Water mass characteristics in the Makassar Strait and Flores Sea in August-September 2015

L L Silaban\textsuperscript{1*}, A S Atmadipoera\textsuperscript{1}, M T Hartanto\textsuperscript{1} and Herlisman\textsuperscript{2}

\textsuperscript{1}Department of Marine Science and Technology, Faculty of Fisheries and Marine Science, IPB University, Dramaga, Bogor 16680, West Java, Indonesia
\textsuperscript{2}Research Center for Marine Fisheries (KKP), Indonesia

*E-mail: laurence.lambok@gmail.com

Abstract. Makassar Strait is one of the main entrance points for Indonesian Throughflow (ITF), which carries water from the North Pacific through Flores Sea. ITF has a crucial role as a branch of the thermohaline circulation system in controlling the Indonesian marine ecosystem as well as regional climate variability. This research aims to describe the structure and stratification of water mass and the distribution parameters of chemical physics in the area of Makassar Strait up to Flores Sea at the month of August-September 2015 as much as 8 casts of data CTD is obtained from the result of expedition STOKAS BRKP-KKP using research vessel Baruna Jaya VIII. Research results indicate that the origin of the water mass from the North Pacific is still dominant in the thermocline layer (NPSW) also in the intermediate (NPIW). On average the depth of mixed water layers 60m (± 12.59) with temperature variation between 25.62 – 27.65 °C, the average depth of thermocline 130m (±43.65) with temperatures between 18.29 °C – 21.88 °C. Temperature, pH, and dissolved oxygen distribution tends to be higher in the northern region. Fluorescence distribution in the south is higher than the northern region due to inputs from the Makassar upwelling.

Keywords: Flores Sea, ITF Water Mass, Makassar Strait, stratification, water mass

1. Introduction

Indonesian Throughflow (ITF) is a current thermocline system that flows from the Pacific Ocean to the Indian Ocean through the deep waters of the Indonesian Sea as well as the main branch of the current from the global thermohaline circulation that carries warm and high salinity water masses from the Pacific [1]. Water masses from the Pacific Ocean flows into the Indian Ocean due to the difference in sea level between the two sides of the ocean, where the Pacific side is always higher than the Indian side [2]. ITF enters Indonesian waters through two inflow gates, called the west gate through the Sulawesi Sea and the east gate through the Halmahera Sea and the Maluku Sea. The components that makeup ITF water mass consist of water masses from the North Pacific and South Pacific [3].

Geographically, the Makassar Strait is located between two large islands, Kalimantan and Sulawesi. Previous research has stated that there is a North Pacific water mass that crosses the Makassar Strait [3, 4]. The North Pacific water mass is carried by the Mindanao Current, which enters Indonesia through the Sulawesi Sea to the Makassar Strait. In the western part of the Flores Sea, about 20% of the water mass exits to the Indian Ocean through the Lombok Strait and the rest is forwarded to the Flores Sea and Banda Sea [5]. The phenomenon of water mass movement that occurs throughout the year in Indonesian waters will result in variability of oceanographic parameters such as temperature, salinity,
and current [6] so that ITF plays a role in the strength of the flow and the character of the Makassar Strait water mass [7].

The water masses that were crossing the Makassar Strait have been identified as water masses from North Pacific Subtropical Water (NPSW) with maximum salinity (34.7) above the thermocline layer and North Pacific Intermediate Water (NPIW) below the thermocline characterized by a minimum salinity of 34.45 [4]. The stratification of the Makassar Strait water column will then be influenced by the presence of the two water masses [8]. The mass flow of water that passes through Indonesian waters undergoes characteristic modifications depending on the route of entry and length of stay in Indonesian waters [9]. The water mass that enters Indonesian waters through the Makassar Strait will be transformed and result in a reduction in the original characteristics of the water mass. Changes in the characteristics of this water mass are also influenced by global and regional climatic conditions. The study is expected to add information on the stratification and structure of water masses and the effect of water mass transformation on the distribution of physio-chemical parameters in the study area and help study and utilize aquatic resources in the study area.

2. Data and Methodology

The study area is located in Makassar Strait – Flores Sea. Data acquisition was carried out from 20 August until 02 September 2015 by the STOKAS BRKP – KKP Expedition using Research Vessel Baruna Jaya VIII. Study area is shown in Figure 1.

![Research Location Map](image)

**Figure 1.** Research Location Map of Makassar Strait – Flores Sea.

2.1 Procedure

Processing started by preprocessing, data processing, the analysis and visualization of the physical and chemical parameters. The flow chart is shown in Figure 2.
Data acquired from CTD cannot be analyzed directly but must go through a series of processes, including preprocessing, sorting, and editing. Disturbances in the CTD data recording sometimes were observed due to shake-up or noise when dropped into the water depths 0 – 500 m, so it is necessary to do preprocessing before further analysis. Data preprocessing was carried out using SBE Data Processing 7.26.4.0 software through several stages [10]. The preprocessed data is then manually corrected and filtered using MATLAB software using the *filtfilt* method before being analyzed.

### 2.2 Data Analysis

Water mass stratification analysis was carried out by calculating changes in temperature gradients, aimed to identify the thickness of the thermocline layer in the waters. Determination of the water mass layer is based on the temperature gradient ($G_j$). The temperature gradient value is then used to calculate the thickness of the water mass layer by determining the depth of the thermocline layer first, where the temperature gradient value of the thermocline layer is more than or equal to 0.05 C/m [11]. The temperature gradient is calculated using the following formula [8]:

$$G_j = \frac{T_{j+1} - T_j}{D_{j+1} - D_j}$$  \hspace{1cm} (1)

**Notes:**

- $j$ = 1, 2, 3, ..., $n$
- $G_j$ = temperature gradient
- $T_{j+1}$ = temperature after $j$ depth
- $T_j$ = temperature at $j$ depth
- $D_{j+1}$ = depth after $j$
- $D_j$ = Depth at $j$
3. Results and Discussion

The vertical temperature distribution pattern shows a decrease with increasing depth with a range of values ranging from 7 - 28.9°C (Figure 3). The horizontal temperature profile shows homogeneity in the surface layer to a depth of 20 - 60 m, indicated by the temperature value in the range of 25.8 - 27.6°C with varying depth limits, namely 22.87 m (St.4) to 65.63 m (St.1). The thermocline layer is characterized by a fairly large temperature drop, with a temperature gradient greater than or equal to 0.05°C. In the thermocline layer, the temperature values in all stations are in the range of 18.29 - 21.88°C. The thickness of the thermocline layer is the thickest at station 5 and the thinnest at Station 3. The difference in thickness of the mixed layer can be caused by circulation in the mixed layer [3].

![Figure 3. Horizontal (a) and vertical (b) profile of potential temperature.](image)

The temperature value at the northern station tends to be warmer than the station in the southern part of the Makassar Strait or west of the Flores Sea. The changes in ocean current patterns due to the influence of the Indonesian Monsoon Current impact the distribution of SST in the Makassar Strait to the Flores Sea, especially on the surface layer [12]. In the southeast monsoon, the current pattern shows the mass movement of water from the Flores Sea with a lower SST turning north-northwest into the Makassar Strait. Based on the distribution of the SST, the lower temperature conditions start from the south to the north. In addition, the water mass from the surface layer is pushed by the southeast east wind to the Java Sea. The gap of the water mass in the surface layer causes the lower layer of water mass to rise and fill the void. Based on previous research [13], it is known that there was an El Nino phase during 2015-2016. El Nino causes a reduction in the intensity of rain in Indonesia due to the shift of the Warm Pool to the east of the equatorial Pacific region so that the water mass becomes colder. During 2015-2016 El Nino phase, it was found that there was weak upwelling in the southern part of Makassar, which was indicated by a decrease in SST. The upwelling system in the Makassar Strait is more regulated by the monsoon than the ENSO phase.
Figure 4. Water mass stratification.

The water mass in the Makassar Strait to the Flores Sea is divided into 3 layers, namely the surface layer, the thermocline layer, and the inner layer. The surface layer (0 - 60 m) is indicated by a temperature value that tends to be warm and homogeneous, with a range of 25.83 - 27.64 °C and an average low salinity value of 34.17 - 34.5 PSU. In the thermocline layer, with a depth of 70 - 200 m, there is a significant decrease in temperature with an average of 18.29 - 21.88 °C and an average high salinity value of 34.55 - 34.6 PSU. While the inner layer, which is below the thermocline layer, is characterized by an average low-temperature value of 11.76 - 15.37 °C.

Table 1. Thermocline layer structure in station point.

| Station | Upper Limits (m) | Lower Limits (m) | Depth (m) | Temperature Gradient (°C/m) |
|---------|------------------|------------------|-----------|-----------------------------|
| 1       | 65.63            | 25.05            | 193.84    | 128.21                      | 0.09 |
| 2       | 42.76            | 25.87            | 177.94    | 135.18                      | 0.08 |
| 3       | 45.74            | 26.66            | 127.26    | 81.52                       | 0.14 |
| 4       | 22.87            | 27.49            | 205.76    | 182.89                      | 0.08 |
| 5       | 41.77            | 24.81            | 225.63    | 183.86                      | 0.07 |
| 6       | 54.69            | 25.74            | 205.76    | 151.07                      | 0.09 |
| 7       | 32.82            | 26.54            | 198.81    | 165.99                      | 0.08 |
| 8       | 31.82            | 28.31            | 200.79    | 168.97                      | 0.09 |
| Average | 42.26            | 25.74            | 205.76    | 149.71                      | 0.09 |
| Maximum | 65.63            | 28.31            | 225.63    | 183.86                      | 0.14 |
| Minimum | 22.87            | 24.81            | 127.26    | 81.52                       | 0.07 |
| St. Dev | 13.56            | 1.19             | 29.34     | 34.29                       | 0.02 |

The variations in the depth of the upper limit, lower limit, and thickness of the thermocline layer are shown in Figure 4 and Table 1. Overall, the depth of the upper limit of the thermocline layer has a depth range of 22.87 - 65.63 m, with an average of 45.99 m. The temperature value in the upper boundary
The temperature of the upper limit layer varies between 24.8 - 27.48 °C. The maximum depth of the upper limit is at Station 2 and the smallest is at Station 4. The variation of temperature values in the thermocline layer is in the range of 11.79 – 28.31 °C. The thickness of the thermocline layer at each station varied from 81.52 - 183.86 m. The thickest thermocline layer is found at Station 5 and the smallest is at Station 3. The thickness of the lower limit is in the depth range of 127.26 - 225.63 m, with an average depth of the lower limit of 191.97 m. The temperature value at the lower limit did not vary significantly between 11.76 - 15.37 °C.

**Figure 5.** Horizontal (a) and vertical (b) profile of salinity.

The salinity value in the Makassar Strait to the Flores Sea ranges from 34.08 - 34.84 PSU, indicated by the transverse and vertical profiles presented in Figure 5. The average salinity value in the surface layer is between 34.17 - 34.51 PSU, with the maximum salinity value being at Station 5 and the minimum at station 5 stations 1. In the thermocline layer, a maximum salinity value was found, indicated by the isohaline line 34.7 PSU, which was located north of the transect. The salinity value in the deep layer did not show a significant change, where after a depth of 200 meters, the salinity value tended to be constant in the range of 34.48 - 34.56 PSU. There is a water mass transformation in the Makassar Strait, which is indicated by the decrease in salinity values to the south of the Makassar Strait towards the Flores Sea. The salinity value in the surface layer in the southern part of the study area ranges from 34.09 – 34.23 PSU, in accordance with research [14] which states that the salinity value found in the Flores Sea has decreased in line with the ITF route from its origin in the North Pacific Ocean to 34.8-35 PSU towards the Sulawesi Sea at 34.6-34.8 to the Makassar Strait at 34.5-34.8 PSU then ends at the Flores Sea with surface salinity values ranging from 33.6-34.52 PSU.
Fluorescence is defined as the light emitted by chlorophyll as another result of photosynthesis. Fluorescence describes how chlorophyll works during the photosynthesis process, which is then related to productivity. Fluorescence value is used to detect the presence of algae and phytoplankton in water. The maximum fluorescence value indicates a high amount of phytoplankton in that location [15]. The distribution of fluorescence in the Makassar Strait - Flores Sea is presented in Figure 6. Fluorescence values varied between 0.01 - 1.25 mg/m³ in the depth range of 0 - 100 m. The dominant fluorescence in the surface layer with maximum values is at stations 1, 2, and 6 in the depth range of 18 - 53 m with a value range of 1 - 1.25 mg/m³. The lowest value is at station 5, which is 0.25 mg/m³. The deeper the water, the value of the fluorescence concentration will increase to the maximum concentration and will decrease after passing the maximum concentration. Fluorescence concentration reaches its maximum value at different depths at each station with a range between 26.85 - 51.71 m. The high fluorescence value is influenced by river runoff or anthropogenic activities from Sulawesi and Kalimantan because low salinity values are indicated as freshwater inputs [16].
The concentration of dissolved oxygen in the waters of the Makassar Strait to the Flores Sea represented in 8 stations overall ranged from 3.06 - 6.31 mg/l with the lowest concentration being at station 4 at depth near the bottom and the highest at station 1 at the surface layer (Figure 7). The average concentration of dissolved oxygen in the mixed layer ranges from 5.64 - 6.19 mg/l, the thermocline layer is 4.32 - 5.02 mg/l, while in the deep layer below 200 m, the dissolved oxygen concentration decreases to reach the range of 3.31 - 4.11 mg/l. The vertical distribution pattern shows that the dissolved oxygen concentration decreases with increasing depth. The concentration of dissolved oxygen tends to be higher at the surface layer. This happens because of the diffusion process between water and free air and the process of photosynthesis. With increasing depth, there will be a decrease in dissolved oxygen levels because photosynthesis is decreasing and the oxygen content is widely used for respiration and oxidation of organic and inorganic materials [17].

The value of dissolved oxygen concentration tends to be higher in the southern part of the study area and lower towards the north. The maximum concentration value in the surface layer was found at Station 1 (6.32 mg/l) and the minimum at stations 2 and 8 (6.10 mg/l). The dissolved oxygen concentration then decreased to a range of 3.62 - 6.20 mg/l in the thermocline layer. The highest concentrations were found at stations 3 and 8 and the lowest at Stations 5. The minimum concentrations were found at depths near the bottom (250 - 500 m) are 3.05 mg/l (Station 4) and 3.69 mg/l (Station 2). The high concentration of dissolved oxygen in the south compared to the north of the study area is due to an indication of upwelling. Indications of upwelling in the southern part of the Makassar Strait close to the Dewakang Sill triggered the rise of nutrients to the surface. In the upwelling center, the nutrient concentration tends to be low but the chlorophyll concentration increases. This condition indicates that the nutrients from deep seawater are used for photosynthesis [16].

**Figure 8.** Horizontal (a) and vertical (b) profile of pH.

pH is the total concentration of dissolved hydrogen ions in the water column. The pH measurement results are displayed in the form of transverse and vertical profiles, which are presented in Figure 8. The overall pH value range is 8.30 - 8.84, with the lowest value being in the deep layer at station 4 and the highest value being in the surface layer at station 8. The pattern of pH distribution in the waters Makassar Strait to Flores Sea shows a decrease in pH value with increasing depth. The tendency of the pH value indicates that the bottom layer is relatively more acidic than the top layer [18]. In the surface layer, the
average pH value reaches 8.76 - 8.82, then decreases with an average of 8.63 - 8.73 in the thermocline layer and gets lower in the deep layer. There are 8.49 - 8.63. A decrease in the pH value until it reaches the measurement depth (500 m) indicates a decrease in oxygen. The high pH value on the surface is due to the presence of phytoplankton organisms [19]. The photosynthesis process by phytoplankton utilizes CO₂ in the form of HCO₃⁻, followed by an increase in the concentration of CO₃²⁻ from the CaCO₃ dissociation process and respiration, thereby increasing the pH.

Figure 9. T-S (a), T-O (b), dan S-O (c) diagram water mass in Makassar Strait – Flores Sea.

The structure of the water mass along the observation stations is described using T-S, T-O, and S-O diagrams as shown in Figure 9. Four types of water masses pass through the observation station. In the surface layer (0 - 100 m), local water masses were found in the southern part of the study area, the Flores Sea (St. 1), local water masses were found which were thought to be the result of a mixture of North Pacific water masses flowing from the Makassar Strait and water masses from the Sea. The front of water masses occurs due to the strengthening of the southeast monsoon, which blows from east to west and affects the current pattern. The strong southeast monsoon current causes the water mass of the Banda Sea, which has a temperature of 25-26°C and salinity of 34.1 – 34.4 PSU [20]. The local water mass, which is thought to result from the front of two water masses, is characterized by a temperature range of 23.5 - 26.3 °C and salinity of 34.09 - 34.4 PSU.

In a layer with a depth of 100 - 200 m, the water mass identified is the mass of water with a temperature of 16 - 22 °C and a salinity of 34.56 - 34.65 PSU. At a depth of 100 - 150 m, North Pacific Subtropical Water (NPSW) is found, which is characterized by a temperature value of 20 – 24 °C and a salinity that ranges from 34.8 - 35.2 PSU [4]. In the deeper layer, 250-350 m, there is a water mass with a temperature of 7 - 11.5°C and a salinity value of 34.4 - 34.5 PSU. It is suspected that this water mass is North Pacific Intermediate Water (NPIW) which is characterized at a depth of 300 - 600 m with a temperature value between 7 - 11°C and salinity between 34.1 - 34.5 PSU. The characteristics of the water mass from the Makassar Strait to the Flores Sea can be seen in Table 2. This shows that the mass of water in the upper layer of the thermocline is thought to originate from North Pacific Subtropical Water (NPSW) and the mass of water in the lower layer of the thermocline is thought to originate from North Pacific Intermediate Water (NPIW). The water mass characteristics of the Makassar Strait to the Flores Sea are presented in Table 2.
Table 2. Water masses characteristic based on station point.

|                  | Local Water Mass | NPSW     | NPIW     |
|------------------|------------------|----------|----------|
| Depth (m)        | 0 - 100          | 100-200  | 250-350  |
| Potential Temp. (°C) | 23.50 - 26.30   | 16 - 22  | 7 - 11.50|
| Salinity (PSU)   | 34.09 - 34.40    | 34.56 - 34.64 | 34.40 - 34.50 |
| Oxygen (mg/l)    | 5.20 - 6.32      | 3.71 - 4.81 | 3.10 - 4.10 |
| pH               | 8.74 - 8.82      | 8.48 - 8.72 | 8.31 - 8.55 |
| Fluorescence (mg m-3) | 0.09 - 1.39    | 0.01 - 0.16 | 0 - 0.04  |

4. Conclusion

There are three types of water masses identified from the TS, TO, and SO diagrams, i.e. local water masses, North Pacific Subtropical Water (NPSW) water masses in the upper layer thermocline (100 - 200 m), and North Pacific Intermediate Water (NPIW) water masses in the bottom of the thermocline (250 – 350 m). The thickest thermocline layer was found near the North of Sulawesi Island (Station 5) and the thinnest at Station 3. Temperature distribution tends to be warmer in the northern region of the study compared to the south. Salinity and pH values in the north region are also higher than in the south. Oxygen and fluorescence distribution are higher in the south region due to indications of upwelling in southeast monsoon.

References

[1] Gordon A L 1986 Interocean exchange of thermocline water. Journal Geophys Research. 91(C4): 5037-5046.
[2] Rezeki H A, Munasuk and Kunarso 2017 The effect of ENSO to the variability of sea surface height in western Pacific Ocean and eastern Indian Ocean and its connectivity to the Indonesia Throughflow (ITF) IOP Conf. Series: Earth and Environmental Science
[3] Wyrtki K 1961 Physical oceanography of the Southeast Asian Water Naga Report 2. (San Diego. CA: Scripps Institution of Oceanography)
[4] Ilahude A G and Gordon A L 1996 Thermocline stratification within the Indonesian seas Journal of Geophysical Research. 101(C5) 12401-12409
[5] Murray S P and Arief D 1988 Throughflow into the Indian Ocean through Lombok Strait, January 1985 – January 1986 Nature. 333 444-447
[6] Gordon A L 2005 Oceanography of the Indonesian seas and their throughflow Oceanography. 18(4) 15-27
[7] Naulita Y 2014 Variabilitas suhu dan arus pada lapisan termoklin Selat Makassar dari data mooring instant (Juli 2005 – November 2006) J. Agroekologi Dan Konservasi Sumber Daya Alam 1(1) 59-76
[8] Putra T W L, Kunarso and Dwi A R T 2020 Distribusi suhu, salinitas, dan densitas di lapisan homogen dan termoklin perairan Selat Makassar Indonesia J. of Oceanography 2(2) 1-11
[9] Atmadipoera A S, Molcard R, Madec G, Wijffels S, Sprintall J, Koch-Larrouy A, Jaya I and Supangat A 2009 Characteristics and variability of the Indonesian Throughflow water at the outflow straits Deep-Sea Res. 56 1942-1954
[10] McTaggart K E, Johnson G C, Johnson M C, Delahoyde F M and Swift J H 2010 Notes on CTD/O2 data acquisition and processing using Sea-Bird hardware and software (as available) IOCCP Report 1(134) 1-10
[11] Bureau 1992 Oceanographic Survey Data Processing in The Spefication for Oceanographic Survey (China: Standard Press of China)
[12] Hassanuddin M 1998 Arus Lintas Indonesia (ARLINDO) Oseana 23(2) 1-9
[13] Anugrah N N, Samad W and Berianty D 2020 The changes in oceanographic condition of Makassar Strait related with El Nino Southern Oscillation (ENSO) events of 2009 - 2019 *Earth and Environmental Science*

[14] Naulita Y 1998 Karakteristik Massa Air Pada Perairan Lintasan Arlindo *Master Thesis* IPB University, Bogor

[15] Iskandar M R and Purwadana A 2015 Ditribusi temperatur, salinitas, dan fluoresensi massa air di Selat Makassar pada bulan Juni 2013 *Oseanologi dan Limnologi di Indonesia* 41(2) 167-179

[16] Rosdiana A, Prartono T, Atmadipoera A S and Zuraida R 2017 Nutrient and chlorophyll-a distribution in Makassar Upwelling Region: From MAJAFLOX CRUISE 2015. *IOP Earth and Environmental Science*

[17] Salmin 2005 Oksigen terlarut (DO) dan kebutuhan oksigen biologi (BOD) sebagai salah satu indikator untuk menentukan kualitas perairan. *Oseana* 30(3) 21-26

[18] Meirinawati H and Iskandar M R 2019 Karakter fisika dan kimia perairan di Laut Jawa – Ambang Dewakang *Oseanologi dan Limnologi di Indonesia* 4(1) 41-52

[19] Triyulianti I, Wijaya D, Era W, Arief T, Widagti N, Dipo P and Trenggono M 2012 Distribusi vertikal pH dan alkalinitas perairan Selatan Jawa dan Samudera Hindia *Proc. on Seminar Nasional Tahunan IX Hasil Penelitian Perikanan dan Kelautan (Yogyakarta, Indonesia)*

[20] Kusmanto E and Suriani D 2016 Stratifikasi massa air di Teluk Lasolo, Sulawesi Tenggara *Oseanologi dan Limnologi di Indonesia* 1(2) 17-29