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VARIABILITY OF SEA SURFACE CHLOROPHYLL-A, TEMPERATURE AND FISH CATCH WITHIN INDONESIAN REGION REVEALED BY SATELLITE DATA

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ABSTRACT

The investigation of sea surface chlorophyll-a (SSC) and sea surface temperature (SST) in relation to fish catch variability within the Indonesian region were conducted by using satellite data of NOAA-AVHRR, SeaWiFs and Aqua MODIS. The investigation focused in the region of the coastal area of Java, Lampung Bay and South Kalimantan as representation of the environment diversities of the Indonesian seas. The result shows that seasonal variation in fish productivity has a strong correlation with SSC variability. High fish productivity corresponded well with high concentration of SSC, and the productivity tended to decrease when the SSC concentration was declined. High SSC variability in the coastal area of Java and Lampung Bay was governed by the upwelling that induced high nutrient load into the sea surface during the southeast monsoon, while in the northern coastal area of Java and South Kalimantan, it was governed by high precipitation ocurring during the northwest monsoon that enhanced the nutrient load through the rivers and coastal discharge.

Keywords: sea surface chlorophyll-a, temperature, fish catch variability, Indonesian, satellite data.

INTRODUCTION

Indonesia stretch roughly from 6ºN to 10ºS and from 95ºE to 142ºE and occupies a central position of Indo-Pacific creating permeable barriers between the Pacific and Indian Oceans and the Asian and Australian Continents. It has more than 17,500 islands and coastline in excess of 80,000 km. As the world's largest archipelago, Indonesia is positioned in a strategic location with respect to global ocean circulation patterns. The dynamic nature of the archipelagic seas shows the interaction with the Pacific and Indian Oceans and monsoonal climate, and it may explain the high marine biodiversity of the region to a great extent. Since the climate of the archipelago is under the influence of the Asian-Australian monsoon system, the climate exerts a major influence on the large-scale circulation pattern of intra-archipelagic seas and it plays a significant role in the production of the coastal and marine ecosystems.

On the other hand, variations in the environmental conditions affect the recruitment, distribution, abundance and availability of fishery resources. It is not possible to measure remotely the entire range of information needed to assess changes in the marine environment. Knowledge of particular conditions and processes affecting fish populations, however, may often be obtained using measurements made by remote sensors, e.g., variations in primary production, distribution of surface isotherms, regions of upwelling, currents and water circulation patterns. The parameters providing information on these environmental factors may allow a forecast of fish distribution or more generally the definition of marine fish habitats (Kemmerer, 1980). Estimation of a fishery resource can be assisted by the measurement of parameters which

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affect distribution and abundance. Much of the research dealing with environmental effects related to fisheries is concerned with the correlation of a single parameter with the spatial and temporal distribution of fish. It is most likely, however, that fish respond to the sum of environmental factors. Thus, it becomes necessary to correlate a large number of parameters, obtained by remote sensing techniques, with fish distribution.

Since the satellite Nimbus 7 with the Coastal Zone Color Scanner (CZCS) sensor was launched in 1978, the investigation of global (Harris et al., 1993) and local (Fuentes-Yaco et al., 1997) marine productivity by using satellite data has been widely popular among the scientists to understand various phenomena of the marine environment through the ocean color detection. The concentration of chlorophyll pigments (the photosynthetic pigments of phytoplankton) is often considered as an index of biological productivity in an oceanic environment, and it can be related to fish production. Chlorophyll concentrations above 0.2 mg m^{-3} indicate the presence of sufficient planktonic biomass to sustain a viable commercial fishery (Gower, 1972). 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. Multi spectral observations from airborne or spaceborne sensors, therefore, allow the detection of phytoplankton concentration.

To understand marine productivity, ocean circulation, fish migration and their abundance, some observations by using the CZCS have been carried out by various researcher (Bricaud et al., 1987; Denvort et al., 1999; Banse, 2000; Kim et al., 2000), AVHRR, OCTS, SeaWiFs and MODIS data (Laur, 1984;Tameishi and Shinomiya, 1989; Ishizaka, 1998, Legard and Thomas, 1987; Legard and thomas, 2006; Venegas et al., 2007; Hensen and Thomas, 2007; Crawford et al., 2007) have been conducted successfully in the temperate area, however, in the tropical area, the observation was still limited.

Indonesia as one of the largest maritime continent in the tropical area with the large diversity of local environment problems is to be one of an ideal and important area to assess the ability of satellite data for the regional and local marine environmental study as well as marine productivity. Hence in this study, the discussion will be focused on the case of the coastal area around Java, Lampung Bay and South Kalimantan as interesting area expressing the different environmental situation and representing the Indonesian seas region for marine productivity observation.

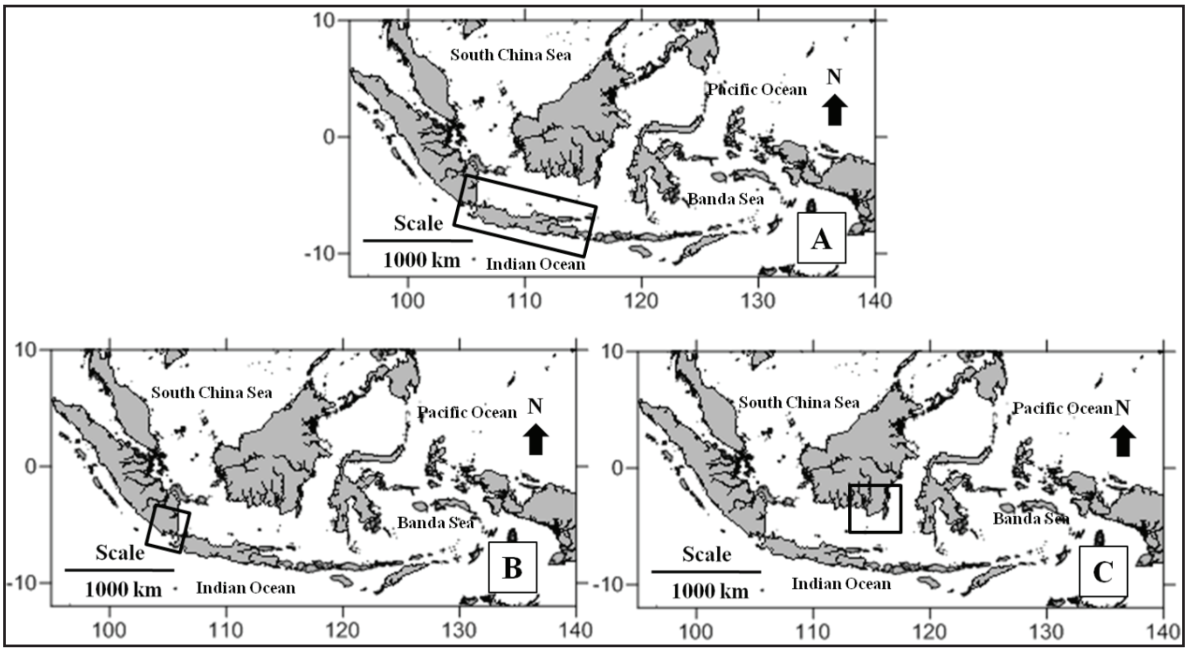

Figure 1. Study area in the coastal area around Java (A), Lampung Bay (B) and South Kalimantan (C).

MATERIAL AND METHODS

Study Area

The study area covered Indonesian seas region with special attention focused on the coastal area around Java, Lampung Bay and South Kalimantan (Fig.1). The coastal area around Java covers the Java Sea in the northern part and the Indian Ocean in the southern part with the position between 103−118°E and 4−10°S. In the western and eastern parts, the area is bounded by Sunda Strait and Bali Strait, respectively. These straits connect the Java Sea to the Indian Ocean. Bathymetry of the Java Sea is shallower than 200 m and that of the Indian Ocean is deeper than 1000 m (Fig. l).

Lampung Bay is a semi enclosed bay located in the southern coastal area of Sumatera and faces to the Sunda Strait 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). Coastal area of South Kalimantan located at longitude 114−118^{o}E and latitude 1.5−6^{o}S. The area exists in the northern part of the Java Sea with bounded by the Makassar Strait in the eastern part and a big river of Barito in the western part.

Data Collection and Analysis

A series of monthly mean Sea Surface Chlorophyll-a (SSC) and Sea Surface Temperature (SST) data 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 2005 to study in the coastal area of South Kalimantan, Lampung Bay and the other Indonesian region. The spatial resolution of this data is about 9 km and 1.1 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 for SeaWiFs data of Level 3 with spatial resolution 9 km was collected for the period of 1998 (http://disc.sci.gsfc.nasa.gov/giovanni/).

The nutrient data (DIN: nitrate) of Damar, (2003) was obtained by sampling of sea surface water (depth of 0 to 1.5 m) using PVC Van Dorn bottle The sample water was then filtered through MFS nucleopore (diameter 47 mm and pore size of 0.2 mm) and analyzed at the main laboratory in Bogor by using spectrophotometric according to Grasshoff et al. (1983). Fish production data in the coastal area of South Kalimantan and Lampung Bay as reference of the marine productivity was collected from the biggest fish landing area at Muara Kintab and fish landing area of Lampung Bay for the period of 2003 to 2005. While for southern coastal area of Java, NOAA-AVHRR SST data of 1995−1997 and SeaWiFs SSC data of 1998 as well as fish catch data from some places in the southern coastal area of Java were collected to understand the environmental and marine productivity within this region. To support this study, the meteorological data (precipitation) was also collected to understand the influence of monsoonal system on the marine productivity among the area. To understand seasonal variability of SSC, SST and their impact on the pelagic fish productivity among the area, a series of monthly mean SSC, SST and fish catch data were plotted to obtain the information of their temporal and seasonal variability.

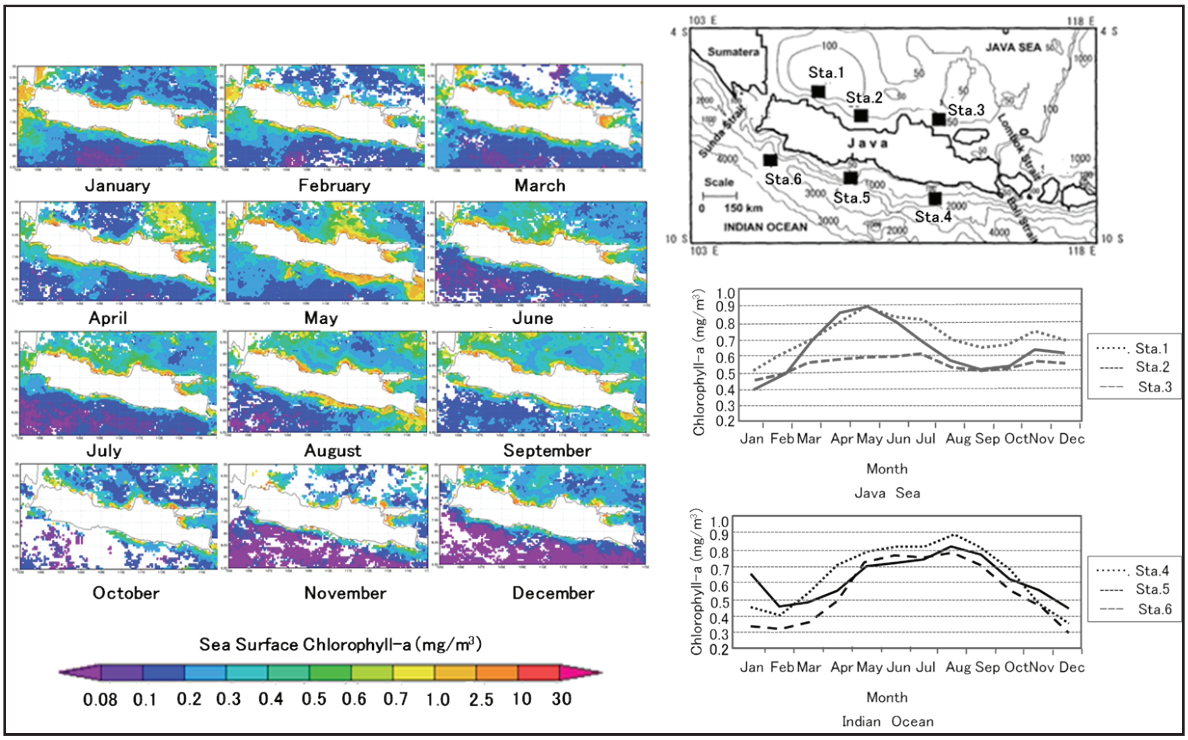

Figure 2. Monthly mean SSC distribution around Java derived from SeaWiFs in 1998.

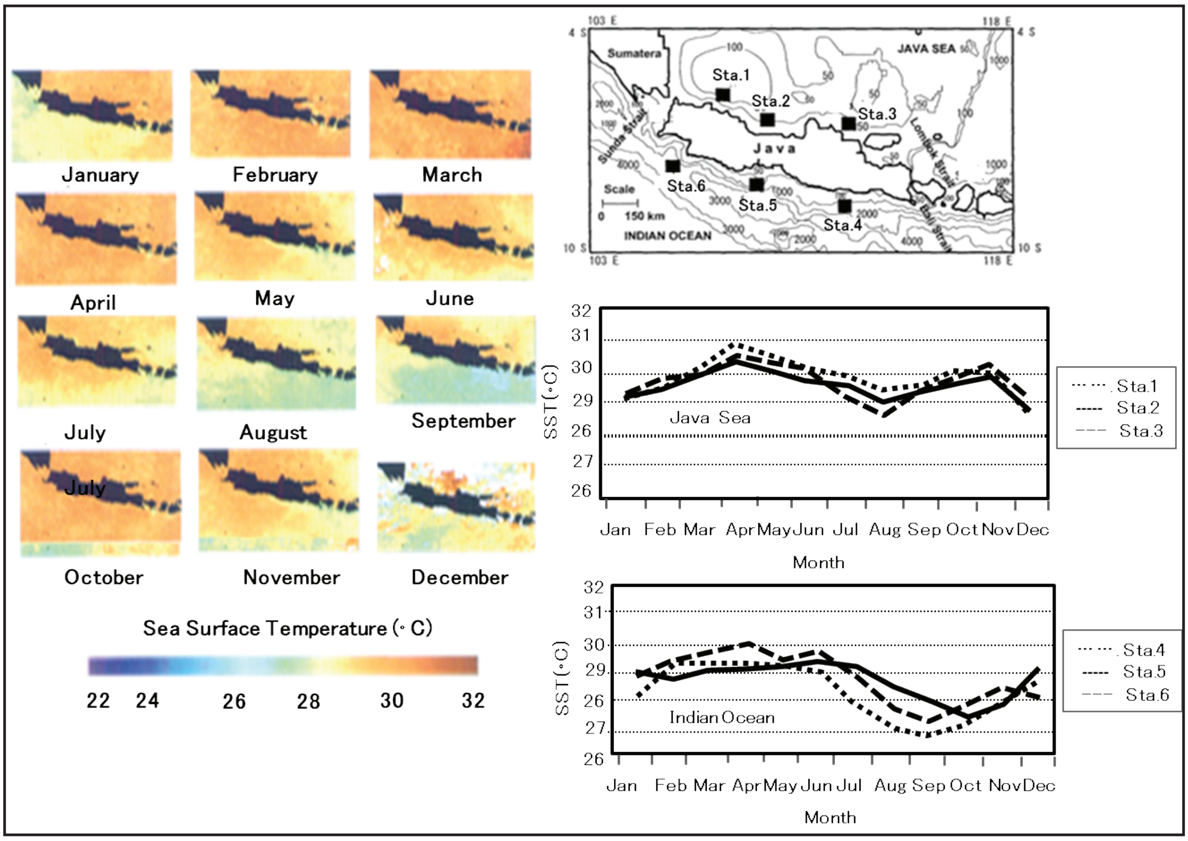

Figure 3. Monthly mean SST distribution around Java derived from NOAA-AVHRR in 1998.

RESULT AND DISCUSSION

Sea Surface Chlorophyll-a (SSC) and Sea Surface Temperature (SST) within Indonesian water vary among the region and is affected by monsoonal system as well as local and regional environment. The similar situation was also shown on fish catch variability. In this study, the brief discussion will concern on the coastal area of Java, Lampung Bay and South Kalimantan regions.

Coastal Area of Java

The environment of coastal area of Java was affected by monsoonal system as well as the local and regional environment. Figure 2 and 3 show an annual cycle of 9 km resolution SSC and 1.1 km resolution SST distributions around Java. During the northwest monsoon from January to March, SSC concentration is relatively high within 0.12–0.90 mg/m^3 in the Java Sea, particularly in the inner and central shelf of this area. High concentration of SSC during the northwest monsoon was also found in the southern coastal area of Java, Bali and Lombok.

Variability of SSC and SST which are obtained from some sampling points in the northern (Java Sea) and southern coastal area of Java (Indian Ocean) show different characters between these two areas. In general, average of SSC in the Indian Ocean was relatively higher than that in the Java Sea and the opposite for SST. SSC variability around Java shows almost the similar pattern to that of SST, that is, in the northern coastal area of Java semi annual variation is dominant, but in the southern coastal area of Java, annual variation is dominant. In the Java Sea, SSC and SST maxima occur twice around the transition periods, that is, SSC in April-May and November, and SST in April and November. SSC and SST maxima in the Java Sea are within 0.60–0.90 mg/m^3 and 30.5−31.0 °C, respectively. On the other hand, in the Indian Ocean, SSC maximum and SST minimum occur once a year in August and September, respectively, as shown in Fig. 2 and 3. SSC maximum and SST minimum within this area are 0.80−0.90 mg/m^3 and 26.5−27.0°C, respectively.

As response to high SSC concentration due to the upwelling in the southeast monsoon (June to September), fish catch along the southern coastal area of Java was higher than that in the northwest monsoon (December to March) as shown in Fig. 4. High fish catch in January in the western part of southern coastal area of Java (Sukabumi) may be due to high SSC generated by mixing process between the enriched water mass of Sunda Strait and eastward south Java current during the northwest monsoon. In the Java Sea, fish catch shows a similar pattern to the SSC variability shown in Fig. 2 and 3, that is, fish catches at Tangerang, Cirebon and Probolinggo increase during the period of March to June and October to November as well as SSC. Such situation suggests that fish catch has a strong correlation to SSC variability.

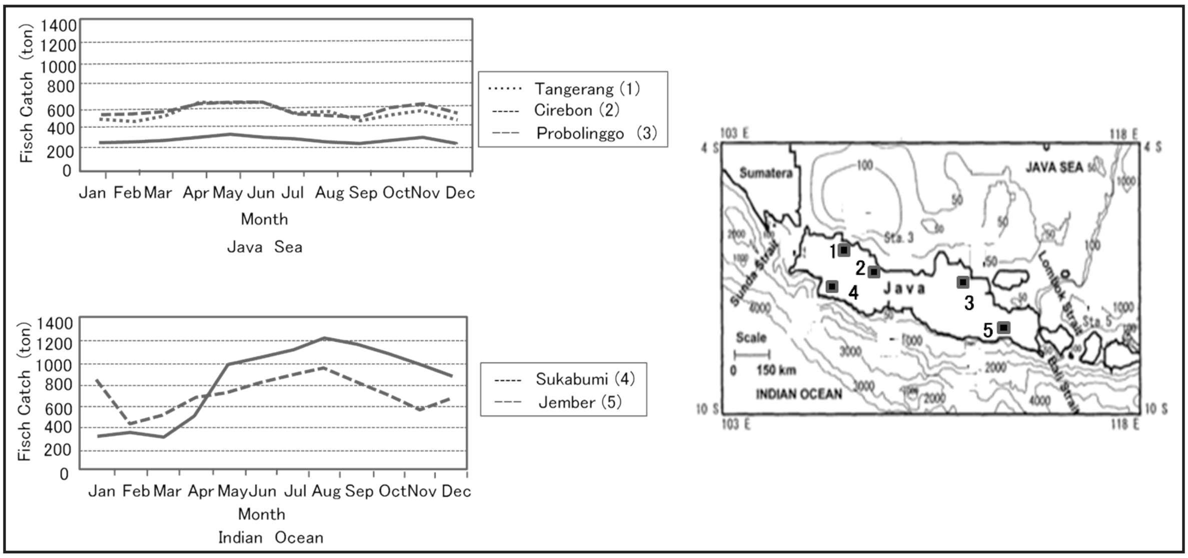

Figure 4. Temporal variation of fish catch of the northern and southern coastal areas of Java in 1998

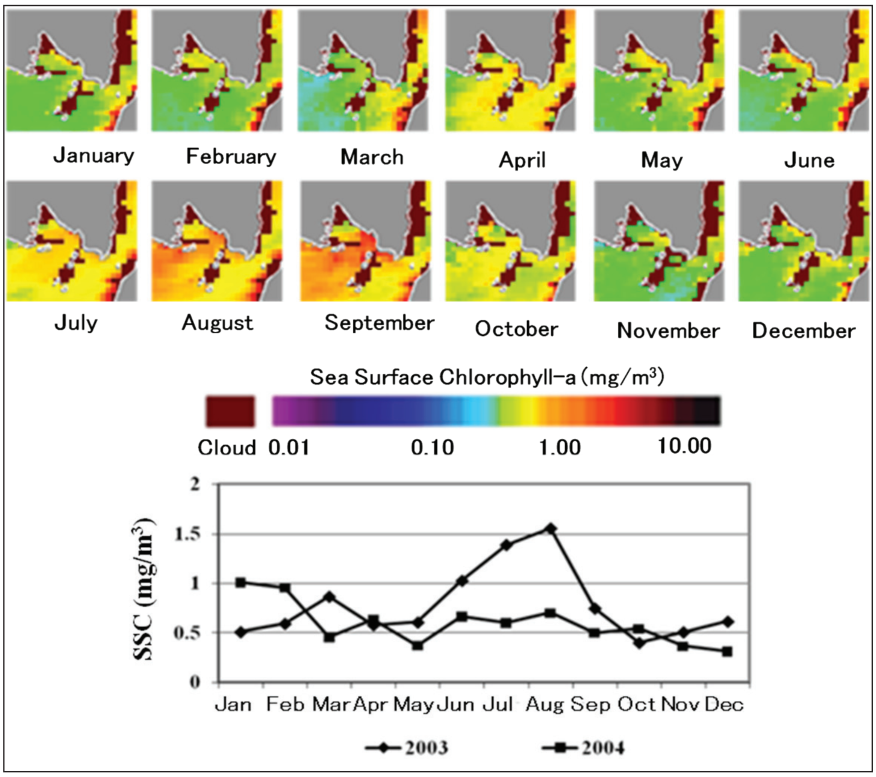

Figure 5. Spatial and temporal variability of SSC in Lampung Bay in 2003 and 2004.

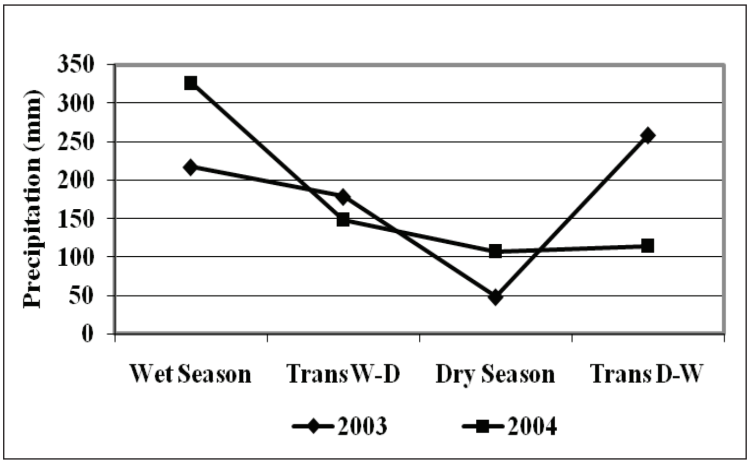

Figure 6. Precipitation variability in Lampung Bay.

Lampung Bay

Spatial and temporal variability of SSC in Lampung Bay where averaged value is obtained in the broken line of Fig. 1B are shown in Fig. 5. 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. 6) 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 season, 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 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 harbor, 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) as the most important nutrients discharged by the city.

Temporal and spatial distributions of the nutrients concentrations (DIN) 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. 7). The strong influence occurred only in the limited area close to the incoming rivers and in the inner part of the bay. In the middle part

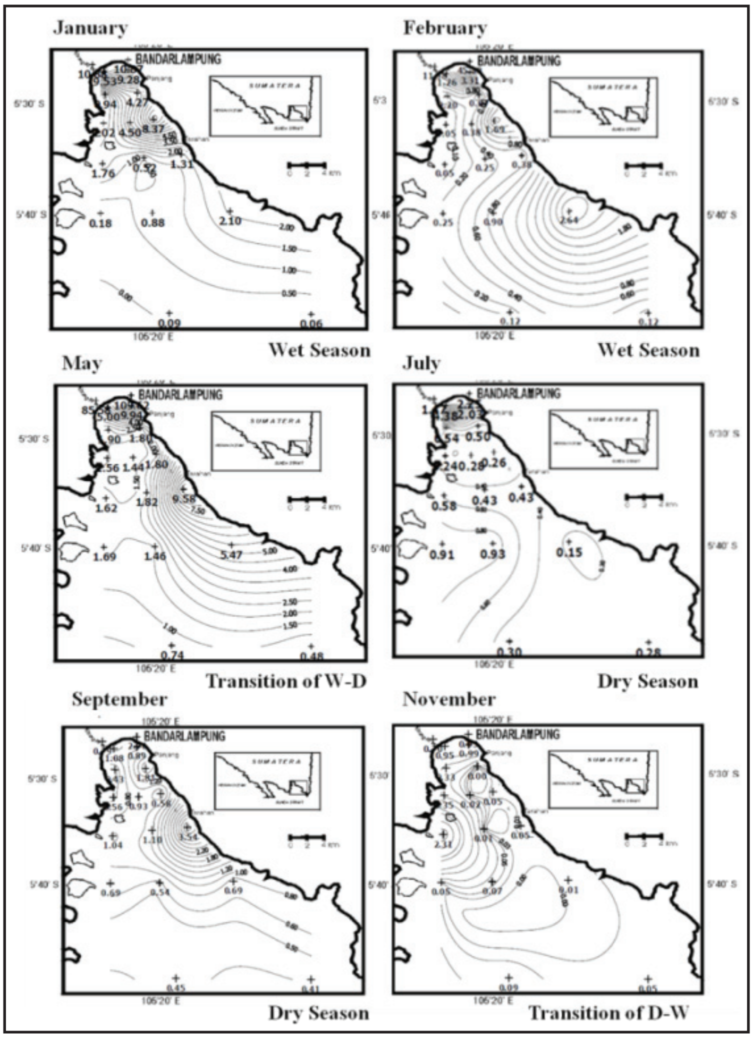

Figure 7. Spatial and temporal variability of DIN in Lampung Bay (Damar, 2003).

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.

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. 5). 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. 8. 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. 9.

The intrusion of cold subsurface water mass in the western part of Lampung Bay during the period of June to July as shown in Fig. 10 (Hayami et al., 2003) has indicated the existing of the upwelling occurrence in Lampung Bay. The existing of the upwelling event is also seen by increasing DIN (nitrate) concentration in the outer part of Lampung Bay during the southeast monsoon (July and September) as shown in Fig. 7 (Damar, 2003). In the transition period of dry to wet season (D-W) in October to November, the concentration of chlorophyll-a was then sed following the decrease of nutrient concentration (Fig. 5 and 7).

The existence of upwelling and precipitation has enriched 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.

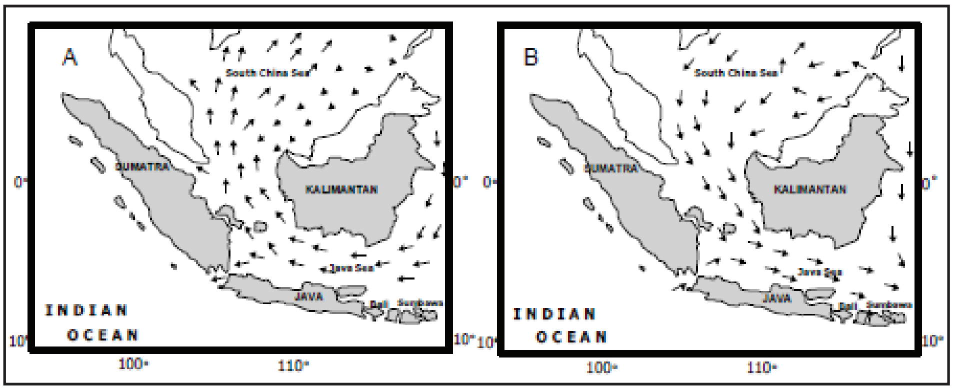

Figure 8. Sea surface current movement in the Southeast (A) and Northwest monsoon (B).

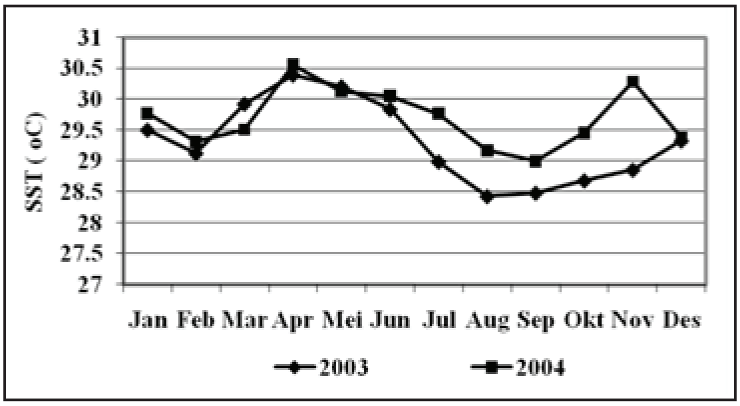

Figure 9. Spatial and temporal variability of average SST in Lampung Bay.

High chlorophyll-a in the northwest and southeast monsoon was followed by high pelagic fish catch in the same seasons as shown in Fig. 11. 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 was then decreased as similar as decreasing of chlorophyll-a concentration during this period.

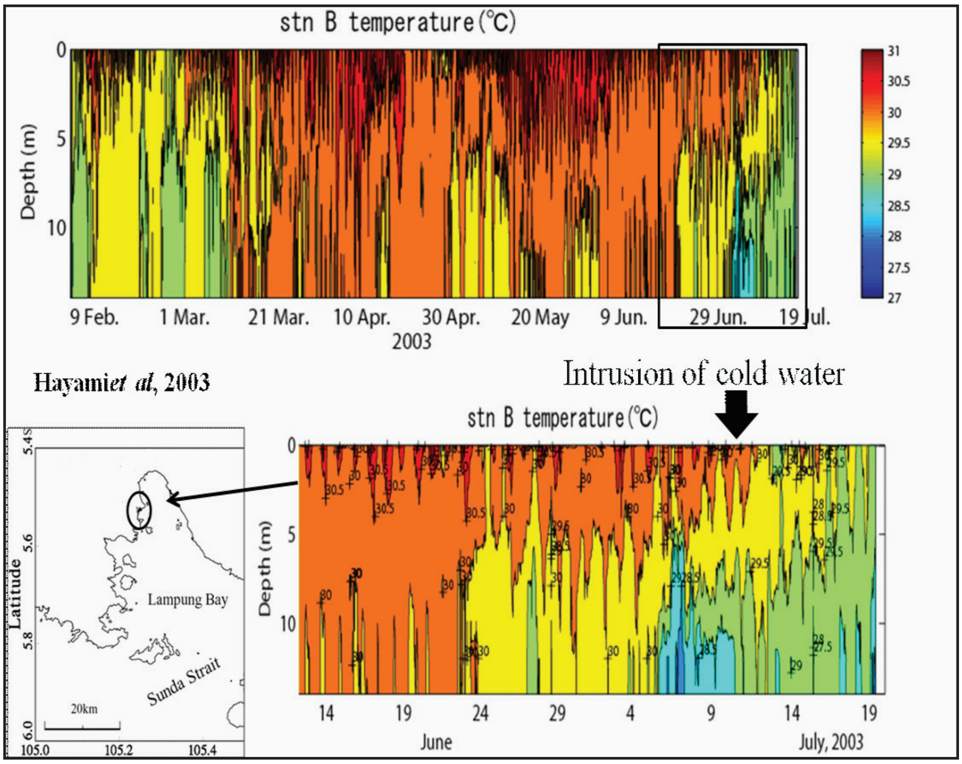

Figure 10. The intrusion of cold subsurface water mass in the western part of Lampung Bay during the period of June to July (Hayami et al, 2003).

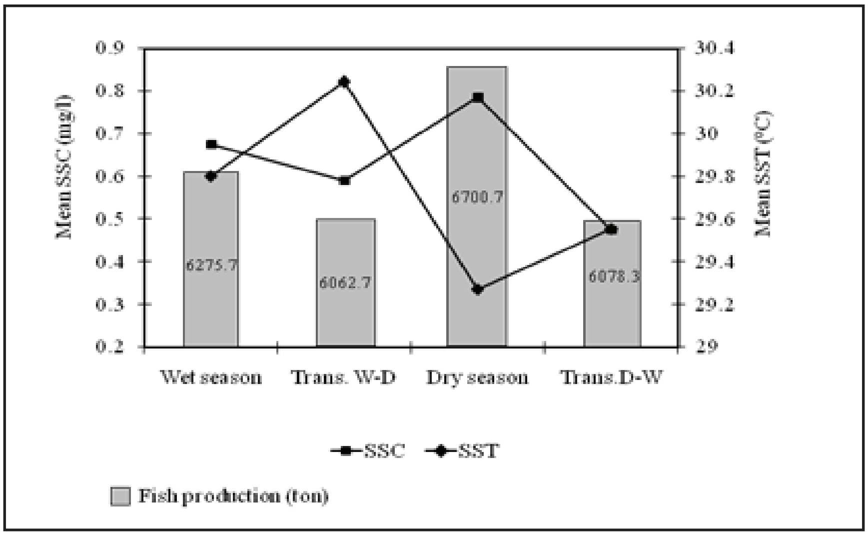

Figure 11. Seasonal variability of SSC, SST and Fish Catch in Lampung Bay.

Coastal Area of South Kalimantan

Temporal and seasonal variability of SSC in the coastal area of South Kalimantan was shown in Fig. 12. A relatively high concentration and wide distribution of SSC were obviously seen during the period of Northwest Monsoon (Wet Season) from December to March and the transition period of the Northwest Monsoon to the Southeast Monsoon (Dry Season) from April to May (Transition W-D). During these periods, high chlorophyll-a tends extend to the southeastward as response to the surface current movement due to the northwesterly wind. Increasing chlorophyll-a concentration from the period of the Northwest Monsoon (Wet Season) to the Transition W-D seems to be associated with high precipitation during this period (April–May) as shown in Fig. 13.

High precipitation has caused the enrichment of the coastal area of the South Kalimantan due to the enhancement of the nutrient concentration through Barito River in the western part of the coastal area. The upwelling evidence was not found within this area. This situation indicated that marine productivity within this area was governed by nutrient load from the river that was controlled by monsoonal system. The similar pattern was also

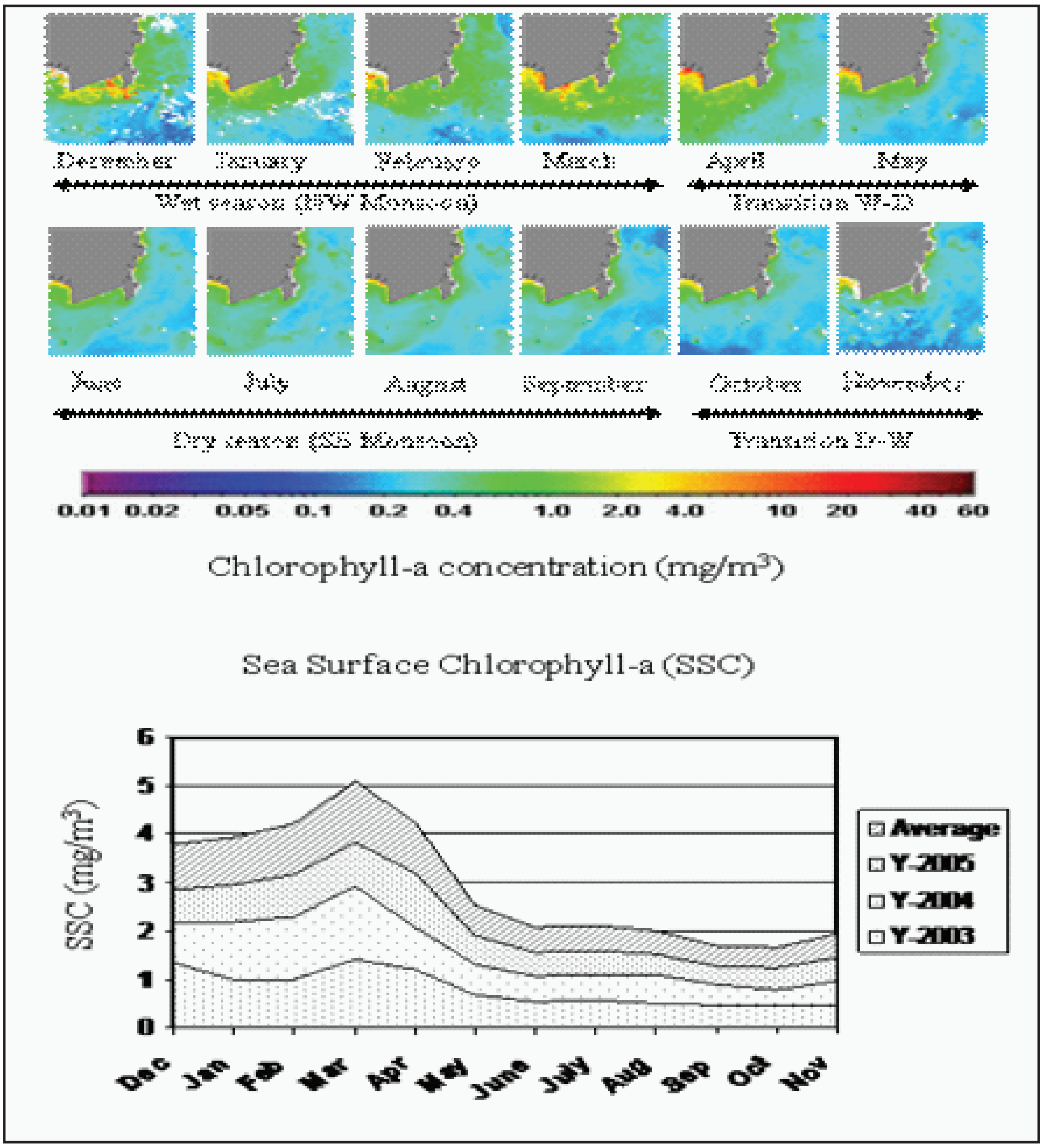

Figure 12. Temporal and seasonal variability of SSC in the coastal area of South Kalimantan.

seen in the abundance variability of the pelagic fish as shown in Fig. 14.

During the period of the Northwest Monsoon (Wet Season) from December to March and the Transition period of Northwest Monsoon to Southeast Monsoon (Trans W-D) in April to May, fish abundance was high and it decreased in the Southeast Monsoon (Dry Season) from June to September and Transition period of the Southeast Monsoon (Dry Season) to the Northwest Monsoon (Wet Season) in October to November (Transition D-W). The temporal change of fish abundance was similar to the temporal variation of SSC (Fig.12) and precipitation (Fig. 13). This situation revealed that combined effect of meteorological and oceanographical processes that are controlled by monsoonal system has influenced the variability of marine productivity within the coastal area of South Kalimantan. Seasonal variability of SSC, SST and Fish Catch are seen in Fig. 14.

Since the Indonesian Throughflow (ITF) passes the Makassar Strait, it also seems to affect on the environment of the south Kalimantan coastal area. Circulation of the ITF varies along

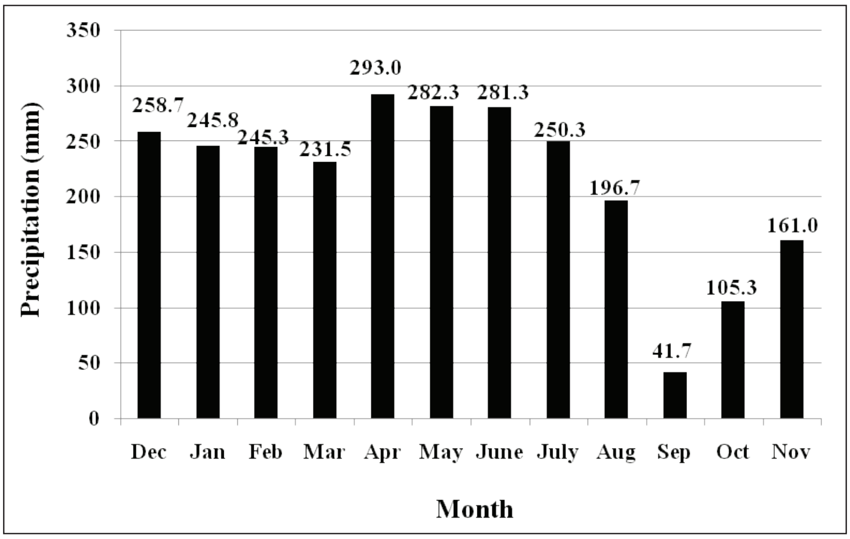

Figure 13. Precipitation and precipitation day in the South of Kalimantan.

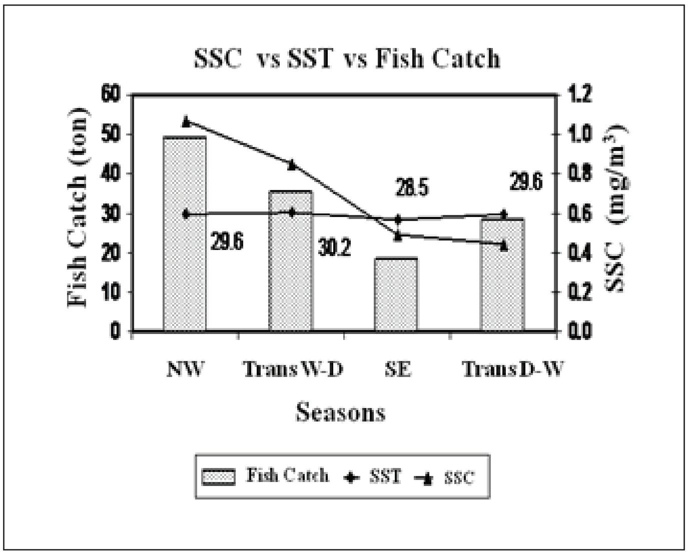

Figure 14. Seasonal variation of SSC, SST and fish catch in the coastal area of South Kalimantan.

with large-scale monsoon system. During June to August, southeasterlies of the southeast monsoon predominate over Indonesia and drive strong Ekman divergence (southwestward flow in the Southern Hemisphere thus increasing ITF to 15 Sv) whereas from December to February, Northwest Monsoon westerlies serve to directly reduce the ITF. During monsoon transitions, strong westerly winds in the eastern Indian Ocean force equatorial downwelling (eastward moving, eastward flow) that propagate through the Indonesian passages as coastally trapped Kelvin waves and serve to reduce the ITF flow with a minimum in April of 9 Sv. The Indonesian Throughflow (ITF) transported warm and low salinity water mass from the western equatorial Pacific Ocean. To understand the influence of the ITF to the environment of south Kalimantan coastal area, further investigation should be carried out in the future.

CONCLUSIONS

Satellite data is an effective tool and applicable for marine productivity study as well as for identifying and assessing fish abundance in the tropical water area. Variabilities of marine productivity in the coastal area of Java, Lampung Bay and South Kalimantan corresponded well to the Sea Surface Chlorophyll-a (SSC) variability. High concentration of SSC has been followed by increasing of fish abundance significantly. The enrichment mechanism of the coastal water in the South Java and Lampung Bay was governed by upwelling process, while in the northern coastal area of Java and South Kalimantan was governed by nutrient supply from the rivers discharge that associated with high precipitation controlled by monsoonal system. High precipitation has generated phytoplankton bloom within this region. To understand the ITF influence to the environment of south Kalimantan coastal area, further investigation should be set up in the future.

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