Fuzzy Analysis to Determine Potential Catching Areas of Skipjack Tuna on Southeast Sulawesi Waters

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Abstract. Southeast Sulawesi is one of the catching fisheries bases in the Eastern Indonesia Region which deals directly with the Banda Sea. Skipjack Tuna (*Katsuwonus pelamis*) is classified as an important economic pelagic fish resource and is one of the export commodities. The existence of skipjack tuna is certainly influenced by the condition of the ocean. The parameters used in the analysis of the determination of skipjack fish catches are Sea Surface Temperature, the distribution of chlorophyll-a and catches. The purpose of this study was to analyze the catching area of skipjack fish around the waters of the Southeast Sulawesi. To determine of skipjack tuna fishing area is supported by Fuzzy Mamdani method. The results showed that the catching area of skipjack fish on the peak catching season in the waters around Southeast Sulawesi May was in position 03°00'30.2 S / 122°25'17.4 E to 03°00'48.8 S / 122°42'32.7 E. In June the potential area is at point 03°00'47.4 S / 122°41'02.3 E and on July potential area at point 03°00'50.8 S / 122°41'16.3 E.

1. Introduction

Southeast Sulawesi is one of the catching fisheries bases in Eastern Indonesia which faces directly to the Banda Sea. The Banda Sea is a vast ocean that separates several large islands and small islands around it. Data from the Directorate General of Capture Fisheries of the Ministry of Maritime Affairs and Fisheries in 2011 stated that the potential for large pelagic fish resources in the Banda Sea is estimated to reach 104,100 tons per year [2].

Skipjack tuna (*Katsuwonus pelamis*) is classified as an important economic pelagic fish resource and is one of the export commodities. The existence of tuna skipjack fish is certainly influenced by the condition of the ocean. The parameter used in the analysis of the determination of skipjack fish catches is Sea Surface Temperature or SST. SST observation to predict the presence of skipjack fish is used because skipjack tuna is a fish species whose swimming layer is found in the surface layer [4]. Another parameter that also affects the distribution area of skipjack fish is the distribution of chlorophyll-a. Chlorophyll is an ingredient in the process of plant photosynthesis. The chlorophyll-a concentration of a water is largely determined by the intensity of light and the presence of nutrients. Tropical marine waters generally have low chlorophyll-a content due to nutrient limitations and strong stratification of the water column. Furthermore, based on the chlorophyll-a distribution pattern both seasonally and spatially, in some parts of the water a high concentration is found. Chlorophyll-a on the surface of the

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waters are grouped into three categories: low, medium and high which are contains chlorophyll-a of <0.07 mg/m³, 0.07 mg/m³ -0.14 mg/m³ and > 0.14 mg/m³ consecutively [6]. The potential for catching skipjack fish is closely related to environmental parameters, especially optimum SST in the range of 29.9 - 31.0°C and optimum chlorophyll-a in the range of 0.12-0.22 mg/m³ [4].

The Artificial Intelligence method that can be used in this case is Fuzzy Logic. Fuzzy Logic allows membership values between 0 and 1, gray level and also black and white, and in linguistic form which have an uncertain concepts like “little”, “pretty”, and “very”. This logic is related to fuzzy sets and probability theories.

2. Research Methods

Sea Surface Temperature data and chlorophyll-a distribution used in this system are Terra / MODIS satellite image correction data from the NASA website (oceancolor.gsfc.nasa.gov), while the Catch Result data is obtained from the data collection from Indonesian Fisheries Port Information Center (pipp.djpt.kkp.go.id) using data from May to July 2016.

This research uses Fuzzy Mamdani method which is interpreted in Fuzzy Interference System (FIS). Every data that has been obtained will go through the correction process before being used in system analysis. The Fuzzy Mamdani method requires fuzzyfication process, inference, and defuzzyfication.

3. Results and Discussion

3.1. Fuzzyfication

In this section, each dataset is entered into the system by changing the crisp value to a fuzzy set. The SST (Sea Surface Temperature) dataset has a unique linguistic set of “Cold”, “Warm”, and “Hot” with a range of values of 20°C - 24°C, 23°C - 27°C, and 26°C-30°C respectively. Descriptions in the graph can be seen in figure 1 and the degree of membership in mathematics formula can be seen in equation (1).

\[
\mu[x] = \begin{cases} 
\frac{24-x}{24-20}; & x = 20; \\
\frac{x-23}{27-23}; & x = 25; \\
\frac{30-x}{30-26}; & x = 30;
\end{cases}
\]

Figure 1. Graph representation for membership degree of SST

In equation (1), \( \mu [x] \) states the function of the \( x \) variable or input which is initialized as \( x \). “Cold”, “Warm”, and “Hot” is a linguistic classification of SST (Sea Surface Temperature) variables. The triangle curve in figure 1 states the value of the cluster set range.

Chlorophyll-a dataset has a linguistic set that is “Low” which is between 0 - 0.075 mg/m³, “Medium” is between 0.065-0.145 mg/m³, and “High” has a set between 0.135-0.2 mg/m³. The drawing with the curve can be seen in figure 2.

\[
\mu[x] = \begin{cases} 
\frac{0.075-x}{0.075-0}; & x = 0; \\
\frac{x-0.065}{0.145-0.065}; & x = 0.1; \\
\frac{x-0.135}{0.2-0.135}; & x = 0.2;
\end{cases}
\]

Figure 2. Graph representation for membership degree of chlorophyll-a variable
Based on figure 2, the degree of membership can be formulated with the \( \mu[x] \) function in equation (2), with \( x \) represents the input value.

The Catch Dataset are grouped in a linguistic set of “Less” with values ranging from 0-125 amount of fishes, “Sufficient” with values ranging from 100-200 fishes, and “Plentiful” with values ranging from 175-300 fishes, the description of which can be seen in figure 3.

\[
\mu[x] = \begin{cases} 
\frac{125-x}{125} ; & x = 0; \\
\frac{x-100}{200-100} ; & x = 150; \\
\frac{300-x}{300-175} ; & x = 300; 
\end{cases}
\] (3)

Figure 3. Graph representation for membership degree of catch result

Based on figure 3, the membership degree can be formulated with the function \( \mu[x] \), and \( x \) is the initialization of input (processed dataset) by using equation (3).

Based on the purpose of the study, the output variable is determined as “Potential-Area”. This variable contains three attributes with successive linguistics, namely “Not-Potential”, “Potential-Medium”, and “Potential-High”. The range of the set of output variables is determined between 0 to 1. The picture can be seen in Figure 4.

\[
\mu[x] = \begin{cases} 
\frac{0.4-x}{0.4=0} ; & x = 0; \\
\frac{x-0.3}{0.7} ; & x = 0.5; \\
\frac{1.0-x}{1.0-0.6} ; & x = 1.0; 
\end{cases}
\] (4)

Figure 4. Graph representation of membership degree in the potential catching area cluster of skipjack tuna

Based on figure 4, the membership degree can be formulated with the equation of the function \( \mu[x] \), where \( x \) is the value of the dataset processed.

Equation (1) to equation (4) is written based on the rules of formulation in the triangle representation which is used to describe the graph of the membership degree of each variable.

3.2. Inference

Inference is part of the process of making a fuzzy system that connects or analyzes the relationship between each variable and is made in sentences called rule base. Based on the relationship that has been observed from the three variables and input data set that is managed, the rule base used in this system are listed in Table 1.

By applying substitution of the membership value into the inference, then the solution using the minimum rules formula can be written in equation (5).

\[
\alpha = \min (\mu[x_i] \cap \mu[x_j] \cap \mu[x_k])
\] (5)
Equation (5) states that the three determinants are i, j, k, which are sequentially SST, chlorophyll-a, the catch result, registered as a set of α values and has an AND operator. The AND operation result is the minimum value between the three variables which will then be used in the defuzzification process. After getting the value of the implication function, the rules are compiled using the Max method. The Max method is written by registering each value function implication.

\[
\mu(z) = \begin{cases} 
\alpha_3; z \leq A_1 \\
\frac{A_2-z}{A_2}; A_1 \leq z \leq A_2 \\
\frac{A_3-z}{A_3}; \alpha_1; A_3 \leq z 
\end{cases}
\] (6)

In equation (6), \(\mu[z]\) denotes the set of \(z\) functions, where \(z\) is the result of the calculation of the implication function, \(\alpha\) denotes the predicate value of each implication function or is the output value of equation (5), while \(A\) states the threshold value of each set.

| No. | Rule Base |
|-----|-----------|
| 19  | If (SPL is Warm) and (Chlorophyll-a is Low) and (Catch is Less) then (Potential-Area is Not-Potential) |
| 20  | If (SPL is Warm) and (Chlorophyll-a is Low) and (Catch is Sufficient) then (Potential-Area is Potential-Medium) |
| 22  | If (SPL is Warm) and (Chlorophyll-a is Medium) and (Catch is Less) then (Potential-Area is Not-Potential) |
| 23  | If (SPL is Warm) and (Chlorophyll-a is Medium) and (Catch is Sufficient) then (Potential-Area is Potential-Medium) |
| 24  | If (SPL is Warm) and (Chlorophyll-a is Medium) and (Catch is Banyak) then (Potential-Area is Potential-High) |
| 10  | If (SPL is Hot) and (Chlorophyll-a is Low) and (Catch is Less) then (Potential-Area is Not-Potential) |
| 11  | If (SPL is Hot) and (Chlorophyll-a is Low) and (Catch is Sufficient) then (Potential-Area is Not-Potential) |
| 12  | If (SPL is Hot) and (Chlorophyll-a is Low) and (Catch is Plentiful) then (Potential-Area is Potential-Medium) |
| 13  | If (SPL is Hot) and (Chlorophyll-a is Medium) and (Catch is Less) then (Potential-Area is Not-Potential) |
| 14  | If (SPL is Hot) and (Chlorophyll-a is Medium) and (Catch is Sufficient) then (Potential-Area is Potential-Medium) |
| 15  | If (SPL is Hot) and (Chlorophyll-a is Medium) and (Catch is Plentiful) then (Potential-Area is Potential-Medium) |
| 16  | If (SPL is Hot) and (Chlorophyll-a is High) and (Catch is Less) then (Potential-Area is Not-Potential) |
| 17  | If (SPL is Hot) and (Chlorophyll-a is High) and (Catch is Sufficient) then (Potential-Area is Not-Potential) |
| 18  | If (SPL is Hot) and (Chlorophyll-a is High) and (Catch is Plentiful) then (Potential-Area is Potential-Medium) |

3.3 Defuzzification

This study uses the centroid method for defuzzication. The formulation of defuzzification using the centroid method is written in equation (7).

\[
Z = \frac{M_1 + M_2 + M_3 + M_4}{L_1 + L_2 + L_3 + L_4} 
\] (7)

The \(M\) variables is the implementation of the median value of each composition of the implication function registered, while the \(L\) value is the implementation of the area value of each composition. The median value is written in equations (8.1), (8.2), (8.3), and (8.4).

\[
M_1 = \int_{0}^{A_1} (\alpha_3) \, dz; \quad (8.1)
\]
\[
M_2 = \int_{A_1}^{A_2} \frac{A_2-x}{A_2} \, dz; \quad (8.2)
\]
\[
M_3 = \int_{A_2}^{A_3} (\alpha_2) \, dz; \quad (8.3)
\]
\[ M_4 = \int_{A_3}^{\max} \frac{A_3 - z}{A_3} \, dz; \] (8.4)

Value \( L \) or Area of \( A \) can be formulated in equation (9.1), (9.2), (9.3) and (9.4).

\[ L_1 = A_1 \alpha_3; \] (9.1)
\[ L_2 = (\alpha_3 + \alpha_2)(A_2 - A_1)/2; \] (9.2)
\[ L_3 = (A_3 - A_2) \alpha_2; \] (9.3)
\[ L_4 = \left( \text{max} - A_3 \right) \alpha_1; \] (9.4)

There are four \( M \) and \( L \) variables which represent the total number of variables both input and output in the system.

The proposed system combines the Fuzzy Interference System library with Matlab Graphic User Interface. The results obtained from the analysis can be seen that the average potential level of the skipjack fishing area is in the medium potential class, as expressed in Table 2 which clearly reveals the results of the fuzzy system and the manual clustering results. Clustering is done manually by looking at the predetermined threshold value and listed in the pink area in figure 5.

| Month | Position | Potential value | Potential class |
|-------|----------|-----------------|-----------------|
| May   | 03\(^{\circ}\), 08’ 30, 2 S / 122\(^{\circ}\), 25’17, 4 E | 0.5 | Medium potential |
|      | 03\(^{\circ}\), 09’48, 30 S / 122\(^{\circ}\), 42’24, 7 E | 0.5 | Medium potential |
|      | 03\(^{\circ}\), 09’48, 8 S / 122\(^{\circ}\), 42’32, 7 E | 0.5 | Medium potential |
|      | 03\(^{\circ}\), 09’16, 15 S / 122\(^{\circ}\), 42’49, 2 E | 0.658008 | Medium potential |
| June  | 03\(^{\circ}\), 09’16, 6 S / 122\(^{\circ}\), 42’49, 1 E | 0.173422 | Not potential |
|      | 03\(^{\circ}\), 10’24, 5 S / 122\(^{\circ}\), 43’05, 5 E | 0.17964 | Not potential |
|      | 03\(^{\circ}\), 10’19, 4 S / 122\(^{\circ}\), 41’13, 8 E | 0.173422 | Not potential |
|      | 03\(^{\circ}\), 09’47, 4 S / 122\(^{\circ}\), 41’02, 3 E | 0.5 | Medium potential |
| July  | 03\(^{\circ}\), 07’03, 5 S / 122\(^{\circ}\), 43’04, 5 E | 0.185667 | Not potential |
|      | 03\(^{\circ}\), 05’50, 8 S / 122\(^{\circ}\), 41’16, 3 E | 0.5 | Medium potential |
|      | 03\(^{\circ}\), 04’22, 0 S / 122\(^{\circ}\), 39’15, 6 E | 0.185667 | Not potential |

In Table 2, the position states the coordinate point of the skipjack tuna fishing area from east to south (E, S). The value obtained in the fuzzy system that has been made is expressed by the potential value in Table 2, and the clustering results are expressed in the potential class column. In May, it was entirely above the threshold value of 0.5 potential value, even at the last point it continued to rise to about 0.6 units of potential value, this indicates that these points are in a medium potential class that allows fishermen to get enough skipjack fish in the area. In June a drastic decline occurred, this is known from the potential value generated by the fuzzy system is very different from the previous month at the same point. Potential values obtained at the points 03009’16.6 S / 1220 42’49.1 E to the point 03010’19.4 S / 1220 41’13.8 E only ranged from 0.17 potential value units and were in the class area which was not potential for tuna fishing, but in point 03009’47.4 S / 122041’02.3 E in June is in the medium potential class because its potential value is above the threshold of 0.5 potential value units. In July, the points 03007’03.5 S / 122043’04.5 E and 03004’22.0 S / 122039’15.6 E had a potential value ranging from 0.18 units of potential value so that the points did not become a potential catching area for skipjack fish, but point 03005’50.8 S / 122041’16.3 E has a potential value of 0.5 units of potential value and is on the threshold of potential “medium” class value of skipjack tuna fishing grounds.
The system finds that the average potential area is in the “medium” potential class. The appearance of potential tuna fishing areas around Southeast Sulawesi from May to June 2016 is shown in figure 5.

4. Conclusion
The catching area of skipjack fish in the waters of Southeast Sulawesi for May is in the position of 03°00'30.2 S / 122°02'17.4 E up to 03°00'48.8 S / 122°04'32.8 E. In June the potential area is at the point 03°00'47.4 S / 122°01'02.3 E, and in July the potential area is at the point of 03°00'50.8 S / 122°04'16.3 E. Classification of potential fishing areas for skipjack tuna from May, June, and July 2016 is entirely at moderate potential.

This study uses an old dataset so that the results cannot be implemented at this time. The system also does not process satellite imagery directly so that further research is needed with the ability of the system that can process satellite imagery in order to facilitate the analysis process.

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