Egyptian Journal of Aquatic Biology and Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 29(5): 2579 – 2596 (2025)
www.ejabf.journals.ekb.eg

Hydrographic Profiling of Temperature–Salinity Vertical Gradients in Fisheries Management Area 715, Maluku Sea, Indonesia

Amir Machmud Suruwaky[1*], Daniel Heintje Ndahawali[1], Muhfizar[2], Ismail[1], Mulkan Nuzapril[3], Endang Gunaisah[1], Mustasim[1], Ratna[4], Mestiria Harbani[3] and Ilham Misbakudin Al Zamzami[5]

[1]Departement of Fishing Technology, Sorong Marine and Fisheries Polytechnic, Sorong 98411, Indonesia
[2]Departement of Fishing Mechanization, Sorong Marine and Fisheries Polytechnic, Sorong 98411, Indonesia
[3]Departement of Capture Fisheries, Lampung State Polytechnic, Lampung 35141, Indonesia.
[4]Departement of Fisheries Resource Management, Faculty of Fisheries, Muhammadiyah University of Sorong, Sorong 98416, Indonesia
[5]Coastal and Marine Research Center Brawijaya University, Brawijaya University, Malang 65145, Indonesia

[*]**Corresponding Author: suruwaky@polikpsorong.ac.id**

ARTICLE INFO
Article History:
Received: July 6, 2025
Accepted: Sep. 25, 2025
Online: Oct. 16, 2025

Keywords:
Thermocline,
Halocline,
Indonesian throughflow,
Maluku Sea,
Ecosystem-based fisheries management

ABSTRACT
Understanding the vertical structure of temperature and salinity is essential for explaining thermohaline dynamics and supporting ecosystem-based fisheries management (EBFM) in tropical seas. The Maluku Sea, located within Fisheries Management Area (WPP) 715 of Indonesia, represents a key transition zone of the Indonesian Throughflow (ITF), where strong vertical stratification governs nutrient cycling and pelagic fish distribution. This study aimed to determine the vertical distribution patterns and gradient indices of temperature and salinity at 10-meter depth intervals across three observation blocks, Aru, Obi, and Seram. Hydrographic data were collected in February 2020 using a Conductivity–Temperature–Depth (CTD) profiler (XR-420) and analyzed using Ocean Data View software. Results show a distinct thermocline layer between 100–160m in Aru, 50–130m in Obi, and 100–210m in Seram, with the highest temperature gradient of –0.295°C/m in Aru. The halocline occurred between 100–150m, with the strongest salinity gradient (0.094 PSU/m) recorded in Seram. These patterns indicate limited vertical mixing and strong density stratification that regulate oxygen and nutrient exchange. The identified thermohaline layers correspond to potential pelagic fish aggregation zones, emphasizing their importance for sustainable fisheries management. Continuous monitoring of thermohaline structures is recommended to enhance predictive oceanographic models, support spatial planning, and strengthen data-driven EBFM implementation in eastern Indonesian waters.

INTRODUCTION

The ocean plays a vital role in regulating the Earth's climate system and sustaining marine biodiversity through its control of heat, salinity, and biogeochemical cycles. In tropical regions such as Indonesia, oceanographic parameters particularly temperature and salinity strongly influence ecosystem productivity, pelagic fish distribution, and the stability of coastal and offshore environments **(Purba *et al.*, 2021; Debiyanti *et al.*, 2025)**. Given Indonesia's position within the equatorial current system, small-scale variations in these parameters can significantly modify vertical stratification, energy transfer, and nutrient cycling in the marine ecosystem. Variations in these parameters determine the vertical structure of the water column, forming thermocline and halocline layers that act as natural boundaries controlling the exchange of heat, nutrients, and dissolved oxygen **(Zhang *et al.*, 2022; Priyadarshini & Veeresha, 2023)**.

The Maluku Sea, situated within the Fisheries Management Area (WPP 715) of Indonesia, represents one of the most dynamic hydrographic regions in the western Pacific. This area is directly influenced by the Indonesian Throughflow (ITF), a major inter-ocean exchange system that transfers Pacific water masses into the Indian Ocean **(Yudowaty *et al.*, 2025)**. The ITF significantly affects vertical mixing processes, stratification intensity, and thermal structure, thereby shaping the spatial distribution of nutrients and pelagic fish habitats **(Alvarez *et al.*, 2021; Foltz *et al.*, 2025)**. However, despite extensive ITF studies, most existing observations and models have concentrated on large-scale or surface dynamics, leaving fine-scale vertical structures inadequately characterized.

Previous studies in eastern Indonesian waters have mostly emphasized large-scale ocean circulation and seasonal variability **(Napitupulu, 2024; Wang, 2024)**, but few have provided high-resolution vertical profiles that can describe the precise depth and intensity of thermocline and halocline layers. This lack of fine-scale profiling represents a crucial research gap, as it limits the understanding of how microstratification processes govern nutrient fluxes and pelagic fish aggregation. Consequently, the linkage between hydrographic structures and ecosystem-based fisheries management (EBFM) remains poorly defined. As fish productivity, especially for pelagic species such as skipjack and tuna, is closely associated with thermocline dynamics **(Dell'Apa *et al.*, 2023; Pratama *et al.*, 2025)**, accurate mapping of vertical gradients is fundamental for predicting biological hotspots and managing sustainable fishing zones in tropical seas.

The state of the art in tropical oceanography has increasingly focused on coupling physical and biological parameters to understand how vertical water column structures drive marine productivity and biodiversity **(Shakya & Allgeier, 2023; Yang *et al.*, 2024)**. Yet, studies addressing the spatial variability of thermohaline stratification in the Maluku Sea (WPP 715) remain scarce, and available ITF datasets capture only surface or near-surface patterns. As a result, the vertical structure that directly affects pelagic fish behavior and ecosystem functioning is still insufficiently quantified.

The novelty of this study lies in addressing that gap through the use of high-resolution CTD (Conductivity Temperature Depth) measurements at 10-meter vertical intervals across three representative subregions, Aru, Obi, and Seram within WPP 715.

This fine-scale profiling enables a detailed quantification of thermocline and halocline gradients and their ecological implications for pelagic ecosystem structure and fisheries productivity in tropical archipelagic waters. Therefore, the objective of this study was to (1) determine the vertical distribution patterns of temperature and salinity in the Maluku Sea, (2) calculate the gradient index of these parameters at 10-meter depth intervals, and (3) interpret the ecological and fisheries implications of thermohaline stratification as a scientific basis for supporting ecosystem-based fisheries management (EBFM) in Indonesia's eastern waters.

MATERIALS AND METHODS

Study area

This study was conducted within the Fisheries Management Area (WPP) 715 of Indonesia, covering the Maluku Sea, which includes three primary observational zones: the Aru block, Obi block, and Seram block (Fig. 1). The area lies between 120°–124° E and 2° N–5° S, representing a hydrodynamically complex region influenced by the Indonesian Throughflow (ITF) that transports Pacific water masses toward the Indian Ocean. The survey consisted of 19 observation stations, distributed among three observation blocks: six in Aru, seven in Obi, and six in Seram (Table 1). The survey focused on deepwater zones (≤480 m depth) that are known to support pelagic fish habitats and high oceanographic variability. Field sampling was carried out in February 2020 during the northwest monsoon season, when stratification is typically the strongest in eastern Indonesian seas.

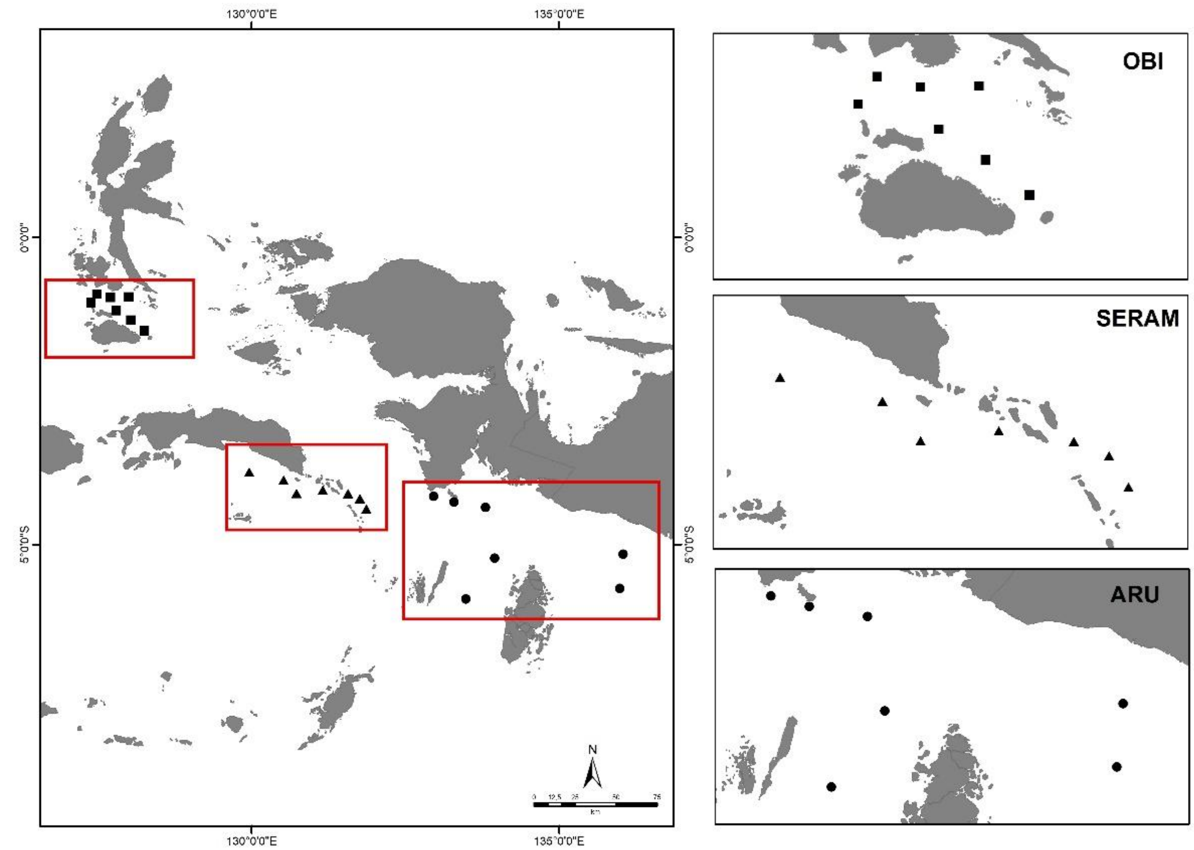

Fig. 1. Blocks of Aru, Obi, and Seram within Fisheries Management Area 715

Table 1. Sampling station in the Seram Sea

No of Station	Aru Block		Seram Block		Obi Block	
	Lotitude	Longitude	Lotitude	Longitude	Lotitude	Longitude
1	-4.211178°	132.959530°	-4.419157°	131.866532°	-1.519742°	128.256963°
2	-4.304217°	133.294720°	-4.248271°	131.760245°	-1.341020°	128.033875°
3	-5.154430°	136.043977°	-4.169022°	131.567032°	-1.184809°	127.796326°
4	-5.710695°	135.989444°	-4.110286°	131.155637°	-1.057080°	127.385640°
5	-5.218619°	133.955654°	-3.948754°	130.519548°	-0.965693°	128.001081°
6	-5.884441°	133.488096°	-3.817122°	129.959182°	-0.970869°	127.702575°
7					-0.917787°	127.482571°

Data collection and quality control

This research applied an oceanographic survey method to describe the vertical characteristics of temperature and salinity in the Maluku Sea. The main instrument used was the conductivity temperature depth (CTD) profiler model XR-420, which measures temperature, salinity, and depth throughout the water column. The CTD was lowered vertically into the sea using a rope and winch system to ensure stable descent and accurate recording. Each sampling station's position was determined using a Global

Positioning System (GPS) for precise spatial referencing. Sampling was conducted between 10:00 and 15:00 local time under stable weather conditions, with wind speeds of 0–5 knots and wave heights of 0–0.5 meters, to ensure consistent results. Data from the CTD profiler were processed using Ocean Data View (ODV) software to visualize and analyze vertical and spatial distributions. The results were then verified and compared among stations within each block to ensure data consistency and accuracy.

Data analysis

Vertical distribution of temperature and salinity was analyzed using a Cartesian graph, plotting depth on the Y-axis and parameter values on the X-axis. The temperature gradient for every 10-meter depth interval was calculated using the formula proposed by **Thomson and Emery (2024)**:

$$\Delta T_i = \frac{T_i - T_{(i-1)}}{X_i - X_{(i-1)}}$$

Where, ΔT_i is the temperature gradient, T is the water temperature, and X is depth.
The salinity gradient was calculated following **Tally *et al.* (2011)**:

$$\Delta S_i = \frac{S_i - S_{(i-1)}}{X_i - X_{(i-1)}}$$

Where, ΔS_i is the salinity gradient, S is the water salinity, and X is depth.

Thermocline layers were identified where the temperature gradient exceeded ±0.05°C/m, and halocline layers were determined from the salinity gradient profile at depths where a significant increase occurred. The Ocean Data View (ODV) application was used to generate graphical representations and visualize the thermocline and halocline layers across observation blocks.

RESULTS

Temperature distribution and thermocline structure

Temperature profiles in the Maluku Sea (WPP 715) revealed a consistent decrease with increasing depth across all observation blocks, Aru, Obi, and Seram, indicating the presence of well-defined thermocline layers that separate warm surface waters from colder subsurface layers. At the Aru block, surface temperatures ranged from 29.5–29.9°C, gradually declining to 8.6°C at 500m depth, with an average of 22.3°C throughout the water column. A sharp temperature decline was recorded between 100–160 m, identifying the thermocline zone.

The maximum vertical temperature gradient reached –0.295°C/m (St.05), while the mean gradient across all six stations was –0.270°C/m, confirming a strong and narrow thermocline (Table 3). This pattern indicates a sharp density transition driven by limited vertical mixing and intense surface warming. The vertical profiles (Fig. 2) illustrate the pronounced curvature of temperature decline at mid-depths.

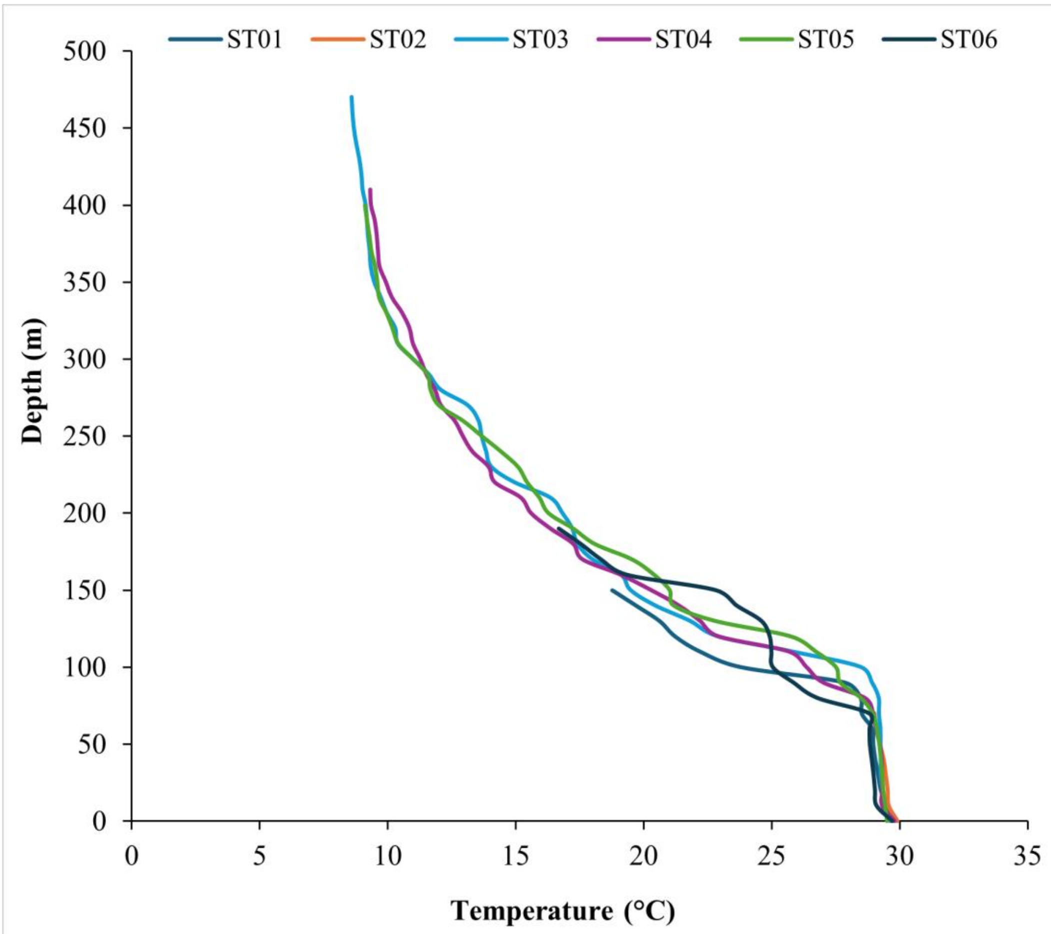

Fig. 2. Vertical temperature profiles at Aru block showing thermocline layers

In contrast, the Obi block exhibited a shallower thermocline. Surface waters were slightly warmer (29.3–30.8°C) with temperatures decreasing to 8.0°C at 480m (average 19.8°C). The thermocline occurred between 50– 130m, with a maximum gradient of –0.230°C/ m at St.02 and an average of –0.200°C/ m across all stations. The vertical pattern (Fig. 3) suggests a dynamic surface layer with higher mixing rates, likely due to local topographic upwelling and monsoonal influences. The presence of a shallow thermocline implies more active nutrient exchange between surface and sub-surface layers.

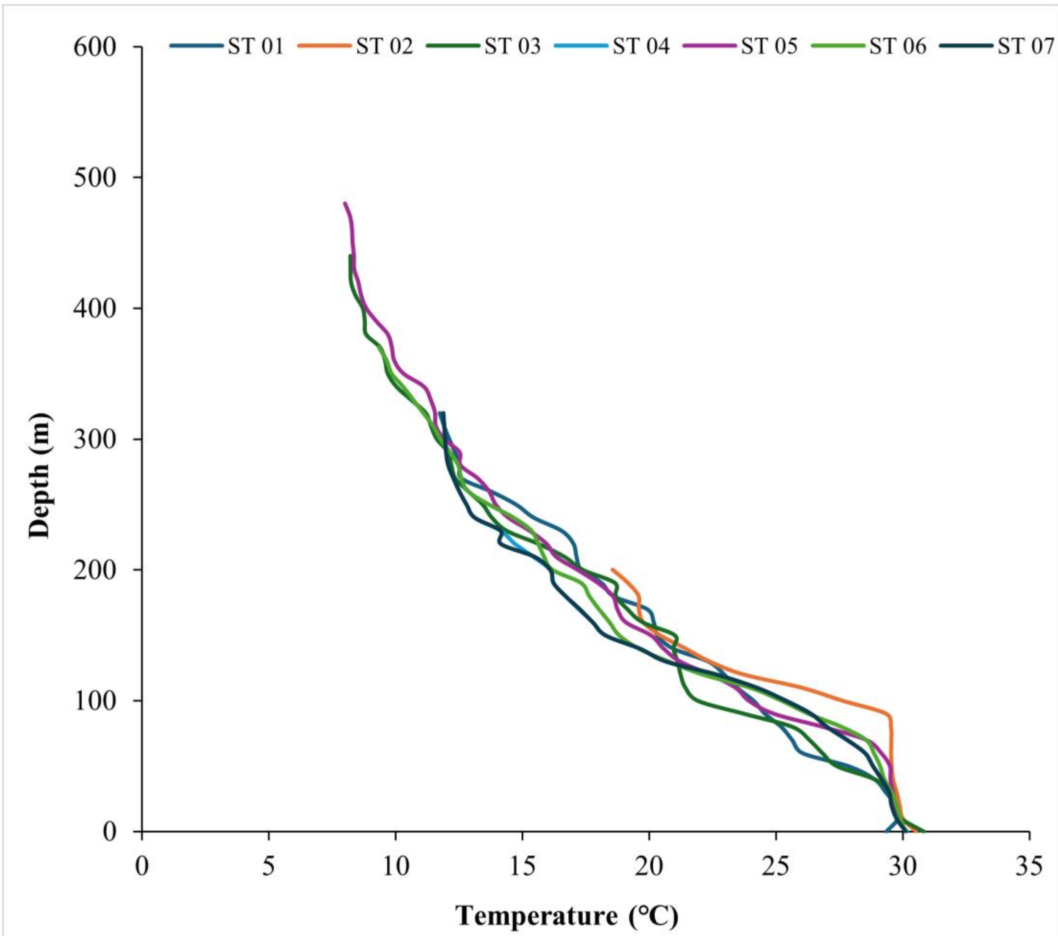

Fig. 3. Vertical temperature profiles at Obi block showing thermocline layers

The Seram block demonstrated the deepest thermocline among all locations. Surface temperatures reached 29– 31°C, declining to 8– 10°C at depths greater than 400m. Thermocline depths varied considerably between stations with 100– 120m at St.03 and St.06, and up to 210m at St.01 indicating heterogeneous mixing conditions. The maximum temperature gradient was –0.274°C/ m at St.02, while mean gradients across stations ranged between –0.046 and –0.071°C/ m. The deeper and thicker thermocline layer in Seram reflects a more stable stratification regime with less vertical turbulence (Fig. 4).

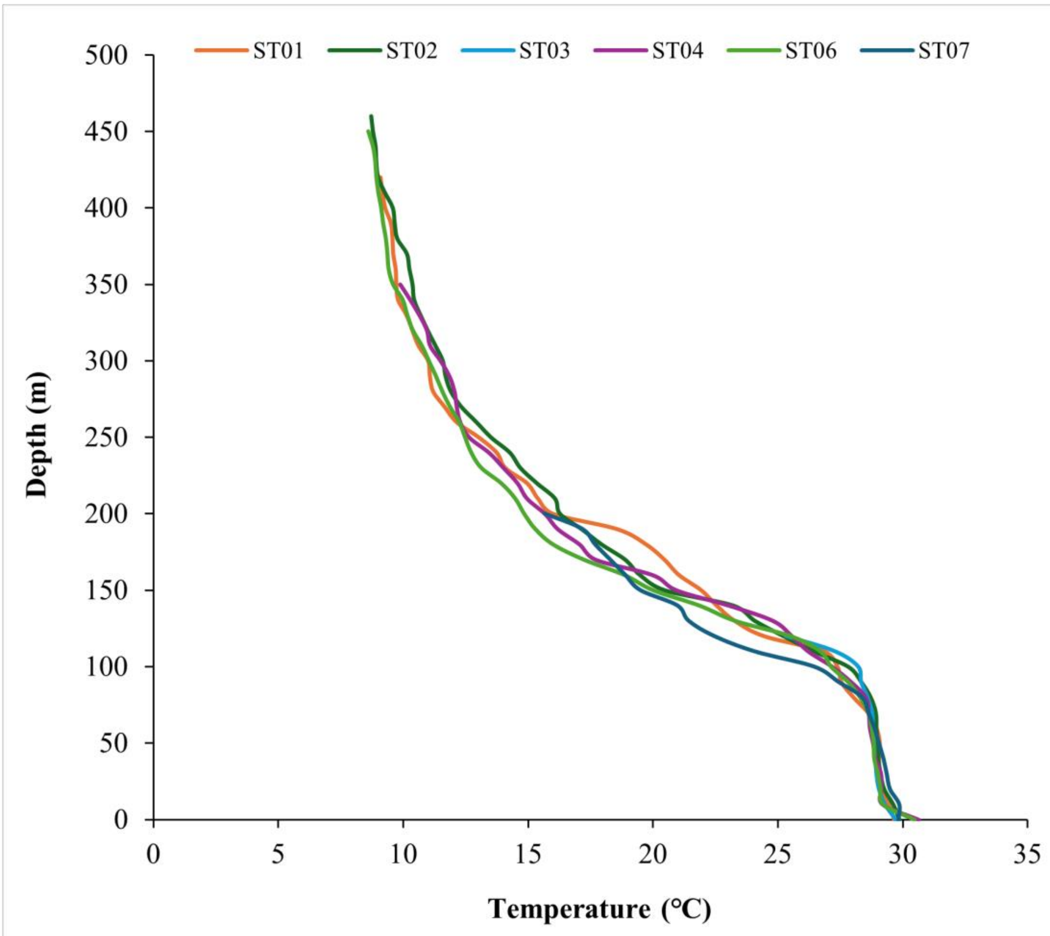

Fig. 4. Vertical temperature profiles at Seram block showing thermocline layers

Table 2. Summary of temperature gradient characteristics for each block

Block	Depth Range (m)	Mean Gradient (°C/m)	Max Gradient (°C/m)	Thermocline Depth (m)	Remarks
Aru	0–470	–0.045 to –0.072	**–0.295**	100–160	Sharp, deep thermocline
Obi	0–480	–0.046 to –0.060	**–0.230**	50–130	Shallow, active mixing
Seram	0–460	–0.037 to –0.071	**–0.274**	100–210	Deep, stable layer

Salinity distribution and halocline structure

Salinity increased steadily with depth across all surveyed blocks, reflecting the transition from low-salinity surface waters influenced by precipitation and freshwater inflow to more saline, dense deep waters characteristic of the Indonesian Throughflow (ITF) system. Surface salinity ranged from 33.0–33.9 PSU, gradually increasing to 34.84 PSU at depths exceeding 400m (mean 34.37 PSU). The most pronounced change occurred between 50– 150m, with the maximum salinity gradient reaching 0.055 PSU/m

(St.01). Below 150m, salinity stabilized, suggesting limited vertical mixing in deeper layers (Fig. 5).

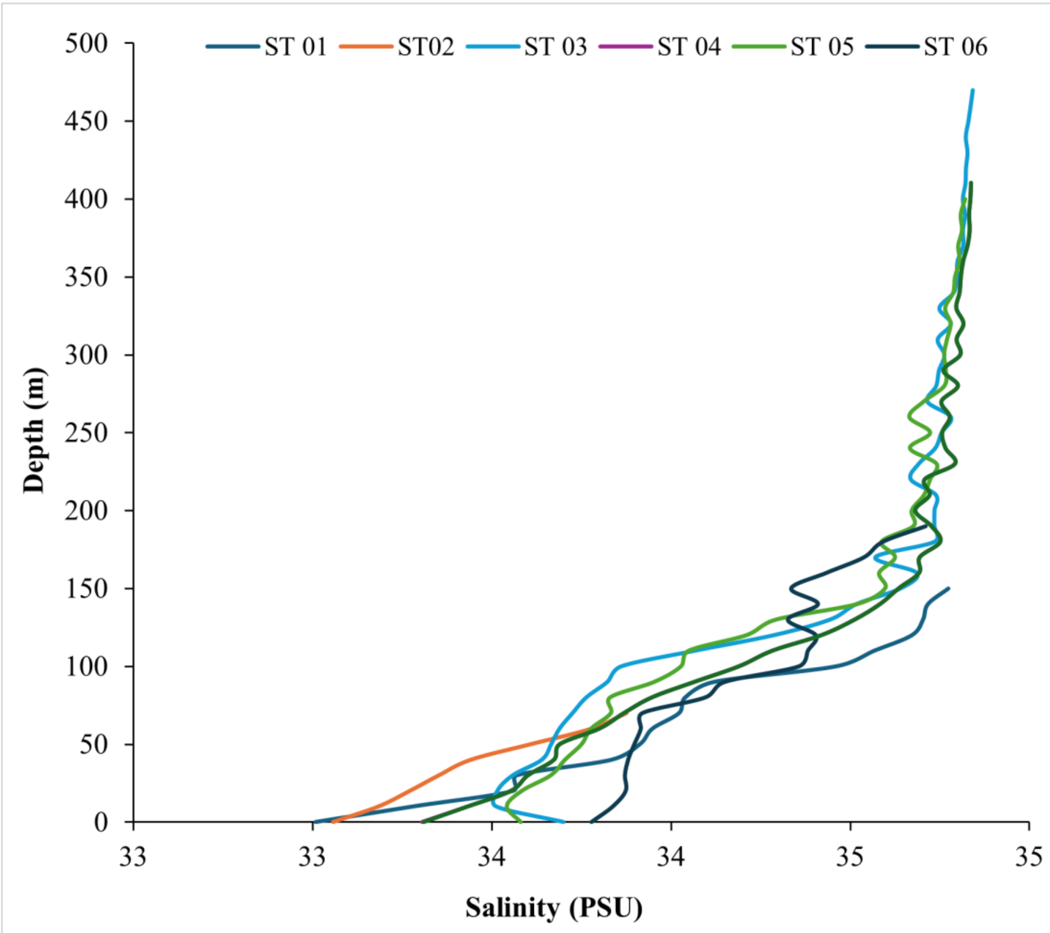

Fig. 5. Vertical salinity profiles at Aru block illustrating halocline formation

The Obi block displayed a slightly higher average salinity (34.45 PSU). Surface salinity values were 33.2 PSU, increasing to 34.85 PSU near 420m depth. The most active halocline was detected between 100– 150m, with a gradient of 0.012 PSU/m (St.04). The salinity transition zone corresponded closely to the thermocline depth, indicating a coupled thermal haline stratification pattern typical of tropical ocean waters (Fig. 6).

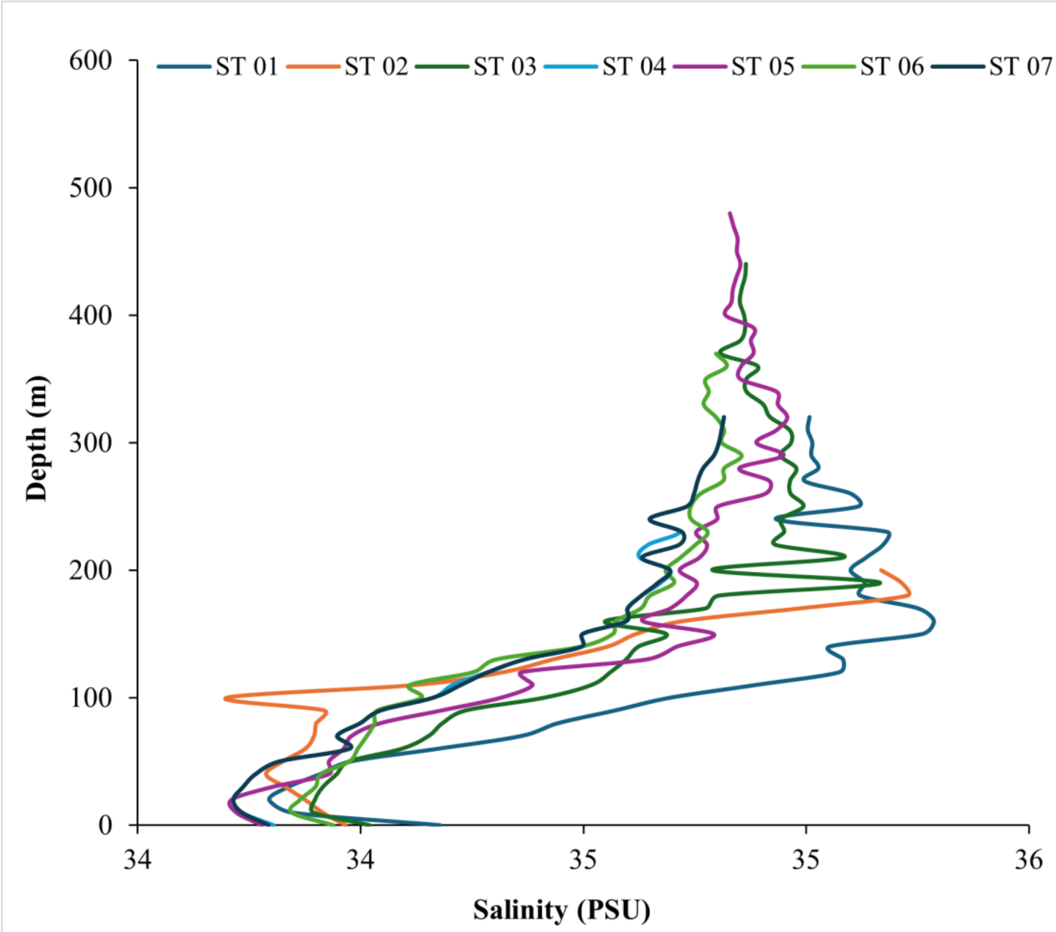

Fig. 6. Vertical salinity profiles at Obi block illustrating halocline formation

The Seram block exhibited the highest variability and strongest halocline. Surface salinity started at 33.5 PSU, reaching up to 34.83 PSU below 400m (mean 34.42 PSU). The maximum salinity gradient was observed at 0.094 PSU/m (St.03) between 100–120m, indicating strong vertical mixing and possible water-mass convergence from surrounding basins (Fig. 7). The stable deep-water salinity suggests persistent stratification reinforced by local topography and ITF inflow.

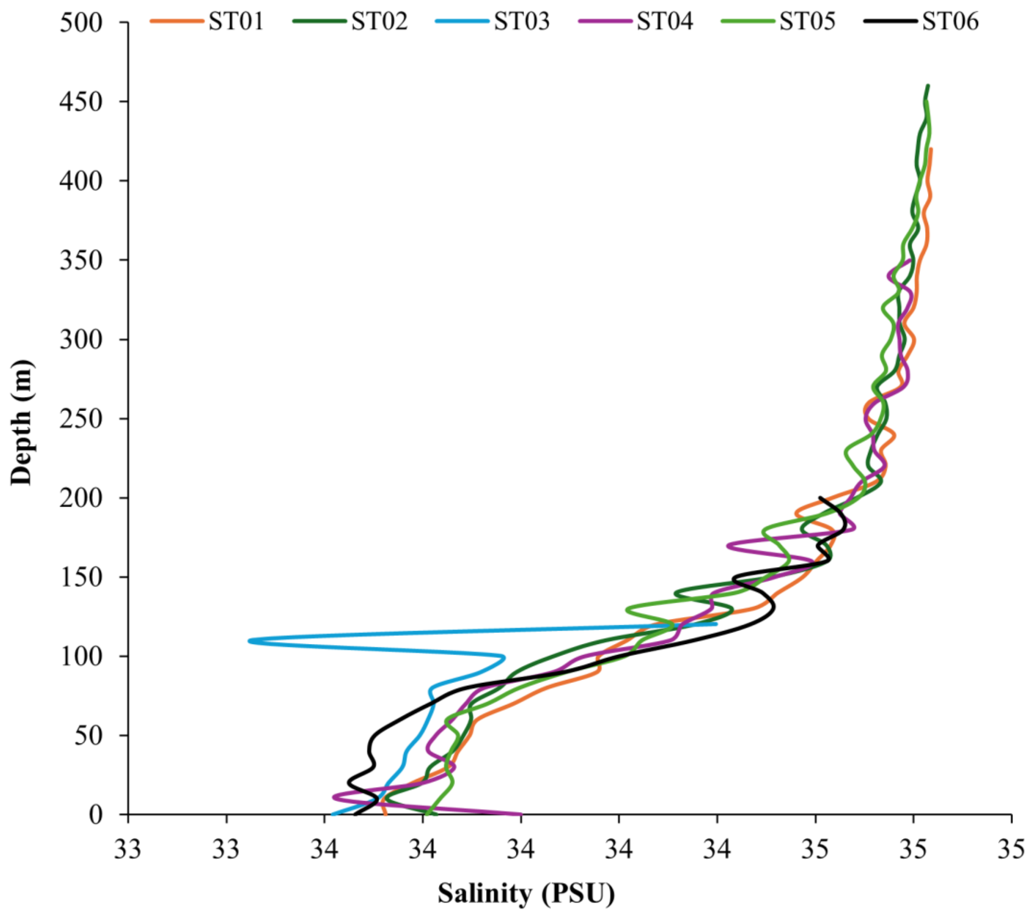

Fig. 7. Vertical salinity profiles at Seram block illustrating halocline formation

Table 3. Salinity gradients and halocline characteristics across blocks under study

Block	Depth Range (m)	Mean Salinity (PSU)	Max Gradient (PSU/m)	Halocline Depth (m)	Remarks
Aru	0–470	34.37	**0.055**	50–150	Moderate stratification
Obi	0–480	34.45	**0.012**	100–150	Coupled with thermocline
Seram	0–460	34.42	**0.094**	100–150	Strongest salinity gradient

DISCUSSION

Thermohaline stratification dynamics

The vertical temperature distribution across WPP 715 reflects a strong thermohaline structure typical of tropical marginal seas influenced by the Indonesian Throughflow (ITF). The presence of sharp thermocline layers between 50– 210m in the Aru, Obi, and Seram blocks indicates limited vertical heat exchange and strong stratification. The Aru block exhibited the sharpest gradient (–0.295°C/m), implying minimal vertical mixing between warm surface water and colder subsurface water. This feature aligns with the stratified conditions reported by **Iskandar *et al.* (2023)** in the Banda and Maluku Seas, where ITF intrusion forms distinct density layers that control vertical circulation. Such strong thermal gradients are characteristic of oligotrophic tropical waters where sunlight heating and calm wind conditions restrict convective overturn **(Chérubin & Burgman, 2022)**.

In the Obi block, the thermocline appeared shallower (50– 130m), suggesting more dynamic mixing in surface and mid-depth layers. Shallow thermoclines are often associated with higher nutrient entrainment and biological productivity due to enhanced vertical diffusion **(Oglethorpe *et al.*, 2025)**. The interaction between wind-driven turbulence and basin topography likely contributes to this condition, promoting localized upwelling along the Obi ridge. Similar shallow thermoclines have been documented in tropical eastern Pacific systems, where wind-induced mixing increases nutrient supply and supports high pelagic fish biomass **(Lin *et al.*, 2025)**. This implies that the Obi block may play an important role as a productive fishing zone within WPP 715.

In contrast, the Seram block showed a deeper thermocline (100– 210m) and lower gradient (–0.274°C/ m), reflecting a more stable thermal regime. The deeper thermocline corresponds to regions dominated by warm, low-density surface waters overlaying denser subsurface waters with minimal turbulent exchange. This pattern is similar to the deep thermocline structures observed in semi-enclosed tropical basins such as the Celebes Sea **(Li *et al.*, 2023; Kurniawan *et al.*, 2024b)**. The stable stratification in Seram reduces vertical nutrient transport, creating low-nutrient, low-chlorophyll (LNLC) conditions that influence phytoplankton dynamics and subsequent trophic transfer efficiency **(Ventura *et al.*, 2021)**.

From an ecological perspective, thermocline formation acts as both a physical and biological boundary in the oceanic water column. It regulates nutrient supply, oxygen distribution, and the vertical migration of marine organisms. The occurrence of strong thermocline layers in WPP 715 suggests that biological productivity and fish aggregation zones are concentrated near this transition layer. Pelagic species such as the skipjack (*Katsuwonus pelamis*) and the yellowfin tuna (*Thunnus albacares*) are known to prefer habitats around thermocline depths **(Istnaeni *et al.*, 2023; Salamah *et al.*, 2024)**, where temperature and oxygen gradients create favorable feeding conditions. Consequently, the mapped thermocline zones can be used as a predictive tool for locating pelagic fish schools, optimizing fishing efforts while minimizing fuel and time costs.

The thermohaline gradient also influences the spatial extent of oxygen minimum zones (OMZs). Strong stratification reduces vertical oxygen replenishment, allowing suboxic layers to form beneath the thermocline **(Mahaffey *et al.*, 2023; Kurniawan *et al.*, 2024a)**. In the Maluku Sea, such conditions could lead to periodic hypoxia, impacting mesopelagic fauna and nutrient remineralization processes. Monitoring the vertical temperature gradient, therefore, becomes essential for predicting ecological stress zones and managing habitat resilience under climate change scenarios. Studies by **Brandt *et al.* (2021)** have shown that intensified ocean warming deepens thermoclines globally, expanding OMZs and altering fish distribution patterns.

From a fisheries management perspective, the spatial variability of thermocline depth among the Aru, Obi, and Seram blocks holds implications for ecosystem-based fisheries management (EBFM). By integrating thermocline mapping into fisheries data systems, managers can predict productive layers, define spatial closures, and schedule fishing activities according to oceanographic dynamics. This approach aligns with the recommendations of **Longhurst (2010)** and **FAO (2018)** for linking physical oceanography with fishery productivity models. In WPP 715, adaptive management strategies that consider thermocline variability can enhance stock sustainability, especially for migratory pelagic species sensitive to vertical temperature gradients.

Halocline stratification dynamics

The salinity profiles of WPP 715 further support the presence of a layered thermohaline system, where salinity increases consistently with depth and forms well-defined haloclines between 100– 150m. The observed maximum salinity gradients 0.055 PSU/m (Aru), 0.012 PSU/m (Obi), and 0.094 PSU/m (Seram) reflect contrasting hydrodynamic regimes influenced by freshwater inputs, ITF transport, and vertical diffusion. In the Aru block, the moderate halocline suggests mixing between low-salinity surface waters, possibly influenced by rainfall and continental runoff, and high-salinity subsurface waters. Such vertical stratification patterns are typical of tropical archipelagic seas where precipitation–evaporation imbalance controls near-surface salinity **(Duan *et al.*, 2021)**.

In the Seram block, the steepest salinity gradient (0.094 PSU/m) indicates strong density stratification and potential water-mass convergence. This feature is consistent with the region’s function as a transition zone for ITF inflow from the Pacific through the Halmahera and Lifamatola passages **(Wattimena *et al.*, 2018; Perwira *et al.*, 2020)**. The convergence of distinct water masses enhances halocline sharpness, which in turn stabilizes the water column and reduces vertical mixing. Such conditions are known to modulate nutrient upwelling, creating patchy productivity hotspots that can sustain pelagic fish aggregations despite overall oligotrophy **(Santora *et al.*, 2021; Al Zamzami *et al.*, 2025)**.

In the Obi block, the weaker halocline and higher vertical mixing imply more active water exchange between surface and mid-depth layers. The overlap of halocline and thermocline zones suggests a coupled stratification regime, where both temperature and salinity gradients jointly control density distribution **(Wang *et al.*, 2024; Kurniawan *et al.*, 2025)**. This coupling may promote localized upwelling during monsoonal transitions, enhancing the availability of nutrients and supporting small-scale fisheries productivity. Similar interactions between halocline dynamics and biological responses have been reported in the South China Sea and equatorial Pacific **(Chen *et al.*, 2018; Anggayasti *et al.*, 2025)**.

Ecologically, halocline layers influence the vertical distribution of planktonic organisms and the energy flow through the pelagic food web. Salinity gradients affect buoyancy regulation, metabolic rates, and larval dispersal patterns. Strong halocline stratification in Seram may restrict vertical migration of zooplankton and limit nutrient transport, whereas weaker stratification in Obi could enhance ecological connectivity between surface and subsurface ecosystems **(Samini *et al.*, 2024; Sukoso *et al.*, 2025)**. This spatial heterogeneity underlines the importance of hydrographic mapping for ecosystem modeling in tropical marine systems.

From the fisheries perspective, halocline depth and intensity determine the vertical habitat of many pelagic species. Tuna and mackerel schools tend to aggregate near halocline boundaries where prey density and favorable temperature–salinity combinations coincide **(Norelli, 2023; Ismail *et al.*, 2025)**. In WPP 715, integrating halocline monitoring into fisheries forecasting systems can enhance catch predictability and minimize overexploitation by focusing efforts in ecologically sustainable layers. This is especially critical under the EBFM framework, which emphasizes the coupling between physical ocean processes and biological productivity **(Ruiz-Díaz, 2023; Mas'ud *et al.*, 2025)**.

Finally, halocline dynamics have direct implications for regional climate and carbon cycling. Stratified haline layers inhibit the vertical exchange of carbon and nutrients, influencing the ocean's biological pump efficiency **(Chowdhury *et al.*, 2025)**. Thus, continuous monitoring of temperature salinity interactions in WPP 715 is essential for assessing the response of tropical seas to climate variability and anthropogenic pressure. Integrating hydrographic profiling into Indonesia's marine observation network can provide baseline data for adaptive fisheries governance, aligning with SDG 14 (Life Below Water) through science-based management and conservation.

CONCLUSION

The vertical structure of temperature and salinity in Fisheries Management Area (WPP) 715 of the Maluku Sea demonstrates a distinct thermohaline stratification that strongly influences the region's oceanographic and ecological dynamics. The thermocline was identified at depths ranging from 50 to 210 meters, with the sharpest temperature gradient (–0.295°C/m) in the Aru block, while the halocline appeared between 100 and 150 meters with a maximum salinity gradient of 0.094 PSU/m in the Seram block. These stratifications indicate limited vertical mixing, forming density layers that regulate nutrient availability and biological productivity. Ecologically, the thermocline and halocline zones represent key habitats for pelagic fish such as tuna and skipjack, which aggregate around these transition layers due to optimal thermal and oxygen conditions. From a management perspective, understanding the vertical thermohaline structure is essential for improving fishing ground prediction and implementing ecosystem-based fisheries management (EBFM) in tropical Indonesian waters. The integration of hydrographic data with fisheries monitoring systems will support adaptive management, enhance resource sustainability, and contribute to national efforts toward achieving the Sustainable Development Goals (SDG 14: Life Below Water). These findings emphasize the importance of continuous thermohaline observation as a scientific foundation for sustainable marine resource governance in eastern Indonesia.

REFERENCES

Al Zamzami, I.M.; Yona, D. and Kurniawan, A. (2025). Decoding halophilic biofilm development across salinity gradients in hypersaline environments. Biodiversitas J. Biol. Divers., 26(6): 1–10.

Alvarez, I.; Rasmuson, L.K.; Gerard, T.; Laiz-Carrion, R.; Hidalgo, M.; Lamkin, J.T. (2021). Influence of the seasonal thermocline on the vertical distribution of larval fish assemblages associated with Atlantic bluefin tuna spawning grounds. Oceans, 2(1): 64–83.

Anggayasti, W.L.; Pramudia, Z.; Susanti, Y.A.D.; Al Zamzami, I.M.; Moehammad, K.S.; Wardana, I.N.G. and Kurniawan, A. (2025). Epilithic biofilm as a potential biomonitor for microplastics contamination in Brantas River of Malang City, Indonesia. Case Stud. Chem. Environ. Eng., 11: 101083.

Brandt, P.; Hahn, J.; Schmidtko, S.; Tuchen, F.P.; Kopte, R. and Kiko, R. (2021). Atlantic Equatorial Undercurrent intensification counteracts warming-induced deoxygenation. Nat. Geosci., 14(5): 278–282.

Chen, Y.; Wu, Z. and Li, Q.P. (2018). Temporal change of export production at Xisha of the northern South China Sea. J. Geophys. Res.: Oceans, 123(12): 9305–9319.

Chérubin, L.M. and Burgman, R.J. (2022). Effects of climate change and water management on West Florida Shelf dynamics. Bull. Mar. Sci., 98(3): 393–418.

Chowdhury, S.U.M.B.; Hoque, M.M.; Karmakar, A.; Chowdhury, N.U.M.K.; Chowdhury, K.A.; Tahsin, T.H. and Moontahab, A. (2025). Seasonal and interannual variability of mixed-layer depth and surface chlorophyll-a in the Bay of Bengal: insights into physical-biological coupling. Ocean Sci. J., 60(4): 41.

Debiyanti, D.; Gunawan, D. and Budiyanto, S. (2025). Patterns of oceanographic factor distribution and tuna fishing potential: spatial and temporal analysis. Remote Sens. Technol. Def. Environ., 2(1): 60–77.

Dell'Apa, A.; Boenish, R.; Fujita, R. and Kleisner, K. (2023). Effects of climate change and variability on large pelagic fish in the Northwest Atlantic Ocean: implications for improving climate resilient management for pelagic longline fisheries. Front. Mar. Sci., 10: 1206911.

Duan, W.; Cheng, X.; Zhu, X. and Ma, T. (2021). Variability in upper-ocean salinity stratification in the tropical Pacific Ocean. Acta Oceanol. Sin., 40(1): 113–125.

FAO. (2018). The State of World Fisheries and Aquaculture 2018: Meeting the Sustainable Development Goals. FAO, Rome.

Foltz, G.R.; Eddebbar, Y.A.; Sprintall, J.; Capotondi, A.; Cravatte, S. and Brandt, P. (2025). Toward an integrated pantropical ocean observing system. Front. Mar. Sci., 12: 1539183.

Iskandar, M.R.; Jia, Y.; Sasaki, H.; Furue, R.; Kida, S.; Suga, T. and Richards, K.J. (2023). Effects of high-frequency flow variability on the pathways of the Indonesian throughflow. J. Geophys. Res.: Oceans, 128(5): e2022JC019610.

Ismail, E.; Prihanto, A.A.; Sukoso; Kartikaningsih, H.; Huda, N. and Al Zamzami, I.M. (2025). Isolation and characterization of a novel acid protease from striped marlin (*Kajikia audax*) stomach with potential as a rennet substitute in dairy processing. Egypt. J. Aquat. Biol. Fish., 29(4): 1593–1613.

Istnaeni, Z.D.; Gaol, J.L.; Zainuddin, M. and Fitrianah, D. (2023). Implementation of the pelagic hotspot index in detecting habitat suitability area for bigeye tuna (*Thunnus obesus*) in the eastern Indian Ocean. Biodiversitas J. Biol. Divers., 24(9): 1–10.

Kurniawan, A.; Amin, A.A.; Yanuar, A.T.; Pramudia, Z.; Susanti, Y.A.D.; Al Zamzami, I.M. and Amenan, M. (2024a). Exploring viability and innovation requirements for novel salt production: a case study of Kangen Beach, Malang Regency's South Coast, Indonesia. Cogent Soc. Sci., 10(1): 2434667.

Kurniawan, A.; Dhea, L.A.; Ulfa, S.M.; Yanuar, A.T.; Al Zamzami, I.M. and Nurjannah. (2025). Assessment of water quality in the upper Brantas River through microplastic-associated biofilms and heavy metal accumulation. Int. J. Environ. Stud., 82(4): 1707–1729.

Kurniawan, A.; Pramudia, Z.; Susanti, Y.A.D.; Al Zamzami, I.M. and Yamamoto, T. (2024b). Comparative biosorption proficiency in intact and autoclaved biofilm matrices. J. Ecol. Eng., 25(4): 1–12.

Li, J.; Tan, W.; Sun, W.; Yang, L.; Lin, L. and Fu, Q. (2023). Seasonal–interannual–decadal variations of sea level in the South China Sea and connections with the tropical–subtropical Pacific. Int. J. Climatol., 43(11): 5196–5207.

Lin, L.; Sun, Z.; Lv, T.; Wang, Y.; Tan, W.; Jin, K. and Xiang, D. (2025). In-phase Pacific Decadal Oscillation and El Niño–Southern Oscillation enhance the interannual variability of spring blooms in the Yellow Sea. Ocean-Land-Atmos. Res., 4: 0083.

Longhurst, A.R. (2010). Ecological Geography of the Sea. Elsevier, London.

Mahaffey, C.; Hull, T.; Hunter, W.; Greenwood, N.; Palmer, M. and Sharples, J. (2023). Climate change impacts on dissolved oxygen concentration in marine and coastal waters around the UK and Ireland. MCCIP Sci. Rev., 31(10.14465): 1–15.

Mas'ud, F.; Maftuch; Musa, M.; Lestariadi, R.A. and Al Zamzami, I.M. (2025). Sustainable Vannamei shrimp farming in Bonorowo, Indonesia wetlands: growth performance, land suitability, and ecological challenges. Egypt. J. Aquat. Biol. Fish., 29(4): 897–919.

Napitupulu, G. (2024). Monthly variability of wind-induced upwelling and its impact on chlorophyll-a distribution in the southern and northern parts of the Indonesian Archipelago. Ocean Dyn., 74(10): 859–878.

Norelli, A.P. (2023). Assessing the Dynamics of Mixed School Tropical Tuna to Reduce Juvenile Mortality from Surface Fleets. Doctoral Dissertation, University of Miami, USA.

Oglethorpe, K.; Castro, B.F.; Spingys, C.P.; Naveira Garabato, A.C. and Williams, R.G. (2025). The role of mesoscale eddy stirring and microscale turbulence in sustaining biological production in the subtropical gyres. Glob. Biogeochem. Cycles, 39(9): e2024GB008180.

Perwira, I.Y.; Ulinuha, D.; Al Zamzami, I.M.; Ahmad, F.H.; Kifly, M.T.H. and Wulandari, N. (2020). Environmental factors associated with decomposition of organic materials and nutrient availability in the water and sediment of Setail River, Banyuwangi, Indonesia. IOP Conf. Ser.: Earth Environ. Sci., 493(1): 012025.

Pratama, G.B.; Wijayanti, L.A.S.; Maqbul, I.; Muhyun, A.A.; Sahar, R.A.; Ayu, R.G. and Firdaus, M.R. (2025). Multi-algorithm species distribution modeling for skipjack tuna fishing ground detection in the Indian Ocean: a case study of Indonesian FMA 572. Environ. Qual. Manag., 35(1): e70166.

Priyadarshini, P. and Veeresha, P. (2023). Analysis of models describing thermocline depth–ocean temperature and dissolved oxygen concentration in the ocean–plankton community. Waves Random Complex Media, 1–25.

Purba, N.P.; Pranowo, W.S.; Ndah, A.B. and Nanlohy, P. (2021). Seasonal variability of temperature, salinity, and surface currents at 0° latitude section of Indonesia seas. Reg. Stud. Mar. Sci., 44: 101772.

Ruiz-Díaz, R. (2023). Using an EBFM lens to guide the management of marine biological resources under changing conditions. Fish. Fish., 24(2): 199–211.

Salamah, L.N.; Al Zamzami, I.M.; Pramudia, Z.; Susanti, Y.A.D.; Dhea, L.A. and Kurniawan, A. (2024). Distribution of microplastics in Lusi Island, Sidoarjo, Indonesia. IOP Conf. Ser.: Earth Environ. Sci., 1328(1): 012012.

Samini, H.; Aliakbari Bidokhti, A.A.; Ezam, M. and Valinassab, T. (2024). Seasonal patterns in phytoplankton and zooplankton across the north of Gulf of Oman: a numerical study. Pol. J. Environ. Stud., 33(3): 1–10.

Santora, J.A.; Schroeder, I.D.; Bograd, S.J.; Chavez, F.P.; Cimino, M.A. and Fiechter, J. (2021). Pelagic biodiversity, ecosystem function, and services. Oceanography, 34(2): 16–37.

Shakya, A.W. and Allgeier, J.E. (2023). Water column contributions to coral reef productivity: overcoming challenges of context dependence. Biol. Rev., 98(5): 1812–1828.

Sukoso; Kartikaningsih, H.; Ma'rifat, T.N.; Zubir, M.; Sinaga, S.; Rahayuningsih, E.S.; Adilah, L.H.; Susanti, Y.A.D. and Al Zamzami, I.M. (2025). Optimizing the trash fish supply chain: a sustainable model for marine fisheries in East Java, Indonesia. Egypt. J. Aquat. Biol. Fish., 29(4): 2437–2449.

Talley, L.D. (2011). Descriptive Physical Oceanography: An Introduction. Academic Press, London.

Thomson, R.E. and Emery, W.J. (2024). Data Analysis Methods in Physical Oceanography. Elsevier, Amsterdam.

Ventura, A.; Simões, E.F.; Almeida, A.S.; Martins, R.; Duarte, A.C.; Loureiro, S. and Duarte, R.M. (2021). Deposition of aerosols onto upper ocean and their impacts on marine biota. Atmosphere, 12(6): 684.

Wang, L.; Liu, J.; Bao, Z.; Ma, X.; Shen, H.; Xie, P. and Chen, J. (2024). Thermocline stratification favors phytoplankton spatial overlap and species diversity in a subtropical deep reservoir. Sci. Total Environ., 913: 169712.

Wang, M.H. (2024). Variability of Indo-Pacific ocean basin circulation and its impact on climate change. Int. J. Mar. Sci., 14: 1–10.

Wattimena, M.C.; Atmadipoera, A.S.; Purba, M.; Nurjaya, I.W. and Syamsudin, F. (2018). Indonesian Throughflow (ITF) variability in Halmahera Sea and its coherency with New Guinea Coastal Current. IOP Conf. Ser.: Earth Environ. Sci., 176(1): 012011.

Yang, Y.; Ju, Y.; Gao, Y.; Zhang, C. and Lam, K.M. (2024). Remote sensing insights into ocean fronts: A literature review. Intell. Mar. Technol. Syst., 2(1): 10.

Yudowaty, S.O.; Radjawane, I.M.; Fajary, F.R. and Napitupulu, G. (2025). Heat transport variability within the inlet and outlet of Makassar Strait. Malay. Appl. Geogr. (MAGG), 3(1): 38–44.

Zhang, X.; Wang, Z.; Cai, H.; Chai, X.; Tang, J.; Zhuo, L. and Jia, H. (2022). Summertime dissolved oxygen concentration and hypoxia in the Zhejiang coastal area. Front. Mar. Sci., 9: 1051549.