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The Seasonal Variations of the Thermocline in the Banda Sea and its Water Mass Characteristics

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Abstract: This research was conducted to examine the seasonal variations in the Banda Sea's thermocline layer and its water mass characteristics. The research was conducted by analyzing Argo Float data. The data consists of six observation stations in West Season and Transitional Season II, and four stations in Transition Season I and East Season The thermocline layer thickness was identified based on the depth where the temperature decreased ≥ 0.05ºC/m. The thermocline layer's distribution of depth and thickness and the distribution of temperature and salinity seasonally in the thermocline layer were analyzed with Microsoft Excel 2010. The analysis results showed that East Season and Transition Season II have a shallower upper boundary depth of the thermocline layer, a deeper lower boundary of the thermocline layer, and the thermocline layer is thicker when compared to the West Season and Transition Season I. The average temperature distribution is higher and the average salinity is lower in the West Season and Transition Season I. The mean rate of change in salinity and temperature in the thermocline layer seasonally ranged from 0.002-0.004 PSU/m and 0.06-0.08ºC/m. The thermocline layer's stratification is stronger in the West Season and Transition Season I.

Keywords: Banda sea; Salinity; Temperature; Thermocline layer; Thermocline layer thickness

Introduction

The thermocline is a water mass layer that lies between the thin mixed surface layer and the inner layer. The thermocline layer is characterized by a drastic change in temperature values with an increase in depth. The depth of the thermocline layer is the depth where the water conditions are unstable and the temperature decreases drastically with increasing depth (Yang et al., 2021). Furthermore, Zhang et al. (2019) and Fernandez De Puelles et al. (2023) stated that the temperature value of the thermocline layer decreased ≥ 0.05 ºC/m. Bureau of Technical Supervision of the Sriwijayanti et al. (2019) stated that the thermocline layer's temperature value had decreased ≥ 0,05ºC/m. Changes in the thermocline layer's depth and thickness are strongly influenced by the dynamics of the water mass of the mixed surface layer. Meteorological factors greatly influence the surface layer; one of the most influential factors is wind. The speed and direction of wind might vary seasonally. These variations affect the movement and the mixing of water masses. The Banda Sea is affected by the monsoon winds seasonally.

The monsoon winds caused the development of the Indonesian monsoon current, which carried the water masses of the water surface layers moving towards and leaving the Banda Sea (Handoko et al., 2024). The development of monsoon winds also causes upwelling in the Banda Sea in the East Monsoon and downwelling in the West Monsoon (Atmadipoera et al., 2019). The Banda Sea is also the passage of the Indonesian Throughflow (Arlindo), which carries the water mass of the Pacific Ocean to the Indian Ocean (Taufiqurrahman et al., 2020). Arlindo's movement is related to the

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thermocline layer. Fadlan-Abida et al. (2015) stated that the Arlindo flow in the Celebes Sea intensifies at a depth of between 150 m and 250 m with a maximum speed of about 60 cm. Masoleh et al. (2018) also analyzed Arlindo transport at a depth of 100 m in the Timor Sea waters; thus the depth of Arlindo's movement is in the thermocline layer. Seasonal variations in surface water mass dynamics and Arlindo crossing the Banda Sea water will affect the seasonal variations and characteristics of the thermocline layer's water mass (Nie et al., 2023). At the time of downwelling, the water mass will sink and assume that the thermocline layer's depth will fall or get deeper. On the other hand, when there is upwelling, the thermocline layer will be lifted and become shallower.

This condition and the influence of Arlindo water mass movement will further affect the variations in the water mass characteristics of the Banda Sea's thermocline layer. Research on the relationship between the thermocline layer and its depth and thickness has been carried out by Romero et al. (2023) carried in the southern waters of Java to Timor Island, which found that the depth of the thermocline's upper boundary in the east monsoon is deeper than during the west monsoon. In the Savu Sea found that the depth of the upper boundary of the thermocline layer in the northern part of the Savu Sea, south of Solor Island, Lembata Island, and Pantar Island is shallower compared to the waters of the northern part of Adonara Island, Lembata Island and Pantar Island (Flores Sea) due to upwelling in the Savu Sea. Lana et al. (2017) found a thermocline layer at a depth of 44.70-61.70 m in the Makassar Strait.

Yuan et al. (2022) based on their research in the waters of the North of Jayapura, found that the upper boundary distribution of the thermocline layer is at a depth of between 49.71 – 99.42 m with a temperature of 28.78 – 29.86 ºC, and the depth of the lower boundary of the thermocline layer is at a depth between 268.34 – 566.08 m with temperatures ranging from 7.03 - 12.30 ºC. Jamshidi (2017) stated that the thickness of the thermocline layer in the southern waters of Southwest Maluku varies between 257-352 m, with the upper limit of the thermocline at a depth of 44-60 m and a lower limit at a depth of 267-352 m. Aji et al. (2017) found the upper limit of the thermocline layer at a depth of 44m and a lower limit at a depth of 233m in the Bali Sea. Also, research on the thermocline layer in the Banda Sea has been carried out by Zhu et al. (2019). Rahma et al. (2020), found that the structure of the Banda Sea's southern water layer found S-maximum at a depth of 100-200 dbar and S-minimum at a depth of 250-350 dbar. The S-maximum value degenerates from 34.55 to disappear at depths where the temperature is less than 10 ºC.

Latuapo et al. (2024) found that in the Banda Sea's southern waters, the thermocline layer structure is the same as the Makassar Strait and the Flores Sea, where the thermocline layer is between 60 and 300 dbar with temperatures decreasing from 27.0-10 ºC. It is also similar to the thermocline layer in Luat Flores, between 80-300 bar, and has a large temperature gradient, starting from 26 ºC. Research concerning seasonal variations of the thermocline layer's depth and thickness and its relationship with the distribution of temperature and salinity in the Banda Sea, however, has not been carried out. Based on that background, we feel the need to conduct a study on the seasonal variation of the Banda Sea thermocline layer and its characteristics. This study aims to assess the seasonal variations in the depth of the upper and lower limits of the thickness of the thermocline layer in the Banda Sea and variations in the water mass characteristics of the thermocline layer, including the distribution of temperature and water salinity.

Method

The data used in this study is obtained from the ARGO Float recording data in the Banda Sea, which consists of temperature and salinity data. This data resulted from recording data at every depth to a depth of approximately 1000 m, obtained from the website www.coriolis.eu.org. The data used in this study were recorded from 30 July 2017 to 11 May 2018, which consists of 20 observation stations grouped seasonally, namely six stations in West Season, four stations in Transition Season I, four stations in East Season, and six stations in Transition Season II (Figure 1). The data obtained will then analyzed with the software Microsoft 2020 to study the stratification of the waters. The analyzed data was then displayed in the form of a seasonal vertical distribution graph. Thermocline layer analysis was carried out by determining the depth of the thermocline layer's upper boundary, the depth of the thermocline layer's lower boundary, the thickness of the thermocline layer, and the water mass characteristics of the thermocline layer. The analysis was carried out spatially, namely looking at the variations between the research stations and temporally, by comparing seasons.

The depth of the thermocline layer's upper and lower limits is determined based on the approach proposed namely the thermocline layer as a depth or position where the temperature gradient is greater than or equal to 0.05ºC/m. To calculate the vertical temperature gradient, we used the equation proposed by (Tan et al., 2023):

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

Annotation:
G_j = vertical temperature gradient between standard depths D_j and D_{j+1}
T_j = water temperature at standard depth D_j
D_j = depth of the j waters

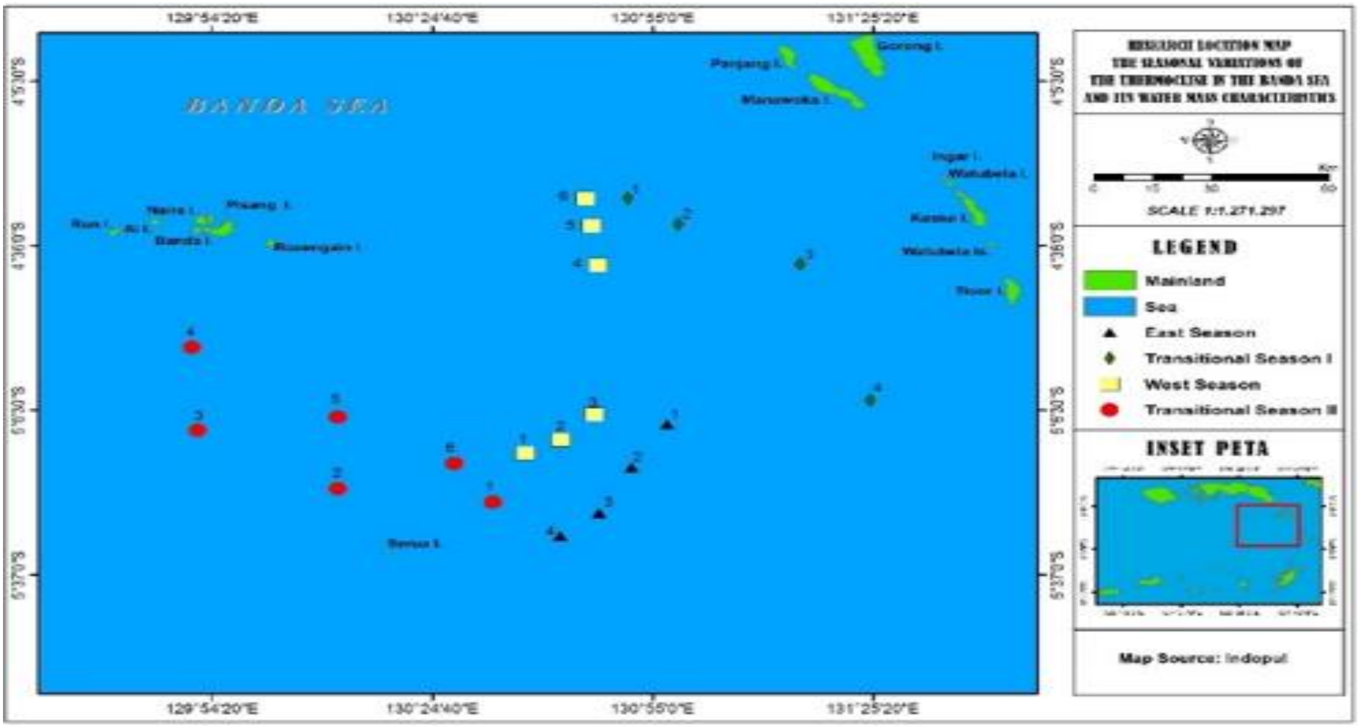

Figure 1. Research location

Result and Discussion

Variations in the Depth and Thickness of the Thermocline Layer

The Banda Sea water mass's stratification showed variations in the thermocline layer, both in spatial and temporal depth and layer thickness. Spatially, there was a variation between observation stations, while temporally, the water mass coating showed a seasonal difference. In the West Season, the variation in the depth of the upper boundary of the thermocline layer in the Banda Sea was at a depth of 21.70-67.60 m, and the lower boundary was at a depth of 255.90-297.50 m with a thickness of the thermocline layer varied between 190.50-265.80 m (Figure 2). Spatially, the thermocline layer at stations located further south (Stations 1-3) was generally thicker. The thermocline layer's upper boundary stations were shallower, and the lower boundary of the thermocline layer was deeper compared to stations located further north (Stations 4-6).

In Transitional Season I, observation stations are located further east of the Banda Sea and approaching the Kesui Islands to the Watubela Islands. The depth distribution of the upper boundary of the thermocline layer in the Banda Sea during the Transitional Season I was 15.70-78.40 m and the depth of the lower boundary for the thermocline layer varied between 273.50-307.10 m with variations in the thickness of the thermocline layer between 213.40-257.80 m. Stations that are located a little to the south, namely near the Watubela Islands (Stations 3-4), have a shallower upper and lower boundary of the thermocline layer than slightly north stations (Stations 1-2). However, Station 1 and Station 2 have a thicker thermocline layer than Stations 3 and 4 (Figure 2).

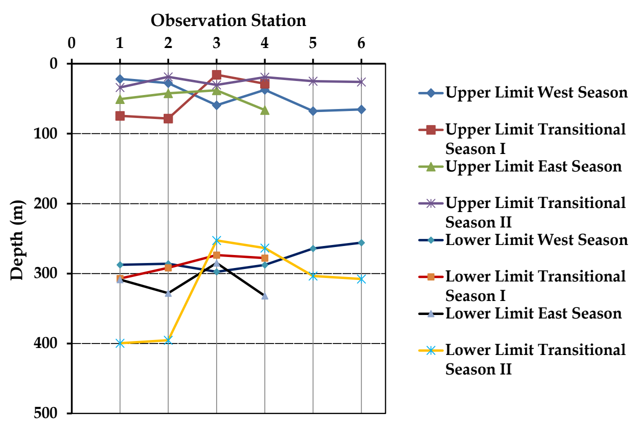

Figure 2. Seasonal distribution of the upper and lower limit of the thermocline layer of the Banda Sea

In the East Season, when the Southeast Monsoon winds blow, the distribution of the thermocline layer's depth and thickness at the four observation stations located further south was lower when compared to the West Season and Transition I. The upper boundary ranges from 38-66.20 m with a mean of 49.30±12.50 m, while the lower boundary of the thermocline layer ranges from 284.80-331.80 m with a mean of 313.30±21.50 m, and the thickness of the thermocline layer ranged between 246.80-285.80 m with a mean of 264.0 ± 16.4 m. The thermocline layer's distribution showed that Station 3 had a shallower upper and lower boundary depth than the other observation stations in the East Monsoon. The deepest thermocline layer's upper boundary was found at Station 4, while the deepest lower boundary was found at Station 2 (Figure 2).

In Transition Season II, we found that in almost all observation stations, the distribution of the upper limit's thermocline depth was generally shallow, ranging from a depth of 18.70 to 33.90 m with an average of 25.50 ± 6 m. The lower limit of the thermocline layer showed spatial variation. Observation stations located further west (Stations 3 and 4) had a shallower depth compared to other stations. The depth of the lower limit of the thermocline layer in Transitional Season II ranged from 252.70-399.50 m with a mean of 320.40 m. The thermocline layer thickness in the Banda Sea during Transitional Season II ranged from 222.40 to 376.70 m with a mean of 294.80 m. Spatially it can be seen that Station 2 had a deeper upper limit of the thermocline layer, but the lower limit of the thermocline layer was shallower than the other stations. This condition caused the thermocline layer's thickness at Station 2 to be thinner compared to other stations. Station 1, located slightly to the east in the south of the Banda Sea, had a thicker thermocline layer characterized by a deeper upper and lower limit than other stations. Temporally, variations in the thermocline layer's thickness and depth's upper and lower limits show seasonal differences.

The depth distribution of the thermocline layer's upper limit showed that Transitional Season II has a shallower depth, while Transitional Season I tended to be deeper. A similar pattern is also seen in the depth distribution of the lower boundary and thickness of the thermocline layer, indicating that the East and Transitional Season II were deeper and thicker compared to the West and Transitional Season I (Figure 3). Seasonal variations in the thickness and depth of the upper and lower limits of the thermocline layer in the Banda Sea are caused by water dynamics that occur in response to the monsoon winds' blowing. Apriansyah et al. (2023), Rachman et al. (2020), and Rachmayani et al. (2019) stated that seasonal changes in the direction of the monsoon winds caused upwelling in the Banda Sea waters during the Southeast (Horhoruw et al., 2020) said that from January to March, Ekman transport led to convergence, which is downwelling in the Banda Sea.

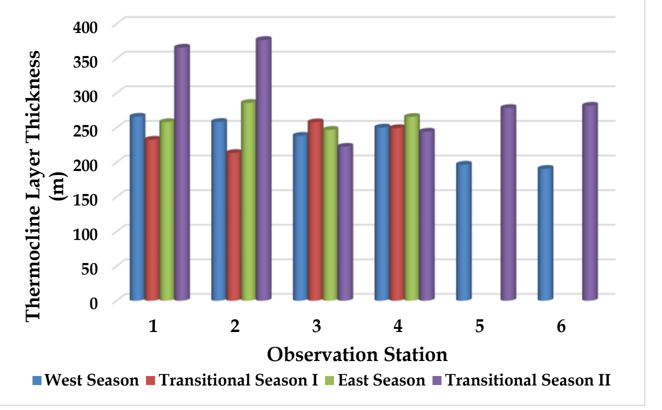

Figure 3. The distribution of Banda Sea thermocline's layer thickness seasonally

Characteristics of the Water Mass of the Upper and Lower Boundaries of the Thermocline Layer Temperature of Waters

The variation of the thermocline layer and the dynamics of the water's surface layer impacted variations in water temperature. If there is an uplifting of water mass, the surface water mass is cooler, and the thermocline layer is getting more shallow. On the other hand, if the thermocline layer's location is deeper, the temperature of the thermocline layer with a cooler characteristic is at a deeper depth. The dynamics of Banda Sea waters vary seasonally in response to the blowing of the monsoons. The distribution of water temperature at the top of the thermocline layer in the Banda Sea, namely at a depth of 21.70-67.60 m during the West Season, ranged from 28.69-30.09 ^{o}C with an average of 29.20 ± 0.51 ^{o}C. In the Transitional Season I, the temperature distribution ranged from 28.48-29.62 ^{o}C with an average of 28.99 ± 0.47 ^{o}C at the top of the thermocline layer at a depth of 15.70-74.50 m.

The Banda Sea temperature in the East Season at the top of the thermocline layer, which was at a depth of about 38.0-66.2 m, ranged from 25.09-26.96 ^{o}C with an average of 26.06 ± 0.80 ^{o}C. In Transition Season II, the temperature distribution at the top of the thermocline layer at a depth of 18.70-33.90 m ranged from 26.03-29.65 ^{o}C with an average of 27.93 ± 1.59 ^{o}C (Figure 4) (Putra et al., 2023) stated that in the Southeast Monsoon, which is in the East Season, the thermocline layer in the Banda Sea's western waters began with isotherm 25 ^{o}C. Thus, the results of this study indicated almost the same value.

Temporally, the temperature distribution over the thermocline layer shows seasonal variations. The temperature distribution showed that the water mass at the top of the thermocline layer is cooler in the East Season and the beginning of Transitional Season II compared to the West Season, Transition Season I, and the end of Transitional Season II. The upwelling in the Banda Sea caused the water masses' coldness during the East and Early West Monsoons in response to the Southeast Monsoon winds' blowing. Upwelling causes the cold deep water mass to rise to the top layer and causes the surface layer water mass to become colder. Retraubun et al. (2023), Kusuma et al. (2017) said that the distribution of sea surface temperature in the very cold Banda Sea indicates an upwelling phenomenon from June to October, with a fairly high upwelling intensity occurring in August.

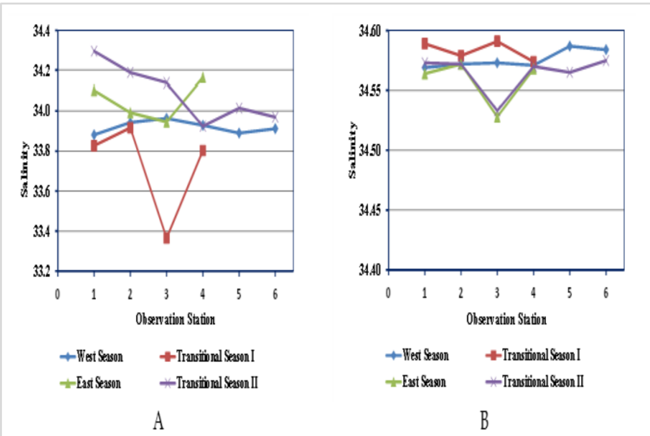

Figure 4. The distribution of temperature at the upper and lower boundary of the thermocline layer seasonally at each observation station in the Banda Sea. A = Waters temperature at the upper limit of the thermocline layer; B = Waters temperature at the lower boundary of the thermocline layer

The cause of upwelling in the Banda Sea is Ekman Pumping (Ismail et al., 2020; Wirasatriya et al., 2021). Ekman pumping is the Ekman transport process caused by blowing wind. The blowing of the Southeast Monsoon winds was causing the surface water mass of the Banda Sea to move westward. This condition caused a surface water mass vacuum in the Banda Sea's eastern waters (Purba et al., 2023). Tristianto et al. (2021) stated that upwelling in the Banda Sea lasted for four months and three weeks to five months and two weeks, starting from May to October. In the Western Season and Transitional Season I, the water mass at the top of the thermocline layer was warmer. During the western season, the warmer thermocline layer was caused by the movement of warm water mass from West Indonesian waters into Eastern Indonesian waters. In the Transitional Season I, because the sun was around the equator, the sea surface tended to receive more light energy besides that, in the transitional season, the wind blowing over the waters tended to be weak in an irregular direction causing the transfer of heat from water bodies to the air to become small. This causes sea surface temperatures to become warmer.

Accumulation of water masses and warm surface water masses caused the downwelling of warm water masses. This caused the thermocline layer to have a higher temperature when compared to other seasons. Habibullah et al. (2021) stated that seasonally, the Banda Sea's surface temperature is determined by upwelling during the Southeast Monsoon, namely from July to September, and downwelling, which occurs from January to March. The water mass characteristics of the lower boundary of the thermocline layer in the Banda Sea throughout the year indicated that the water temperature ranges from 9.05-12.67 °C with an average of 11.21 ± 0.96 °C.

Thus, the temperature variation at the lower boundary depth of the thermocline layer was relatively homogeneous. However, the temperature distribution pattern at the thermocline layer's lower boundary showed that the water temperature is cooler during the East Season and Transition Season II compared to the West Season. In the West Season, the temperature ranges from 10.86-12.67 °C with a mean of 11.72 ± 0.60 °C, in the Transition Season I, it ranged from 10.14-12.08 °C with a mean of 11.23 ± 0.81 °C, while In the East Season the temperature ranged from 10.42-11.89 °C with a mean of 11.06 ± 0.63 °C and in the Second Transition Season it ranged from 9.05-12.16 °C with a mean of 10.79 ± 1.40 °C.

Salinity of Waters

Vertically, the salinity of the waters has increased with increasing depth. However, at the same depth, salinity varied spatially and temporally. The variation of salinity in the thermocline layer was highly dependent on the dynamics of the surface layer of the water and the movement of water masses in that layer. The dynamics of the Banda Sea surface layer vary seasonally (Atmadipoera et al., 2019; Hao et al., 2023; Ismail et al., 2020). In the West Monsoon, the northwest monsoon winds caused surface water masses to move from West Indonesian waters to East Indonesia and experience accumulation in the waters of the Banda Sea and its surroundings, and the impact was submerging of surface water masses (downwelling). In the East Season, the Southeast Monsoon winds and causes surface water masses' movement to the West of Indonesian waters. This movement caused a reduction in surface water mass and triggered upwelling.

The distribution of salinity at the upper boundary of the thermocline layer in the Banda Sea showed seasonal variations. The waters' salinity was lower in the West Season and Transitional Season I and higher in the East Season and Transition Season II. Salinity at the upper boundary of the Banda Sea thermocline layer in the West Monsoon ranged from 33.88-33.96 PSU with a mean of 33.92 ± 0.03 PSU, and in the Transitional Season I ranged from 33.27-33.92 PSU with a mean of 33.73 ±

0.25 PSU. In the East Season, the distribution of salinity at the upper boundary of the thermocline layer in the Banda Sea ranged from 33.95-34.16 PSU with a mean of 34.05 ± 010 PSU, and in Transition Season II, the salinity ranged from 33.90-34.30 PSU with a mean of 34, 09 ± 014 PSU (Figure 5). The lower salinity at the upper boundary of the thermocline layer in the West Season was due to the Banda Sea surface layer's water mass, which tends to come from West Indonesian waters with lower salinity characteristics that flow through the Java Sea and The Flores Sea.

The water mass characteristics of the upper boundary of the thermocline layer in Transition Season II showed lower salinity values when compared to other seasons even though the depth of the thermocline layer's upper boundary is much deeper. The lower salinity is probably due to the influence of surface water masses flowing from west Indonesian waters with low-temperature characteristics and the influence of water masses' sinking phenomenon. Apart from that, during Transition Season I, the relative position of the sun to the earth was around the Equator line so that the reception of sunlight energy by the Banda Sea surface was higher than the other season, also in this season, the wind is weak in an uncertain direction so that water stratification occurs well. As a result, the mixed surface layer becomes thicker, and the thermocline layer's upper boundary becomes deeper.

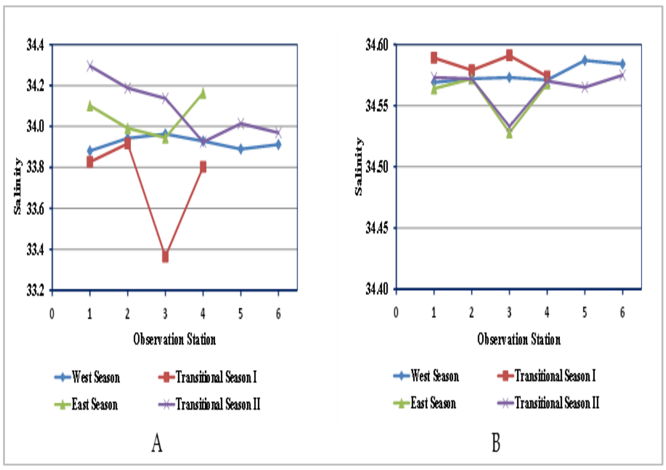

Figure 5. Seasonal distribution of salinity (PSU) at the upper and lower limits of the thermocline layer at each observation station in the Banda Sea. A = water salinity at the upper boundary of the thermocline layer; B = Salinity of the waters at the lower boundary of the thermocline layer

The distribution of salinity at the lower boundary of the thermocline layer in the Banda Sea tended to be homogeneous, ranging from 34.53-34.59 PSU. However, we observed a difference between salinity distribution in the West Season and Transition I with East Season and Transitional Season II. The depth of the lower boundary of the thermocline layer in the East Season and Transitional Season II was deeper with a mean depth of 313.3 m and 320.40 m, respectively, compared to the West Monsoon and Transitional Season II (279.80 m and 287.50 m, respectively). On the contrary, the salinity was slightly lower, with a mean of 34.56 ± 0.02 PSU, compared to the West Season and Transitional Season II (34.58 ± 0.01 PSU) (Figure 5).

Thermocline Layer Water Mass Characteristics

Temperature of Waters

Annually, the variation in the Banda Sea thermocline layer's depth ranged from 15.7 m to 339.5 m, with the thickness of the thermocline layer ranging from 190.5 to 376.7 m (Figure 2). The distribution of the depth and thickness of the Banda Sea thermocline layer shows seasonal variations. The difference in depth and thickness of the thermocline layer impacted the vertical distribution of water temperature. The temperature of the thermocline layer of the Banda Sea during the West Season varied from 28.69-30.09 °C at the upper boundary of the thermocline layer to 10.86-12.67 °C at the lower boundary of the thermocline layer or decreased by 16.15-18.54 °C with an average of 17.47 ± 0.96 °C or an average temperature reduction rate of 0.08 °C /m. In Transition Season I, the average rate of decline in water temperature in the thermocline layer was 0.07 °C /m or decreased from the thermocline layer's upper limit to the lower limit of the thermocline layer ranged from 16.40-18.84 °C with an average of 17.76 ± 1, 07 °C.

Changes in temperature from the upper limit to the lower limit of the thermocline layer in the East Season in the Banda Sea ranged from 14.30 to 15.96 °C with an average of 14.99 ± 0.72 °C or an average temperature reduction rate of 0.06 °C /m. In Transition Season II, the average temperature reduction rate in the thermocline layer was 0.06 °C , with changes in temperature values between the upper and lower limits of the thermocline layer ranging from 14.84-18.97 °C with an average of 17.14 ± 0.72 °C (Figure 6). Taking into account the rate of temperature reduction in the thermocline layer, which ranged from 0.06-0.08 °C /m with an average of 0.07 °C in the Banda Sea, it can be said that the rate of change is relatively similar to the waters of North Jayapura. Chu et al. (2019) and Irmasyithah et al. (2019) found that the temperature gradient of the thermocline layer was 0.043–0.095 °C/m with an average of 0.078 °C/m in the North Jayapura waters, while (Priyono et al., 2020), found a temperature gradient for the thermocline layer in the Makassar Strait waters of 0.07 °C /m. Mulyadi et al. (2019), in the southern waters of Southwest Maluku in May obtained a temperature gradient in the thermocline layer of 0.06-0.07 °C /m.

Based on the temperature distribution at the upper boundary and the limit of the thermocline layer, it can be said that the rate of temperature change in the West Season and Transitional Season I was greater than in the East Season and Transitional Season II. Thus, the Banda Sea thermocline layer's stratification was stronger during the West Season and Transition Season I. Also, the temperature distribution in the thermocline layer shows that in the East Season, the water temperature was colder, ranging from 10.42-26.96 °C with a mean of 16.58 ± 4.17 °C while the highest mean temperature was observed in the West Season with a range of 10.86-30.09 °C with a mean of 20.67 ± 5.41 °C. In Transition Season I and Transition Season II, the distribution of water temperature in the thermocline layer ranged from 10.14-29.62 °C with a mean of 20.16 ± 5.91 °C and 9.05-29.65 °C with a mean of 19, 60 ± 5.52 °C.

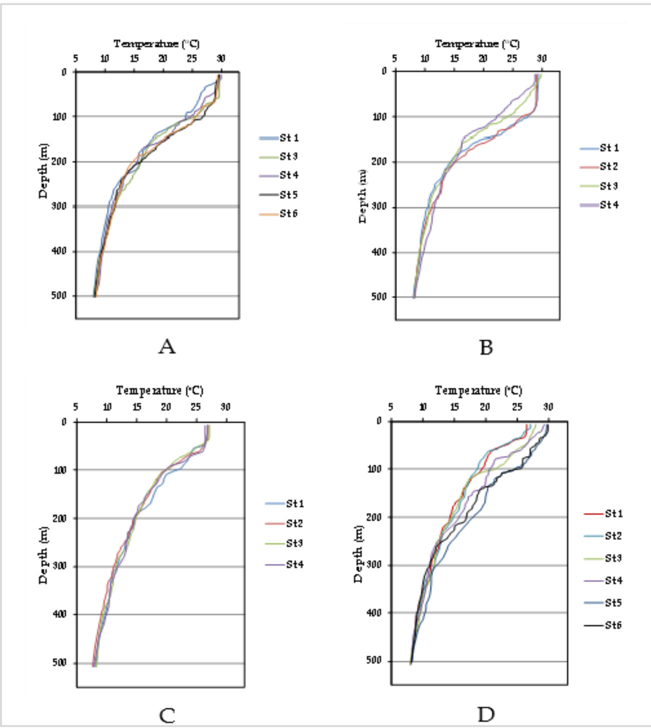

Figure 6. Seasonal vertical distribution of Banda Sea temperature. A = West Season; B = Transitional Season I; C = East Season; D = Transitional Season II

Vertically, in the Banda Sea thermocline layer at a depth of 75, 100, 150, 200, and 250 m, the temperature distribution showed seasonal variations. At a depth of 75 m, the water mass was warmer in the West Season and Transitional Season I with mean temperatures of 26.77 ± 1.09 °C and 26.45 ± 2.39 °C, respectively, than in the East Season and Transitional Season II, namely 23.23 ± 0.71 °C and 23.38 ± 3.04 °C. Seasonally, the temperature at a depth of 75 m varied more during Transition Season I and Transition Season II, compared to the West Season and East Season (Figure 7). The high variation in the Transition Season I was due to the more diverse characteristics of the water mass because it was influenced by the warm water mass that sinks (downwelling) in the West Season and cold water mass due to upwelling in May (Horhoruw et al., 2020). The coldness of the masses in the East Season was caused by upwelling in the Banda Sea in response to the Southeast Monsoon winds' blowing. Zhang et al. (2023), also explained that seasonally the surface temperature is determined by Ekman's upwelling during the Southeast monsoon from July to September along with the Nusa Tenggara islands and in the Banda Sea.

At a depth of 100 m, the Banda Sea's mean temperature in the West Season and Transition I was around 25 °C, while the mean temperature in the East Seasonand Transition Season II was 20.16 ± 0.81 °C and 21.58 ± 2.70 °C, respectively (Figure 7). Thus, the temperature at a depth of 100 m in the East Season was colder than the other seasons, with a 4.82 °C difference compared to the West Season. The large difference in temperature values indicates a different dynamic between the West and East Seasons. The phenomenon of upwelling played a role in the cold water mass in the East Season. The phenomenon brought the cold mass from the inner layer to the layer above, whereas warm water on the Sea's surface would sink during the western season. (Saputra et al., 2018), found that the water mass on the Banda Sea surface cooled down due to upwelling in the East Season. According to Pusparini et al. (2017) and Muskananfola et al. (2021), upwelling in the Banda Sea occurred during the East Monsoon to September and October (Transitional Season II).

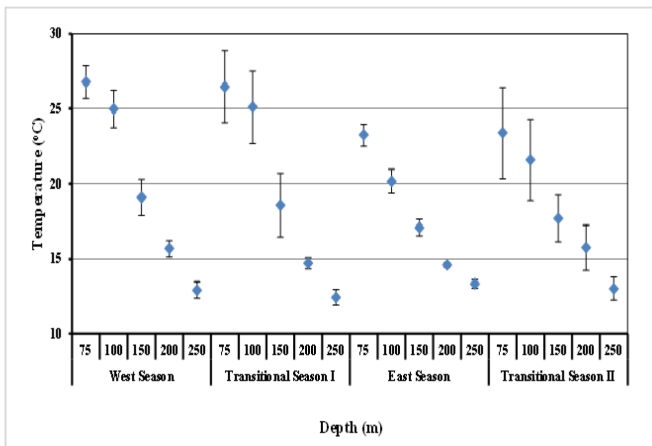

Figure 7. Seasonal distribution of temperatures at various standard depths in the thermocline layer of the Banda Sea

At a depth of 150 m, the mean water temperature seasonally showed the same pattern as the temperature distribution at a depth of 75 and 100 m. At a depth of 150 m, the mean water temperature in the West Season was 19.10 ± 1.20 °C, 18.58 ± 2.13 °C in the Transitional Season I, 17.08 ± 0.56 °C in the East Season and 17.68 ± 1, 56 °C in the Transitional Season II (Figure 7). Based on the temperature distribution at a depth of 150 m, we concluded that the East Season temperature was colder with a more homogeneous distribution pattern, while higher distribution variations were found in the Transitional Season I. At this depth, we also observed a temperature difference of almost 2 Celcius degrees between the East and West Seasons.

At a depth of 200 m and 250 m, the temperature distribution pattern showed a different pattern with a depth of 75 m, 100 m, and 150 m. At a depth of 150 m, temperature variations tended to be homogeneous with the distribution of temperatures showing colder in the Transition Season I and East Season with a mean temperature of <15 ^{o}C while in the West Season, the average temperature was 15.67 ± 0.52 ^{o}C and Transitional Season II is 15.74 ± 1.51 ^{o}C. At a depth of 250 m, the temperature of the Banda Sea was seasonally relatively homogeneous. However, the water mass is slightly colder in the West and Transition I Season than in the West and Second Transitional Seasons (Figure 7).

Salinity of Waters

The salinity stratification of the Banda Sea waters showed spatial and temporal variations. Spatially, the depth of the halocline layer was different between observation stations. There was also a difference in the depth of the halocline layer on a seasonal basis, temporarily. The halocline layer is a layer where the salinity gradient increases drastically with increasing depth. Based on the graph of the vertical distribution of salinity in the Banda Sea seasonally, it can be seen that the halocline layer in the East Season was shallower compared to other seasons, while the halocline layer in the Transitional Season I was deeper when compared to other seasons (Figure 8).

By referring to the water temperature stratification, especially about the thermocline layer's distribution in the Banda Sea, the results of the analysis of the salinity of the waters in the thermocline layer showed a seasonally different salinity distribution. In the West Season, the salinity of the waters at the thermocline layer's upper boundary, at a depth of 21.7-67.6 m, ranged from 33.88-33.92 PSU with a mean of 33.92 ± 0.03 PSU. On the other hand, the salinity at the lower boundary of the thermocline layer, at a depth of 255.9-297.5 m, ranged from 34.57-34.59 PSU with a mean of 34.58 ± 0.01 PSU. Thus, in the thermocline layer with a thickness of 190.5-265.8 m, there was a change in the increase in salinity of 0.002-0.004 PSU/m with an average of 0.003 PSU/m.

In Transition Season I, the salinity of the waters in the thermocline layer in the Banda Sea showed a distribution between 33.37-33.92 PSU with a mean of 33.73 ± 0.25 PSU at the upper boundary of the thermocline layer and is in the range of 34.57-34.59 PSU with a mean of 34.38 ± 0.01 PSU at the lower limit. The thickness of the thermocline layer in Transition Season I ranged from 213.4 to 257.8 m with an average of 238.3 ± 19.6 m. Thus, at the upper and lower limits of the thermocline layer, there was a change in salinity between 0.66-1.23 PSU with a mean of 0.86 ± 0.25 PSU, or the rate of increase in salinity was 0.004 PSU/m.

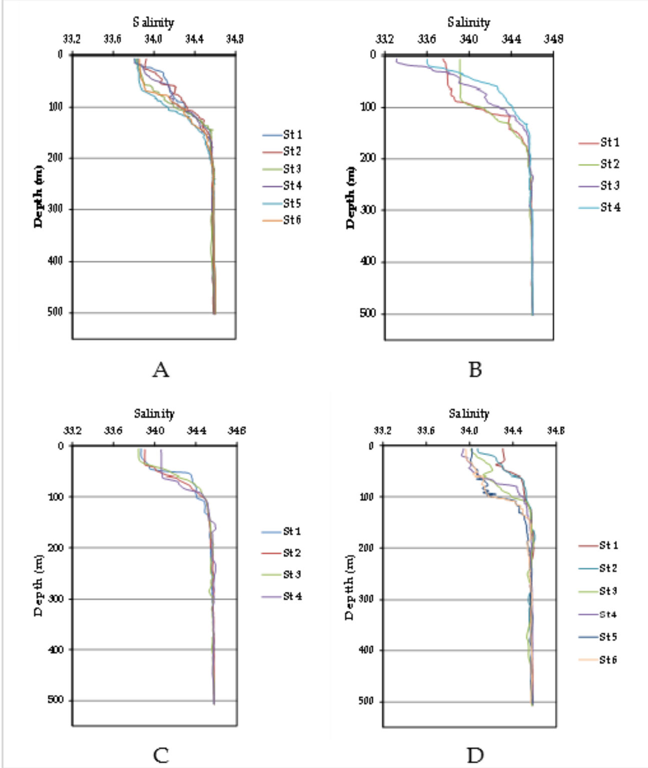

Figure 8. Seasonal vertical distribution of Banda Sea salinity. A = West Season; B = Transitional Season I; C = East Season; D = Transitional Season II

In the East Season, the salinity of the waters changed from the range of 33.95-34.16 PSU at the upper limit of the thermocline layer to 34.53-34.57 PSU at the lower limit of the thermocline layer. With the thermocline layer thickness ranging from 246.8-285.800 m and an average layer thickness of 264.0 ± 16.40 m, the rate of increase in salinity in the thermocline layer was 0.002 PSU/m. The distribution of salinity at the upper boundary of the thermocline layer during Transition Season II ranged from 33.92-34.30 PSU with a mean of 34.09 ± 0.14 PSU and at the lower limit of the thermocline layer ranged from 34.53-34.58 PSU with a mean of 34. 56 ± 0.02 PSU. The thickness of the thermocline layer in Transitional Season II ranged from 222.40 to 376.70 m with a mean of 294.80 ± 63.20 m and changed in salinity from the upper to the lower limit of the thermocline layer ranged from 0.28 to 0.65 PSU with a mean of 0.48 ± 0.15 PSU, the rate of increase in salinity with increasing depth was 0.002 PSU/m.

Overall, the distribution of salinity in the thermocline layer in the Banda Sea showed that salinity is lower at the thermocline layer's upper boundary during the West Season and Transition Season I than the East Season and Transition Season II. At the lower boundary of the thermocline layer, the salinity distribution showed a different pattern from the thermocline layer's upper boundary; the salinity was higher in the West Season and Transitional Season I when compared to the East Season and Transitional Season II. Likewise, the salinity distribution for each depth in the thermocline layer showed that the average salinity was higher in the East Season, which is 34.50 ± 0.12 PSU, and the lowest was in Transition Season II with an average of 34.36 ± 0.26 PSU.

The analysis of the rate of increase in salinity with increasing depth also showed that the thermocline layer's stratification was stronger in Transitional Season I and West Season when compared to East Season and Transitional Season II. This can be seen from the value of the increase in salinity which is greater than the East Season and Transitional Season II. Vertically, the distribution of salinity throughout the year in the thermocline layer showed a higher variation at depths of 75 m and 100 m, while depths of 150 m, 200 m, and 250 m are relatively homogeneous. Seasonally, salinity distribution was more homogeneous in the East Season and more diverse in the Transition Season I (Figure 9).

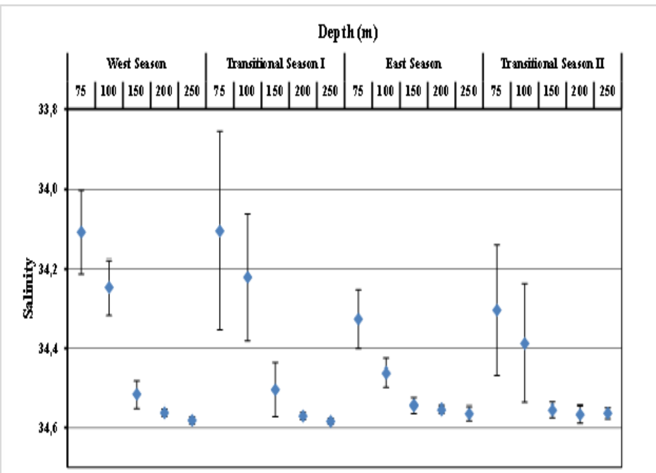

Figure 9. Seasonal distribution of salinity at various standard depths in the Banda Sea Thermocline layer

Seasonally, at a depth of 75 m, 100 m, and 150 m, the mean salinity in the West Season and Transitional Season I tended to be lower when compared to the East Season and Transitional Season II and vice versa at a depth of 250 m where the average salinity was higher in the West and Transitional Seasons I when compared to the East Season and Transitional Season II. In general, the water salinity of the Banda Sea's thermocline layer throughout the year at a depth of 200-250 was more homogeneous, with a salinity ranging between 34.55 PSU and 34.58 PSU.

Conclusion

The thermocline layer in the East Season and Transitional Season II had a shallower upper boundary depth, a deeper lower boundary, and a thicker thermocline layer when compared to the West Season and Transitional Season I. The thermocline layer's water mass was colder with higher salinity in the East Season and Transitional Season II. The mean rate of change in salinity and temperature in the thermocline layer seasonally ranged from 0.002-0.004 PSU/m and 0.06-0.08°C/m. The Banda Sea thermocline layer's stratification was stronger during the West Season and Transition Season I compared to the East Season and Transition Season II.

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Author Contributions
Conceptualization, S.T., R.D.H. and D.E.K.; methodology, S.T. and R.D.H.; validation, D.E.K.; formal analysis, S.T. and D.E.K.; investigation, S.T., R.D.H. and D.E.K.; resources, S.T.; data curation; R.D.H.; writing—original draft preparation, S.T.; writing—review and editing, R.D.H and D.E.K.; visualization, D.E.K. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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