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Impact of Climate Changes on Skipjack tuna (*Katsuwonus pelamis*) catch during May-July in the Makassar Strait

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Abstract. Climate change is underway, with unexpected consequences for various fields including fisheries. Fish distribution pattern shifts are not random, but are influenced by oceanographic factors and climate variability. This study aimed to analyze the impact of changes in climate on Skipjack tuna (*Katsuwonus pelamis*) catch in Makassar Strait. Time series satellite data on Sea Surface Temperature (SST) and Chlorophyll-a (chl-a) concentration (MODIS-aqua) during May-July were obtained for the period from 2012 to 2016. Catch per Unit Effort (CPUE) data for Skipjack collected during May-July 2017 were used to analyze the impact of oceanographic changes on the skipjack tuna fishery. This study used the anomaly method to analyze unusual phenomena in these time series. A Generalized Additive Model (GAM) was used to analyze the effect of climatic changes on skipjack tuna catch using the R 3.1.3 software package. Spatial data were mapped using ArcGIS 10.5 software. The results indicate that climatic changes included a significant increase in SST (0.26 – 0.80ºC) and chl-a concentration (0.0280 – 0.0937 mg m^{-3}) during May-July over the period 2012 - 2016 in the southern Makassar Strait. These conditions were significantly associated with increasing skipjack tuna catch, particularly chl-a in southern part of Makassar Strait.

1. Introduction

Makassar Strait is one of the unique seaways in Indonesian waters because it is influenced by the dynamics of the global oceanography of the Pacific Ocean to the north and east and the Indian Ocean to the south and west [1]. Important stocks of large pelagic fish such as skipjack tuna *Katsuwonus pelamis*) pass through this seaway [2]. These fisheries resources should be utilized optimally while still paying attention to resource sustainability.

The skipjack tuna (*Katsuwonus pelamis*) is an economically important fisheries commodity in Indonesian waters. Fisheries statistics from 7 districts and cities along the Makassar Strait coast show an average increase in skipjack tuna production of 3.47% per year over six years, rising from 3,580.5 tons in 2008 to 4,201.7 tons in 2012 [3]. It is clearly important to be able to estimate the abundance and distribution of skipjack tuna for the effectiveness and efficiency as well as the sustainability if this fishery. Fish distribution patterns do not shift randomly; rather, they are influenced by oceanographic parameters and the variability of climatic factors. Oceanographic parameters such as Sea Surface Temperature (SST) and chlorophyll-a (chl-a) can be limiting factors for the distribution of fish and even their survival, while climatic phenomena such as El Nino and La Nina can also have a negative or positive impact on fish [4,5,6,7]. In Indonesian waters, climatic changes have been shown to have an impact on the catch of pelagic fish in the Bali Strait and Bone Bay [4,8].

Anthropogenic climate change is now occurring with unexpected consequences for various fields including fisheries. Impacts on the fishery sector include changes in fish distribution (both sedentary and migratory patterns) and fish abundance, which are thought to be due, at least in part, to changes in primary and secondary productivity [7,9]. Global oceanographic phenomena originating in the Pacific Ocean (e.g. El Nino) and in the Indian Ocean (e.g. the Indian Ocean Dipole, IOD) are drivers of climatic variability [4,10]. The occurrence of El-Nino and La-Nina events ha been shown to lead to a shift in the distribution patterns and abundance of skipjack tuna in the West Pacific Ocean [11], while other studies also show that climate change can (and indeed has) affected catch volume and the size of individual fish [4,11].

In order to adapt to changes in climate, future monitoring and research must be closely linked to responsive, flexible and reflexive management systems [12]. The abundance of skipjack tuna is expected to decline due to changes in the world's oceans associated with climatic change [9]. It therefore considered important to understand the impact of climatic changes on skipjack tuna catch.

2. Material and Methods

2.1. Study area

This research was conducted from May to July 2017, using survey methods. The survey sites were the fishing bases in Pinrang and Barru Regencies, Indonesia and fishing grounds in the Makassar Strait. Analysis of chlorophyll-a content was conducted at the Water Quality Laboratory of the Faculty of Marine Science and Fisheries, Hasanuddin University. Data processing was carried out at the Capture Fisheries Information System Laboratory of the Marine Science and Fisheries Faculty of Hasanuddin University.

2.2. Skipjack catch data and oceanographic parameters

Primary data were collected on skipjack tuna catches and oceanographic parameters by following the fishing operations of purse seine fishing vessels operating in the Makassar Strait during the study period (May-July 2017). Sea Surface Temperature (SST)(°C) was measured *in-situ* and water samples were collected for analysis to measure Chlorophyll-a (Chl-a)(mg m^{-3}). The data were analysed and organized into a database. Catch data were overlaid with the SST anomalies (°C) and Chlorophyll-a anomalies (mg m^{-3}) identified based on measured oceanographic parameters [4,7]. These primary data were used to verify the secondary data used.

2.3. Satellite remote sensing data

Secondary data in the form of remote sensing satellite data were also used in this research. These data comprised MODIS satellite data from the NASA (National Aeronautics and Space Administration) database with a spatial resolution of 4 km, with acquisition during May to July 2012-2017. The satellite data used were Sea Surface Temperature (SST) and Chlorophyll-a (chl-a) datasets [7,13,14,].

2.4. Anomaly Method

An anomaly method was implemented to evaluate changes in oceanographic conditions over a 5 year period (2012-2016), and to identify decreases (negative anomalies) and increases (positive anomalies) in oceanographic factors relative to normal conditions over this period in time. This analysis used the anomaly formula given in [15], implemented in ArcGIS 10.5, in order to identify anomalies in oceanographic conditions (SST and chl-a). The formula was as follows [15]:

$$\delta_{ij} = \bar{T}_{ij} - \bar{T}_i \quad (1)$$

Where:

δ_{ij} = the anomaly of the oceanographic factor (SST or chl-a) in month *i* and year *j*;
$\bar{T}_{ij}$ = the average value of the oceanographic factor (SST or chl-a) in month *i* and year *j*;
$\bar{T}_i$ = the oceanographic factor (SST or chl-a) in month *i*.

2.5. Generalized Additive Model (GAM)

One purpose of this study was to determine the effect of oceanographic parameters and environmental abnormalities on the catch of skipjack tuna in Makassar Strait. GAM is a non-parametric analysis which can produce more accurate information on the relationship between parameters. The GAM analysis was implemented in R version 3.4.3. The model applied was as follows [16]:

$$log(cpue + 1) = \alpha + s(SST) + s(SSTanom) + s(CHL) + s(CHLanom) + \varepsilon \quad (2)$$

Where:

α = constant;
$s(.)$ = spline smooth function of SST, SST anomaly, Chl-a, and Chl-a anomaly;
ε = random error term.

3. Results and Discussion

Sea Surface Temperature was the oceanographic factor that had the most influence on the skipjack tuna (*Katsuwonus pelamis*) catch [7]. Changes in skipjack tuna (*Katsuwonus pelamis*) due to increased ocean temperatures caused by global warming have been reported previously [16]. The anomaly analysis showed that, during May-July 2017, there were fluctuations in SST, with both, positive anomalies or negative anomalies (Fig.1).

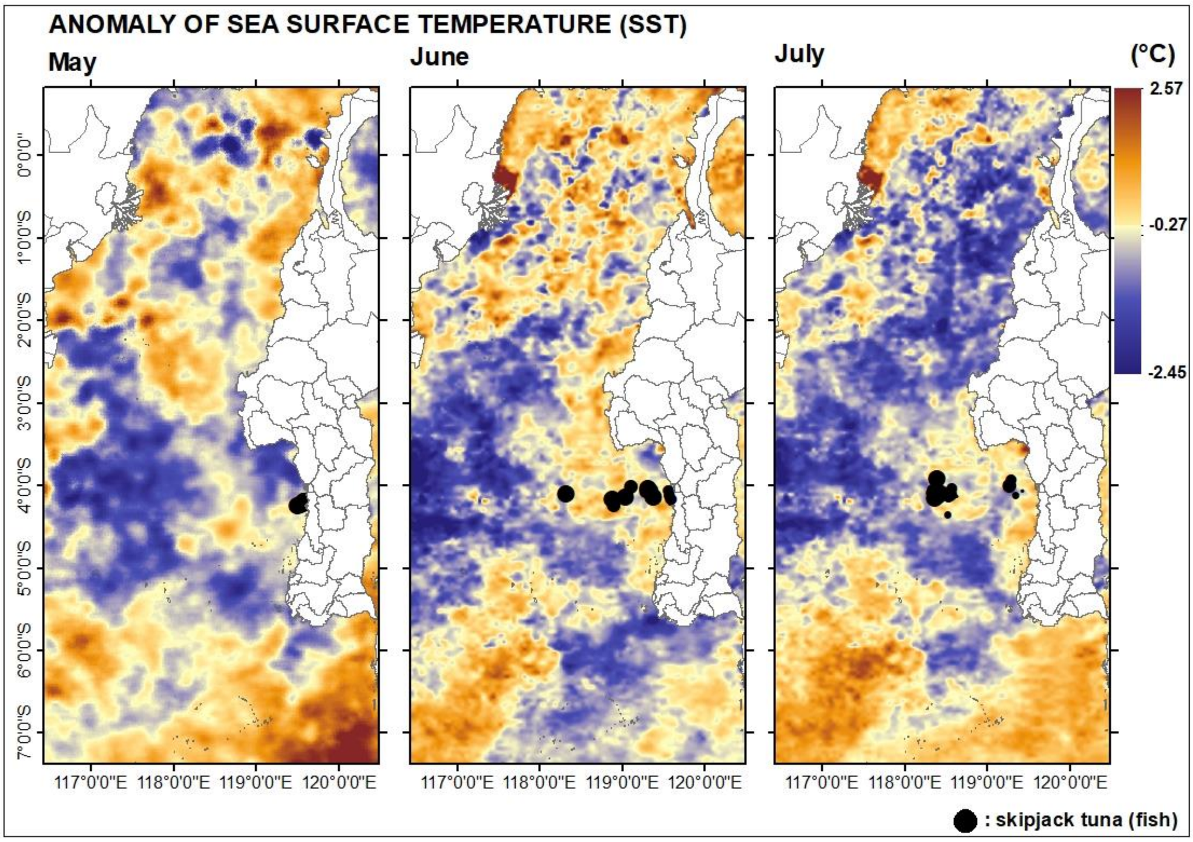

Figure 1. The Sea Surface Temperature anomalies in Makassar Strait during May-July 2017

In May, there was a positive anomaly (about 0.27 – 2.05 ºC) in almost all parts of the Makassar Strait, with the highest anomaly occurring in the south eastern part of the Makassar Strait. There were negative anomalies in May which occurred only in the western reaches of the Makassar Strait and in a small area of the eastern Makassar Strait (in the waters of Majene and Takalar Regencies (about -0.71

to -0.53 ºC), and Parepare Regency (about -2.50 to -0.91 ºC). Then, in June a negative anomaly occurred only in the western reaches of Makassar Strait (about -2.50 to -0.91 ºC) and in a small area of the southern Makassar Strait (in the waters of Takalar and Jeneponto Regencies) about -1.46 to -0.91). However in July there was a negative anomaly in the northern and western areas of Makassar Strait in a range from (-0.33 to - 0.80 ºC) then a positive anomaly occurred in the eastern and southern Makassar Strait (0.27 – 2.05 ºC).

In Figure 1 it can also be seen that skipjack tuna (*Katsuwonus pelamis*) were caught in the waters with a negative anomaly (colder than average SST for the last 5 years). The oceanographic indicators may correspond well with the potential feeding ground for skipjack tuna [17]. The GAM model indicated that SST was the most important in explaining the temporal and spatial dynamics of skipjack tuna (*Katsuwonus pelamis*) distribution and abundance, as previously reported from Bone Bay [18].

The Chl-a front provides a key oceanographic indicator for global understanding on skipjack tuna (*Katsuwonus pelamis*) habitat hotspots [13]. Figure 2 shows that chl-a concentration during May-July tended to be almost constant over the 5 year study period in almost all areas of the Makassar Strait. During this period, Chlorophyll-a concentration increased during May-July within the range of -0.6664 – 0.8871 mg m^{-3}. The change in chl-a concentration during May-July was only occurred on the surrounding estuary of the river of the eastern of Kalimantan Island and in the southern coast of South Sulawesi Province. Around the mouth of the rivers in eastern Kalimantan Island in May and June, there was an increase in chl-a concentration (positive anomaly) reaching 0.0866 – 0.0937 mg m^{-3}. In July, a chlorophyll-a positive anomaly was almost uniformly distributed across the Makassar Strait (0.0280 – 0.8871 mg m^{-3}).

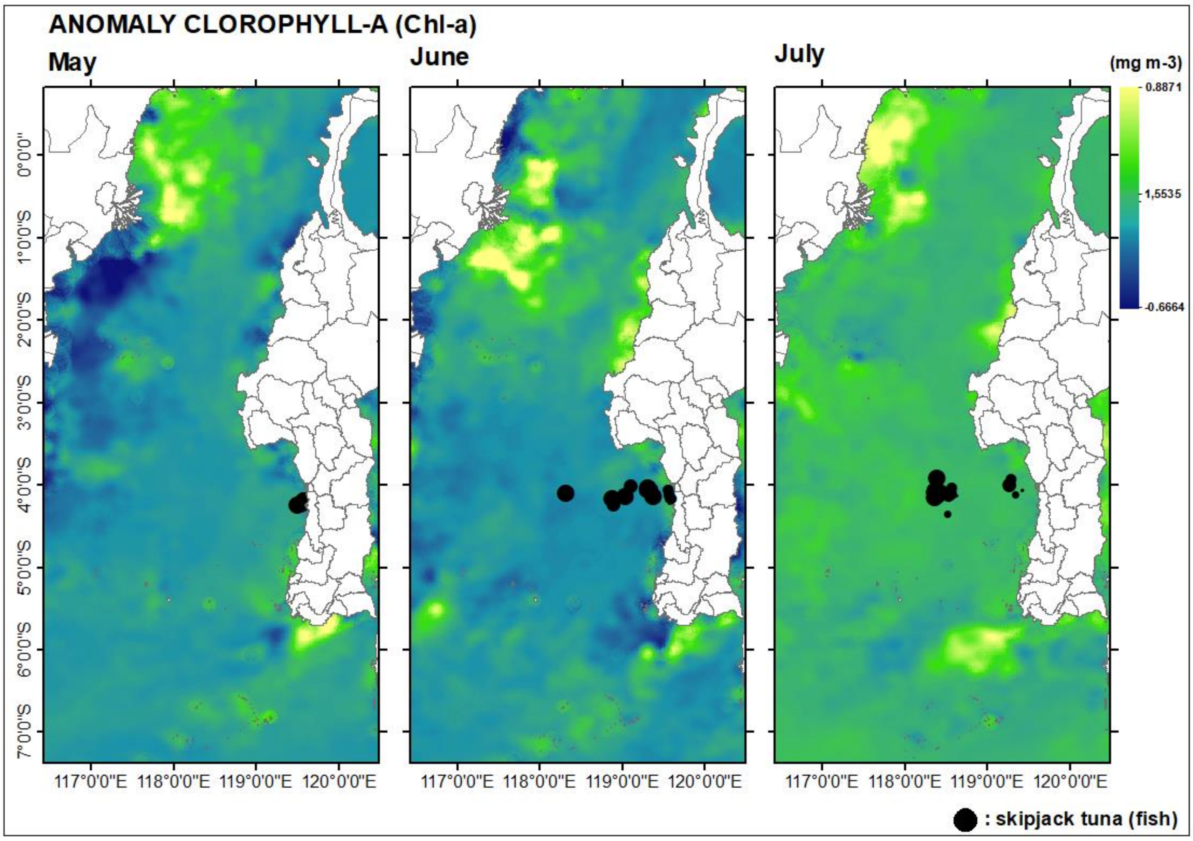

Figure 2. The anomaly of Chl-a Concentration in Makassar Strait during May-July 2017

Oceanographic factors that greatly affect the distribution and abundance of skipjack tuna (*Katsuwonus pelamis*) are SST and chl-a; SST affects fish physiology, while chl-a affects nutrition

[19,20]. Thus the anomalies of these two factors will greatly affect fish, which will be spatially distributed in the waters that can be tolerated by their bodily metabolism, especially in fish such as skipjack tuna (*Katsuwonus pelamis*) which migrate over long distances. In figure 3, we can see that the highest frequency of skipjack tuna (*Katsuwonus pelamis*) fishing took place within an SST range of 29.2 – 29.4 ºC with 16 trips (Figure 3a). Whereas based on the SST anomaly factor, the highest catch was obtained in negative anomalies (-0.4 to -0.3 ºC) with 15 trips (Figure 3b).

Chlorophyll-a factor in Figure 3c and 3d shows that skipjack tuna (*Katsuwonus pelamis*) was most commonly found in the chl-a range of 0.20 – 0.25 mg m^{-3} with a fishing frequency of about 18 trips. The highest fishing activity (15 trips) took place in negative chl-a anomalies in the range of -0.05 to -0.025 mg m^{-3}.

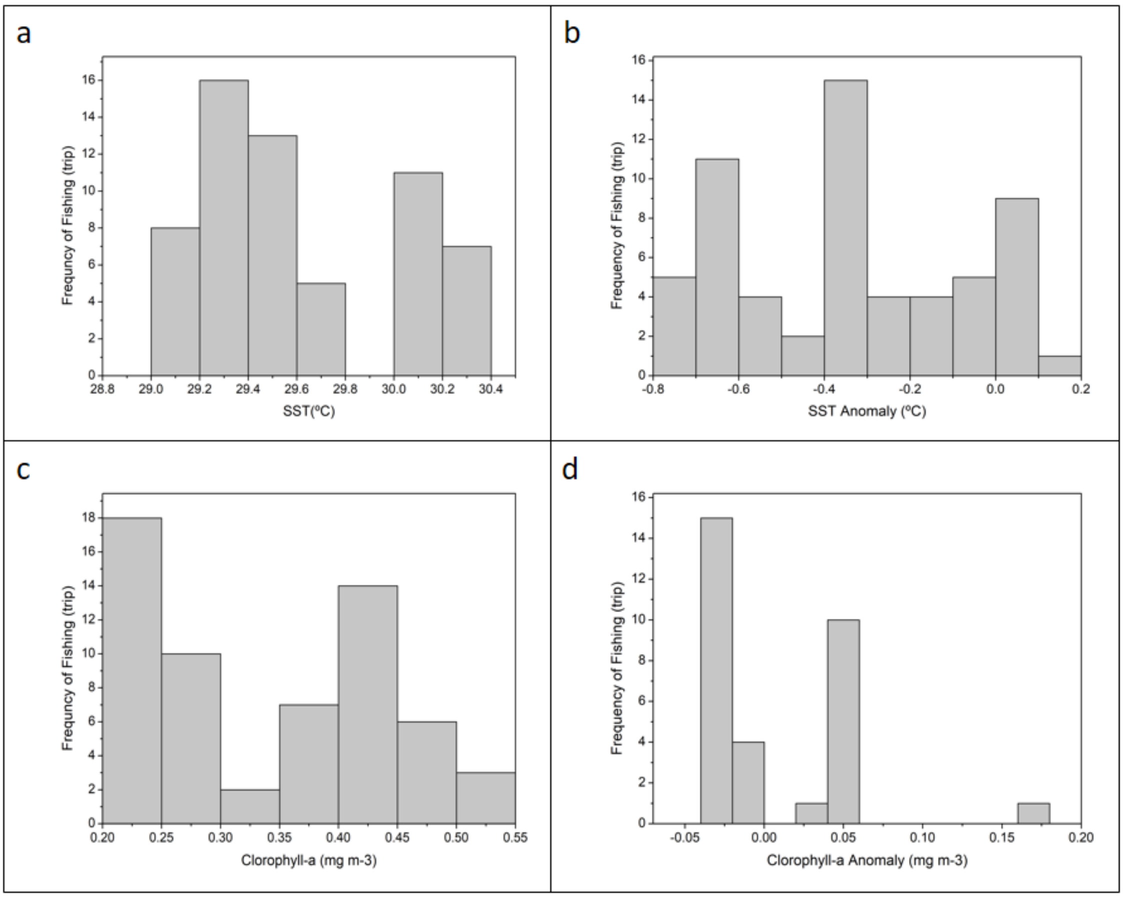

Figure 3. Graph of oceanographic factor relations to the frequency of fishing skipjack tuna (*Katsuwonus pelamis*) in Makassar Strait during May-July 2017

Many studies have used GAM analysis to evaluate the effect of variable x (independent variable) o variable y (dependent variable) [7,14,16]. In this research, GAM analysis showed that the significance value of SST was about 0.275, while that of SST anomalies was about 0.446; for Chl-a the significance was about 0.125, and for Chl-a anomalies about 0.255. This means that chl-a was the factor with the strongest influence on skipjack tuna (*Katsuwonus pelamis*) catches, with a significance value of 0.125 (Table 1).

Table 1. Results of the GAM model test

Variable	Edf	Df	F value	Pr (>F)
s(SST)	1.000	1.000	1.215	0.275
s(SSTanom)	1.463	1.806	1.000	0.446
s(chl)	1.000	1.000	2.436	0.125
s(chlanom)	1.000	1.000	1.321	0.255
R-sq.(adj) = 0.418, Deviance explained = 46.2%				

Regressions for these four factors (Figure 4) show that environmental abnormalities had an impact on skipjack tuna (*Katsuwonus pelamis*) catches. This is indicated by the distance of the gray area boundary from the black line (center line) (R-sq. = 0.418). This is similar to the results of a study on skipjack tuna (*Katsuwonus pelamis*) in the Gulf of Bone [7].

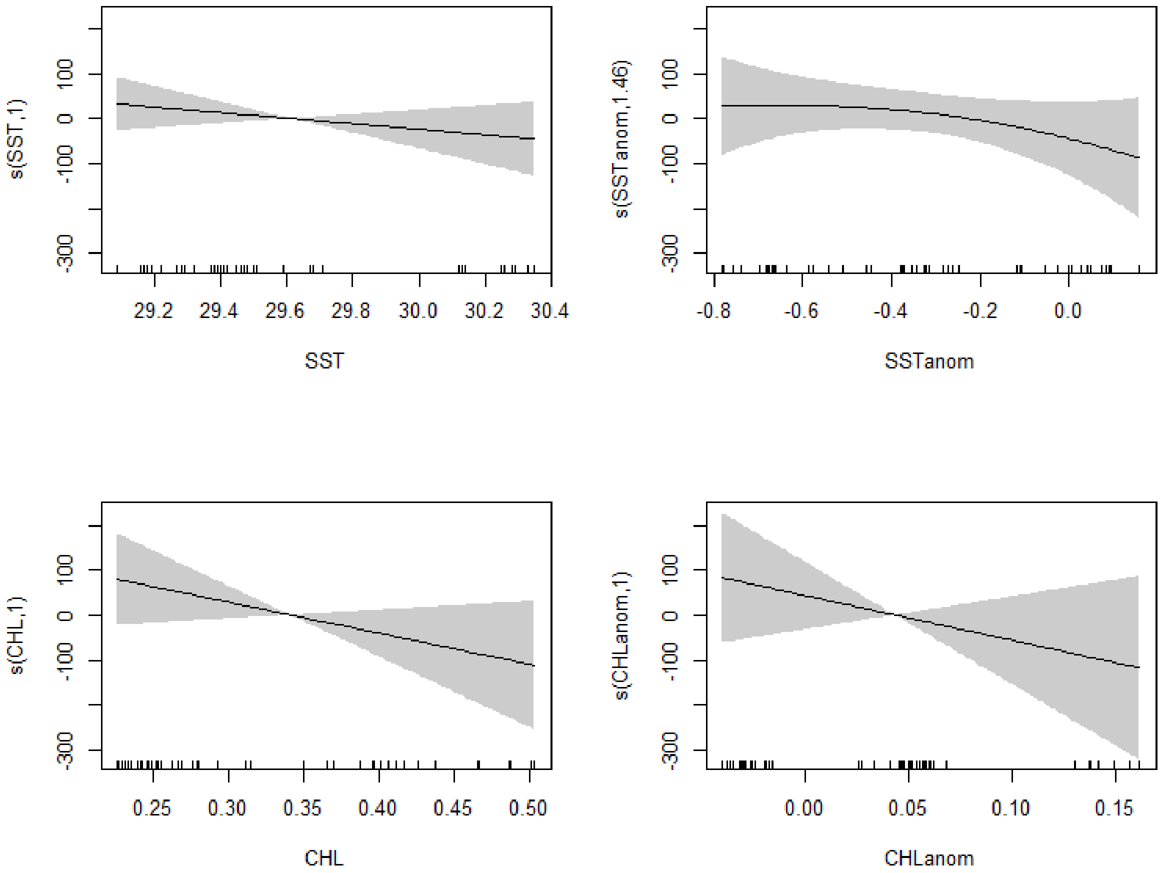

Figure 4. The effect of oceanographic factors on skipjack tuna (*Katsuwonus pelamis*) catches in Makassar Strait during May-July 2017

4. Conclusions

The occurrence of environmental abnormalities over the last 5 years as a result of the global phenomenon of climate change have had an effect on skipjack tuna (*Katsuwonus pelamis*) catches in the Makassar Strait. The effects of climate change are reflected in significantly increased SST and chl-a concentrations during May-July 2012 - 2016 in the southern part of Makassar Strait. These conditions, particularly chl-a concentration, were associated with significant increases in skipjack tuna catch in the southern Makassar Strait.

Acknowledgments

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