# ORGANIC MATTER AND NUTRIENT PROFILE OF THE TWO-CURRENT-REGULATED-ZONE IN THE SOUTHWESTERN SUMATRAN WATERS (SSW)

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**ABSTRACT**

The Indian Ocean is influenced by monsoon systems which alter the ocean's physical and chemical properties. Specifically, the southwestern Sumatran waters in the eastern Indian Ocean are considered a dual current regulated zone i.e. affected by South Equatorial Counter Current (SECC) and South Java Current (SJC). This area is considered as having an important role in the transfer of organic matter or the biological pump. However, the information about this area is minimal, especially in terms of organic matter and nutrient profile. This study will update the recent information about the area, including the profile of particulate organic matter (POM), macro-nutrients, total suspended solids (TSS), macromolecule-degrading bacteria, and soft bottom macrobenthic organisms sampled from 26 stations in both the SECC-regulated zone and the SJC-regulated zone. The physical profile is typical of tropical waters and both zones have a distinct profile of organic matter and nutrients. The particulate organic carbon (POC), particulate organic nitrogen (PON), and TSS of the SECC-regulated zone can be considered higher than those of the SJC-regulated zone. This region is categorized as mesotrophic waters, especially from the surface up to 100 m. The production of nutrients and organic matter in the water column in this area contribute significantly to the abundance of heterotrophic bacteria and benthic organisms.

**Keywords:** organic matter, biological pump, biogeochemistry, microbial loop, plankton dynamics

## INTRODUCTION

Equatorial eastern Indian Ocean (EIO) region is considered as a part of the Indo-Pacific warm pool region with high sea surface temperature (SST), deep thermocline, active ocean-atmosphere interactions region affecting monsoons and also has relation with seasonal upwelling (Chen *et al.,* 2016).

In the whole regional term, the equatorial area of the Indian Ocean also plays an important role in oscillation and water-mass transformation which is not found in other waters *e.g.* the Madden-Julian Oscillation (MJO), the Indian Ocean Dipole (IOD) and the Equatorial Jet or Wyrtki Jet (Nagura and Mc Phaden, 2010; Zhang, 2005; Wyrtki, 1973). Wyrtki Jets, the strong eastward equatorial surface currents, occur during monsoon transition periods in spring and fall (Duan *et al,* 2016; Schott *et al*, 2001; Wyrtki, 1973), which is suggested can modulate zonal distribution of upper ocean mass, heat and salinity flux over the equatorial Indian Ocean and has relation with

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development of IOD events (Duan *et al.,* 2016; Zhang *et al.,* 2014; Nagura and Mc Phaden, 2010). During monsoon transition periods also, the Kelvin waves propagating eastward was generated by equatorial westerlies, this waves become coastally trapped waves along Sumatera and Java islands and considered as an important role in the upwelling and downwelling process along these coasts (Susanto *et al.*, 2001).

The Sumatran coast is influenced by regional winds associated with the moonsoon climate and other Indian climatic phenomenon due to its location as a border of eastern Indian Ocean. This region exhibit unique features such as one of the ITF outflow region carrying low salinity water to open Indian Ocean, its variability in monsoonal winds and rainfall, water mass exchanges may modify physical and biogeochemical conditions in the Eastern Indian Ocean (Yu *et al.,* 2016).

More specifically, there is a zone in the southeastern tropical Indian Ocean *i.e.* the southern part of Sumatran coast considered as the dual current regulated area. At around 8°S in the Indian Ocean, there is a westward flow, called the South Equatorial Current (SEC) with a velocity of less than 0.3 m/s and a shallow depth of less than 200m. The SEC flows westward throughout the year toward the Sea of Madagascar (Wyrtki 1961; Quadfasel *et al.,* 1996). In addition to the SEC, the west coast of Sumatra is also influenced by the strong eastward flow called the South Equatorial Counter Current (SECC) with a speed of 0.5 - 0.8 m/s. The SECC converges with SEC in the oceans to the west/southwest of Sumatra (Tomczak, Godfrey, 1994). However, more towards the coast of the Southwestern Sumatran Waters (SSW), there is another dual current regulated zone affected by both the SJC and the SECC (Schott *et al.*, 2001; Schott and McCreary 2009; Hood *et al.,* 2011). According to Iskandar *et al.,* (2005) this area also considered have intraseasonal variations (*e.g.* intraseasonal sea level variations with a typical period of 20 - 40 days and 60 - 90 days) that associated with coastal Kelvin waves (phase speed ranging from 1.5 to 2.86 m/s). This area is considered to be an important zone for national and regional interests, as part of the Nusantara Ship Route Network (PELNI 2006) and a proposed fishing zone (LAPAN 2015). The SSW is also affected, in a minor way by the Java Sea and the Sunda Strait water mass transport. The Sunda Strait affects the area by its water mass and sediment which contains rich organic matter (Baumgart *et al.,* 2010).

Profiles of the chemical constituents of particulate organic matter (POM, including particulate organic carbon and nitrogen) and solid organic ligand (SOL) show unique vertical distribution along the water column, where the maximum concentration is at the surface and gradually decreases with depth (Boyd *et al.*, 1999; Hirose and Tanoue 1998; Hirose *et al.*, 2011). The vertical profile of particulate organic matter at a depth of between 100-1000 m shows the biogeochemical process, especially the sinking of biogenic material, which is produced by plankton in the euphotic layer (Hirose *et al.,* 2011). This process is already well known as the biological pump (Turner, 2015). Meanwhile, nutrients such as phosphate, nitrate, nitrite or ammonium, tend to bind to the organic matter and concentrate in the water column or on the seafloor (Walker and Wood**,** 2005). Their chemical processes, i.e. nitrification or denitrification, occur as the phenomena that affects bacteria and phytoplankton (Bianchi *et al.* 1994; Bianchi *et al.,* 1995; Ward *et al.,* 1989). This has subsequently become known as the phenomena correlated to the biological pump (Herndl and Reinthaler, 2013, Jiao and Zheng, 2011; Sanders *et al.,* 2014; Tortell *et al.,* 1999).

Considering the facts about the area profile, the southwestern Sumatran waters are expected to play an important role in biogeochemical processes such as the transfer of organic matter, the biological pump and pelagic-benthic coupling. Because of the minimal information, the organic matter and nutrient profile should be examined, especially in relation to the accompanying biogeochemical processes in the Eastern Indian Ocean. Baumgart *et al.*, 2010 explained that the maximum sedimentary organic matter in the Java-Sumatra upwelling region is 3.0% and 0.31% for organic carbon and nitrogen, respectively. Since the only available information is for the sedimentary organic matter, our study will provide important data and information in the organic matter of the water column. Therefore, in order to examine the organic matter and nutrient profile, we analyzed profiles of particulate organic carbon (POC), particulate organic nitrogen (PON), total suspended solids (TSS) and macronutrients (i.e. phosphate, nitrate, nitrite, ammonium, silicate). Softbottom benthic organisms, phytoplankton in the surface and bacteria in the water column were also profiled in order to estimate the contribution in the biological pump. The aim of this study is to verify the hypothesis that there are differencies of the organic matter and nutrient profile between SJC and SECC-regulated zone.

## MATERIALS AND METHODS

### Sampling Locations

The sampling was conducted during a research cruise of the *Ekspedisi Widya Nusantara* (EWIN) 2015. Several transects from the Sunda Strait up to the waters around Enggano Island were undertaken. Detailed information about EWIN can be retrieved from Arifin (2014) and Wahyudi *et al.,* (2015). We set 34 stations in total that covered by about 11 days of cruising in May 2015. However, due to field conditions, only 26 tracks and stations were realized as shown in Figure 1. We divided the location into the SJC and the SECC regulated zone. The SJC regulated zone consists of the Sunda Strait and its surrounding area (site 1-17). The SECC regulated zone is the area that consists of site 18 to 34.

### Hydrographic Sampling

The hydrography data, including temperature and salinity, was recorded by a conductivity, temperature, and depth (CTD) cast Seabird 911 Plus from 21 stations. Meanwhile, the current data was measured by a shipboard Acoustic Doppler Current Profiler (sADCP) along cruise track.

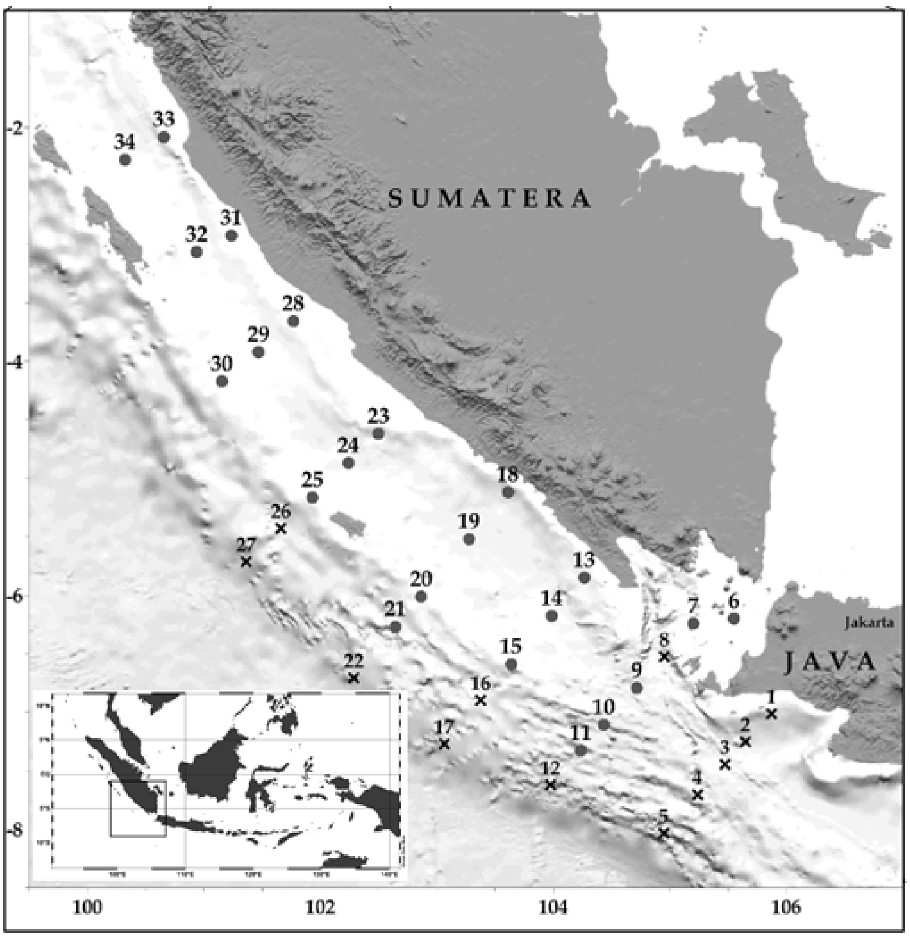


**Figure 1.** Study site of E-WIN 2015 shows the sampling station (●). Courtesy of P. Avianto (RCO LIPI)

Water samples were taken using Niskin bottles of 12 rosette sampler where the CTD apparatus was deployed. The depths were 5, 50, 100, 200, 300 m and the deep layer (2000 m). Water samples for microbial activity were collected in an aseptic way using a sterile falcon tube 50 ml.

To show the water mass change, we used Temperature-Salinity diagram (TS Diagram) snapshots along the equator and overlaid these on to the EWIN 2015 sites. The TS-diagram snapshot were taken from the World Ocean Database (WOD) NODC-NOAA in 1975 and 1999 during transition monsoon periods (Boyer *et al.*, 2013). The surface layer current pattern in the whole Indian Ocean was taken from OSCAR during May 2015 (Dohan and Lagerloef, 2015).

**Sample Collection**

The plankton samples were collected at 16 stations. The phytoplankton samples were collected using a Kitahara net (ring 0.31 m, length 1 m, and mesh size 80 µm), while the zooplankton samples were collected using a Norpac net (ring 0.45 m, length 1.8 m, and mesh size 300 µm). Both phytoplankton and zooplankton were collected in the vertical haul from 100 m and 300 m, respectively. The bulk sample was then stored in 250 ml bottles. Formaldehyde (40%) then was added *i.e.* 2 ml per 100 ml sample (Edler and Elbrachter, 2010).

Benthic and sediment was sampled from various depths using box cores (60 cm x 50 cm x 55 cm) at 13 stations. For each station, sediment samples inside the box core were documented by photograph while information on station label, depth and on deck time was recorded. Sub-samplings of the sediment were conducted for some studies *i.e.* benthos, microbial, chemical and geological profile. The benthos samples were collected by filtration of the sediment sub-samples (40 cm x 50 cm; 15 cm thick from sediment surface) using a sieve (pore diameter 1 mm). The benthic samples were then preserved using 96% ethanol for further analysis. Surface sediment sub-samples (10 - 15 cm of the box core sample) were collected using a stainless steel shovel (20 ml), placed in 250 ml containers and stored in -20°C for further analysis.

**Laboratorium Analysis**

**Chlorophyll-*a***

The measurement of chlorophyll-*a* was conducted using fluorometric methods according to Cochlan and Hendorn (2012). About 0.1 – 1.0 L sea waters were filtered using Whatman CNM filter paper (0.45 µm, D 25 mm). In order to save time, the vacuum pump was used with pressure not more than 30 cmHg. The filtrate then was extracted using acetone 90% and centrifuged (4000 rpm) for 30 minutes. The supernatant fluid that contained chlorophyll-*a* were measured for its fluorescence using a Fluorometer Turner Trilogy Type AU-10. Chlorophyll–*a* concentration was estimated using the following formula (Cochlan, Hendorn, 2012):

Chlorophyll-*a* (µg/L) = ((y-b)/m)(v/V)

where:

y = fluorescence value

b = y axis value that crosses calibration curve

m = regression slope of the standard calibration curve

v = extract volume with addition of acetone 90% (ml)

V = filtered sample volume (ml)

**Measurement of the Particulate Organic-Carbon and Nitrogen (POC and PON)**

Sea water (1.0 L) was filtered into the Whatman GF/F glass fiber filter (ϕ 25 mm). The filtrate then was acidified to remove inorganic carbon using HCl fume for 1 minute. The filtrate was then neutralized by placing it in a vacuum desiccator with concentrated NaOH for 24 hours. The filtrate then was oven dried at 60ºC up to a constant weight.

Each filtrate sample (in glass fiber filter GF/F) was then packed in a tin capsule (Lüdiswiss Sn 98, ϕ 9/10 mm) after dry weight measurement. Further analysis was conducted using an elemental analyzer *i.e.* Thermo Delta Plus XP coupled to a trace GC Ultra with a Combi PAL Autosampler. The analysis was conducted in the Iso-trace Research Facility, University of Otago (New Zealand).

### Nutrient Analysis

A total of 500 ml water was put in a polyethylene bottle. Dissolved oxygen (DO) was measured by the Winkler method. The degree of acidity (pH) was measured using a pH meter pHTestr 20. For nutrients analysis, water samples were filtered using nitrocellulose filter paper (pore diameter 0.45 µm). Nutrients were analyzed spectrophotometrically using a spectrophotometer Shimadzu UV-1201V. The wavelength used was 885 nm for phosphate, 543 nm for nitrate and nitrite, 630 nm to 810 nm for ammonium and silicate. Phosphate ($PO_4$) was analyzed by the formation of blue complex compound molybdate based modified method (Strickland and Parsons, 1972). Nitrate ($NO_3$) was analyzed as nitrite by reduction in Cd-Cu column and reacted with sulfanilamide in acidic solutions based method (Parsons *et al.,* 1984). Note that the nitrite procedure is similar to that of nitrate procedure but without sustained reduction. The ammonium was analyzed by adding reagent A and reagent B and allowed until blue coloration (Strickland and Parsons, 1972), whereas the silicate ($Si(OH)_4$) were analyzed through the formation of compounds silico-molybdate (Strickland and Parsons, 1972).

### Determination of the Macromolecule Decomposition

Samples of water as much as 100 mL from Falcon tube with the dilution of $10^{-1}$, $10^{-2}$ and $10^{-3}$ were planted into 3 different media with two replications. Whereas sediment samples were prepared by taking 1 gr sample and dilute into buffer fosfat until $10^{-4}$. The media used was Mineral Medium enriched with gelatin (5 gr/L), starch (5 gr/L) or Tween 20. The gelatin hydrolysis was determined by using reagent Frazier poured into the petri dish. Starch hydrolysis was determined by using Lugol solution. Fats hydrolysis was measured by the formation of a clear zone around the colonies of bacteria (Mudryk *et al.,* 2011). Counting the number of bacteria were performed after 7 days of incubation.

### Estimation of Bacteria Density

Content amounts of bacterial cells were determined by using Acridine Orange Direct Count (AODC) method. This amount can be determined by the total biomass of bacteria. Sea water or sediment samples (dilution $10^{-1}$) as much 1ml was put in a tube containing 5 ml solutions of Acridine Orange, then stored in the refrigerator until bacterial cells were counted in the laboratory using microscope epifluorescence.

### Total Suspended Solid (TSS)

One liter of seawater was filtered by filter papers (pore size 0.045 mm and dry weight recorded). Filter papers from the distillate were then dried and weighed. TSS concentration per liter volume was obtained by subtracting the total dry weight of filtrate and filter paper with the dry weight of blank filter paper.

## RESULTS

### Oceanographic Conditions

The current velocity at surface layer (15 m) in Indian Ocean during May 2015 is represented in Figure 2 (arrow showing direction and shaded color showing current velocity). This figure indicate the existence of Wyrtki jet in the equator of Indian Ocean shown by fast current at the surface layer near 70 - 85$^{o}$E. Figure 3 represents TS-diagram along the equator until EWIN 2015 cruise area , and show the changes in temperature and salinity indicating the mixing process along the equator to the western coast of Sumatra. This trend was expected as the currents along the equator flow toward the western coast of Sumatra and turn south with a lower velocity than those in the equatorial region. In addition to the description of the mixing process and geographic distribution of water masses, the TS diagram can also describe the movement of water masses (Stewart, 2008). Note that the TS diagrams (i-v) were taken from the World Ocean Database (WOD) NODC-NOAA in 1975 and 1999 (Boyer *et al*., 2013). While the TS diagrams (vi-ix) are the observation results from the EWIN 2015 cruise (Figure 2, detailed In Figure 5). The

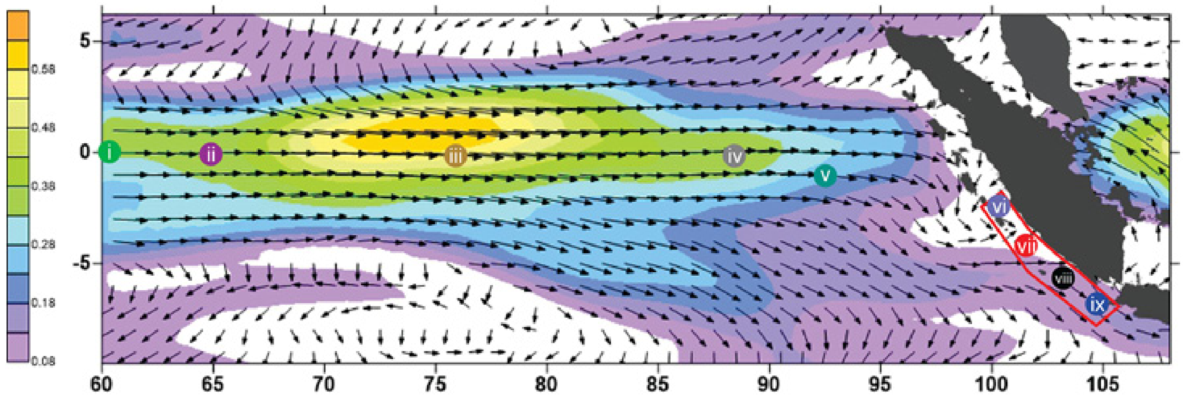


**Figure 2.** Snapshot of direction and current velocity at surface layer (15 m) in the Indian Ocean from monthly mean data OSCAR (Dohan & Lagerloef, 2015). Arrow represents the current direction, whereas shaded color represents current velocity in m/s. Roman number (i-ix) with colored circle represents the location for TS-Diagram snapshot in Figure 3.

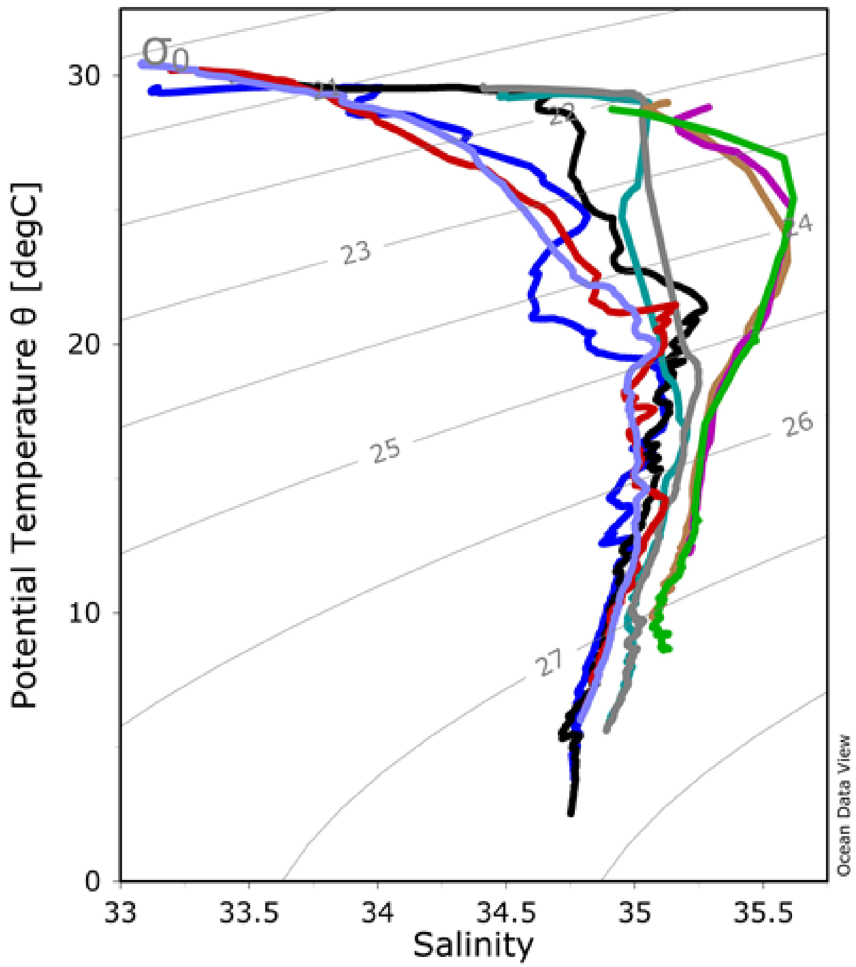


**Figure 3.** TS-diagram snapshot of the selected sampling area

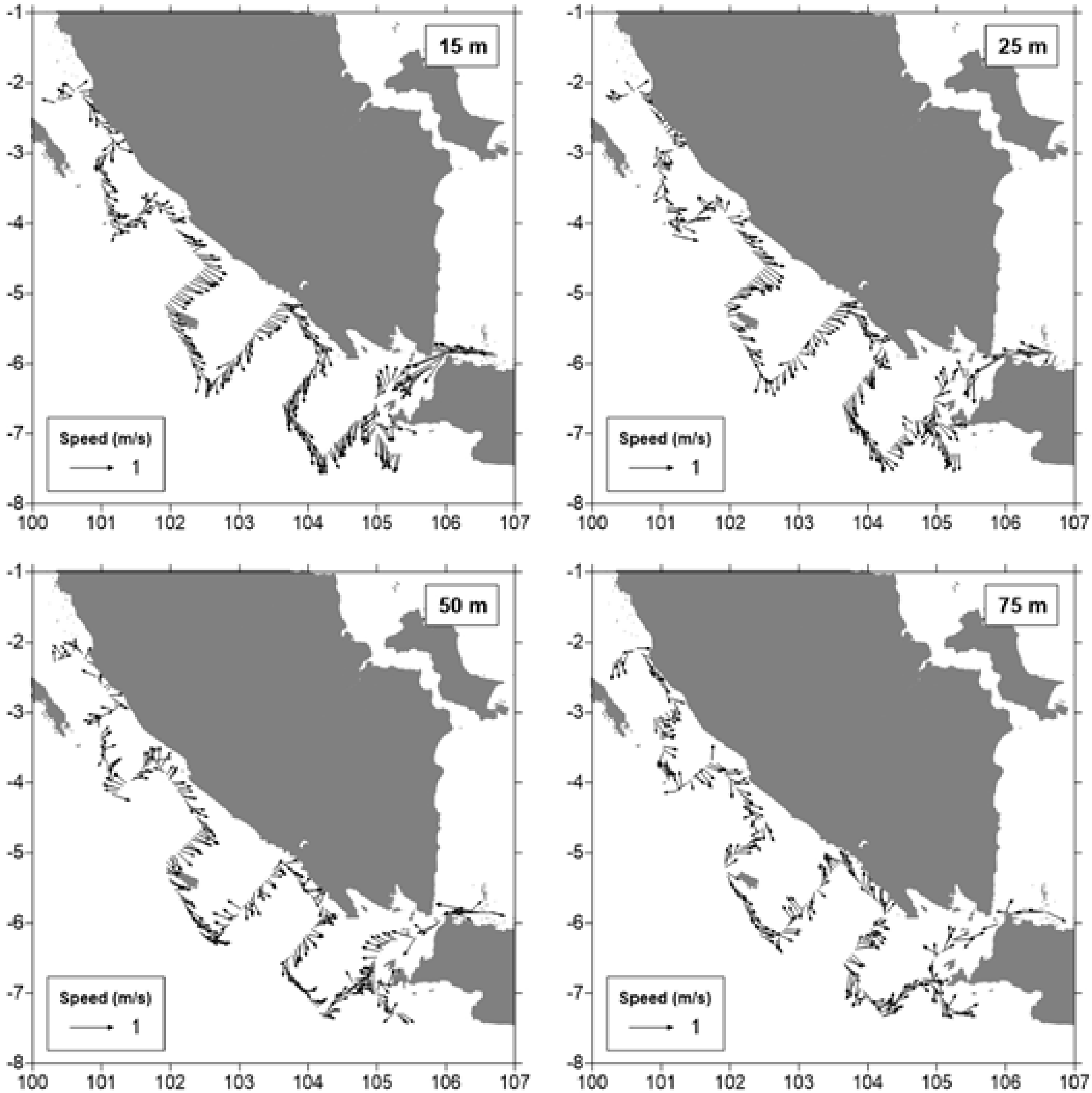


**Figure 4.** Current profile according to the sADCP (May 2015)

acoustic doppler current profiler (ADCP) data shows that surface current patterns off the west coast of Sumatra tend to the south towards Java at an average of 0.21 m/s at measured depth (Figure 4), while the surface circulation patterns in the Sunda Strait tend toward the Indian Ocean. The currents of the Sunda Strait meet the currents from the western coast of Sumatra at the mouth of the Sunda Strait before flowing to the south coast of Java, as the SJC. The water mass from the Java Sea is carried out by the current in the Sunda Strait into the Indian Ocean. The ADCP currents recorded in the Sunda Strait are about 0.36 m/s at a measured depth.

## Chl-*a*, Macro-nutrient, POC, PON, and TSS

Concentrations of chlorophyll-*a* in the western Sumatran waters in May 2015 were within the range of extremely low to high for oceanic waters, ranging between 0.03 – 1.51 mg/m$^3$ from the surface layer to a depth of 200 m. Spatially, the concentration of chlorophyll-*a* in the water close to the mainland tended to increase. However, the concentration was lower mainly in the surface layer to a depth of 75 m. The high concentrations of surface chlorophyll-*a* were found in the Sunda Strait, where the water mass is influenced by the waters of the Java Sea and the Gulf of Lampung. Meanwhile, at the

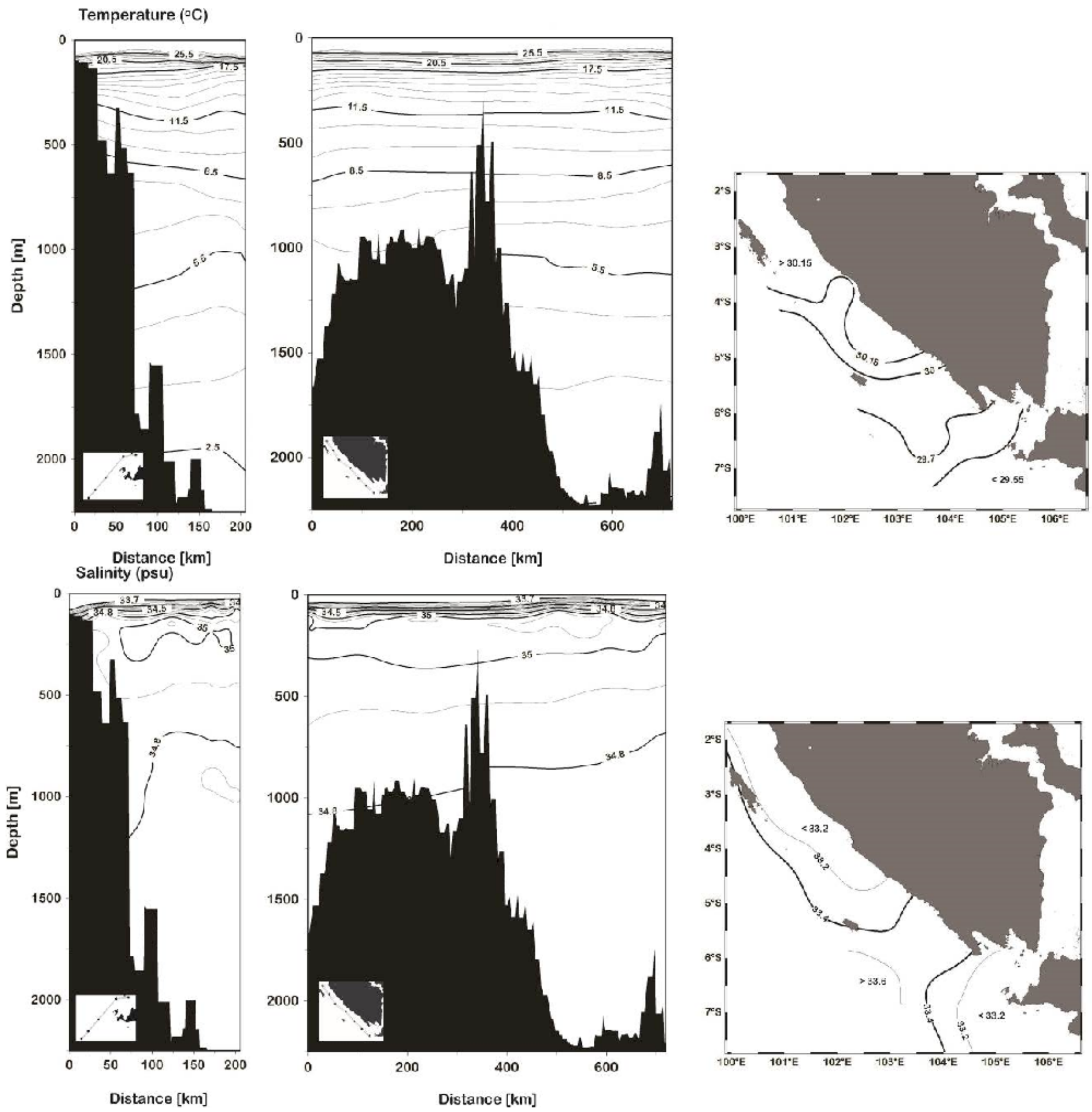


**Figure 5.** Temperature and Salinity profile in Sunda Strait and Southwestern Sumatran Waters (SSW)

**Table 1.** Range and the average value of the concentration of chlorophyll-*a* in the western Sumatran waters

| Depth (m) | Concentration of Chlorophyll-*a* ($mg/m^3$) | |
|---|---|---|
| | Range | Average value |
| 5 | 0,13 – 0,90 | 0.32 ± 0,15 |
| 25 | 0,20 – 0,85 | 0,44 ± 0,18 |
| 50 | 0,38 – 1,51 | 0,95 ± 0,37 |
| 75 | 0,32 – 1,27 | 0,86 ± 0,84 |
| 100 | 0,12 – 0,73 | 0,40 ± 0,19 |
| 200 | 0,03 – 0,31 | 0,09 ± 0,07 |

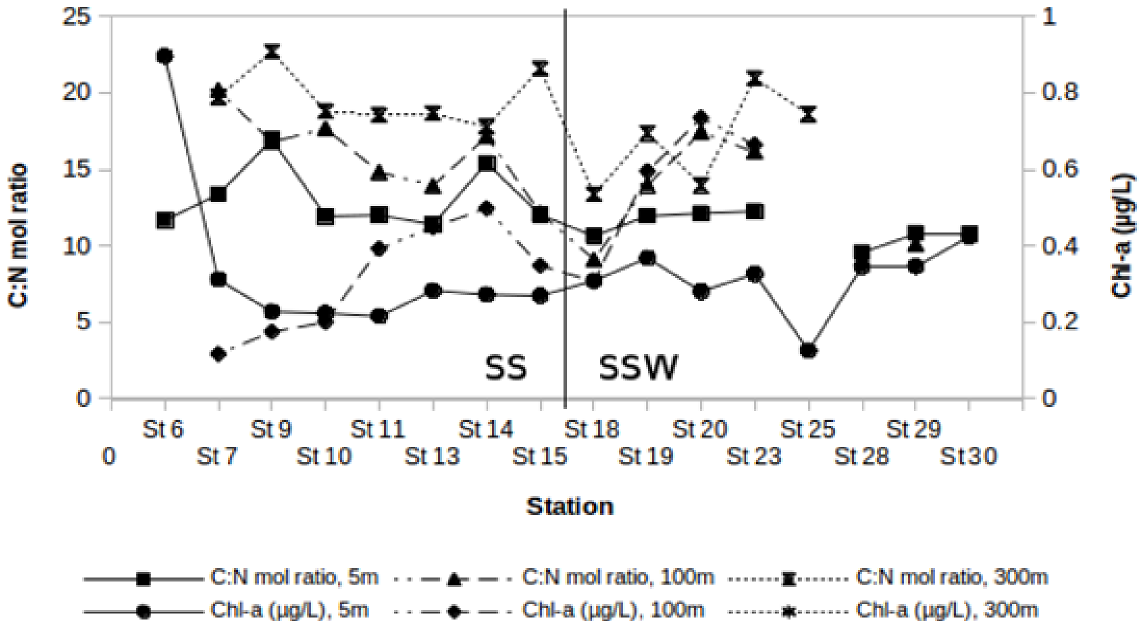


**Figure 6.** Profile of Chl-a compared to C:N mol ratio in the SJC-regulated zone and SECC-regulated zone. The SJC regulated zone includes Lampung Bay and Sunda Strait (SS), the SECC-regulated zone includes the Enggano and Western Bengkulu waters (southwestern Sumatran water; SSW)

depth of chlorophyll maximum (50-75 m), high concentrations were observed around Enggano and western Bengkulu waters (Figure 6). The POM profile in the area affected by the Sunda Strait and the South Java Current (SJC), stations 6-15, had a relatively comparable value of the POC and PON, in contrast to the areas affected directly by the Sumatra Current (SC). However, the stations 6-15 had higher variabilities of POC and PON concentrations (Figure 7).

The profile of carbon stable isotopes ($^{13}C$) shows that the main component of POM (especially POC) is planktonic organisms. The mean value of $\delta^{13}C$ is -23.94‰. This value is the same as the profile/signature of POM, in general (see Wahyudi *et al.*, 2013).

The pH value ranged from 7.76 to 8.48 (average 8.20). The minimum pH value in the surface, thermocline, and bottom layers were 8.31, 8.06 and 7.76, respectively. The maximum pH value in the surface, thermocline, and bottom layers were 8.48 at station 32, 8.19 at station 20 and 8.35 at station 28 (depth 60 m), respectively. Dissolved oxygen (DO) concentrations ranged from 1.71 to 5.54 mg/l with an average of 3.57 mg/l. The minimum DO concentration in the surface layer was 4.91 mg/l, in the thermocline was 2.16 mg/l and in the bottom layer was 1.71 mg/l. The maximum DO concentration in the surface layer was 5.54 mg/l (station 15), in thermocline layer was 3.26 mg/l (station 13) and in the bottom layer was 4.05 mg/l (station 28). The result follows the natural pattern in which the DO concentration in the bottom layer is lower than that in the surface layer. This is due to the air-sea oxygen diffusion in the surface layer, while in the bottom layer the oxygen is used to decompose materials.

The phosphate concentrations ranged from 0.001-0.093 mg/l with an average of 0.038 mg/l. The average concentration of phosphate in the surface, thermocline and the bottom layers were 0.007 mg/l, 0.042 mg/l and 0.067 mg/l, respectively. Nitrate concentrations ranged from 0.014-0.582 mg/l with an average of 0.271 mg/l. The average concentration of the surface was 0.070 mg/l, the thermocline was 0.324 mg/l and the bottom layer was 0.457 mg/l. The silicate concentrations ranged from 0.073 - 5.214 mg/l with an average of 0.968 mg/l. The average concentration in the surface layer is 0.139

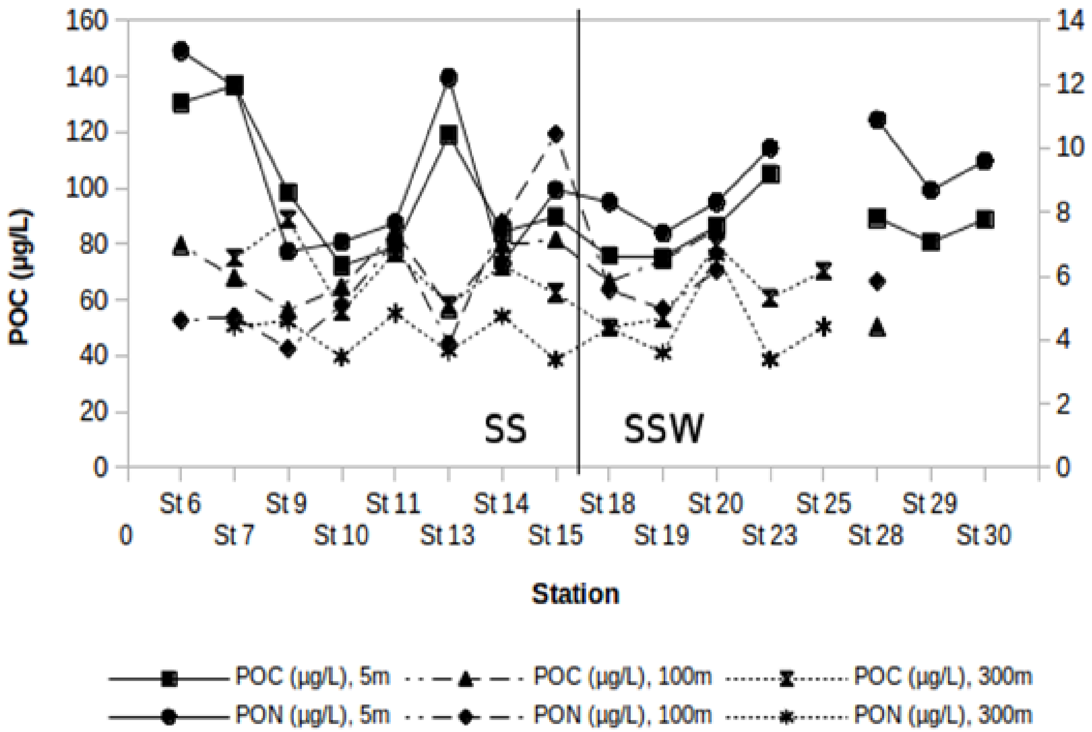


**Figure 7.** Profile of POC and PON in the Sunda Strait (SS) affected zone and Southwestern Sumatran Water (SSW). SS affected zone is regulated by SJC and the SSW is regulated by the SECC

mg/l, while the average concentrations in the thermocline and the bottom layers were 0.569 mg/l and 2.236 mg/l, respectively.

The nitrite concentration ranged from 0.003 -0.011 mg/l, with an average of 0.005 mg/l. The average concentration in the surface layer was 0.005 mg/l, in the thermocline was 0.005 mg/l and in the bottom layer was 0.005 mg/l. Ammonia concentrations ranged from 0.004-0.011 mg/l, with an average is 0.006 mg/l. The average concentration in the surface, thermocline and bottom layers are 0.006 mg/l, 0.006 mg/l and 0.006 mg/l, respectively. Detailed averaged macronutrient concentrations are presented in Table 2.

**Table 2.** The range and the average macronutrient of the study site

| Macronutrient | Range | | Average (+ SD) | |
|---|---|---|---|---|
| | SS* | SSW* | SS | SSW |
| Nitrate (mg/l) | 0,026-0,078 | 0,053-0,138 | 0,153+0,057 | 0,078+0,028 |
| Nitrite (mg/l) | 0,003-0,006 | 0,004-0,006 | 0,005+0,001 | 0,005+0,001 |
| Silicate (mg/l) | 0,091-0,243 | 0,091-0,167 | 0,153+0,057 | 0,120+0,033 |
| Ammonium (mg/l) | 0,005-0,007 | 0,005-0,007 | 0,006+0,001 | 0,006+0,001 |
| Phosphate (mg/l) | 0,001-0,025 | 0,003-0,014 | 0,009+0,009 | 0,005+0,004 |

*SS=Sunda Strait affected zone (St 1- St 15); SSW=Southwestern Sumatran Water (St 18-34). SS affected zone is regulated by SJC and the SSW is regulated by the SECC.

The distribution of total suspended solid (TSS) in the surface layer (Figure 8) varies between 37.5 to 207 mg/l. The lowest value was observed in the waters around the Sunda Strait (St 7), and the highest value was observed in

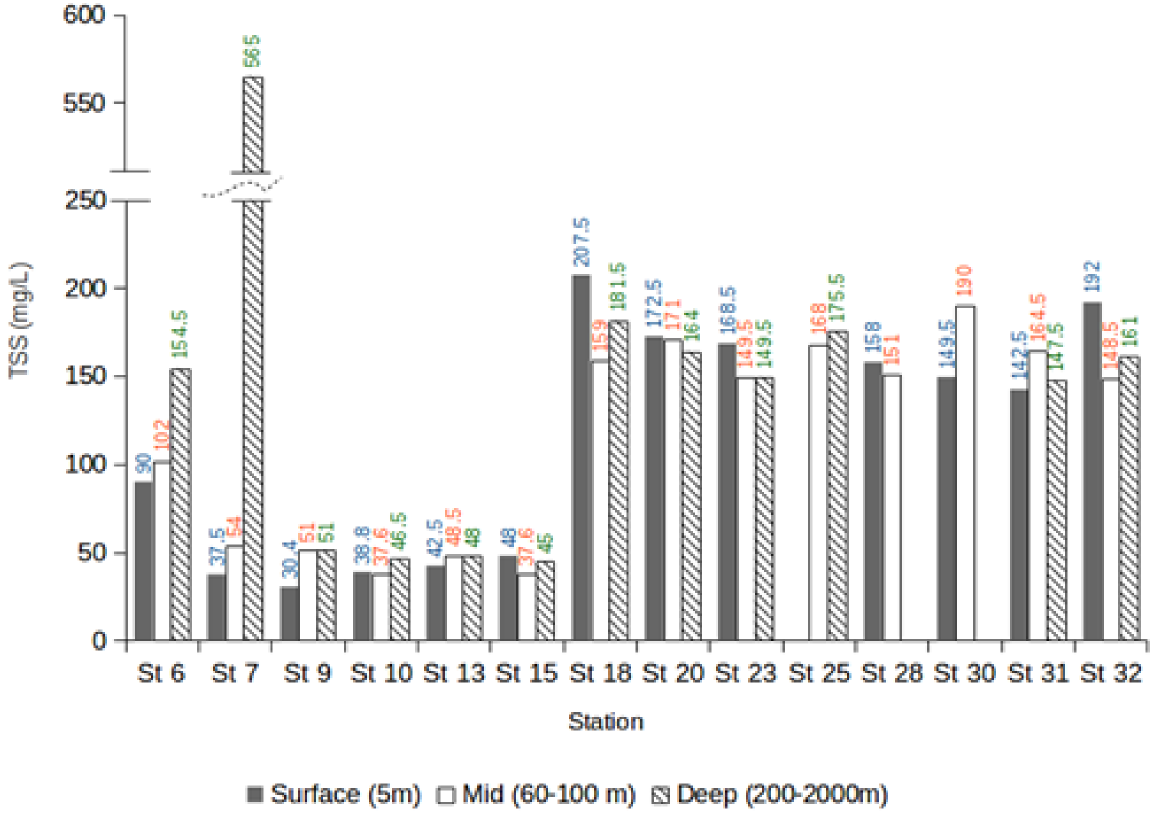


**Figure 8.** Total suspended solid (TSS) in Sunda Strait affected zone (St 6-15) and Southwestern Sumatran Water (St 18-32). SS affected zone is regulated by SJC and the SSW is regulated by the SECC

western Sumatran waters (around the Bengkulu and Enggano waters; St 18). TSS value of the thermocline layer varied between 37.6 (St 10) to 207 mg/l (St 18). The TSS value of the deep layer also varies between 45 mg/l (St 7-15) up to 190 mg/l (St 30). The bar chart of the TSS value in Figure 6 shows that the sites around the Sunda Strait (SJC regulated zone) have TSS values lower than the sites in the southwestern Sumatran waters (SECC regulated zone; St 18-32).

### Bacteria and benthic organisms

The carbohydrate-degrading bacteria (amylolytic) in the surface layer was between 3x$10^2$ to 1x$10^4$ CFU/ml. The highest amount was observed at St 15 and St 28 whilst the lowest was at St 19 (Figure 9). The protein-degrading bacteria (proteolytic) varied between 2x$10^2$ (St 7) up to 1.60 x $10^4$ CFU/ml (St 11). Furthermore, the lipid-degrading bacteria (lipolytic) ranged between 2.50x$10^2$ (St 32) to 1.00x$10^4$ CFU/ml (St 14). The average value of amylolytic, proteolytic and lipolytic bacteria of the SJC and the SECC regulated zones were 1.53x$10^{-3}$, 3.05x$10^{-3}$, and 1.45x$10^{-3}$ CFU/ml, respectively. These bacteria play an important role also in sediment during organic compound degradation processes (Nealson, 1997). It will provide nutrient for benthic community life in sediment via nitrogen and sulfur cycles. The average densities of the three macromolecule degrading bacteria were 3,26x$10^{-4}$ CFU/ml, 7,31x$10^{-4}$ CFU/ml, dan 6,01x$10^{-4}$ CFU/ml, respectively.

Benthic obtained during EWIN 2015 cruise consisted of echinoderm, arthropods (subphylum Crustacea), annelids (subphylum Polychaeta), mollusks, and some from other phyla. Many polychaetes can be found in all of the sampling stations (high frequency), followed by the crustaceans. Meanwhile, echinoderm (*i.e.* Ophiuroidea and Echinoidea) had low numbers and frequency. Mollusks were obtained from seven stations, but the individual number was not high. Figure 10 shows the correlation between the substrate and the benthic organisms availability.

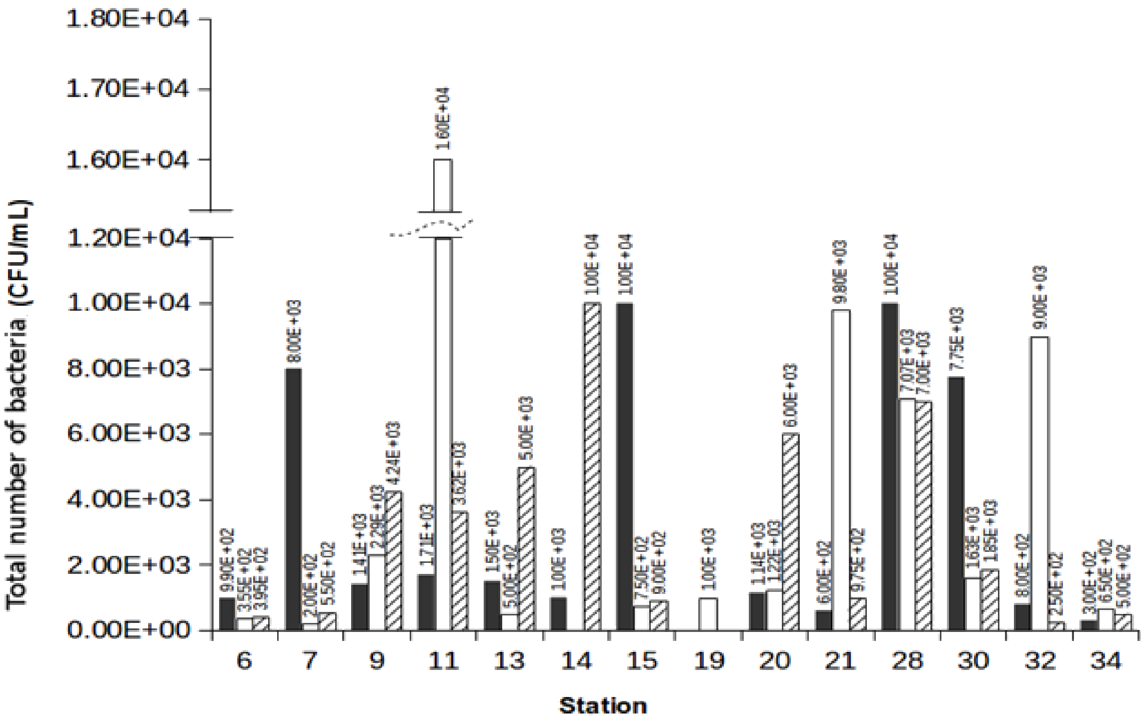


**Figure 9.** The total number of macronutrient-degrading bacteria in Sunda Strait affected zone/SJC-regulated zone (St 6-15) and Southwestern Sumatran Water/SECC-regulated zone (St 18-32)

The high number of specimens was obtained from the substrate that contains mud (*i.e.* sandy mud, muddy sand or muddy).

## DISCUSSION

Stratification of water masses in terms of temperature, salinity, and density also show unique characteristics. The pattern of temperature distribution in the third transect locations showed a mixed layer (>25°C) until a depth of 50 m. The thermocline (8 - 12°C), indicated by a rapid drop in temperature by depth, is found at a depth of 50 – 500 m, with the deeper layer (<8°C ) found at over 500 m (Figure 5). On the horizontal temperature distribution in the surface layer, low temperatures (<29.5°C) are scattered in the Sunda Strait, while the highest temperatures (>30.25°C) are found near the equator. Horizontally low salinity water masses are located off the northern coast of Sumatra (<33.4 psu), which may be affected by the river run-off and high precipitation process over the warm pool of the eastern Indian Ocean. On the other hand, the low salinity water mass (<33.4 psu) are found in the exit gate of the Sunda Strait from the Java Sea into the Indian Ocean, as has been confirmed by the current profile in this region.

The maximum salinity layer (>34.9 psu), in the upper thermocline depth at 100 - 300 m, is characteristic of the North Indian Water, NIW (Wijffels *et al*., 2002; You and Tomczak, 1993). This high salinity layer is derived from the mixing process in salty marginal seas (Red Sea and Persian Gulf) as well as the flow of cross-equatorial water masses in the north of the equator (Wijffels *et al*., 2002). At depths of > 800 m, there are characteristics of the Indonesian Intermediate Water (IIW) with a salinity range at 34.6 to 34.8 psu (Wyrtki, 1961). The IIW does not reach to the northern part of study sites because it is blocked by the sill. At all stations, in the deeper layer circumpolar deep water (CDW), characterized by high values of dissolved oxygen, can be found. Characteristics of temperature-salinity in the research area can be seen in Table 3.

Western Sumatran waters, during the expedition in May 2015, were categorized as mesotrophic waters, especially from the surface up to 100 m. Carr *et al.,* (2006) suggest that

**Table 3.** Type and characteristics of the water mass in western Sumatran waters

| Core layer | Characteristics | Potential Temperature θ (°C) | Salinity(psu) |
|---|---|---|---|
| North Indian Water (NIW) | High S;<br>High T;<br>Low $O_2$ | 24,0 - 30,0 | 35,5 - 36,8 |
| *Indonesian Intermediate Water* (IIW) | Low S;<br>800 - 1200 m | 3,5 - 5,5 | 34,5 - 34,9 |
| *Circumpolar Deep Water* (CDW) | High $O_{2;}$<br>~1000 - 3000 m | 1,0 - 2,0 | 34,62 - 34,83 |

waters that have a chlorophyll-*a* concentration less than 0.2 mg/m$^3$ are classified as oligotrophic oceanic waters, whilst those with a chlorophyll-*a* concentration more than 0.2 mg/m$^3$ are categorized as mesotrophic oceanic waters. Furthermore, it is suggested that the waters having chlorophyll-*a* concentration >0.2 mg/m$^3$ can guarantee the survival of commercial fishing (Mukhlis *et al.,* 2009).

Vertically, chlorophyll-*a* concentration is low in the surface layer and then increases with depth and reaches a maximum concentration at 50-75 m depth, which is just above the thermocline layer. These results are similar to those found by Matsuura *et al.,* (1997) coastal shelf waters of Western Australia, the northeast of the Indian Ocean, where the concentration of chlorophyll-*a* in the surface layer is minimal and starts to increase towards the bottom of the surface layer. The concentration then mixes reaching a maximum concentration at 75-100 m depth. We suggest that the chlorophyll-maximum-layer in southwestern Sumatran waters was deeper in May 2015 due to the influence of the Wyrtki Jet Current. Schott *et al.,* (2009) explained that in the tropical regions of the Indian Ocean, the Wyrtki Jet Current (WJC), also known as the Equatorial Jet, is formed eastward on first (April-May) and second transitional periods (September-October). The (WJC) plays an important role in accumulating the mass of warm surface water and making the mixed layer deeper. The (WJC) may also eliminate upwelling in the region.

Meanwhile, phosphate concentrations in the bottom layer are higher than in the surface layer. This is because the phosphate in the surface layer is discharged by the biologically intense uptake in the euphotic zone and the concentration rises with the increase of the depth as a result of the conversion from organic phosphate to dissolved phosphate (Paytan, McLaughlin 2007). Horizontally, maximum phosphate concentrations can be observed in the southeastern part of the Indian Ocean. This was expected because the Sunda Strait carries nutrients from the Java Sea.

In contrast to the chlorophyll-*a* and the macronutrient, the TSS profile of the southwestern Sumatran waters shows a distinct spatial distribution (Figure 8). There is a significant difference between the SJC- and the SECC-regulated zones. The POC and PON also show a similar trend, that there is a different profile between the SJC- and the SECC-regulated zones.

The high TSS value in the SECC-regulated zone, especially in the waters around Bengkulu province may be caused by coastal erosion. This result has a positive correlation with the spatial distribution of POC, planktonic organisms and the primary production (chlorophyll-*a*). Furthermore, the TSS value in the middle layer (around the thermocline) is more than 20mg/l (standard of the Indonesian Ministry of Environment and Forestry). The TSS value in this layer ranges from 37.6 up to 207 mg/l. This result was expected becasue of the moderately high levels in the thermocline layer.

The presence of amylolytic and proteolytic bacteria in this region shows that its carbon and organic proteins can be utilized by the heterotrophic bacteria. We suggest that the high number of heterotrophic bacteria at station 15 and 28 correlates with the high value of particulate organic matter (POM) in the region. Carbohydrates are the primary energy source for the heterotrophic organisms and provide

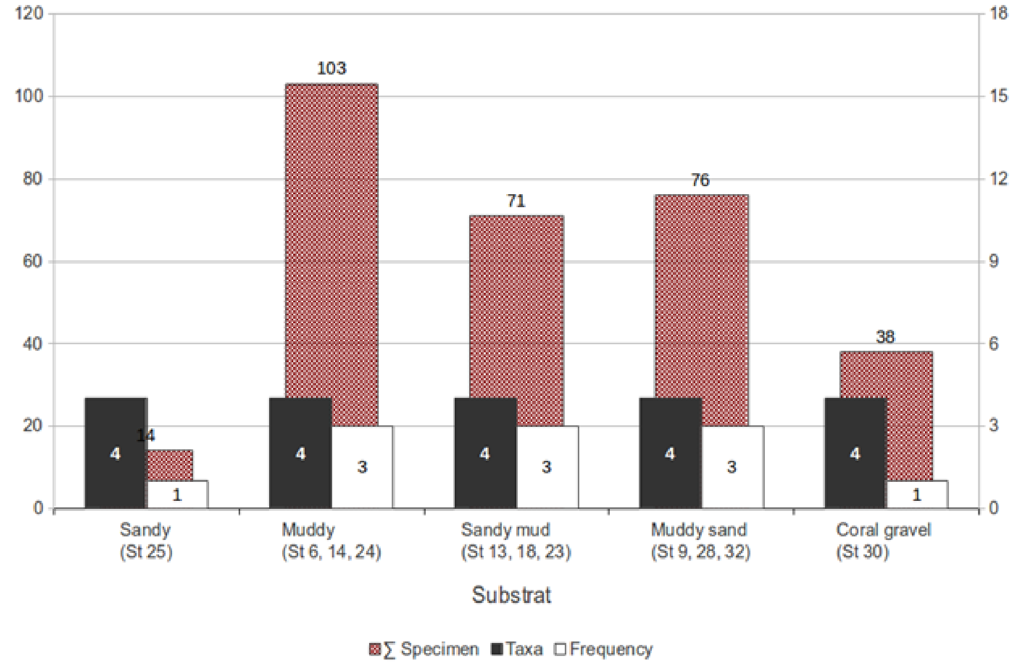


**Figure 10.** The availability of benthic organisms according to the substrate

60% of energy consumption. Dissolved organic carbon (DOC) will also be used as a carbon source by heterotrophic bacteria which will then be transformed into cell biomass (Kirchman *et al.*, 2009). Compared to amylolytic or lipolytic, the proteolytic bacteria are more abundant. We suggest that this may be caused by the high organic protein compounds resulting from the excretion of phytobenthic or phyto- and zooplankton. Spatially, the highest bacteria distribution was located in the waters around Enggano and Mentawai. For instance, Station 25 near Enggano (150 m depth) contains 1.55 x $10^4$, 9.49 x $10^3$ C, and 1.08 x $10^4$ CFU/ml, for amylolytic, proteolytic and lipolytic, respectively. We suggest that the waters toward the coastal areas have a high abundance of the heterotrophic bacteria due to high terrigenous nutrients.

The western Sumatran waters are greatly influenced the water mass of the SJC. The waters are also influenced by the SECC and the South Monsoon Current (SMC). These currents affect the biogeochemical profile as shown by the positive correlation among the abundance of plankton, macromolecule-degrading bacteria, as well as the primary productivity, especially in the Northern Enggano Waters. The profile of macronutrients is supported by the spatial profile of the POM. The distribution of bacterial communities positively correlates with the abundance of the benthic communities in the aquatic sediments. Generally, the substrate of the bottom of the western Sumatran waters is mud, muddy sand, or sandy mud. On those substrates, there were many specimens of benthic organisms found compared with the sand or coral substrates (Figure 10). The muddy substrates (or muddy sand or sandy mud) are found in areas close to the mainland (*i.e.* Sumatra). Comparisons of the water column profiles, *i.e.* abundance of plankton (data not shown) and primary productivity (Figure 6), indicate that there is a positive correlation with the abundance of benthic organisms. The primary productivity in the area closer to the mainland tends to have a higher value. The abundance of macromolecule-degrading bacteria in the area also tends to be higher (Figure 9). It can be presumed that the production of nutrients and organic matter in the water column in this area contribute significantly to the abundance of benthic organisms in the region. Thus, the pelagic-benthic coupling may occur with the biological pump mechanisms of the organic matter (*e.g.* POM) from the surface to the bottom. Turner (2015) state that the main components of the biological pump are phytodetritus (*e.g.* phytoplankton), fecal pellets from zooplankton and nekton organisms, transparent exopolymer particles (TEP), and POM. The response of benthic communities is determined by inputs of organic matter from the surface. This response may include increased oxygen consumption, time reproduction adjustment, microbial activity and pattern of the life cycle of the benthic organisms. This general trend is related to the enrichment of sedimentation of the organic matter from the surface (Turner 2015).

## CONCLUSION

The SJC-and SECC-regulated zones which are represented by the Sunda Strait affected area (SS) and the southwestern Sumatran waters (SSW) shows a distinct profile of organic matter and nutrients. The POC, PON, and TSS value of the SECC-regulated zone can be considered higher that the SJC-regulated zone. We presume that the production of nutrients and organic matter in the water column in this area contribute significantly to the abundance of heterotrophic bacteria and benthic organisms in the region. We also expect that the pelagic-benthic coupling occurs with the biological pump mechanisms of the organic matter (*e.g.* POM) from the surface to the bottom.

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