WATER MASS CHARACTERISTICS OF WEDA BAY, HALMAHERA ISLAND, NORTH MALUKU

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ABSTRACT
The water quality parameters at 23 observation points in Weda Bay were collected using the Sea-Bird's Conductivity Temperature and Depth (CTD) 911 and Dissolved Oxygen (DO) meter ARO-USB 66 during Weda Expedition in 13 – 23 March 2013 (transition monsoon) with research vessel Baruna Jaya VII. The main goal of this research was to identify characteristics of water masses in Weda Bay. The results showed that the thickness of mixed layer in Weda Bay was about 40 m with the average levels of temperature, salinity, and oxygen at about 29.2 °C, 34.0, and 7.0 mg/L, respectively. Within thermocline layers, it was observed that there was the water type of Southern Subtropical Lower Water (SSLW) identified by the presence of salinity maximum above 35.0 occupied between 25.7 and 24.5 sigma-theta (16,2 °C < θ < 20,5 °C). Furthermore, there were oxygen homogenous layers at 5.1 mg/L situated at between 26 and 24.7 sigma-theta (15°C < θ < 20°C). In addition, oxygen inversion was found at 0.15 mg/L in the layer of between 26.8 and 26.0 sigma-theta (10°C < θ < 15°C). In the intermediate layer (>500 m), the temperature and salinity tended to be constant at 7.8 °C and 34.7, controlled by the sill separating Halmahera sea and Western North Pacific Ocean (WNPO). These water mass characteristics revealed the strong influences from WNPO to Weda Bay. The water, driven by Indonesian throughflow (ITF), flowed into Halmahera Sea before turned into Weda Bay.

Keywords: temperature, salinity, oxygen, SSLW, Weda bay

I. INTRODUCTION

Halmahera sea is one of Indonesian Throughflow (ITF) eastern pathways bringing water masses from Western North Pacific Ocean (WNPO) waters. It is about 30 % of total ITF transport flowing through eastern pathways while the rest is through western pathways (Ffield dan Gordon, 1992; Gordon, 2005; Gordon *et al.*, 2010). Itensity of ITF transport is seasonally influenced by monsoon winds, which reach a maximum during southeast monsoon (from southeast winds) and a minimum during northwest monsoon (from northwest winds, Wyrtki, 1961; Gordon, 2005; Gordon *et al.*, 2010). The ITF water masses from the two pathways meet in Banda sea before exiting to Indian Ocean through Timor passage and Ombai strait (Gordon, 2005).

The circulation around Halmahera sea was mainly driven by New Guinea Coastal current (NGCC) and New Guinea Coastal under current (NGCUC) (Lukas *et al.*, 1991; Wijffels *et al.,* 1995; Cresswell and Luick, 2001). According to numerical result (Miyama *et al.*, 1995), the former flowed northwestward from boreal spring (April-June) to summer (July-September) and southwastward from autumn (October-December) to winter (January-March). The latter always flowed northwestward and intensified during borel summer. However, the retroflection flow of Mindanau current (MC) between Mindanao and Halmahera shifts southward and become stronger in autumn than it is in winter (Miyama *et al*., 1995). As consequence of this, the SPTW boundary in autmn was further to southward than it was in winter (Kashino *et al*., 1996).

Weda Bay was situated in front of Central and Eastern Halmahera Coast in which Weda Bay Nickel (WBN Project), the second largest nickel company in Indonesia, located and its location was facing direclty to Halmahera sea. This water played an important role for local people because most of them worked as fisherman with Weda Bay as main fish ground. However, marine ecosytem of Weda Bay would be threatened due to the plan of WBN to dump million tonnes of its tailing to the unique Weda Bay (Uliyah *et al.*, 2010). As consequence of this, fish from Weda Bay cannot be consumed anymode if the plan is not stopped.

Information about water mass characteristics in Weda Bay is very limited, especially for vertical distribution. Even, It might be that this published hydrographic observation in this area was for the first time. The main aim of this study is to give more information about the caracteristics of water masses in Weda Bay so that it can be used as preliminary data to monitor the water condition of Weda Bay. In addition, the results of this study can be used as a quantitative basis for modelling ecosystems in local and regional areas, especially in eastern Indonesian waters, leading to improve fisheries and water-quality management and species preservation. In this study, the characteristics of water masses in Weda Bay during transition monsoon (on March) will be discussed by analysing the distributions of physical and water quality data both in horizontal and vertical distribution.

II. METHODS

2.1. Field Sites

The observation were conducted in 23 stations in which 18 stations designated for hydrology (open circle) and 5 stations designated for biology (shaded blue box) located close to the shore (Figure 1). The water depth around the biology stations (B1, B2, B3, B4, and B5) were only between 35 m and 70 m, while the depth for hidrology stations were between 300 m and 1700 m.

The morphology of Weda Bay formed a deep and steep basin with the depth of between 500 m and 1700 m in the middle of this bay(Figure 2). This condition could lead to the water masses in Weda Bay had uniform physical conditions in horizontal distribution. Furthermore, the depth was decreasing toward the Southern and Eastern Halmahera coasts while the depth was increasing toward Halmahera Sea.

2.2. Conductivity Temperature Depth (CTD)

The *Conductivity-Temperature-Depth* (CTD) *Sea Bird Electronics* SBE - 911 (CTD-911) was vertically cast down in 18 stations to measure temperature, depth pressure, and conductivity. The maximum depth of CTD measurement was up to 6800 m. The accuracy and resolution of temperature sensor was 0.001 ^{o}C and ±0.0002 ^{o}C. The accuracy and resolution of conductivity sensor was 0.0003 Siemens/meter (S/m) and ±0.00004 S/m. The accuracy and resolution of pressure sensor was 0.015% of full scale and 0.001% of full scale. The data collected from measurements were processed by *SBE Data Processing* 5.37e before analysing them.

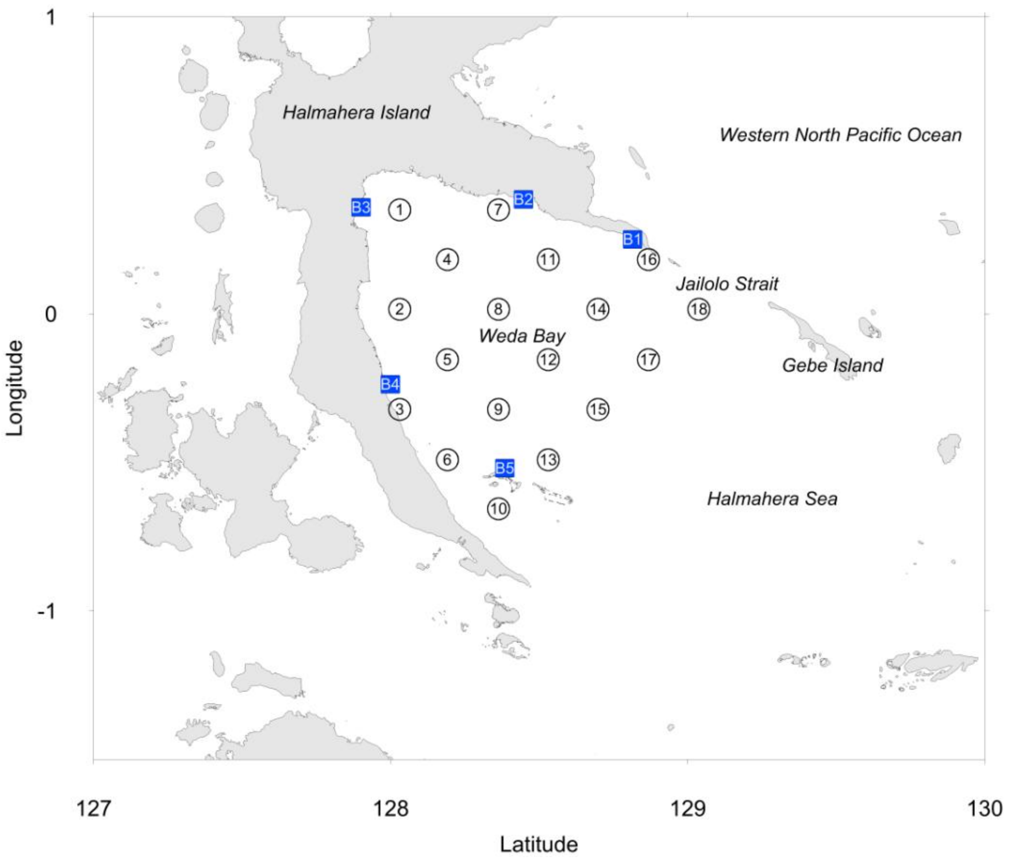

Figure 1. Twenty three observation stations; 18 hydrology stations (in open circle) and 5 biology stations (in shaded blue box), in Weda Bay, North Maluku.

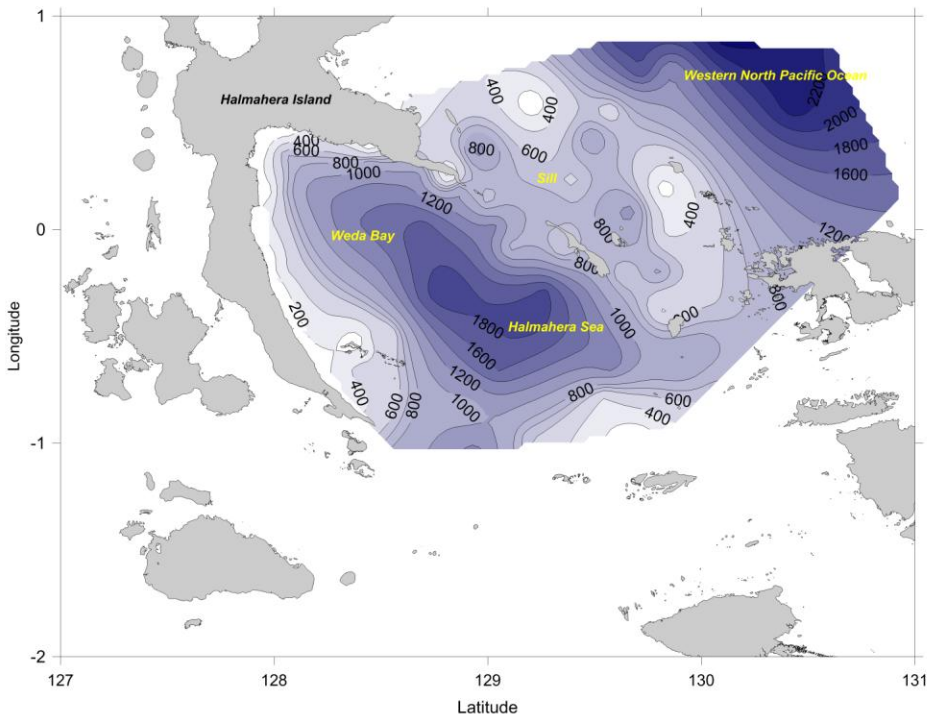

Figure 2. Bathymetric map around Weda Bay

2.3. Dissolved Oxygen (DO)

The phosphorescent memory DO meter with ARO-USB 66 model was cast to obtain vertical profile of oxygen at hydrology stations. This equipment has resolution of 0.001 tp 0.004 mg/L and the measurment ranges of dissolved oxygen and water temperature are 0 to 20 mg/L and -5 to 45 °C respectively. The data collected from measurements were processed by *infinity series acquisition tools.*

2.4. Data Analysis

The horizontal and vertical profiles of temperature (T), salinity (S) and density (D) for the 18 stations were made to identify general caracteristics of water mass. In addition, T-S and T-O diagrams were made to analyse the relation between salinity and temperature; temperature and oxygen in the same time along the water column to identify the water mass characteritics (Neumann and Pierson, 1966; Emery, 2003). In this study, the analyse was made to identify the origin of water masses refer to water mass classsification of Wyrtki (1961) and Kashino et al (1996).

III. RESULTS AND DISCUSSION

3.1. Water Masses Properties at Biology Stations

The graph shows that the values of temperature, salinity, and density at Biology Stations (B1, B2, B3, and B4) were nearly uniform, at about 29.4 °C, 34.0, and 21.2 kg/m^3 respectively (Figure 3). Turbulence generated by the winds, air-sea fluxes of heat/freshwater, breaking waves, current shear and other physical processes are the main factors that cause the sea water in surfaces areas mix and thus lead to a thin layers with uniform values temperature and salinity as called mixed layer (Wijesekera and Gregg, 1996; Steward, 2003). The influence of freshwater was more obvious at station 3 in which there was salinity at 33. 83 within 3 m that was not found in other stations.

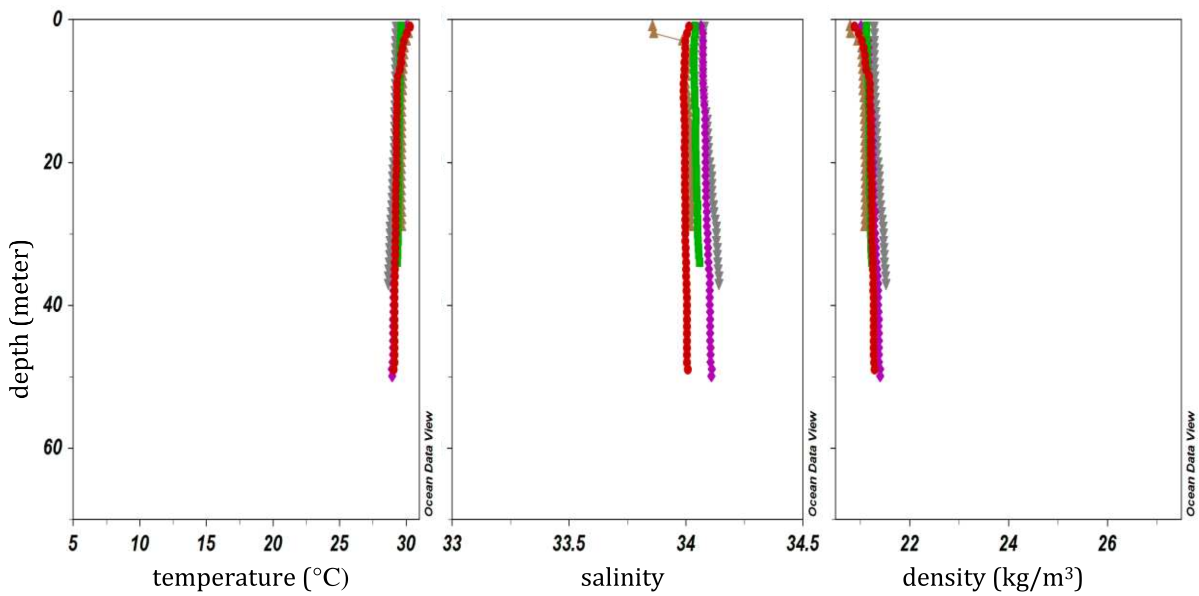

Figure 3. Vertical profile of temperature and salinity to the at biology stations in Weda Bay.

3.2. Water Mass Properties at Hydrology Stations

The range of depth among 18 hydrology stations was between 300 m (station 6) and 1700 m (station 15) and the deepest measurement was up to 1500 m (at station 15). There were 9 hydrology stations (4, 8, 11, 12, 14, 15, 16, 17, and 18) with more than 1000 m deep but there were only at 4 stations (8, 11, 15 and 18) for collecting data with CTD and DO meter at more than 1000 m depth.

Surface waters

The uniform values of water quality parameters were also observed in the water surface coloumn of the hydrology stations. In these coloumns, the average values of temperature, salinity and sigma-theta were at about 29.2 °C, 34 , and 21.3 kg/m^3 respectively. By using Mixed Layer Depth (MLD) Criteria proposed by Wyrti, 1964; Levitus, 1982), it was found that MLDs in these areas were located within 50 m from the surfaces. This result was similar to the MLD around Western Equatorial Pacific Ocean found by Lukas (1991).

The lowest salinity at the surface was found at stations 17 at about 33.6 at σ_θ= 21(at 1 m depth) (Figure 4). At this station, the salinity with less then 34.0 was found until 59 m depth (σ_θ= 21.54). Similarly, this profile was also found at station 18. These levels were even less than the salinity at stations around the Weda Bay coast. The salinity with less than 34.0 was also observed at stations 9 and 11 but only up to 3 m depth. The spatial distribution of salinity between 1 and 5 m was shown in Figure 3. It is suggested that the water mass with low salinity at station 17 and 18 was mainly from the surface water masses of Western North Pacific Ocean. Atmadipoera *et al.* (2004) found that there was extremely low salinity (less then 34.0) during March, May and June in Western North Pacific ocean at 2° N, 130°E (based on TRITON buoy data) that was at just northern Halmahera sea. Therefore, from the two similirities as mentioned above, it is suggested that these waters enter into Halmahera seas and then turn into Weda Bay. However, this influence seems to decrease when the waters enter toward the Weda Bay Coast. This was indicated by the higher salinity at about 0.06 toward the coast (Figure 3).

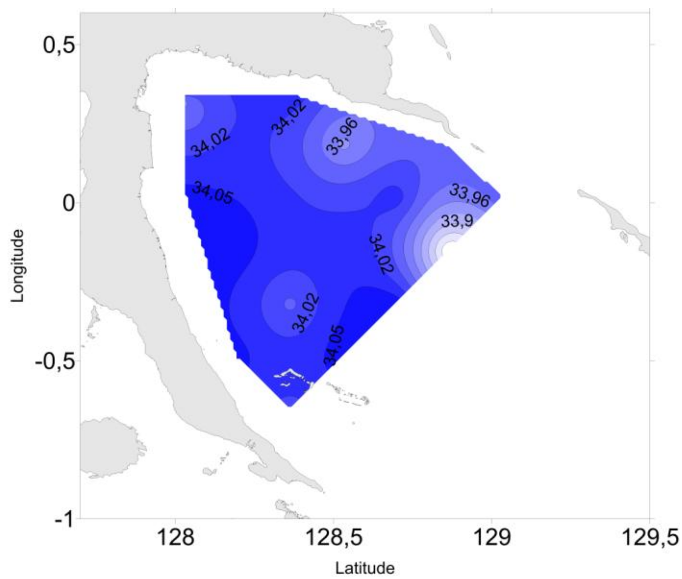

Figure 4. Horisontal distribution of salinity within the depth of between 1 and 5 m at 18 hydrology stations in Weda Bay.

3.3. Thermocline Waters

From Figure 5, there was a significant decrease of termperature from 29°C at 50 m depth and 21.4 sigma-theta to 12°C at 300 m depth and 26.4 sigma-theta. It was obtained that the average termocline thickness and thermocline depth (DTC) at 18 hydrology stations of Weda Bay was around 116 m (Figure 6) and around 163 m respectively (Figure 7). The former was obtained by considering the minimal surface temperature and its variability around this area, it was proposed that the thickness of thermocline layer may be said to extend between 23 and 15 °C) by Wyrtki (1961). The later was estimated by using the definition of DTC as proposed by Kessler (1990) and Wang *et al.*(1999) i.e., the depth at which the temperature around Pacific Ocean is 20°C from the sea surface. As comparison, the annual average of thermocline thickness and thermocline depth around Halmahera Sea were > 100 m (Wyrtki, 1961) and 150 m (Wang *et al.,* 1999) respectively. The depth and thikness variations of thermocline are mainly influenced by dynamical processes such as seasonal weather variation, tide and current (Wyrtki, 1961; Thorpe,2009).

It was observed that there were water masses with the salinity maximum at more than 35 within the thermocline layers at hydrology stations, except at around station 1, at around 25.0 sigma theta (Figure 8 & 9). This water mass type was similar to the water mass type of Western North Ocean Pacific identified by Wyrtky (1961). He found that there was influence of Southern Subtropical Lower Water (SSLW) in Western North Pacific Ocean characterized by the existence of salinity maximum within the thremocline layers (Table 1). Similarly, this characteristic was also observed by Ilahude and Gordon (1996) at Halmahera Sea and Kashino *et al.* (1996) at just North Halmahera sea (Pacific Ocean). Therfore, it is suggested that the present of SSLW in Weda Bay within thermocline layer was from Western North Pacific Ocean flowing through Halmahera Sea before turned into Weda Bay. The influence of SSLW decreased toward the coast of Weda bay as indicated by the salinity maximum at station 1 at just below 35 (Figure 9).

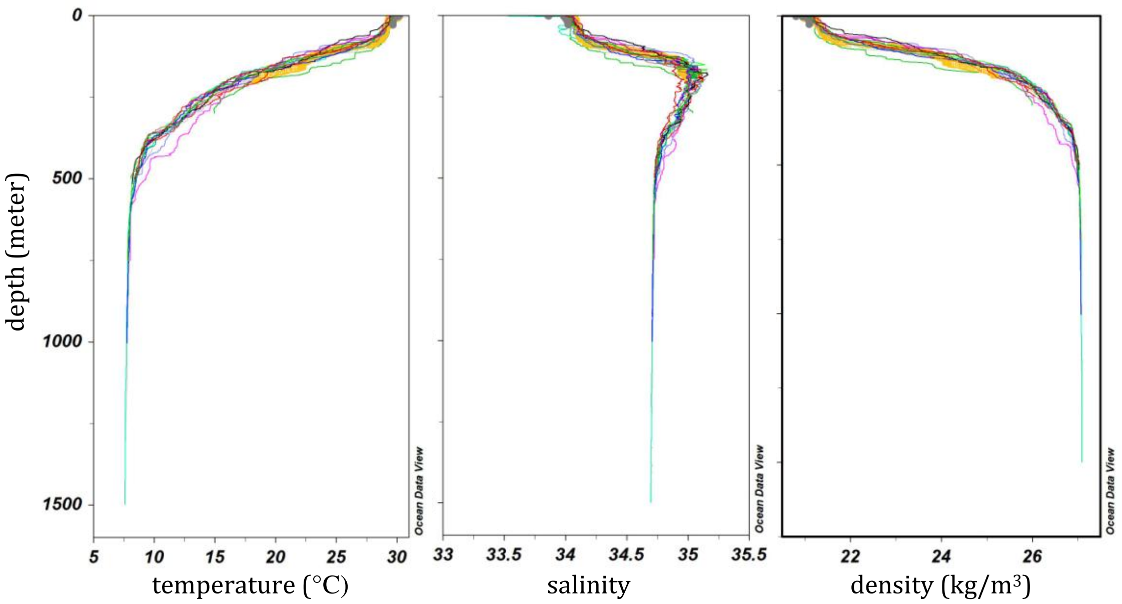

Figure 5. Vertical profile of temperature (left), salinity (middle) and density to the depth at 18 hydrology stations in Weda Bay.

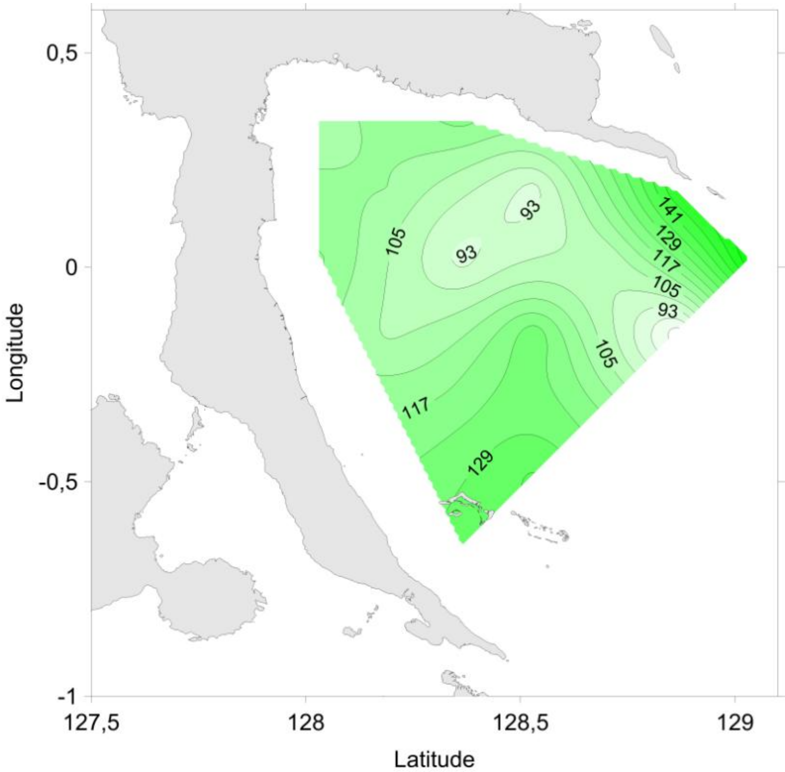

Figure 6. The thickness of thermocline layers at 18 hydrology stations in Weda Bay.

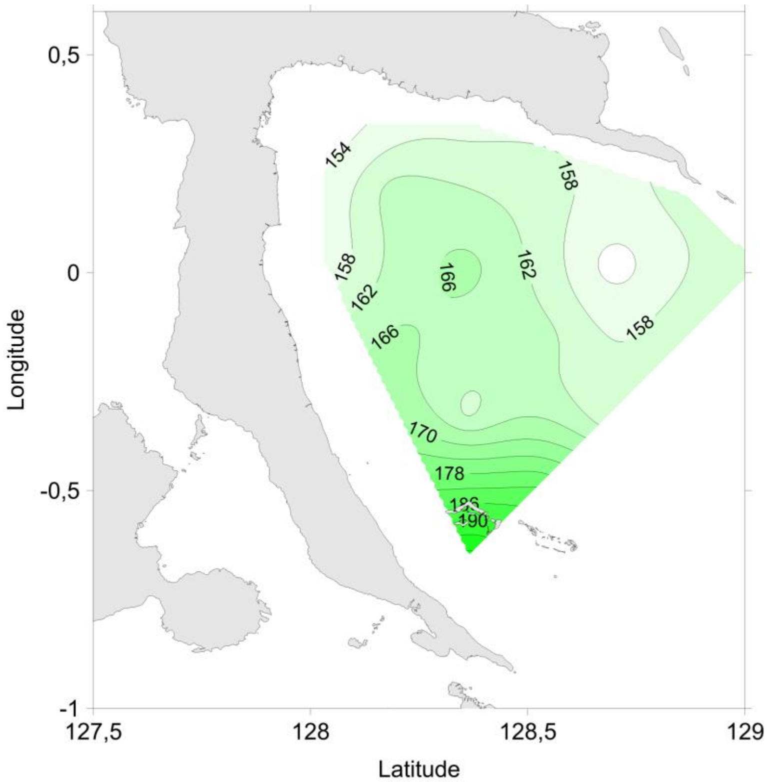

Figure 7. The depth of thermocline layers at 18 hydrology stations in Weda Bay.

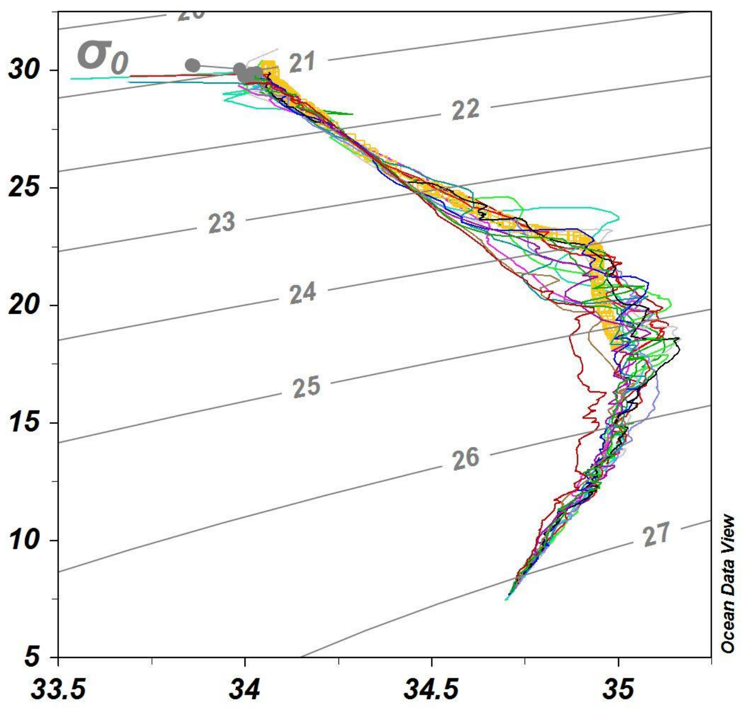

Figure 8**.** T-S diagram at 18 hydrology stasions in Weda Bay.

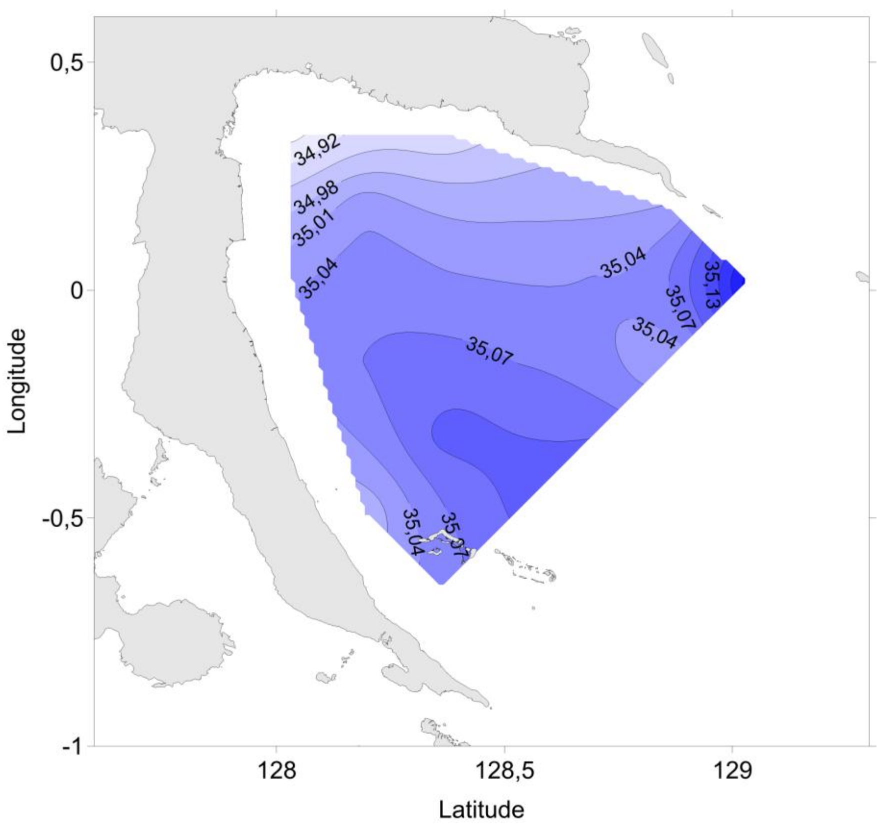

Figure 9**.** Salinity distribution on sigma-theta of 25 kg/m3 in Weda Bay.

Tabel 1. Properties of subsurface water masses in the Western North Pacific Ocean (WNPO) (Wyrtki 1961; Kashino *et al.* 1996) and Weda Bay.

Water mass	Charac-teristics	Water type					
		Southern subtropical lower water (SSLW)			Antarctic intermediate waters (AAIW)		
		T	S	O_2	T	S	O_2
WNPO by Wyrtki (1961)	Smax	19 - 27	35.0 - 35.6	3.2 - 3.5	-	-	-
	S_{min}	-	-	-	5 - 7	34.45 - 34.6	1.9 - 3.0
	O_{min}	-	-	-	3.5 - 5	34.5 - 34.6	2.0 - 2.4
WNPO by Kashino *et al* (1996)	S_{max}	20	35.2	4.5	-	-	-
	O_{hom}	10 - 20	34.55 - 35.45	4	-	-	-
Weda Bay	S_{max}	18 - 20	35.0 - 35.2	5.1 - 5.2	-	-	-
	O_{hom}	15 - 20	34.98 - 35.2	4.1	-	-	-

The influence of SSLW was also identified from Temperature-Oxygen (T-O) diagram. In general, the concentration of oxygen in Weda Bay decreased significantly from 7.0 mg/L at the surface to 5.2 mg/L at 20 °C. After that, the concentration decreased sligthly and tended to be constant at about 5.1 mg/L in between 20 °C and 15 °C. This oxygen homogenous (O_{hom}) layer is one of the characteristics from SSLW that cannot be found in NSLW (Tsuchiya *et al.*1989, Kashino *et al.*, 1996). The oxygen homogenous layer around Halmahera sea was also found by Kashino *et al.* (1996) that confirmed the presence of SSLW influence to the water mass conditions of Weda bay waters (Table 1).

In addition, the water type of SSLW in Weda bay waters was also indicated by the existence of oxygen inversion found between 15 °C and 10 °C (Figure 10). The oxygen content in this layer was higher by 0.15 mg/L compared to the upper layer (20 °C $< \theta <$ 15 °C). The oxygen concentration increased from 5.1 mg/L at 15 °C to reach a maximum at about 5.25 mg/L at 11 °C (Figure 10). Then, the oxygen decreased and tended to reach a minimum below 8 °C. The finding of oxygen inversion was similar to the Wyrtki (1961) observation around Halmahera Sea. The formation of oxygen inversion was related to the movements of water masses rather than to biological processes (Wyrtki ,1961). A rapid opposite horizontal movement at the boundary of the two water masses (Subtropical Lower Water and Intermediate Water) can cause the vertically downward movement of Lower Water with relatively low oxygen content to exchange Intermediate Water with relatively high oxygen content lied below it, so that the inversion is observed at the boundary between the two water masses (Wyrtki ,1961). In Weda Bay, the center of inversion lied at around 15 °C and this was the boundary between the two water masses as discussed in section 3.3, that comfirmed Wyrtki (1961) theory.

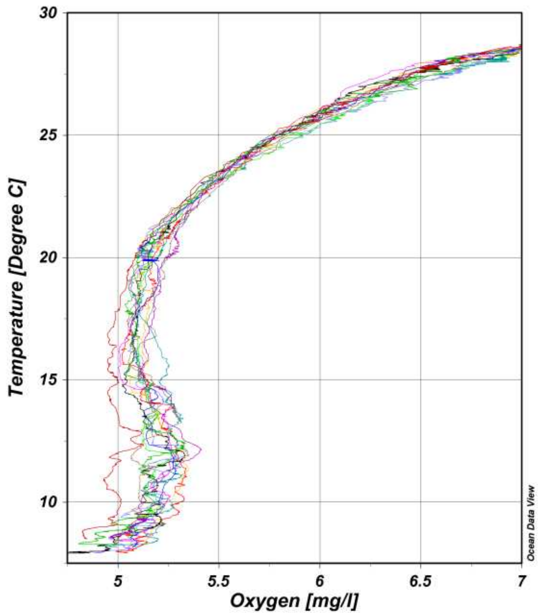

Figure 10. Temperature-salinity (T-O) diagram at 18 hydrology stations in Weda Bay.

3.4. Intermediate waters

The temperature, salinity and sigma-theta tended to be constant at about 7.8, °C 34.7 and 27.1 respectively in the deeper 600 m up to 1700 m (maximum depth of this observation). The characteristics of Antarctic Intermediate waters (AAIW) in Pacific Ocean were indicated by the presence of salinity minimum and oxygen minimum 34.55 and 2.5 ml/L with sigma theta 27.2 (θ = 6 °C) (Table 1) (Wyrtki, 1961; Tsuchiya, 1990; Kashino et al, 1996). These characteristics were not seen in this observation area. It was suggested that the disappearance of AAIW in this area was due to the existence of sill with the depth of about 700 m separating Halmahera Sea and Pacific Ocean, so it was inhibiting the flow from Pacific Ocean to Halmahera Sea (Cresswell and Luick, 2001). These results agreed with the water masses of Halmahera Sea observed during *Snellius I* expedition 1929-1930 by (Van Riel, 1937) and during northwest monsoon (January – March 1994) by Ilahude and Gordon (1994). Weda Basin was adjacent to Halmahera Basin in which the depth increased toward Halmahera Basin and no sill found between the two basins. As consequence of this, the waters of Weda bay within thermocline layer and depeer were renewed by the flow of Halmahera Sea and thus the water mass characteristics in Weda Bay was strongly influenced by the water masses from Halmahera Sea.

IV. CONCLUSION

There was strong influence from the water masses of Western North Pacific Occean (WNPO) to the conditions of Weda Bay water. This water was derived from Halmahera Sea driven by ITF before turned into Weda Bay. In the surface layer, the influence was indicated by the low salinity at just below 34.0 . In the thermocline layer, the influence of WNPO was indicated by the presence of SSLW water type. In the intermediate layer, the water type of AAIW was not detected, due to the sill separating Halmahera Sea from WNPO.

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