Impact of increasing sea surface temperature on skipjack tuna habitat in the Flores Sea, Indonesia

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Abstract. The Flores Sea is a water mass transfer route from two large oceans, namely the Pacific Ocean to the Indian Ocean known as Indonesian Throughflow (ITF). This flow certainly has an impact on the waters it passes through, including the Flores Sea, making the Flores Sea a hotspot for changes in oceanographic conditions. This study used satellite data to determine the increase in Sea Surface Temperature (SST) in the Flores Sea during 2015-2019. It used the Generalized Additive Model (GAM) analysis to analyze the effect of increasing SST on skipjack tuna habitat in the Flores Sea. The results showed that there had been an increase in SST of up to 2.5 °C over the past 15 years in the Flores Sea. This increase in SST affects the tuna skipjack habitat, as evidenced by the decrease in catches in areas with warmer temperatures than usual. This study is important in considering the sustainable management of tuna fisheries, especially in tropical waters.

1. Introduction

Indonesian waters are unique and complex. Indonesian seas are the only low latitude waters through which Indonesian Throughflow (ITF) passes [1]. ITF is a flow that connects two major oceans, namely the Pacific Ocean and the Indian Ocean [2,3]. The Pacific Ocean is famous for the phenomenon of El Nino (increase in water temperature) [4,5], while in the Indian Ocean, the Indian Ocean Dipole (IOD) phenomenon occurs [5]. So, of course, the flow of water masses from the Pacific Ocean to the Indian Ocean has an oceanographic impact on the waters it passes through, including the Flores Luat. This flow makes the Flores Sea a hotspot for changes in oceanographic conditions, especially the Sea Surface Temperature (SST) anomaly.

Several researchers have been able to show that SST trends have been increasing in Indonesian waters [5–9]. SST affects the physiological activity of fish [7,10], influences the migration patterns of fish [11], and chlorophyll-a levels in water [12]. The increase in SST in pacific waters has been proven to have made skipjack tuna move north away from Indonesian waters [4]. [10] predicts that due to increased SST fish, body size will decrease by 14-24% in 2050, especially in tropical waters. However, in another study, it was stated that when the temperature warms up in American waters, habitat is suitable in most of the study areas for the skipjack tuna species [7].
Suitable oceanographic conditions drive the presence of skipjack tuna in waters [13–15]. Each fish species has its tolerance limit for water temperature. Several previous studies in tropical waters stated that skipjack tuna was caught in the SST 29 - 31°C range [16], 29.5 – 31.5 °C range [13], 28.6 – 31.12 °C [17], and >26.5 °C [15]. A study states that the lower thermal limit for tuna skipjack is ≤ 18 °C [14], while the upper limit is 33 °C [18]. So, the increase in SST is estimated to have a significant impact on the abundance and distribution of skipjack tuna in the Flores sea. The results of this analysis can later be used for tuna fisheries management, especially in tropical waters.

2. Methods

2.1. Study site
The Flores Sea is one of the waters with a very high catch of skipjack tuna in Indonesian waters. Skipjack tuna fishing in these waters uses pole and line and purse seine. We simulate the research location shown in Figure 1.

The Flores Sea is the natural boundary between South Sulawesi Province in the North and Nusa Tenggara Barat Province in the South. In the division of fisheries management areas, the Flores Sea is located in the Fisheries Management Area of 713, Indonesia along with the Makassar Strait, Bone Bay and the Bali Sea. The condition of the waters of Flores is affected by water masses from the ITF flow. It is estimated to get heat propagation from the El Nino phenomenon that occurs in the Pacific Ocean and IOD that occurs in the Indian Ocean.
2.2. **Observational datasets**

This study took observational data in the form of the position of the tuna skipjack catch (latitude and longitude), the CPUE (catch per unit effort (fish/setting)), and SST (°C) during March to May 2019. Data were collected by following the one-day purse seine operation with a fishing ground in the Flores Sea. The CPUE was calculated by the following equation [19,20]:

\[
CPUE = \frac{\Sigma \text{Catch}}{\Sigma \text{Fishing effort}}
\]

(1)

Where \( \Sigma \text{Catch} \) was the sum of catches and \( \Sigma \text{Fishing effort} \) was the sum of fishing efforts.

2.3. **Satellite Remote Sensing Data**

Long-term data are needed in the analysis of oceanographic conditions anomalies (SST), so that remote sensing data from [https://oceancolor.gsfc.nasa.gov/](https://oceancolor.gsfc.nasa.gov/) is used. The type of data used is AQUA MODIS (Moderate-resolution Imaging Spectroradiometer) data with 4 km resolution from March to April 2005-2019 (the last 15 years).

2.4. **Data analysis**

2.4.1. **Anomaly analysis.** Anomaly analysis was used to determine the increase in SST during the last 15 years (2005-2019). The anomaly analysis formula is as follows [21]:

\[
\delta_{ij} = \frac{\text{SST}_{ij}}{\text{SST}_i} - \frac{\Sigma \text{SST}_i}{\Sigma \text{SST}_{ij}}
\]

(2)

where:

- \( \delta_{ij} \) = the anomaly of SST in month \( i \) and year \( j \);
- \( \overline{\text{SST}}_{ij} \) = the average value of the SST in the month \( i \) and year \( j \);
- \( \overline{\text{SST}}_i \) = the SST in month \( i \).

2.4.2. **Generalized Additive Model (GAM).** GAM is a non-parametric statistical analysis [22]. The GAM was used to determine the nature of the relationship between CPUE and the environmental variables [23]. The model applied was as follows [8,23]:

\[
\log(CPUE + 1) = \alpha + s(\text{SSTanomaly}) + \epsilon
\]

(3)

Where \( \alpha \) is constant, \( s(\text{SSTanomaly}) \) is a spline smoothing function of the SST anomaly, and \( \epsilon \) is a random error term. CPUE is a catch per unit effort of skipjack tuna.

3. **Results and Discussion**

3.1. **SST Increase in the Flores Sea (2005-2019)**

SST is a fundamental variable affecting fish species. SST can be used as a parameter to predict the presence of organisms in waters, especially fish [24]. SST is one of the fundamental factors limiting the presence of fish in a sea [7]. SST affects the physiological functions of aquatic animals [7,10], such as affecting swimming ability [25], spawning activity [26], and larval growth [27]. Indirectly, SST can also promote migration patterns [11], and prey species dynamics [28]. Thus, increasing SST will have a significant impact on the skipjack tuna habitat.

Many recent studies have reported that there has been an increase in SST globally [7,9,20,29], as well as in Indonesian waters [6,8]. We tried to simulate how this SST increase affects the skipjack tuna habitat. The increasing trend of SST in tropical waters reached 0.8 - 1.4 oktas per century [9]. In a recent study in Indonesian waters, it was also stated that there had been an increase in SST in the
waters of the Gulf of Bone Indonesia reaching 0.7 °C over the last ten years [6] and in the waters of the Makassar Strait going 0.8 °C over the previous five years [8].

On a multi-decadal scale, Figure 2 showed there had been an increase in SST in the Flores Sea during the last 15 years (2005-2019). In March 2019 an increase occurred in the northeast and southwest Flores Sea, in April almost all of the Flores Sea area had an increase in SST (except in the northern part), while in May there was an increase in SST throughout the eastern part of the Flores Sea.

![Spatial distribution of skipjack tuna CPUE (fish/setting) from March to May 2019 overlain the SST anomaly in 2019 (for the last 15 years from 2005 to 2019)](image)

**Figure 2.** The spatial distribution of skipjack tuna CPUE (fish/setting) from March to May 2019 overlain the SST anomaly in 2019 (for the last 15 years from 2005 to 2019)

Spatial distribution of catches shows that skipjack tuna is mostly caught in areas with decreased SST compared to regions with increased SST (Figure 2). The skipjack tuna catching is at positions 121 - 122 °E and 6 – 7 °S, namely in the southern part of the Flores Sea. [4] stated in his research that the
increase in temperature in Pacific waters caused the spatial distribution of skipjack tuna to shift north away from Indonesian waters.

The highest number of catches was captured in the negative SST anomaly range, namely -0.6 - (-0.41) with the number of catches 1136 fish/setting (Figure 3). When the water temperature warms up > 0 to 0.59 °C, the skipjack tuna CPUE decreases, and it reaches only 35 fish/setting. These results are the same as research in the Makassar Strait, namely the highest caught skipjack tuna in the low SST anomaly range (-0.3 - (-0.4)) [8].

![Figure 3. The total CPUE skipjack tuna over a certain SST range anomaly](image)

GAM analysis results showed SST anomaly has a relationship with skipjack tuna habitat (Table 1). The value of 0.00305 from the results of the GAM analysis showed that SST anomaly significantly affects the skipjack tuna habitat with a 99% confidence level. The increase in SST due to climate change is also said to affect the suitability of the habitat for bluefin tuna and skipjack tuna in the Intra-Americas Sea [7]. [20] pointed out also that warming oceans under climate change are likely to result in shrinkage and shifting of fish habitats.

| Variable          | Edf | Df  | F value | Pr (>F) |
|-------------------|-----|-----|---------|---------|
| s(SST anomaly)    | 4.813 | 5.721 | 3.591   | 0.00305 ** |

| Signif. codes: 0 *** 0.001 ** 0.01 * 0.05 + 0.1 - 1 |

From Figure 4, it can be seen that the highest distribution of tuna skipjack catches is in the SST anomaly range -0.1 - (-0.3)°C. Tuna skipjack catches were found in strong association with SST anomaly of about -0.1 - (-0.3). It is assumed that the tuna skipjack does not like areas with SST heating and leaves areas with hot temperatures. So that skipjack tuna is found in areas with negative anomalies (low). Skipjack tuna catches were found in strong association with SST anomaly of about -0.1 - (-0.3)°C.
Figure 4. GAM analysis results illustrating the effect of SST anomaly on tuna skipjack habitat. Dashed lines indicate 95% confidence intervals. The rug plot on the x-axis showed the relative density of data points.

The GAM model developed proved that the increase in SST significantly affected the skipjack tuna habitat. The rise in SST causes a decrease in abundance and a shift in the distribution of skipjack tuna to a cooler area reaching -0.1 - (-0.3 °C). The results of this study are supported by previous research which states that anomalies in oceanographic conditions cause changes in distribution patterns and a decrease in skipjack tuna catches.

4. Conclusion
This study provides evidence that there has been an increase in SST in the Flores Sea over the last 15 years (2005 - 2019) to 2.5 °C. This increase in SST affects the tuna skipjack habitat, as evidenced by the decrease in catches in areas with warmer temperatures than usual. This study provides valuable insight into how the skipjack tuna habitat is affected by increased SST and is the basis for the sustainable management of tuna skipjack fisheries in the future based on warming waters in tropical waters, particularly in Indonesia sea.

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