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The roles of mixed layer depth in affecting chemical and biological characteristics of Makassar straits, Indonesia

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Abstract. Mixed Layer Depth (MLD) is able to determine the amount of light and nutrients abundance for the growth of phytoplankton, its known that phytoplakton pigments are the main absorbers and light scatterers in the ocean. Location wich has deeper MLD and large seasonal variations are the most productive areas, also could have blooming or the maximum growth of large phytoplankton occurring in the existence of a limited number nutrients for several days. The aims of this study are to understand the characteristics of the MLD and it roles to the abundance of Chlorophyll and nutrient in Indonesia Through-Flow/ITF (Indonesia: ”ARLINDO”), specifically the area along Makassar Strait. The Chlorophyll and oceanographic parameters were obtained based on measuring by CTD in TIMIT 2016 expedition. The MLD was deep (~43 m) in the northern part of the transect (around Central Sulawesi Island) and shoaled progressively until about 13 m in the southern transect (the Southern Makassar Strait). The Chlorophyll-a (Chl-a) concentration show a decline pattern from the north to the south transects with the maximal Chl-a is 0.37 mg/m^3. Nutrient parameters in southern Makassar Strait studied were NODC (National Oceanographic Data Center) data from WOA (World Ocean Atlas), it can indicated a correlation between nutrient (Nitrate) with Chlorophyll. The mean correlation in mixing layer for whole area is 0.78, showing that Nitrate concentration is highly related proportional to Chlorophyll abundance, while below the mixing layer, correlation value is -0.52, indicating the inverse relation between Chlorophyll and nutrient. Based on those correlation, and assumption that the source of Chlorophyll is from phytoplankton, it can be concluded that phytoplankton needs Nitrate in its metabolism process as well as other productivities reason in mixing layer, while in depth below the mixing layer, growth of phytoplankton is no longer depends on concentration of Nitrate nutrient.

1. Introduction

Ecosystem condition in a region can be estimated by the physical and biological processes in it. The physical processes which involved are temperature, salinity, and light. While the biological process is due to energy cycle in food chain, which involved nutrient, phytoplankton, and zooplankton [1]. In physical processes, variations on values of temperature, salinity, and light distribution, are closely related with air-sea interactions. Wind stress on the sea surface, is capable to generate water mass movement in turbulent flow. The different of those turbulence movement could induce fluid mixing processes on a large scale. This mixing processes generally occurs in Mixed Layer Depth (MLD), with depth starts from below ten meters of sea surface [2],[3].

Mixing layer is an interface layer between the atmosphere and the ocean, and it has an important role to determaine the average conditions and variability of the sea [4]. The forces that occur in atmosphere (e.g. wind, solar heating, evaporation, and precipitation) along with waves from the sea will caused turbulence in mixing layer. The turbulence will give very high vertical mixing uniformity [5]. When solar radiation and wind gust weakened, the depth of mixing layer will become shallower, as it obtained more stratified ocean and blocking the vertical mixing process [6]. In addition, turbulent mixing can also be caused by internal wave breaking events due to the topography of the waters, such as the narrowing area and/or the existence of seamounts [7]. The differences of water depth are capable to generated different currents in surface and below layers, furthermore this type of currents can generate the formation of water patterns with relatively stable temperature changes in mixing layer [8].

The mass mixing in MLD could affect Chlorophyll, which is one of the parameter that necessary to determine primary productivity in the ocean [9]. Vertical and horizontal distribution of Chlorophyll depend on temperature, salinity, and light. However in the tropics region horizontal distribution has a little differences. Generally, Chlorophyll could be found in plants, photosynthetic bacteria, and algae (phytoplankton) [10]. Mass mixing phenomenon and vertical fluid movement will greatly affect the phytoplankton life for photosynthesis needs, which also affect the nutrient distribution in water column [11].

Makassar Strait is main pathway of Indonesia Through-Flow (ITF), this water mass flow formed as a result from sea level differences between Pacific Ocean and Indian Ocean, and lead the water mass moves through the straits in Indonesia [12]. The transport of mass which has been reviewed in Januari 2004 up to November 2006 is up to 11.6±3.3Sv (Sv=10^6 m^3/s), carrying out 80% ITF mass [13]. Previous research showed that there are a vertical diffusivity and heat flux release from wind stress, and lead the intensity of vertically mixing in Makassar Strait to increase [14]. The vertical change in both of water mass mixing and fluid movement will affect nutrient distribution in water column, and also photosynthesis process of phytoplankton [11].

The aims of this study are to understand the characteristics of MLD and its role to the abundance of Chlorophyll and nutrient in the main pathway of ITF, especially along the Makassar Strait. The assumption used in this study are; (a) Chlorophyll assumed as a Phytoplankton because we already know that most of Chlorophyll in the ocean can be found in the form of algae (phytoplankton), (b) Nitrate can be assumed as a Nutrient because in of the effect of Nitrate concentration on Chlorophyll-a has a greater value than the other nutrients in Makassar Strait [3].

2. Research methods

The data used in this study were obtained from The Transport, Internal Wave and Mixing in The Indonesia Through Flow Region and Its Impact in Marine Ecosystem (TIMIT) expedition, which is a collaboration between *Badan Penelitian dan Pengembangan Kelautan dan Perikanan (Balitbang KP)* and *Pusat Penelitian Oseanografi Lembaga Ilmu Pengetahuan Indonesia (P2O LIPI)* by using Baruna Jaya VIII research vessel in September 2016. Data were retrieved by using Conductivity Temperature Depth (CTD) multi-cylinder water sampler. Locations of data retrieval were divided into 12 observation stations, which spread across Makassar Strait to Lombok Strait. The study area starts from $0^0$47’9.60 N to $8^0$25’19.20 S and $119^0$46’19.20 E to $115^0$57’57.59 E (Figure 1). Depth ranges of CTD were between 300-2242 meter, depending on the depth of the water column. Meanwhile, Nitrate data were obtained from National Oceanographic Data Center (NODC) collection data by World Ocean Atlas (WOA) in September 2016. To find out the depth of MLD and Chlorophyll abundance value, it requires temperature and fluoresecence data along the depths that obtained by CTD.

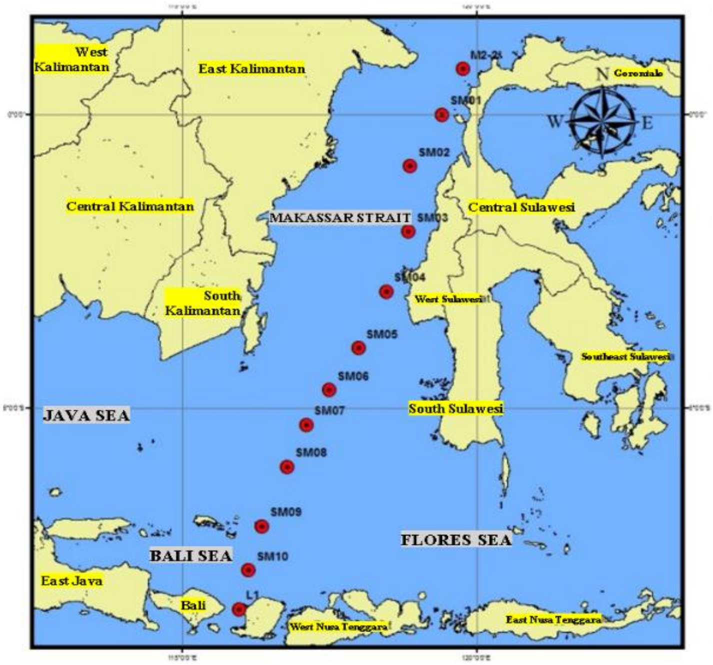


Figure 1. Location of Data Retrieval

2.1. Estimation of Mixed Layer Depth (MLD)

The determination of MLD criteria based on temperature data can be estimated by using threshold method which has previously been used in Pacific Ocean [15]. The implementation of this method is based on the similarity of water criteria as the water mass movement in Makassar Strait and Lombok Strait are sourced from Pacific Ocean. The source of water brought by ITF is from northern and southern Pacific Ocean while Makassar Strait is more influenced by the northern Pacific Ocean water [16]. The threshold method was implemented by estimating based on the depth of reference which is started from 10 meters while the $\Delta T = 0.1^0C$.

2.2. Estimation of Chlorophyll Abundance and Nitrate

Chlorophyll has physical properties such as it could receive and reflect light and fluorescence with different spectrum [17]. So, the fluorescence data recorded in CTD could be used as an input data for abundance Chlorophyll estimation at each depth. Meanwhile, the Nitrate abundance can be estimated from NODC WOA data collection at each depth.

2.3. Estimation of Correlation and Magnitude of Influences

The relations of Nitrate-Chlorophyll, MLD-Nitrate and MLD-Chlorophyll can be estimated by using the analysis methods of linear regression and correlation. The linear regression method was implemented by using scatter graph to produce result as in the form of r-square value. R-squared or determination coefficient can be used to estimate how far a variable is able to provide information related to other variables [18]. The range of R-squared value is between 0 and 1. If the r-squared value is close to zero then it shows that the ability of a variable to gives information about the other variable is restricted. Meanwhile, if r-squared value close to one, it shows that the variable is able to give various information of the other variables.

Correlation value consists of negative and positive values as both of the correlation values can show the relation between each variables. Positive correlation shows that the tested variables are directly proportional while negative correlation the opposite relationship [3].

3. Result and discussion

3.1. Mixed Layer Depth (MLD) Conditions

The MLD condition in Makassar Strait tends to shallowing from north to south as it is showed in Figure 2. The deepest MLD is up to 42.76 m located in SM02 station near Central Sulawesi. Meawhile, the shallowest MLD is up to 12.93 m located in SM09 station in the southern Makassar Strait. The data that was retrieved on September represents the southeast monsoon period (July-September) as the wind was blown from Flores Sea to Java Sea. In general, the sea surface temperature (SST) distribution shows that souther stations tend to have cooler SST as a result from rapturing deep water mass by Ekman Upwelling during the southeast monsoon period [19],[20].

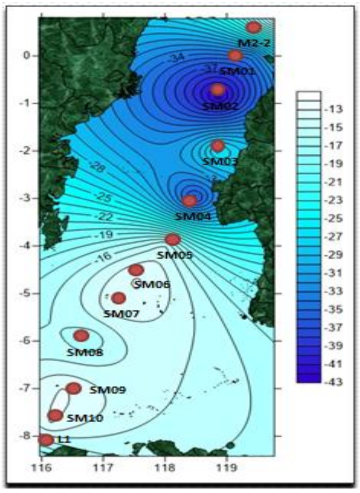
Figure 2 shows that the deeper MLD are located in Central Makassar Strait, i.e. SM01, SM02, SM03, and SM04 stations with the MLD value respectively are 33.31, 42.76, 25.36, and 36.79 m. In fact, the four stations have deep water-depth as the depths are 1002 m for SM01, SM02 and SM03 while SM04 has a water depth of 2002 m. The deepest depth is located in SM04 station that is located in Labani Channel which has the narrowing topography characteristic. The characteristic causes internal waves breaking which is one of the factors of turbulent mixing [7].

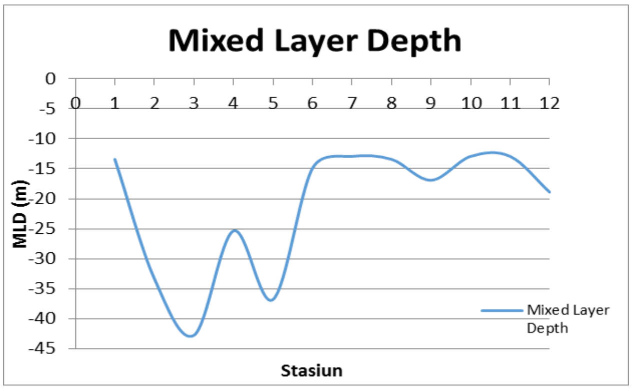
Meanwhile, M2-2 station that is located in northern Makassar Strait and SM06 to L1 stations thatare located in southern Makassar Strait, both of them are have a shallow MLD with respectively values are 13.43 m in M2-2, and in the southern Makassar Strait the range values are about 12.93 m up to 18.90 m. The shallow MLD dominantly influenced by the location of station where adjacent to Sulawesi Sea and Java Sea. The condition of a location lose to Java Sea can be influenced by a direct water mass mixing i.e. the movement of the water mass upward rapidly that will cause a relatively small homogenous conditions [11].

3.2. Chlorophyll and Nitrate Distribution

The thinning event of MLD thickness can be seen drastically starting from SM04 station located in central Makassar Strait, headed to SM05 in the south with the change of 21.88 meter. This change is the starting point of the shallowing of MLD and will continue to SM09 station in the depth of 12.93 m. It shows that the phenomenon on stations located between SM04 and SM09 are intriguing, so the study on how big the influence of MLD to ecosystem condition—represented by Chlorophyll and nitrate distribution—needs to be specifically-conducted.

Chlorophyll distribution value can be known by grouping the maximum value of





Numb.	1	2	3	4	5	6	7	8	9	10	11	12
Station	M2-2	SM01	SM02	SM03	SM04	SM05	SM06	SM07	SM08	SM09	SM10	L1

Figure 2. MLD Chararcteristics on each station

Chlorophyll in MLD and below MLD. The fluorescence data that has been measured with CTD showing that the Chlorophyll in MLD tends to decrease from north to south. The highest concentration is up to 0.37 mg/m^3 located in SM04 while the lowest concentration is up to 0.12 mg/m^3 located in SM08. Meanwhile, the chorophyll abundance below MLD tends to increase from north to south as the highest concentration is up to 1.28 mg/m^3 located in SM09 and the lowest concentration is up to 0.61 mg/m^{3}located in SM04.

Nitrate distribution also can be known by grouping the maximum value in MLD and below MLD. Based on NODC WOA data collection, nitrate concentration in MLD from north to south (SM06 station) tends to decrease, then increase again to SM09. The highest concentration is up to 1.16 μmol/l located in SM04 and the lowest concentration up to 0.12 μmol/l located in SM06. Meanwhile below the MLD, nitrate concentration tends to decrease from north to south, although there is an increase at SM08.

Based on the Chlorophyll and nitrate distribution patterns that are showed in Figure 3 and Figure 4, and also in Table 1, it is known that in the MLD, the highest Chlorophyll and nitrate concentration is located in SM04 station which is the nearest station to equator. In this location, there is a considerable warming in sea surface that will induce upwelling to decrease the temperature of the surface layers. This upwelling process causes an increase of nitrate concentration on the surface, so the abundance of Chlorophyll become higher. There is an increase of Chlorophyll concentration and primary productivity in equatorial area that is caused by upwelling in divergence area of equator [21].

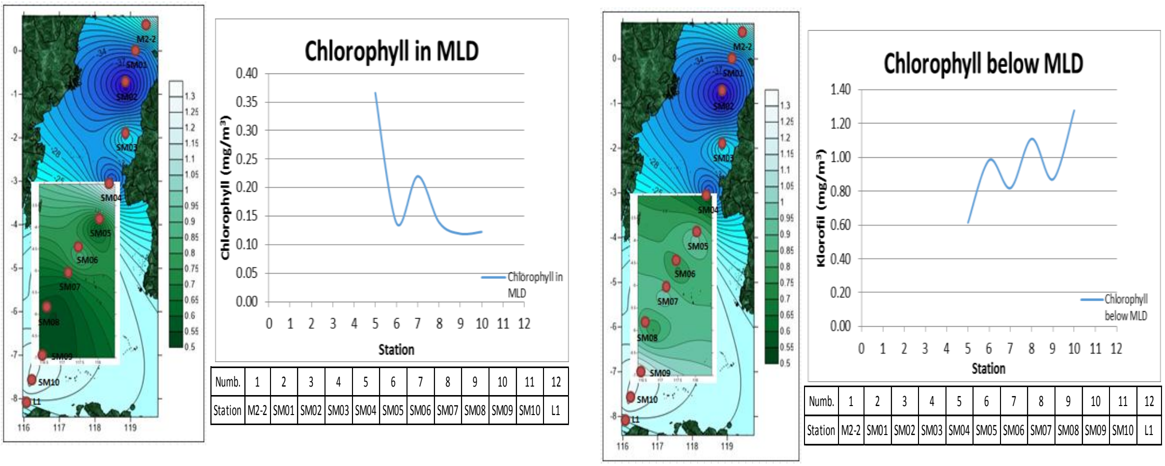


Figure 3. Chlorophyll horizontal distribution

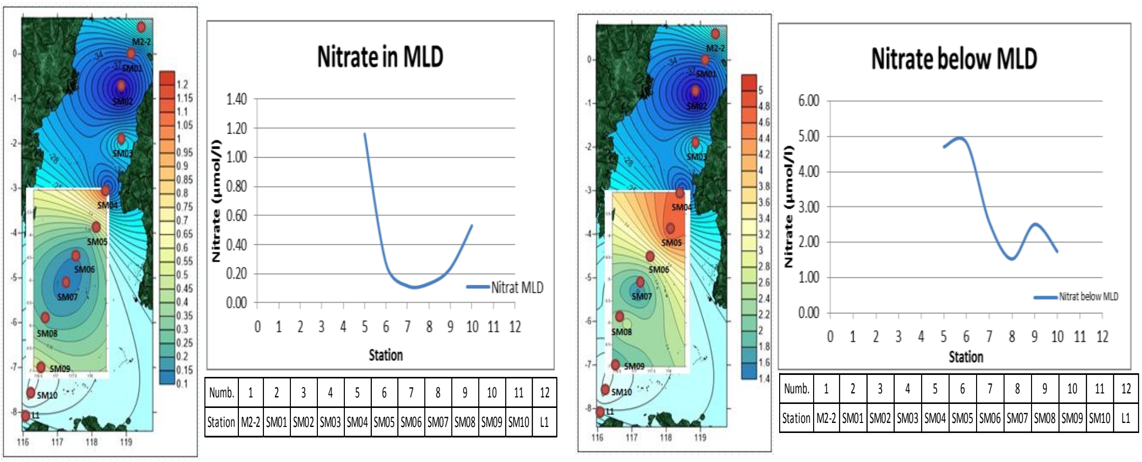


Figure 4. Nitrate horizontal distribution

Table 1. Chlorophyll and Nitrate Value

Station	MLD	MLD		Below MLD	
		Chlorophyll	Nitrate	Chlorophyll	Nitrate
SM04	-36.79	0.37	1.16	0.61	4.71
SM05	-14.92	0.14	0.27	0.98	4.82
SM06	-12.93	0.22	0.12	0.82	2.57
SM07	-13.43	0.14	0.13	1.11	1.53
SM08	-16.91	0.12	0.24	0.87	2.51
SM09	-12.93	0.12	0.53	1.28	1.74

3.3. The Influence of MLD and Correlation between parameters

The influence of MLD on the abundance of Chlorophyll and nitrate concentration can be known by the correlation value between each parameters and the range of depth waters. The correlation value for Chlorophyll and Nitrate in MLD, respectively are 0.88 and 0.91. Meanwhile in the depth below MLD, the correlation value respectively are -0.74 and 0.63. Based on these results, it shows that on Chlorophyll case, as the MLD going deeper, the Chlorophyll concentration will be higher due to the presence of homogeneous layer and uniformity lighting which support the Chlorophyll growth. Meanwhile in the depth below MLD, the correlation value classified as a strong negative correlation showing that Chlorophyll concentration will be decreased along with the increasing depth. This event can be caused by the light that can't reach the deep waters.

In another case, both nitrate parameter are having positive correlation, with strong classified in MLD and medium classified on below MLD depth. Based on those correlation, it shows that as the MLD becomes deeper, nitrate concentration will be higher. That event also happens on the depth below MLD as the nitrate concentration will be higher along with the increasing depth. The high concentration of nitrate in deeper MLD is due to the presence of mixing process from upwelling, while in the depth below MLD case, the concentration have higher value because of there already are a lot of settled nitrate on the sea floor.

The correlation between Clorophyll and nitrate can be seen by using Pearson correlation method because both parameters are having scale depth interval. Based on the results, it shows that Chlorophyll and nitrate correlation has different value in MLD and below MLD. Chlorophyll and nitrate correlation value in MLD is 0.78, classified as strong positive correlation. This correlation shows that as the nitrate concentration increases, the Chlorophyll abundance also increases in MLD. It is caused by the presence of nutrient (nitrate) abundance and lighting uniformity which supports the Chlorophyll growth. Meanwhile in below MLD depth, the correlation has been classified as a medium negative correlation with the value of -0.52. This correlation shows that Chlorophyll is inversely proportional to nitrate concentration, although nitrat concentration have higher value at deeper waters. The decreased Chlorophyll concentration can be caused by the minimum light penetration in deep waters.

The determination of correlation criteria is in accordance with the statement explaining that correlation criteria (r) value in range of 0.40 – 0.59 are classified as medium correlation, and (r) value with range of 0.60 – 0.79 classified as strong correlation [22]. R-square value of the three scatter graphs that have been calculated show that in MLD the r-square have higher values than on below MLD. The influence—quantified as r-square value—of MLD to Chlorophyll and nitrate abundance are 0.78 and 0.83, respectively, while the influence of nitrate to Chlorophyll in MLD is 0.60. Meanwhile on below MLD, the influences for same cases are 0.55, 0.40, and 0.28, respectively.

Based on correlation value and assumption of Chlorophyll as phytoplankton, it can be concluded that in MLD, phytoplankton community depends on nitrate concentration for metabolism and other activities, while on below MLD phytoplankton community growth is not depend on nitrate concentration. This result shows that the growth rate of phytoplankton is directly proportional to the increase of nutrient concentration until it reaches the nitrate saturation limit, after that, phytoplankton growth no longer depend on nitrate concentration [23].

4. Conclusion

Based on the measurements on TIMIT expedition, it can be shown that the MLD from northern Makassar Strait to Lombok Strait on the southeast monsoon period is divided into three waters with different characteristics as the characteristics from north to south tends to be shallowing. The deepest MLD is up to 42.76 m at SM02 station near the Central Sulawesi and the shallowest MLD is up to 12.93 m at SM09 station, southern of Makassar Strait .

In MLD, the Chlorophyll and Nitrate concentration will be higher on deeper MLD. Meanwhile on the depth below MLD, Chlorophyll concentration will be decreased, while nitrate concentration is getting higher along with increasing water depth. Phytoplankton metabolism in MLD depends on nitrate concentration, while on depth below MLD nitrate no longer have big influences to phytoplankton growth.

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