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Prediction Potential Fishing Zone of the Yellowfin Tuna (*Thunnus albacares*) in the Southern Flores Sea Using Satellite Remote Sensing Data

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ABSTRACT

Flores Sea has a very huge potential for large pelagic fish which is dominated by tuna. However, efforts to predict potential fishing areas are still very limited, especially by using Satellite Remote Sensing Data. The methods generally used are conventional methods which have limitations in terms of data accuracy, area coverage, and efficiency. This study aimed to map the oceanographic conditions of potential fishing zones through the interpretation of Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery and to determine the oceanographic conditions favored by the yellowfin tuna (*Thunnus albacares*) in the Southern Flores sea. The data collection was conducted directly in the field using longline fishing gear, where the fishing position and catch per trip were categorized as primary data. To analyze the data, the Generalized Additive Model (GAM) using oceanographic parameters (chlorophyll-a, depth, temperature, and salinity) was used. Using the Generalized Additive Model (GAM) with a CED value of 60.40% and an AIC value of 770.8742, the results showed that the sea surface temperature (SST), chlorophyll-a concentration, salinity, and depth are variables that affect fish catch. Oceanographic parameters in the yellowfin tuna fishing potential zone include a temperature range from 28.5 to 29°C, chlorophyll-a concentration of 0.10- 0.14mg/ m^3, salinity of 33.7– 34ppt, and depth of 3500–1500m, with the largest Zone of Potential Fishing (ZPPI) in September 2023 covering 31,808 km2, with the largest fish catch amounting to 1038kg.

INTRODUCTION

In general, Indonesia's ocean-shaped territory, which covers thousands of islands, makes it a maritime country. Marine fishery resources, such as the yellowfin tuna, are essential for food security and sustainable economic development. However, overuse will jeopardize future availability. Therefore, sustainable management of marine fisheries resources through responsible fishing practices, regulatory enforcement, marine habitat protection, and stakeholder collaboration is essential. This is in line with Sustainable

Development Goal (SDG) No. 14 on the sustainable conservation and utilization of marine resources. This concerted effort will ensure the availability of seafood resources for current and future generations, supporting food security and sustainable economic development. Tuna is an economically important fish with a high market value worldwide and plays an important role in the seafood trade **(Galland *et al.*, 2016)**. Large pelagic fish groups include tuna, and skipjack, which are fish species that have great potential in Indonesia **(Firdaus *et al.*, 2018)**.

In terms of the utilization of fishery resources, in the southern Flores Sea district has relatively large potential, especially for small-scale fishery resources. The area is home to a wide variety of economical fish, including pelagic fish (tuna, bonito, dragon, tuna, mackerel and sunglir) and demersal fish (grouper, snapper, redfish, yellowtail, lobster, squid, and mussels).

A common type of large pelagic fish caught is the yellowfin tuna, which is one of the most valuable fish resources in the southern Flores Sea. The yellowfin tuna is a pelagic fish that migrates far and is distributed not only in subtropical regions but also in most tropical regions of the world **(Hoolihan *et al.*, 2014)**. It has the habit of staying in the surface layer of mixed layers at night and diving into deep waters during the day **(Weng *et al.*, 2009)**.

However, efforts to identify potential tuna fishing grounds still face challenges, especially with traditional methods that rely on natural conditions and instincts. The structure of capture fisheries in Indonesia is still dominated by small-scale fishermen, thus impacting the production of main products (illegal, unreported, and unregulated fishing (IUUF)) and the sustainability of capture fisheries **(Karina, 2021)**.

Therefore, determining the fishing area is very important and must be known by every fisherman to catch the desired fish. The existence of fishing grounds greatly determines their accessibility for fishermen, thereby reducing high operational costs **(Paulangan *et al.*, 2020)**. One approach to obtaining information about natural resources is the use of remote sensing technology **(Lan *et al.*, 2017; Shah *et al.*, 2020)** and geographic information systems **(Shaari & Mustapha, 2018; Halid, 2022)**. Remote sensing technology is used to collect various types of information quickly. Moreover it can be used in various fields of science, saving both time and effort **(Zainuddin & Farhum, 2010; Edward, 2019)**.

The previous study **(Tambengi *et al.*, 2019)** showed that a good distribution of large pelagic fish can be found in various locations, including the northern and southern waters of Flores Island, as well as in the waters west and east of Kupang based on remote sensing imagery, while this study differs in terms of analysis methods and the number of parameters used, with the aim of mapping areas that are considered potential in fishing specifically based on fish catches obtained with oceanographic parameters.

MATERIALS AND METHODS

1. Time and place of research

The study was carried out for 6 months, from July to December 2023, in the southern Flores Sea. Direct observation was performed during fishing operations using hand line fishing gear in Flores Sea waters. Fishing operations were carried out from July to December 2023, with 105 capture points. The primary data used includes fishing area coordinates and catches obtained directly from the field, while secondary data consists of Aqua-MODIS daytime level 3 SMI (Standard Mapped Image) satellite image data with a resolution of 4 km². The satellite image data, recorded from July to December 2023, were sourced from oceancolor.gsfc.nasa.gov. The results of the data were then tabulated to obtain changes and developments in the form of tables and graphs, looking for relationships between oceanographic parameters.

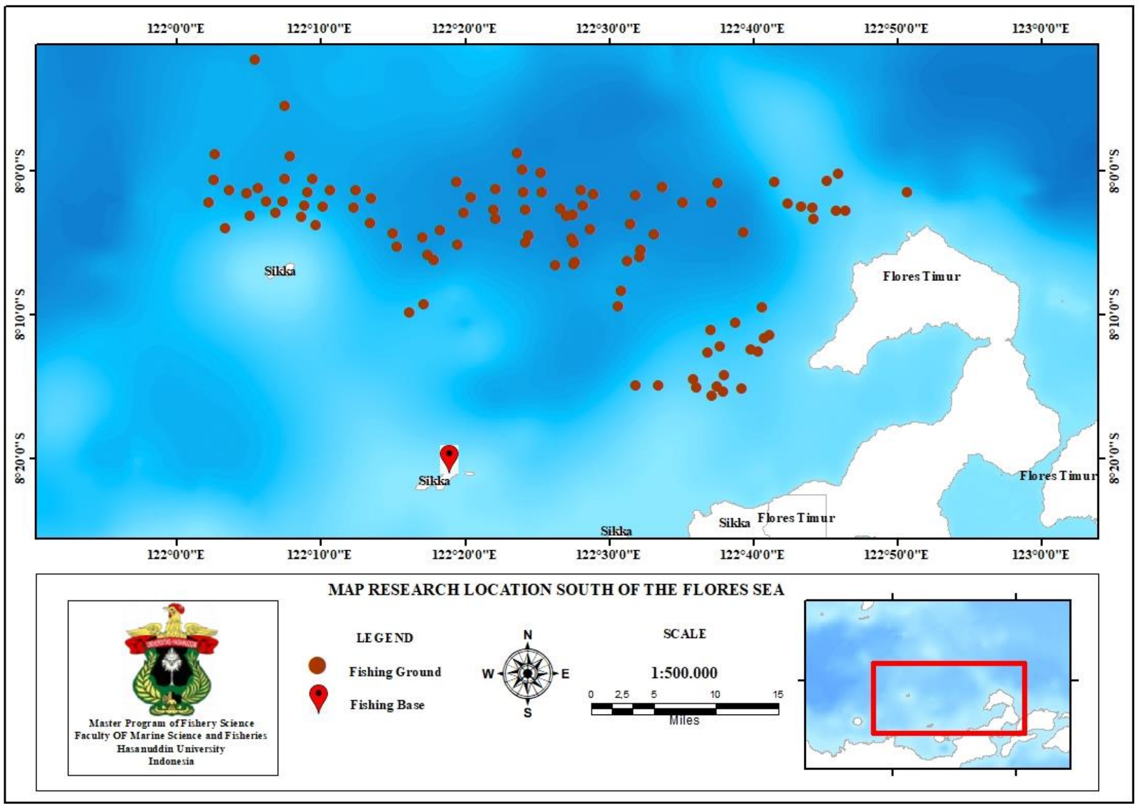

Fig. 1. Map of the research location

2. Data analysis

This study used analytical and descriptive techniques for its analysis. Through descriptive analysis, an overview and explanation of the estimated range of distribution of fish abundance in the Southern Flores Sea were presented. The methods used in this study include image cropping, overlaying, satellite image data processing, secondary data collection methods, primary data collection methods, and qualitative map analysis.

Level 3 data was used in the data processing stage to identify potential fishing areas based on MODIS satellite imagery. Four ocean distribution measurements (chlorophyll-a, sea surface temperature (SST), salinity, and depth) were used to identify potential fishing grounds. In addition to marine data and fishing location data, fish catches were also used as a reference for potential fishing areas

2.1 Remote sensing analysis

Oceanographic parameter data (SST, Clorophyll-a, salinity, and depth) were downloaded through satellite image sites MODIS, Gebco and Copernicus analyzed using SeaDAS software version 8.3.0 for Windows. Then, the distribution of oceanographic data at the research location (southern Flores sea waters) was determined and the relationship between oceanographic data and fish yield was analyzed. Data that have been downloaded in NetCDF (Network Common Data Form) format were cropped according to the research location through SeaDAS software. Cropping data was stored in NC format. After obtaining data in NC format, data processing was continued using Microsoft Excel. Then the distribution of oceanographic parameters was made using ArcGIS 10.8 software so that spatial data and contours were obtained. The data were then presented in graphical form and further analyzed according to the time and place of fishing operations.

2.2 Prediction of potential fishing zones with GAM models

Potential Fishing Zone (PFZ) determination began by examining the relationship and influence of sea condition (expressed in as SST, chlorophyll-a, depth, and salinity) on pelagic fishing grounds (based on location and catch). PFZ was then determined using patterns of relationships and influences of each or a combination of these parameters. To obtain spatial prediction models, GAM must be designed as an exploration tool. This step was carried out to determine the nature of the relationship between environmental factors and fishing results.

In the second stage, after identifying the relationship between fishing yield and each predictor (sea surface temperature and chlorophyll-a, salinity, and water depth), the corresponding function for parameterizing the shape was a linear model **(Zainuddin *et al.,* 2013)**. The general additive model (GAM) was a semiparametric multiple regression model that requires less normality of data distribution. This method was nonlinear and can be used to overcome weaknesses related to the assumption of a normal distribution of observed environmental parameters and the absence of a linear relationship between the two variables **(Mugo *et al.,* 2010; Susilo & Arief Wibawa, 2016)**. The linear model in this study included capture (tail or hauling) as a variable of the SST response, and chlorophyll-a, current, depth, and salinity as predictor variables produced by the GAM. The application of GAM_s statistical models was as follows:

Fishgam=gam(Catch~s(SST)+s(Chl)+s(Salinity)+s(Depth), data=data

The capture is a constant value, s(.) is a fine spline function of the predictor variables (SST, chlorophyll-a, salinity, and depth), and the data contain random errors.

GAM modeling was performed using the mgcv package included in the R software. The model used the Guassin distribution and the Identitylink function as response or catch variables, and the explanatory variables were SST, chlorophyll a, salinity, current, and depth.

To predict the potential distribution of pelagic fishing grounds based on the Akaike Information Criterion (AIC), the deviance of each model and the level of significance of each variable were used, to estimate the spatial distribution of fish stocks within the study area. The selection of the best model was based on the highest CDE and the lowest AIC **(Wood *et al.,* 2006)**. The deviation and AIC indicate the degree of accuracy of the explanatory variable in explaining the variation in the response variable of each GAM equation. GAM_s are commonly used to determine the nature of the relationship between fish catches and environmental variables **(Suri & Siregar, 2018)**.

The GAM equation with the lowest deviation value, highest AIC, and explanatory variable significance level was used to determine the potential of the fishing area. PFZ was carried out via spatial analysis via GIS (Geographic Information System) using ArcGIS/Acview software based on criteria and equations of GAM results. The use of Geographic Information Systems (GIS) in the capture fisheries sector facilitates fishing activities and saves time searching for fishing areas **(Siregar, 2019)**.

RESULTS AND DISCUSSION

1. Catch data of the yellowfin tuna

The data on tuna catches based on observations made for 6 months from July - December 2023 vary greatly, where catches were obtained from 105 fishing operation points using hand line fishing gear in Flores Sea waters. The most dominant catch of the yellowfin tuna (*thunnus albacares*) occurred in September. The total number of catches obtained was 1038kg, with 14 capture locations point. The total catch was the lowest in July, with a total catch of 522kg and 11 fishing locations.

2. Parameter oseanografi

Determining the spatiotemporal distribution of abundance, the structure of size and weight, and the influence of environmental variables is critical for promoting sustainable fisheries and efficient fisheries resource management plans **(Nóbrega *et al.,* 2023)**. Water oceanographic parameters are one of the factors that can support the success of fishing gear operations **(Ziyad *et al*., 2022)**, since the distribution and abundance of biological resources in water bodies cannot be separated from the conditions and variations in oceanographic parameters. Several oceanographic parameters were used to determine the potential of the yellowfin tuna (*thunnus albacares*) in the southern Flores Sea, namely:

2.1 Sea surface temperature

Sea surface temperature (SST) is one of the oceanographic parameters that characterizes the mass of water in the ocean and is related to the state of the seawater layer below, so it can be used in analyzing phenomena that occur in the ocean **(Suhana, 2018)**. The temperature of the body of water is an important factor for the life of organisms, both in metabolic activity and in determining the presence and spread of fish **(Paillin *et al.*, 2020)**.

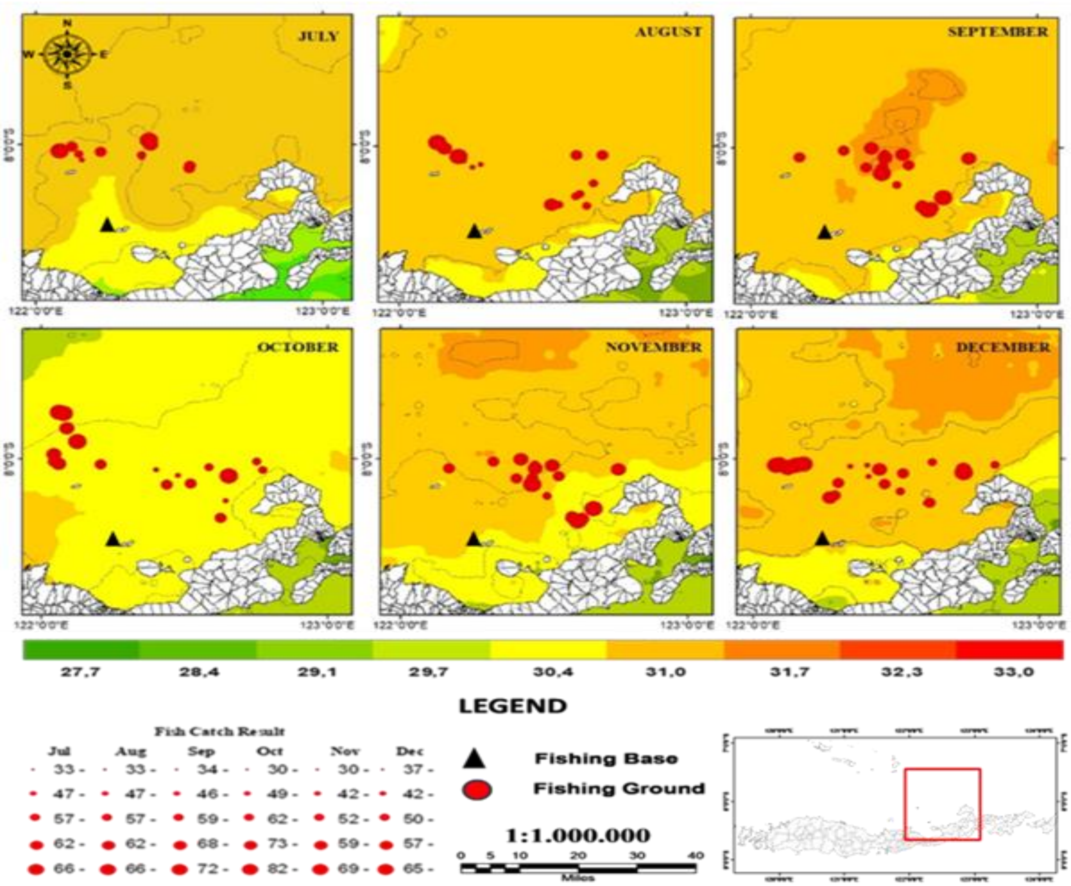

Fig. 2. Map of SPL Distribution in July-December 2023

In Fig. (2), the distribution of fishing shows that an increase in temperature occurs in November and December, where in November the maximum value of sea surface temperature is 31.23°C with an average temperature value of 30.88°C, and the catch pattern is grouped in the northern part of Pemana Island. In December, the maximum sea surface temperature was 31.49°C with an average temperature value of 31.26°C, and the catch pattern spread with the largest amount of catch (kg) in the northern part of Sukun Island, while the lowest temperature range occurred in August and September 2023. The sea surface temperature in August was in the range of 26.33– 29.11°C, with the highest fish catch of 70kg at 28.79°C. In September, the temperature range was between 26.51 and 29.11°C, and the highest fish catch distribution of 70kg occurred at 28.96°C, with the highest total catch during the study period reaching 1038kg. This indicates that tuna are found in waters that tend to be cold.

The correlation of the distribution of sea surface temperature with the concentration of sea surface chlorophyll-a in the waters of the Makassar Strait and Flores Sea has a negative relationship with the optimum sea surface temperature of 30.5°C **(Safruddin, 2022)**. Based on previous research, skipjacks are found living in the waters of Bone Bay, Flores Sea, with water temperatures ranging from 29.5 to 31.5°C **(Zainuddin *et al.*, 2017)**.

2.2 Chlorophyl-a

The level of water fertility can be indicated by the presence of chlorophyll-a content in a body of water, which is a food source for fish **(Putri, 2021)**.

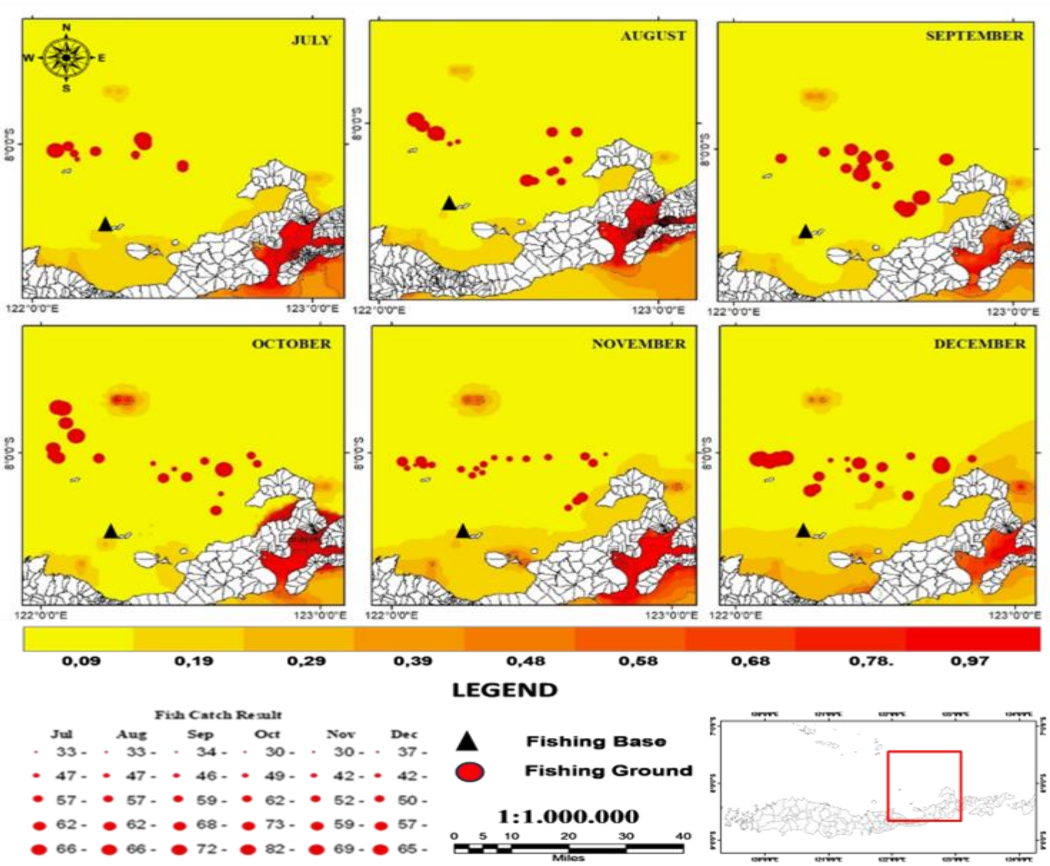

Fig. 3. Distribution map of chlorophyll-a content in July -December 2023

Chlorophyll-a is a green pigment that can be found in algae, plants, and cyanobacteria **(Agung *et al.*, 2018)**. The fertility level of water can be determined by the presence of chlorophyll-a in a-water, that is a source of food for fish. The fish life cannot be separated from the influence of various aquatic environmental conditions **(Daris *et al.*, 2021)**.

The chlorophyll-a concentration ranged from 0.10- 0.18mg/ m³, had the highest total catch in September, with a range of 0.1– 0.14mg/ m³. The chlorophyll-a concentrations increased in November and December, and in November the maximum chlorophyll-a concentration was 0.21mg/ m³, with an average temperature of 0.19mg/ m³. In December, the maximum chlorophyll-a concentration was 0.22mg/ m³, with an average temperature of 0.18mg/ m³. This phenomenon indicates that factors other than chlorophyll-a concentration play a role in determining fishing productivity during the study. The highest chlorophyll-a concentration is one of the determinants of the fertility level of water plant. Previous studies, have shown that the skipjack tuna is heavily contaminated with chlorophyll-a at concentration ranging from 0.15- 0.35m/ mg³ in the Bone Bay-Flores Sea **(Sahidi *et al.*, 2015; Zainuddin *et al.*, 2017)**.

2.3 Depth

The fishing area is influenced not only by the type of fish that is the target catch, but also by the water depth. The results showed that the range was within 3500– 1000m, with an average value of -2240.41m. The deepest depth range occurred in July, with a range of -1499– 3178m and a total catch of 522kg. The catch distribution pattern tends to be separated. While in August–December there was an equalization of the average depth where the range was between -1891– 2283m, with the highest total catch in September at a depth of -508– 3336m. The results of previous studies ranged from ±705,280-5,298.9m, where this is already a water area that is offshore **(Tangke *et al.*, 2011)**.

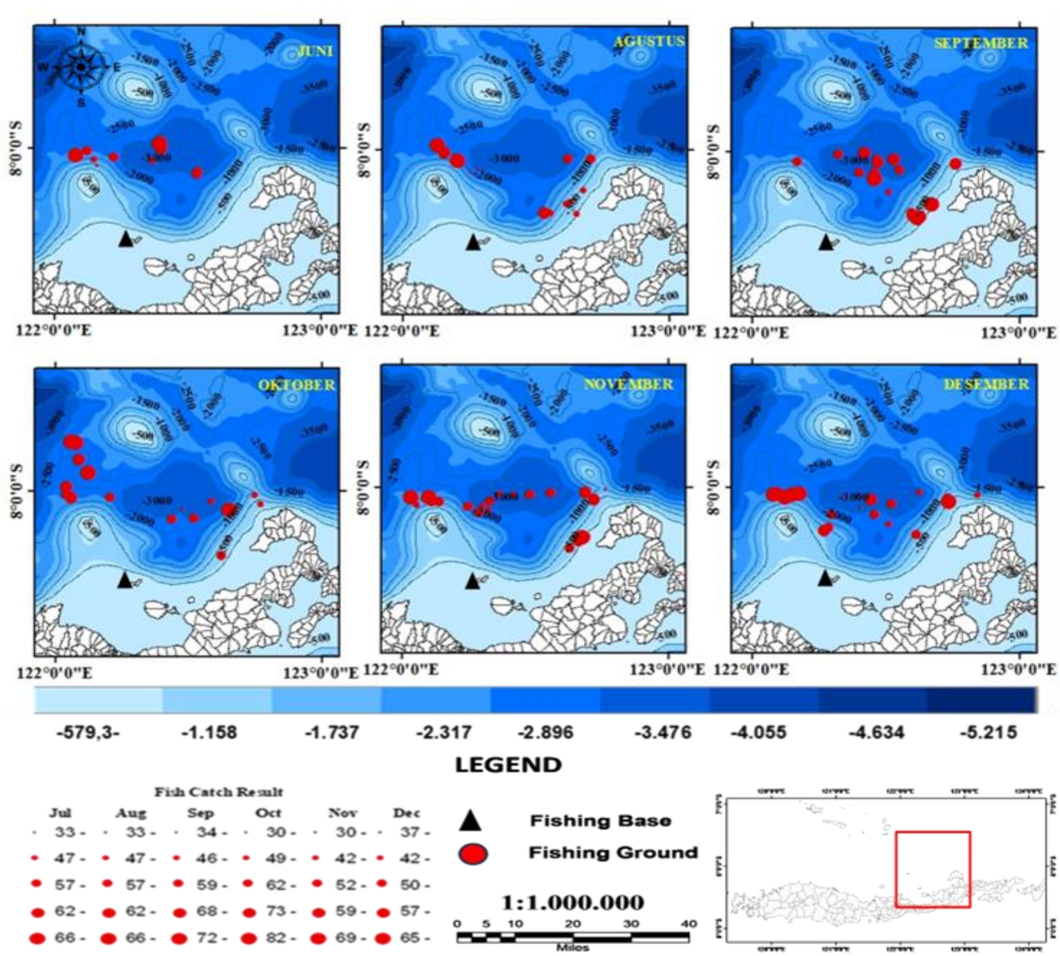

Fig. 4. Map of current velocity distribution in July - December 2023

2.4 Salinity

Salinity strongly influences the osmoregulatory process of marine organisms, especially fish. Fish tend to choose a medium with a salinity that is more in line with the osmotic pressure of their respective bodies. Changes in salinity stimulate fish to migrate to places where the salinity matches the osmotic pressure of their bodies.

The results showed that the salinity range was 33.5– 34.44ppt. Salinity distribution increased in September and October. In September, the maximum value of salinity reached 34.32ppt, with an average value of 34.26ppt. This increase in salinity indicates a change in the condition of the aquatic environment, influenced by various factors such as water circulation patterns and rainfall. In October, the maximum value of salinity reached 34.44ppt, with an average value of 34.40ppt. The highest catch occurred in September, totaling 1038kg. Meanwhile, in July, November, and December, there tends to be an equalization of the average value of salinity, with a range of values between 33.5 and 33.7ppt. The highest catch occurred in September, with a total of 1038. Based on its distribution, the average tuna caught is in the salinity range of 33.3– 33.7psu **(Yanti Siregar *et al.*, 2018; Vaihola & Kininmonth, 2023)**.

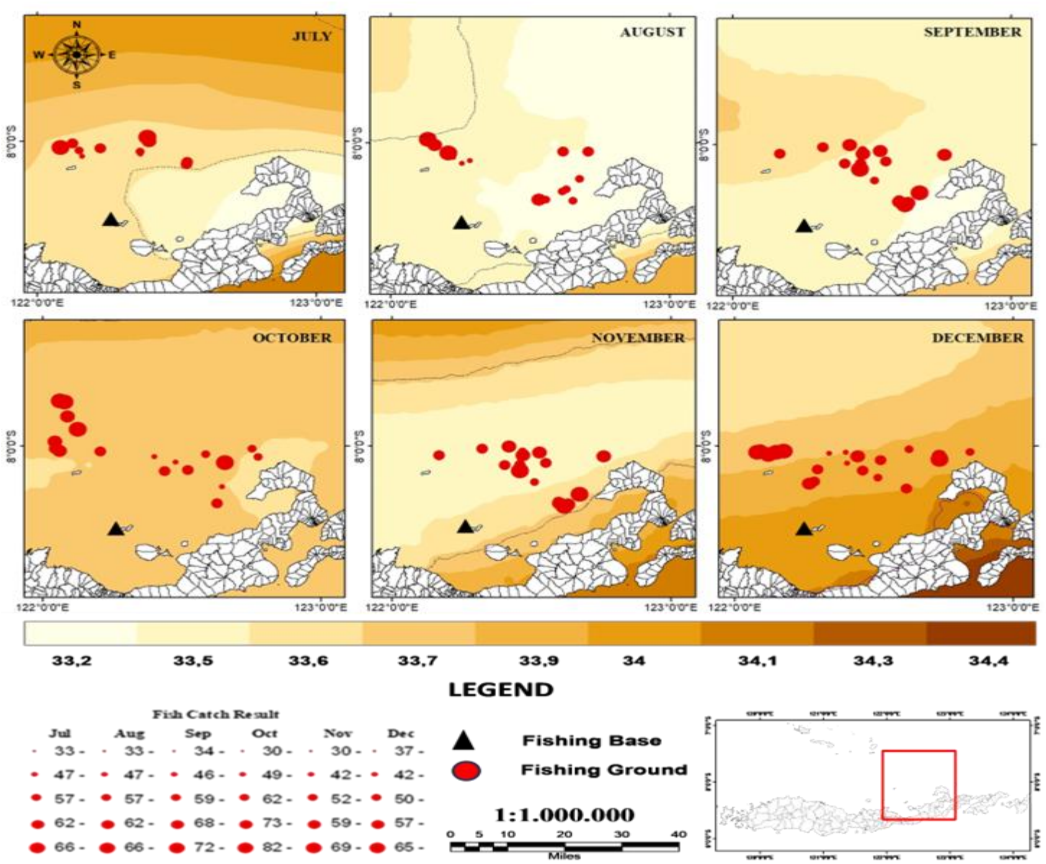

Fig. 5. Distribution map of salinity content in July - December 2023

3. Trends in oceanographic parameters in the Southern Flores Sea (July–December)

Based on the time series plot data provided, it can be interpreted that there are fluctuations in the values of parameters such as sea surface temperature (SST), chlorophyll (CHL), salinity, and depth. SST values showed an increase from July to December, with the highest value recorded in December at 31.26°C and the lowest in August at 28.72°C. Meanwhile, CHL values tended to increase from July to November, with the highest value of 0.19 in November but decreasing slightly in December. For the salinity parameter, there was an increase from July to October, with the highest value of 34.40 in October, then a slight decrease in November and December. The depth value fluctuated from month to month without showing a clear pattern, with the deepest value of -2674.43 in July and the shallowest being -1891.27 in August.

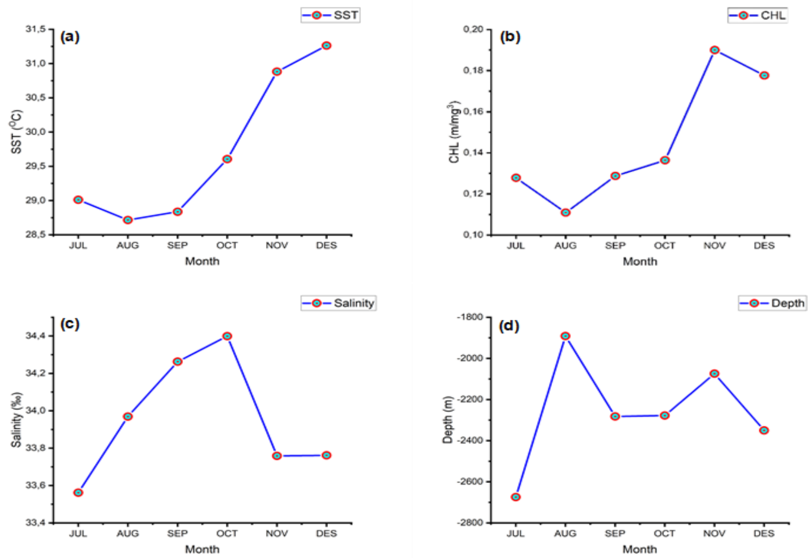

Fig. 6. Time series data plots of **(a)** SST, **(b)** CHL, **(c)** salinity, and **(d)** depth from July to December 2023

4. Interpretation of standard deviation of oceanographic data in the Southern Flores Sea, July–December 2023

A standard deviation is a measure that shows how much the data spreads from its average value in a data distribution.

In Fig. (7), the fluctuating standard deviation of sea surface temperature from July to December shows the fluctuation of the data distribution around the mean value. In July, the data distribution was centered with a small deviation (0.07), but in August (0.09) it increased and showed a wider distribution. September recorded a significant decrease (0.18) with a high concentration with little variation, while October showed a greater concentration (0.11). However, although it was still concentrated in November, there was a slight dispersion (0.25). Finally, December saw a sharp increase (0.10).

The standard deviation value of chlorophyll shows a constant pattern of change in data fluctuations from July to December. The standard deviations in July, September, and August were 0.11 to 0.13, indicating that the fluctuations in chlorophyll data were relatively small and the values were close to the mean. Variability increased slightly in

October with a standard deviation of 0.14, then increased significantly in November with a standard deviation of 0.19, and decreased slightly in December to 0.18. The increased variability during the last two months indicates that chlorophyll levels are more dispersed than average.

The standard deviation value of salinity shows the stability and consistency of salinity data variations from July to December. From July to October, the standard deviation was low (0.02- 0.04), indicating that the salinity data tended to be stable and consistent with little variation. The standard deviation increased significantly in November (0.07) and decreased slightly in December (0.05), but was still higher than the beginning, indicating greater variability and spread in the salinity data.

The standard deviation shows the spread of data from the mean, with high values indicating a large spread of data from the mean. The standard deviation value increased from 596 in July to 817 in August and peaked at 1109 in September. Although the figure dropped to 795 in October and 773 in December, it was still high. This number increased again in November to 957.

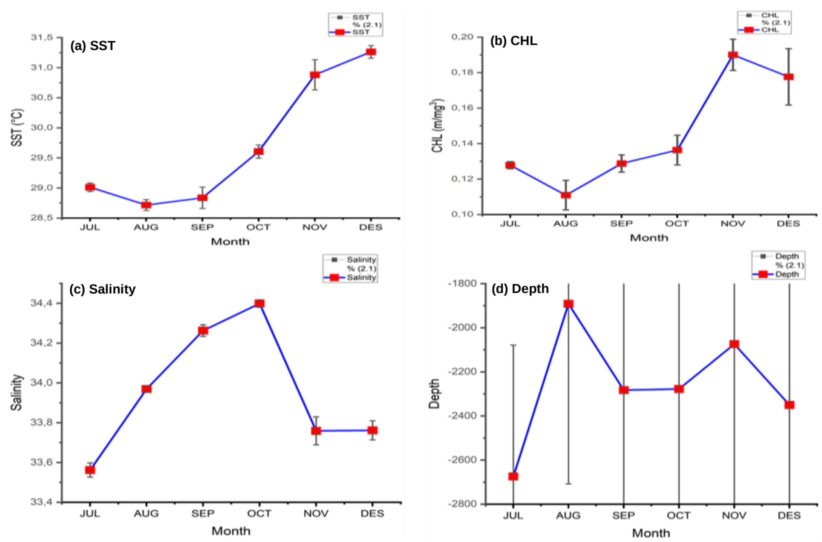

Fig. 7. Interpretation of standard deviation of **(a)** SST, **(b)** CHL, **(c)** Salinity, and **(d)** Depth data in the Southern Flores Sea, July–December 2023

5. Analysis of the relationship between oceanographic parameters and GAMs.

From the results of modeling oceanographic variables, four variables are included in the modeling, which is considered a good model based on the smallest Akaike's Information Criteria (AIC) value and the largest Cumulative Devience Explained (CDE) value, with the level of significance of each equation, namely SST, CHL, salinity, and depth. According to the modeling results, model 1 of the depth data is the best model of the four parameters since it has a large CDE value (27.9%) and a small AIC value (803.0581). Selection of the best model is based on the model that has the highest CDE value and the highest AIC value **(Mugo *et al.*, 2010)**. In modeling variables (SST, CHL, salinity, and depth) that have significant values and are very influential on the prediction of fishing grounds, the significant values are dominated by the salinity and depth variables.

5.1 GAM model rugplot curve and histogram parameter oseanografi

Fig. (8) shows the effect of each oceanographic parameter, SST, clorophyll, salinity and depth, on the yellowfin tuna catches during the study period. Using GAM analysis was used to conduct AIC tests from July-December 2023. The X-axis shows the value of each variable described, and the Y-axis shows the smoother'*s* contribution to the value tested. The horizontal axis shows the values of the observed data; a thick line indicates the exact function. The dashed line or gray shading, represents a 95% confidence interval.

The center line passing through 0 is considered to have a good influence on the distribution of large pelagic fish. The results of the curve test in this study show good oceanographic parameters that tend to be favored and abundant for the tuna fish, namely for SST ranging from 28.5- 29.8°C, a chlorophyll-a content value of 0.10- 0.14mg/ m2, a salinity content value of 33.7- 34ppt, and a and a depth value of 3500- 1500m. The results of the curve test in this study show that the oceanographic parameters are good or tend to be favorable and abundant for the tuna fish.

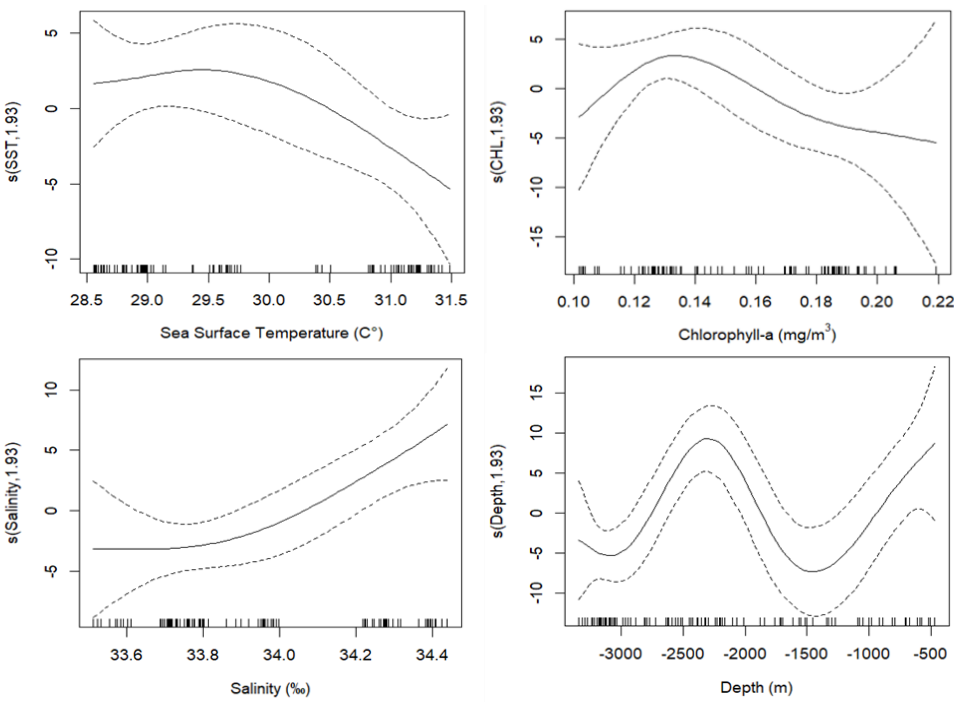

Fig. 8. Rugplot curve of the GAM model

The results of the hitogram in Fig. (9) show good oceanographic parameters or tend to be favored and abundant for tuna, namely, SST ranging from 28.5- 29.8°C, chlorophyll content values of 0.10- 0.14mg/ m2, salinity values of 33.7– 34ppt, and depth values of 3500– 1500m.

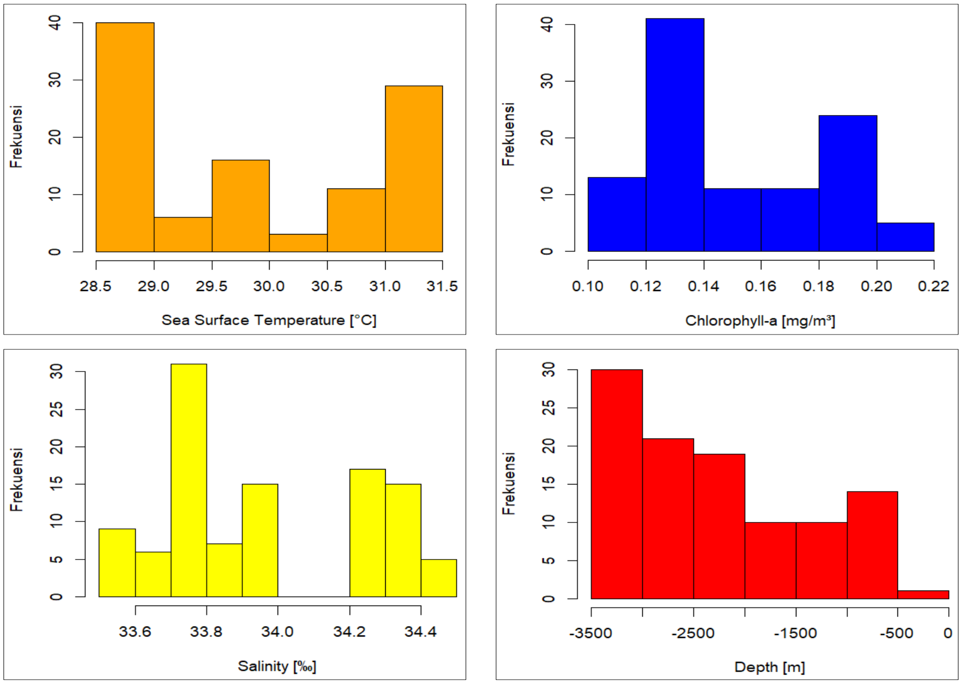

Fig. 9. Histogram of the GAM model

Based on the histogram results above sea surface temperature, which ranges from 28.5- 29.8°C. The results indicated a substantial impact on fish captures based on the results of the GAM analysis. Therefore, it is believed that the temperature did not fluctuate much during the study and remained within the range that large pelagic fish in the southern Flores Sea waters could tolerate. This suggests that waters with a tendency to be warm are home to tuna. in keeping with other findings, the skipjack tuna in NTT waters is primarily infected at water temperatures between 26.5 and 29°C **(Fanly *et al*., 2019)**.

Based on the results of the GAM analysis, chlorophyll-a was found to significantly affect fish catches with a range between 0.10- 0.18mg/ m. In general, chlorophyll-a concentrations tend to be higher in coastal areas due to the large supply of nutrients from river flows, while in the high seas tend to be low. On the other hand, under some circumstances, moving water masses bringing nutrients from elsewhere like upwelling areas may also result in high concentrations of chlorophyll-a in the high seas **(Enam *et al*., 2022)**.

The results showed that the relationship between salinity and fish catch ranged from 33.6 to 34ppt, based on the results of GAM analysis. The results of GAM analysis are in line with previous research on vertical and transverse distribution of salinity in the southern waters of Java, which obtained a maximum salinity of 34.67ppt and a minimum salinity of 34.03ppt **(Suhana, 2018)**.

Based on the results of the GAM model analysis, the relationship between depth and fish catch is very significant with a value in the range of 1000- 3500m. The results of previous studies range from ±705.280- 5,298.9m, where this is already a water area located offshore **(Schaefer *et al*., 2014)**.

6. Prediction mapping of the tuna fishing potential zone (*Thunnus albacres*)

In this study, the yellowfin tuna fishing area was based on five indicators, namely the number of catches, SST, chlorophyll-a, salinity, and depth of the water. The fishing potential area is obtained from the overlay results of combining several oceanographic parameters, which are obtained from the processed histogram in GAM analysis for 6 months from July-December 2023.

In July, a potential area of 2,594km2 was identified with a total catch of 522kg. August showed an increase in potential area to 15,533km^2, with a catch of 628kg. September recorded the highest potential area of 31,808km^2, resulting in a catch of 1,038kg. In October, a potential area of 30,517km^2 at coordinates 7°17'21.239 "S - 8°55'40.645 'S and 119°59'6.000 'E - 123°23'34.800" E yielded a catch of 30,536kg from 18 sites in the southern Flores Sea.

In November, the area decreased to 15,679 km^2 at coordinates 7°20'12.858 "S - 8°14'55.072 'S and 120°0'52.772 'E - 123°23'57.732" E, with only 2 points (9%) out of 22 sites producing 1,032kg of catch. December recorded a potential area of 5,860km^2 at coordinates 7°15'33.977 "S - 8°15'16.524 'S and 120°0'52.772 'E - 123°23'57.732" E, with 12 points (57%) out of 21 sites producing 986kg of catch in the southern Flores Sea. The overlay results from July-August were then combined to obtain a comprehensive fishing potential zone with a total combined area of 107,495km^2, yielding a catch of 5,210kg from 105 fishing points at coordinates 7°11'24.634 "S - 9°7'54.538 'S and 120°0'11.574 'E - 123°23'59.438" E.

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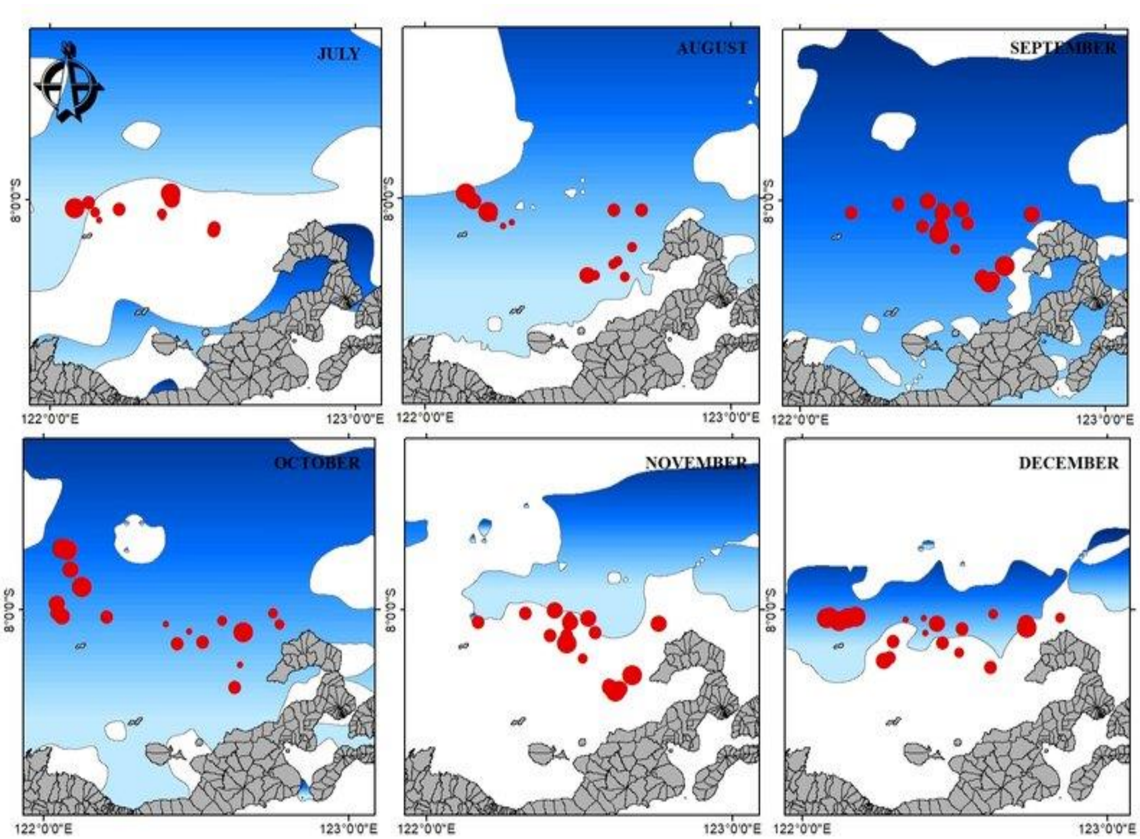

Fig. 10. Prediction map of potential fishing zones for July-December 2023 in the Southern Flores Sea waters

Based on the results of the potential fishing zone (PFZ) prediction conducted for the period July to December 2023, it was found that as many as 31 out of a total of 105 fishing points or about 30% were in areas predicted as potential zones having low fish concentrations. This finding indicates that the value of one or more oceanographic parameters that are not in accordance with fish habitat preferences will affect the potential fishing zone (PFZ).

This is in accordance with what is stated by **Yuliani *et al.* (2018)**, salinity is very influential on the osmoregulation process of marine biota, especially fish. Fish tend to choose a medium with a salinity that matches the osmotic pressure of their respective bodies. Changes in salinity will stimulate fish to migrate to places that have salinities that match their body osmotic pressure. As a result, changes in salinity in the waters cause the movement of fish, resulting in a shift in fishing grounds.

CONCLUSION

Understanding how environmental conditions affect fish catches is an important step toward ecosystem-based fisheries management and a standard approach in management policy. For example, the impacts of climate change will alter fishing grounds and increase costs associated with fishing vessel operation. The oceanographic factors identified in this study can be used to predict the distribution and abundance of fish species in the future. Thus, the results of this study show the following;

1. The Generalized Additive Model (GAM), which includes the variables of sea surface temperature (SST), chlorophyll-a concentration, salinity, and depth, is the best model to predict the yellowfin tuna catch. This model has the smallest Akaike Information Criterion (AIC) value (770.8742) and Cumulative Devience Explained (CDE) value (60.4%), indicating that the model can explain about 60.4% of the variation in catch data.
2. Based on the statistical results of GAM variables of sea surface temperature (SST), chlorophyll-a concentration, salinity, and depth, are variables that affect fish catch in this study, based on the results of analysis using the Generalized Additive Model (GAM), with a CED value of 60.40% and an AIC value of 770.8742.
3. The optimal oceanographic parameter characteristics for yellowfin tuna fishing in the July–December period were:
    a) Sea surface temperature (SST) ranges from 28.5 to 29°C.
    b) Chlorophyll-a concentration ranging from 0.10 to 0.14mg/ m^3
    c) Salinity ranged from 33.7 to 34ppt.
    d) Depth ranged from 3500 to 1500m.
4. The largest potential fishing zone (PFZ) for yellowfin tuna occurred in September, with an area of 31,808km² and a total catch of 1,038kg.

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