Spatial distribution of potential fishing grounds for skipjack tuna *Katsuwonus pelamis* in the Makassar Strait, Indonesia

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Abstract. Skipjack tuna (*Katsuwonus pelamis*) is one of the large pelagic fish with great potential in the Makassar Strait. Its fishing, migration, and physiology are inseparable from the oceanographic conditions of the waters. This study aimed to identify the relationship between the skipjack tuna catch and oceanographic variables and to analyse the potential fishing ground for skipjack tuna in the Makassar Strait. We used the survey method to collect the fishing and oceanographic data from July to October 2018. The data was analysed using the Multiple Linear Regression (MLR) to find out the relationship between the skipjack tuna catch and oceanographic variables, Sea Surface Temperature (SST) and Chlorophyll-a (Chl-a). Potential skipjack tuna fishing grounds were mapped using ARCGIS 10.2 software package based on MLR output. The results showed that the high catches were associated with chlorophyll-a (0.15 - 0.2 mg m^{-3}) and SST (29.5 - 30°C). The results of the MLR analysis showed the distribution and movement of the fishery data (in-situ data) were consistent with the prediction of the potential fishing grounds for skipjack tuna and reached a peak in October during the period of the study. Spatial patterns of the potential fishing grounds for skipjack tuna fishing were mostly located at the areas of 0°00′ to 4°30′ S and 118°0‘E to 119°00′ E. These results illustrate that spatial distribution of skipjack potential fishing grounds provide important information for conservation and fishing management strategies.
Key Words: chlorophyll-a, multiple linear regression, satellite oceanographic data, SST.

Introduction. Skipjack tuna (*Katsuwonus pelamis*) is one of the large pelagic fish with great potential in the Makassar Strait (Hidayat et al 2019a; Putri & Zainuddin 2019a), making it one of the main catches of purse seine in these waters. The *K. pelamis* production data in FMA (Fisheries Management Area) of 713 (including the Makassar Strait, Flores Sea, Bone Gulf, and Bali Sea) showed an increase of about 44.37% from 2005 - 2014 i.e. from around 24,978 tons to 56,299 tons (Marine and Fisheries Ministry of Indonesia 2015).

Changes in oceanographic parameters such as temperature and chlorophyll-a cannot be separated from the role of currents in the oceans and one of the most influential water mass flows in Indonesia is the Indonesian Throughflow (ITF) (Fan et al 2013; Gordon 2005; Iwatani et al 2018; Nababan et al 2016; Susanto & Gordon 2005). Pacific warm water reaches Indonesia through the Makassar Strait, which significantly impacts the state of these waters (Gordon 2005; Sprintall 2019). The condition of the bottom topography of Indonesian waters is complex and diverse. The presence of the ITF adds to the complexity of the physical processes taking place in Indonesian waters, which also has an impact on fish species that respond to aquatic conditions, such as *K. pelamis*. An example is a process of mixing two different masses of water, upwelling, downwelling, and so on (Fan et al 2013; Gordon 2005; Sprintall 2019).

Research to clarify the mechanisms involved in the geographical distribution of *K. pelamis* is important to enrich science and support strategies for managing *K. pelamis* capture (Ashida 2020; Putri & Zainuddin 2019b). The complex, unique, and dynamic nature of Indonesian waters make oceanographic condition data from satellite observations a technological choice that can be used to observe in near real-time and continuously (Butler et al 1988; Nurdin et al 2017; Putri & Zainuddin 2019b; Putri et al 2018; Zainuddin et al 2017). Therefore, the objectives of the research were to identify the relationship between the *K. pelamis* catch and oceanographic variables and to analyze the spatial distribution of the potential fishing grounds for *K. pelamis* in the Makassar Strait, Indonesia.

Material and Method. This research was carried out in Barru and Pinrang Regencies, which are fishing bases for fishers who do *K. pelamis* fishing in the waters of the Makassar Strait (Figure 1). The research was conducted from July to October 2018 by participating to purse seine fishing operations.

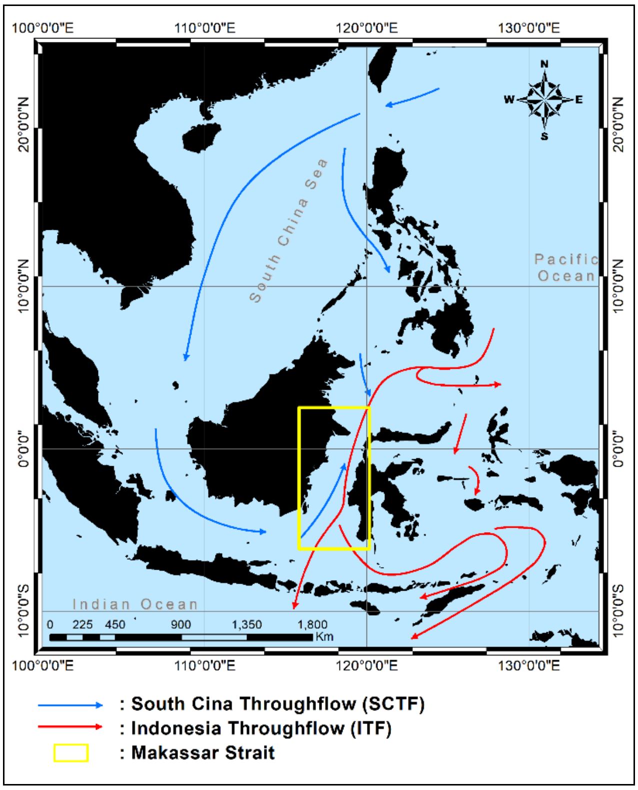

Figure 1. The selected study area map of Makassar Strait with the ITF and SCTF routes. The ITF and SCTF routes were obtained from Fan et al (2013).

The data used consists of two types of data, namely primary data, and secondary data. Primary data consists of *K. pelamis* fishing points data, *K. pelamis* Catch per Unit Effort (CPUE), SST, and Chl-a. While secondary data is in the form of SST and Chl-a satellite data used to map SST and Chl-a spatially and temporally during the study period, and the secondary data table can be seen in Table 1.

Table 1

Secondary data types used

No	*Oceanographic factors*	*Satellite/Sensor*	*Data Source*
1	SST	Aqua/MODIS	www.oceancolor.gsfc.nasa.gov
2	Chl-a	Aqua/MODIS	www.oceancolor.gsfc.nasa.gov

We developed the Multiple Linear Regression (MLR) to predict the potential fishing grounds of *K. pelamis*, spatially and temporally in the Makassar Strait. MLR is an analysis model used to find the relationship between independent (predictor variables) and dependent (response variable) factors, with oceanographic factors (SST and Chl-a) as the independent variables and the CPUE of *K. pelamis* as the dependent variable. The MLR formula is as below:

$$y = \alpha + b_1(SST) + b_2(Chl) + e$$

Where "y" is the CPUE prediction of *K. pelamis*, "ɑ" is an intercept, "b" is a slope, SST is the monthly SST value from satellite data, Chl is the monthly chlorophyll-a concentration value from satellite data, and "e" is a random error.

After that, we proceeded with predicting potential catches spatially and temporally based on the results of values ɑ and b obtained from regression analysis. The potential fishing grounds of *K. pelamis* were analysed using ArcGIS 10.2 package spatially and temporally.

Results

Spatial and temporal variabilities of SST and Chl-a concentration.

Sea Surface Temperature (SST). To find out the optimum distribution of SST values distribution every month during the study period, an SST count values histogram was made (Figure 2). Figure 2 showed that in July, the optimum SST was at SST 30°C. While in August to October, it was in the range of 29.5 - 30°C. So, it was found that the optimum SST for potential skipjack fishing areas is 30°C. The results of this study are supported by previous research, which shows that *K. pelamis* habitat temperatures in tropical waters are in the range of 29.5 to 31.5°C (Zainuddin et al 2017).

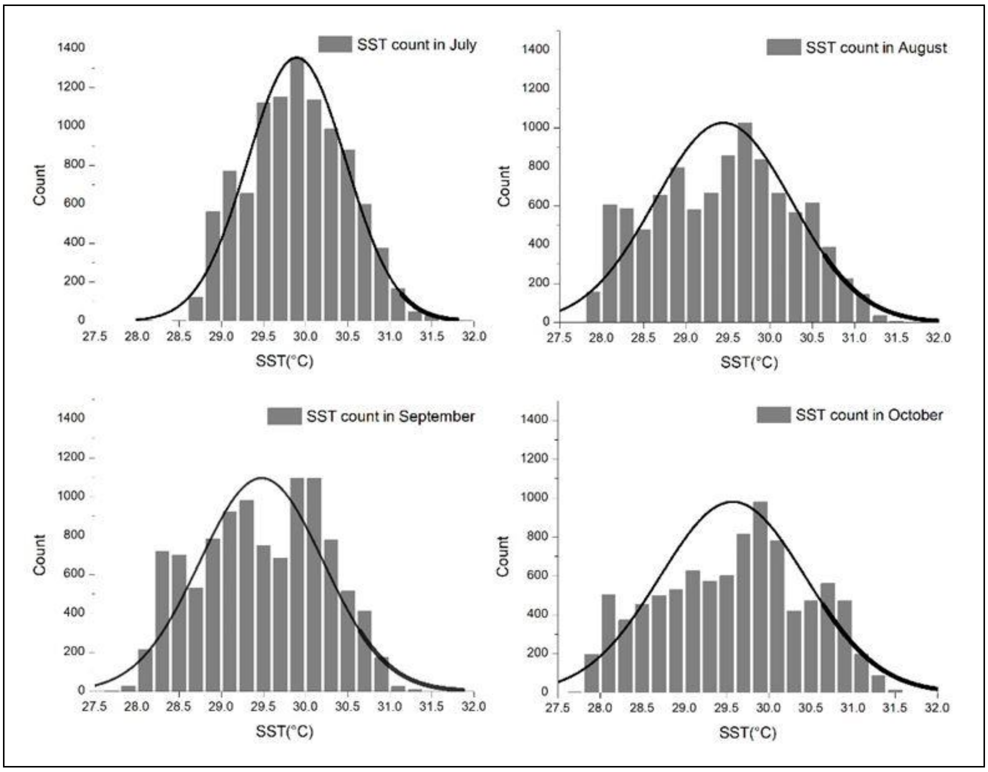

Figure 2. Histogram of the SST count values in a certain range. The black line shows the SST value distribution curve.

The SST was then displayed on a spatial and temporal contour map (Figure 3). Contour lines were used to describe the *K. pelamis* potential fishing grounds spatially and temporally at the study site.

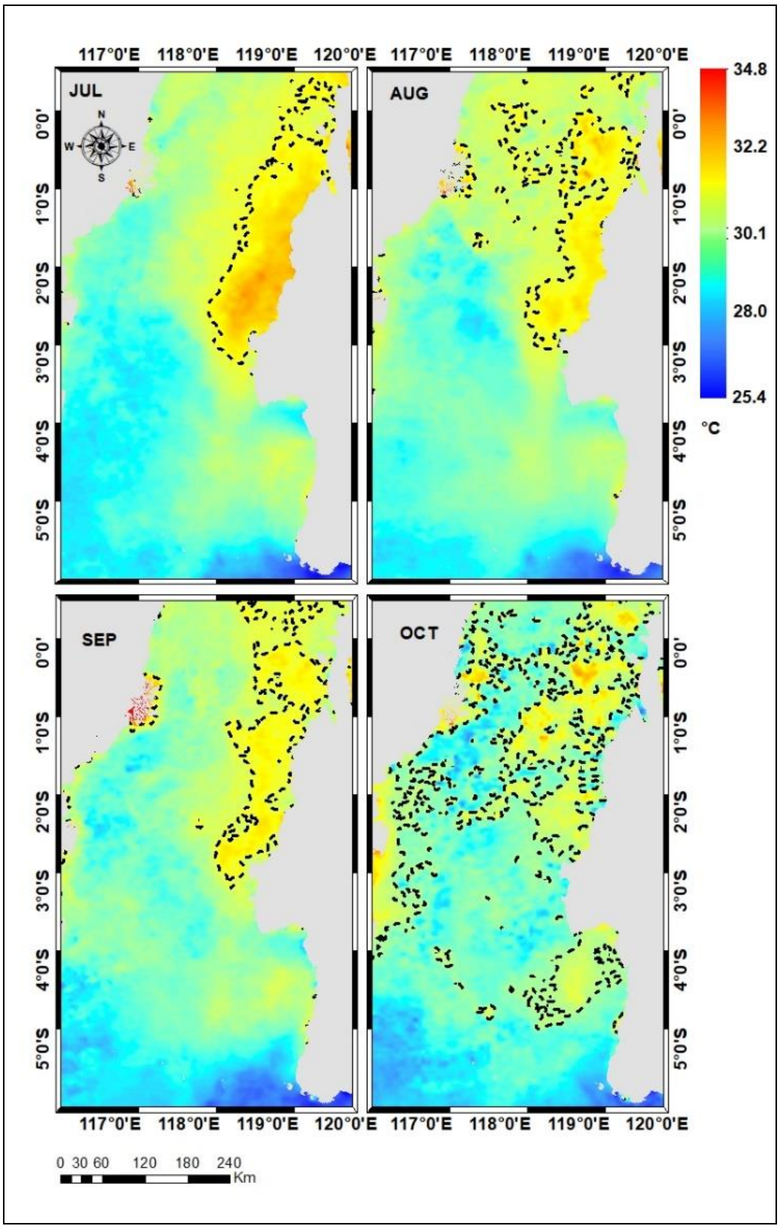

Figure 3. Spatial and temporal map of the variability of SST distribution in the Makassar Strait. Black dashed lines show the optimum SST contour lines (30°C).

Based on this map (Figure 3), it is shown that from July to August *K. pelamis* has the potential to be in the northern waters of the Makassar Strait or the waters of West Sulawesi. Whereas in October with the optimum SST conditions for *K. pelamis* scattered almost along the Makassar strait.

Chlorophyll-a (Chl-a). The Chl-a concentration in the Makassar Strait from July to October has the highest values between 0.15 to 0.2 mg m^{-3} (Figure 4).

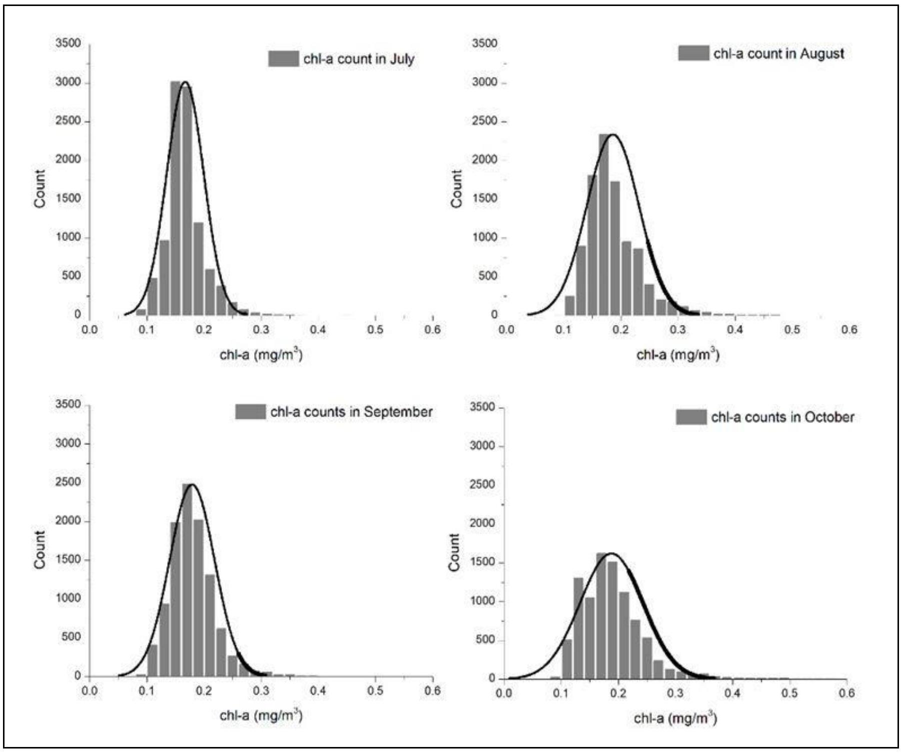

Figure 4. Histogram of the Chl-a count values in a certain range. The black line shows the Chl-a value distribution curve.

Figure 5 indicated that the chlorophyll-a content from July to October was in the range of 0.07 - 1.5 mg. The distribution of Chl-a content was seen to be high in coastal areas (shallow waters), while lower in deep water areas. The Chl-a contour line showed the area boundaries with the optimum Chl-a content for *K. pelamis*. By paying attention to the map, it can be known the potential prediction area of *K. pelamis* based on the parameter Chl-a concentration.

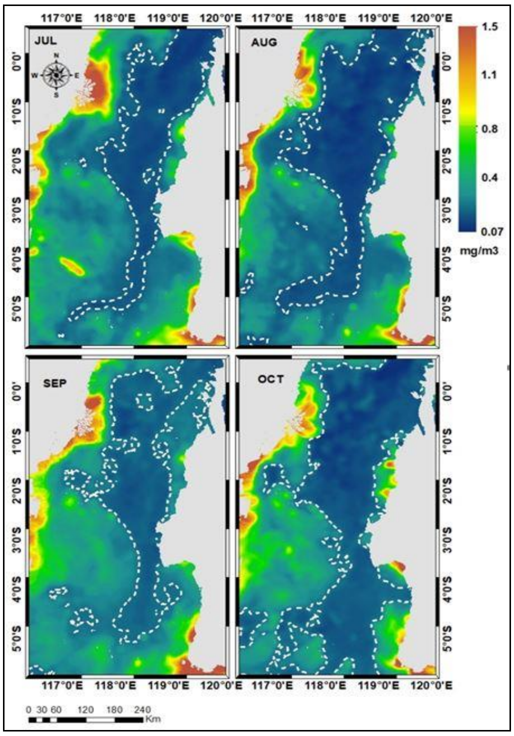

Figure 5. Map of the variability of Chl-a distribution in the Makassar Strait spatially and temporally. White dashed lines showed the optimum Chl-a contour lines (0.2 mg/m^3).

***K. pelamis* catches**. The highest catch of *K. pelamis* was in October (around 800 skipjacks/setting), and the lowest in August (around 150 skipjacks/setting) (Figure 6).

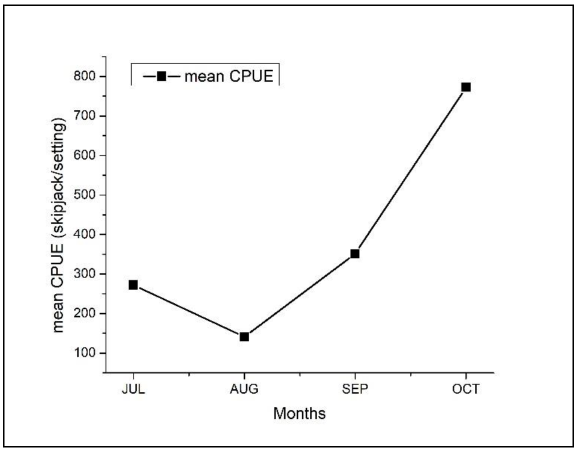

Figure 6. The average catch of skipjack tuna during the study period in the Makassar Strait.

Fishery data (primary data) was used to verify the results of the MLR analysis, the results were the same as the average fish catch graph (Figure 6). The predicted catch was also expected to be high in October and lowest in August. The graph (Figure 6) demonstrated the same results as the spatial and temporal prediction maps based on the SST parameter (Figure 3) that the highest catch was obtained in October.

***The prediction of spatial distribution of potential fishing ground*.**

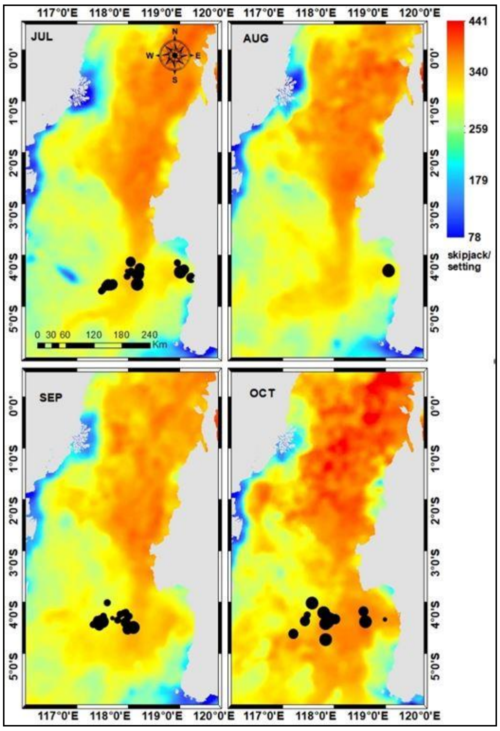

Figure 7. Spatial and temporal distribution of predicted skipjack catches from July to October in the Makassar Strait. The black dots are the CPUE of skipjack tuna.

Figure 7 was mapped by performing a combination of SST and Chl-a optimum values, based on the coefficients ɑ and b obtained from the MLR analysis. The optimum combination of predictor factors (SST and Chl-a) can produce maps of potential fishing grounds and horizontal distribution of fish in the waters. Thus, it was known that almost all of Makassar Strait waters are potential areas for *K. pelamis* fishing, especially on the coast of Sulawesi. Spatial potential fishing grounds for *K. pelamis* fishing were mostly located in the areas determined from 0°00′ to 4°30′S and 118°0‘E to 119°00′E. Predictions of potential *K. pelamis* fishing vary temporally.

Figure 7 displayed that from July to October, October was predicted with the highest catch compared with other months during the study period. However, to determine the best season of catching *K. pelamis*, further analysis is needed.

Discussion

Spatial and temporal variabilities of SST and Chl-a concentration.

Sea Surface Temperature (SST). SST is one important indicator that influences the collection, migration, and physiology of fish (Bertrand et al 2002; Muhling et al 2015; Pauly & Cheung 2017; Zainuddin 2011). SST anomalies affect the spatial and temporal distribution and abundance of *K. pelamis* (Putri et al 2018). *K. pelamis* itself has a limit of SST tolerance at every stage of its life. A study mentioned that *K. pelamis* spawning temperature is in the range of 29.5 - 30°C (Venegas et al 2019). Whilst, the upper limit of SST for *K. pelamis* is estimated to be no more than 33 °C (Barkley et al 1978; Bernal et al 2017). The smaller size (> 4 kg) are found in the surface layer while the larger size are found under the thermocline layer with lower SST (Bernal et al 2017). This study confirmed that SST greatly influences the amount of *K. pelamis* catches.

Chlorophyll-a (Chl-a) concentration. Besides SST, Chl-a also is one of the key factors to know the habitat selection of skipjack tuna (Wang et al 2018; Zainuddin et al 2017). Chl-a is one of the parameter indicators of water fertility. Therefore, this parameter is almost always included in a study to analyze the potential fishing zone of pelagic fish. In a previous study in the Bone Gulf-Flores Sea, that supports the results of this study, also found that the Chl-a optimum for *K. pelamis* is in the range 0.15 - 0.35 mg/m^3 (Zainuddin et al 2017). So, in *K. pelamis* habitat research like this, Chl-a concentration is used as one of the determining factors in the analysis of potential fishing grounds.

Katsuwonus pelamis catches. Tuna capture is generally done with Fish Aggregating Devices (FAD) fishing (Guillotreau et al 2011; Hidayat et al 2019b; Jaquemet et al 2011), as is done in the Makassar Strait. Not only oceanographic factors such as SST and Chl-a, but *K. pelamis* catches are also influenced by catching season (Fujino 1972; Andrade & Santos 2004). There are even certain times that fishermen prefer not to go to the sea because the catch is not worth the capital spent on fishing operation. In one study, it was mentioned that tuna catches were also influenced by prey density and prey characteristics (Bertrand et al 2002).

The prediction of spatial distribution of potential fishing ground. The potential zones map (Figure 7) showed areas in waters with a high probability of *K. pelamis* aggregation based on the calculation of SST and Chl-a optimum for *K. pelamis*. A previous study has shown that using fish catch data can determine the potential zones of fish species (Zainuddin et al 2008). Previous research in the Indian Ocean also mentions that the peak season for tuna catch includes October (Nurani et al 2016).

This study clarifies the relationship of oceanographic parameters in the form of SST and Chl-a to the *K. pelamis* catch and the spatial and temporal fishing grounds potential of *K. pelamis* in the Makassar Strait. This research is important to enrich knowledge and support conservation and fishing management strategies.

Conclusion. The determination of *K. pelamis* habitat preferences were done by combining the optimum conditions of oceanographic factors of SST and Chl-a. The highest *K. pelamis* catches were predicted to be in the range of SST 29.5 - 30°C and Chl-a 0.15 - 0.2 mg m^{-3}. This study suggested that the optimum combination of SST and Chl-a was a good method for determining the preferences of *K. pelamis* habitat in tropical waters. Spatial potential fishing grounds for *K. pelamis* fishing were mostly located at the areas of 0°00′S to 4°30′S and 118°0‘E to 119°00′E.

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