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SEASONAL VARIATIONS AND SPATIAL RELATIONSHIPS BETWEEN *THERMAL FRONTS* AND THE DISTRIBUTION OF SKIPJACK TUNA (*Katsuwonus pelamis*) IN WPP-NRI 573

Variasi Musiman dan Hubungan Spasial Antara Thermal Front dan Distribusi Ikan Tuna Cakalang (*Katsuwonus pelamis*) Di Wpp-Nri 573

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ABSTRACT

The Indonesian Fisheries Management Area (IFMA/WPP-NRI) 573 is an important migration route for skipjack tuna (*Katsuwonus pelamis*). This study aims to analyze seasonal variations and spatial relationships between *thermal front*s and the distribution of skipjack tuna in the IFMA 573 during the period from 2019 to 2020. Satellite-derived sea surface temperature (SST) and ocean current data were obtained from MODIS and Copernicus Marine Service, while catch data (CPUE) were obtained from the Nizam Zachman Jakarta Ocean Fisheries Port. Thermal fronts were identified using the Single Image Edge Detection (SIED) method based on the Cayula and Cornillon algorithms. The study's results indicate that high-intensity thermal fronts (ΔSPL $\geq$ 0.5°C) are more widespread and intense during the southeast monsoon season, particularly in the waters south of Java to Nusa Tenggara. The distribution of skipjack tuna follows a seasonal pattern, with a tendency to migrate according to the direction of currents and thermal front zones during the southeast monsoon season. The highest CPUE was recorded during the transition from the western season (February–March) with a value of 25,765 kg/trip and during the eastern season (July – September) with a value of 47,150 kg/trip. However, Spearman's correlation analysis revelead a weak relationship between thermal front values and CPUE (r = -0.23), indicating no statistically significant correlation. Despite this weak correlation, the spatial pattern suggests the potential use of *thermal front*s as a supporting indicator in determining skipjack tuna fishing zones. These findings are important for adaptive and ecosystem-based tuna fisheries management in the IFMA 573 region.

Keywords: CPUE, Skipjack Tuna, Seasonal Migration, *Thermal front*, WPP-NRI 573

ABSTRAK

Wilayah Pengelolaan Perikanan Negara Republik Indonesia (WPP-NRI) 573 merupakan jalur migrasi penting bagi ikan tuna cakalang (*Katsuwonus pelamis*). Penelitian ini bertujuan untuk menganalisis variasi musiman dan hubungan spasial antara *thermal front* dengan sebaran ikan cakalang (*Katsuwonus pelamis*) di Wilayah Pengelolaan Perikanan Negara Republik Indonesia (WPP-NRI) 573 selama periode 2019–2020. Data suhu permukaan laut (SPL) dan arus laut diperoleh dari citra satelit MODIS dan Copernicus Marine Service, sedangkan data hasil tangkapan (CPUE) diperoleh dari Pelabuhan Perikanan Samudera Nizam Zachman Jakarta. *Thermal front* diidentifikasi menggunakan metode *Single Image Edge Detection (SIED)* berbasis algoritma Cayula dan Cornillon. Hasil penelitian menunjukkan bahwa *thermal front* dengan intensitas tinggi (ΔSPL ≥ 0,5°C) cenderung lebih luas dan intens pada musim timur, khususnya di perairan selatan Jawa hingga Nusa Tenggara. Distribusi ikan cakalang bersifat musiman, dengan kecenderungan migrasi mengikuti arah arus dan zona *thermal front* selama musim timur. Titik CPUE tertinggi berada pada bulan musim barat menuju peralihan (Februari – Maret) dengan nilai 25,765kg/trip dan pada musim timur dengan nilai 47,150 kg/trip. Meskipun demikian, hasil analisis korelasi Spearman menunjukkan hubungan yang lemah antara nilai *thermal front* dan CPUE (r = -0,23), menandakan bahwa secara statistik tidak terdapat hubungan signifikan. Meskipun korelasi lemah, pola spasial menunjukkan potensi penggunaan *thermal front* sebagai indikator pendukung dalam penentuan zona penangkapan ikan. Temuan ini penting untuk pengelolaan perikanan tuna secara adaptif dan berbasis ekosistem di wilayah WPP-NRI 573.

Kata Kunci: CPUE, Ikan Cakalang, Migrasi Musiman, *Thermal front*, WPP-NRI 573

INTRODUCTION

The waters of Indonesia are part of the tropical region characterized by high productivity, supporting the presence of various pelagic fish species, one of which is skipjack tuna (*Katsuwonus pelamis*). The Fisheries Management Area of the Republic of Indonesia (WPP-NRI) 573, encompassing the Indian Ocean waters south of Java to Nusa Tenggara, is known as an important migratory route for large pelagic fish such as skipjack tuna.

Oceanographic dynamics in this region are influenced by seasonal phenomena such as monsoons, upwelling, the Indonesian Throughflow (ARLINDO), the Indian Ocean Dipole (IOD), and the El Niño–Southern Oscillation (ENSO), which can trigger the formation of thermal fronts (Syamsuddin *et al.*, 2024; Trinugroho *et al.*, 2019).

Thermal fronts are zones of convergence between water masses with different temperature characteristics that can create areas with high nutrient concentrations and fertile primary productivity (Hamzah *et al.*, 2014). These zones have the potential to become aggregation sites for pelagic fish because they provide ideal environmental conditions, including abundant food. Skipjack tuna are known to prefer temperatures of 28–30°C and are frequently found around productive waters such as upwelling zones and thermal fronts (Sukresno *et al.*, 2015; Zainuddin *et al.*, 2017).

Several previous studies have shown a positive relationship between thermal front locations and tuna distributions, including skipjack tuna, in various tropical ocean regions (Mugo *et al.*, 2010; Zainuddin *et al.*, 2017). However, this relationship has not been extensively investigated in a spatiotemporal context in WPP-NRI 573, particularly concerning seasonal variations. Meanwhile, catch trends of skipjack tuna in this region demonstrate fluctuations from year to year (Nursan *et al.*, 2022), highlighting the importance of understanding environmental factors affecting their distribution.

This study was conducted to address this gap, aiming to analyze seasonal variations of thermal fronts and examine their spatial association with the distribution of skipjack tuna in WPP-NRI 573 during the 2019–2020 period. By integrating satellite-derived sea surface temperature and ocean current data with catch data (CPUE), this study is expected to provide scientific information supporting sustainable and ecosystem-based tuna fisheries management.

METHODS

Research Location and Time

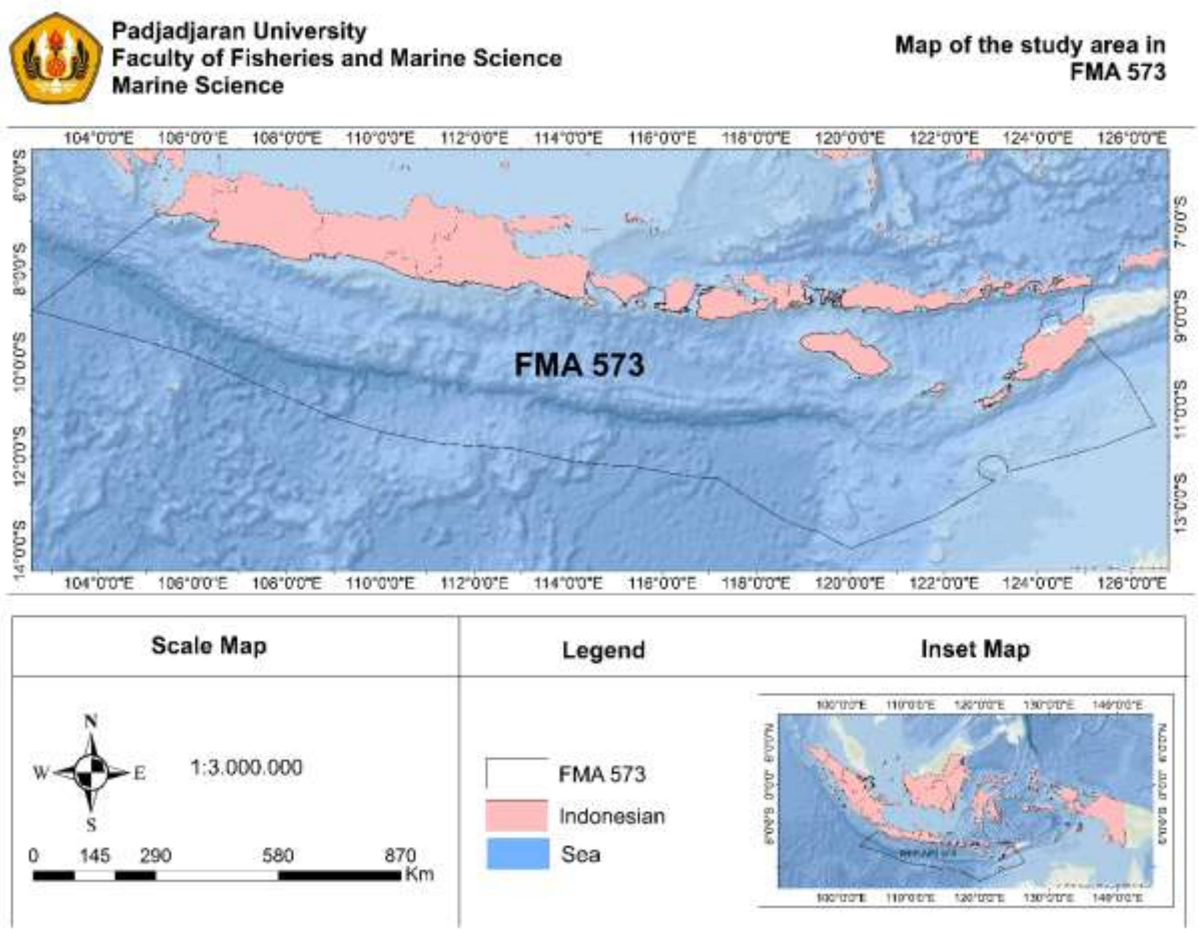


Figure 1. Map of research studies in WPP-NRI 573

This research was conducted in the Republic of Indonesia's National Fisheries Management Area (WPP-NRI) 573, which encompasses the Indian Ocean south of Java to southern Nusa Tenggara, including the Sawu Sea and the western Timor Sea. The analysis was conducted retrospectively using data from January 2019 to December 2020.

Research Tools and Data

The tools used include ArcGIS 10.8 software for image processing and map overlay, Jupyter Notebook for statistical analysis and visualization, and Microsoft Excel for CPUE calculations. The data used consists of:

1. Sea Surface Temperature (SST) and currents: Monthly data at 0.25° x 0.25° resolution from Aqua MODIS and Copernicus Marine Service satellite imagery in NetCDF format.
2. Skipjack tuna catch data: Includes fishing positions and catch results from the Nizam Zachman Jakarta Ocean Fishing Port (PPSNZJ), in .csv format.

Research Procedures

This study uses a quantitative approach with spatial and temporal analysis. Thermal fronts were identified using the Single Image Edge Detection (SIED) algorithm of Cayula and Cornillon (1992) operated through the MGET toolbox in ArcGIS. SST values were converted from decimal to integer format by multiplying by 10, and a threshold of $\Delta SPL \geq 0.3°C$ was applied for weak thermal fronts and ΔSPL ≥ 0.5°C for strong thermal fronts. The position and catch of skipjack tuna were converted into Catch Per Unit Effort (CPUE) values (kg/trip). CPUE data were then spatially overlaid with the thermal front map to examine the spatial distribution relationship.

Data analysis

Thermal front variability was analyzed seasonally (west and east monsoons) using spatial visualization of SST, currents, and CPUE. The relationship between thermal fronts and CPUE was analyzed using the Spearman correlation test to determine the strength and direction of the relationship between thermal front intensity and catch.

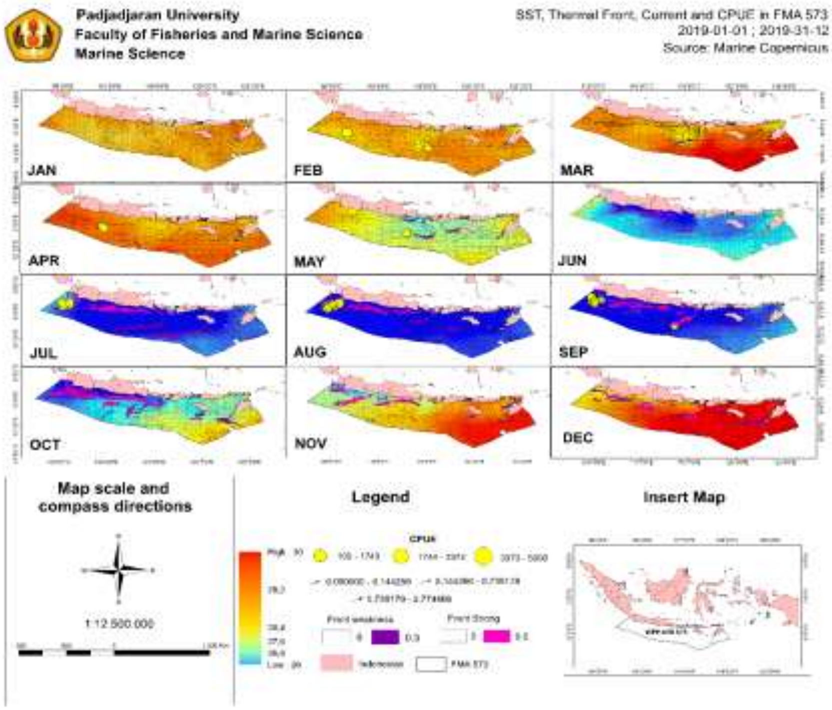
This study is based on the hypothesis that thermal front zones, which form seasonally, play a role in determining the spatial distribution patterns of skipjack tuna, particularly during the east monsoon when oceanographic dynamics are more intense.

RESULTS

Seasonal Pattern of Thermal Fronts and Distribution of Skipjack Tuna

SST analysis for 2019–2020 showed the highest values during the west and transitional seasons I (28.4–30°C) and the lowest during the east season (26–27.6°C). Thermal fronts exhibit a clear seasonal pattern, with weak to moderate intensity dominating during the west season and the expansion of strong thermal fronts during the east season. The highest CPUE values were recorded during the east season (especially in 2020), while fishing activity continued during the transitional seasons I and II, albeit unevenly. During the west season, CPUE was very low, even undetectable.

(a)



(b)

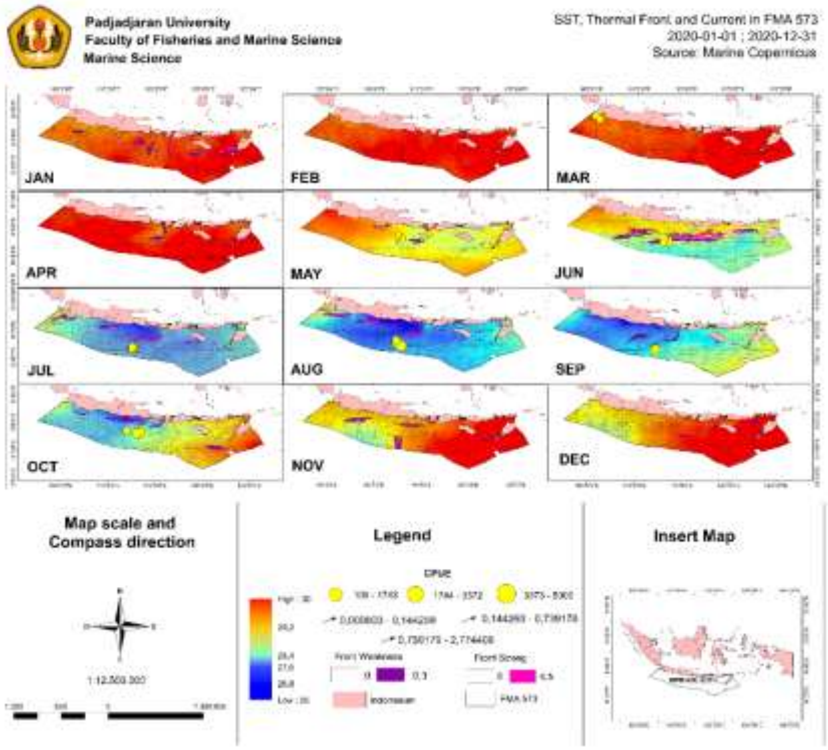


Figure 2. Visualization of SPL, Current, Thermal front and CPUE in WPP-NRI 573 in 2019 (a), 2020 (b).

Seasonal Distribution of Weak and Strong Thermal Fronts

The extent of thermal fronts in the 2019–2020 period shows that the extent of weak thermal fronts (ΔSPL 0.3°C) is consistently more dominant than strong thermal fronts (ΔSPL 0.5°C) in the 2019–2020 period. The peak extent of weak thermal fronts occurred in June–

September 2019 (>5,000 km²) and June–July 2020 (±4,000 km²), while the strong thermal fronts reached a maximum in September–October 2019 (±3,000 km²) and decreased in the following year. This pattern indicates seasonal dynamics, where thermal fronts tend to expand in the east monsoon and weaken in the west monsoon. Fluctuations in fish catches showed an increasing trend during periods of expanding thermal fronts, especially in mid-2019 and mid-2020. However, the relationship was not entirely linear; in some periods (late 2019–early 2020), catches remained high even though the thermal front area decreased.

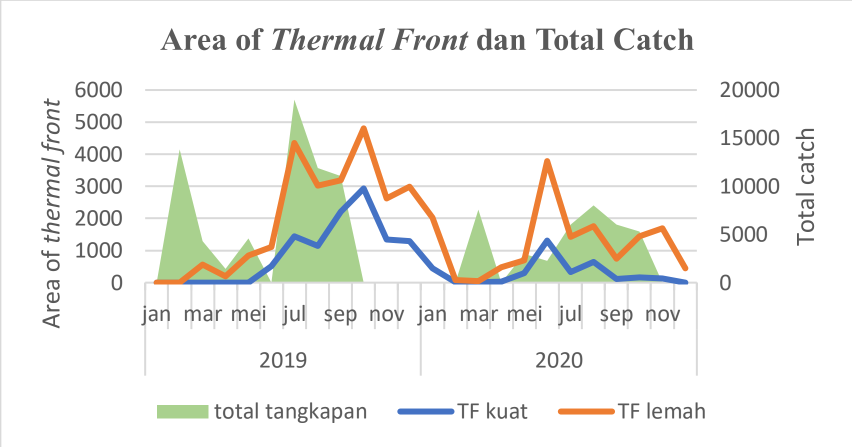


Figure 3. Thermal front area and total catchment in WPP-NRI 573 in 2019 - 2020

Catch Per Unit Effort (CPUE) of Skipjack Tuna (*Katsuwonus pelamis*) in WPP-NRI 573

The seasonal distribution of skipjack tuna was analyzed using CPUE values from 2019 to 2020. Results showed that CPUE tended to increase during the east and transitional seasons II, indicating increased concentration and potential availability of skipjack tuna during these periods. Conversely, during the west and transitional seasons I, CPUE values tended to be low and unevenly distributed. To strengthen the identification of fishing seasons, a seasonal index was used, namely the ratio of monthly catches to the annual average. Index values >100% indicate months with above-average catches, while values <100% indicate months with below-average catches. The results of this index are visualized in a seasonal graph that supports the CPUE pattern and indicates peak and low periods of skipjack tuna fishing in the study area.

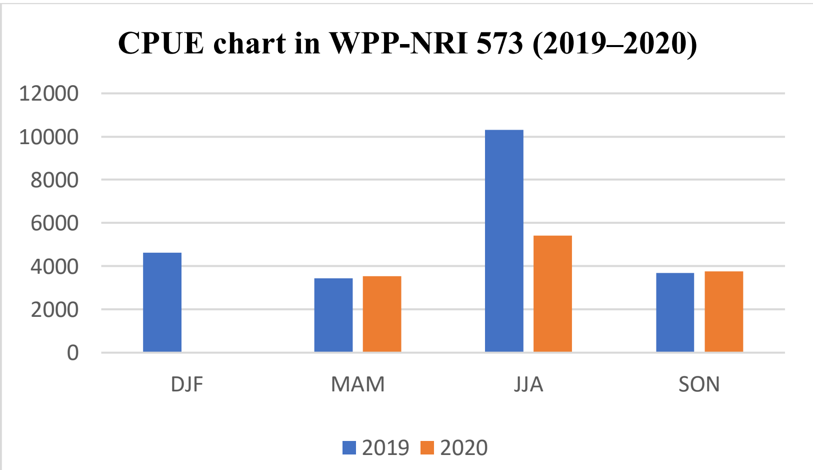


Figure 4. Seasonal average CPUE of skipjack tuna (Katsuwonus pelamis) in WPP-NRI 573 in 2019 – 2020

Based on Figure 4, the seasonal index for skipjack tuna fishing showed the highest values in February (159.43%), March (137.05%), July (287.67%), August (228.99%), and September (196.19%). These values indicate that fishing activity in these months was well above the annual average. Conversely, the lowest seasonal index value was recorded in June (18.17%), while in November and December, the index reached 0%, reflecting the absence of fishing activity during those periods. These results indicate significant seasonal variation in skipjack tuna fishing in the study area.

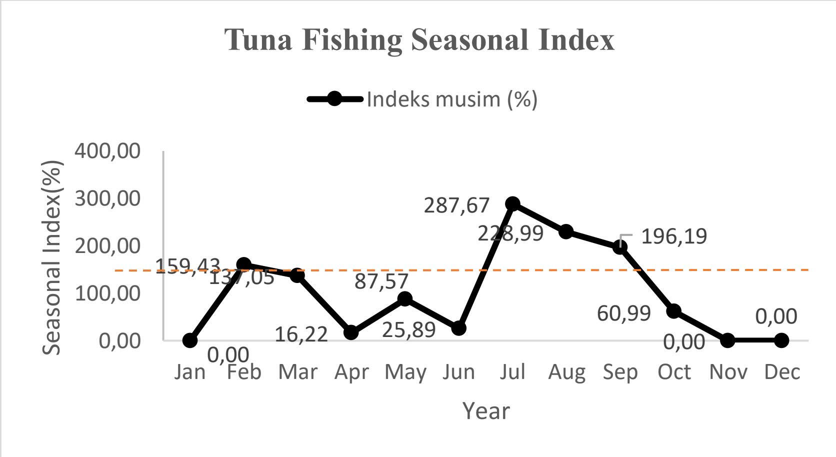


Figure 5. Seasonal index value of skipjack tuna (*Katsuwonus pelamis*) catch in WPP-NRI 573 in 2019 – 2020

Spatial Correlation Test between Thermal Front and CPUE

The spatial relationship between thermal fronts and CPUE of skipjack tuna was analyzed based on the spatial-temporal distribution of both parameters throughout 2019–2020. Thermal fronts were determined based on the sea surface temperature gradient (ΔSST), while CPUE was calculated from the ratio of catch to fishing effort. The distribution of thermal fronts across seasons was visually compared with the distribution of CPUE points to observe the spatial relationship between the two.

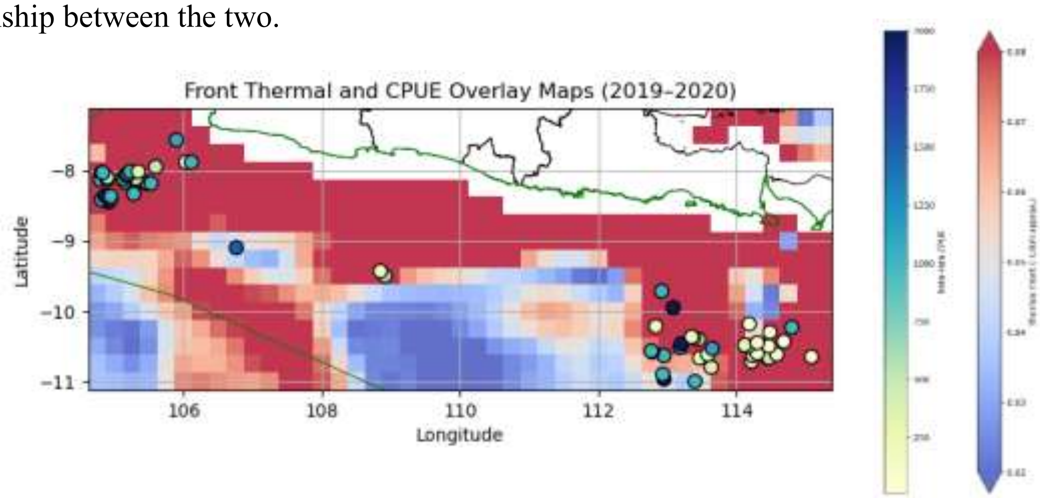


Figure 6. Thermal front and CPUE overlay map in WPP-NRI 573 in 2019 - 2020

A statistical correlation test between thermal front intensity and CPUE values yielded a Spearman correlation coefficient of -0.23. This value indicates no significant correlation between the two variables. The random distribution of the data and the nearly horizontal regression line indicate that thermal front intensity is not the sole factor determining the variability of skipjack tuna CPUE in the WPP-NRI 573 region.

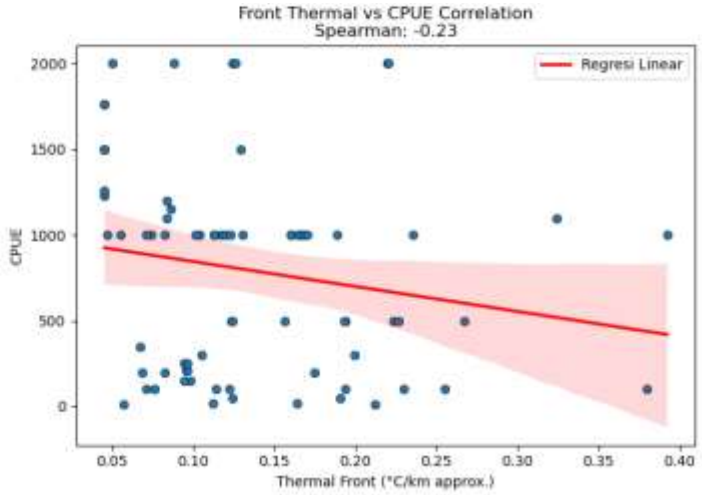


Figure 7. Pearson correlation graph between thermal front and CPUE in WPP-NRI 573 in 2019 - 2020

DISCUSSION

The results of the study indicate a clear seasonal pattern between the formation of thermal fronts and the distribution of *skipjack tuna* in WPP-NRI 573. Strong thermal fronts (ΔSPL $\geq$ 0.5°C) tend to develop during the east season, coinciding with intensified upwelling south of Java–Nusa Tenggara due to the influence of the southeast monsoon winds (Syamsuddin *et al.*, 2024; Setyawan *et al.*, 2025). These conditions enrich the waters with nutrients, enhance primary productivity, and provide habitats that support the presence of pelagic fish, including *skipjack tuna*.

The CPUE distribution shows the highest values during the west season towards transition I (February–March) and during the east season (July–September), with average values of 25.765 kg/trip and 47.150 kg/trip, respectively. These periods coincide with the expansion of strong thermal fronts, particularly during the east season. This phenomenon indicates that thermal fronts can serve as prey concentration zones, thereby increasing the likelihood of capturing *skipjack tuna*. This is consistent with the findings of Zainuddin *et al.* (2017), who reported that tuna, including *skipjack tuna*, tend to aggregate around thermal front zones due to the abundance of phytoplankton and small fish as food sources.

Fishing activities also begin to appear during transition I (April–May) and transition II (October), although the values are uneven across different locations. These findings support the notion that, in addition to the east season, transition periods may provide fishing opportunities, albeit on a more limited scale. This is consistent with the seasonal migration characteristics of *skipjack tuna*, which follow changes in currents and food availability (Hidayat, 2021).

However, the results of the Spearman correlation test indicate a weak relationship between thermal front intensity and CPUE values (r = –0.23). This suggests that although thermal fronts contribute to increased capture opportunities, other factors also play significant roles. These factors include the natural migration of *skipjack tuna*, surface current variability influenced by ARLINDO and ENSO, and the intensity of fishing effort (Trinugroho *et al.*, 2019; Nursan *et al.*, 2022). Furthermore, the spatial distribution of CPUE not fully coinciding with thermal front zones reinforces the assumption that thermal fronts are not the sole primary indicator for determining fishing grounds.

Thus, thermal fronts can be used as a supporting indicator, rather than a standalone indicator, in determining *skipjack tuna*fishing zones. Ecosystem-based management requires the integration of various oceanographic parameters, including temperature, currents, chlorophyll-a, as well as fish migration information, to develop adaptive fisheries strategies.

CONCLUSION

This study successfully identified the seasonal variation patterns and spatial relationship between thermal fronts and the distribution of *skipjack tuna* (*Katsuwonus pelamis*) in WPP-NRI 573 during the 2019–2020 period. The results show that strong thermal fronts ($\Delta SPL \geq 0.5°C$) are more extensive and intense during the east season, coinciding with increased upwelling activity in the waters south of Java to Nusa Tenggara. These conditions align with higher CPUE values, particularly in February–March and July–September, indicating that the presence of thermal fronts plays a role in influencing the migration patterns and aggregation of *skipjack tuna* in the study area.

Nevertheless, the results of the Spearman correlation test ($r = –0.23$) indicate that the relationship between thermal front intensity and CPUE values is statistically weak and insignificant. This suggests that thermal fronts are not the sole factor determining variations in catch, but are also influenced by surface currents, regional climate phenomena (ENSO, IOD, ARLINDO), and the dynamics of fishing effort.

Overall, this study confirms that thermal fronts have the potential to serve as a supporting indicator in determining *skipjack tuna* fishing zones, particularly during the east season. However, for adaptive, sustainable, and ecosystem-based fisheries management, integration with other oceanographic parameters such as temperature, currents, and primary productivity is required within the fisheries monitoring system in WPP-NRI 573.

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