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IMPACT OF INCREASING SEA SURFACE TEMPERATURE ON POTENTIAL FISHING ZONE OF SKIPJACK TUNA *Katsuwonus pelamis* IN MAKASSAR STRAIT

PENGARUH KENAIKAN SUHU PERMUKAAN LAUT TERHADAP ZONA POTENSIAL PENANGKAPAN IKAN CAKALANG DI PERAIRAN SELAT MAKASSAR

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ABSTRACT

Makassar Strait plays a vital role as one of the skipjack tuna fishing grounds in Indonesia. This study aimed to detect the skipjack tuna preference of sea surface temperature (SST) and chlorophyll-a (Chl-a) in Makassar Strait and to map out the possible shifting potential fishing zone (PFZ) of skipjack tuna by simulating sea surface temperature increase. We analyzed the skipjack catch data from July to November 2020, and we added the previous data in June, July, August, October, and December 2019 in the same study area. We analyzed together with satellite imagery data set of SST and Chl-a using GAM. We used three scenarios for the SST increase model simulation, which are 0.25, 0.5, and 1°C. The results showed that skipjack tuna is relatively high in SST ranging from 28.3 to 30.4°C and Chl-a ranging from 0.18 to 0.28 mg/m^3. The PFZ based on sea surface temperature simulation showed that PFZ area form in the northern part shifting to the southern part of Makassar Strait based on the increasing sea surface temperature simulation visible in September, which shifted from 0.017-5.421ºS to 2.923-6.802ºS and October shifted from 0.017-6.802ºS to 5.007-6.802ºS. Knowing the shifting of the potential fishing zone of skipjack tuna could be an important step toward fishing operation and management for skipjack tuna resource management in Makassar Strait.

Keywords: sea surface temperature increase, skipjack tuna, potential fishing zone

ABSTRAK

Selat Makassar memegang peranan penting sebagai salah satu perairan yang menjadi daerah penangkapan ikan cakalang di Indonesia. Penelitian ini bertujuan untuk mendeteksi preferensi suhu permukaan laut (SPL) dan klorofil-a (Chl-a) di perairan Selat Makassar serta memetakan potensi pergeseran zona penangkapan ikan cakalang dengan simulasi kenaikan suhu permukaan laut. Data tangkapan cakalang dianalisis dari bulan Juli-November 2020, dan ditambahkan dengan data sebelumnya pada bulan Juni, Juli, Agustus, Oktober, dan Desember 2019 di wilayah studi yang sama. Kemudian dianalisis bersama dengan kumpulan data citra satelit SPL dan Chl-a menggunakan GAM. Terdapat 3 skenario kenaikan SPL yang digunakan yaitu 0,25, 0,5, dan 1°C. Hasil penelitian menunjukkan bahwa ikan cakalang relatif tinggi berada pada suhu permukaan laut berkisar antara 28,3 sampai 30,4°C dan klorofil-a berkisar antara 0.18 sampai 0,28 mg/m^3. Simulasi kenaikan SPL menunjukkan bahwa kawasan zona penangkapan ikan cakalang potensial terbentuk di bagian utara perairan Selat Makassar dan bergeser ke bagian selatan perairan Selat Makassar yang terlihat jelas pada bulan September dimana zona potensial penangkapan bergeser dari 0,017-5,421ºLS ke 2.923-6.802ºS dan pada bulan Oktober bergeser dari 0,017-6,802ºLS ke 5,007-6,802ºLS. Mengetahui pergeseran zona potensial penangkapan ikan cakalang dapat menjadi langkah yang penting dalam operasi penangkapan dan pengelolaan sumberdaya ikan cakalang di perairan Selat Makassar.

Kata kunci: *cakalang, kenaikan suhu permukaan laut, zona potensial penangkapan ikan*

I. INTRODUCTION

The Indonesian Through Flow (ITF), which transports water from the Pacific Ocean to the Indian Ocean, passes through Makassar Strait (Gordon, 2005). The influence of water mass flowing from the Pacific Ocean interacting with the monsoon winds affect the oceanographic conditions in Makassar Strait, such as current circulation system, heat transport, upwelling and downwelling, variability of sea surface temperature, and chlorophyll-a concentration, and salinity (Habibi *et al.*, 2012). Physical changes in water are closely related to behavior, migration pattern, and distribution of phytoplankton and pelagic fish that live in the water. The oceanographic process will affect the distribution of pelagic fish in water areas where the fish look for suitable habitat for feeding, spawning, migration, and as a foraging habitat (Palacios *et al.*, 2006).

Skipjack tuna is a species that has a broad migration pattern, both horizontal and vertical. Several studies have shown a relationship between the distribution and abundance of skipjack in waters which is influenced by several oceanographic factors such as sea surface temperature and chlorophyll-a (Andrade, 2003; Zainuddin *et al.,* 2017). Sea surface temperature is important to the thermoregulation process and physiological adaptation for tuna, while chlorophyll-a is used as an indicator that can directly indicate the presence of food and migration routes for tuna (Polovina *et al.*, 2001). Together with the catch data, these oceanographic parameters can be used as an indicator to detect the potential fishing zone for skipjack. A potential fishing zone (PFZ) is a location that identifies the best fishing site. Chlorophyll is abundant in these areas, which is required for plankton growth. Planktons provide food for the fish, which can be found in large quantities. It indicates where possible fish shoals could be found. The presence of fish is indicated by features such as oceanic fronts, eddies, and upwelling zones. Chl-a levels and differences in SST are also indicators of fish aggregation in the water (Jagannathan *et al*., 2012; Subramanian *et al*., 2014).

Global climate change has an impact on many aspects of marine life. It showed the significant impact of sea surface temperature increase which affects the habitat of marine species (Dueri *et al.,* 2014; Muhling *et al.*, 2015). Environmental factors affect their migration, growth, and reproduction, resulting in their abundance and catchability to the fisheries industry (Dueri *et al.*, 2014). In this study, we used monthly data to see the short-term oceanographic changes related to skipjack tuna catch. This research aims to detect the skipjack tuna oceanographic preference and determine the shifting of PFZ with oceanographic factors and skipjack tuna catch.

II. RESEARCH METHODS

2.1. Study Area

This study was conducted in Makassar Strait (Figure 1), the eastern part of Indonesia, one of the most biologically productive skipjack fishing grounds. In addition, the study area is known as one of the pathways of Indonesian Throughflow (ITF) (Gordon, 2005). This area is influenced by the tropical monsoon climate, which affects the current circulation system, heat transport, upwelling and downwelling, variability of sea surface temperature and chlorophyll-a concentration, and salinity (Habibi *et al.*, 2012).

2.2. Fishery Data

Skipjack tuna catch data was obtained from purse seine operations in the study area. The field data include fishing positions (latitude and longitude) and skipjack tuna catch data in the number of skipjack and effort (fishing set) by following the purse seine operations in the study area of several months, which are June, July, August, October, December 2019 and from July to

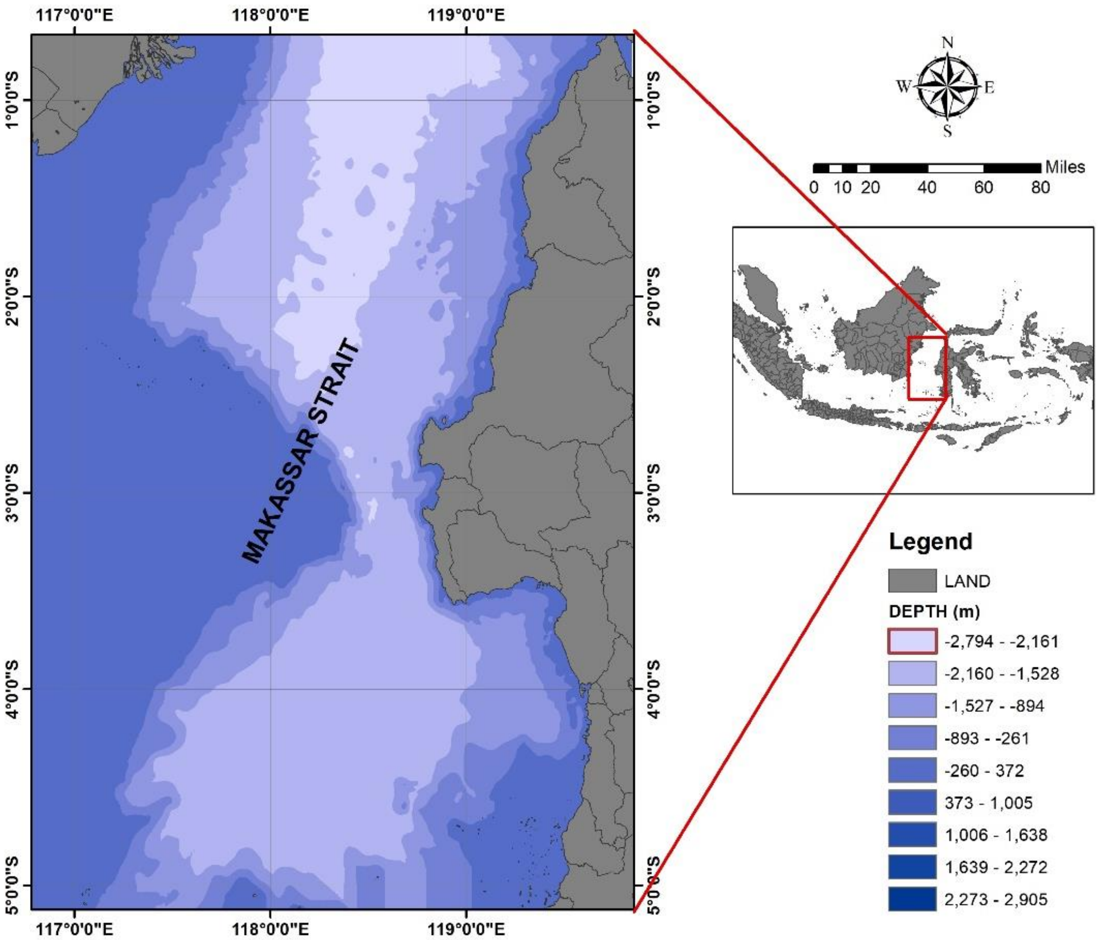


Figure 1. The study area in Makassar Strait, Indonesia.

November 2020. Catch per unit effort (CPUE) is derived from the number of fish per fishing set.

2.2.1. Remotely Sensed Environmental Data

Sea surface temperature and chlorophyll-a data set was obtained from satellite data of high-resolution moderate-resolution imaging spectroradiometer (MODIS) with 4 km of longitude, and latitude spatial resolution downloaded from https://oceancolor.gsfc.nasa.gov/. It distributes *Standard Mapped Image* (SMI), level 3 binary data with *Hierarchy Data Format* (HDF). The data used in this study were monthly temporal resolution of June, July, August, October, December 2019, and from July to November 2020. The data set was processed further in SEADAS (*SeaWiFS Data Analysis System*) version 7.5.3 to get image data throughout the study area.

2.3. Generalized Additive Model (GAM)

We combined the fisheries data from the same study area for June, July, August, October, December 2019, and July-November 2020 for the statistical analysis. The monthly data of sea surface temperature and chlorophyll-a were obtained from satellite images then further tested with GAM. The statistical model used is the Generalized Additive Model (GAM) with the R program (3.6.2). GAM is a non-linear model, usually used to understand the relationship between observed variables by identifying a range of values that have a positive effect. We chose the GAM model because it did not relate to the normality of the data used, so it is easier to use for the data analysis. GAM with Gaussian distribution was applied to determine the effect of environmental factors on skipjack tuna distribution (Zainuddin *et al*., 2019; Wiryawan *et al*., 2020). The response variable µi (fish number of skipjack tuna catch) and the predictor variables (SST and Chl-a) can be formulated as follows:

$$g\ (\mu i) = \alpha_0 + s_1\ (sea\ surface\ temperature) + s_2\ (chlorophyll\text{-}a) + \varepsilon$$

Information: g is a smooth spline function; µi is the expected value of the response variable (fish number of skipjack tuna catch); α_0 is the model constant-coefficient; s_n is the smoothing function of the predictor variables; ε is the random error term.

2.4. Simulation Model

In this simulation, we considered the sea surface temperature scenario of the SST increase based on AR5 of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014). These climate change scenarios describe the best estimate of projected global surface warming of 0.65-1.06 °C, based on the relationship between the forces driving greenhouse gas and aerosol emission and their global evolution from 1880 to 2012 (IPCC, 2014)). Each scenario represents the different demographic, social, economic, technological, and environmental developments (IPCC., 2007)). We used SST increases of 0.25, 0.5, and 1°C to examine the possible effect of climate change on shifting a potential fishing zone of skipjack tuna. We used the original SST values plus each scenario of the sea surface temperature increases (0.25, 0.5, and 1 °C) respectively to get three new SST values set. These three scenarios of sea surface temperature increasing were determined based on the deviation value of sea surface temperature in the study area. This method is adapted from ICES Journal, which uses a temperature increasing scenarios model approach to evaluate climate change impacts on fisheries resources (Saitoh *et al*., 2011). Furthermore, we run the process by using spatial analyst tools in the ArcGIS 10.2 software package.

III. RESULT AND DISCUSSION

3.1. Distribution of Skipjack Tuna Catch in Makassar Strait Based on Oceanographic Factors

The Aqua MODIS satellite imagery of sea surface temperature from July to November 2020 in Makassar Strait showed that the variation of sea surface temperature is both spatial and temporally. In July, sea surface temperature appears to be lower than the following months, which range from 27.99 to 32 °C and continue to increase every month. Furthermore, the sea surface temperature in the northern part of Makassar Strait is generally warmer than the sea surface temperature in the southern part of Makassar Strait.

During the study from July to November 2020, we found that the skipjack tuna were distributed in the study area ranged from 29.78 to 31.55 °C (Figure 2). It shows that the skipjack tuna is occupied in the warmer area of sea surface temperature. It is in line with the previous studies, which stated that the potential habitat for skipjack tuna is in the surface layer of warm water in the tropical and subtropical ocean (Lehodey *et al.*, 1998; Arai *et al*., 2005).

Aqua MODIS satellite imagery of chlorophyll-a concentration from July to November 2020 in Makassar Strait shows that the chlorophyll-a concentration is in the range of 0.11-1.49 mg/m^3. The distribution of chlorophyll-a tends to be higher in the coastal area with the value range of 0.63-1.49 mg/m^3 than in the offshore tends to be lower with a value range of 0.11-0.46 mg/m^3. Kurniawati *et al.* (2015) stated that the chlorophyll-a concentration in the sea difference according to geographical location and water depth.

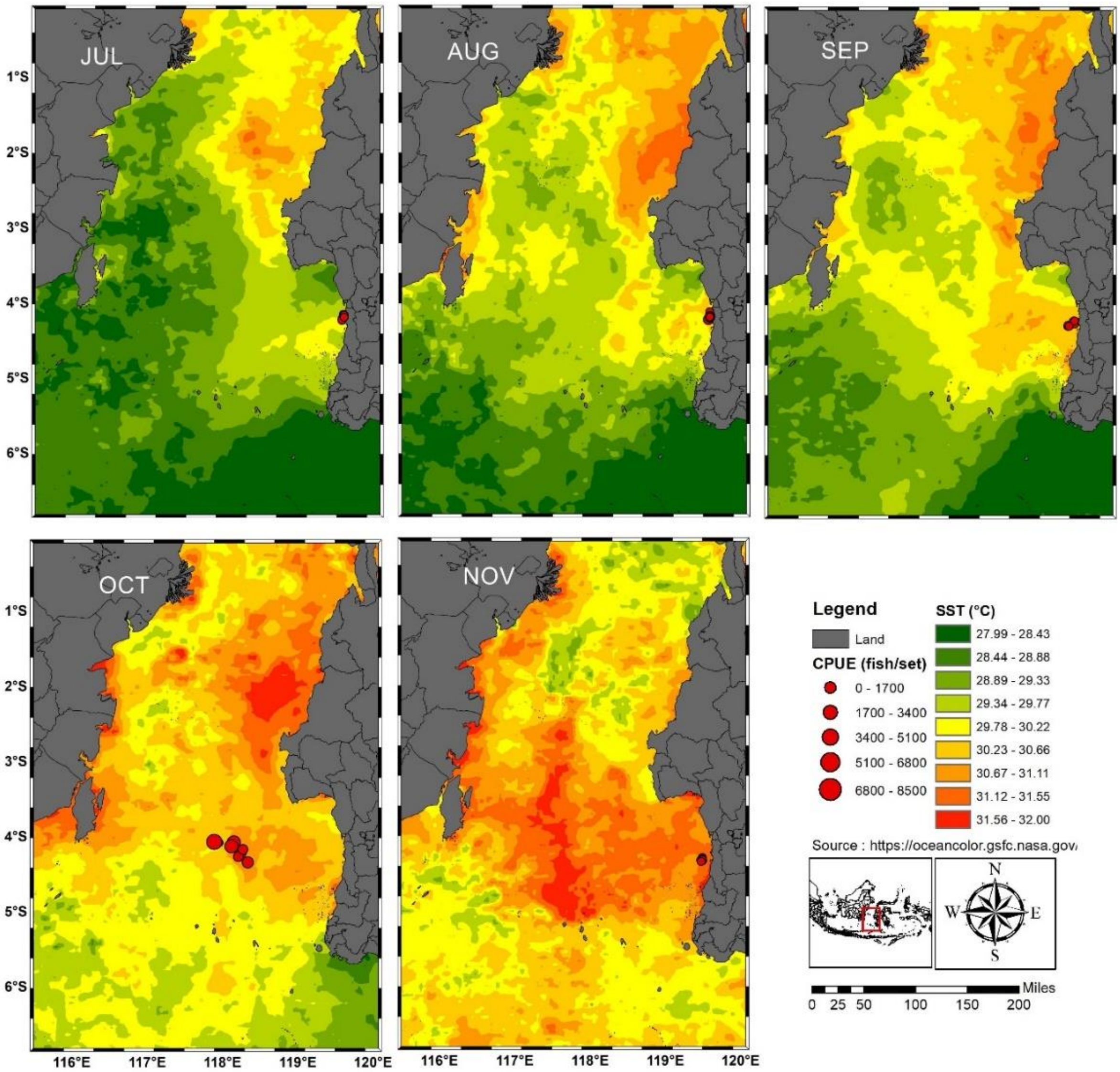


Figure 2. The spatial distribution of skipjack tuna catches (shown as dots) overlaid on sea surface temperature from July to November 2020 in Makassar Strait.

The difference in the sunlight intensity and the nutrient concentration cause the change. We found that the distribution of skipjack tuna from July to November 2020 presence in the chlorophyll-a concentration range from 0.11 to 0.33 mg/m^3 (Figure 3). According to Zainuddin *et al.* (2015), a specific range of chlorophyll-a corresponds to the presence and abundance of skipjack tuna in the water. The potential fishing area for skipjack tuna is not with the high chlorophyll-a concentration nor the low chlorophyll-a concentration. The presence of chlorophyll-a concentration in the waters is thought to be used by fish as the foraging habitat. Polovina *et al.* (2001) stated that chlorophyll-a could act as a factor that can directly indicate the presence of the food for fish and tuna migration route detected at a chlorophyll-a concentration of 0.2 mg/m^3.

3.2. Relation Between the Oceanographic Factors with Skipjack Tuna Catch

Oceanographic factors can be used as an indicator of the presence of fish in the water. Each type of fish has a different tolerance to the range of sea surface temperature for their survival, as same as the

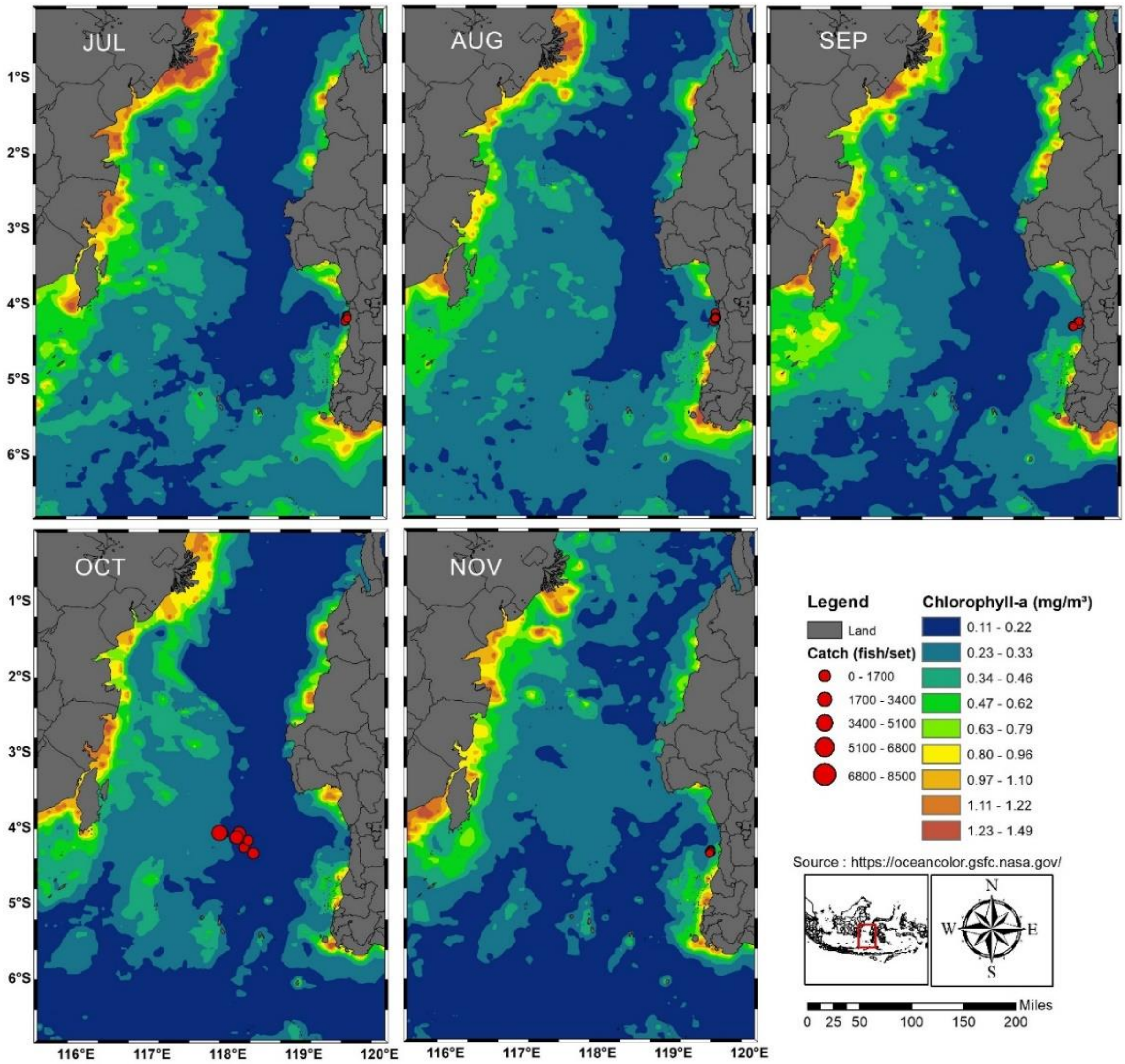
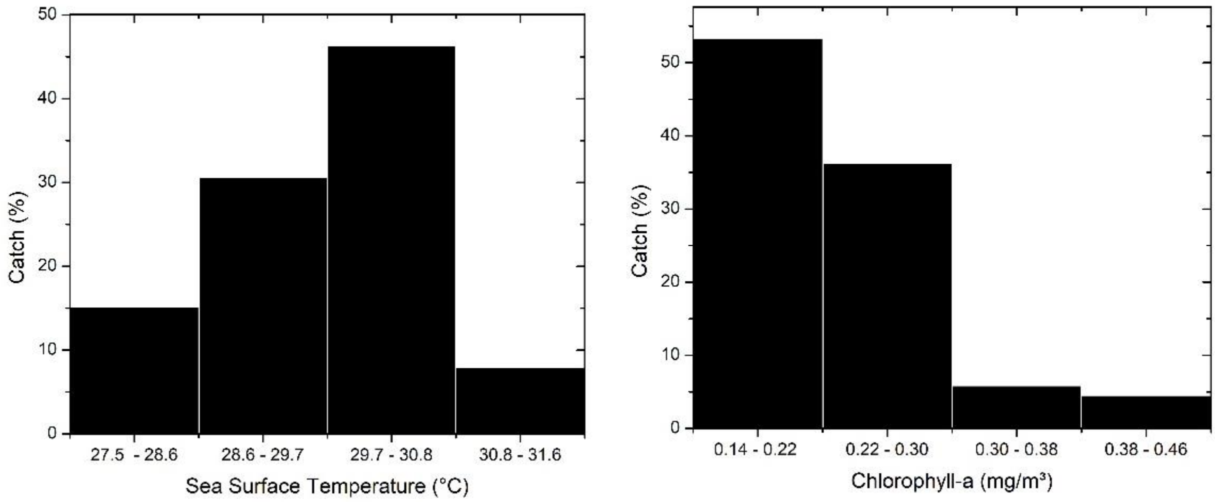


Figure 3. The spatial distribution of skipjack tuna catches (shown as dots) overlaid on chlorophyll-a from July to November 2020 in Makassar Strait.

chlorophyll-a concentration. To analyze the relationship of oceanographic factors with skipjack tuna catch, we combined the fisheries data from June, July, August, October, and December 2019 and July-November 2020 with the same study area. The result showed that the highest catch at the sea surface temperature ranged from 29.7 to 30.8 °C, as much as 46.35% of the total catch (Figure 4a). The chlorophyll-a concentration ranging from 0.14 mg/m^3 to 0.22 mg/m^3 as many as 53.35% from the total catch (Figure 4b).

The relation between oceanographic factors with skipjack tuna catch using GAM shows that sea surface temperature and chlorophyll-a have a significant effect (Table 1). It shows that the p-value of sea surface temperature and chlorophyll-a are 0.0189 and 0.0000191. The significance value of the two parameters is <0.05; it can be concluded that SST and CHL significantly influence the skipjack tuna catch in Makassar Strait. The GAM plot can interpret the individual effect of each predictor variable and the response variable. The x-axis interprets the predictor



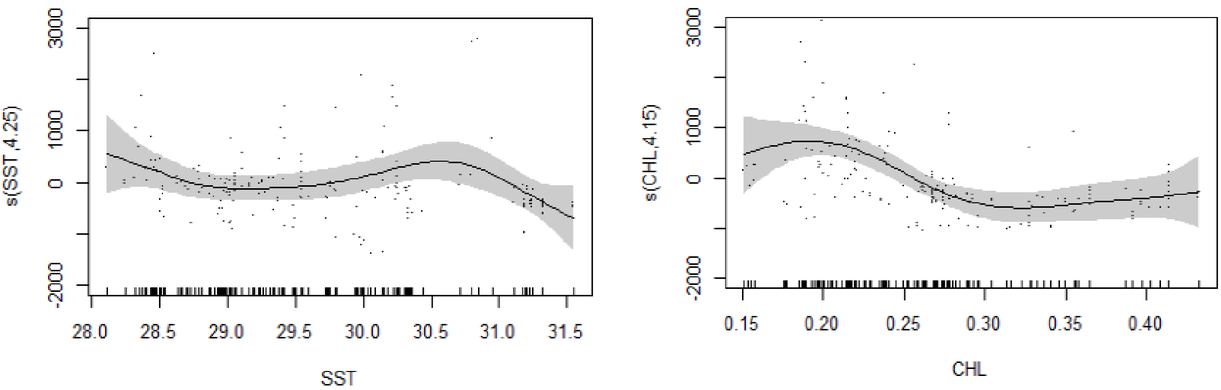
(a) (b)

Figure 4. Skipjack tuna catch data with oceanographic factors. (a) Sea surface temperature and (b) Chlorophyll-a.

Table 1. GAM analysis of oceanographic variables effect on skipjack tuna catches.

	Edf	Ref.df	F	p-value	
s(SST)	4.250	5.241	2.795	0.0189	*
s(CHL)	4.146	5.096	6.321	0.0000191	***

Signif. codes: 0 ‘***’ 0,001 ‘**’ 0,01 ‘*’ 0,05 ‘.’ 0,1 ‘ ‘



(a) (b)

Figure 5. GAM analysis of oceanographic factors with skipjack tuna catches: (a) sea surface temperature and (b) chlorophyll-a. The Grey area indicates the 95% confidence intervals. The relative density of data points is shown on the x-axis.

variables, such as sea surface temperature and chlorophyll-a, while the y-axis interprets the smoother’s contribution to the response value, which is the fish number of skipjack tuna catch. The result shows that skipjack tuna is concentrated in sea surface temperature ranging from 28.3 to 30.4°C (Figure 5a), and the chlorophyll-a concentration ranges from 0.18 mg/m^3 to 0.28 (Figure 5b).

3.3. Potential Fishing Zone Based on The Increasing of Sea Surface Temperature

Monthly skipjack tuna formation based on an overlay of optimum oceanographic factors (sea surface temperature and chlorophyll-a) and a scenario of increasing sea surface temperature of + 0.25 °C, + 0.5 °C, and + 1 °C (Figure 6). The map shows that the

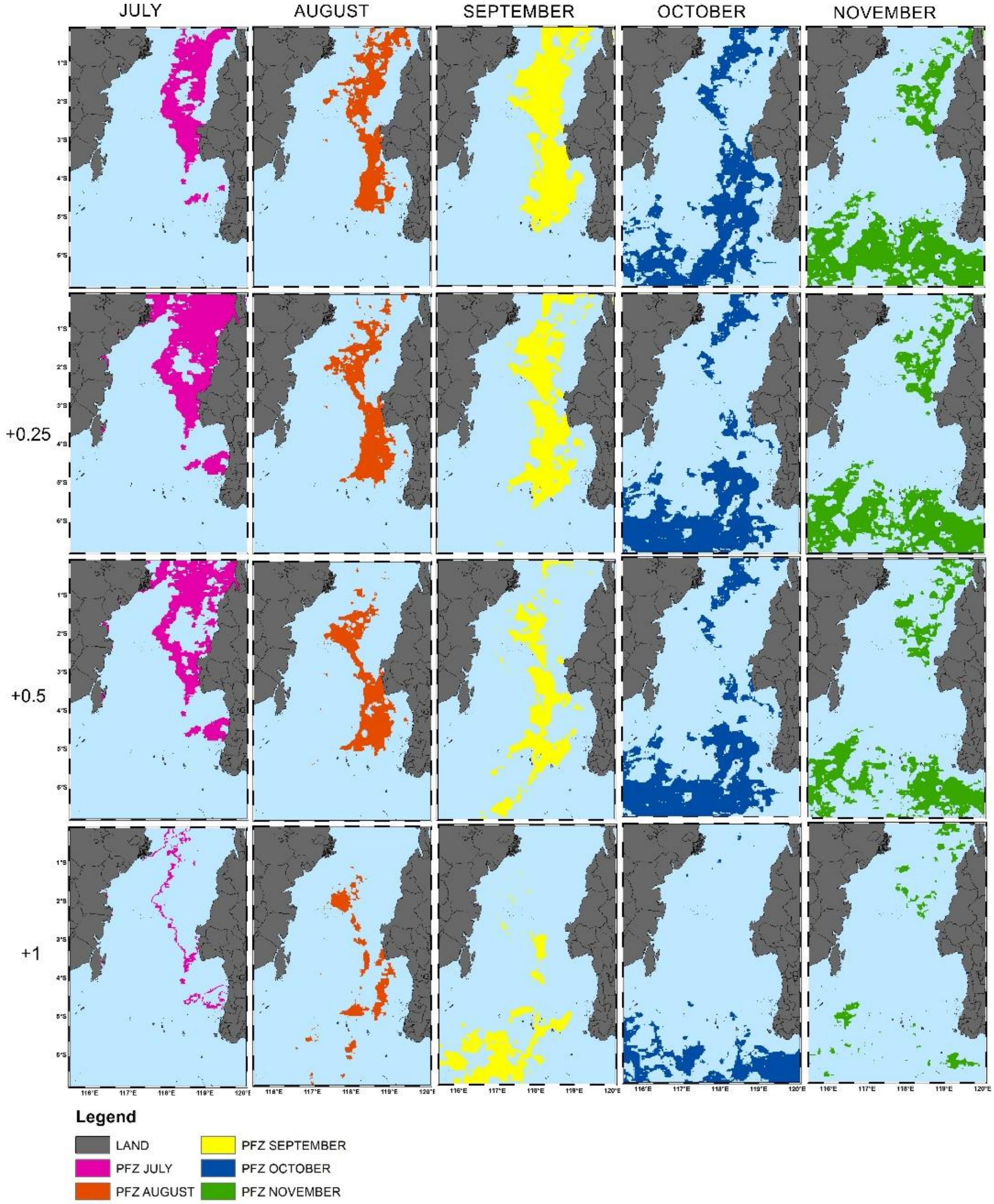


Figure 6. The map of the potential fishing zone of skipjack tuna simulating with increasing sea surface temperature scenarios.

potential fishing zone (PFZ) formation in July to November seems to have shifted from north to south waters of the Makassar Strait, and the area of the PFZ formation has decreased from sea surface temperature with current conditions until sea surface temperature increases of up to 1 °C where it is visible in September and October. In September, the potential fishing zone was formed at 0.017-5.421 ºS latitude, around Central Sulawesi, West Sulawesi, and South Sulawesi waters. After simulating with a scenario of increasing sea surface temperature values of 0.25 °C, 0.5 °C, and 1 °C, the area seems to be narrowing and shifting towards the southern part of Makassar Strait until the scenario of 1 °C the area formed at latitude 2.923-6.802 ºS latitude. While in October, the potential fishing zone was formed in the northern part of Makassar Strait to the southern part at 0.017-6.802 ºS latitude and after simulating with a scenario of increasing sea surface temperature values under 1 °C, the area appears to be shifting towards the southern part of Makassar Strait formed at 5.007-6.802 ºS latitude. This result is in line with Jung *et al.* (2014) predicted that by 2030, the sea surface temperature, particularly in tropical areas, will be warmer than in the past years, especially in tropical areas. Muhling *et al.* (2015) explain that the sea surface temperature increases in some parts of the world, and the distribution of fish is shifting more and more.

IV. CONCLUSION

We concluded that according to the GAM analysis model, it shows that oceanographic factors influence skipjack tuna, and it is known that skipjack catches are relatively higher in the sea surface temperature range from 28.4 to 30.4 °C and the concentration chlorophyll-a range from 0.18 to 0.27 mg/m^3. Also, based on the map of the potential fishing zone, PFZ shifted from the northern part to the southern part of Makassar Strait, and the area tends to be decreased, which is visible in September and October.

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