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To cite this article: R Hidayat *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **253** 012045

Skipjack Tuna (*Katsuwonus pelamis*) catch in relation to the Thermal and Chlorophyll-a Fronts during May – July in the Makassar Strait

R Hidayat[1], M Zainuddin[2], S Safruddin[2], A Mallawa[2] and S A Farhum[2]

[1]Department of Fisheries Science, Faculty of Marine Science and Fisheries, Graduate School of Hasanuddin University, Makassar 90245, Indonesia
[2]Department of Fisheries Science, Faculty of Marine science and Fisheries, Hasanuddin University, Makassar 90245, Indonesia

Email: mukti_fishocean@yahoo.co.id

Abstract. Skipjack tuna (*Katsuwonus pelamis)* is a highly migratory fish that has high economic value and wide market acceptance. This research aimed to analyse the relationship between thermal and chlorophyll-a fronts and skipjack tuna catch in coastal waters around Barru, Makassar Strait, Indonesia. This study used two dataset types, data collected in-situ (fishing positions and skipjack tuna catch), and remotely sensed data (Sea-surface temperature and chlorophyll-a, with spatial and temporal resolutions of 4 km and monthly, respectively). Thermal and chlorophyll-a fronts were estimated using a Single Image Edge Detection (SIED) algorithm, and the distances from each catch data point to the nearest fronts was calculated in ArcGIS 10.5. We then analysed the data using the Generalized Additive Model (GAM) statistical model. The results showed that both fronts were detected in every month (May – July). The optimum distance between the thermal front and catch distributions was in the range of 0 - 50 km and the highest catches occurred at a distance of 0 - 10 km with a horizontal gradient of 0.1 - 0.5°C. Meanwhile the distance between the chlorophyll-a front and catch distribution was in the range of 0 - 50 km and the highest catches occurred at a distance of 10 - 20 km with a horizontal gradient of 0.01 - 0.02 mg m^{-3}. We suggest that skipjack tuna distributions in the study area may be positively associated with the thermal and chlorophyll-a fronts.

1. Introduction

The fisheries potential of Fisheries Management Area (FMA) 713 in terms of large pelagic fish, including skipjack tuna (*Katsuwonus pelamis)*, is estimated at 419,342 tons [1]. The Makassar Strait is part of FMA 713 and is considered one of the best places to catch skipjack tuna. This is because of the high chlorophyll-a and primary productivity of the Makassar Strait, both of which are closely related to the Indonesian Throughflow (ITC) [2]. The pattern of skipjack distribution is greatly influenced by marine environmental factors such as sea surface temperature (SST), chlorophyll-a and sea-level anomalies [3,4].

Hotspots represent key habitat for determining the spatial distribution of skipjack tuna [5]. Skipjack tuna hotspots are also thought to be strongly associated with front, eddy and upwelling dynamics [6,7,8,9]. A front is the boundary between two different water bodies [10]. Chlorophyll-a thermal fronts can be used as indicators in the marine environment [11,7,12]. Information on the state of oceanographic parameters can be obtained using remote sensing technology [13]. Some studies have used remote sensing technology with regard to the relationship between swordfish fishing and thermal fronts in the North Atlantic [14]. Spatial and temporal dynamics of skipjack tuna have been found to be related to the thermal and chlorophyll fronts around the Seram Sea [15].

2. Research methods

This research was conducted during May - July 2017 in the waters of Barru, Makassar Strait, South Sulawesi, Indonesia. The study focused on the purse seine fishing operations based in Siddo Village, Soppeng Riaja Sub-district, Barru District.

2.1. In-situ and ex-situ data collection

In-situ data were obtained through direct observation by following fishing operations using purse seine vessels operating out of Siddo Village. We collected data from 60 fishing ground points, with coordinates determined using Global Positioning System (GPS). Data collected consisted of fishing positions, skipjack tuna (*Katsuwonus pelamis*) catch per unit effort (CPUE) per trip, sea surface temperature, and chlorophyll-a.

Ex-situ data on sea surface temperature and chlorophyll-a were obtained from high-resolution satellite data of Spectra-Resolution Imaging Spectroradiometer (MODIS) aqua with a spatial resolution of 4 km during May to July 2017. In this study we used a monthly temporal resolution.

2.2. Thermal and chlorophyll-a fronts detection with SIED

The input data used for the front detection process were sea-surface temperature and chlorophyll-a derived from satellite imagery. The algorithm used was Single Image Edge Detection (SIED) [16]. The sea surface temperature and chlorophyll-a image data format used was NetCDF (NC). The data were processed using SeaDAS in order to determine the area to be processed. The data were then converted from floating points to raster data using the kriging facility in the spatial analyst tool in ArcGIS 10.2.

The data were then changed from raster data to integer format using map algebra in the spatial analyst tools in ArcGIS 10.2. The resulting integer data was then processed using the Marine Geospatial Ecology Tools (MGET) plugin in the ArcGIS toolbox. The plugin automatically determined the line of the front, with a horizontal gradient based on specified temperature and chlorophyll-a levels.

2.3. Statistical analysis using GAM

Temperature and chlorophyll-a data were obtained from satellite imagery using MODIS sensors with spatial resolution of 4 km and monthly temporal resolution, and the data were then further analysed using the R program. The statistical model used was the Generalized Additive Model (GAM) in R (version 3.3.2). GAM is a non-linear model, usually used to understand the interrelationships between observed variables through the identification of positive value ranges. The μi response variable (the number of skipjack tuna captured) and the predictor variable (front distance) can be formulated by the following equation.

$$g(\mu i) = \alpha + s\ (\text{front distance}) + \varepsilon \quad (1)$$

Where g is the spline fine function, μi is the expected value of the response variable (the number of skipjack catches), α is the constant coefficient model, s is a predictor variable smoothing function and ε is a random error term.

Prior to GAM modelling, dataset exploration first aims to identify the sine and co-linearity data between each explanatory variable. GAM modelling used the mgcv package in R (version 3.3.2). GAM modelling used a Gaussian distribution and the identity link function. The response variable was the catch, while the explanatory variable was the front distance.

3. Result and discussion

3.1. Distribution of Sea Surface Temperature and Chlorophyll-a versus Capture of Skipjack Tuna

3.1.1. Sea Surface Temperature. Sea surface temperature can be used to predict the presence of organisms in aquatic environments, especially fish. The direct effects of temperature on marine life are related to the rate of photosynthesis of plants and animal physiological processes, especially metabolic rates and reproductive cycles [17]. Based on temperature variations, high water temperatures are important factors in determining the migration of fish species [18]

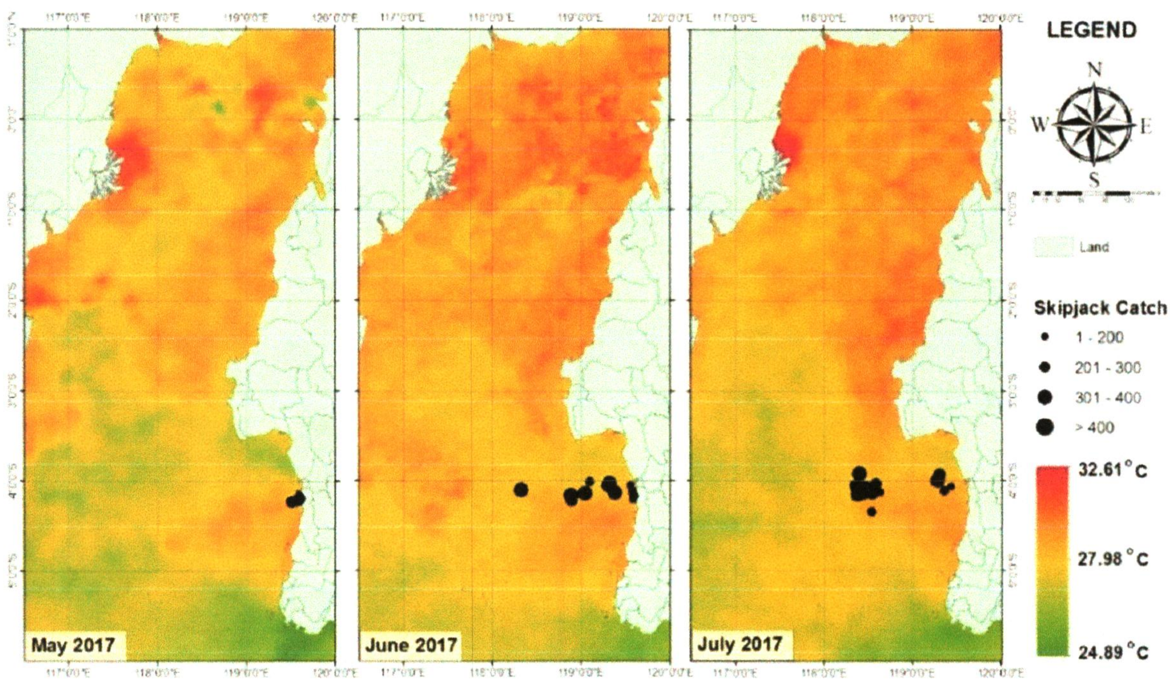

Figure 1. The distribution of sea surface temperature from May to July 2017 versus skipjack tuna (*Katsuwonus pelamis*) catch in the Makassar Strait

The optimum temperature range for skipjack tuna is 29.00°C - 31.50°C [19]. The distribution of sea surface temperature in Makassar Strait during May to July 2017 (Figure 1) ranged from 24.89°C - 32.61°C. The average temperature range of fishing grounds in the Makassar Strait was 29.13°C - 30.36°C. The highest catch (620 fish) occurred at a temperature of 29.19°C. Figure 2 shows that skipjack tuna fishing in the Makassar Strait during May - July 2017 took place in waters at temperatures of 29 - 30.5 ° C. The highest skipjack catch frequency was at temperatures of 29.5 - 30 ° C (22 fishing grounds) and the lowest frequency was at temperatures of 29 - 29.5 ° C (18 fishing grounds).

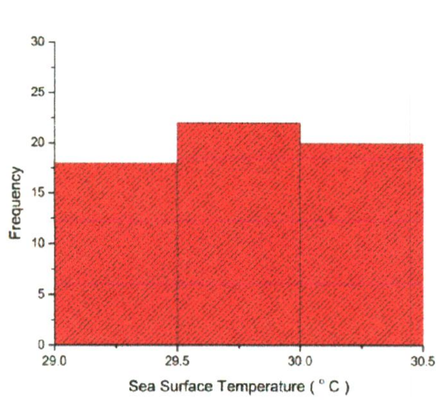

Figure 2. Frequency of Skipjack tuna caught during May to July 2017 in Makassar Strait by sea surface temperature.

3.1.2. Chlorophyll-a. The high dispersion and concentration of chlorophyll-a are strongly related to ocean water conditions. The concentration of chlorophyll-a varies vertically, and is influenced by oceanographic factors such as SST, wind, currents, and others. These fluctuations can be observed by direct measurement or the use of remote sensing technology. The concentration of chlorophyll-a in water results in distinctive seawater colouration, so that through satellite sensing methods, the pigment concentration can be estimated [20]. Physically, chlorophyll-a concentration distribution can be determined through visual analysis of maps, where the chlorophyll-a concentration is indicated using a colour scale.

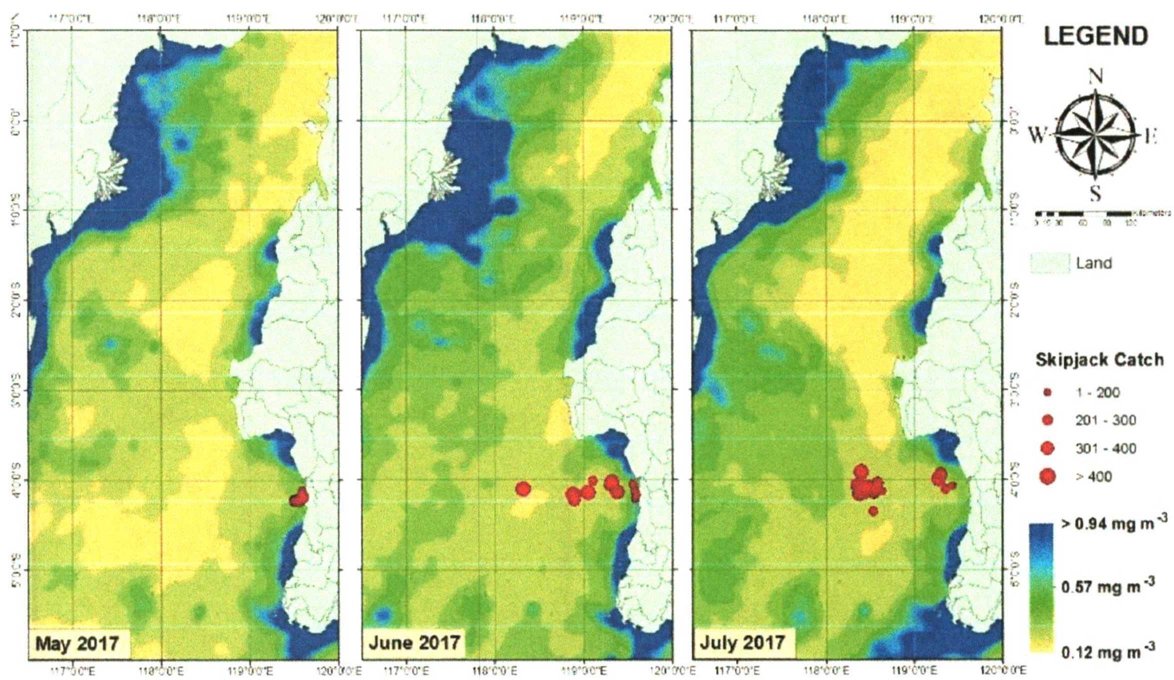

Figure 3. The distribution of chlorophyll-a during May to July 2017 versus skipjack tuna (*Katsuwonus pelamis*) catch in the Makassar Strait.

The chlorophyll-a concentration in the Makassar Strait from May to July 2017 (Figure 3) was in the range 0.12 to 0.94 mg m^{-3}. The chlorophyll-a concentration distribution shows that concentration tended to be high in coastal waters, and lower in deep sea waters with a range of 0.12 - 0.57 mg m^{-3}. The highest catch was 620 skipjack tuna, at a chlorophyll-a concentration of 0.24 mg m^{-3}.

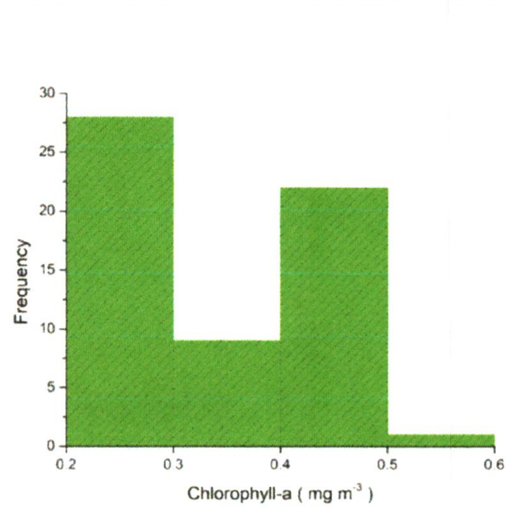

Figure 4. Frequency of Skipjack tuna caught in the Makassar Strait during May to July 2017 at different chlorophyll-a concentrations.

Skipjack tuna fishing in the Makassar Strait during May - July 2017 took place in waters with chlorophyll-a concentrations of 0.2 - 0.6 mg m^{-3}. The skipjack tuna catch rate was highest in the range 0.2 - 0.3 mg m^{-3} (29 fishing grounds) and the lowest in the range 0.5 - 0.6 mg m^{-3} (1 fishing ground).

3.2. Thermal and Chlorophyll-a Front Detection

3.2.1. Thermal Fronts. Temperature differences in surface waters will result in the movement of water masses from higher temperatures to lower temperatures [15]. This movement of water masses will lead to a boundary between warm water and cold water so that the front area is one of the oceanographic phenomena that affect the abundance and distribution of fish.

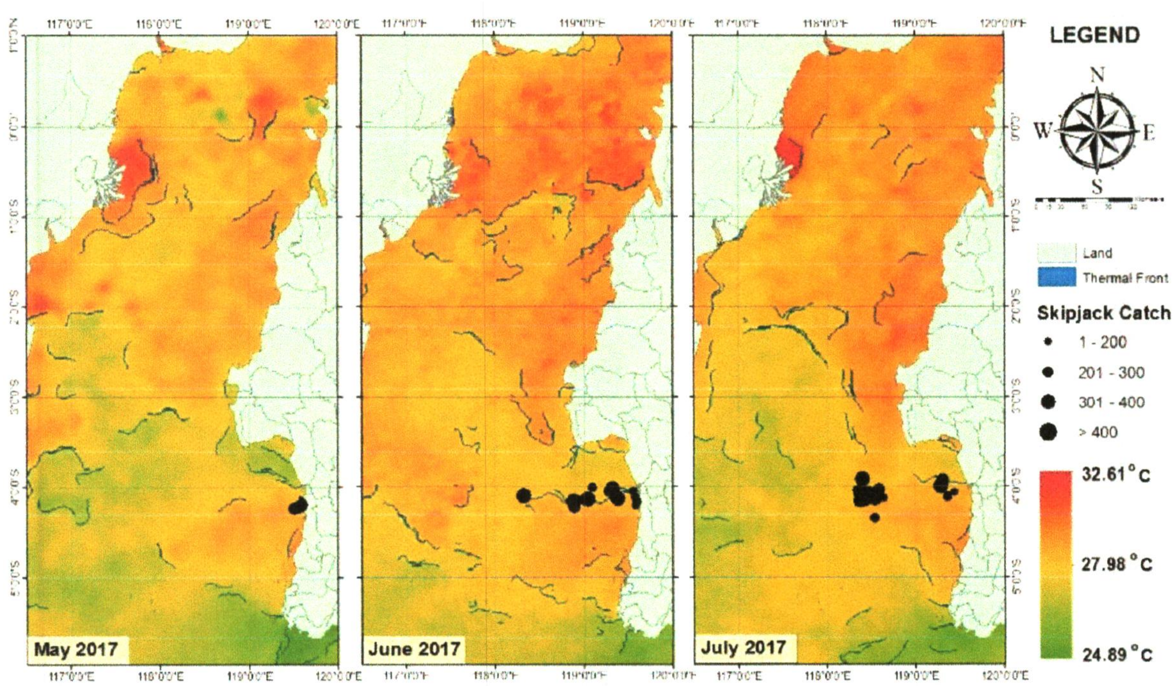

Figure 5. Map of thermal fronts in the Makassar Strait during May to July 2017 detected using the SIED method

The thermal front detected in June is seen to be in harmony with the distribution of fishing grounds. The resulting front had a horizontal gradient of 0.1 - 0.5°C along the line of the front. The highest catch was in the range of 0 - 10 km, comprising 34.34% of the total catch. From the above diagram, it can be concluded that the Skipjack tuna catch was relatively higher at fishing grounds closer to the front (Figure 6).

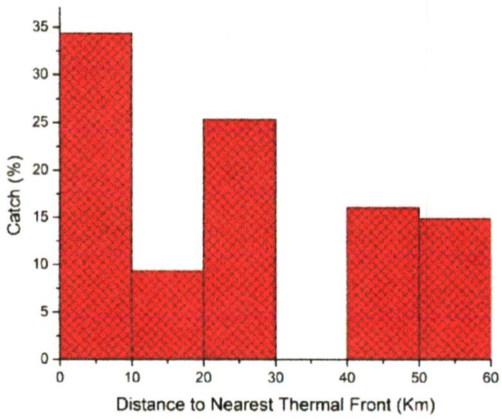

Figure 6. Skipjack tuna catch in the Makassar Strait by distance from a thermal front, based on front detection using the SIED method, during May to July 2017

3.2.2. Chlorophyll-a Fronts. The map of chlorophyll-a fronts detected in the Makassar Strait during May - July 2017 (Figure 7) using the SIED algorithm shows that fronts were present during every month of observation, especially in waters near to the coast. Some fishing grounds were quite close to a front.

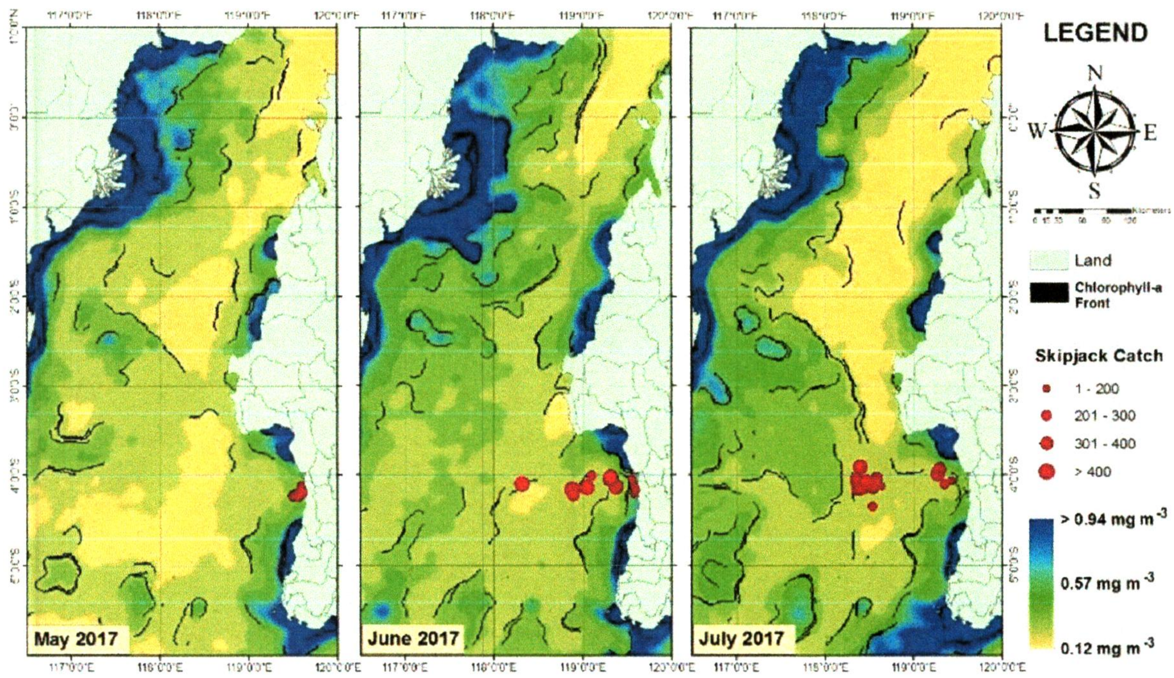

Figure 7. Map showing chlorophyll-a fronts detected using the SIED method from May to July 2017 in the Makassar Strait

Chlorophyll-a fronts detected during the period May – July are seen adjacent to fishing grounds. The fronts had horizontal gradients of 0.01 - 0.02 mg m^{-3} along the line of the front. The catch was highest at a distance of 10 - 20 km from the front, and comprised 33.74% of the total catch (Figure 8).

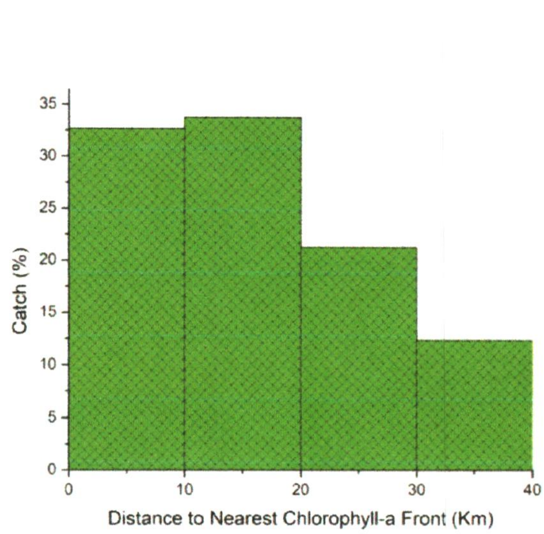

Figure 8. Skipjack tuna catches by distance from a chlorophyll-a front, based on front detection using the SIED method, during May to July 2017 in the Makassar Strait

3.3. Relation of skipjack tuna catch with distance from thermal and chlorophyll-a fronts using GAM
The relationship of skipjack tuna catch with distance from thermal and chlorophyll-a fronts was further tested using a GAM statistical method. The GAM analysis of the relation of skipjack tuna catches during June - September 2017 with distance from thermal and chlorophyll-a fronts based on the SIED method (Figure 9) shows relatively high catch volume between 0 - 10 km for thermal fronts and 10 - 20 km for chlorophyll-a fronts, similar to the results in Figures 6 and 8).

Based on the results of skipjack catch point analysis with respect to thermal and chlorophyll-a fronts, the catch is relatively higher close to the front. This could occur because the areas around a front tend to be fertile, with abundant food for small fish that in turn attract larger pelagic fish [12]. The GAM results (Tables 1 and 2) indicate that the relationship of catch with the distance from a front was significant for thermal fronts (Pr = 0.03107) (Table 1) but not for chlorophyll-a fronts (Pr = 0.4531), however the nonparametric advanced test of the latter showed a significant relationship (Pr = 0.00433) (Table 2). Based on these results (Pr <0.05), it can be concluded that thermal and chlorophyll-a parameters, specifically the distance from thermal and chlorophyll-a fronts, significantly affect skipjack tuna catch volumes in the Makassar Strait.

Table 1. The result of GAM model test for thermal Front

	Df	Sum Sq	Mean Sq	F Value	Pr (>F)	
S(Distance)	1	98741	98741	4.8969	0.03107 *	
Residuals	55	1109026	20164			
Significance level codes :	0 '***'	0.001 '**'	0.01 '*'	0.05 '.'	0.1 ' '	1

Table 2. The result of GAM model test for chlorophyll-a Front

	Df	Sum Sq	Mean Sq	F Value	Pr (>F)	
S(Distance)	1	12608	12608	0.571	0.4531	
Residuals	55	1214464	22081			
Nonparametric Anova (Intercept)						
S (Distance)	3			4.8996	0.00434 **	
Signif. Codes :	0 '***'	0.001 '**'	0.01 '*'	0.05 '.'	0.1 ' '	1

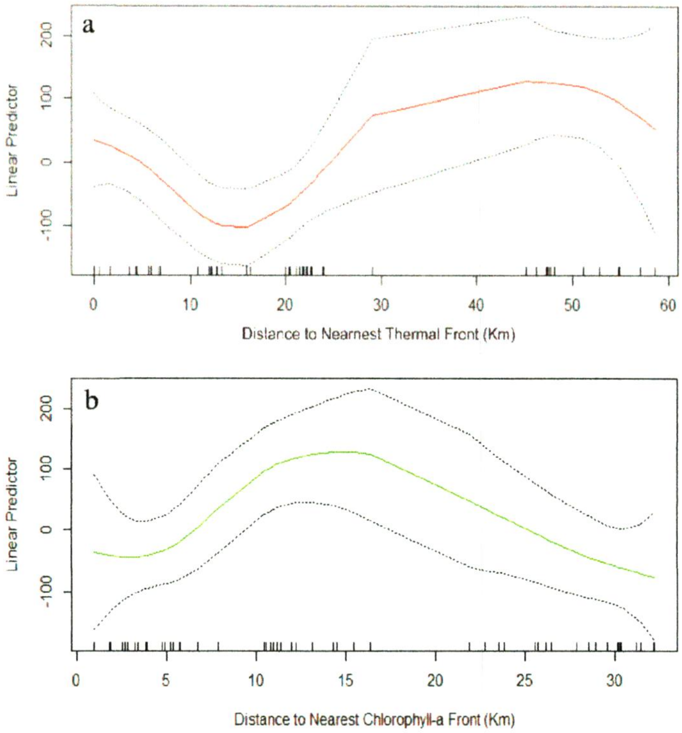

Figure 9. General additive modell (GAM) analysis based on front detection in the Makassar Strait by the SIED Method:

(a) Relationship between distance (km) from a thermal front and skipjack tuna catches

(b) Relationship between distance (km) from a chlorophyll-a front and skipjack tuna catches.

4. Conclusion

The optimum distance between thermal fronts and fishing grounds was in the range of 0 - 50 km and the highest catches occurred at distances of 0 - 10 km with a horizontal gradient of 0.1 - 0.5°C. Meanwhile, the distance between chlorophyll-a fronts and fishing grounds was in the range of 0 - 50 km and the highest catches occurred at distances of 10 - 20 km with a horizontal gradient of 0.01 - 0.02 mg m^{-3}. The distance from both fronts significantly affected the skipjack catch in the Makassar Strait during the study period.

Acknowledgments

This study was funded under the scholarship program of the Ministry of Research, Technology and Higher Education of the Republic of Indonesia (PMDSU research Grant), a National Competitive Research Grant (PTUPT 2018), and a Regional Competitive Research Grant (BMIS 2018). We also wish to thank the Skipjack Spot Hunter team.

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