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Fishing Zone for Mackerel Tuna In Fisheries Management Area 714 (FMA 714) Using PHI Model Approach

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ABSTRACT

A potential site for mackerel tuna fishing in Indonesian waters is the Banda Sea FMA 714. The primary factor that constrains the distribution and abundance of fish is oceanographic factors. This research aimed to ascertain the relationship between fish dispersion and sea surface temperature in relation to chlorophyll-a, and delineate suitable mackerel tuna fishing spots in the Banda Sea. The analytical results endorsed the utilization of the pelagic habitat index (PHI) study. The results demonstrated a notable association between the distribution of mackerel tuna and the ideal sea surface temperature range of 29.15 to 31.85°C, together with chlorophyll-a concentrations of 0.05 to 0.40mg/ m³.The designated fishing zones are firmly defined, with March and October identified as the peak months. Hotspots, defined by oceanographic preferences, correlate with the spatial distribution of possible mackerel tuna fishing sites, hence enhancing the probability of feeding. This research indicated that fishing strategies, management, and conservation in the Banda Sea FMA 714 can be improved through the spatial regulation of high-potential fishing areas.

INTRODUCTION

The first goal of SDG 14 is to preserve the sustainability of marine habitats and to mitigate the impacts of climate change on these ecosystems. To achieve this, we aimed to assess the status of mackerel tuna catches in the FMA 714 fishing zone. The Fishery Management Area (FMA) 714 includes the Banda Sea, which is more open than the Makassar Strait. The characteristics of the Pacific Ocean water mass, the Indonesian Throughflow (ITF), and monsoon changes affect the water mass in the Banda Sea **(Gordon & Susanto, 2001)**. Variations in chlorophyll-a (chl-a) concentration and sea surface temperature (SST) in the surrounding environment are influenced by the interaction between the monsoon and the ITF **(Wajsowicz *et al.*, 2003)**.

One way to determine whether Indonesia is experiencing an El Niño or La Niña event is by observing the SST conditions in the Banda Sea. These conditions indicate SST variations and are likely to form two water masses, as warm and cold waters gather in an area known as the thermal front **(Kitagawa *et al*., 2006; Zainuddin, 2011; Syah & Sholehah, 2021)**. The Banda Sea is a highly productive mackerel tuna fishing area in eastern Indonesia. Exploitation of mackerel tuna resources in the western Banda Sea appears to be increasing annually, as evidenced by the growing number of boats operating in these areas and the rising catch levels **(PPS, 2023)**.

Remote sensing satellites and geographic information systems (GIS) are widely used in aquatic research to study the relationship between fish distribution and sea conditions, which can be identified using remote sensing technology, statistical models, and GIS techniques. Research has shown that Komo tuna in the Java Sea spawn in areas with high chlorophyll-a levels **(Hidayat *et al.*, 2017)**. The fishing grounds for skipjack tuna in the strait of Malacca can be predicted using satellite data on sea surface temperature and chlorophyll-a **(Fadhilah *et al.*, 2021)**. Additionally, studies **(Thorson, 2015; Safruddin *et al.*, 2021; Jonker *et al.*, 2023)** demonstrate the positive results of using remote sensing data to identify habitats in aquatic environments. **Zainuddin *et al.* (2017)** developed the pelagic hotspot index (PHI) method, which is not yet widely used. This method differs from others by considering the relationship between oceanographic parameters, fish abundance indices, and the frequency of fishing efforts to detect spatial patterns. The PHI model has also been applied to the pelagic bigeye tuna hotspot index in the eastern Indian Ocean **(Istnaeni *et al.*, 2023)**.

The increasing market demand, which threatens resource sustainability, presents an additional challenge for mackerel tuna fisheries, particularly in FMA 714. Therefore, identifying the potential habitat of mackerel tuna is crucial for developing sustainable fisheries management plans. The objective of this research is to identify potential mackerel tuna catch zones in the southern Banda Sea and to present these zones in a spatial and temporal context. By integrating primary data and satellite imagery, the pelagic hotspot index (PHI) model is recognized as one of the most significant ecological methodologies. The PHI model is based on a suitability index that quantifies habitat conditions in relation to one or more environmental variables.

MATERIALS AND METHODS

Study site

In 2023, mackerel tuna harvest data were obtained over a 12-month period through collaboration with fishing vessels employing purse seine nets in the Banda Sea. The research conducted yielded a total of 526 data points for catch position (latitude and longitude) and CPUE catch outcomes. Then, remote sensing data were used in the PHI model. The CPUE of mackerel tuna is expressed in mackerel tuna per set, indicating the number of catches (fish) per set. To achieve the objectives of this research, we focused our analysis on the high catch period (2023) of the mackerel tuna in the Banda Sea. Weekly oceanographic variables obtained remotely during 2023 include sea surface temperature (SST) and chlorophyll-a (chl). The moderate resolution imaging spectroradiometer (MODIS) aqua standard mapped image (SMI), with a spatial resolution of approximately 4 × 4 km, was downloaded from ocean color (http://oceancolor.gsfc.nasa.gov). Oceanographic data were processed and cropped using the SeaWiFS Data Analysis System (SeaDAS) version 7.5.3 (NASA, Greenbelt, MD, USA) according to the study area. Additionally, the data were overlaid and analyzed in the ArcGIS 10.2 software package (ESRI, Redlands, CA, USA).

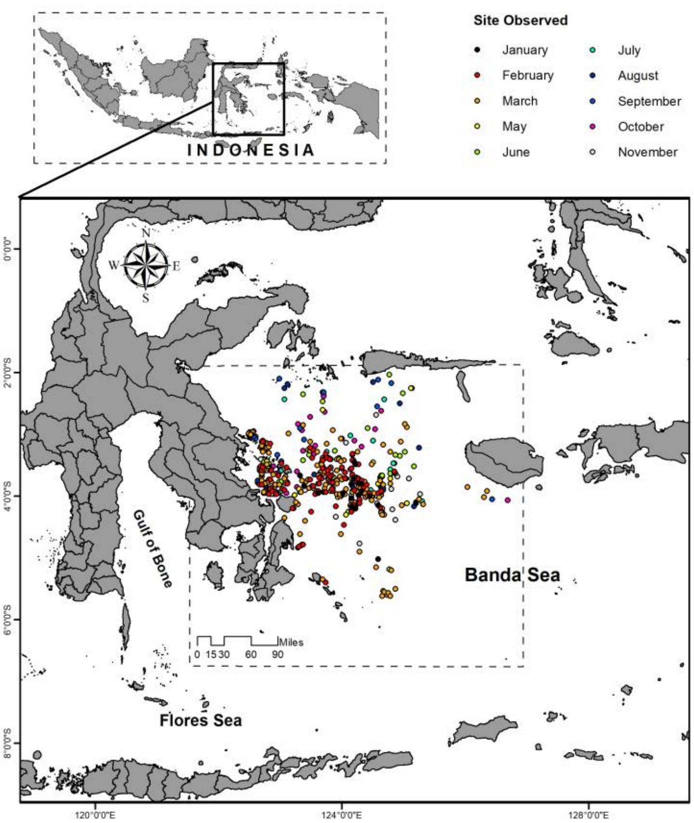

Fig. 1. Study area in the southern waters of the Banda Sea, Indonesia

Data analysis

PI CPUE represents the average probability index for mackerel tuna, obtained from the correlation between CPUE and the two oceanographic variables, SST and PP, for each histogram graph. CPUE represents the CPUE value of oceanographic variable i for interval class j; $CPUE_{max}$ indicates the maximum CPUE value for oceanographic variable i; n specifies the total count of variables. Plf is the average probability index obtained from the association between the frequency of mackerel tuna captures and the oceanographic variables illustrated in the histogram. F specifies the fishing frequency value of the oceanographic variable i for interval class j; Fi_{max} indicates the maximum fishing frequency value for the oceanographic variable i, and PHI represents the pelagic hotspot index. The PHI equations can be written as follows **(Zainuddin *et al.*, 2017)**:

$$PI_{CPUE} = \frac{\sum \frac{CPUE_{ij}}{CPUE_i max}}{n}$$

$$Plf = \frac{\sum \frac{F_{ij}}{F_i max}}{n}$$

$$PHI = \frac{(PI_{CPUE} + Plf)}{2}$$

This PHI analysis employs a 0-1 weighting method, where values approaching 1 indicate an increased possibility of locating the mackerel tuna. A PHI value of ≥ 0.75 signifies an appropriate environment for the mackerel tuna. A diminished value signifies a region with a reduced likelihood of encountering the mackerel tuna. The ArcGIS 10.2 Package was utilized to delineate the possible fishing zones for the mackerel tuna following the PHI study. Subsequently, the model was validated by creating scatter plots that correlate PHI with mackerel tuna CPUE. This graphic can determine the suitability of this model.

RESULTS AND DISCUSSION

The beginning of the year was marked by the peak catch and the largest fleet of fishing vessels. The number of boats and the catch of mackerel tuna declined in the following months; however, the average catch per boat remained relatively stable until the end of the year (Fig. 1). This graph illustrates the frequency of captures in relation to sea surface temperature. The frequency is at its highest between 29 and 31°C, with a decreasing trend at higher or lower temperatures. This suggests that fishermen tend to fish in regions with lower sea surface temperatures. According to this graph, mackerel tuna catches are most productive and frequent in areas with low chlorophyll-a concentrations and sea surface temperatures ranging from 29 to 31°C (Fig. 2).

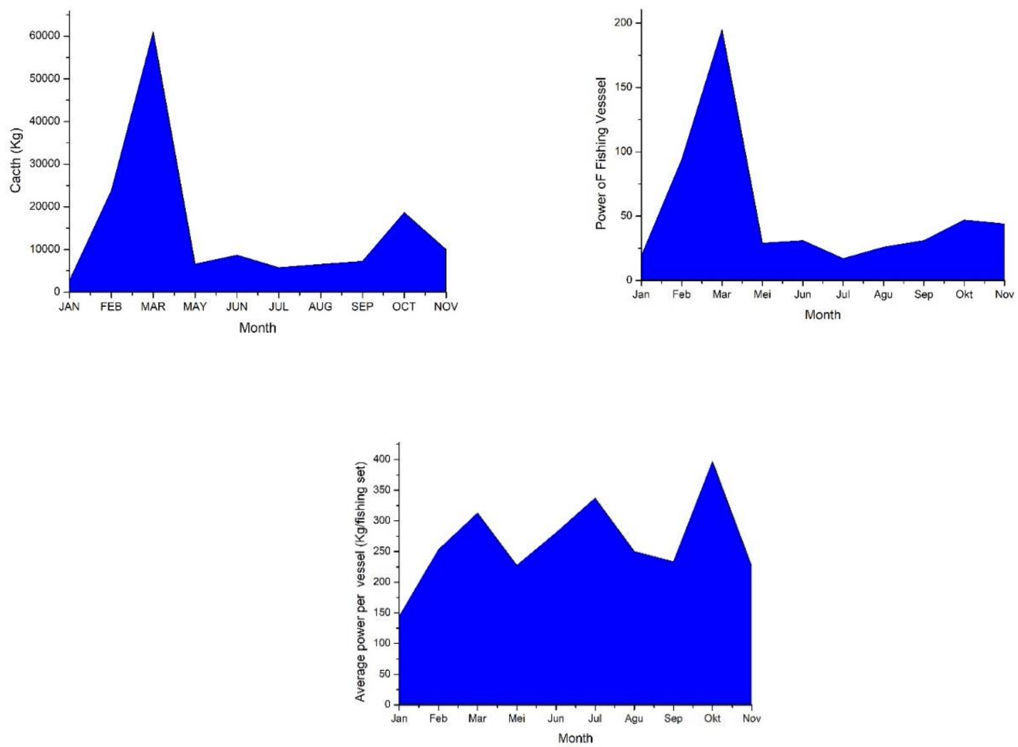

Fig. 2. Monthly avarenge of catch per month, power of fishing vessel, average catch per vessel

Fig. (2) shows the results of our research where the relationship between catch results, fishing trips, and average catch per trip (kg) was found. The highest catch results were obtained in March, supported by a high number of fishing trips during that month. Then, in October, high catch results were also found with the same number of trips. These results differ from the findings of the study by **Syah and Sholehah (2021)**, where the highest catch of the mackerel tuna in the waters of Bali occurred in September and October. This discrepancy may be influenced by the differing conditions of the Bali Sea and the Banda Sea, which affect the catch results. Fig. (3) shows the relationship between catch frequency, catch amount, and the distribution of MODIS sea surface temperature and MODIS chlorophyll-a. The graph shows that the catch frequency and amount are highest at sea surface temperatures ranging from 29.00 to 32.00°C. Meanwhile, the chlorophyll-a conditions are in the range of 0.05 – 0.4mg/ m³.

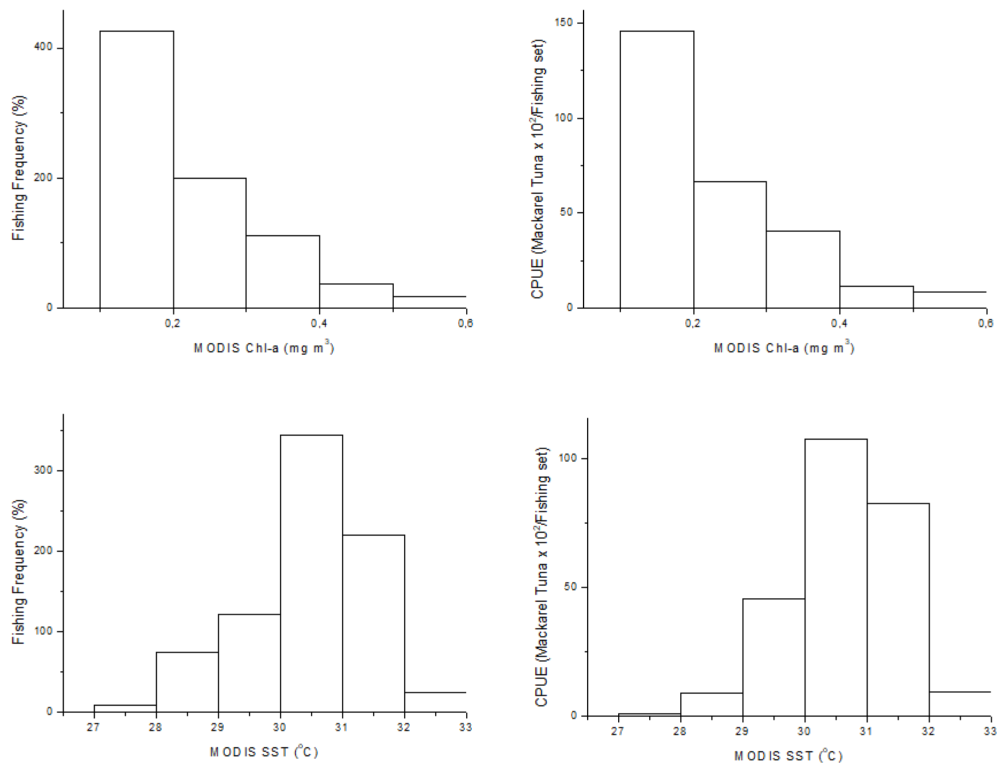

Fig. 3. The graph shows the relationship between CPUE – chlorophyll-a; Catch Frequency - Chlorophyll-a; CPUE - SST; Catch Frequency – SST

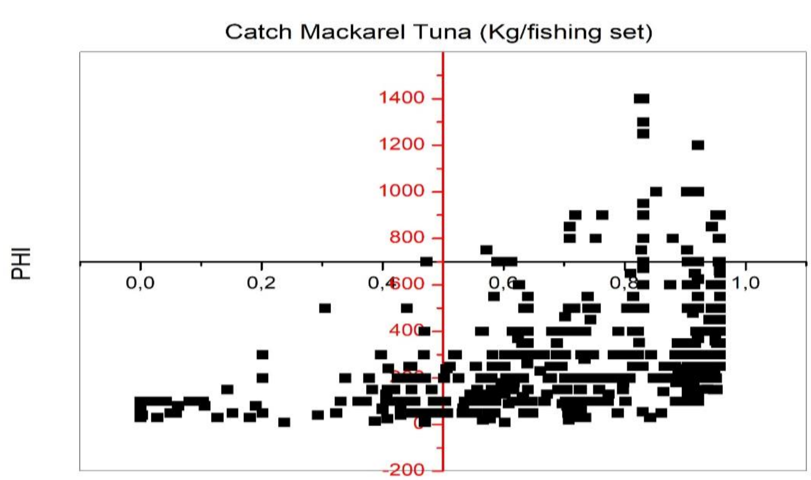

Fig. 4. The distribution of PHI values for extracted validation points

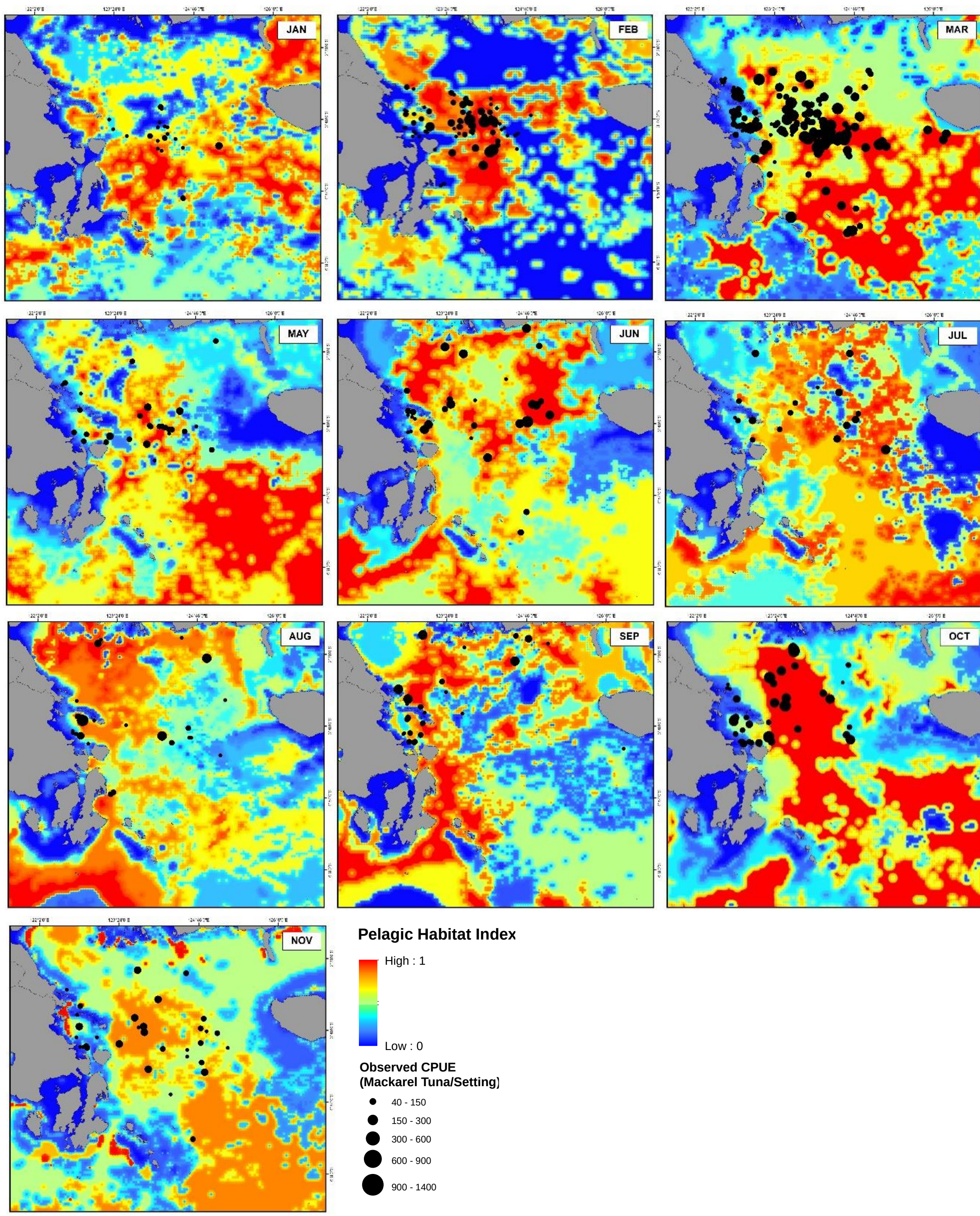

Fig. 5. Spatial distribution of enduring pelagic habitat hotspots for mackerel tuna during the peak season from January to December (frequency per annum) in the Banda Sea, Indonesia

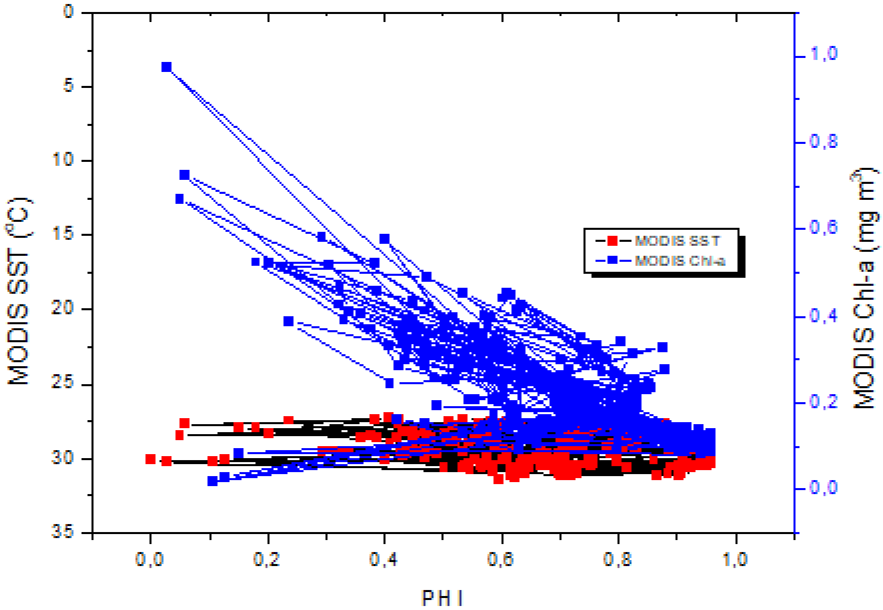

Fig. 6. The relationship between "PHI" and MODIS SST - MODIS chlorophyll-a

Satellite-based oceanographic data related to mackerel tuna fishing activities highlight specific areas where these fish are most commonly found (Fig. 3). Overall, the catch per unit effort (CPUE) related to sea surface temperature (SST) indicates that most catches are concentrated in areas with SST ranging from 29.15 to 31.85°C, as shown in the histogram (Fig. 3). A similar trend is observed in the 3D graph, which shows the relationship between catch frequency and SST, with both histograms indicating that the preferred SST tends to center around 30.5°C, suggesting the highest likelihood of finding fish under these conditions. This is in contrast with sea surface temperature trends observed in the Banda Sea in 2018, where the optimal SST range for mackerel tuna was around 20-22°C **(Wijaya *et al.*, 2018)**. Similarly, **Fadhilah *et al.* (2021)** found that the optimal SST for mackerel tuna in the Makassar Strait was around 26-29°C.

The total CPUE for the mackerel tuna related to chlorophyll-a was at its highest in areas with environmental variables ranging from 0.05 to 0.40mg/ m³ (Fig. 3). The relationship between mackerel tuna catch frequency and surface chlorophyll-a shows a similar pattern (Fig. 3), with a preference for chlorophyll-a concentrations mostly concentrated around 0.26mg/ m³. Additionally, **Fadhilah *et al.* (2021)** found that chlorophyll-a concentrations above 0.20 mg/m³ correlated with a significant potential for mackerel tuna catches. A chlorophyll-a concentration of 0.26mg/ m³ corresponds to the maximum CPUE and catch frequency for mackerel tuna.

The hotspot habitat area potentially suitable for mackerel tuna is most prominent in May and October, covering the waters of the entire Banda Sea. The average pelagic hotspot index (PHI) across the study area during peak seasons ranges from 0.60 to 0.90.

Our findings show that the mackerel tuna catches are primarily concentrated in hotspot areas, with the most suitable habitat forming strongly in the southern and northeastern parts of the Banda Sea. This may serve as the habitat preference for the mackerel tuna in the coming years. The spatial distribution of these habitat hotspots varies (Fig. 5), but their average positions do not change significantly. The habitat center in the southern part of the Banda Sea is more prominent than in the eastern part, indicating that the high habitat for the mackerel tuna spans a wide area. The spatial and temporal map (Fig. 5) shows that March and October are peak seasons for mackerel tuna in the western Banda Sea, while the abundance of the mackerel tuna may be the lowest in July and August compared to other months during the study period.

Our findings are the first in the Banda Sea regarding the peak and lean seasons for mackerel tuna, as determined using the PHI model. This is supported by interview results with fishermen, who reported a shift in the peak catch season. This information can be valuable for further research, establishing fishing seasons, and monitoring the mackerel tuna catches in the future. We have developed a satellite-based environmental data-catch performance relationship model to explore and map the spatial distribution patterns and sustainability of pelagic mackerel tuna hotspots. Our model essentially generates pelagic habitat hotspots by identifying the optimal combination of two environmental factors (SST and chlorophyll-a) from areas with high catch performance. Several studies support the importance of this combination of sea surface temperature and chlorophyll-a in explaining and identifying pelagic fish habitats **(Sartimbul *et al*., 2010; Nurdin *et al.*, 2015; Satya *et al*., 2017; Fadhilah *et al.*, 2021; Imron *et al.*, 2021; Syah & Sholehah, 2021; Syamsuddin *et al.*, 2023)**. Our research shows that the mackerel tuna habitats are associated with environments that have warm sea surface temperatures and specific chlorophyll-a concentrations conducive to fishing.

The PHI model has been used by **Zainuddin *et al*. (2017)** to identify potential habitats for the skipjack tuna, by **Istnaeni *et al.* (2023)** for the bigeye tuna in the eastern Indian Ocean, and by **Putri *et al.* (2021)** to map potential skipjack tuna regions in the Southern Makassar Strait. The PHI model indicates that SST and chlorophyll-a significantly influence the mackerel tuna catch. For spatial model validation, Fig. (5) shows that the spatial distribution of fish catch data throughout 2023 mostly occurred in predicted habitat hotspots (PHI > 0.85). We used spearman rank correlation analysis and found a strong positive correlation (0.5374) between the mackerel tuna catch data and PHI analysis. This positive correlation suggests that PHI analysis can be used to determine potential areas for optimal mackerel tuna catch in the Banda Sea.

In this study, chlorophyll-a concentration and SST features obtained from satellite remote sensing were integrated with statistical modeling and GIS techniques. However, other factors, such as wind and current patterns, salinity, sea surface height, and lunar index, may also influence the presence of the mackerel tuna in the Banda Sea. Oceanographic parameters are crucial for researching potential fishing grounds for mackerel tuna. A reliable and rapid forecast of potential fishing locations can assist fishermen in making decisions and can reduce search time, ultimately resulting in higher catches with less effort.

CONCLUSION

Pelagic mackerel tuna habitat hotspots in FMA 714, Banda Sea, are influenced by oceanographic factors, specifically sea surface temperature and chlorophyll-a, which can be identified from satellite imagery. The CPUE of the mackerel tuna sharply increases in areas with the highest pelagic hotspot index (PHI). Our findings conclude that sea surface temperature and chlorophyll-a are the most influential habitat predictors for the distribution of the mackerel tuna in the Banda Sea, accurately identifying areas highly suitable for the highest mackerel catches, as indicated by the elevated PHI. The mackerel tuna habitat predictions suggest that the peak season for the mackerel tuna occurs in March and October. These results provide valuable insights for future research and the management of mackerel tuna resources.

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