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IDENTIFICATION OF FRONT PATTERNS IN THE WATERS AROUND RUMAHTIGA AND GALALA-HATIVE

Identifikasi Front Pada Perairan di Sekitar Rumahtiga Dan Galala-Hative Kecil

Erick Sipahelut[1], Simon Tubalawony [2*], Yunita Angnetjie Noya[2]

[1]Postgraduate Student, Marine Science Study Program, Pattimura University Postgraduate,
[2]Marine Science Study Program, Faculty of Fisheries and Marine Sciences, Pattimura University, Ambon City, Indonesia

Ir. Muhammad Putuhena Street, Ambon City, Indonesia

[*]Coresponding author: simontubalawony003@gmail.com

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ABSTRACT

The waters of Ambon Rumahtiga and Galala-Hative Kecil are part of the waters of Ambon Bay which connects Outer Ambon Bay (TAL) and Inner Ambon Bay (TAD). The characteristics of the waters are influenced by the tides and the input of fresh water which flows into the surrounding waters. This research aims to analyze front events both horizontally and vertically based on the distribution of temperature, salinity and water density. The research was conducted in August 2023 at 9 observation stations. Temperature, salinity and density measurements were carried out in-situ using a CTD (CTD type), and analysis of the vertical and horizontal distribution of temperature, salinity and density using ODV software version 5.6.2 and Surfer 12. Front analysis used a quantitative discrete method approach by comparing differences in temperature, salinity and density characteristics. The research results show that a front is formed on the water surface to a depth of 5 m between the water mass moving from TAD (Station 8) with a temperature of 26.16-26.58 ^oC, salinity of 30.98-33.37 Psu and sigma-t of 19.92 -21.64 Kg/m^3 and water mass from TAL (Station 5) with a characteristic temperature of 25.97 ^oC, salinity of 33.03-34.22 Psu and sigma-t of 21.47-22.47 Kg/m^3. Front events also occur between water masses with temperature characteristics of 26.17-26.32 ^oC, salinity 34.12-34.32 Psu, sigma-t 21.66-22.30 Kg/m^3 (Station 6) with water masses with temperature characteristics 26.43-26.41^oC, salinity 33.37-34.22 Psu and sigma-t 21.66-22.42 Kg/m^3 (Station 9). Tidal currents and freshwater input that flows from the Wairuhu River are the causes of fronts.

Keywords: Ambon Bay, Front, Temperature, Salinity, Density

ABSTRAK

Perairan Ambang Rumahtiga dan Galala-Hative Kecil merupakan bagian dari perairan Teluk Ambon yang menghubungkan Teluk Ambon Luar (TAL) dan Teluk Ambon Dalam (TAD). Karaktesterik perairan dipegaruhi oleh pasang surut dan masukan air tawar yang bermuara di sekitar perairan ambang tersebut. Penelitian ini bertujuan untuk menganalisis kejadian front

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baik secara horizontal maupun vertikal berdasarkan sebaran suhu, salinitas dan densitas perairan. Penelitian dilakukan bulan Agustus 2023 pada 9 stasiun pengamatan. Pengukuran suhu, salinitas dan densitas dilakukan secara *in-situ* dengan menggunakan CTD, dan analisis sebaran suhu, salinitas dan densitas secara vertikal dan horizontal menggunakan perangkat lunak ODV versi 5.6.2 dan Surfer 12. Analisis *front* menggunakan pendekatan metode diskritif kuantitatif dengan membandingkan perbedaan karakteristik suhu, salinitas dan densitas. Hasil penelitian menunjukkan bahwa *front* terbentuk pada permukaan perairan hingga kedalaman 5 m antara massa air yang bergerak dari TAD (Stasiun 8) dengan karakter suhu 26,16-26,58 ºC, salinitas 30,98-33,37 Psu dan sigma-t 19.92-21.64 Kg/m^3 dan massa air dari TAL (Stasiun 5) dengan ciri suhu 25,97ºC, salinitas 33,03-34,22 Psu dan sigma-t 21,47-22,47. Kejadian *front* juga terjadi antara massa air dengan karakteristik suhu 26,17-26,32 ºC, salinitas 34,12-34,32 Psu, sigma-t 21,66-22,30 Kg/m^3 (Stasiun 6) dengan massa air dengan karakteristik suhu 26,43-26,41ºC, salinitas 33.37-34,22 Psu dan sigma-t 21,66-22,42 Kg/m^3 (Stasiun 9). Arus pasang surut dan masukan air tawar yang bermuara dari sungai Wairuhu merupakan penyebab terjadinya *front*.

Kata kunci: Teluk Ambon, Front, Suhu, Salinitas, Densitas

INTRODUCTION

Fronts are narrow areas that separate large areas with different types of stratification and/or water masses. Front events are associated with several phenomena such as salt transport and heat transport in the ocean, atmosphere-ocean interactions, ecosystem function, eddy formation, upwelling, intrusion of deep sea water masses to the surface, and intrusion of river discharge into the ocean (Belkin & Cornillon, 2003; Ginzburg & Kostianoy, 2009). According to Puthezath (2014), based on the characteristics of the water mass, fronts can be divided into thermal fronts (fronts due to differences in ocean temperature), salinity fronts (fronts due to differences in ocean salinity), density fronts (fronts due to differences in ocean density). Yanagi (1987), based on the place of formation, fronts consist of fronts in coastal areas (Coastal Sea Front), fronts on the continental shelf (Continental Shelf Front), and fronts in the wide ocean (Open Sea Front). Fronts can occur on a daily, seasonal or annual time scale over an area of meters to thousands of kilometers (Belkin et al., 2009).

The waters of Ambang Rumahtiga-Galala Hative Kecil, Ambon Bay are the entry and exit points for sea water masses from TAL to TAD and vice versa. The movement of water masses is influenced by tidal currents. Tides in Ambon Bay are one of the generating forces for the mixing of TAL and TAD masses (Hamzah & Wenno, 1987). The waters of Rumahtiga-Galala Hative Kecil are also where the Wairuhu River flows into. The water discharge of the Wairuhu River fluctuates seasonally. In the east season, rainfall is high so that the mass input of river water into the sea becomes greater. The river water input will experience mixing with the sea water mass as a result of being influenced by the tides. The meeting of these water masses causes a front to occur.

This research aims to identify and analyze transverse and horizontal fronts that occur in the Rumahtiga-Galala Hative Kecil waters during the east season.

METHODS

This research was carried out in the east season, namely in August 2023 in the waters of Ambang Rumahtiga-Galala Hative Kecil, Ambon Bay. The research data is in the form of primary data, namely measuring data on temperature, salinity and density of waters using CTD from the surface of the waters to near the bottom of the waters. Front analysis uses a quantitative discrete method approach by comparing differences in temperature, salinity and density characteristics. Measurements were carried out at 9 observation stations grouped into

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3 transects (Figure 1). Transect 1 is on the coast (Station 1, 4 and 7), Transect 2 (Station 2, 5 and 8) and Transect 3 (Station 3, 6 and 9) are in the middle of the Gulf (Figure 1). The positions of Stations 1, 2 and 3 are towards TAD and Stations 7, 8 and 9 are towards TAL. Observations were made during the period when the water was moving at high tide.

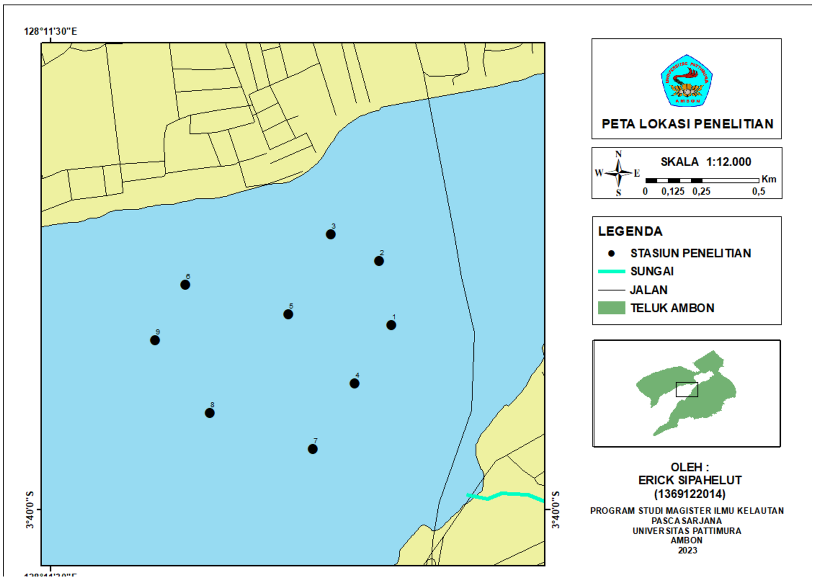

Figure 1. Research Location

Temperature, salinity and density data are then displayed in the form of a transverse distribution graph using Ocean Data View (ODV) software version 5.6.2 and in the form of a horizontal distribution of 0, 1, 3 and 5 m using Surfer 12 software. Analysis front uses a quantitative discrete method approach by comparing differences in temperature, salinity and density characteristics between two different water masses.

RESULT

Temperature (Thermal Front)

The water temperature of the Rumahtiga-Galala Hative Kecil Threshold from the surface to the observation depth (30 m) ranges between 24.86-26.64 oC with an average of 25.98 oC. In general, the water temperature at the time of the study was relatively low. The low water temperature is caused by the influence of the upwelling water masses of the Banda Sea which enter Ambon Bay due to tidal currents (Wyrtki, 1961). Apart from that, the cold water temperature is caused by the influence of weather, namely high rainfall. The temperature distribution pattern shows that water masses moving into the TAD tend to be cooler than water masses moving out of the TAD. The transverse temperature distribution also shows that at the time of observation, namely when the water was moving at high tide, there were still remnants of receding water masses originating from the TAD (Wenno & Anderson, 1984).

The transverse temperature distribution pattern in Transect I (Stations 1, 4 and 7) ranges between 26.11-26.34 oC (Figure 2a). The position of the station on this transect is on the coast with a depth of approximately 2 m. Water masses are generally cold. The transverse temperature distribution pattern shows water masses with lower temperatures moving into the TAD (Station 7) while water masses with higher temperatures tend to move out of the bay (Station 1 and 4).

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In Transect II (Stations 2, 5 and 8) the temperature ranged between 25.04-26.63°C (Figure 2b). The transverse temperature distribution pattern shows that the water mass at Station 8 has a lower temperature when compared to the water mass at Stations 2 and 5. The temperature distribution pattern also shows that there is a movement of water masses from TAD (Station 2 and 5) towards TAL while at Station 8 water masses tend to move towards TAD (Station 5). This movement pattern shows the occurrence of a water mass meeting (front) between Stations 5 and 8 at a depth of 1-5 m. The meeting of water masses (thermal front) occurs between water masses with temperatures ranging between 26.29-26.58°C and water masses with temperatures ranging between 25.97-26.26°C. The vertical distribution of temperature also shows the occurrence of water mass stratification between cold surface water masses with a temperature of 25.98-26.16°C (1 m depth) and water masses at a depth of 2 m with temperatures ranging from 26.26-26.29°C at Stations 5 and 8.

The temperature on Transect III (Stations 3, 6 and 9) from the surface to a depth of 30 m ranged between 24.86-26.64°C (Figure 2c). The temperature distribution pattern shows that on the water surface the water masses at Stations 3 and 6 have a higher temperature, namely 26.36°C when compared to Station 9 with a temperature of 26.23°C. A different pattern can be seen at a depth of 2-5 m where the water mass at Stations 3 and 9 is higher than at Station 6. The temperature distribution pattern shows the existence of a thermal fornt between the water masses at Station 3 with temperatures ranging between 26.26-26.64°C with the water mass of Station 6 with a temperature ranging between 26.11-26.32°C and also between the water mass of Station 6 and the water mass of Station 9 with a temperature ranging between 26.43-36.61°C. Vertically, the temperature distribution shows strong water stratification between depths 5 and 6 at Station 9 with a gradient of 0.17°C/m.

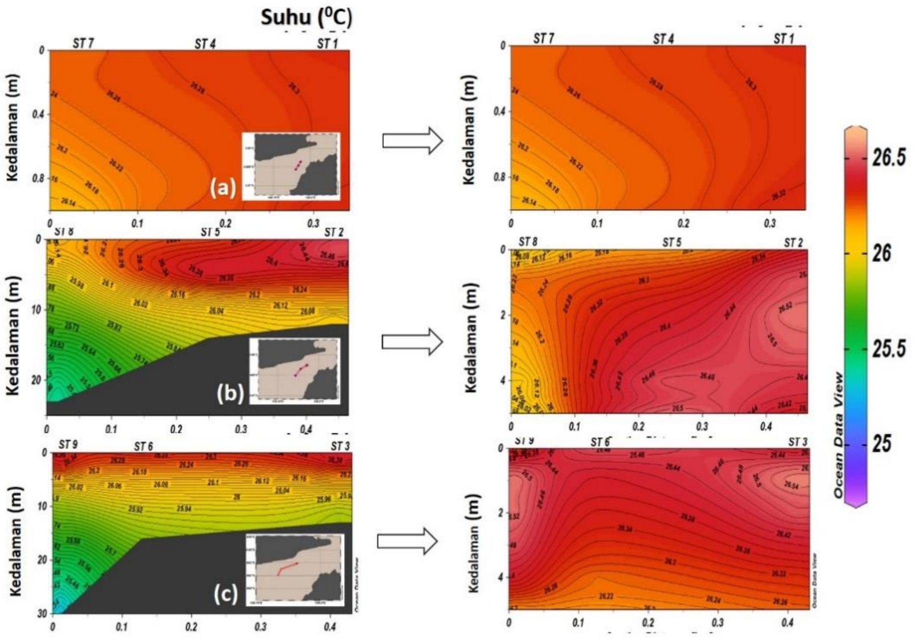

Figure 2. Transverse distribution of water temperature at Rumahtiga-Galala Hative Kecil threshold in Ambon Bay (a) Transect I, (b) Transect II, (c) Transect III

The surface temperature distribution (0 m depth) of the waters of Ambang Rumahtiga-Galala Hative Kecil at the time of the study ranged from 25.98-26.53°C and at a depth of 1 m ranged from 26.11-26.64°C (Figures 3a and 3b). The horizontal distribution pattern on the

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surface of the water (0 m) and a depth of 1 m shows the same pattern, namely the colder water mass (Station 8) moving towards TAD due to the tidal movement of the water, however, water masses with a slightly higher temperature are still found moving towards the outside of the bay at Station 3. At depths of 3 and 5 m, the horizontal distribution pattern of temperature also shows cold water masses at Station 8, and water masses with slightly higher temperatures are found at Station 5. Based on the horizontal distribution it can be seen that the thermal front of the threshold waters Rumahtiga-Galala Hative Kecil occurs in the waters around Station 5 between the cold water mass from TAL and the water mass with a temperature slightly higher than TAD (Figures 3c and 3d).

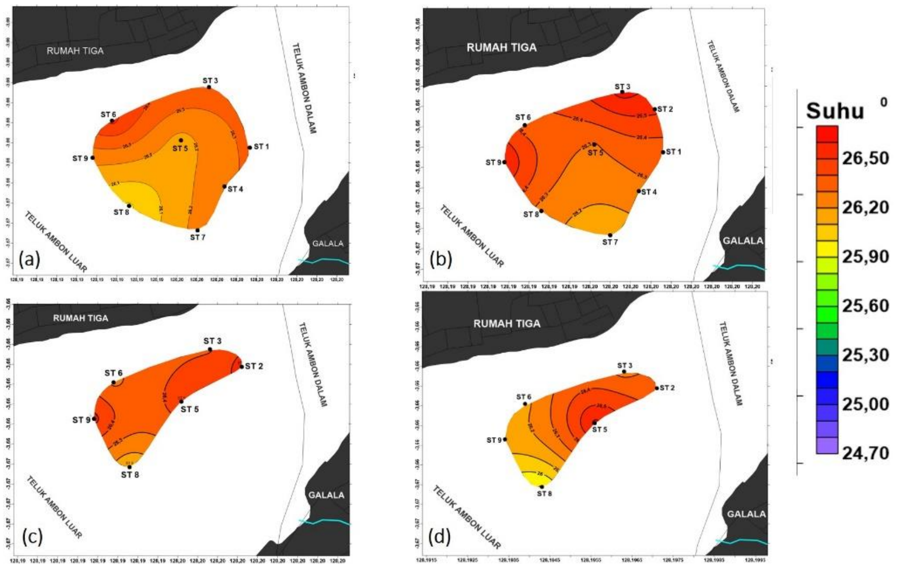

Figure 3. Horizontal distribution of water temperature at the Rumahtiga-Galala Hative Kecil threshold in Ambon Bay. (a) 0 m, (b) 1 m and (c) 3 m, (d) 5 m

Salinity (Salinity front)

The salinity of the waters of the Rumahtiga-Galala Hative Kecil threshold of Ambon Bay from the surface to a depth of 30 m at the time of the research ranged from 27.86 to 34.60 psu with an average of 33.92 psu (Figure 4). The low salinity below 30 psu is caused by the influence of fresh water input from the Wairuhu River and rainfall. The salinity distribution pattern shows that water masses from the TAL with higher salinity appear to be sinking and occupy deeper parts, while surface water masses with lower salinity are in the surface layer.

The transverse distribution of salinity in coastal waters (Transect 1) ranges between 32.59-33.67 psu (Figure 4a). This value indicates that the water mass is influenced by fresh water which causes low salinity. The salinity distribution pattern shows that the water mass at stations towards TAD has low salinity while the water mass towards TAL has higher salinity.

In Transect 2, the cross-sectional distribution of salinity ranges from 27.86-34.60 psu. This value shows that the water mass of the threshold waters has quite high variations. The high variation in salinity is influenced by the input of high salinity oceanic water masses, the influence of estuarine water masses from TAD and the influence of fresh water input from the Wairuhu River. The temperature distribution pattern shows the occurrence of salinity fronts both horizontally and vertically. Horizontally, it can be seen that there is a meeting of water masses at a depth of 1-4 m at Station 2 which has a higher salinity ranging from 33.63-34.11 psu with a lower salinity water mass ranging from 30.64-33.37 psu at Station 5. The salinity

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front also occurs vertically at a depth of 2-3 m at Stations 2 and 8 and at a depth of 3-4 m at Station 5. This condition indicates stratification based on salinity values.

The salinity of the waters of the Rumahtiga-Galala Hative Kecil threshold in Transect III ranges from 29.45-34.60 psu. Salinity is generally higher except at Station 3 which is located towards TAD. This pattern shows the strong influence of oceanic water masses due to tidal currents. However, there are still low salinity water masses on the surface of the waters at Station 3. The low salinity is probably caused by the fact that these water masses are TAD estuary water masses that move out of the bay when the water recedes. In Transect III, horizontally, it can be seen that there is a water mass meeting (salinity front) at a depth of 0-3 between a water mass with a salinity of 29.35-33.15 psu (Station 3) and a water mass with a salinity of 33.28-34.12 psu (Station 6). Vertically, the salinity gradient is stronger at a depth of 0 to 1 meter, especially at Station 3 with a gradient of 3.54 psu/m. In this way, water masses meet vertically through layering of water masses.

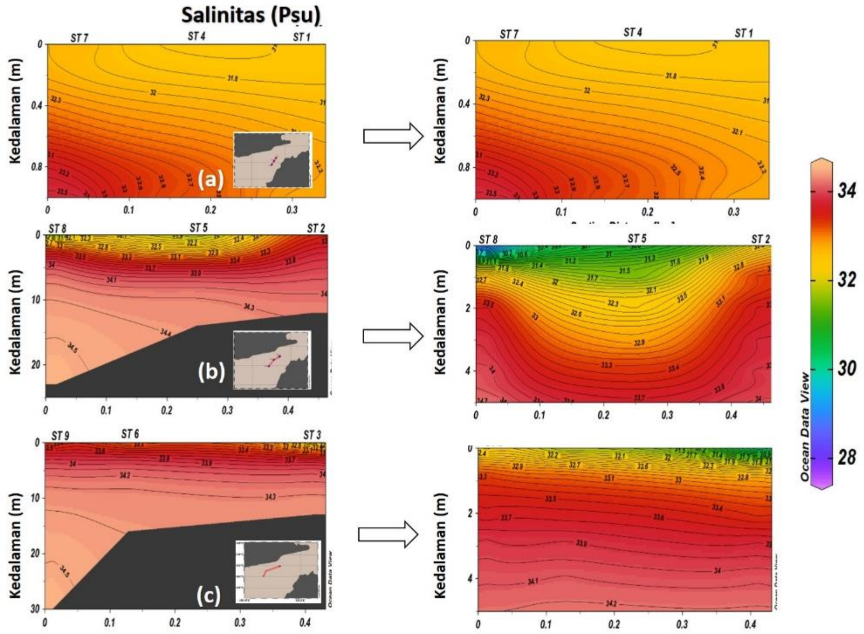

Figure 4. Transverse distribution of salinity in the waters of the Rumahtiga-Galala Hative Kecil threshold of Ambon Bay (a) Transect I, (b) Transect II, (c) Transect III

The horizontal distribution of salinity on the surface waters (0 m) of the Rumahtiga-Galala Hative Kecil threshold waters ranges between 27.86-32.05 psu. At a depth of 1 m, salinity ranges from 30.98-33.91 psu, while at a depth of 3 m, salinity ranges from 31.78-33.99 psu and at a depth of 5 m it ranges from 33.64-34.31 psu. This value indicates that the surface salinity of the threshold waters is very low. The low salinity of the waters is influenced by the influence of fresh water through the Wairuhu River and also due to the influence of estuary water masses from the TAD (Mann & Lazier, 1991). The distribution pattern of salinity on the water surface (0 m) shows that there is a meeting of water masses (Salinity front) between water masses with low salinity (Stations 3 and 8) and water masses with slightly higher salinity at Station 5. Different from the water surface, the distribution of salinity There are depths of 1, 3, and 5 m, indicating that the water mass at Station 5 generally has lower salinity compared to the water mass originating from oceanic waters (TAL) and TAD waters. This condition is

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thought to be due to the influence of fresh water entering the bay due to the influence of tidal currents.

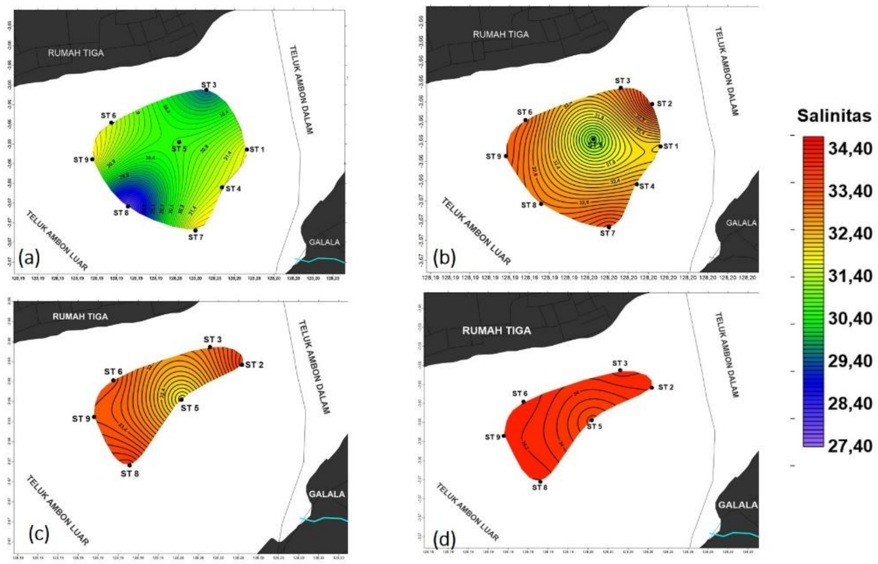

Figure 5. Horizontal distribution of salinity in the waters of Ambon Bay's Rumahtiga-Galala Hative Kecil threshold. (a) 0 m, (b) 1 m and (c) 3 m, (d) 5 m

Sigma-t (Density Front)

The density of the Rumahtiga-Galala Hative Kecil threshold waters as indicated by the sigma-t value from the surface to a depth of 30 m ranges between 17.66-23.31 Kg/m3. Sigma-t is a water density value which is based on water temperature and salinity values (Stewart, 2002). The transverse distribution pattern of sigma-t shows a similar pattern to the transverse distribution of salinity. Thus, the density distribution of the Rumahtiga-Galala Hative Kecil threshold waters is more influenced by salinity than water temperature.

Transversely, the sigma-t distribution of threshold waters shows that there is a thin layer with low density water mass on the surface of the waters to a depth of 2 m. Sigma-t in Transect I which is located on the Galala Hative Kecil coast has a low value with a range of 20.23-22.00 Kg/m3 (Figure 6a). The sigma-t distribution pattern shows that on the surface of the water the water mass with low density moves from Station 1 towards Station 7 or from TAD to TAL while there is a part near the bottom of the water at Station 7 (1 m deep) water mass with higher density moving into TAD waters.

In Transect II, the sigma-t of threshold waters ranges from 17.66-23.12 Kg/m3 (Figure 6b). On this transect the lowest density was found at the water surface of Station 5 and Station 8. At Station 5, the sigma-t value at the water surface (1-2 m depth) ranged between 19.70-19.92 Kg/m3 while at Station 8 in water surface (depth 0) sigma-t of 17.66. This low sigma-t value indicates that this part of the waters is influenced by fresh water masses which causes a decrease in the density of water masses. Thus, the mass of fresh water entering through the Wairuhu River greatly influences changes in the water mass characteristics of the Rumahtiga-Galala Hative Kecil threshold waters. Horizontally, it can also be seen that there is a meeting of water masses on the surface of the waters with low density characteristics with a sigma-t range of 17.70-19.92 Kg/m3 (Stations 5 and 8) with water masses with a higher density, namely with higher sigma-t values. ranges from 21.84-22.03 Kg/m3 (density front). Vertically, the sigma-t distribution also shows strong stratification at the surface of the waters. At Station 2, water masses with low density are found at a depth of 0-3m and high ones start at a depth of 4

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m. At Station 5, the surface water mass to a depth of 5 m has a low density with an increasing gradient as the depth increases, ranging from 0.22-0.68 kg/m3/m. At Station 8, the vertical distribution of water density shows that water masses with low density are located up to a depth of 5 m, however changes in density with greater gradients generally occur at the surface to a depth of 3 m with a gradient range of between 0.75-3.81 kg/m3 /m. Thus, the strong density stratification of waters causes the meeting of water masses with different densities (density front) between layers, especially at a depth of 3-5 m.

The transverse sigma-t distribution of the Rumahtiga-Galala Hative Kecil threshold waters in Transect III ranges between 18.78-23.2 Kg/m3 (Figure 6c). In general, the distribution of sigma-t for each depth on this transect except for surface waters is relatively higher when compared to Transects I and II. This condition shows that the water mass at the surface is still influenced by fresh water masses with a sigma-t range of between 18.74-20.67 Kg/m3, while the sigma-t of water mass at a depth of 3 m is in a range greater than 22. This shows that the water mass of Transect III is dominated by the water mass of oceanic waters. The sigma-t distribution pattern on Transect III also shows the meeting of water masses with different densities (density front) on the water surface between Stations 6 and 9. Station 6 is characterized by a low density water mass originating from the TAD and Station 9 is characterized by a high density water mass. high is oceanic (TAL).

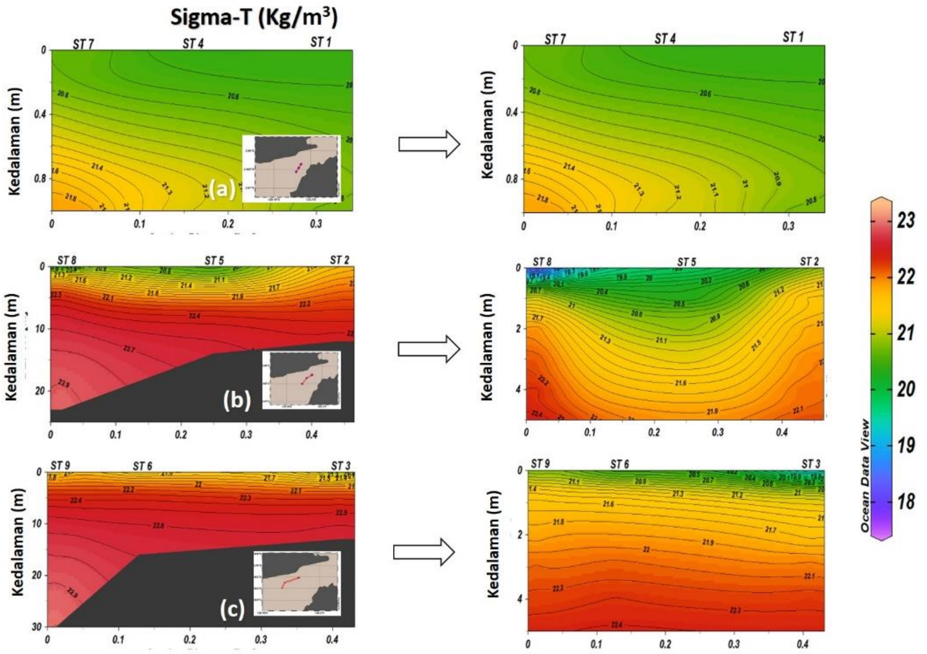

Figure 6. Transverse distribution of Sigma-t in the waters of Ambon Rumahtiga-Galala Hative Kecil Ambon Bay. (a) Transect I, (b) Transect II, (c) Transect III

The horizontal distribution of sigma-t in the waters of the Rumahtiga-Galala Hative Kecil sill shows different patterns between surface waters with depths of 1, 3 and 5 m (Figure 7). At the water surface (0 m), the water density looks quite low with sigma-t values ranging from 17.66-20.74 Kg/m3. This value shows that the entire water surface of the Rumahtiga-Galala Hative small threshold is influenced by fresh water masses. The fresh water comes from the mouth of the Wairuhu River (Station 8) and from TAD (Station 3). Based on the image of the horizontal distribution of sigma-t on the water surface, it can be seen that Station 5 is the meeting place for water masses (density front) between low density masses from Station 8 and

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Station 3 with higher density water masses that move into the bay (Station 9). At depths 1, 3 and 5, the sigma-t distribution pattern shows that there is a low density center at Station 5. It is suspected that this condition may be due to the strong mixing of water masses that occurs vertically.

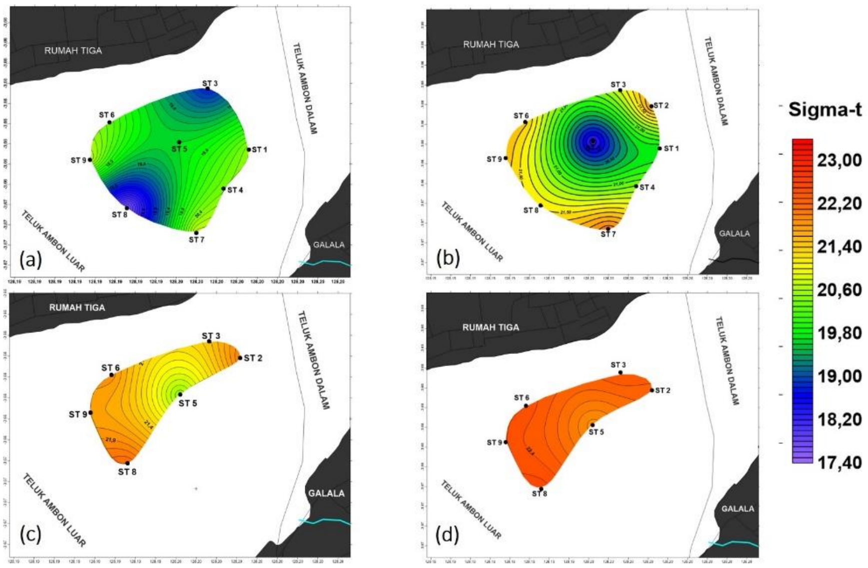

Figure 7. Horizontal distribution of Sigma-t in the waters of Ambon Bay's Rumahtiga-Galala Hative Kecil threshold. (a) 0 m, (b) 1 m and (c) 3 m, (d) 5

DISCUSSION

The front in the Galala-Hatiwe Kecil Waters shows a meeting of water masses, namely cold water masses from TAL and warm water masses from TAD. The research results show that a front is formed on the water surface to a depth of 5 m between the water mass moving from TAD (Station 8) with a temperature of 26.16-26.58oC, salinity of 30.98-33.37 Psu and sigma-t of 19.92- 21.64 Kg/m3 and water mass from TAL (Station 5) with a characteristic temperature of 25.97oC, salinity of 33.03-34.22 Psu and sigma-t of 21.47-22.47. This is due to the influence of warm water masses moving out of the TAD (Putri et al., 2008; Kesaulya et al., 2022) and the input of Banda Sea water masses (Anderson & Sapulete, 1982; (Wenno & Anderson, 1984; Kesaulya *et al*., 2022; Salamena *et al*., 2021).

Based on the transverse distribution in the Galala-Hatiwe Kecil waters, it shows that the thermal front is clearly visible during the high tide to low tide phase. low surface salinity on the coast and high salinity far from the coast. This is due to the movement of TAD water masses, rainfall and water input from rivers. According to Nahas et al, 2005, they found the same water character in bay conditions limited by sills. On the other hand, salinity experienced a decrease in TAL towards TAD. TAD is where a number of rivers flow which flow fresh water into the waters, especially during the rainy season. The salinity distribution pattern appears to be more dominant in Transect 2, due to the input of river water at the surface. The meeting of two water masses with different characteristics will disrupt the stability of the water column (Rudels, 2016; Haine et al., 2015). The results of the study show that salinity stratification is stronger vertically and horizontally up to a depth of 3-4 m ranging from a value of 27, 86-34.60 Psu (Figure 4b). Previous research stated that salinity stratification at the threshold occurred at depths of 3 m and 6 m (Salamena et al., 2021). and sea water masses from TAL. Indications of the meeting of these water masses can also be seen from the stratification of density values ranging from 17.66 Kg/m3 at the surface. In the waters of the Galala-Hatiwe Kecil Threshold,

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water masses are more dominant due to differences in salinity shallow waters and close to the coast (Beer, 1997)

CONCLUSION

Based on the distribution of temperature, salinity and sigma-t both vertically and horizontally, it can be concluded that the waters of Ambang Rumahtiga-Galala Hative Kecil during the east season are found to have thermal fronts, salinity fronts and density fronts. Fronts occur on the water surface, namely at a depth of 0-5 m. The front is influenced by tides, input of oceanic water masses, water masses from Inner Ambon Bay, and fresh water masses entering via the Wairuhu River or other rivers in the vicinity.

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