Application of remotely sensed satellite data to identify Skipjack Tuna distributions and abundance in the coastal waters of Bone Gulf

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Abstract. Skipjack tuna is a typical tropical tuna species with very large potential, so that it becomes the main target among Bone Gulf fishermen. Oceanographic factor anomalies have an impact on the distribution and abundance of skipjack tuna. This study aimed to analyze the relationship between satellite data of Sea Surface Temperature (SST) and Chlorophyll-a (chl-a) anomalies and, skipjack tuna catch and distribution. Using the remote sensing data from May to August 2012-2018, we analyzed the SST and chl-a anomalies. The oceanographic and skipjack tuna Catch per Unit Effort (CPUE) data, we identified their relationship using the Generalized Additive Model (GAM). The results of this study indicated that positive and negative anomalies have occurred where SST ranging from -0.8 – 0.6 °C and, chl-a ranging from -0.06 – 0.08 mg m⁻³ during the study period. We found that the anomalies of both oceanographic factors influenced a shift in the distribution pattern of Skipjack tuna in the coastal waters of Bone Gulf. The SST and chl-a anomalies were statistically significant factors affecting skipjack tuna abundance. This study suggests that these variables play an important role in developing tuna fisheries management and conservation.

1. Introduction
Skipjack tuna is a typical tropical tuna species, which is one of the significant species in global tuna species [4]; [11]. Indonesia is one of the tropical countries with high skipjack tuna production. In fisheries management area 713 of Indonesia, total skipjack tuna production reached 21038.8 tons in 2015. Bone Gulf contributed 40.37% of it namely 8493.3 tons [3].

The presence of nutrient namely chlorophyll-a (chl-a), Sea Surface Temperature (SST), and oxygen had a significant effect on the survival of skipjack fish [14]; [15]; [13]. The high concentration of chl-a is positively correlated to fish abundance in the waters, in relation to the fish food chain [10]. SST can affect the physiology and habits of various types of fish resources [2]; [6].

So that, their movement and vulnerability were affected by their preferred habitat [5]. If the anomaly occurs in its habitat, it will affect the distribution pattern and abundance of skipjack tuna [6]; [8], including SST and chl-a anomalies (Yu et al., 2018; [10]; [12].

Satellite data can be used to view anomalies that occur over a certain period of time [7]; [10]. So that, it can be used as consideration in the management of skipjack tuna. Although the abundance of skipjack tuna resources, but if the exploitation is not managed properly, the time will also run out and experience...
extinction. Skipjack management needs to be carried out in order to maintain the sustainability of the ecosystem and its resources. This study aimed to analyze the relationship between satellite data of Sea Surface Temperature (SST) and Chlorophyll-a (chl-a) anomalies and, skipjack tuna catch and distribution.

2. Material and Methods

2.1. Study area
This study conducted on May-August 2018 in Bone Gulf, Indonesia (Figure 1). Bone Gulf, located in Sulawesi Province, Indonesia is one of the waters where the target was the operation of pole and line fishing gear to catch skipjack tuna.

![Figure 1. Map of research location (Bone Gulf, Indonesia).](image)

2.2. Data collections
In this study, we used primary and secondary data. The primary data namely Skipjack tuna Catch per Unit Effort (CPUE) data (skipjack/hauling) and oceanographic parameters. Skipjack tuna CPUE data were collected during the study, namely May-August 2018 by following the operation of pole and line to catch skipjack tuna in Bone Gulf. Fishing was carried out using Fish Aggregating Devices (FADs) or without FADs. The skipjack CPUE data were calculated using a counter every hauling time. While calculating the amount of catch, the other colleagues also take samples of seawater to measure the oceanographic parameters namely Sea Surface Temperature (SST) and chlorophyll-a (chl-a). The SST was directly cured in the field using a digital thermometer. While to find out the concentration of chl-a, seawater sample was stored in a dark bottle for analysis in the water quality Laboratory of Hasanuddin University.

While, the secondary data namely satellite image data, which downloaded from https://oceancolor.gsfc.nasa.gov/ in May-August 2012-2018. Remote sensing satellite data used was Moderate Resolution Imaging Spectrometer (MODIS) SST and chl-a data to analyze environmental parameter anomalies during 2012-2018.
2.3. Anomaly method
Using the remote sensing data from May to August 2012-2018, we analyzed the oceanographic parameter anomalies. This method would find SST anomalies and chl-a that have occurred during May-August for the last 7 years (2012-2018). The formula was as follows [1]:

\[ \delta_{ij} = \bar{T}_{ij} - \bar{T}_i \]  

(1)

Where \( \delta_{ij} \) denotes the anomaly of the considered variable (SST or Chl-a) in month \( i \) and year \( j \), \( \bar{T}_{ij} \) represents the mean of the variable in month \( i \) and year \( j \), and \( \bar{T}_i \) signifies the monthly mean of the variable for 7 years.

2.4. Generalized additive model (GAM)
Generalized Additive Model (GAM) used to analyze the relationship between oceanographic parameters and anomalies with CPUE skipjack. To apply this model, we used R software with the formula:

\[ \log(\text{cpue} + 1) = \alpha + s(\text{SST}) + s(\text{SSTanom}) + s(\text{CHL}) + s(\text{CHLanom}) + \epsilon \]  

(2)

Where \( \alpha \) is constant, \( s(\cdot) \) denotes the spline smooth function of SST, SST anomalies, chl-a, and chl-a anomalies, and \( \epsilon \) denotes the random error term.

3. Results and Discussion
Skipjack tuna during May - August 2018 in Bone Gulf caught on 3°0’ S - 4°30’ S and 120°30’ E - 121°30’ E. Skipjack tuna at the bone gulf were mostly caught by pole and line fishermen. Based on the interviews with them, from October to December the distribution will spread to the south towards the Flores Sea.

Figure 2. Graph of the distribution of skipjack tuna catches for each environmental parameter and anomalies.
Based on Figure 2a, most skipjack caught at chl-a concentrations of 0.2 - 0.3 mg/m³ which were caught up to 118 skipjack/hauling. This is in accordance with Zainuddin [14] on the Bone Gulf-Flores Sea. Furthermore, by looking at Figure 2b, the distribution of skipjack tuna spread over a temperature range of 28.5 – 31 °C which reaches 115 skipjack/hauling. The range was slightly wider than what Zainuddin [14] said in their paper. It could be caused by the expansion of the tolerance range of skipjack tuna due to SST anomalies.

In this study also seen the distribution and abundance of catches based on environmental parameter anomalies namely SST and chl-a (Figure 2c and 2d). The distribution of skipjack tuna catches was in the positive and negative chl-a anomaly ranges between -0.06 – 0.08 mg/m³ with the highest dominant catches in the range of -0.06 – 0.02 mg/m³ which reaches 118 skipjack/hauling (Figure 2c). While for SST anomaly parameters (Figure 2d) shown that skipjack tuna caught in a range of SST anomalies of -0.8 – 0.6 °C, with high catch frequency in the range of positive anomalies namely 0 – 0.25 °C.

Anomalies indicate a state, which is anomalies or irregularities occur from the circumstances that normally occur. In this study, we looked at anomalies chl-a (Figure 3) and SST anomalies (Figure 4) during May to August for the last 7 years (2012-2018).

From Figure 3, it can be seen that at the Bone Gulf during the study period there had been negative and positive anomalies. The skipjack tuna caught on positive anomalies from chl-a, which means that skipjack fish tend to like the situation when chl-a concentration increased from the average for the last 7 years. Figure 3 also shown that negative chl-a anomalies occured in waters near the coast.

Figure 3. Distribution patterns of skipjack tuna catches of chl-a anomalies in May-August for the last 7 years (2012-2018).

Anomaly method was also applied to see the spatial distribution of the SST anomalies at the Bone Gulf during the study period. The results can be seen in Figure 4, it can be seen that in May to June there was a positive anomaly (an increase in SST) from the average of the last 7 years. While in the following months, July to August, they tend to experience negative anomalies (decreases in SST) from the average of the last 7 years.
Figure 4. Distribution patterns of skipjack tuna catches of SST anomalies in May-August for the last 7 years (2012-2018).

We used GAM analysis to see the relationship between CPUE of skipjack tuna and oceanographic parameters, other study also did this [5]; [7]; [9]. This method found that Significance value of SST about 0.0272, SST anomaly about 0.6107, Chl-a about 0.3385, and Chl-a anomaly about 0.0682. So, it is mean that SST and chl-a anomalies were the influencing factor the skipjack tuna (Katsuwonus pelamis) catches by significance value namely 0.0272 and 0.0682 (Table 1).

Table 1. Result of GAM model test.

| Variable      | Edf | Df  | F value | Pr (>F) |
|---------------|-----|-----|---------|---------|
| s(SST)        | 7.069 | 7.745 | 2.210 | 0.0272* |
| s(CHL)        | 1.000 | 1.000 | 0.925 | 0.3385 |
| s(SSTanom)    | 3.221 | 3.753 | 0.750 | 0.6107 |
| s(CHLanom)    | 1.481 | 1.774 | 2.224 | 0.0682 |

Signif. Codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

R-sq.(adj) = 0.266, Deviance explained = 35.4%

We found that the anomalies of both oceanographic factors influenced a shift in the distribution pattern of Skipjack tuna in the coastal waters of Bone Gulf which marked by the further away of the gray area from the black line (center line) with a 90% confidence level. The SST and chl-a anomalies were statistically significant factors affecting skipjack tuna abundance. This study suggests that these variables play an important role in developing tuna fisheries management and conservation. So it was important to consider these factors in the management of sustainable use of skipjack fish in the future in the Bone Gulf waters.
Figure 5. The relationship between skipjack tuna catches with SST (a), chl-a (b), SST anomalies (c), and chl-a anomalies (d).

4. Conclusions
In summary, there had been negative (decrease) or positive (increase) anomalies in the Bone Gulf waters for the last 7 years (2012 to 2018) in May to August on the SST and chl-a concentration parameters. These had a significant effect on the distribution and abundance patterns of skipjack tuna. So it was important to consider these factors in the management of sustainable use of skipjack fish in the future in the Bone Gulf waters.

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