay (Damar, 2003).

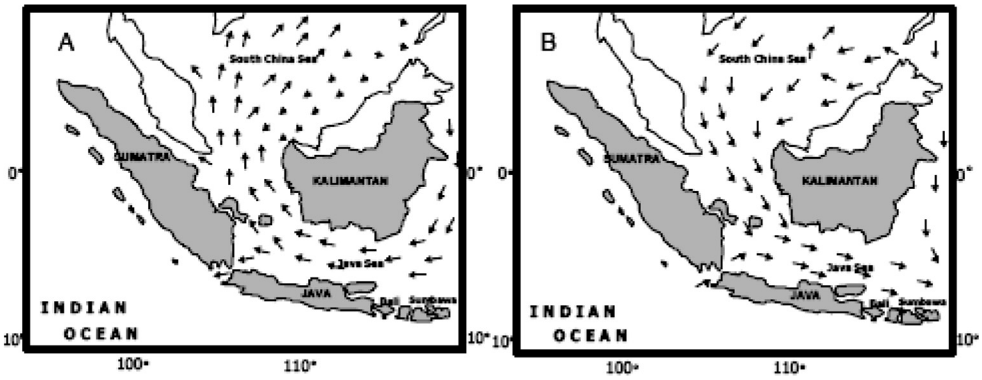

Fig. 6. Sea surface circulations during the dry (A) and the wet (B) seasons in the region (Damar, 2003).

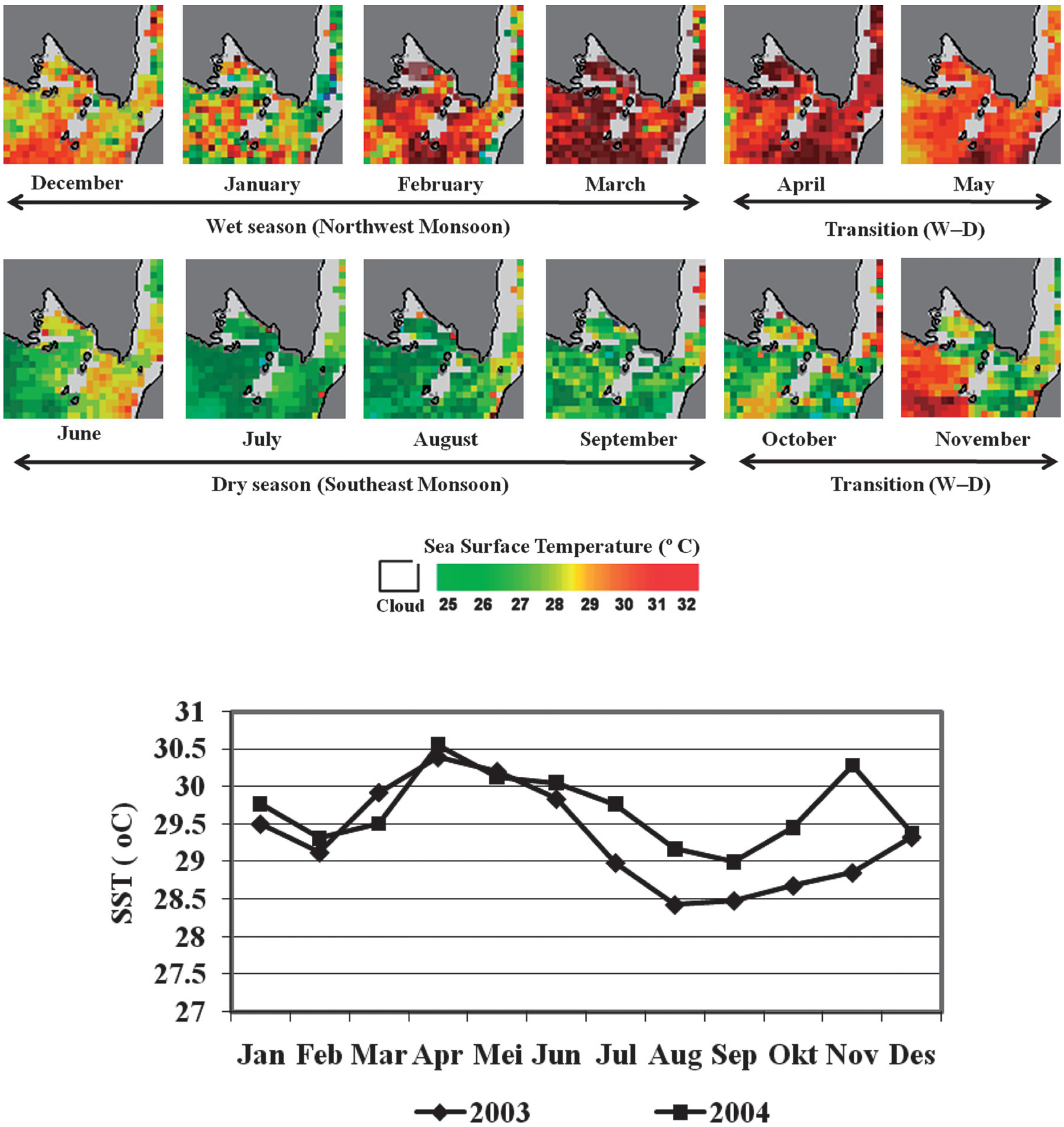

Fig. 7. Seasonal spatial (above) and temporal variability (below) of sea surface temperature (SST) in Lampung Bay.

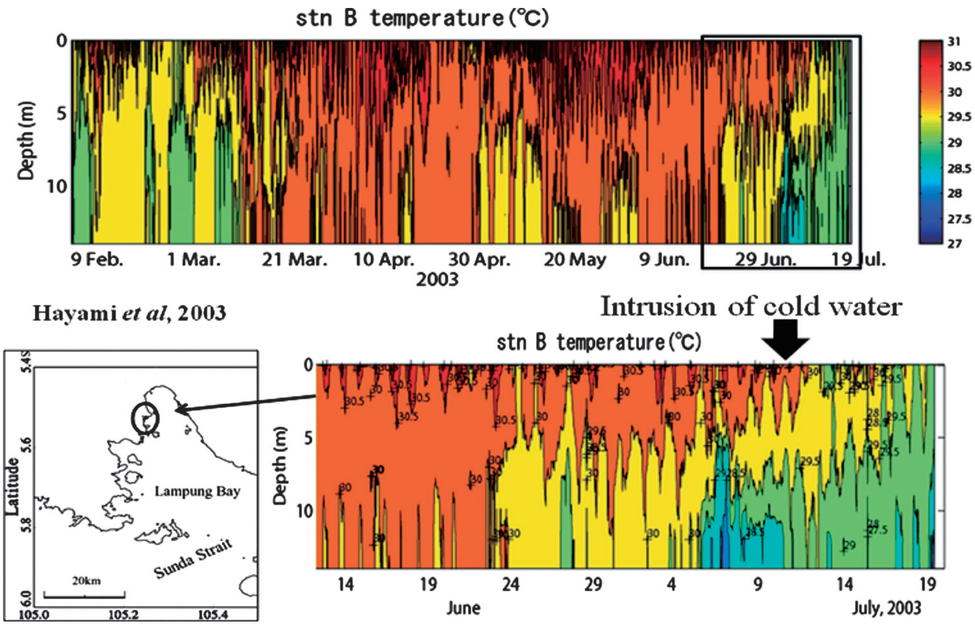

Fig. 8. Temporal variation in vertical water temperature distribution in the western coastal area of Lampung Bay (Hayami *et al.*, 2003).

May, the chlorophyll-*a* concentration was decreased following declining precipitation and low river and coastal discharge.

In the southeast monsoon (dry season) occurred during June to September, a relatively high concentration and wide distribution of SSC were obviously seen in and outer part of Lampung Bay (Fig. 2). High concentration of chlorophyll-*a* tends extending to the northeastward of the Sunda Strait and penetrates into Lampung Bay as response to the surface current movement derived by the southeasterly wind as shown in Fig. 6. High concentration of chlorophyll-*a* during this period seems to be stimulated by the inducing high nutrient water mass due to the upwelling. The occurrence of the upwelling in Lampung Bay was identified by the appearance of low sea surface temperature (SST) as shown in Fig. 7. The intrusion of cold subsurface water mass in the western part of Lampung Bay during the period of June to July (Fig. 8) has indicated the existing of the upwelling occurrence in Lampung Bay (Hayami et al., 2003). The existing of the upwelling event also seen by increasing DIN (nitrate) and DIP (phosphate) concentration in the outer part of Lampung Bay during the southeast monsoon (July and September) as shown in Fig. 4 and 5 (Damar, 2003). As similar as in the southern coastal area of Java (Sachoemar and Yanagi, 2000), the upwelling in Lampung Bay seems to be generated by the Ekman transport as response to the strong southeast wind force during the southeast monsoon (Fig. 9). In the transition period of dry to wet season (D–W) occurred in October to November, the concentration of chlorophyll-*a* was then decreased following the decrease of nutrient concentration (Fig. 2, 4 and 5).

The existence of upwelling and precipitation has en-

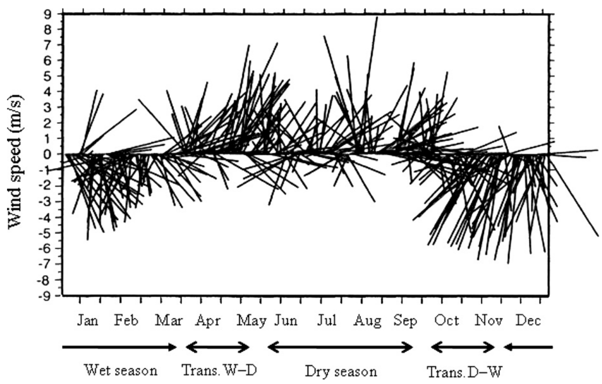

Fig. 9. Seasonal variation of wind vector within the region of Lampung Bay.

riched the marine environment of Lampung Bay and provided a good impact on fish production. This situation indicated that marine productivity within this area was governed by nutrient load from the river and coastal discharge as well as the upwelling that is controlled by monsoonal system. High chlorophyll-*a* in the northwest and southeast monsoon was followed by high pelagic fish catch in the same seasons as shown in Fig. 10. During the period of the northwest monsoon (wet season) January-March, fish abundance was high and was decreased in the transition period of W-D in April-Jun. In the southeast monsoon (dry season) occurred during the period of July to September, fish catch was increased significantly following the increasing of chlorophyll-*a* concentration due to the upwelling that is indicated also by low SST. While in the transition period of the southeast monsoon (dry season) to the northwest monsoon (wet season) occurred in October to December (transition period of D-W), fish catch

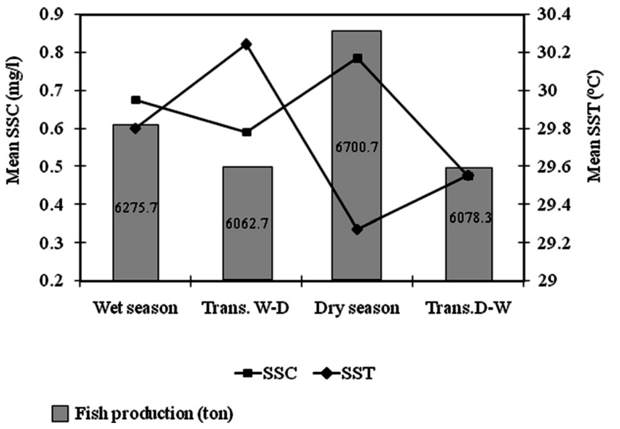

Fig. 10. Seasonal variability of SSC, SST and fish production in Lampung Bay.

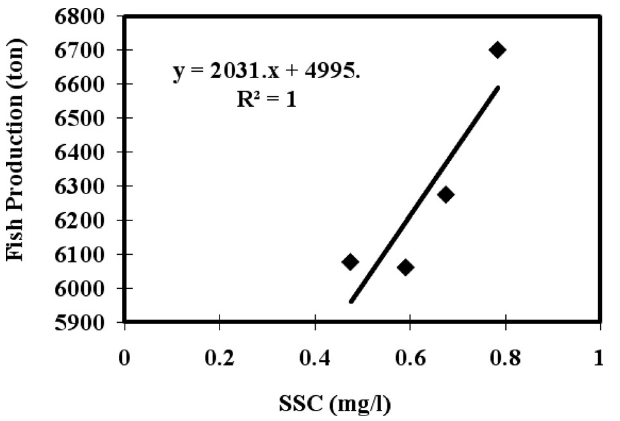

Fig. 11. Correlation between SSC (mg/l) and fish production (ton) in Lampung Bay.

was then decreased as similar as decreasing of chlorophyll-*a* concentration during this period. This situation indicated that the catch of pelagic fish has strong correlation to the chlorophyll-*a* as shown by the result of regression analysis in Fig. 11.

The characteristics of the pelagic fish in Lampung Bay was dominated by small pelagic fish such as anchovies, red snappers, sardine, trevallies, breams, mackerel, yellowtail and the other pelagic fish as shown in Fig. 12. During the wet and dry seasons, high concentration of the SSC has been followed by increasing small pelagic fish (anchovies) as well as the larger pelagic fish such as snapper, yellowtail, mackerel, sardine and others. This condition shows that SSC bloom has stimulated increasing the abundance of pelagic fish within this region and indicated the existence of the connectivity among species of small and larger pelagic fish in a tropic level ecosystem. Since the observation of the biological characteristics of the pelagic fish and their behavior were limited within this region, further study to understand more detail information of the connectivity among species of pelagic fish in a tropic level ecosystem is necessary to be established.

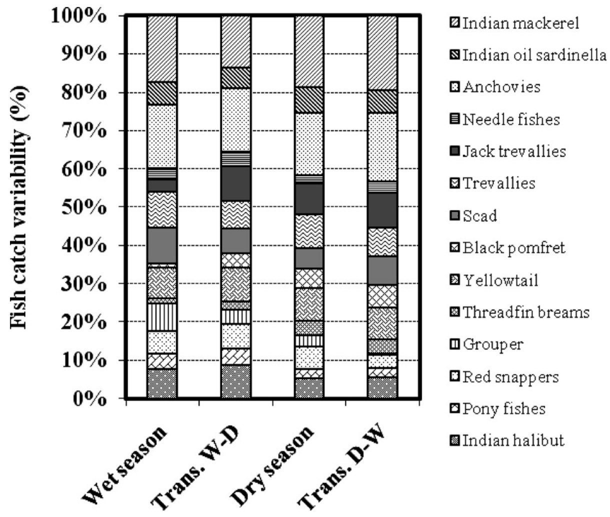

Fig. 12. Seasonal variability of fish catch in Lampung Bay.

Conclusion

Seasonal variability of SSC in Lampung Bay was strongly to be governed by monsoonal system that affects the meteorological and oceanographic variability. The existing of high precipitation in the wet season (northwest monsoon) and the upwelling in the dry season (southeast monsoon) has enriched the ocean environment by increasing the nutrient concentration and generated chlorophyll-a bloom within this region. Increasing of the SSC in the wet and dry seasons (northwest and southeast monsoon) have provided a good impact on the increment of pelagic fish catch within the region. The availability of high SSC within the surface water was well corresponded to high fish catch. The mechanism of the enrichment of the coastal water in Lampung Bay was influenced by high nutrient load supplied from the rivers and the other sources surrounding the bay that is associated with high precipitation and inducing of the subsurface cold and rich nutrient water mass generated by the upwelling. This mechanism is controlled by monsoonal system.

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