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THE INFLUENCE OF SEA SURFACE TEMPERATURE AND CHLOROPHYLL-A ON THE MIGRATION PATTERNS OF SKIPJACK TUNA (*Katsuwonus pelamis*) IN GULF OF BONE LUWU REGENCY

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ABSTRACT

This study was conducted from May to October 2024 with the aim of analyzing the effect of Sea Surface Temperature (SST) and chlorophyll-a concentration (CHL) on the migration patterns of skipjack tuna (*Katsuwonus pelamis*) in Bone Bay, Luwu Regency. Primary data consisted of skipjack tuna catch data, geographic coordinates, and on-site SST measurements, collected by directly following fishing operations using fishing gear. Secondary data included satellite imagery from Sentinel-3 that included SST, CHL, and current velocity (CUR). The results showed that SST ranged from 29 to 31°C, with a significant relationship indicated by a p-value <0.005, especially at 31.0°C, while the lowest influence was observed around 30.5°C with a p-value <0.001. Based on the CHL parameter, the most influential relationship was found at a concentration of 0.5–0.7 mg/m^3 with a p-value >0.005 and the lowest at 0.4 mg/m^3. The best model based on AIC and CDE values was a combination of SST and CHL. However, partially, only SST had a significant effect on catches (p <0.05), while CHL was not statistically significant (p >0.05). This indicates that sea surface temperature is the most dominant oceanographic factor affecting fish catches.

Keywords: Bone Bay, migration patterns, pole-and-line, SST, chlorophyll-a, current velocity.

INTRODUCTION

The waters of Bone Bay are a potential fishing area in South Sulawesi, boasting a significant pelagic fish resource, particularly skipjack tuna (*Katsuwonus pelamis*). This commodity has significant economic value and is the primary target of fishing activities in the coastal areas of Luwu Regency. Fluctuations in skipjack tuna catches from year to year indicate that the presence and distribution of fish are significantly influenced by aquatic environmental

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conditions.

The distribution and migration of skipjack tuna are influenced by oceanographic parameters, particularly sea surface temperature (SST) and chlorophyll-a concentration. Sea surface temperature plays a role in determining habitat preferences and fish metabolic activity, while chlorophyll-a is a primary productivity indicator related to the availability of natural food sources. The use of remote sensing technology through oceanographic satellite imagery allows for effective, extensive, and sustainable monitoring of marine environmental parameters (Rochman et al., 2015). Several previous studies have shown a relationship between oceanographic parameters and skipjack tuna catches. Research by Angreani et al. (2014) stated that sea surface temperatures in Bone Bay range between 29.5–31°C, which is consistent with skipjack tuna fishing grounds. Furthermore, Zainuddin et al. (2013) explained that the highest CPUE values were obtained at chlorophyll-a concentrations of 0.16–0.17 mg/m^3. Integrating satellite imagery with catch data and statistical analysis such as the Generalized Additive Model (GAM) can provide more accurate information regarding the relationship between oceanographic factors and skipjack tuna distribution and catch (Mursyidin et al., 2015).

However, previous research has generally focused only on partial relationships between oceanographic parameters and catch, and has not examined the effect of combined oceanographic parameters using the GAM approach specifically in Bone Bay waters, particularly in Luwu Regency. Furthermore, information on the oceanographic parameters that most dominantly influence skipjack tuna catches is still limited. Therefore, this study is important to analyze the relationship between sea surface temperature and chlorophyll-a on skipjack tuna catches using the GAM approach based on oceanographic satellite imagery data.

MATERIALS AND METHODS

Study Area

This study utilized both primary and secondary data. Primary data were obtained through direct observations during skipjack tuna (*Katsuwonus pelamis*) fishing activities using pole-and-line gear in the waters of

Bone Bay, Luwu Regency, during the period of May to October 2024 (Figure 1). The primary data included fish catch (kg), geographic coordinates of fishing locations (GPS), and in situ measurements of Sea Surface Temperature (SST) during each fishing operation. Secondary data consisted of oceanographic data derived from Sentinel-3 satellite imagery, including SST (SLSTR product), chlorophyll-a concentration (OLCI product), and surface current velocity data. The satellite imagery data were obtained from Copernicus Marine Service and the Copernicus Data Space Ecosystem, with a spatial resolution of approximately ±0.5 km.

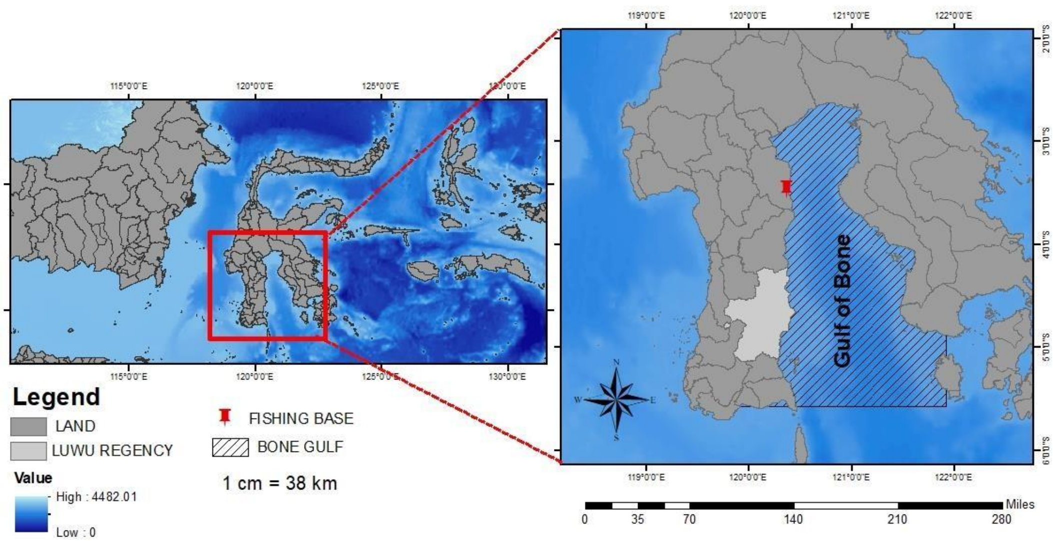

Figure 1 Map of the Study Area

Data Collection

In accordance with the research objectives, this study utilized primary data obtained through direct field observations by following the fishing operations. These data included the total catch and the geographic positions of skipjack tuna fishing grounds.

Secondary data consisted of satellite imagery of sea surface temperature (SST) and chlorophyll-a distribution derived from Sentinel-3, with a spatial resolution of 500 m (0.5 km). These data were obtained from the Sentinel-3 multi-mission satellite, which is equipped with four main instruments, including the Ocean and Land Colour Instrument (OLCI) and the Sea and Land Surface Temperature Radiometer (SLSTR).

In addition, surface current data were obtained from the Copernicus Marine

Service, specifically using the Eastward Sea Water Velocity (UO) and Northward Sea Water Velocity (VO) parameters.

Data Analysis

Satellite image processing included Sea Surface Temperature (SST) from Sentinel-3 SLSTR, chlorophyll-a from Sentinel-3 OLCI, and ocean current data. All datasets underwent several processing stages, including data collection, reprojection, cropping to the study area, masking, and compositing to obtain monthly average values. Chlorophyll-a processing was carried out using the Case-2 Regional Coast Colour (C2RCC) algorithm for atmospheric correction and chlorophyll-a extraction, while current data were processed by calculating current speed and direction using Microsoft Excel. The processed data were then visualized and analyzed using ArcGIS 10.8.

The prediction map of Potential Fishing Zones (PFZ) was developed based on the classification of optimal values of sea surface temperature and chlorophyll-a. These two parameters were then combined using an overlay method to produce a PFZ map representing potential fishing areas within the study region.

Relationship between Oceanography and Catch using GAM

The relationship between oceanographic variables and catch results was analyzed using the Generalized Additive Model (GAM) with a Gamma distribution. This model was selected because it can capture nonlinear relationships between the response variable (catch) and predictor variables (SST, chlorophyll-a, and current velocity). The best model was determined based on the lowest Akaike Information Criterion (AIC) and the highest Cumulative Deviance Explained (CDE).

Skipjack tuna gam formula:

gam (cpue ~ s(spl) + s(chlorophyll_a) +s(current_velocity) + s(EKE) + s(salinity) + s(primary_productivity) + s(sea_level), data

Note:

Skipjack tuna: link function and expected value of the response variable.

cpue: constant

s(.): smooth line function of the predictor variable

Fishing Ground Gravity Index

The analysis of fish migration patterns using the Gravity Index is a method to determine the spatial shift of fishing activity centers based on catch weight and geographic position. The Gravity Center Index (GCi) was calculated on a weekly basis to identify the direction and dynamics of skipjack tuna distribution during the study period.

$$GC_{ij} = \frac{\sum L_{ij}(CPUE)_{ij}}{\sum CPUE_{ij}}$$

where GC represents the monthly center of gravity of the fishing ground determined based on the longitude and latitude position (L_{ij}), while $CPUE_{ij}$ is the catch per unit effort, measured as the number of fish caught per fishing operation at position.

RESULTS AND DISCUSSION

Skipjack Tuna Production (Katsuwonus pelamis)

The production of skipjack tuna (*Katsuwonus pelamis*) during the study period, collected from pole-and-line fishing vessels over 66 trips from May to October 2024 showed a fluctuating pattern. Production in May reached 478 kg, with an average catch of 31.7 kg per trip. In June, production was 392 kg, with an average of 26.1 kg per trip. In September, production increased significantly to 2,838 kg, with an average catch of 157.7 kg per trip. Meanwhile, in October, production reached 548 kg, with an average of 32.2 kg per trip. The production of skipjack tuna is presented in Figure 2.

CPUE of Pattern of Coral Trout Grouper

Based on the analysis of Catch Per Unit Effort (CPUE) of coral trout grouper (*Plectropomus leopardus*) at the Paotere Fish Landing Base during the period 2019–2023, a clear seasonal fluctuation pattern was observed. CPUE values tended to increase at the beginning of the year, particularly from January to March, with the highest peak occurring in March. Subsequently, CPUE values gradually decreased toward the end of the year. The monthly CPUE fluctuation pattern is presented in Figure 2.

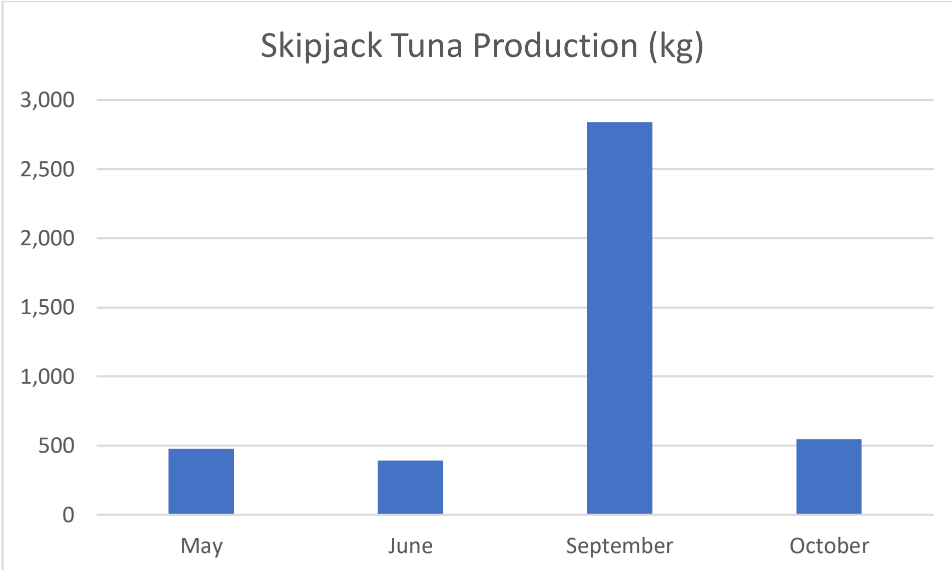

Figure 2 Skipjack Tuna Production From May-October 2024

Relationship Between Skipjack Tuna Catch and Sea Surface Temperature

Sea Surface Temperature (SST) has a significant influence on fishing grounds because it affects the distribution and migration of fish species. Optimal temperature conditions can increase the abundance and distribution of skipjack tuna; therefore, fishing grounds are generally located in waters with temperatures that support the survival of this species. SST also influences skipjack tuna migration patterns, as the species tends to move toward waters with optimal temperatures for feeding and reproduction.

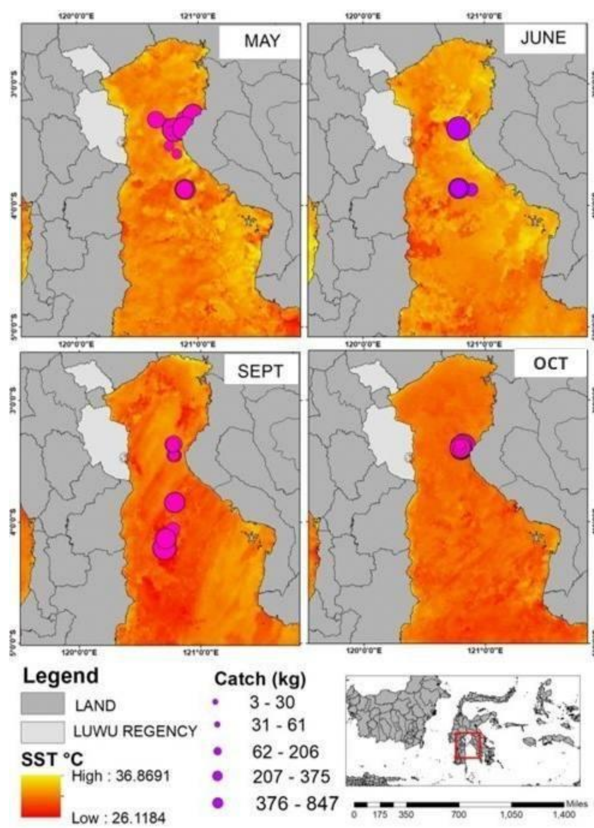

Figure 3 Distribution of Sea Surface Temperature from May to October

Based on the data in Figure 3 the study conducted from May to October 2024 showed that the Sea Surface Temperature in skipjack tuna fishing grounds ranged from 29.5°C to 31°C. The highest catch of skipjack tuna was recorded at an SST of 30.4°C, with a total catch of 2,025 kg. In contrast, the lowest catch occurred at an SST of 31.6°C, with a total catch of 33 kg (Figure 4).

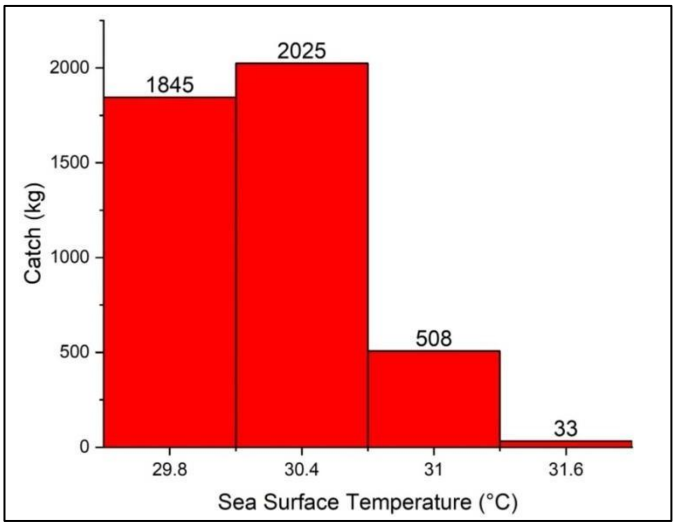

Figure 4 Relationship Between Sea Surface Temperature and Catch Results

Relationship Between Skipjack Tuna Catch and Chlorophyll-a

Chlorophyll-a is a pigment found in phytoplankton and other marine plants that plays a key role in the photosynthesis process, enabling the conversion of sunlight into energy. The presence of chlorophyll-a in marine waters is closely related to primary productivity, which refers to the production of organic matter by photosynthetic organisms such as phytoplankton, forming the base of the marine food chain.

Chlorophyll-a plays an important role in determining the availability of nutrients for marine organisms, which in turn influences fishing grounds. The concentration of chlorophyll-a also affects the type and abundance of fish species in a particular area. Regions with high chlorophyll-a concentrations often support abundant populations of pelagic fish such as skipjack

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tuna, tuna, and mackerel, which depend on plankton as their main food source. Therefore, areas with high chlorophyll-a levels have a greater potential to become productive fishing grounds.

Based on the data presented in Figures 5 and 6, this study was conducted from May to October 2024. The spatial analysis results showed that the optimum chlorophyll-a concentration for fish catches was approximately 0.2 mg/m^3. This value indicates that areas with moderate primary productivity provide suitable habitats for skipjack tuna. At this concentration, the total catch reached 3,875 kg.

However, the GAM analysis demonstrated a wider chlorophyll-a response range, approximately 0.5–0.7 mg/m^3. This difference may occur because GAM statistically models the nonlinear relationship between oceanographic variables and fish catches, meaning that the values shown in the GAM curve represent the model's optimum response range rather than average field conditions alone. Furthermore, the higher chlorophyll-a concentrations indicated by the GAM model may reflect areas with increased water productivity, thereby supporting greater food chain availability for skipjack tuna. In contrast, the lowest catch was recorded at a chlorophyll-a concentration of approximately 1 mg/m^3, with a total catch of only 6 kg.

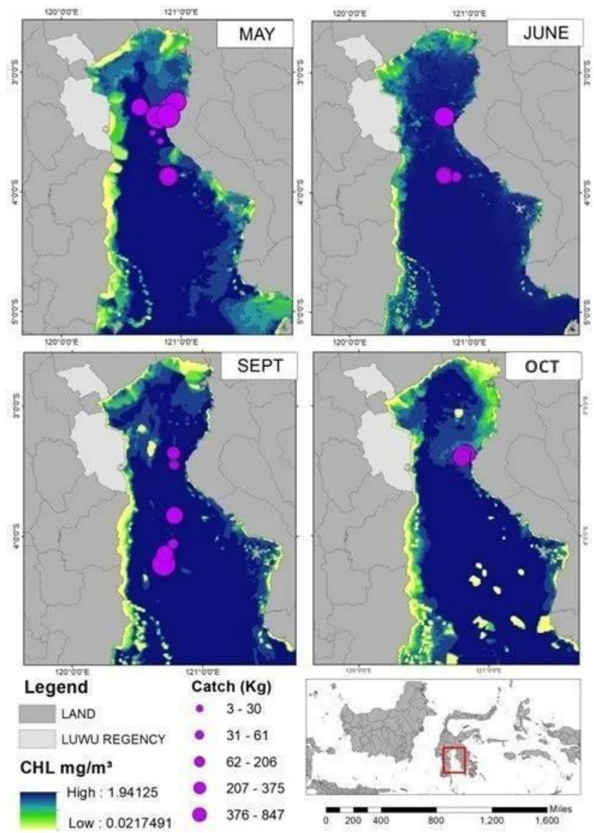

Figure 5 Distribution of Chlorophyll-a from May to October

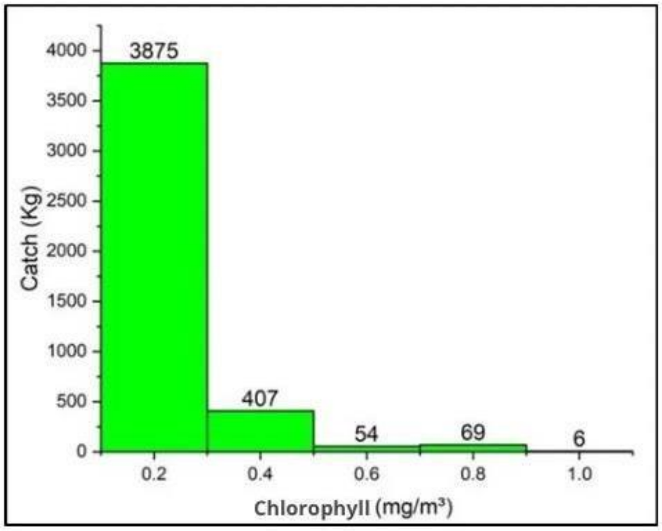

Figure 6 Relationship Between Chrophyll and Catch Result

Relationship Between Skipjack Tuna Catch and Current Velocity

Current velocity has a significant influence on fish migration patterns, particularly in terms of movement direction, migration speed, and food availability. Ocean currents affect the physical and biological conditions of the marine environment, which in turn influence fish behavior. Currents affect migration direction, as fish tend to follow currents to facilitate movement. Strong currents can transport fish to more distant areas with minimal energy expenditure. Conversely, fish moving against the current tend to reduce their migration speed and require more energy to reach their destination.

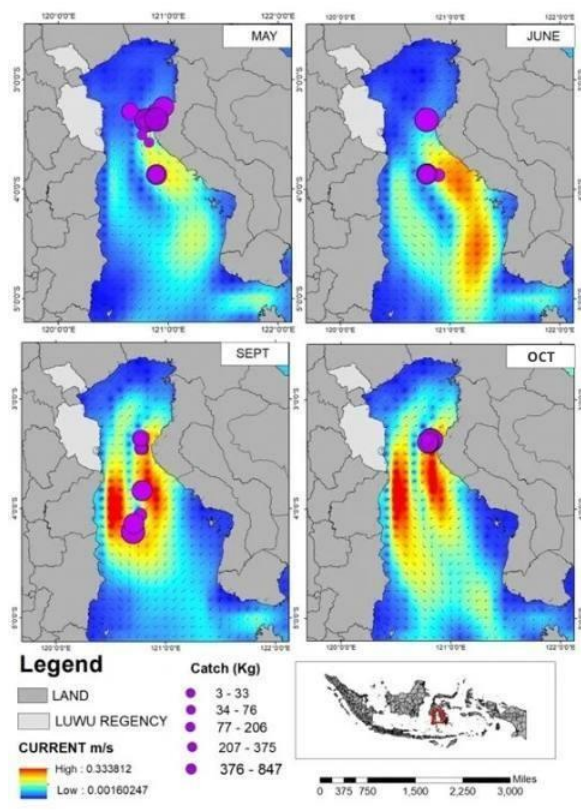

Figure 7 Distribution of Current Velocity from May to October

Currents also influence the distribution of nutrients and food, as ocean currents play a role in transporting plankton and nutrients that serve as the main food source for many fish species. Faster currents can affect the distribution of food across marine waters, and fish may move to areas where currents bring higher concentrations of food resources.

Based on the data in Figures 7 and 8, the study conducted from May to October 2024 showed that current velocity ranged from 0.09 to 0.24 m/s. The highest catch of skipjack tuna was recorded at a current velocity of 0.11 m/s, with a total catch of 1,808 kg. In contrast, the lowest catch occurred at a current velocity of 0.06 m/s, with a total catch of 33 kg.

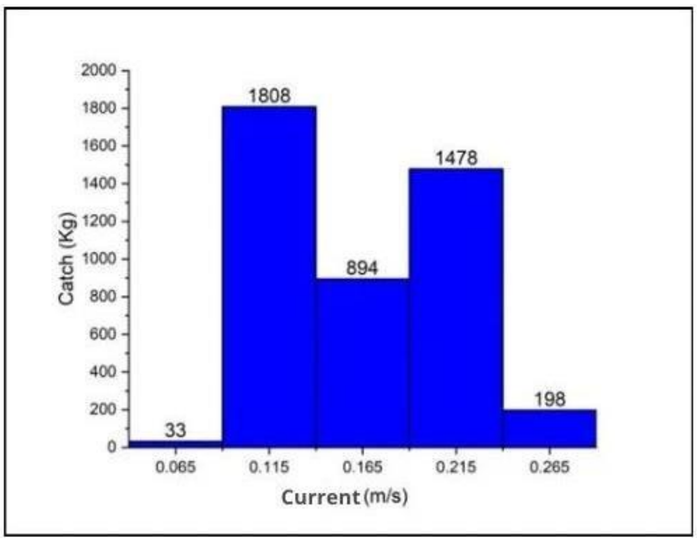

Figure 8 Relationship Between Current and Catch Results

Analysis of the Relationship Between Skipjack Tuna Catch and Oceanographic Parameters

The smoothing curve illustrates the relationship between predictor variables and skipjack tuna catch, where the x-axis represents the values of the variables and the y-axis indicates the contribution of the smoother function. The curve is accompanied by a 95% confidence interval. Values around zero indicate no effect, while values above and below zero represent strong and weak influences of the predictor parameters, respectively.

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The results of the Generalized Additive Model (GAM) analysis showed that Sea Surface Temperature (SST) had a significant effect within the range of 29–31°C (p-value < 0.005), with the strongest influence observed at approximately 30.5°C (p-value < 0.001). Chlorophyll-a (chl-a) also showed a significant effect at concentrations of 0.5–0.7 mg/m^3, while the weakest influence occurred at around 0.4 mg/m^3 (p-value < 0.001). The increase in the GAM curve occurred because chlorophyll-a is an indicator of primary productivity in the waters. At concentrations of 0.5–0.7 mg/m^3, water productivity increased, leading to greater availability of phytoplankton as the base of the marine food chain. This condition supports the presence of zooplankton and small fish that serve as prey for skipjack tuna, causing the fish to aggregate in these areas.

In the GAM graph, the more pronounced increase in the chlorophyll-a curve compared to SST indicates that chlorophyll-a had a stronger influence on fish catches. The peak of the curve at approximately 0.6 mg/m^3 indicates the optimum chlorophyll-a range based on the GAM model response.

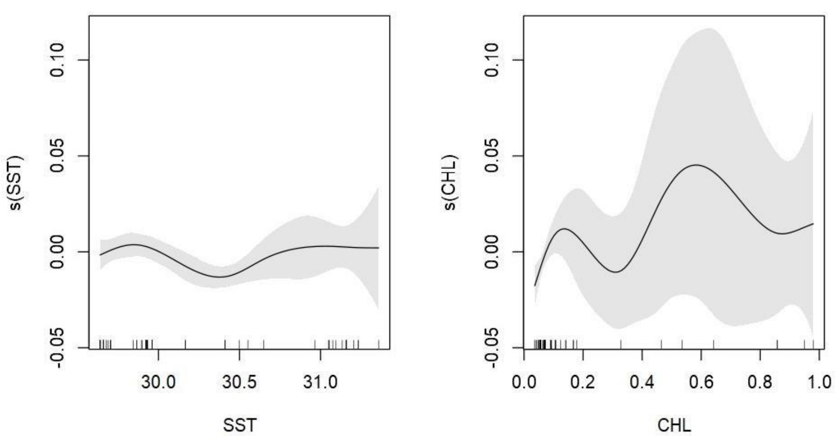

Figure 9 Analysis of the Relationship Between Catch and Using the GAM Method

From the Results of GAM Modeling Analysis

Based on the GAM modeling results obtained in this study, the best model was the one with the combination of SST + CHL variables, which showed the lowest AIC value and the highest CDE value. This model had the lowest AIC value of 654.05 and the highest CDE value of 55.40% (Table 1). The addition of the current velocity variable did

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not provide a significant contribution to the model performance.

Table 1 GAM Test Results of Parameter Effects on Catch

No	Variables	P.Value	CDE (%)	AIC
1.	SPL	0,0002***	41,70%	671,861
2.	CHL	0,0576***	29,50%	692,366
3	CUR	0,00724***	28,20%	686,522
4	SPL	0,00138***		
	CHL	0,06184*	55,40%	654,05
5.	SPL	0,217***		
	CUR	0,377*	42,10%	6776,29
6.	CHL	0,07474***		
	CUR	0,00449*	45%	663.593
7.	SPL	0,2822***		
	CHL	0,0876*	55,40%	
	CUR	0,4183*		656,275
	Signif.codes	0 '***'	0.001 '**'	0.01 '*' 0.05 '.' 0.1 ' ' 1

Based on this study, Sea Surface Temperature (SST) is the most influential parameter affecting skipjack tuna. Temperature influences the survival of skipjack tuna through metabolic processes, spawning, and feeding behavior, thereby affecting fish presence and ultimately

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influencing catch productivity (Zulkhasyni, 2015).

Prediction of Skipjack Tuna Potential Fishing Zones

Based on the total fishing points obtained during the study period from May to October, which were then plotted on a weekly basis, nine groups of fishing locations were identified. Each month consisted of 2 to 3 weeks of observation. From the spatial distribution map, the following patterns were observed: In week 1, fishing locations were in the Flores Sea, between Sulawesi Island and Flores Island, which is a migration route for pelagic fish. In week 2, the location shifted to Bone Bay, a semi-enclosed and productive water area between Makassar City and Kendari.

In week 3, fishing activity returned to the Flores Sea, indicating a southward shift toward the waters connecting to Maumere Bay. Week 4 remained in the Flores Sea, particularly around the Makassar Strait, which serves as a current transition zone.

Furthermore, weeks 5 and 6 were again concentrated in Bone Bay, indicating stable oceanographic conditions that support the presence of skipjack tuna. Week 7 showed a shift toward the eastern part of the Flores Sea. In weeks 8 and 9, fishing locations were concentrated in the Maumere Bay region, indicating a dominance of skipjack tuna presence in the southern– eastern part of the Flores Sea toward the end of the observation period.

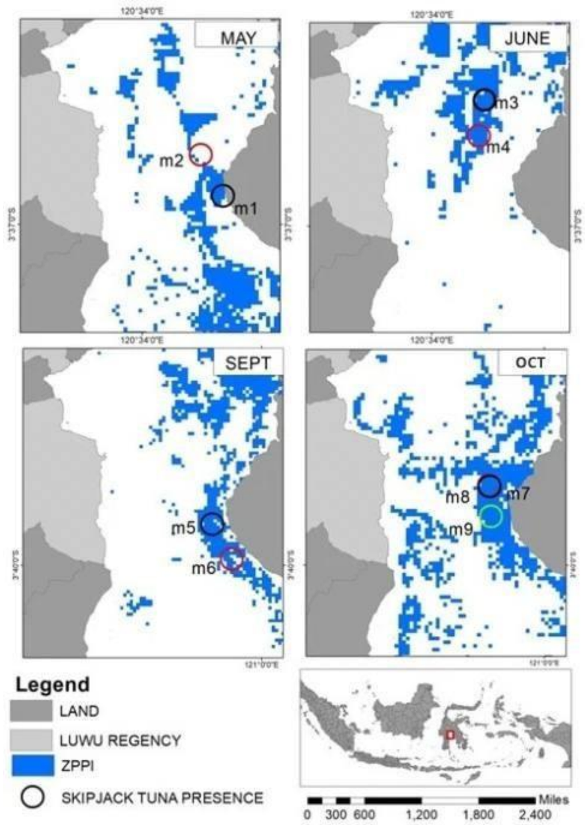

Figure 10 Prediction of Skipjack Tuna Fishing Zones from May to October

Analysis of the Fishing Ground Gravity Center Index for Skipjack Tuna

The Fishing Ground Gravity Center Index is used to determine the center of fish catch distribution and to analyze fish movement patterns spatially. Based on Figure 11, the migration pattern of skipjack tuna from May to October 2024 showed a gradual movement from northern coastal waters toward southern and more open waters. During the early weeks, the fish were distributed near coastal areas, then gradually moved southward and southwestward toward deeper waters until week 9. This pattern indicates the migration of skipjack tuna from coastal areas toward offshore waters.

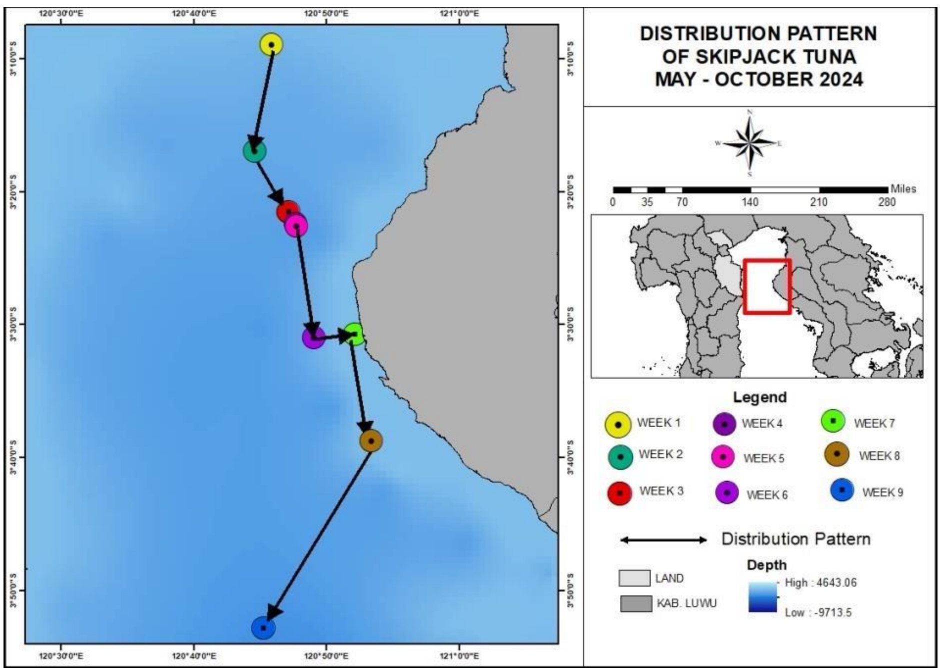

Figure 11 Distribution Pattern of Skipjack Tuna from May to October

CONCLUSION

This study on the influence of oceanographic parameters on the migration patterns and catch distribution of skipjack tuna (*Katsuwonus pelamis*) in the waters of Bone Bay, Luwu Regency, during May–October 2024 showed that sea surface temperature (SST), chlorophyll-a, and current velocity affected the distribution and catch of skipjack tuna. The highest catch was recorded at sea surface temperatures ranging from approximately 30.4–30.5°C, while the optimum chlorophyll-a concentration ranged from 0.1–0.3 mg/m^3.

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Current velocity that supported the presence of skipjack tuna was around 0.11 m/s.

The Generalized Additive Model (GAM) analysis indicated that sea surface temperature was the most dominant oceanographic parameter influencing skipjack tuna catches. The best model was obtained from the combination of SST and chlorophyll-a, with the lowest AIC value of 654.05 and the highest CDE value of 55.40%, indicating that both parameters were able to explain the variation in catch results effectively.

The distribution of skipjack tuna fishing zones during the study period showed a shift in fishing locations from the Flores Sea toward Bone Bay and subsequently moving toward Maumere Bay. In the early observation period, fishing zones were predominantly located in the Flores Sea, which serves as a migration pathway for pelagic fish. During the middle observation period, fishing zones became concentrated in Bone Bay, which has more productive oceanographic conditions. Toward the end of the observation period, the distribution of fishing zones shifted to the eastern and southern parts of the Flores Sea up to Maumere Bay, indicating fish movement following optimum environmental conditions.

The results of this study can be used as a basis for determining potential fishing zones for skipjack tuna and for supporting more effective and sustainable fisheries management in Bone Bay waters.

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