Nutrient and chlorophyll-a distribution in Makassar Upwelling Region: From MAJAFLOX CRUISE 2015

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Abstract. Upwelling is an important mechanism on productivity enhancement in the Southern Makassar Strait (MAK). Previous studies found correlation between upwelling and chlorophyll-a blooms, which is perhaps caused by nutrient regeneration from deeper water. Through a multi-disciplinary study “MAJAFLOX Cruise” in August 2015, CTD casts and seawater samples have been collected from Southern Makassar Strait. The present study aims to investigate relationship between physical processes of upwelling and nutrient usage, especially for nitrate, phosphate and silicate from regenerated processes to be used for the primary productivity (chlorophyll-a). The results show that upwelling centre is found near Dewakang Sill around station 5, associated with the highest chlorophyll-a concentration (0.438 µgL⁻¹). Relatively high nutrient is also revealed in other station of observation. In sea surface layer, nitrate is high in station 1 to 3, phosphate high in station 2 and silicate high in station 9. This shifting of high nutrient concentration may indicate spatial variation of biogeochemical processes in the surface layer associated with nutrient fluxes.

1. Introduction

Upwelling is an upward movement of deeper waters to the surface area. Upwelling generally bring materials from the bottom including nutrients [1,2], so that upwelling associated with the nutrient regeneration [3]. The nutrient regeneration may increase the rate of photosynthesis, thus potentially increasing marine productivity and fishery resources [4,5].

The Southern Makassar Strait (abbreviated MAK) lies between the southern part of Kalimantan and Sulawesi Island. Makassar Strait is the western path of Indonesian Throughflow (ITF), that carry the Pacific water into the Indian Ocean. Fluctuation of the throughflow is affected by the monsoonal wind [6], strong tidal current [7] and El Ninõ-Southern Oscillation (ENSO) signals [8,9].

Former research found that MAK is an upwelling region with high fishery resources [10,11]. Winds that occur during Southeast Monsoon (May-October) are responsible for that upwelling formation. On the Southeast Monsoon, the surface wind blows northwestward and led the Ekman current moves away from the coast. The empty space on surface area then filled by waters from deeper layer. The pattern of Southeastal winds with a maximum speed occurs in the August [12]. Details of physical mechanism in the upwelling had been described by a numerical model approach Regional Ocean Modeling System (ROMS) [13].

Transport of deep and nutrient-rich waters to the surface are characterized by increase of chlorophyll-a concentration and decrease of sea surface temperature (SST) along the coast. Some
evidences found phytoplankton blooms in MAK during Southeast Monsoon based on chlorophyll-a data from satellite imagery [12,14,15] and water sampling [16]. Indication of upwelling variability is also found based on sea surface temperature from satellite data [12,14,17].

In the tropical ocean, areas of upwelling have high nutrient concentrations during some periods of the year [18]. Nutrient supply (in particular N, P, and Si for diatoms) and its ratios have a decisive effect on the species composition of the phytoplankton [19], then change the primary production and sinking rate of organic matter [1]. This study is the first attempt to understand both physical and chemical interaction based on in-situ data from Makassar upwelling region. Two major objectives were established in this study : (1) to detect the center of upwelling and (2) to find possibility of nutrient regeneration.

2. Methods
This study was part of the cruise expedition "MAJAFLOX 2015". The main goal of this cruise is to understand the relation between water mass characteristics, biogeochemical distribution and aquatic ecosystem in the Java Sea, Makassar Strait and Flores Sea (JMF Triangle Seas). JMF triangle seas is an area crossed by ITF, where nearly 75% of total flow (15106 m$^3$ s$^{-1}$) through the Makassar Strait [8]. This area is also have potency on small pelagic fisheries such as mackerel and oil sardine [15,20].

This cruise is conducted on Research Vessel Geomarin III, which sailed from the north coast of Cirebon (Java Sea) to the southern Kangean Island (Flores Sea). Southern Makassar Strait (MAK) region represented by transect along 600 km, starting from Station 1 on the edge of the Java Sea to Station 9 in southwestern Selayar Island (figure 1).

This study is divided into three parts : (1) sampling and preservation, (2) sample analysis and (3) data processing. The sampling and preservation was conducted in August (year 2015) that represent the Southeast Monsoon in MAK. The instrument used for sampling is Rosette Sampler; consists of a Seabird CTD sensor V19 Plus and 12 Niskin Bottles (8 liters capacity). Rosette Sampler is operated on profile mode which CTD sensor continuously record four data per second (4 Hz) of depth, temperature and salinity. At the same time, Niskin Bottle took seawater samples at nine depth points, i.e. 5, 20, 50, 100, 200, 300, 400, 500 and 1000 meters.

Seawater samples from Niskin Bottles preserved on board by filtration using Whatman membrane filter CNM 0.45 μm (Ø47 mm) and vacuum pump (with the suction force is less than 30 cmHg). Water samples then added by HNO$_3$ solution until pH = 2 then kept on HDPE bottle. The membrane filters also wrapped by aluminum foil. Water samples and membrane filters are stored in a cooler (with temperatures ≤4 °C) until ready to be analyzed [21].

Nutrients in seawater samples analyzed in the laboratory using a spectrophotometer Shimadzu UV-1201V. Analysis of dissolved nitrate-N using cadmium reduction method, while the analysis of dissolved orthophosphate-P and silicate-Si using staining methods [22]. For chlorophyll-a analysis, membrane filters are destructed by Aseton solution (v/v 90%) then detected by a fluorometer Trilogy® [23].

Data processing is included CTD and seawater samples. Data records from CTD are converted and corrected using software SBE Data Processing series 7.21a. Data from the analysis of nutrients and chlorophyll-a tabulated using software Microsoft Excel. Data CTD, nutrient and chlorophyll-a then displayed using software Ocean Data View (ODV). Especially for the nutrient ratios shown in a diagram using software Microsoft Excel based on logarithmic scale [24,25].
Figure 1. Map of study location in Southern Makassar Strait (MAK) region. The inset shows study location (red box) on the Indonesian map.

3. Results and Discussion

3.1 Water Mass Characteristics and Signals of Upwelling

Based on CTD record in this research, bathymetry between Station 1 to 3 forming a basin with maximum depth centered at Station 2 (1800 meters). From Station 4 to 6 lies Dewakang Sill that makes seabed topography becomes more complex. Later on Station 6 to 9 lies Selayar Slope with an average depth of 350 meters.

Water mass of Southern Makassar Strait (figure 2) is divided into three layers: mixed layer, thermocline layer and deep layer. Mixed layer with a relatively high and homogeneous high temperature (>25 °C), low salinity (34 PSU) and low density (22 kg m\(^{-1}\)) is in depth 0 to 100 m. Thermocline layer at depth 100 to 200 m is characterized by isotherm 20. In the thermocline layer, there is isohaline 34.5 as a marker for North Pacific thermocline waters. Still on the thermocline layer, there is some undulations of isopical 24 and 25 that indicate internal waves activity. The deep layer located below the thermocline that characterized by homogeneous low temperature (<5 °C), high salinity (<34.5 PSU) and high density (>27 kg m\(^{-1}\)). Through the same figure, it appears that the isotherm 25 (figure 2a), isohaline 34.5 (figure 2b) and isopical 23 (figure 2c) increase from the thermocline to the mixed layer. These three parameters move to the upper layer possibly due to upwelling that centered near Dewakang Sill around station 5.

The structure of water masses in Southern Makassar Strait described by using T-S diagram (figure 3). The water mass on the upper layer of the thermocline (isopical \(\sigma_0 = 24\)) with a maximum salinity (>34.6 PSU) is characteristic of North Pacific Subtropical Water (NPSW). The section on the bottom layer of the thermocline (isopical \(\sigma_0 = 26.5\)) with minimum salinity (34.4 PSU) is characteristic of North Pacific Intermediate Water (NPIW). It is known that the North Pacific waters enter Makassar Strait through the western path from its entrance in the northeastern Sulawesi Sea. The maximum salinity of NPSW in this study decrease gradually from the north (station 3) to the south (Station 6). Instead, the minimum salinity of NPIW in the northern part was 34.40, then increased to 34.52 in the south. Changes in salinity may be due to mixing with more fresh waters or mixing with South Pacific waters that came from eastern part in the Banda Sea [26,27].
3.2 Nutrient Characteristics

The nutrients distributions in Southern Makassar Strait are generally varied within depth (Figure 4). Concentration of nutrients in the surface tends to be low, although at some stations increased. Nutrients in the mixed layer to the upper thermocline (depth <200 meters) is also low. The
concentration of nutrients then increase gradually from the center of thermocline to the deep layer. Maximum nutrient concentration averaged found below the depth of 230 meters. From that distribution, we agree that the Indonesian throughflow influences Indian Ocean biogeochemistry by supplying an effective or net flux of nutrients primarily to thermocline waters [28]. Variation of nutrients concentration is consequence of different biological processes and water mass characteristics [28]. Nutrients from the surface water get utilized by the phytoplankton, thereby depleting their level in the upper layer. Nutrient itself or through dead cell of organisms then sink and accumulate in the thermocline layer. Some particle trapped in the thermocline, while the other part sink to the deeper layer. In deep layer, some bacterias degrade organic matter so that nutrient regenerates, thus make nutrient higher at bottom [29].

![Figure 4](image)

**Figure 4.** Scatter of (a) nitrate, (b) phosphate and (c) silicate concentration in Southern Makassar Strait during Southeast Monsoon. Map below the scatter diagrams show color symbol for each station.

Upwelling generally trigger nutrient to the surface layer. It was mentioned before that center of upwelling is in station 5 near Dewakang Sill (Figure 2). However, from this study we found that center of upwelling is low nutrient (Figure 5). Nutrients lower at station 5 allegedly due to its use by the autothrops. Increase of chlorophyll-a in the surface station 5 (figure 6) indicates higher photosynthesis rate than the other stations. Relationships between chlorophyll a and nutrients were opposite, suggesting that in the short term phytoplankton controlled nutrient concentrations [30].

High concentration of nutrients in the surface varied within location. Nitrate was high at Station 1 to 3 (Figure 5a), while phosphate (figure 4b) high at station 2 and silicates (figure 4c) high at station 9. Shifting of high nutrient concentration is associated with environmental condition. Station with
higher nutrient in the surface apparently had lower salinity (Figure 2b). The lower salinity can be indicates an input of fresh water. Then we can assume that another input of nutrient to the Makassar Strait is came from river run-off or human activity near the coast of Sulawesi and Kalimantan [16].

Figure 5. Concentration of (a) nitrate, (b) phosphate and (c) silicate in Southern Makassar Strait during Southeast Monsoon

Figure 6. Concentration of chlorophyll-a in Southern Makassar Strait during Southeast Monsoon

Figure 7 shows the distribution of molar ratios between Si: N: P that gathered in quadrant N and P. Quadrant N is indicating the nitrate deficient, whereas quadrant F indicating phosphat deficient. Various biological processes in water such as death, predation, autocatalysit and remineralization of plankton cells can affect the ratios [3]. In Figure 4, range of nitrate (0.022-2.978 μM) and phosphate (0.001-1.89 μM) remained lower than silicate (0.157-54.533 μM). This higher silicate concentration possibly reflecting the small rate of dissolution of biogenic silica in the upper ocean that mediated by diatoms [18]. Some reason is that waters upwelling to the surface are generally slightly depleted in N relative to P (below Redfield) [1]. The persistence of high Si:N ratios also carry the signature of biologically spent water in the upper mixed layer [32].
Figure 7. Diagram of the molar ratios between atomic Si: N: P in the Southern Makassar Strait during Southeast Monsoon. The Si:N and N:P atomic ratios of 1:1 and 16:1 are indicated by the horizontal and vertical lines, respectively. Nutrient limitation (assuming sufficient concentration) within each quadrant are indicated by the lettering. [24,25]

4. Conclusion

Physical properties such as temperature, salinity and density during observation show the upwelling signal near Dewakang Sill. Apparently, nutrient profiles in this study areas show a common oceanic nutrient type that lower in the upper and higher in the deeper layer, suggesting their involvement in the biogeochemical processes. At the center of upwelling, nutrient tend to be low but the chlorophyll-a is high. This condition shows that nutrient from deeper layer had been used for photosynthesis. Slightly lower N and P also indicate dominant activity of organism especially for diatoms in the ocean.

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5. References

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