**Bigeye tuna fishing ground analysis using oceanographic features in Eastern Indian Ocean off Southern Java**

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**Abstract.** The Eastern Indian Ocean off Southern Java is one of the bigeye tuna fishing hotspots and has a fishing potential of 27%. Analyses of bigeye tuna fishing areas focus on the South Java-Bali waters at coordinates of 105°-120°E and 5°-20°S. Oceanographic parameters affect the habitat of Bigeye tuna. Sub-surface temperature is an important and major factor in fishing layers. Time series of sub-surface temperature data from 2005-2017 was used as an input for the analysis of the fuzzy inference system method. This method has been widely used in fisheries areas but has not yet been applied to fishing ground predictions. The use of vertical temperature data variation such as 100 m, 150 m, 200 m, 250 m, and 300 m are expected to be able to map the most optimal fishing potential area for bigeye tuna fishing ground. The model output is verified using actual coordinate data to obtain a relationship between the model results and coordinate catch point. The result show that at 200 m is the best fishing layer of bigeye tuna.

1. **Introduction**

The existence of bigeye tuna is spread throughout tropical and subtropical waters. The Eastern Indian Ocean is one of the tuna fishing hotspots [1] and has accounted for 24% of bigeye tuna supply of the world [35]. [14] reported that the Eastern Indian ocean have high commercial value and the second largest bigeye stock producer in the world after the Pacific Ocean at around 60% [2]. At present, bigeye tuna in the south Java waters, Eastern Indian Ocean, has decreased [3][4][5][37]. Bigeye tuna fishing activities in this area are dominated by longline vessels.

The decline in the number of bigeye tuna commodities in the eastern Indian ocean off south of Java was corroborated by the statement of [3] based on bigeye tuna fish stock in 1998 to 2005, where the stock of bigeye tuna in the Southern Java waters was decreasing. There are air-sea interaction like ENSO and IOD occurs in the Southern Java region have an impact on the fertility of the waters which causes the waters of the South Java area to become a hotspot for bigeye tuna [6][1]. At present, bigeye tuna has been explored around 84% in Indian Ocean waters. Even so, bigeye tuna stocks in the waters are still classified as not overfished and not a subject for overfishing, such as yellowfin tuna [36] Therefore, it is necessary to study bigeye tuna habitat for conservation of fishing areas and get the optimal catch from habitat preference.

Identification of bigeye tuna habitat (hotspots) can be done using a Geographic Information System (GIS) approach to determine the potential of fishing grounds. Besides, there are other methods to identify hotspots, such as knowledge-based expert system, generalized adaptive model, maximum entropy, empirical cumulative distribution, data mining [4][11]. Some researchers claim bigeye tuna in
layer with temperature between 12.0 °C-15.9 °C [8], further study was used sea surface temperature as oceanographic parameter indicator for bigeye tuna habitat [22]. Here, we intent to analyse the habitat preferences from fishing layer approach using sub surface temperature. The presence of bigeye tuna according to [13] is in the thermocline layer, so sub surface temperature data is more appropriate than sea surface temperature to predict habitat preferences. Fuzzy inference system used as new method to determine the existence of habitat preferences.

The purpose of this study is to identify bigeye tuna fishing areas using oceanographic parameter data and find out the effectiveness of the fuzzy inference system can be used to map bigeye tuna fishing areas. It is hoped that the results will be new method to use in determining fishing areas using data models and easily available to be a reference in management and presence policies for bigeye tuna in the Eastern Indian Ocean [15].

2. Material and method

2.1. Study area

Study area is located in Eastern Indian Ocean region off South of Java (Figure 1). The area is limited to only 105°-120° E, and 5°-20° S. In this region there are phenomena of the interaction of currents and ocean circulation

![Figure 1. Study area in Indian Ocean off Southern Java (a, South Java Current (SJC); b, Indonesian through flow (ITF); c, Indian Ocean Kelvin waves (IOKWs), d Rossby Waves (RWs)) [30].](image)

2.2. Oceanographic parameter

Sub surface temperature or temperature under surface layer dataset as oceanographic parameter was used for 12 years, since 2006-2017. The data source from MULTIOLS_GLO_PHY_REP_015_002, CMEMS, can be freely downloaded from the website http://marine.copernicus.eu/. The spatial resolution of the data is 0.25° x 0.25° with monthly temporal resolution. This is a multi-observation data from The Global ARMOR3D L4 dataset in NetCDF format with various depth levels between 0 m (surface) to 5500 m (33 depth levels). It has been reprocessed by combining in situ observations
(temperature profiles) and satellites (sea surface temperature) data through statistical methods. Sea surface temperature data are projected vertically using a multiple linear regression method and using covariance analysis. In this study, sub temperature data used from several different depth, that is 100 m, 150 m, 200 m, 250 m, 300 m. All the data extracted using MATLAB software in order to analyse and plot based on time series.

2.3. Fishery data
Bigeye tuna catch data set was obtained from scientific observer programs and port sampling conducted by Research Institute for Tuna Fisheries, Benoa Bali for 12 years from 2006-2017, including coordinates of the fishing grounds and number of hooks used. Fisheries data include data on the coordinate position of bigeye tuna catches and the number of daily catches that are made on average to determine the monthly hook level. Hook rate is calculated based on the number of fish caught per 1000 hooks. Hook rates was used to calculate fish abundance [27][28][29][31]. It can also be referred to as catch per unit effort [30]. Hook rate used because there are limitations in situ data and trends of CPUE and according to [5] in his research, CPUE and hook rate are almost similar pattern.

2.4. Fuzzy inference system
Fuzzy inference system is a part of fuzzy logic and one of the tools that are useful to ensure the relationship between two or more data and to avoid the level of ambiguity, less precision, vagueness of a data or statement. Fuzzy was introduced by [17]. The basic fuzzy logic is found when creating fuzzy sets for the determination of membership functions. Fuzzy logic expert system has been applied in marine biodiversity and fisheries, such as evaluating the vulnerability of marine fishes to fishing [33], also applied to the determination and grading of the fishing area [16]. Here, fuzzy applications are used to determine the relationship between fishing layer of bigeye tuna habitat preference with oceanographic parameters (subsurface temperature).

Fuzzy set application is not only useful for truth level categories but fuzzy can produce more than one category [32]. To reduce errors in reading data, a class of truth from a statement in fuzzy set was made such as low, medium and high (0-1). The number 0 indicates the degree of probability is low, and when the output value of the crisp input is high, the suitability of the data approaches the value of 1. Process in the fuzzy inference system are shown in Figure 2.

![Figure 2. Schematic fuzzy inference system.](image)

Figure 2 illustrates the stages and processes that need to be carried out during the fuzzy inference system. These stages include the process of determining the input crisp or input parameters to be analysed, the fuzzification or process conversion a linguistic form using membership functions based on the knowledge base [7], the inference system based on the knowledge base (Table 1), then the defuzzification process for concluding. Fuzzy inference system uses heuristic rules expressed in the form:

\[ \text{If } X \text{ then } Y \]

(1)

Where X is the crisp input as a premise and Y is the conclusion from a premise statement. The result of fuzzy inference system will follow the premise (crisp input) based on the rule of knowledge base then it can conclude. Full process in this study showed in Figure 3.
To obtain a good output of the fuzzy inference system, we use criteria based on previous research, referring to the [8]. The determination of the catchment knowledge base is shown in Table 1.

**Table 1.** Characteristics of oceanographic feature for habitat preference of bigeye tuna based on [8].

| Environmental variables | Range of environmental variables | Range of environmental variables |
|-------------------------|----------------------------------|----------------------------------|
| Depth                   | >6.4 160-219.9 m                 | 6.5 160-179.9 m                  |
| Temperature             | >5.4 13.0-15.9°C                 | 7.3 14.0 - 14.9 °C               |

From Table 1 can be seen that the presence of bigeye tuna in Indian Ocean waters tends to be at a temperature of 13 °C to 15.9 °C and at a depth of 160 - 219.9 m. So, based on Table 1, we made a rule set based on the data used as in Table 2.

**Table 2.** Rule set to determine habitat preferences for bigeye tuna based on temperature per depth layer.

| Condition  | Range               | Fishing layer probability Subset | Range of subset |
|------------|---------------------|---------------------------------|-----------------|
| Temperature| 0-25 °C THEN        | Low                             | More than 12-13.9 °C |
|            | THEN High           | High                            | In between 12-13.9 °C |
|            | THEN Medium         | Medium                          | Less than 12-13.9 °C |

Based on Table 2 about rule set to determine the best layer, the example rule set there are:

IF Temperature High then Fishing Layer Probability is Low
IF Temperature Medium then Fishing Layer Probability is High
IF Temperature Low then Fishing layer Probability is Medium

After the rule set process in the inference system is complete, the next stage is defuzzification. At this stage, a conclusion will be obtained in the form of a probability level (0 to 1) of the existence of bigeye tuna on the fishing layer.
3. Result and discussion

3.1. Spatio-temporal bigeye tuna fishing ground

The location of bigeye tuna fishing ground from Research Institute for Tuna Fishery during 12 years is displayed on a map based on monthly data as shown in Figure 4.

Figure 4 showed monthly fishing catch of bigeye tuna during 2006-2017. Coordinates are taken based on data obtained that shows the lowest point for the fishing ground area in January. July is the month that has the most catch coordinates compared to the previous month, they are January to June. Then the point of catch increased with increasing months. But, the point of catch from August to December appear to be getting lower.

Figure 5. Total catch and hook rate of Bigeye Tuna during 2005-2017 (source: Research Institute for Tuna Fishery data processing).
In temporal pattern (Figure 5) catch rate of bigeye tuna every month for 12 years is analysed using hook rates (graphs with red lines), and total catches (graphs with blue lines). Lack of bigeye tuna catch data obtained makes the lines on the graph are interrupted. In specific months, the hook and total catch rate has the same increasing pattern.

3.2. Sub surface temperature profile in the Eastern Indian Ocean off Southern Java

Based on the distribution, sub surface temperature varies due to the influence of water mass movement and the phenomena that occur in the waters (Figure 1). However, in spatially the difference in sub surface temperature is not too different. Figure 6 showed the vertical profile of the sub surface temperature representative.

![Temperature profile](image)

Figure 6. Sub-temperature vertical profile (a) representative of sub temperature vertical profile during 2006-2017 at coordinates 11.125°E and 111.625°S, (b) sub temperature profiles in various depths (100 m, 150 m, 200 m, 250 m, and 300 m).

The representative pattern shown in Figure 6 illustrates the temperature pattern at various depth (100 m, 150 m, 200 m, 250 m, and 300 m). These depths used based on the presence of bigeye tuna which tends to be around and under thermocline layer [3][5][12][13][21][22]. Whereas the determination of
the centre of the thermocline layer is illustrated by the 20 °C isotherm [23][24][25][26]. Based on Figure 3a, in the Southern waters of Java, the representative depth of the centre thermocline about 100 m.

The determination of different depth analysis is based not only on the thermocline depth analysis but also on the depth of the bigeye tuna fishing layer from various reputable sources. Temperatures at depths of 100 m, 150 m, 200 m, 250 m and 300 m vertically lower with increasing depth and the temperature tends to be stable and not too fluctuating far during study time.

![Figure 7](image_url)

**Figure 7.** Fuzzy time series results about bigeye habitat preferences based on the fishing layer.

Based on Figure 7, the results of the model formed from the ruleset [8] in the fuzzy inference system analysis in the form of the probability of the existence of the most optimal bigeye tuna fish from different depths. The use of temperature per depth analysis aims to determine the level of dominance of bigeye tuna. The high fishing layer preference for the existence of tuna can be seen from the higher probability index. The results of the fuzzy inference system in the form of habitat preferences show that bigeye tuna in the East Indian waters off Java tend to be at a depth of 150 m to a depth of 250 m and lower habitat preferences at depths of 100 m and 300 m. The high probability value at a depth of 200 m that is > 0.8 (as shown in Figure 7) shows that the habitat preference for bigeye tuna tends to be higher at a depth of 200 m.

### 3.3. Discussion

According to [9] that CMEMS data have an accuracy rate of 87.11%. Analysis of bigeye tuna fishing areas using data sourced from CMEMS has the same results as data measurements [9]. The use of datasets in this study has also been applied to determine the spatial analysis of tuna habitats [15].

Scientifically, tuna is a thermo conformer species that tend to be influenced by temperature conditions in the waters [10]. The temperature condition below the surface layer is an indicator to know the existence of water mass transfer vertically or horizontally. This water mass transfer carries nutrients. The change in nutrient concentration affects the fertility of the waters and will have an impact on the distribution of tuna [18].

Environmental factors such as temperature have a strong relationship with the presence of bigeye tuna in the waters [5][15][8]. According to [13] the depth of bigeye tuna swimming in the Indian Ocean tends to be below the thermocline layer, which is around 161-280 m during the daytime and 0-100 m at night. Temperature conditions at certain depths affect the preference for the presence of bigeye tuna. As a visual predator and phototaxis, bigeye tuna fish need light to find food and their lives depend on the input of light into the waters. In the Indian Ocean around the Southern sea of Java and Bali, bigeye tuna fish are more often caught on isotherms 10-15 °C [19][20][21][3].
Bigeye tuna catch coordinates in Eastern Indian Ocean off Southern Java waters (Figure 4) are most abundant in June-October. This indicates in those months the supply of nutrients as a food for small fish is abundant compared to another month. This is consistent with the results of research conducted by [6], which states in June to October coastal upwelling is happening in Southern waters of Java so that the nutrient content in water is abundant.

Rule sets for fuzzy inference system analysis is based on [8] (Table 1). Analysis of temperature per layer at various depths produces different levels of probability. The area of the fishing layer results from the fuzzy inference system showed at a depth of 150-200 m. The tendency of the biggest yield at 200 m can be seen from the high probability value which is above 0.8 (scale 0-1). Figure 6 illustrates the temperature conditions at various depths. It can be seen that the temperature at a depth of 300 m is in the range of 11-12 °C, 12-13 °C (250 m), 13-16 °C (200 m), 18-20 °C (150 m) and a temperature of 100 m at 21.5-25 °C. Based on the ruleset used as in table 1 [8], it is stated that the bigeye tuna is optimum at a temperature of 12 - 13.9 °C.

The interesting thing in this study when viewed from the temperature per depth according to [8], the temperature at a depth of 250 m becomes the most optimum because the temperature range at a depth of 250 m and the temperature based on previous studies [8] are close together. The high probability of fishing layer at a depth of 200 m from the output of the fuzzy inference system is presumably due to the wide temperature range in the 200 m. In Figure 6a generally it seen at a certain point the vertical temperature range at a depth of 200-250 m is in the range 12-14 °C. According to [34], most bigeye tuna caught in the temperature range 12.38 - 14.06 °C at a depth of 200-250 m.

The temperature at a certain depth, such as a depth of 150 m, is one of the bigeye tuna fishing layers. It is known that the temperature in the layer is 18°C-20 °C, with a vertical pattern the temperature is in the range of 14°C - 16°C. This 150 m layer is one of the bigeye tuna fishing layers. This is presumably because it is closest to the thermocline. The 100 m layer being the thermocline centre is marked by the 20 °C isotherm line. Physiologically, bigeye tuna fish will be around the thermocline layer at night and away from the thermocline during the day. This is possible by the output of a fuzzy inference system which showed a depth of 150 m to become a bigeye tuna preference habitat at night. This is confirmed by the statement of [10] based on the ECDF (Empirical distribution function) analysis that bigeye tuna is caught at a depth of about 150 m with temperatures of 16 °C - 21 °C. On the other hand, for verification of the output of the fuzzy inference system, the depth of the fishing line affects the depth of the fishing layer.

4. Conclusions
Identification of Bigeye tuna fishing areas using [8] (Table 1). To find out the existence of bigeye tuna fish using several variations, there are 100 m, 150 m, 200 m, 250 m, 300 m. Based on the profile of temperature vertical (Figure 6a) is various. Up to a depth of 300 m, representative surface temperature variations in the southern waters of Java from 10 °C to 30 °C. The temperature range at 100 m depth is 22-20 °C, at 150 is 20-16 °C, at 200 m is 14-16 °C, and the temperature range at 250 m is 12-14 °C. The results of the analysis of fishing areas based on the fishing layer show that the highest probability of fishing ground bigeye tuna is at the 200 m depth layer. This depth has a probability level of 0.8. then 150 m with 0.6 probability level, and 250 m with a 0.55 probability level.

The results of the fuzzy inference system explain that bigeye tuna tends to be at a depth of 150-250m, this is consistent with some literature that mentions the existence of bigeye tuna at 200-250m [34]. So, the fuzzy inference system method is quite effective for mapping bigeye tuna fishing areas.

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