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Seasonal variation of the oceanic condition along the southern coastal area of Java to Sumbawa, Indonesia

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Abstract : Field observations to understand seasonal variability of the oceanic condition along the southern coastal area of Java to Sumbawa were conducted in the northwest monsoon (April–May 1990) and the southeast monsoon (August–September 1990). The observation was focused on the monitoring of physical (potential temperature, salinity, sigma- θ), chemical (phosphate, nitrate, silicate), and biological (chlorophyll-*a*, DO) characteristics through the season. The oceanic condition was found to be mainly affected by seasonal change of precipitation and upwelling related to the monsoon. The upwelling occurrence in the eastern part of this region was clearly seen by increasing nutrients concentration, especially nitrate and decreasing water temperature at the surface due to the southeast monsoon. The nitrate was a limiting factor for photosynthesis within this region.

Key words : *Seasonal vaariation, oceanic condition, southern coastal area of Java to Sumbawa*

1. Introduction

The southern coastal area of Java to Sumbawa is well known as one of the most productive area of the oceanic migratory fish such as skipjack and tuna in the western Indonesia due to upwelling. That situation has attracted some investigators to observe the upwelling phenomena in and around this area from various points of view. WYRTKI (1962) demonstrated the upwelling occurrence within this region by ascending of low water temperature and rich nutrient (phosphate) water mass near thermocline (200 m) to the surface in the southern part of Sumbawa during the southeast monsoon. PURBA(1995) found the upwelling by SST(Sea Surface Temperature) distribution in the narrow areas of the western Java.

Detailed information of the oceanic condition, however, is still very limited, particularly from the view point of conventional parameters and nutrients distribution as well as their variability in the different seasons along the southern coastal area of Java to Sumbawa. Since the area is considered to be affected by the monsoon (TOMASCIK *et al*, 1997), seasonal observation of the oceanic condition is necessary to be conducted within dhis region in order to confirm the upwelling situation related to the monsoon. The seasonal change is suspected to have strong effect on the water characteristic variability and their distribution in the water column.

To understand seasonal variability of the oceanic condition along the southern coastal area of Java to Sumbawa, we observe the distribution of water temperature, salinity, phosphate, nitrate, silicate, dissolved oxygen and chlorophyll-*a* during the northwest and southeast monsoons.

2. Observations

Intensive observations using R. V. Barunajaya I of The Agency for the Assessment and Application of Technology (BPPT) were carried out to collect the numerous data of physical (water temperature and salinity), chemical (phosphate, nitrate and silicate) and biological (chlorophyll-*a* and dissolved oxygen) parameters. These observations were conducted in

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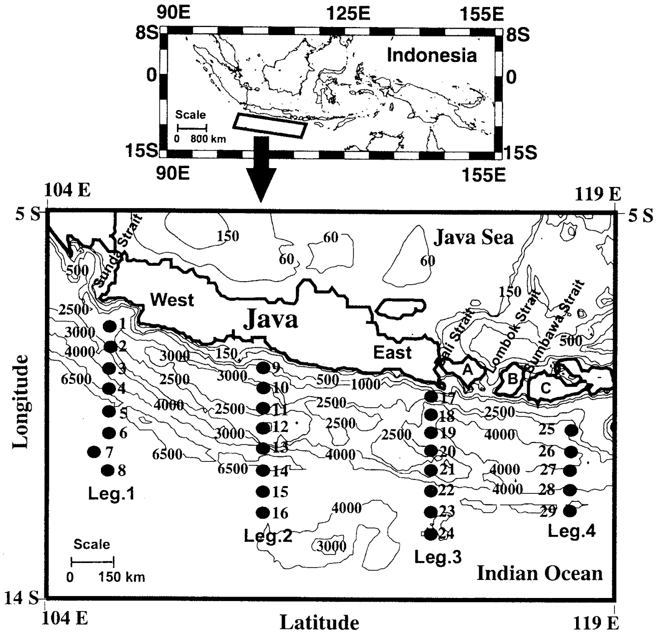

Fig. 1. Study area, observation stations (●) and bathymetry (m) along the southern coastal area of Java to Sumbawa. A denotes Bali Island, B and C are Lombok and Sumbawa Island, respectively. Western part is represented by Legs. 1 and 2, and eastern part by Legs. 3 and 4.

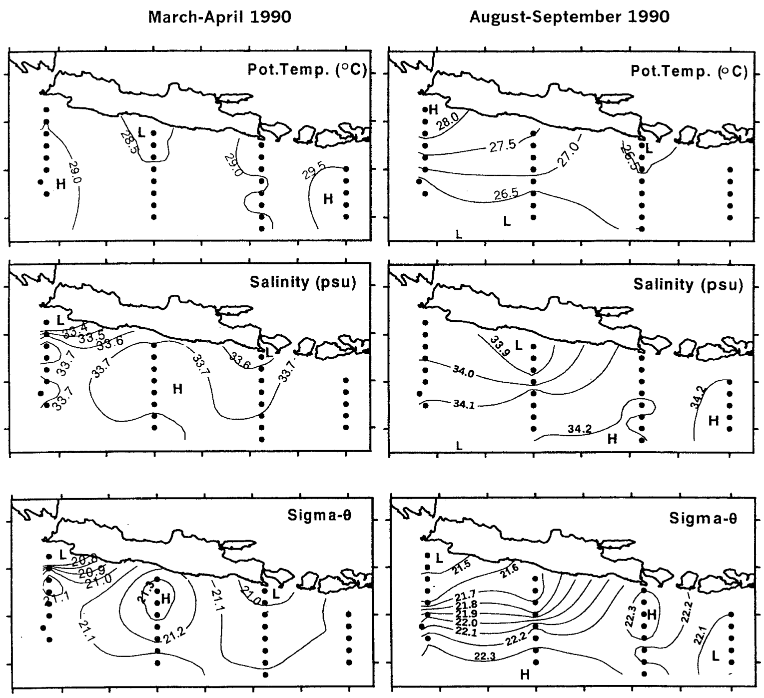

Fig. 2(a). Horizontal distributions of potential water temperature (℃), salinity (psu) and sigma-θ at the surface layer

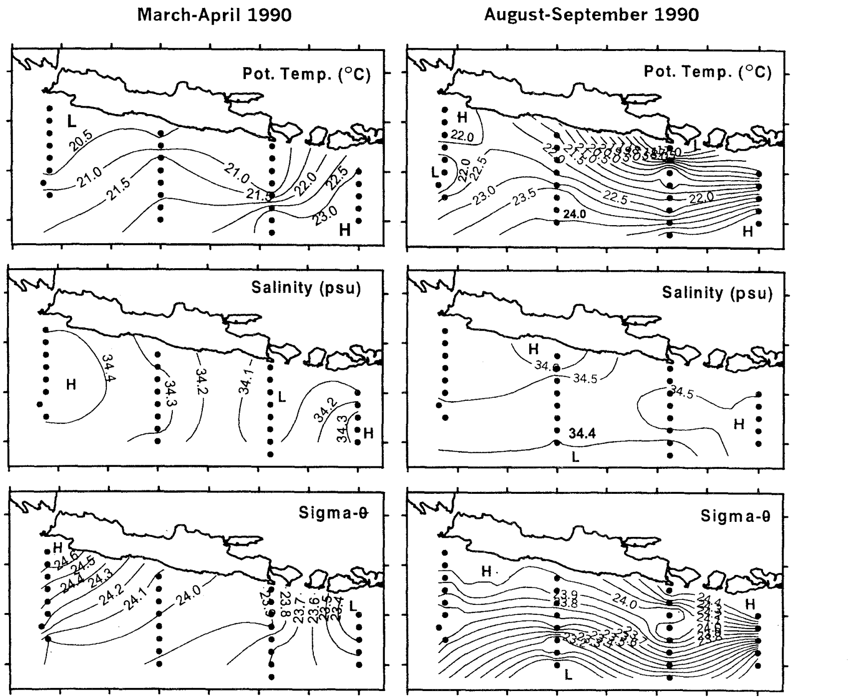

Fig. 2(b). Horizontal distributions of potential water temperature (℃), salinity (psu) and sigma-θ at 100m depth.

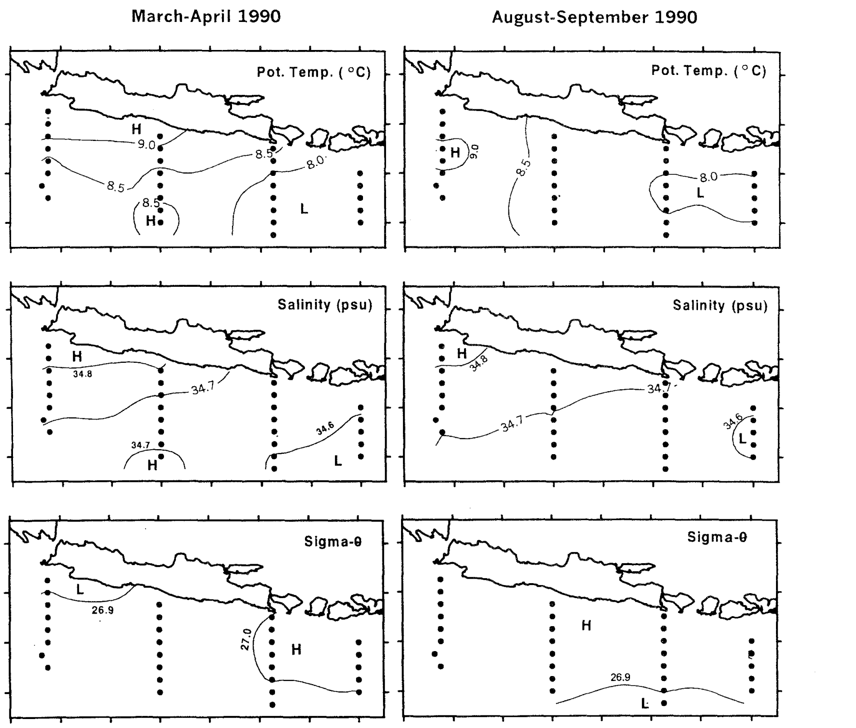

Fig. 2(c). Horizontal distributions of potential water temperature (℃), salinity (psu) and sigma-θ at 500m depth.

March–April 1990 (northwest monsoon) and August–September 1990 (southeast monsoon) at 29 stations along the southern coastal area of Java to Sumbawa. The observation stations are divided into four parallel Legs from the western (Leg. 1 and 2) to the eastern part (Leg. 3 and 4). The distance between Legs is 500km and that between stations of each Leg is 50km. The station number of Leg. 1 to Leg. 3 is 8 stations, and that of Leg. 4 is 5 stations (Fig. 1).

To understand vertical distributions of physical parameters, CTD of the Guildline type was deployed up to 600m depth to record a series of water temperature and salinity. Potential water temperature and sigma-θ was then calculated from water temperature, salinity and the depth (UNESCO, 1973). A series of chemical and biological data (phosphate, nitrate, silicate and dissolved oxygen) were obtained by analyzing water samples at various depths, which were withdrawn from 12 Niskin bottles attached to CTD. Phosphate, silicate and nitrate were then measured by Tecnicon Auto Analyzer and dissolved oxygen by Winkler method (U.S. Hydrographic Office, 1959). Biological parameter (chlorophyll-*a*) was obtained by filtering water samples at various depth using 0.45μ Millipore filter HA WP with diameter of 47mm and was then extracted by 90% acetone and measured by spectrophotometer with the wave length of 665, 645 and 630nm (STRICKLAND and PARSON, 1968). HELLERMAN and ROSENSTEIN (1983) monthly mean wind stress data derived from 1870–1976 for April, May, Augst and September with resolution of $2° \times 2°$, and bathymetry data of the National Geophysical Data Center (NGDC) with resolution of $5' \times 5'$ were also collected to support this study.

3. Results

3.1. Potential water temperature, salinity and sigma-θ

Horizontal distributions of potential water temperature, salinity and sigma-θ at the surface layer, 100m and 500m depths are shown in Figs. 2 (a), (b), and (c), respectively. In the northwest monsoon, potential water temperature is 28.5–29.5 ℃ at the surface layer, 20.5–23.0℃ at 100 m depth and 8.0–9.0 ℃ at 500 m depth. In the southeast monsoon, potential water temperature is 26.5–28.0 ℃ at the surface layer, 16.0–25.0 ℃ at 100 m depth and 8.0–9.0 ℃ at 500 m depth.

In the southeast monsoon, potential water temperature at the surface and 100 m depth are lower than that in the northwestmonsoon. Moreover, during the southeast monsoon, potential water temperature at the surface layer of the estern part (Leg. 3) is remarkably lower than that in the western part (Leg. 1). The similar situation is also found at 100 m depth. The lowest potential water temperature of those layers mainly appears in the nearshore of the southern coastal area of east Java to Bali (Stas. 17 and 18 of Leg. 3) and it spread southwestward to the offshore. At 500m depth, potential water temperature is stable with the similar pattern in both seasons, that is, high in the western part (Leg. 1) and low in the eastern part (Leg. 3).

In the northwest monsoon, salinity and Sigma-θ at the surface layer are within 33.3–33.7 psu and 20.7–21.3, respectively, those at 100m depth are 34.1–34.4 psu and 23.4–24.6 and those at 500m depth are 34.6–34.8 psu and 26.9 27.0. In the southeast monsoon, salinity at the surface layer, 100 m depth and 500 m depth are within 33.9–34.2 psu, 34.4–34.6 psu and 34.6–34.8 psu, respectively. Sigma-θ is within 21.5–22.3 at the surface layer, 23.0–24.4 at 100 m depth and 26.9–27.0 at 500m depth. Salinity and sigma-θ at the surface layer in the northwest monsoon are lower than those in the southeast monsoon. At 100 m depth, salinity is also lower, but sigma-θ is higher in the northwest monsoon. At 500 m depth, salinity and sigma-θ in both seasons are almost stable in the similar range. In addition, salinitiy and sigma-θ at the surface layer both seasons show almost the similar pattern, that is, low in the western part (Leg. 1) and high in the eastern part (Leg. 3) and on the contrary at 100 m depth. The different situation, however, is seen at 500m depth where salinity in both seasons is high in the western part (Leg. 1) and low in the eastern part (Leg. 3).

Vertical distibutions of potential water temperature, salinity and sigma-θ along Leg. 1 and Leg. 3 are shown in Figs. 3(a) and (b),

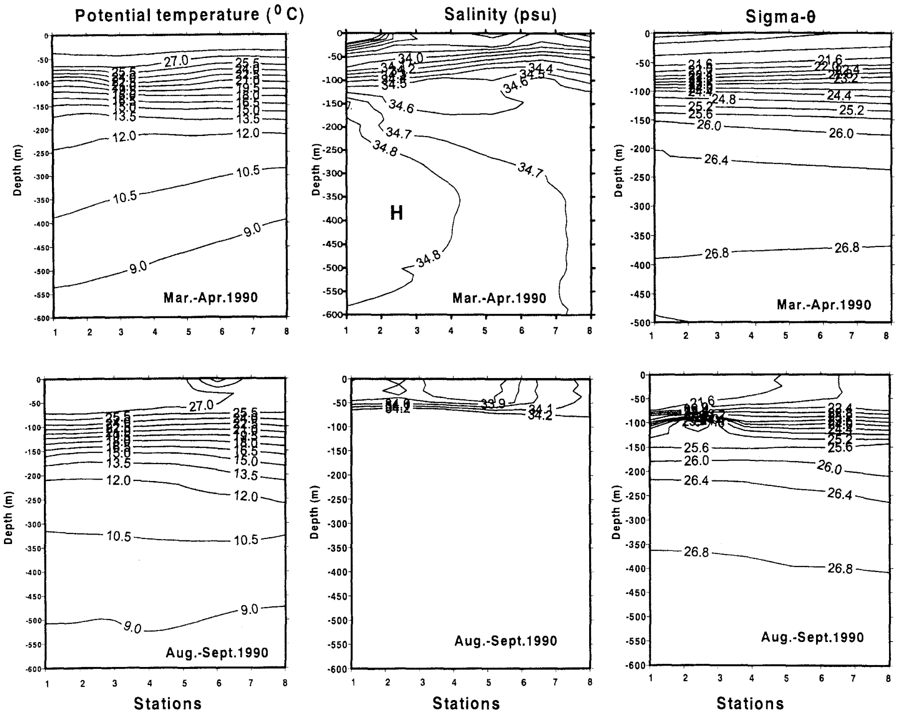

Fig. 3(a). Vertical distributions of potential water temperature (℃), salinity (psu) and sigma- θ along Leg. 1.

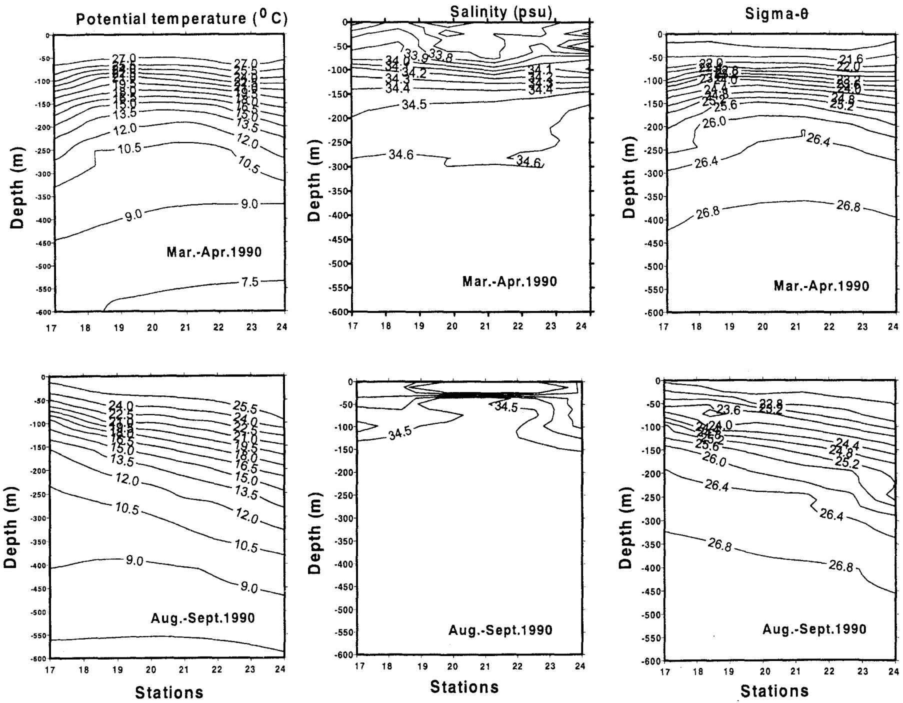

Fig. 3(b). Vertical distributions of potential water temperature (℃), salinity (psu) and sigma- θ along Leg. 3.

respectively. Vertical distributions of potential water temperature along Leg. 1(western part) and Leg. 3 (eastern part) show almost the similar pattern and well stratified in both seasons. In the surface layer, however, potential water temperature during the northwest monsoon (March–April) in the western part (Leg. 1) is slightly lower than that in the eastern part (Leg. 3) and the contrary situation is found in the southeast monsoon (August–September). The lowest water temperature less than 25.5 ℃ in the southeast monsoon is found near the shore of southern coast of east Java (Sta. 17 and 18) in the eastern part (Leg. 3) with shoreward ascending of the isotherm. The reversal situation with the off-shoreward ascending of potential water temperature is found in the northwest monsoon, especially at the depth below 250m in both western (Leg. 1) and eastern parts (Leg. 3). The similar ascending pattern is also found in sigma-θ distribution. Moreover, sigma-θ at the surface layer in the western part (Leg. 1) is slightly lower than that in the eastern part (Leg. 3) in the northwest monsoon and contrary in the southeast monsoon. Different situation is seen in salinity distribution. It is well stratified in the northwest monsoon and vertically well mixed in the southeast monsoon. High salinity water more than 34.8 psu intrudes in the western part (Leg. 1) at the depth below 200m from the near shore region during the northwest monsoon.

3.2. Nutrients and DO

Horizontal distributions of nutrients (phosphate, nitrate and silicate) and DO at the surface layer, 100m and 500m depths during the northwest and southeast monsoons are shown in Fig. 4(a), (b)and(c), respectively. Phosphate concentration at the surface layer does not show a significant difference between the northwest and the southeast monsoon and they are within 0.12–0.27 μ mol/l. The similar situation is also found on the silicate concentration, and they are within 5–9 μ mol/l. Higher concentration of phosphate and silicate in both seasons are found at the near shore region of southern part of the central Java to Sumbawa. On the other hand, nitrate concentration shows a significant difference between the seasons and it is higher in the southeast monsoon, almost 2 to 5 times than that in the northwest monsoon. Nitrate concentration in the southeast monsoon is within 0.5–2.3 μ mol/l, but that in the northwest monssoon is within 0.3–0.5 μ mol/l. The highest concentration of nitrate is also found at the same area with phosphate and silicate.

At 100m depth, phosphate concentration in the southeast monsoon is slightly higher than that in the northwest monsoon. Phosphate concentration in the southeast and northwest monsoons is 0.72–1.62 μ mol/l and 0.72–1.12 μ mol/l, respectively. The similar situation is seen on silicate concentration, that is within 9–11 μ mol/l for both seasons. Nitrate concentration shows significant difference between the seasons, that in the southeast monsoon is higher than that in the northwest monsoon. Nitrate concentration in the southeast monsoon is within 3.7–19.1 μ mol/l and that in the northwest monsoon within 3.7–10.3 μ mol/l. For these nutrients, the highest concentration is seen in the near shore region of southern coastal area of Java to Sumbawa.

At 500 m depth, phosphate and nitrate in the southeast monsoon is slightly lower and higher than those in the northwest monsoon, respectively. Phosphate concentration is within 1.97–2.27 μ mol/l in the northwest monsoon and 1.97–2.17 μ mol/l in the southeast monsoon. Nitrate concentration is within 24.7–33.5 μ mol/l in the northwest monsoon and 29.1–33.5 μ mol/l in the southeast monsoon. Silicate concentration is within 51–65 μ mol/l for both seasons. As similar as at the surface and 100 m depth, the highest concentration of phosphate, nitrate and silicate at 500m depth is also found around the near shore region of southern coastal area of Java to Sumbawa.

Meanwhile DO concentration at the surface layer shows slight difference between the seasons. The DO concentration in the southeast monsoon and northwest monsoon is within 3.95–4.45 ml/l and 4.35–4.45 ml/l, respectively. DO concentration is slightly lower in the southeast monsoon than that in the northwest monsoon. Higher concentration of DO in the southeast monsoon is seen at the southern part of east Java to Sumbawa and that in the northwest

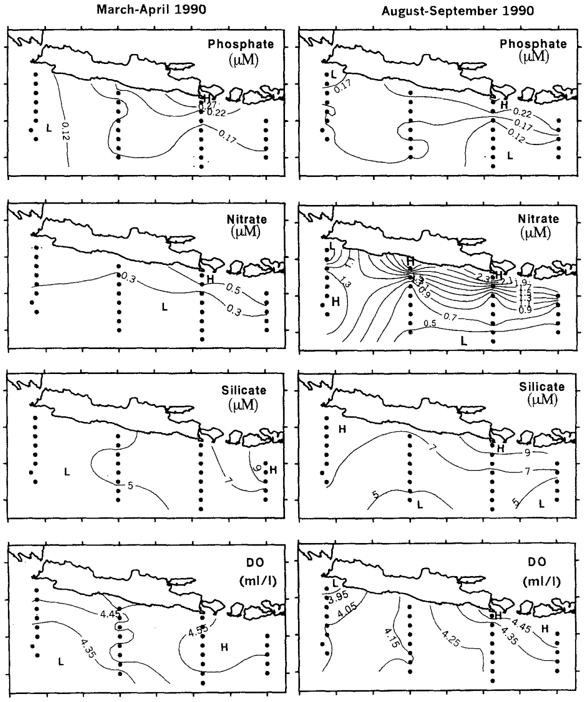

Fig. 4(a). Horizontal distributions of phosphate (μmol/l), nitrate (μmol/l), silicate (μmol/l) and DO (ml/l) at the surface layer.

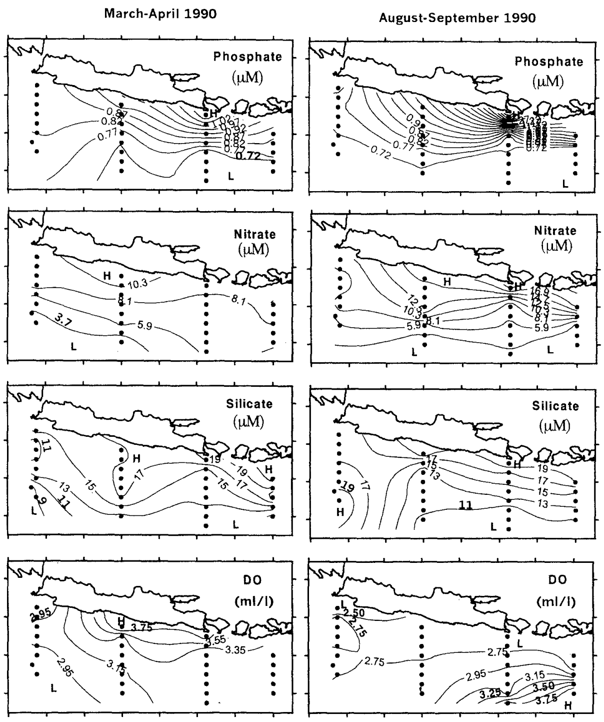

Fig. 4(b). Horizontal distributions of phosphate (μmol/l), nitrate (μmol/l), silicate (μmol/l) and DO (ml/l) at 100 m depth.

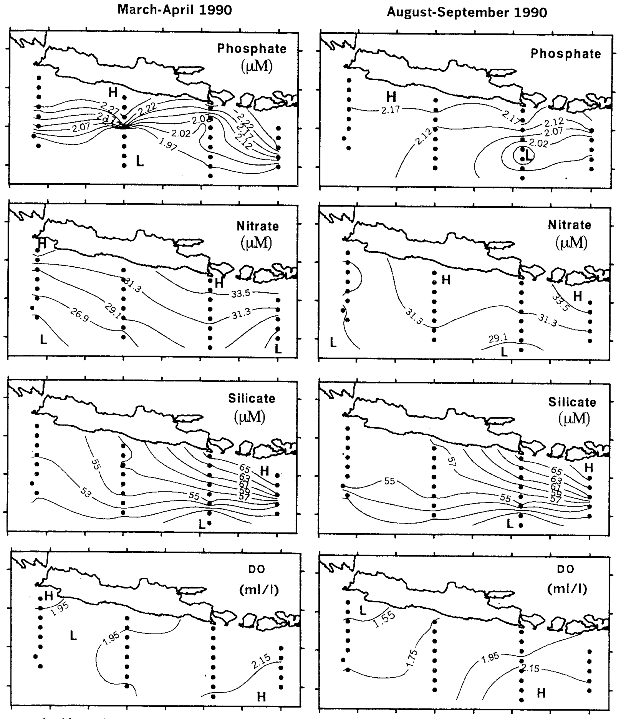

Fig. 4(c). Horizontal distributions of phosphate (μmol/l), nitrate (μmol/l), silicate (μmol/l) and DO (ml/l) at 500 m depth.

monsoon at the region of southern part of Bali to Sumbawa. At 100m and 500 m depths, DO concentration in the southeast monsoon is slightly lower than that in the northwest monsoon. DO concentration at 100m depth is within 2.50–3.75 ml/l in the southeast monsoon and 2.95–3.75 ml/l in the northwest monsoon.

Vertical distributions of phosphate, nitrate, silicate and DO along Legs 1 and 3 are shown in Figs. 5(a) and (b), respectively. At both Legs 1 and 3, phosphate, nitrate, silicate and DO are well stratified in both seasons. Large vertical gradient of phosphate, nitrate and silicate are seen between 50 to 350 m of both Legs 1 and 3. Along Leg. 3, higher phosphate, nitrate and silicate concentrations are seen to be migrated upward near shore as similar as DO during the southeast monsoon. The highest concentration of DO exists in the layer between 0–50 m depth.

3.3 Chlorophyll-*a*

Horizontal distributions of chlorophyll-*a* at the surface and 75m depth are shown in Fig. 6. At the surface layer, chlorophyll-*a* in the southeast monsoon is higher than that in the northwest monsoon. Chlorophyll-*a* is within 0.15–0.75 μg/l in the southeast monsoon and 0.15–0.55 μg/l in the northwest monsoon. High chlorophyll-*a* concentration in the southeast monsoon is concentrated at the near shore region of southern part of east Java and Bali, but in the northwest monsoon it is concentrated near shore region of west Java. At 75 m depth, however, concentration of chlorophyll-*a* in the southeast monsoon is lower than that in the northwest monsoon. Chlorophyll-*a* concentration in the southeast monsoon is within 0.15–0.45 μg/l with high concentration at the near shore region of southern part of east Java to Bali. In the northwest monsoon, chlorophyll-*a* is within 0.25–0.75 μg/l with high concentration at the near shore region of west Java.

Vertical distributions of chlorophyll-*a* along Legs 1(western part) and 3(eastern part) in the northwest and southeast monsoons are shown in Fig. 7. Along Leg 1, chlorophyll-*a* maximum is seen in the near shore region of west Java (Stas. 1–4) at 70–80 m depth in the

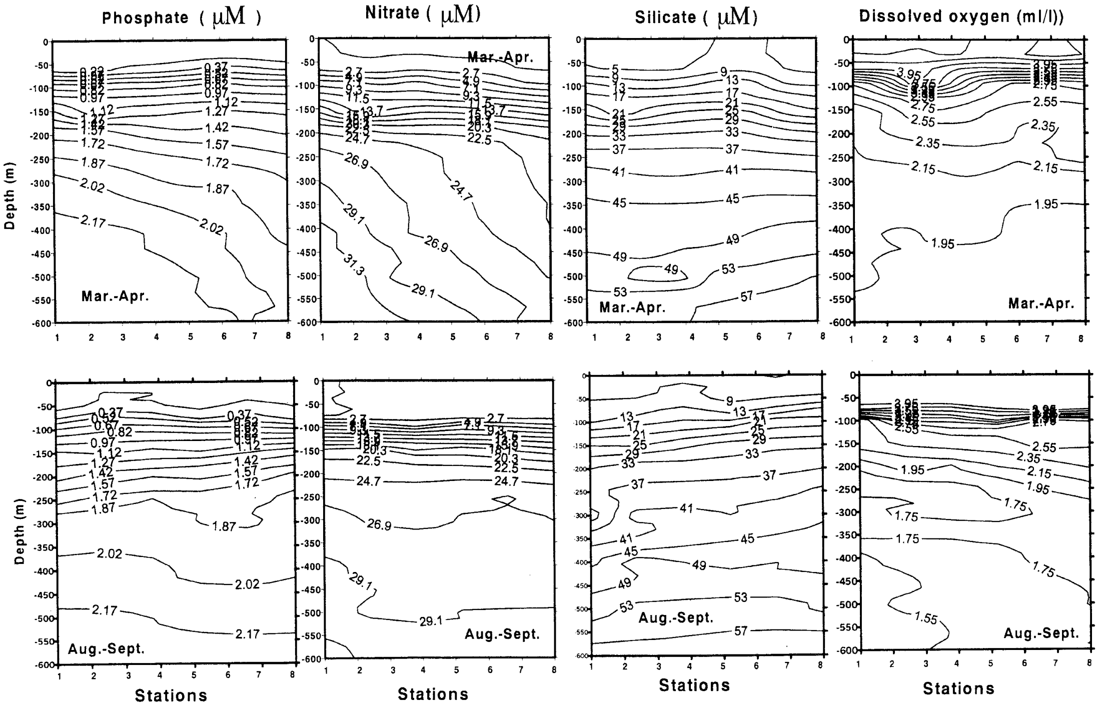

Fig. 5(a). Vertical distributions of phosphate (μ mol/l), nitrate (μ mol/l), silicate (μ mol/l) and DO (ml/l) along Leg. 1.

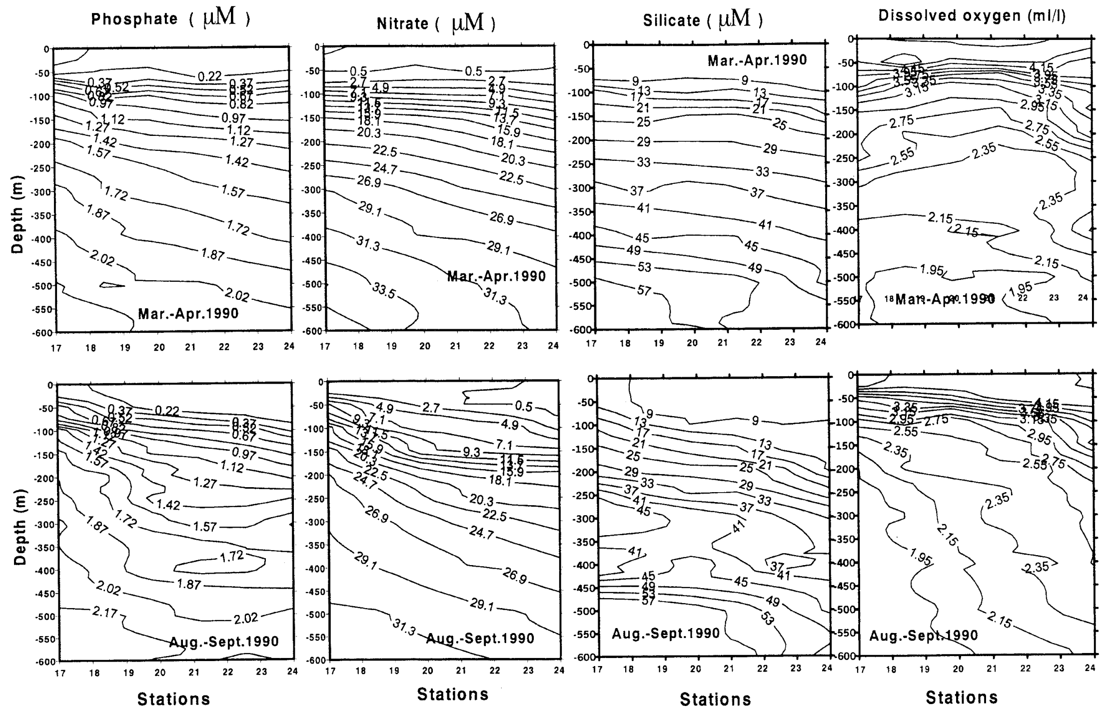

Fig. 5(b). Vertical distributions of phosphate (μ mol/l), nitrate (μ mol/l), silicate (μ mol/l) and DO (ml/l) along Leg. 3.

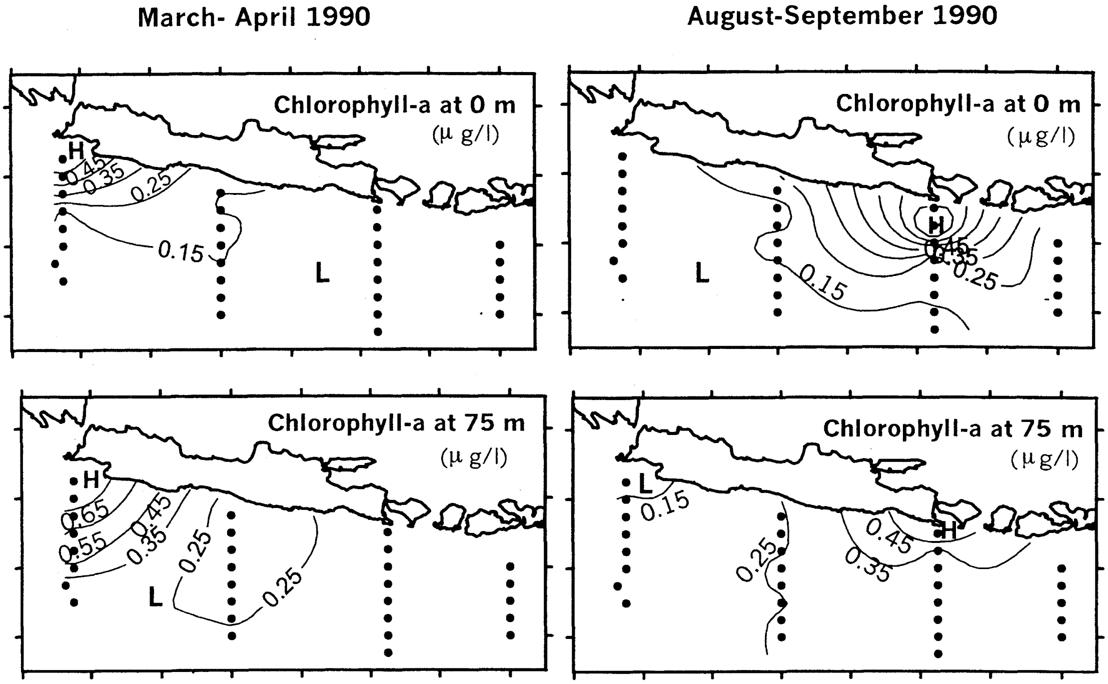

Fig. 6. Horizontal distributions of chlorophyll-*a* (μg/l) at the surface and 75m depth.

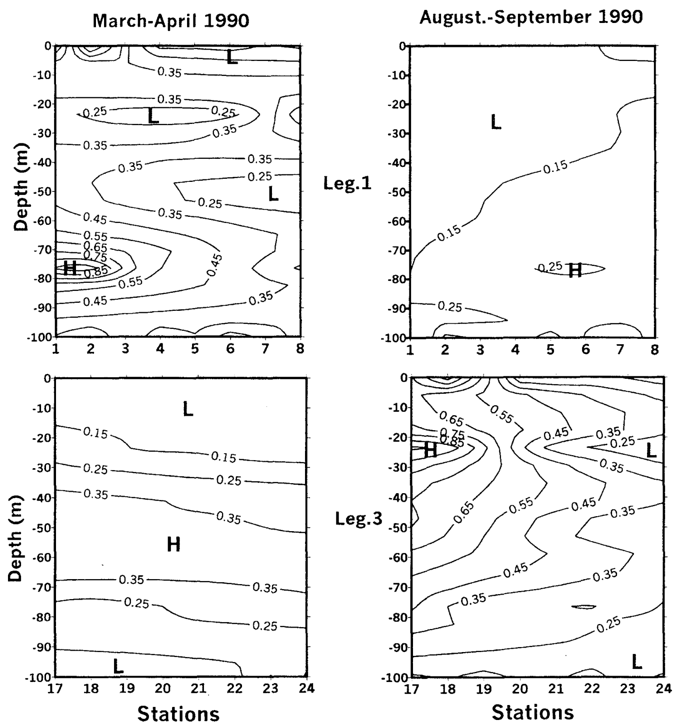

Fig. 7. Vertical distributions of chlorophyll-*a* (μg/l) along Legs. 1 and 3.

northwest monsoon. Along Leg. 3, chlorophyll-*a* maximum is concentrated in the near shore region of southern part of east Java (Stas. 17–20) at 20–30 m depth in the southeast monsoon.

4. Discussion

The oceanic condition along the southern part of Java to Sumbawa(Indian Ocean) is predominantly affected by the meteorological condition. T–S diagram shown in Fig. 8 strengths this argument. The distributions of TS in both seasons are nearly the same except the upper part, that is, water temperature in the northwest monsoon(o) is higher by 1–3 ℃ than that in the southeast monsoon (+). Lower water temperature at the surfave layer by 1–3 ℃ in the southeast monsoon shown in Fig. 2(a) is due to the upwelling generated by the sea surface Ekman transport responding to the southeasterly wind shown in Fig. 9. The occurrence of this upwelling is clearly seen in the horizontal distributions of water temperature and nutrients at the surface and 100m depth shown in Figs. 2(a) and (b) and Figs. 4(a) and (b). Moreover, the subsurface cold water with rich nutrients also appears in the surface layer of near shore region of south Bali due to the upwelling. As shown in Figs. 3(b) and 5(b), the subsurface cold water with rich nutrients along Leg. 3 is seen ascending from 250 m depth to the surface. As consequence, nitrate at the surface and 100 m depth is also increased even more than two times. This situation well agrees with the result of WYRTKI (1962), where the low temperature water mass with high phosphate concentration ascended to the surface from the subsurface laver (200 m). Such condition has generated phytoplankton bloom in the eastern part (Leg. 3) as indicated by chlorophyll-*a* increment at the surface and at 15–75 m depth (Figs. 6 and 7). Nutrients and chlorophyll-*a* are increased, but DO concentration at the surface and 100m depth is almost the same in the southeast monsoon and the northwest monsoon. This situation suggests that photosynthetic activity is low during the upwelling event due to low water temperature.

On the other hand, the distributions of physical and chemical parameters as well as DO at 500m depth show the similar situation between the seasons as shown in Figs. 2(c) and 4(c). This situation indicates that water mass in this layer is stable than those at the surface and 100m depth. In addition, water temperature and salinity are higher in the western part (Leg. 1) than those in the eastern part (Leg. 3) in both seasons. This indicates that a warm and saline water mass is transported eastward from the Indian Equatorial Water.

Higher nutrient concentration at the surface and 100 m depth shown in Figs. 4(a) and (b) in both seasons tends to appear at the near shore region of Bali and spreads to the southwestern part (Leg. 1). This condition may be occurred due to the combined effect of tidal mixing in Bali and Lombok straits and the upwelling generated by southeasterly wind.

The oceanic condition in the southern coastal area of Java to Sumbawa shows a specific variability. Lower salinity and density at the surface layer in the western part (Leg. 1), especially at the near shore region of west Java in the northwest monsoon, is probably due to large river discharge generated by high precipitation (SACHOEMAR and YANAGI, 1999, SACHOEMAR and YANAGI, 2000). This situation, however, does not reach to the lower more than 50m depth and no significant effect on the increasing of nutrients concentration at the surface layer as shown in Figs. 2(a) and 5(a), though high concentration of chlorophyll-*a* at the surface layer is obviously seen at this area (Fig. 6).

Different situation is seen at the eastern part (Leg. 3) in the southeast monsoon where chlorophyll-*a* maximum is found at 20–30 m depth (Fig. 7) as similar as high nutrient concentration as shown in Fig. 5(b). This condition indicates that the upwelling is being occurred at the eastern part (Leg. 3) in the southeast monsoon which is also confirmed by highes chlorophyll-*a* concentration and low water temperature at the surface layer of Sta.18 in Fig. 9. The Rossby's internal deformation length (Lx) along Leg. 3 is calculated by the following formula:

$$Lx = \frac{\sqrt{\dfrac{g h_1 h_2 \Delta\rho}{\rho H}}}{f} \quad \cdots\cdots\cdots\cdots(1)$$

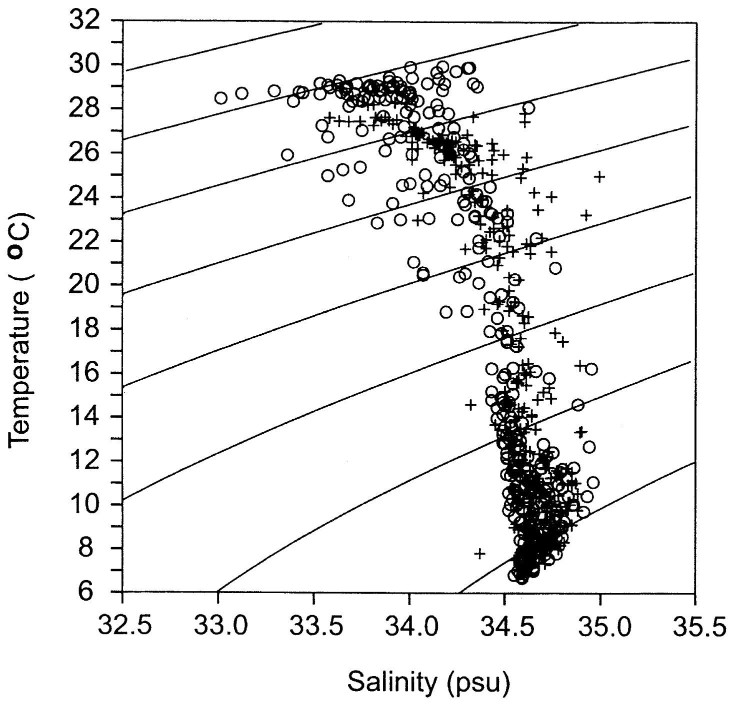

Fig. 8. T–S diagram in the northwest monsoon (o) and in the southeast monsoon (+).

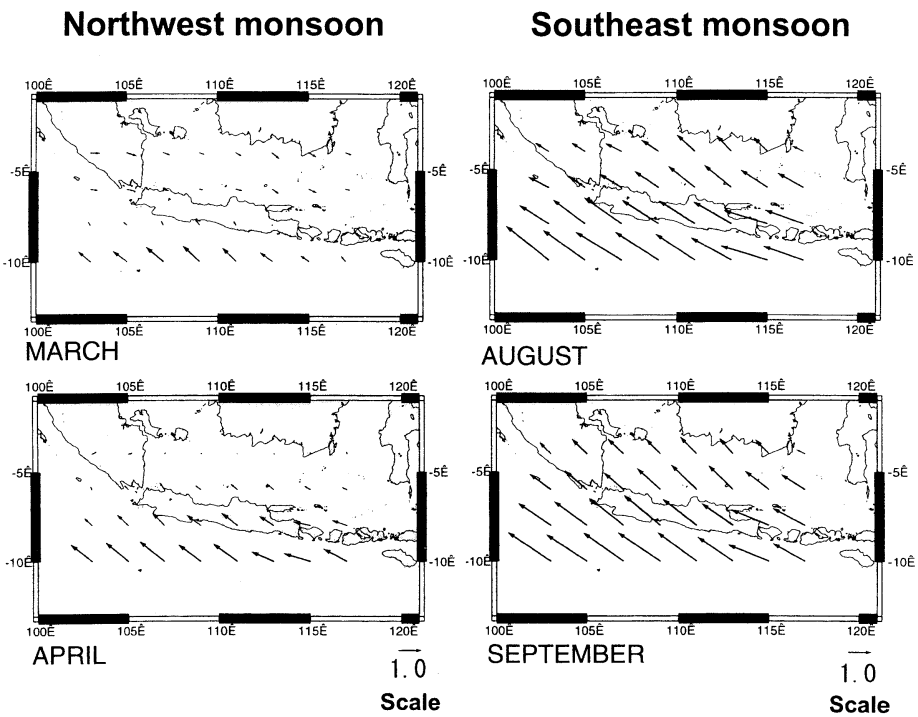

Fig. 9. Monthly mean wind stress (dyne/cm^2) around Java to Sumbawa derived from the data in the period of 1870–1976 (Hellerman and Rosenstein, 1983).

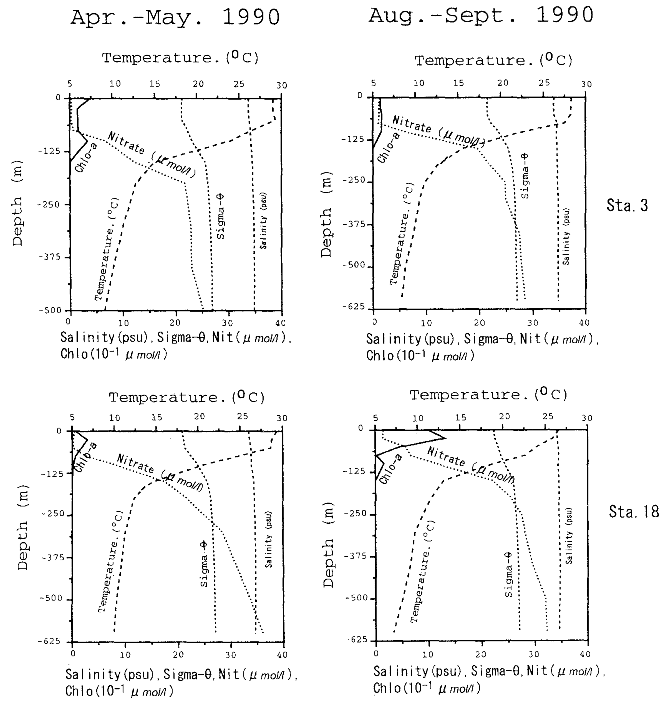

Fig. 10. Vertical profiles of water temperature (℃), salinity (psu), sigma-θ, nitrate (μmol/l), and chlorophyll-*a* (μg/l) at Stas. 3 and 18 in the northwest and southeast monsoons.

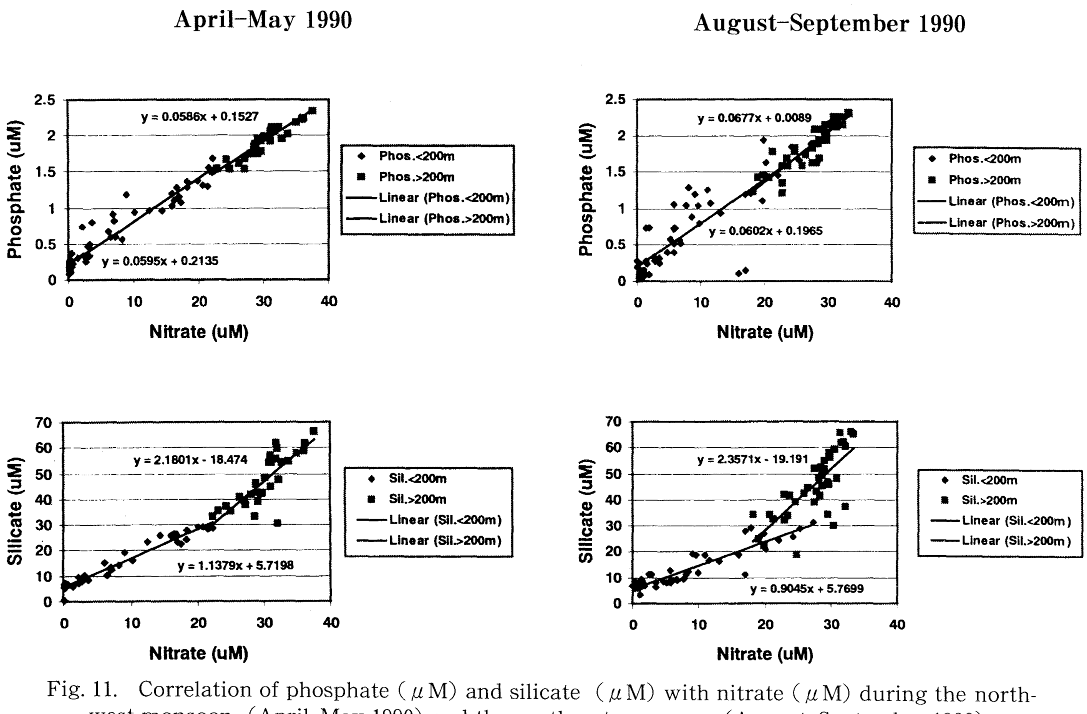

Fig. 11. Correlation of phosphate (μM) and silicate (μM) with nitrate (μM) during the northwest monsoon (April–May 1990) and the southeast monsoon (August–September 1990).

where g ($=9.8\ ms^{-1}$) denotes the gravitational acceleration, h_1($=100$ m) and h_2 ($=900$ m) the thickness of the upper and lower layers, respectively, H ($=100$ m) the water depth, $\Delta\rho$ ($=0.003$) the density difference between the upper and lower layers and ρ ($=1.027$) the density in the lower layer and f ($=2.5\times10^{-5}s^{-1}$) the Coriolis parameter from Fig. 10. The width of the upwelling along Leg. 3 estimated from Equation (1) is about 65km from the coast, which corresponds to the width of low water temperature area (Fig. 2b) and high chlorophyll-*a* (Fig. 6) area along Leg. 3 during the southeast monsoon.

Observational results also denote that nitrate concentration in the surface and 100m depth shown in Figs. 4(a) and (b) are significantly different between both seasons, that is, nitrate concentration is high during the upwelling event in the southeast monsoon. Moreover, nitrate seems to be a limiting factor for photosynthesis within this region because observed N/P ratio of 2–10 in the surface and subsurface layers for both seasons is smaller than the Redfield ratio of 16 and nitrate in the surface and subsurface layers (the depth less than 200m) is completely consumed by phytoplankton for photosynthesis, though phosphate and silicate are remained (Fig.11).

4. Conclusion

Variability of the oceanic condition along the southern coastal area of Java to Sumbawa is strongly affected by the meteorological condition corresponding to the seasonal change of monsoon. The southeast monsoon has generated the upwelling at the eastern part of the observational area. This situation has decreased water temperature at the surface layer up to 26℃ and increased nitrate as well as chlorophyll-*a* significantly more than two times compared to those in the northwest monsoon. The oceanic condition at the surface layer up to 100m depth is more dynamic than that at 500m depth. Low salinity and density water mass due to the effect of high precipitation exists at the area of the western part in the northwest monsoon and it also has increased nutrient concentration which ultimately generates phytoplankton bloom at the surface and 75m depth. Nitrate seems to be a limiting factor for photosynthesis within this region.

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Reference

Hellerman and Rosenstein(1983): Normal monthly wind stress over the world ocean with error estimates; Journal of Physical Oceanography, **13**, 1093–1104.

Purba, M.(1995): Evidence of upwelling and its generation stage off southern west Java during northwest monsoon. Bul. ITK Maritek, **5(1)**, 21–39.

Strickland, J. D. H. and T. R. Parsons(1968): Practical handbook of sea water analysis. Fis. Res. Board. Canada, Bull. No. **167**: 1–1311.

Sachoemar S. I and T. Yanagi(1999): Seasonal variation in water quality at the northern coast of Karawang–West Java, Indonesia. La mer, **37**, 91–101.

Sachoemar S. I and T. Yanagi(2000): Seasonal variation in sea surface temperature around Java derived from NOAA AVHRR. La mer, **38**, 35–75.

Tomascik, T., A. J. Mah., A. Nontji and M. A. Moosa (1997): The ecology of the Indonesia seas. Part One. C. V. Java Books. Jakarta. 642pp.

UNESCO(1973): International Oceanographyc Table, Vol. 2, National Institute of Oceanography of Great Britain and Unesco. Paris.

US. Navy Hidrograpic Office(1959): Introduction manual for oceanographic observation. US. Navy Hydrogr. Off. Pub. **607**, 1–210.

Wyrtki, K.(1962): The upwelling in the region between Java and Australia during the southeast monsoon. Aust. J. Mar. Fresw. Res. **17**, 217–225.

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