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# The Use of statistical models in Identifying Skipjack Tuna Habitat Characteristics during the Southeast Monsoon in Bone Gulf, Indonesia

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**Abstract.** This study aimed to explore the relationship between the oceanographic factors with the distribution and abundance of skipjack tuna obtained by utilizing a pole and line in the Bone Gulf, Indonesia. The research was conducted during every southeast monsoon season (from April to September) from 2015 until 2018. Three oceanographic parameters were used in the process to understand this relationship, i.e., Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), and water depth. Generalized Additive Models (GAMs) and Generalized Linear Models (GLMs) that were used to predict the spatial pattern of the skipjack tuna showed that all considered parameters have a significant influence on the distribution of skipjack tuna in the study area. The fish are mostly distributed from coastal to offshore, ranging between 50 to 2,000 meters and even wider. The concentration tends to be high within the interval of 29.5 to 30.5 °C of SST and 0.25 to 0.35 mg m<sup>-3</sup> of SSC, and 500 to 1,000 meters of water depth. The research has also found that the Skipjack tuna migration to Bone Gulf may have followed the current water interruption during the southeast monsoon. The fished prefer warmer temperatures and lower primary productivities waters in the offshore areas. These preferred conditions may represent the optimal habitat of the skipjack tuna in the Bone Gulf during the southeast monsoon periods.

**Key words:** oceanographic factors, pole and line, skipjack tuna, statistical models.

**Abbreviations** (if any): Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), Catch Per Unit Effort (CPUE), generalized Additive Models (GAMs), Generalized Linear Models (GLMs), Akaike Information Criterion (AIC), Cumulative Deviance Explained (CDE)

**Running title:** Statistical Model for Skipjack Habitat

## INTRODUCTION

Skipjack tuna (*Katsuwonus pelamis*) is the most crucial targeting by marine fisheries in the world's oceans (Galland et al. 2016). Large schools of adult skipjack tuna are often associated with juvenile yellowfin (*Thunnus albacores*) and bigeye tuna (*Thunnus obesus*) (IOTC 2020). Skipjack tuna is a highly migratory pelagic species inhabiting all tropical and subtropical waters (Artetxe-Arrate et al. 2020). However, they are found mainly in the tropical areas of the Atlantic, Indian and Pacific Oceans, with the most incredible abundance seen near the equator. Since juvenile yellowfin and bigeye tuna often school with adult skipjack tuna, they are caught by purse seine and pole and line vessels that the main target is skipjack tuna (Hidayat et al. 2019; IOTC 2019; Safruddin et al. 2020).

The dynamic of oceanographic factors could change the natural fluctuations of the skipjack tuna in distribution and abundance in the coastal and offshore areas (Mugo et al. 2010; Tseng et al. 2010; Wang et al. 2016). The distribution can also influence if the small pelagic fish such anchovy is abundant in the same area (Safruddin et al. 2018). Therefore, information is rapidly needed on the effects of oceanography factors related to skipjack tuna distribution (Andrade and Garcia, 1999). This information is needed to predict fishing ground potential zones for sustainable skipjack tuna fishery in the study area.

Statistical models such as generalized additive models (GAMs) and generalized linear models (GLMs) as a method can be one of the most useful for determining the fish distribution in relation to oceanography factors such as sea surface temperature (SST), sea surface chlorophyll-a (SSC), and water depth (Safruddin 2013; Safruddin et al. 2018; Selao et al. 2019).

The Gulf of Bone is one of the best skipjack tuna habitats in Indonesian waters, with the peak fishing season lasting from early April until the end of September (southeast monsoon). Although skipjack tuna is an iconic species in Bone Gulf, local availability of skipjack tuna is a key economy for pole and line fishery. However, a lack of information about this tuna distribution spatially and temporally. As a result, this study offers the chance to investigate skipjack tuna under

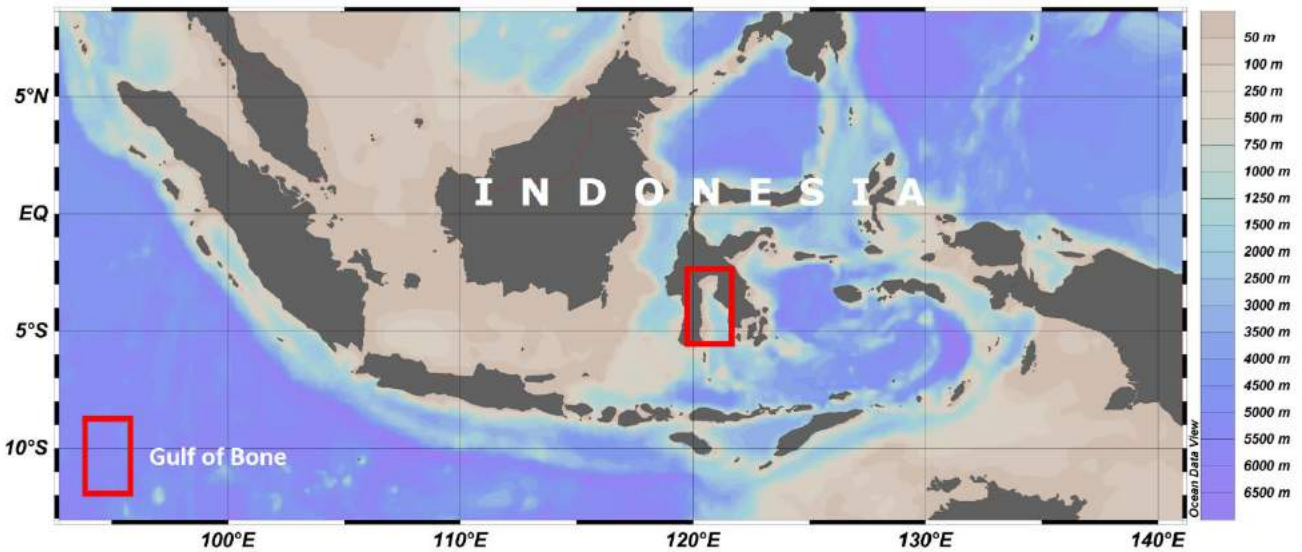
45 various oceanographic conditions connected to the use of pole and line fishing gear and discuss the oceanography elements  
46 impacting skipjack tuna distribution and apply statistical models.

47

## MATERIALS AND METHODS

### Study area

48 The study area was located in Bone Gulf (3 - 5°S) and (120 - 122°E), South Sulawesi, Indonesia (Figure 1). The field  
49 surveys used a pole and line (local commercial fisheries) to investigate the fishing ground positions and the number of  
50 skipjack tuna catches during the study. Oceanography observations (satellite imagery data) were conducted monthly  
51 during the southeast monsoon (in April to September) from 2015 until 2018, respectively.  
52

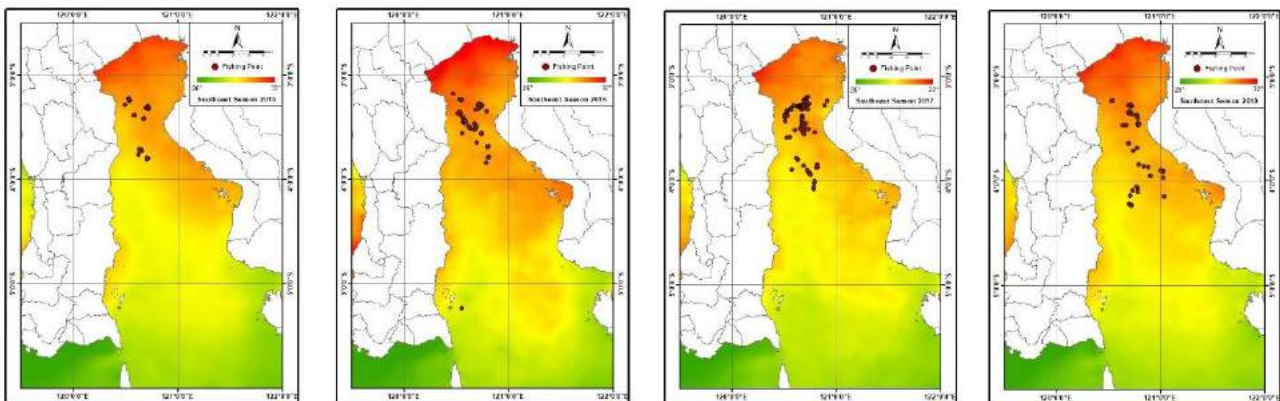


53  
54 **Figure 1.** Map of Indonesia Seas with the Red Box was representing the study area.

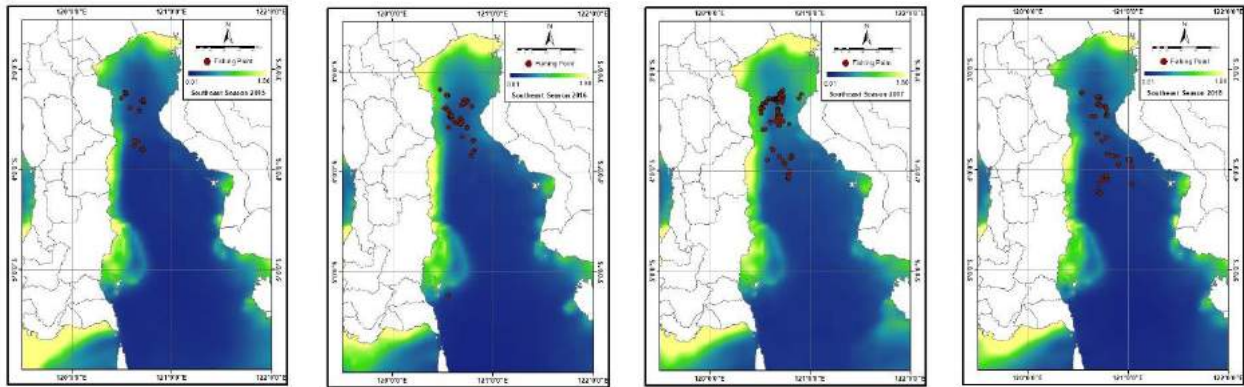
### Procedures

#### Data Collection

55 In-situ data were obtained through the scientific survey, the fishing base at Murante fish landing site, Luwu district. We  
56 were gathered the fishery data from 508 fishing ground positions. A global positioning system (GPS) was used  
57 to determine fishing grounds coordinates (latitude and longitude). The In-situ field data consisted of fishing position and  
58 catch per unit efforts (CPUEs). The oceanographic images data (SST, SSC, and depth) were obtained from satellite  
59 oceanography imaginary data of high-resolution Moderate-Resolution Imaging Spectroradiometer (MODIS) aqua with a  
60 spatial resolution of 4 km April to September 2015 until 2018. The waters depth data was gained from the ETOPO2  
61 satellite database. In this study, we used monthly temporal resolution. Furthermore, the SST and SSC averaged during  
62 southeast monsoon were mapped as shown in Figures 2 and 3.  
63  
64



65  
66 **Figure 2.** The Profiles of SST average during southeast monsoon in 2015 until 2018 overlaid with the skipjack tuna distribution in Bone  
67 Gulf waters.



68  
69 **Figure 3.** The Profiles of SSC average during southeast monsoon in 2015 - 2018 overlaid with the skipjack tuna distribution in Bone  
70 Gulf waters.

71 **Data analysis**

72 Determining the effect of oceanographic parameters on horizontal distributions of skipjack tuna in the sea, statistical  
73 models (Hastie and Tibshirani 1990) are used for the CPUE and oceanographic datasets. The models, such as GAMs and  
74 GLMs, were created using the mgcv package in R-studio (Wood 2006) to predict the spatial patterns of skipjack tuna. The  
75 response variable used skipjack tuna catches (CPUE/fishing trip), and the predictor used oceanographic parameters (SST,  
76 SSC, and depth).

77 So the hypothesized interactions between oceanographic parameters and skipjack tuna are most likely non-linear, GAM  
78 was employed as an experimental technique to determine the forms of the associations. The connections between the  
79 skipjack distribution and each predictor (SST, SSC, and depth) were also determined. In a GLM, the proper functions were  
80 utilized to identify these forms in the linear model, as indicated in Equations (1) and (2) (Safruddin 2013).

81 
$$g(\mu) = \alpha_0 + s_1(\text{SST}) + s_2(\text{SSC}) + s_3(\text{depth}) + \varepsilon \quad (\text{GAM model}) \quad (1)$$

82 
$$g(\mu) = \beta_0 + \beta_1(\text{SST}) + \beta_2(\text{SSC}) + \beta_3(\text{depth}) + \varepsilon \quad (\text{GLM model}) \quad (2)$$

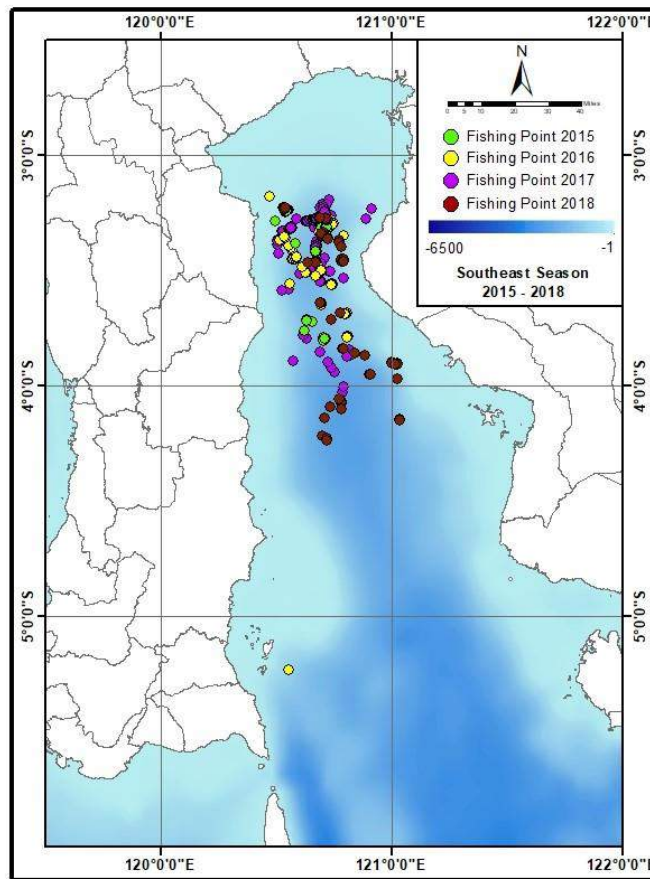
83 where  $g$  is link function,  $\mu$  is the expected value of the dependent variable for the presence of skipjack tuna (CPUE),  $\alpha$   
84 and  $\beta_0$  are the models constant,  $s_n$  is the predictor variables smoothing function, and  $\varepsilon$  is a random error term, and  $\beta_n$  is the  
85 vector of model coefficients.

86 The Gaussian family with identical link functions was chosen since the skipjack tuna CPUE has a continuous  
87 distribution. Models were created from the ground up, with only one independent component, such as SST, and predictor  
88 components added later. Model selection was influenced by the predictor's significance, Akaike Information Criterion  
89 (AIC) reduction, and the deviance explained value. The best model was chosen from a group of seven to build the  
90 GAMs/GLMs. The GAMs/GLMs model was utilized to compare the results of the prediction models using a statistical  
91 criterion. They were also used to explain all observations with multiple variables, including inter-variable correlations  
92 (Safruddin 2013).

93 **RESULTS AND DISCUSSION**

94 **Skipjack Tuna Fishing Ground**

95 Skipjack tuna fishing grounds were mapped on latitude and longitude scales, with SST, SSC, and depth overlay  
96 (Figures 2 - 4). CPUE marks the position along the railway in Figures 2 - 4, and each school is designated as a single point.  
97 Map contours with high SST, SSC, and depth, or the opposite, were also discovered.



**Figure 4.** The profiles of bathymetric overlain with the skipjack tuna distribution during southeast monsoon in 2015 - 2018 in Bone Gulf waters.

98  
99  
100

101 The lowest SST and the highest SSC for the southeast monsoon occur every year. On the otherwise, in the northwest  
102 season. Skipjack tuna was the least abundant in the lower SST area (Figure 3) due to changes in water temperature caused  
103 by water currents from the Flores Sea entrance to Bone Gulf. So it may be a strategy in biological processes under  
104 changing oceanographic conditions related to fish growth. Skipjack tuna stock is positively correlated with oceanographic  
105 factors. Skipjack tuna is distributed mainly in nearshore areas in the water depth range of 50 to 2,000 m (Figure 4). The  
106 horizontal profiles of the SST and SSC structures for the 2015-2018 southeast season, respectively (Figures 2 and 3), are  
107 warmer near the coast than offshore. Skipjack schools occupy areas in the offshore area where they prefer relatively warm  
108 SST and lower SSC (Figures 2 and 3).

109 The environmental conditions of skipjack tuna fishing grounds were used for four monthly datasets (April – August).  
110 As a result, the preference range suggested a possible association between all of the factors examined. For example, figure  
111 4 shows that skipjack tuna were found in temperatures ranging from 29.5 to 31.05 °C. On the otherwise, the skipjack tuna  
112 schools concentrated in the narrow ranges of 0.15-1.00 mg m<sup>-3</sup> regarding SSC.

### 113 **Effects of oceanographic factors on skipjack tuna distribution**

114 The oceanographic condition of the skipjack tuna schooling coordinate was employed in the current study for  
115 displaying the area and further analysis. Tables 1 and 2 show the models built using GAMs/GLMs on the skipjack tuna  
116 distribution scenarios utilizing predictor parameters (SST, SSC, and depth).

117 Tables 1 and 2 present the results for each of the seven GAM and GLM models. Each model's predictor component (s)  
118 significantly affected the skipjack tuna distribution in  $p < 0.05$  reference levels, except depth as two and three predictors  
119 (Table 1). However, only SST substantially contributed to a single model predictor, two model predictors, and three model  
120 predictors in GLMs (Table 2). For the final model combination of SST, SSC, and depth, the cumulative deviance  
121 explained (CDE) was 21.9% (GAMs) and 12.830% (GLMs), respectively. Thus, tables 1 and 2 suggest that the influence  
122 of oceanographic conditions may explain the fluctuation of skipjack tuna abundance distribution. Additionally, GAMs  
123 with the highest CDE were well-suited to characterize the influence of oceanographic conditions on skipjack tuna  
124 distribution and abundance.

125 Tables 1 and 2 show the results of GAMs and GLMs, respectively. For both statistical models, the SST had the largest  
126 deviance explained among the single variable models. According to AIC (6048.045) and CDE (21.9%) and as the best  
127 model predictor of GAM, the combination of SST and SSC predicted relatively more significant variability in skipjack

128 tuna catches. The AIC values for the three-parameter models were low (6049.831), and the most significant deviation was  
 129 explained (21.9%). SST was the sole predictor model with the lowest AIC (6083.072) and the maximum CDE among  
 130 GLMs model (12.870%) and was also found in combining two-parameter models between SST and SSC. The three  
 131 parameter models had the lowest AIC and the highest CDE overall (12.830 % ). All of the results produced by combining  
 132 predictor factors at various levels revealed an increase or decrease in CDE and a higher AIC value of variation.

133 GAMs models were more effective than GLMs in understanding the effect of oceanographic factors on skipjack tuna  
 134 distribution and abundance, as shown in Tables 1 and 2. The result of the GAM plots give impacts of each predictor on  
 135 schooling density of skipjack tuna are shown in Figures 5 and 6. The observed data points are represented by the rug plot  
 136 on the horizontal axis, while the think line shows the fitted function, and the grey shading represents the 95 percent  
 137 confidence interval (Safuruddin 2013).

138 **Table 1.** Oceanographic factor influences on the skipjack tuna distribution (n=508), according to the GAMs Models. Also included are  
 139 the significant factor, AIC value and CDE.  
 140

No.	Model	Oceanographic factor	P-value	AIC	CDE (%)
1.	SST	SST	<2e-16 ***	6054.183	20.400
2.	SSC	SSC	2.22e-06 ***	6121.052	8.400
3.	Depth	Depth	0.000109 ***	6132.647	4.970
4.	SST + SSC	SST	2.46e-15 ***	6048.045	21.900
		SSC	0.000293 ***		
5.	SST + Depth	SST	2.12e-14 ***	6067.725	17.300
		Depth	0.296		
6.	SSC + Depth	SSC	0.000899 ***	6121.672	8.350
		Depth	0.236307		
7.	SST + SSC + Depth	SST	2.44e-15 ***	6049.831	21.900
		SSC	0.000289 ***		
		Depth	0.832189		

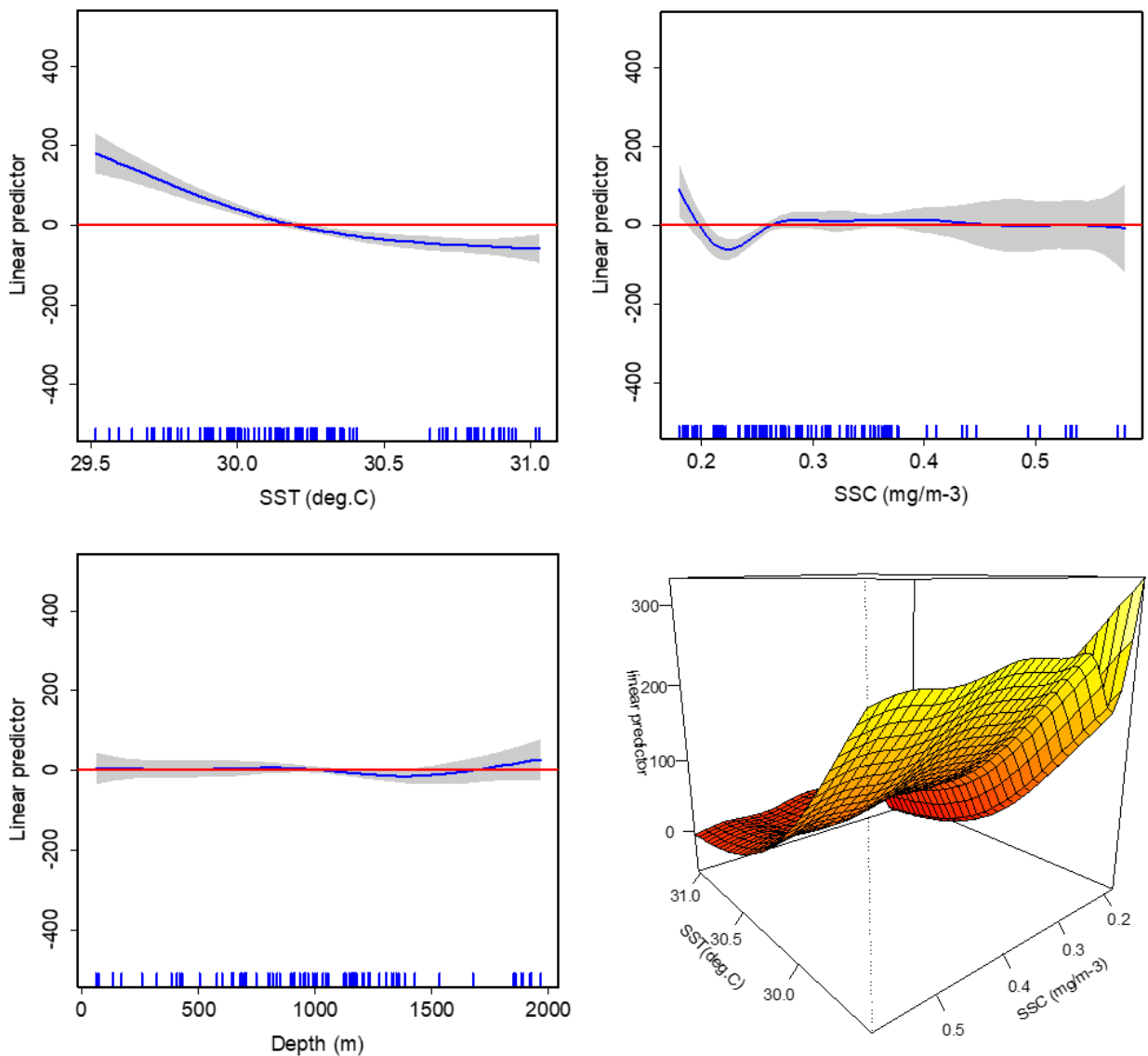
141 Note: Sig. codes: 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*'

142 Figure 5 describes the impact of oceanographic conditions on skipjack tuna distribution. Around 29.5 – 30.5 °C, the  
 143 SST (Figure 5a) had a noticeable positive effect on skipjack tuna distribution. The confidence intervals are broader  
 144 because there are fewer data points at 30.5 - 31.0 °C. In the SSC plot (Figure 5b), there was a beneficial influence on  
 145 school distribution in the SSC ranges of 0.25 - 0.35 mg m<sup>-3</sup>. A consistent influence on skipjack tuna distribution of 50 -  
 146 2,000 m was seen for depth (Figure 5c). The study also found that models combining SST and SSC produced the most  
 147 significant model prediction, with the lowest AIC and highest CDE (Figure 5d). Skipjack tuna distribution in the Northern  
 148 Pacific Ocean near Japan waters had SST and SSC optimal temperatures of 20.5 - 26 °C and 0.3 - 0.37 mg m<sup>-3</sup>,  
 149 respectively, according to Mugo (2010). The findings of this study corroborated those of Zainuddin et al. (2017), who  
 150 discovered that distribution of skipjack tuna in the coastal area was primarily around 50 m depth.

151 **Table 2.** Oceanographic factor influences on the skipjack tuna distribution (n=508), according to the GLMs Models. Also included are  
 152 the significant factor, AIC value and CDE.

No.	Model	Oceanographic factor	P-value	AIC	CDE (%)
1	SST	SST	<2e-16 ***	6083.072	12.960
2	SSC	SSC	0.89413	6154.549	0.194
3	Depth	Depth	0.17566	6152.724	0.165
4	SST + SSC	SST	<2e-16 ***	6084.600	12.870
		SSC	0.494		
5	SST + Depth	SST	<2e-16 ***	6084.987	12.800
		Depth	0.772		
6	SSC + Depth	SSC	0.385	6153.966	0.117
		Depth	0.109		
7	SST + SSC + Depth	SST	<2e-16***	6085.819	12.830
		SSC	0.282		
		Depth	0.379		

153 Note: Sig. codes: 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*'



154  
155 **Figure 4.** Skipjack tuna distribution responses of oceanographic factors; (a) SST, (b) SSC, (c) depth, and (d) best model predictor.

156 **Discussion**

157 Oceanographic circumstances such as SST, which have the most significant impact on growth stages of fish and  
 158 distribution (Yuniarti et al. 2013; Syah et al. 2020), the main role in the natural oscillations of skipjack tuna stocks. As a  
 159 result, SST is a great indicator for the fishing ground of skipjack tuna to have been used by fishermen and investigators for  
 160 decades. Furthermore, changes in oceanic (physical and biological) parameters may significantly impact migration patterns  
 161 and fish growth (Safuruddin et al. 2018).

162 Because the SST in the research region may vary, measurements should be obtained frequently. More samples may be  
 163 required to accomplish this goal. Therefore, one of this research objective about how oceanographic data will be used in  
 164 research (e.g., correlation with skipjack tuna distribution and abundance). Temperature fluctuations are often linked to the  
 165 biological richness (Iskandar et al. 2017; Takarina et al. 2018), such as anchovy distribution and abundance as prey for  
 166 skipjack tuna, and they have an important influence on fish physiology (Kunarso et al. 2011; Olson et al. 2016; Duffy et al.  
 167 2017).

168 Satellite remote sensing imagery directly indicates horizontal and large-area information on oceanographic conditions,  
 169 which may be utilized to understand oceanographic processes in the surface water better. The combination of satellite data  
 170 with acoustic technology will, of course, increase the accuracy of the data. For example, they combine CTD and satellite  
 171 data when conducting data observations (Safuruddin 2013). As a result, four-year datasets of oceanographic conditions  
 172 (SST, SSC, and water depth) on skipjack tuna position were employed, with scatter plots and optimal ranges indicating a  
 173 possible association among all variables observed as shown in Figure 5.

174 Skipjack tuna can be found in coastal areas, where it can sometimes be found in great numbers, particularly in  
175 upwelling areas (Sari et al. 2018; Wijaya et al. 2020). The study detailed the interaction between skipjack tuna and their  
176 oceanographic variable at the aspect of temporal and spatial scales to comprehend the numerous processes involved and  
177 how they might be utilized to model their dynamics and forecast their abundance (Prista et al. 2011; Selvaraj et al. 2020).

178 Oceanographic conditions are essential variables to assess the abundance of fish in the waters, especially skipjack tuna,  
179 representing the original habitats. The distribution of skipjack tuna observed during the daytime is closely related to the  
180 dynamics of oceanographic variables and fishing operations in Bone Gulf. As shown in Tables 1 and 2 and Figure 5, the  
181 effect of oceanographic parameters on the abundance and distribution of skipjack tuna for water depths is also a reference.  
182 The p-value, AIC, and CDE can all be used to assess the impact of changing oceanographic conditions on skipjack tuna  
183 CPUE. As a result, oceanographic variables connected to skipjack tuna distribution are critical to understanding skipjack  
184 tuna habitat preferences.

185 Oceanographic phenomena in the waters such as frontal oceanic zones, eddies, and upwelling area often occur make  
186 different characteristics like in the Bone Gulf and the Flores Sea (Zainuddin et al. 2017, 2019; Hidayat and Zainuddin  
187 2018; Hidayat et al. 2019b). This event makes the waters very dynamic and affects the horizontal distribution of fish in the  
188 Bone Gulf. The dynamic oceanographic parameters in this area produce highly productive habitats and serve as foraging  
189 grounds for various commercially and ecologically important species such as anchovies and skipjack tuna (Safruddin et al  
190 2018; Hidayat et al 2019b)

191 The results of this study indicate that the SST tolerance value for skipjack tuna is in the range of 29.5 to 30.5 °C and  
192 for SSC parameters in the range of 0.25 – 0.35 mg m<sup>-3</sup> (Figures 5a and 5b). however, in addition to SST and SSC,  
193 Indonesian throughflow (ITF) and Asian monsoons also influence the location of the optimum habitat for skipjack tuna  
194 (Gordon 2005). changes in the value of SST in the waters are heavily influenced by the seasonal cycle, in contrast to the  
195 SSC, which is not much influenced by the seasonal cycle. Therefore, the migration of skipjack tuna in the northern waters  
196 of Bone Gulf is thought to have followed the mass movement of water in the southeast monsoon by occupying relatively  
197 warm areas in offshore waters.

198 Based on the lowest AIC value and the highest CDE, the GAM nonlinear model is the best statistical model to  
199 understand the effect of oceanographic parameters on the distribution and abundance of skipjack tuna. This study is also  
200 supported by previous findings in the Makassar Strait, which reported that the GAM model effectively assessed the effect  
201 of oceanographic parameters on skipjack tuna (Hidayat et al. 2019a) and small pelagic fish such as anchovies in Bone Gulf  
202 (Safruddin et al. 2018).

203 This study concludes that the GAM statistical model has succeeded in explaining the effect of oceanographic parameter  
204 conditions on the distribution of skipjack tuna in Bone Gulf. This study also shows the vital role of oceanographic  
205 parameters in understanding the habitat of skipjack tuna related to its abundance and distribution in the waters. The  
206 distribution of skipjack tuna in the ocean shows a strong relationship with several parameters such as SST, SSC, and water  
207 depth. Suitable or optimal conditions for skipjack tuna represent skipjack fishing areas during the study in the southeast  
208 monsoon period. Oceanographic parameters associated with fish catches correspond to the spatial and temporal  
209 distribution of skipjack tuna and have become a hot topic of discussion worldwide (Andrade 2003; Mugo et al. 2010;  
210 Zainuddin et al. 2019). From the results of this study, it can be suggested that management decisions to increase fishery  
211 yields need to consider oceanographic conditions and characteristics in the waters.

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## SUBMISSION CHECKLIST

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The first corresponding author must be accompanied with contact details:

**Give mark (X)**

• E-mail address	<b>X</b>
• Full postal address (incl street name and number (location), city, postal code, state/province, country)	<b>X</b>
• Phone and facsimile numbers (incl country phone code)	<b>X</b>

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• Manuscript has been “spell & grammar-checked” Better, if it is revised by a professional science editor or a native English speaker	<b>X</b>
• References are in the correct format for this journal	<b>X</b>
• All references mentioned in the Reference list are cited in the text, and vice versa	<b>X</b>
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• Charts (graphs and diagrams) are drawn in black and white images; use shading to differentiate	<b>X</b>

290  
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**[biodiv] Submission Acknowledgement**

1 message

**Ahmad Dwi Setyawan** <smujo.id@gmail.com>

Thu, Dec 2, 2021 at 10:42 AM

To: Safruddin Hasyim &lt;safruddin@fisheries.unhas.ac.id&gt;

Safruddin Hasyim:

Thank you for submitting the manuscript, "The Use of statistical models in Identifying Skipjack Tuna Habitat Characteristics during the Southeast Monsoon in Bone Gulf, Indonesia " to Biodiversitas Journal of Biological Diversity. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Submission URL: <https://smujo.id/biodiv/authorDashboard/submission/10023>

Username: safruddin\_75

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Ahmad Dwi Setyawan

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**[biodiv] Editor Decision**

1 message

**Ayu Astuti** <smujo.id@gmail.com>

Wed, Mar 23, 2022 at 7:29 PM

To: Safruddin Hasyim &lt;safruddin@fisheries.unhas.ac.id&gt;, Rachmat Hidayat &lt;rh191993@gmail.com&gt;, St Aisjah Farhum &lt;icha\_erick@yahoo.com&gt;, Mukti Zainuddin &lt;muktizunhas@gmail.com&gt;

Safruddin Hasyim, Rachmat Hidayat, St Aisjah Farhum, Mukti Zainuddin:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "The Use of statistical models in Identifying Skipjack Tuna Habitat Characteristics during the Southeast Monsoon in Bone Gulf, Indonesia".

Our decision is: Revisions Required

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Reviewer A:

Dear Authors,

Thank you for submitting this interesting paper to Biodiversitas. The paper describes the use of models to identify locations for skipjack tuna fishing. The paper has some potential value to those involved in fisheries. Overall, I found the manuscript to be well formatted, with a clear message and repeatable methods. The results are well organised (but see comments on the word manuscript), and the outcomes are clear in the discussion. There are a few relatively small revisions required; details can be found on the manuscript. On the whole, an interesting and well designed study.

Recommendation: Revisions Required  
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# The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia

Manuscript received: 02 12 2021. Revision accepted: ..... 2022.

**Abstract.** This study aimed to explore the relationship between the oceanographic factors and the distribution and abundance of skipjack tuna obtained by pole and line fishing in the Bone Gulf, Indonesia. The research was conducted during the southeast monsoon season (April–September) from 2015 until 2018. Three oceanographic parameters were used to understand this relationship, i.e., Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), and water depth. Generalized Additive Models (GAMs) and Generalized Linear Models (GLMs) used to predict the spatial pattern of the skipjack tuna showed that all considered parameters significantly influenced the distribution of skipjack tuna in the study area. The fish are mostly distributed from coastal to offshore areas, ranging between 50 to 2,000 meters and even wider. The concentration tends to be high within the range of 29.5 to 30.5°C of SST, 0.25 to 0.35 mgm<sup>-3</sup> of SSC, and 500 to 1,000 meters of water depth. The research also found that the skipjack tuna migration to the Bone Gulf may have followed the current water interruption during the southeast monsoon, for preferred warmer temperatures and lower primary productivity waters in the offshore areas. This may represent the optimal habitat of the skipjack tuna during this period.

**Keywords:** oceanographic factors, pole and line, skipjack tuna, statistical models.

**Abbreviations:** Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), Catch Per Unit Effort (CPUE), Generalized Additive Models (GAMs), Generalized Linear Models (GLMs), Akaike Information Criterion (AIC), Cumulative Deviance Explained (CDE)

**Running title:** Statistical Model for Skipjack Habitat

## INTRODUCTION

Skipjack tuna (*Katsuwonus pelamis*) is the most crucial target catch of marine fisheries in the world's oceans (Galland et al. 2016). Large schools of adult skipjack tuna are often associated with juvenile yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) (IOTC 2020). Skipjack tuna is a highly migratory pelagic species inhabiting all tropical and subtropical waters (Artetxe-Arrate et al. 2020). However, they are found mainly in the tropical areas of the Atlantic, Indian, and Pacific Oceans, with the most incredible abundance seen near the equator. Since juvenile yellowfin and bigeye tuna often school with adult skipjack tuna, they are caught by purse seine and pole and line vessels whose main target is skipjack tuna (Hidayat et al. 2019; IOTC 2019; Safruddin et al. 2020).

The dynamics of oceanographic factors could affect the natural fluctuations in the distribution and abundance of skipjack tuna in the coastal and offshore areas (Mugo et al. 2010; Tseng et al. 2010; Wang et al. 2016). The distribution could also be influenced by the abundance of small pelagic fish such as anchovy in the same area (Safruddin et al. 2018). Therefore, there is an urgent need for information on the effects of oceanographic factors on skipjack tuna distribution (Andrade and Garcia 1999) to predict fishing ground potential zones for sustainable skipjack tuna fishery in the study area.

Statistical models such as generalized additive models (GAMs) and generalized linear models (GLMs) can be the most useful methods for determining the fish distribution in relation to oceanographic factors such as the sea surface temperature (SST), sea surface chlorophyll-a (SSC), and water depth (Safruddin 2013; Safruddin et al. 2018; Selao et al. 2019).

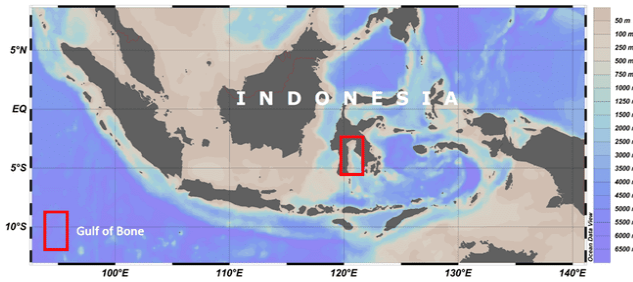
The Bone Gulf is one of the best skipjack tuna habitats in Indonesian waters, with the peak fishing season lasting from early April until the end of September (southeast monsoon). Although skipjack tuna is an iconic species in the Bone Gulf, its local availability is a key factor for the pole and line fishery economy. However, there is a lack of information about its distribution, both spatially and temporally. Hence, this study is an attempt to investigate the availability of skipjack tuna caught using pole and line fishing gear under various oceanographic conditions and to discuss the oceanographic elements impacting skipjack tuna distribution by applying statistical models.

MATERIALS AND METHODS

45

46 **Study area**

47 The study area was located in the Bone Gulf (3–5°S) and (120–122°E), South Sulawesi, Indonesia (Figure 1). The field  
 48 surveys used the pole and line method (local commercial fisheries) to investigate the fishing ground positions and the  
 49 number of skipjack tuna catches during the study. Oceanography observations (satellite imagery data) were conducted  
 50 monthly during the southeast monsoon (April–September) from 2015 until 2018.

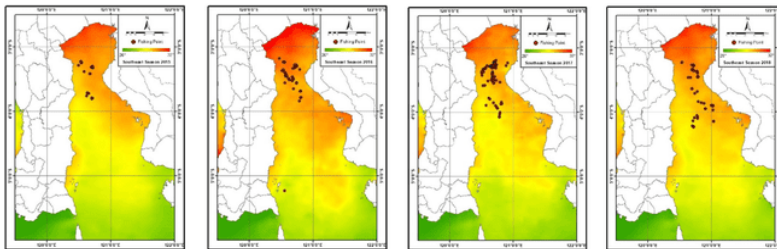


51 **Figure 1.** Map of the Indonesian seas with the red box representing the study area.  
 52

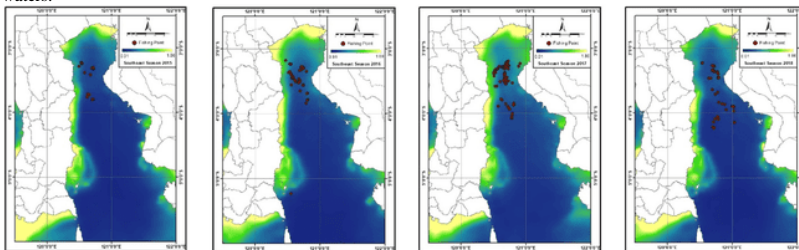
53 **Procedures**

54 *Data Collection*

55 In-situ data were obtained through a scientific survey at the fishing base at Murante fish landing site, Luwu district. We  
 56 gathered the fishery data from 508 fishing ground positions. A global positioning system (GPS) was used to determine  
 57 fishing ground coordinates (latitude and longitude). The in-situ field data consisted of the fishing position and catch per  
 58 unit efforts (CPUEs). The oceanographic parameters (SST, and SSC) were obtained from satellite oceanography imagery  
 59 data of high-resolution Aqua Moderate-Resolution Imaging Spectroradiometer (MODIS), with a spatial resolution of 4  
 60 km, from 2015 until 2018 (April–September). The water depth data was gained from the ETOPO1 satellite database. In  
 61 this study, we used monthly temporal resolution. Furthermore, the SST and SSC averaged during southeast monsoon were  
 62 mapped as shown in Figures 2 and 3, respectively.



63 **Figure 2.** The profiles of SST average during southeast monsoon from 2015 until 2018 overlaid with the skipjack tuna distribution in the  
 64 Bone Gulf waters.  
 65



66 **Figure 3.** The profiles of SSC average during southeast monsoon from 2015 to 2018 overlaid with the skipjack tuna distribution in the  
 67 Bone Gulf waters.  
 68

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69 *Data Analysis*

70 To determine the effect of oceanographic parameters on horizontal distributions of skipjack tuna in the sea, statistical  
 71 models (Hastie and Tibshirani 1990) were used for the CPUE and oceanographic datasets. The models, such as GAMs and  
 72 GLMs, were created using the MGCV package in R-studio (Wood 2006) to predict the spatial patterns of skipjack tuna.  
 73 The response variable used skipjack tuna catches (CPUE/fishing trip), and the predictor used oceanographic parameters  
 74 (SST, SSC, and depth).

75 The hypothesized interactions between oceanographic parameters and skipjack tuna distribution are most likely non-  
 76 linear. GAM was employed as an experimental technique to determine the forms of the associations. The connections  
 77 between the skipjack distribution and each predictor (SST, SSC, and depth) were also determined. In a GLM, proper  
 78 functions were utilized to identify these forms in the linear model, as indicated in Equations (1) and (2) (Safruddin 2013).

79 
$$g(\mu) = \alpha_0 + s_1(\text{SST}) + s_2(\text{SSC}) + s_3(\text{depth}) + \varepsilon \quad (\text{GAM model}) \quad (1)$$

80 
$$g(\mu) = \beta_0 + \beta_1(\text{SST}) + \beta_2(\text{SSC}) + \beta_3(\text{depth}) + \varepsilon \quad (\text{GLM model}) \quad (2)$$

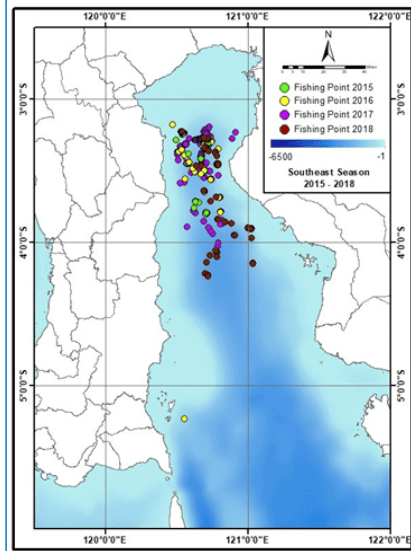
81 where  $g$  is the link function,  $\mu$  is the expected value of the dependent variable for the presence of skipjack tuna  
 82 (CPUE),  $\alpha_0$  and  $\beta_0$  are the respective model's constant,  $s_n$  is the predictor variable's smoothing function,  $\varepsilon$  is a random  
 83 error term, and  $\beta_n$  is the vector of model coefficients.

84 The Gaussian family with identical link functions was chosen since the skipjack tuna CPUE has a continuous  
 85 distribution. Models were created from the ground up, with only one independent component such as SST, and predictor  
 86 components were added later. Model selection was influenced by the predictor's significance, Akaike Information  
 87 Criterion (AIC) reduction, and the deviance explained value. The best model was chosen from a group of seven to build  
 88 the GAMs/GLMs. The GAMs/GLMs model was utilized to compare the results of the prediction models using a statistical  
 89 criterion. They were also used to explain all observations with multiple variables, including inter-variable correlations  
 90 (Safruddin 2013).

91 **RESULTS AND DISCUSSION**

92 **Skipjack tuna fishing ground**

93 Skipjack tuna fishing grounds were mapped on latitude and longitude scales, with SST, SSC, and depth overlay  
 94 (Figures 2–4). CPUE marks the position along the overlay in Figures 2–4, and each school is designated as a single point.  
 95 Map contours with high SST, SSC, and depth, or the opposite, were also discovered.



96 **Figure 4.** The profiles of bathymetric overlay with the skipjack tuna distribution during southeast monsoon from 2015 to 2018 in the  
 97 Bone Gulf waters.

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99 The lowest SST and the highest SSC occur every year during the southeast monsoon period. The reverse happens in the  
 100 northwest monsoon season, skipjack tuna was least abundant in the lower SST area (Figure 2) due to changes in water  
 101 temperature caused by water currents from the Flores Sea entrance to the Bone Gulf. This could be a strategy in biological  
 102 processes related to fish growth under changing oceanographic conditions. Skipjack tuna stock is positively correlated  
 103 with oceanographic factors. It is distributed mainly in nearshore areas in the water depth range of 50 to 2,000 m (Figure 4).  
 104 The horizontal profiles of the SST and SSC structures for the 2015–2018 southeast monsoon season (Figures 2 and 3) are  
 105 warmer near the coast than offshore. Skipjack schools occupy offshore areas where they prefer relatively higher SST and  
 106 lower SSC (Figures 2 and 3).

107 The environmental conditions of skipjack tuna fishing grounds were used for four monthly datasets (April–August). As  
 108 a result, the preference range suggested a possible association between all examined factors. For example, Figure 4 shows  
 109 that skipjack tuna were found in temperatures ranging from 29.5 to 31.05°C. Likewise, the skipjack tuna schools  
 110 concentrated in the narrow ranges of 0.15–1.00 mgm<sup>-3</sup> with respect to SSC.

111 **Effects of oceanographic factors on skipjack tuna distribution**

112 The oceanographic conditions of the skipjack tuna schooling coordinates were employed in the current study for  
 113 displaying the area and further analysis. Tables 1 and 2 show the models built using GAMs/GLMs on the skipjack tuna  
 114 distribution scenarios utilizing predictor parameters (SST, SSC, and depth).

115 Tables 1 and 2 present the results for each of the seven GAM and GLM models. Each model's predictor component(s)  
 116 significantly affected the skipjack tuna distribution in  $p < 0.05$  reference levels, except depth as predictor two and three  
 117 (Table 1). However, only SST substantially contributed to a single model predictor, two model predictors, and three model  
 118 predictors in GLMs (Table 2). For the final model combination of SST, SSC, and depth, the cumulative deviance  
 119 explained (CDE) was 21.9% (GAMs) and 12.830% (GLMs), respectively. Thus, Tables 1 and 2 suggest that the influence  
 120 of oceanographic conditions may explain the fluctuation of skipjack tuna abundance distribution. Additionally, GAMs  
 121 with higher CDE were well-suited to characterize the influence of oceanographic conditions on skipjack tuna distribution  
 122 and abundance.

123 Tables 1 and 2 show the results of GAMs and GLMs, respectively. For both statistical models, the SST had the largest  
 124 deviance explained among the single variable models. According to AIC (6048.045) and CDE (21.9%), and as the best  
 125 model predictor of GAM, the combination of SST and SSC predicted relatively more significant variability in skipjack  
 126 tuna catches. The AIC values for the three-parameter models were low (6049.831) and the most significant deviation  
 127 explained was 21.9%. SST was the sole predictor model with the lowest AIC (6083.072) and the maximum CDE on the  
 128 GLMs model (12.870%) and was also found as a combined two-parameter model between SST and SSC. The three-  
 129 parameter models had the lowest AIC and the highest CDE overall (12.830%). All results produced by combining  
 130 predictor factors at various levels revealed an increase or decrease in CDE and a higher AIC value of variation.

131 GAMs models were more effective than GLMs in understanding the effect of oceanographic factors on skipjack tuna  
 132 distribution and abundance, as shown in Tables 1 and 2. The result of the GAM plots shows the impact of each predictor  
 133 on schooling density of skipjack tuna as shown in Figures 5. The observed data points are represented by the rug plot  
 134 on the horizontal axis, while the thin line shows the fitted function, and the grey shading represents the 95% confidence  
 135 interval (Safruddin 2013).

136 **Table 1.** Oceanographic factor influences on the skipjack tuna distribution (n=508), according to the GAMs models. Also included are  
 137 the significant factor, AIC value, and CDE  
 138

Model	Oceanographic factor	P-value	AIC	CDE (%)
SST	SST	<2e-16 ***	6054.183	20.400
SSC	SSC	2.22e-06 ***	6121.052	8.400
Depth	Depth	0.000109 ***	6132.647	4.970
SST + SSC	SST	2.46e-15 ***	6048.045	21.900
	SSC	0.000293 ***		
SST + Depth	SST	2.12e-14 ***	6067.725	17.300
	Depth	0.296		
SSC + Depth	SSC	0.000899 ***	6121.672	8.350
	Depth	0.236307		
SST + SSC + Depth	SST	2.44e-15 ***	6049.831	21.900
	SSC	0.000289 ***		
	Depth	0.832189		

139 Note: Sig. codes: 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*'

140 Figure 5 describes the impact of oceanographic conditions on skipjack tuna distribution. Around 29.5–30.5°C, the SST  
 141 (Figure 5a) had a noticeable positive effect on skipjack tuna distribution. The confidence intervals are broader because

**Commented [AJ5]:** it is necessary to enter the bathymetric range for the concentration of fish caught in large numbers based on Figure 4 because the abstract contains the bathymetric range numbers

**Commented [S6R5]:** we describe the optimum oceanographic parameters in the next paragraph (lines 140 - 148)

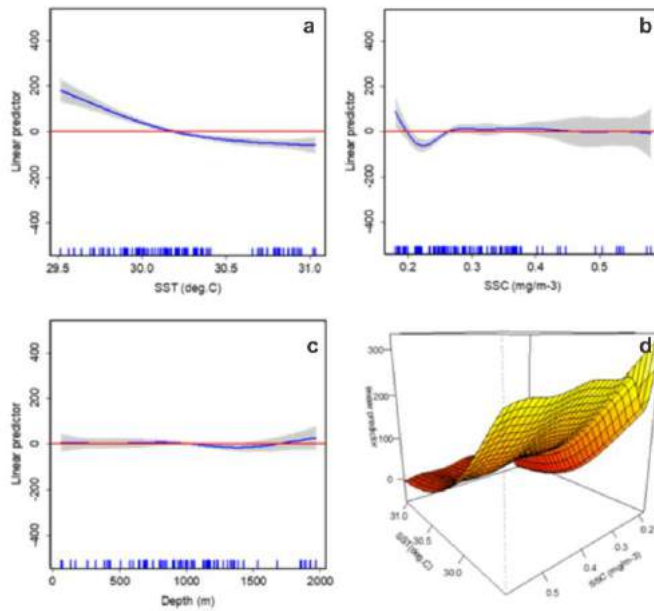
Statistical Model for Skipjack Habitat

142 there are fewer data points at 30.5–31.0°C. In the SSC plot (Figure 5b), there was a beneficial influence on school  
 143 distribution in the SSC ranges of 0.25–0.35 mgm<sup>-3</sup>. A consistent influence on skipjack tuna distribution was seen at a depth  
 144 of 50–2,000 m (Figure 5c). The study also found that models combining SST and SSC produced the most significant  
 145 model prediction, with the lowest AIC and highest CDE (Figure 5d). Skipjack tuna distribution in the Northern Pacific  
 146 Ocean near Japan waters had SST and SSC optimal values of 20.5–26°C and 0.3–0.37 mgm<sup>-3</sup>, respectively, according to  
 147 Mugo (2010). The findings of this study corroborated those of Zainuddin et al. (2017), who discovered that the distribution  
 148 of skipjack tuna in the coastal area was primarily around 50 m depth.

149 **Table 2.** Oceanographic factor influences on the skipjack tuna distribution (n=508), according to the GLMs models. Also included are  
 150 the significant factor, AIC value, and CDE

Model	Oceanographic factor	P-value	AIC	CDE (%)
SST	SST	<2e-16 ***	6083.072	12.960
SSC	SSC	0.89413	6154.549	0.194
Depth	Depth	0.17566	6152.724	0.165
SST + SSC	SST	<2e-16 ***	6084.600	12.870
	SSC	0.494		
SST + Depth	SST	<2e-16 ***	6084.987	12.800
	Depth	0.772		
SSC + Depth	SSC	0.385	6153.966	0.117
	Depth	0.109		
SST + SSC + Depth	SST	<2e-16***	6085.819	12.830
	SSC	0.282		
	Depth	0.379		

151 Note: Sig. codes: 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*'



152 **Figure 4.** Skipjack tuna distribution responses of oceanographic factors: (a) SST, (b) SSC, (c) depth, and (d) best model predictor.  
 153

154 **Discussion**

155 Oceanographic conditions such as the SST, which have the most significant impact on the growth stages of fish and  
 156 their distribution (Yuniarti et al. 2013; Syah et al. 2020), play a main role in the natural oscillations of skipjack tuna stocks.  
 157 As a result, SST is a great indicator for the fishing ground of skipjack tuna to have been used by fishermen and researchers  
 158 for decades. Furthermore, changes in oceanic (physical and biological) parameters may significantly impact migration  
 159 patterns and fish growth (Safruddin et al. 2018).

Commented [AJ7]: Figure 5  
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## Statistical Model for Skipjack Habitat

160 Since the SST in the research region may vary, measurements should be obtained frequently. More samples may be  
161 required to accomplish this goal. Therefore, one of the objectives of this research was to determine how oceanographic  
162 data can be used in research (e.g., correlation between skipjack tuna distribution and abundance). Temperature fluctuations  
163 are often linked to the biological richness (Iskandar et al. 2017; Takarina et al. 2018), such as anchovy distribution and  
164 abundance as the prey for skipjack tuna, and they have an important influence on fish physiology (Kunarso et al. 2011;  
165 Olson et al. 2016; Duffy et al. 2017).

166 Satellite remote sensing imagery directly provides horizontal and large-area information on oceanographic conditions,  
167 which may be utilized to understand oceanographic processes in the surface water better. The combination of satellite data  
168 with acoustic technology will, of course, increase the accuracy of the data. For example, CTD and satellite data are  
169 combined when conducting data observations (Safruddin 2013). As a result, four-year datasets of oceanographic  
170 conditions (SST, SSC, and water depth) on skipjack tuna position were employed, with scattered plots and optimal ranges  
171 indicating a possible association among all variables observed, as shown in Figure 5.

172 Skipjack tuna can be found in coastal areas, sometimes in great numbers, particularly in upwelling areas (Sari et al.  
173 2018; Wijaya et al. 2020). The study detailed the interaction between skipjack tuna and their oceanographic variables,  
174 considering the aspect of temporal and spatial scales to comprehend the numerous processes involved and how they might  
175 be utilized to model their dynamics and forecast their abundance (Prista et al. 2011; Selvaraj et al. 2020).

176 Oceanographic conditions are essential variables to assess the abundance of fish in the waters, especially skipjack tuna,  
177 representing the original habitats. The distribution of skipjack tuna observed during the daytime is closely related to the  
178 dynamics of oceanographic variables and fishing operations in the Bone Gulf. As shown in Tables 1 and 2 and Figure 5,  
179 the effect of oceanographic parameters on the abundance and distribution of skipjack tuna is also a reference for water  
180 depths. The p-value, AIC, and CDE can all be used to assess the impact of changing oceanographic conditions on skipjack  
181 tuna CPUE. As a result, oceanographic variables connected to skipjack tuna distribution are critical for understanding  
182 skipjack tuna habitat preferences.

183 Oceanographic phenomena in the waters, such as frontal oceanic zones, eddies, and upwelling areas, often occur with  
184 different characteristics as seen in the Bone Gulf and the Flores Sea (Zainuddin et al. 2017, 2019; Hidayat and Zainuddin  
185 2018; Hidayat et al. 2019b). This event makes the waters very dynamic and affects the horizontal distribution of fish in the  
186 Bone Gulf. The dynamic oceanographic parameters in this area produce highly productive habitats and serve as foraging  
187 grounds for various commercially and ecologically important species such as anchovies and skipjack tuna (Safruddin et al  
188 2018; Hidayat et al 2019b)

189 The results of this study indicate that the SST tolerance value for skipjack tuna is in the range of 29.5–30.5°C and in  
190 the range of 0.25–0.35 mgm<sup>-3</sup> for SSC parameters (Figures 5a and 5b). However, in addition to SST and SSC, Indonesian  
191 Throughflow (ITF) and Asian monsoons also influence the location of the optimum habitat for skipjack tuna (Gordon  
192 2005). Changes in the value of SST in the waters are heavily influenced by the seasonal cycle, in contrast to the SSC,  
193 which is not influenced much by the seasonal cycle. Therefore, the migration of skipjack tuna in the northern waters of the  
194 Bone Gulf is thought to have followed the mass movement of water in the southeast monsoon, occupying relatively warm  
195 areas in offshore waters.

196 Based on the lowest AIC value and the highest CDE, the GAM nonlinear model is the best statistical model to  
197 understand the effect of oceanographic parameters on the distribution and abundance of skipjack tuna. This study is also  
198 supported by previous findings in the Makassar Strait, which reported that the GAM model effectively assessed the effect  
199 of oceanographic parameters on skipjack tuna (Hidayat et al. 2019a) and small pelagic fish such as anchovies in the Bone  
200 Gulf (Safruddin et al. 2018).

## 201 Conclusion

202 This study concludes that the GAM statistical model has succeeded in explaining the effect of oceanographic  
203 parameters on the distribution of skipjack tuna in the Bone Gulf. This study also shows the vital role of oceanographic  
204 parameters in understanding the habitat of skipjack tuna related to its abundance and distribution in the waters. The  
205 distribution of skipjack tuna in the ocean shows a strong relationship with several parameters such as the SST, SSC, and  
206 water depth. Suitable or optimal conditions for skipjack tuna represented skipjack fishing areas during the study in the  
207 southeast monsoon period. Oceanographic parameters associated with fish catches correspond to the spatial and temporal  
208 distribution of skipjack tuna and have become a hot topic of discussion worldwide (Andrade 2003; Mugo et al. 2010;  
209 Zainuddin et al. 2019). From the results of this study, it can be suggested that management decisions to increase fishery  
210 yields need to consider oceanographic conditions and characteristics in the waters.  
211

## 212 ACKNOWLEDGMENTS

213 We thank the Ministry of Education, Culture, Research, and Technology and Hasanuddin University for their  
214 outstanding contribution in supporting this research through PTUPT research grants (2017–2019) and PDUPT research  
215 grants in 2020 and 2021. We also thank all parties involved in this research.

**Commented [AJ9]:** For Figure 5 about the response to the distribution of skipjack tuna from oceanographic factors, it is necessary to add a brief explanation of the meaning of the graph

**Commented [S10R9]:** We have got an explanation on the figure caption (line 155 - 158)

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# The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia

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**Abstract.** This study aimed to explore the relationship between the oceanographic factors and the distribution and abundance of skipjack tuna obtained by pole and line fishing in the Bone Gulf, Indonesia. The research was conducted during the southeast monsoon season (April–September) from 2015 until 2018. Three oceanographic parameters were used to understand this relationship, i.e., Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), and water depth. Generalized Additive Models (GAMs) and Generalized Linear Models (GLMs) used to predict the spatial pattern of the skipjack tuna showed that all considered parameters significantly influenced the distribution of skipjack tuna in the study area. The fish are mostly distributed from coastal to offshore areas, ranging between 50 to 2,000 meters and even wider. The concentration tends to be high within the range of 29.5 to 30.5°C of SST, 0.25 to 0.35 mgm<sup>-3</sup> of SSC, and 500 to 1,000 meters of water depth. The research also found that the skipjack tuna migration to the Bone Gulf may have followed the current water interruption during the southeast monsoon, for preferred warmer temperatures and lower primary productivity waters in the offshore areas. This may represent the optimal habitat of the skipjack tuna during this period.

**Keywords:** oceanographic factors, pole and line, skipjack tuna, statistical models.

**Abbreviations:** Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), Catch Per Unit Effort (CPUE), Generalized Additive Models (GAMs), Generalized Linear Models (GLMs), Akaike Information Criterion (AIC), Cumulative Deviance Explained (CDE)

**Running title:** Statistical Model for Skipjack Habitat

## INTRODUCTION

Skipjack tuna (*Katsuwonus pelamis*) is the most crucial target catch of marine fisheries in the world's oceans (Galland et al. 2016). Large schools of adult skipjack tuna are often associated with juvenile yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) (IOTC 2020). Skipjack tuna is a highly migratory pelagic species inhabiting all tropical and subtropical waters (Artetxe-Arrate et al. 2020). However, they are found mainly in the tropical areas of the Atlantic, Indian, and Pacific Oceans, with the most incredible abundance seen near the equator. Since juvenile yellowfin and bigeye tuna often school with adult skipjack tuna, they are caught by purse seine and pole and line vessels whose main target is skipjack tuna (Hidayat et al. 2019; IOTC 2019; Safruddin et al. 2020).

The dynamics of oceanographic factors could affect the natural fluctuations in the distribution and abundance of skipjack tuna in the coastal and offshore areas (Mugo et al. 2010; Tseng et al. 2010; Wang et al. 2016). The distribution could also be influenced by the abundance of small pelagic fish such as anchovy in the same area (Safruddin et al. 2018). Therefore, there is an urgent need for information on the effects of oceanographic factors on skipjack tuna distribution (Andrade and Garcia 1999) to predict fishing ground potential zones for sustainable skipjack tuna fishery in the study area.

Statistical models such as generalized additive models (GAMs) and generalized linear models (GLMs) can be the most useful methods for determining the fish distribution in relation to oceanographic factors such as the sea surface temperature (SST), sea surface chlorophyll-a (SSC), and water depth (Safruddin 2013; Safruddin et al. 2018; Selao et al. 2019).

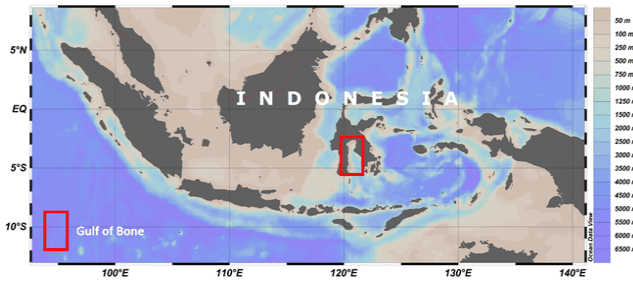
The Bone Gulf is one of the best skipjack tuna habitats in Indonesian waters, with the peak fishing season lasting from early April until the end of September (southeast monsoon). Although skipjack tuna is an iconic species in the Bone Gulf, its local availability is a key factor for the pole and line fishery economy. However, there is a lack of information about its distribution, both spatially and temporally. Hence, this study is an attempt to investigate the availability of skipjack tuna caught using pole and line fishing gear under various oceanographic conditions and to discuss the oceanographic elements impacting skipjack tuna distribution by applying statistical models.

MATERIALS AND METHODS

45

46 **Study area**

47 The study area was located in the Bone Gulf (3–5°S) and (120–122°E), South Sulawesi, Indonesia (Figure 1). The field  
 48 surveys used the pole and line method (local commercial fisheries) to investigate the fishing ground positions and the  
 49 number of skipjack tuna catches during the study. Oceanography observations (satellite imagery data) were conducted  
 50 monthly during the southeast monsoon (April–September) from 2015 until 2018.

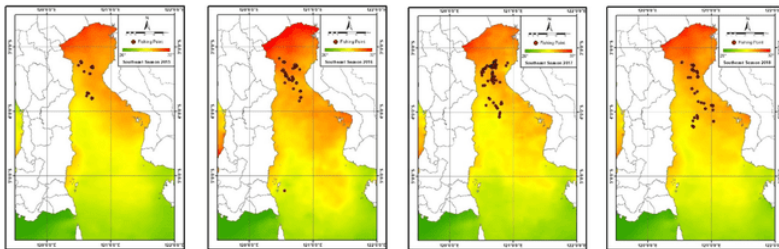


51 **Figure 1.** Map of the Indonesian seas with the red box representing the study area.  
 52

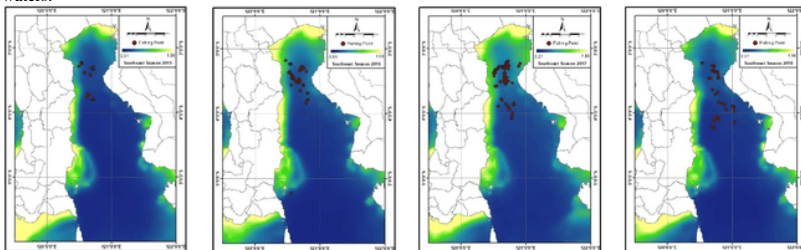
53 **Procedures**

54 *Data Collection*

55 In-situ data were obtained through a scientific survey at the fishing base at Murante fish landing site, Luwu district. We  
 56 gathered the fishery data from 508 fishing ground positions. A global positioning system (GPS) was used to determine  
 57 fishing ground coordinates (latitude and longitude). The in-situ field data consisted of the fishing position and catch per  
 58 unit efforts (CPUEs). The oceanographic parameters (SST, and SSC) were obtained from satellite oceanography imagery  
 59 data of high-resolution Aqua Moderate-Resolution Imaging Spectroradiometer (MODIS), with a spatial resolution of 4  
 60 km, from 2015 until 2018 (April–September). The water depth data was gained from the ETOPO1 satellite database. In  
 61 this study, we used monthly temporal resolution. Furthermore, the SST and SSC averaged during southeast monsoon were  
 62 mapped as shown in Figures 2 and 3, respectively.



63 **Figure 2.** The profiles of SST average during southeast monsoon from 2015 until 2018 overlaid with the skipjack tuna distribution in the  
 64 Bone Gulf waters.  
 65



66 **Figure 3.** The profiles of SSC average during southeast monsoon from 2015 to 2018 overlaid with the skipjack tuna distribution in the  
 67 Bone Gulf waters.  
 68

**Commented [A1]:** Make sure that this is a number of catches of CPUE

**Commented [S2R1]:** we mention it in the data collection section (line 56)

**Commented [A3]:** Please briefly describe the reason

**Commented [S4R3]:** we added an explanation of the southeast monsoon in the lines 50-52

**Commented [A5]:** Map legend both SST and SSC should be clearer. Can be enlarge and put in the white zone of the land

**Commented [S6R5]:** we have replaced figure 2 and 3 with more detailed figures

69 *Data Analysis*

70 To determine the effect of oceanographic parameters on horizontal distributions of skipjack tuna in the sea, statistical  
 71 models (Hastie and Tibshirani 1990) were used for the CPUE and oceanographic datasets. The models, such as GAMs and  
 72 GLMs, were created using the MGCV package in R-studio (Wood 2006) to predict the spatial patterns of skipjack tuna.  
 73 The response variable used skipjack tuna catches (CPUE/fishing trip), and the predictor used oceanographic parameters  
 74 (SST, SSC, and depth).

75 The hypothesized interactions between oceanographic parameters and skipjack tuna distribution are most likely non-  
 76 linear. GAM was employed as an experimental technique to determine the forms of the associations. The connections  
 77 between the skipjack distribution and each predictor (SST, SSC, and depth) were also determined. In a GLM, proper  
 78 functions were utilized to identify these forms in the linear model, as indicated in Equations (1) and (2) (Safruddin 2013).

79 
$$g(\mu) = \alpha_0 + s_1(\text{SST}) + s_2(\text{SSC}) + s_3(\text{depth}) + \varepsilon \quad (\text{GAM model}) \quad (1)$$

80 
$$g(\mu) = \beta_0 + \beta_1(\text{SST}) + \beta_2(\text{SSC}) + \beta_3(\text{depth}) + \varepsilon \quad (\text{GLM model}) \quad (2)$$

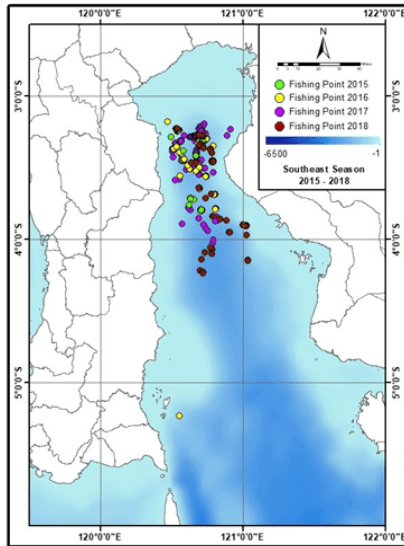
81 where  $g$  is the link function,  $\mu$  is the expected value of the dependent variable for the presence of skipjack tuna  
 82 (CPUE),  $\alpha_0$  and  $\beta_0$  are the respective model's constant,  $s_n$  is the predictor variable's smoothing function,  $\varepsilon$  is a random  
 83 error term, and  $\beta_n$  is the vector of model coefficients.

84 The Gaussian family with identical link functions was chosen since the skipjack tuna CPUE has a continuous  
 85 distribution. Models were created from the ground up, with only one independent component such as SST, and predictor  
 86 components were added later. Model selection was influenced by the predictor's significance, Akaike Information  
 87 Criterion (AIC) reduction, and the deviance explained value. The best model was chosen from a group of seven to build  
 88 the GAMs/GLMs. The GAMs/GLMs model was utilized to compare the results of the prediction models using a statistical  
 89 criterion. They were also used to explain all observations with multiple variables, including inter-variable correlations  
 90 (Safruddin 2013).

91 **RESULTS AND DISCUSSION**

92 **Skipjack tuna fishing ground**

93 Skipjack tuna fishing grounds were mapped on latitude and longitude scales, with SST, SSC, and depth overlay  
 94 (Figures 2–4). CPUE marks the position along the overlay in Figures 2–4, and each school is designated as a single point.  
 95 Map contours with high SST, SSC, and depth, or the opposite, were also discovered.



96 **Figure 4.** The profiles of bathymetric overlay with the skipjack tuna distribution during southeast monsoon from 2015 to 2018 in the  
 97 Bone Gulf waters.  
 98

**Commented [A7]:** -In the discussion section please briefly explain about the difference location of fishing point each year (could be affected by oce factors or others)  
 -Blue color of the ocean represent depth in meter?

**Commented [S8R7]:** Point one, we have added information regarding the difference in fishing locations each year on lines 180 - 183.  
 Point two, we have updated the information shown in figure 4

## Statistical Model for Skipjack Habitat

99 The lowest SST and the highest SSC occur every year during the southeast monsoon period. The reverse happens in the  
 100 northwest monsoon season, skipjack tuna was least abundant in the lower SST area (Figure 2) due to changes in water  
 101 temperature caused by water currents from the Flores Sea entrance to the Bone Gulf. This could be a strategy in biological  
 102 processes related to fish growth under changing oceanographic conditions. Skipjack tuna stock is positively correlated  
 103 with oceanographic factors. It is distributed mainly in nearshore areas in the water depth range of 50 to 2,000 m (Figure 4).  
 104 The horizontal profiles of the SST and SSC structures for the 2015–2018 southeast monsoon season (Figures 2 and 3) are  
 105 warmer near the coast than offshore. Skipjack schools occupy offshore areas where they prefer relatively higher SST and  
 106 lower SSC (Figures 2 and 3).

107 The environmental conditions of skipjack tuna fishing grounds were used for four monthly datasets (April–August). As  
 108 a result, the preference range suggested a possible association between all examined factors. For example, Figure 4 shows  
 109 that skipjack tuna were found in temperatures ranging from 29.5 to 31.05°C. Likewise, the skipjack tuna schools  
 110 concentrated in the narrow ranges of 0.15–1.00 mgm<sup>-3</sup> with respect to SSC.

### 111 Effects of oceanographic factors on skipjack tuna distribution

112 The oceanographic conditions of the skipjack tuna schooling coordinates were employed in the current study for  
 113 displaying the area and further analysis. Tables 1 and 2 show the models built using GAMs/GLMs on the skipjack tuna  
 114 distribution scenarios utilizing predictor parameters (SST, SSC, and depth).

115 Tables 1 and 2 present the results for each of the seven GAM and GLM models. Each model's predictor component(s)  
 116 significantly affected the skipjack tuna distribution in  $p < 0.05$  reference levels, except depth as predictor two and three  
 117 (Table 1). However, only SST substantially contributed to a single model predictor, two model predictors, and three model  
 118 predictors in GLMs (Table 2). For the final model combination of SST, SSC, and depth, the cumulative deviance  
 119 explained (CDE) was 21.9% (GAMs) and 12.830% (GLMs), respectively. Thus, Tables 1 and 2 suggest that the influence  
 120 of oceanographic conditions may explain the fluctuation of skipjack tuna abundance distribution. Additionally, GAMs  
 121 with higher CDE were well-suited to characterize the influence of oceanographic conditions on skipjack tuna distribution  
 122 and abundance.

123 Tables 1 and 2 show the results of GAMs and GLMs, respectively. For both statistical models, the SST had the largest  
 124 deviance explained among the single variable models. According to AIC (6048.045) and CDE (21.9%), and as the best  
 125 model predictor of GAM, the combination of SST and SSC predicted relatively more significant variability in skipjack  
 126 tuna catches. The AIC values for the three-parameter models were low (6049.831) and the most significant deviation  
 127 explained was 21.9%. SST was the sole predictor model with the lowest AIC (6083.072) and the maximum CDE on the  
 128 GLMs model (12.870%) and was also found as a combined two-parameter model between SST and SSC. The three-  
 129 parameter models had the lowest AIC and the highest CDE overall (12.830%). All results produced by combining  
 130 predictor factors at various levels revealed an increase or decrease in CDE and a higher AIC value of variation.

131 GAMs models were more effective than GLMs in understanding the effect of oceanographic factors on skipjack tuna  
 132 distribution and abundance, as shown in Tables 1 and 2. The result of the GAM plots shows the impact of each predictor  
 133 on schooling density of skipjack tuna as shown in Figures 5. The observed data points are represented by the rug plot on  
 134 the horizontal axis, while the thin line shows the fitted function, and the grey shading represents the 95% confidence  
 135 interval (Safruddin 2013).

136 **Table 1.** Oceanographic factor influences on the skipjack tuna distribution (n=508), according to the GAMs models. Also included are  
 137 the significant factor, AIC value, and CDE  
 138

Model	Oceanographic factor	P-value	AIC	CDE (%)
SST	SST	<2e-16 ***	6054.183	20.400
SSC	SSC	2.22e-06 ***	6121.052	8.400
Depth	Depth	0.000109 ***	6132.647	4.970
SST + SSC	SST	2.46e-15 ***	6048.045	21.900
	SSC	0.000293 ***		
SST + Depth	SST	2.12e-14 ***	6067.725	17.300
	Depth	0.296		
SSC + Depth	SSC	0.000899 ***	6121.672	8.350
	Depth	0.236307		
SST + SSC + Depth	SST	2.44e-15 ***	6049.831	21.900
	SSC	0.000289 ***		
	Depth	0.832189		

139 Note: Sig. codes: 0.001 \*\*\*\* 0.01 \*\*\* 0.05 \*\* \*

140 Figure 5 describes the impact of oceanographic conditions on skipjack tuna distribution. Around 29.5–30.5°C, the SST  
 141 (Figure 5a) had a noticeable positive effect on skipjack tuna distribution. The confidence intervals are broader because

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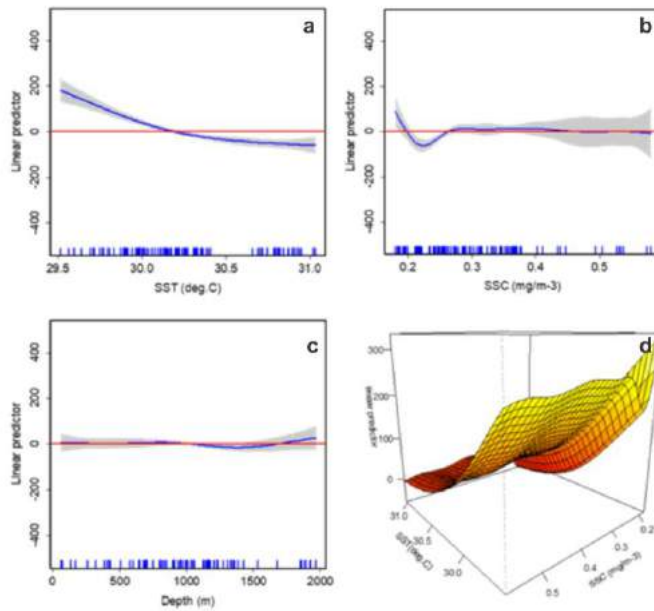
Statistical Model for Skipjack Habitat

142 there are fewer data points at 30.5–31.0°C. In the SSC plot (Figure 5b), there was a beneficial influence on school  
 143 distribution in the SSC ranges of 0.25–0.35 mgm<sup>-3</sup>. A consistent influence on skipjack tuna distribution was seen at a depth  
 144 of 50–2,000 m (Figure 5c). The study also found that models combining SST and SSC produced the do most significant  
 145 model prediction, with the lowest AIC and highest CDE (Figure 5d). Skipjack tuna distribution in the Northern Pacific  
 146 Ocean near Japan waters had SST and SSC optimal values of 20.5–26°C and 0.3–0.37 mgm<sup>-3</sup>, respectively, according to  
 147 Mugo (2010). The findings of this study corroborated those of Zainuddin et al. (2017), who discovered that the distribution  
 148 of skipjack tuna in the coastal area was primarily around 50 m depth.

149 **Table 2.** Oceanographic factor influences on the skipjack tuna distribution (n=508), according to the GLMs models. Also included are  
 150 the significant factor, AIC value, and CDE

Model	Oceanographic factor	P-value	AIC	CDE (%)
SST	SST	<2e-16 ***	6083.072	12.960
SSC	SSC	0.89413	6154.549	0.194
Depth	Depth	0.17566	6152.724	0.165
SST + SSC	SST	<2e-16 ***	6084.600	12.870
	SSC	0.494		
SST + Depth	SST	<2e-16 ***	6084.987	12.800
	Depth	0.772		
SSC + Depth	SSC	0.385	6153.966	0.117
	Depth	0.109		
SST + SSC + Depth	SST	<2e-16***	6085.819	12.830
	SSC	0.282		
	Depth	0.379		

151 Note: Sig. codes: 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*'



152 **Figure 4.** Skipjack tuna distribution responses of oceanographic factors: (a) SST, (b) SSC, (c) depth, and (d) best model predictor.  
 153

154 **Discussion**

155 Oceanographic conditions such as the SST, which have the most significant impact on the growth stages of fish and  
 156 their distribution (Yuniarti et al. 2013; Syah et al. 2020), play a main role in the natural oscillations of skipjack tuna stocks.  
 157 As a result, SST is a great indicator for the fishing ground of skipjack tuna to have been used by fishermen and researchers  
 158 for decades. Furthermore, changes in oceanic (physical and biological) parameters may significantly impact migration  
 159 patterns and fish growth (Safruddin et al. 2018).

## Statistical Model for Skipjack Habitat

160 Since the SST in the research region may vary, measurements should be obtained frequently. More samples may be  
161 required to accomplish this goal. Therefore, one of the objectives of this research was to determine how oceanographic  
162 data can be used in research (e.g., correlation between skipjack tuna distribution and abundance). Temperature fluctuations  
163 are often linked to the biological richness (Iskandar et al. 2017; Takarina et al. 2018), such as anchovy distribution and  
164 abundance as the prey for skipjack tuna, and they have an important influence on fish physiology (Kunarjo et al. 2011;  
165 Olson et al. 2016; Duffy et al. 2017).

166 Satellite remote sensing imagery directly provides horizontal and large-area information on oceanographic conditions,  
167 which may be utilized to understand oceanographic processes in the surface water better. The combination of satellite data  
168 with acoustic technology will, of course, increase the accuracy of the data. For example, CTD and satellite data are  
169 combined when conducting data observations (Safruddin 2013). As a result, four-year datasets of oceanographic  
170 conditions (SST, SSC, and water depth) on skipjack tuna position were employed, with scattered plots and optimal ranges  
171 indicating a possible association among all variables observed, as shown in Figure 5.

172 Skipjack tuna can be found in coastal areas, sometimes in great numbers, particularly in upwelling areas (Sari et al.  
173 2018; Wijaya et al. 2020). The study detailed the interaction between skipjack tuna and their oceanographic variables,  
174 considering the aspect of temporal and spatial scales to comprehend the numerous processes involved and how they might  
175 be utilized to model their dynamics and forecast their abundance (Prista et al. 2011; Selvaraj et al. 2020).

176 Oceanographic conditions are essential variables to assess the abundance of fish in the waters, especially skipjack tuna,  
177 representing the original habitats. The distribution of skipjack tuna observed during the daytime is closely related to the  
178 dynamics of oceanographic variables and fishing operations in the Bone Gulf. As shown in Tables 1 and 2 and Figure 5,  
179 the effect of oceanographic parameters on the abundance and distribution of skipjack tuna is also a reference for water  
180 depths. The p-value, AIC, and CDE can all be used to assess the impact of changing oceanographic conditions on skipjack  
181 tuna CPUE. As a result, oceanographic variables connected to skipjack tuna distribution are critical for understanding  
182 skipjack tuna habitat preferences.

183 Oceanographic phenomena in the waters, such as frontal oceanic zones, eddies, and upwelling areas, often occur with  
184 different characteristics as seen in the Bone Gulf and the Flores Sea (Zainuddin et al. 2017, 2019; Hidayat and Zainuddin  
185 2018; Hidayat et al. 2019b). This event makes the waters very dynamic and affects the horizontal distribution of fish in the  
186 Bone Gulf. The dynamic oceanographic parameters in this area produce highly productive habitats and serve as foraging  
187 grounds for various commercially and ecologically important species such as anchovies and skipjack tuna (Safruddin et al  
188 2018; Hidayat et al 2019b)

189 The results of this study indicate that the SST tolerance value for skipjack tuna is in the range of 29.5–30.5°C and in  
190 the range of 0.25–0.35  $\text{mgm}^{-3}$  for SSC parameters (Figures 5a and 5b). However, in addition to SST and SSC, Indonesian  
191 Throughflow (ITF) and Asian monsoons also influence the location of the optimum habitat for skipjack tuna (Gordon  
192 2005). Changes in the value of SST in the waters are heavily influenced by the seasonal cycle, in contrast to the SSC,  
193 which is not influenced much by the seasonal cycle. Therefore, the migration of skipjack tuna in the northern waters of the  
194 Bone Gulf is thought to have followed the mass movement of water in the southeast monsoon, occupying relatively warm  
195 areas in offshore waters.

196 Based on the lowest AIC value and the highest CDE, the GAM nonlinear model is the best statistical model to  
197 understand the effect of oceanographic parameters on the distribution and abundance of skipjack tuna. This study is also  
198 supported by previous findings in the Makassar Strait, which reported that the GAM model effectively assessed the effect  
199 of oceanographic parameters on skipjack tuna (Hidayat et al. 2019a) and small pelagic fish such as anchovies in the Bone  
200 Gulf (Safruddin et al. 2018).

## 201 202 **Conclusion**

203 This study concludes that the GAM statistical model has succeeded in explaining the effect of oceanographic  
204 parameters on the distribution of skipjack tuna in the Bone Gulf. This study also shows the vital role of oceanographic  
205 parameters in understanding the habitat of skipjack tuna related to its abundance and distribution in the waters. The  
206 distribution of skipjack tuna in the ocean shows a strong relationship with several parameters such as the SST, SSC, and  
207 water depth. Suitable or optimal conditions for skipjack tuna represented skipjack fishing areas during the study in the  
208 southeast monsoon period. Oceanographic parameters associated with fish catches correspond to the spatial and temporal  
209 distribution of skipjack tuna and have become a hot topic of discussion worldwide (Andrade 2003; Mugo et al. 2010;  
210 Zainuddin et al. 2019). From the results of this study, it can be suggested that management decisions to increase fishery  
211 yields need to consider oceanographic conditions and characteristics in the waters.

## 212 **ACKNOWLEDGMENTS**

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# The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia

**Abstract.** Skipjack tuna (*Katsuwonus pelamis*) is the main fishery product in the Bone Gulf, Indonesia, since it has high economic value and is widely accepted by the market. The migration of skipjack tuna can be described by oceanographic dynamics, influenced by seasonal changes. This study aimed to explore the relationship between the oceanographic factors and the distribution and abundance of skipjack tuna obtained by pole and line fishing in the Bone Gulf, Indonesia. The research was conducted during the southeast monsoon season (April–September) from 2015 until 2018. Three oceanographic parameters were used to understand this relationship, i.e., Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), and water depth. Generalized Additive Models (GAMs) and Generalized Linear Models (GLMs) used to predict the spatial pattern of the skipjack tuna showed that all considered parameters significantly influenced the distribution of skipjack tuna in the study area. The fish are mostly distributed from coastal to offshore areas, ranging between 50 to 2,000 meters and even wider. The concentration tends to be high within the range of 29.5 to 30.5°C of SST, 0.25 to 0.35 mgm<sup>-3</sup> of SSC, and 500 to 1,500 meters of water depth. The research also found that the skipjack tuna migration to the Bone Gulf may have followed the current water interruption during the southeast monsoon, for preferred warmer temperatures and lower primary productivity waters in the offshore areas. This factor may represent the optimal habitat of skipjack tuna during the period and can be the basis for determining the skipjack fishing schedule in the Bone Gulf.

**Keywords:** Fishing schedule, Oceanographic factors, Satellite Data, Skipjack Tuna (*Katsuwonus pelamis*) Habitat, Southeast monsoon season.

**Abbreviations:** Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), Catch Per Unit Effort (CPUE), Generalized Additive Models (GAMs), Generalized Linear Models (GLMs), Akaike Information Criterion (AIC), Cumulative Deviance Explained (CDE)

**Running title:** Statistical Model for Skipjack Habitat

## INTRODUCTION

Skipjack tuna (*Katsuwonus pelamis*) is the most crucial target catch of marine fisheries in the world's oceans (Galland et al. 2016). Large schools of adult skipjack tuna are often associated with juvenile yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) (IOTC 2020). Skipjack tuna is a highly migratory pelagic species inhabiting all tropical and subtropical waters (Artetxe-Arrate et al. 2020). However, they are found mainly in the tropical areas of the Atlantic, Indian, and Pacific Oceans, with the most incredible abundance seen near the equator. Since juvenile yellowfin and bigeye tuna often school with adult skipjack tuna, they are caught by purse seine and pole and line vessels whose main target is skipjack tuna (Hidayat et al. 2019; IOTC 2019; Safruddin et al. 2020).

The dynamics of oceanographic factors could affect the natural fluctuations in the distribution and abundance of skipjack tuna in the coastal and offshore areas (Mugo et al. 2010; Tseng et al. 2010; Wang et al. 2016). The distribution could also be influenced by the abundance of small pelagic fish such as anchovy in the same area (Safruddin et al. 2018). Therefore, there is an urgent need for information on the effects of oceanographic factors on skipjack tuna distribution (Andrade and Garcia 1999) to predict fishing ground potential zones for sustainable skipjack tuna fishery in the study area.

Statistical models such as generalized additive models (GAMs) and generalized linear models (GLMs) can be the most useful methods for determining the fish distribution in relation to oceanographic factors such as the sea surface temperature (SST), sea surface chlorophyll-a (SSC), and water depth (Safruddin 2013; Safruddin et al. 2018; Selao et al. 2019).

The Bone Gulf is one of the best skipjack tuna habitats in Indonesian waters (Zainuddin et al. 2020), with the peak fishing season lasting from early April until the end of September (southeast monsoon). Although skipjack tuna is an iconic species in the Bone Gulf, its local availability is a key factor for the pole and line fishery economy. However, there is a lack of information about its distribution, both spatially and temporally. Hence, this study is an attempt to investigate

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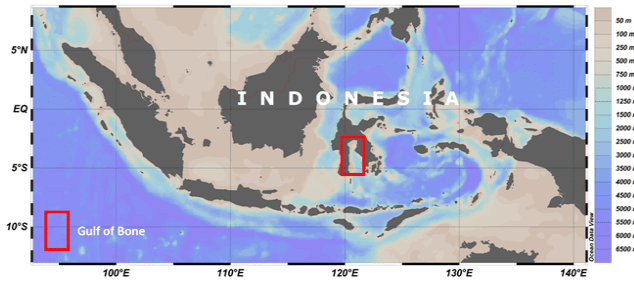
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47 the availability of skipjack tuna caught using pole and line fishing gear under various oceanographic conditions and to  
 48 discuss the oceanographic elements impacting skipjack tuna distribution by applying statistical models.

49 **MATERIALS AND METHODS**

50 **Study area**

51 The study area was located in the Bone Gulf (3–5°S) and (120–122°E), South Sulawesi, Indonesia (Figure 1). The field  
 52 surveys used the pole and line method (local commercial fisheries) to investigate the fishing ground positions and the  
 53 number of skipjack tuna catches during the study. Oceanography and bathymetric observations (satellite imagery data)  
 54 were conducted monthly during the southeast monsoon (April–September) from 2015 until 2018. This study only focuses  
 55 on fishing activities in the southeast monsoon, which is due to the peak season for skipjack fishing in the Bone Gulf takes  
 56 place in the southeast monsoon.

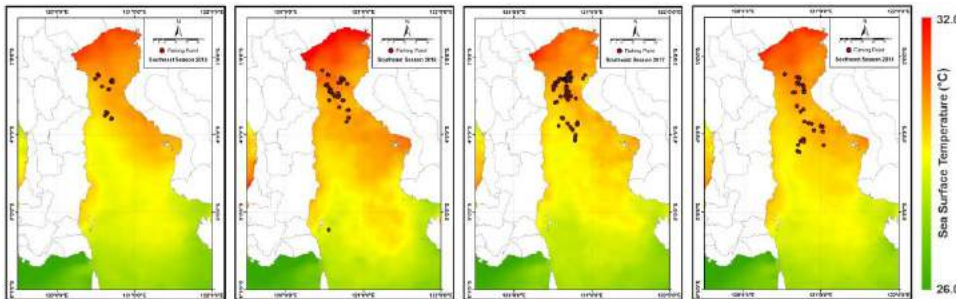


57 **Figure 1.** Map of the Indonesian seas with the red box representing the study area.  
 58

59 **Procedures**

60 *Data Collection*

61 In-situ data were obtained through a scientific survey at the fishing base at Murante fish landing site, Luwu district. We  
 62 gathered the fishery data from 508 fishing ground positions. A global positioning system (GPS) was used to determine  
 63 fishing ground coordinates (latitude and longitude). The in-situ field data consisted of the fishing position and catch per  
 64 unit efforts (CPUEs). The oceanographic parameters (SST, and SSC) were obtained from satellite oceanography imagery  
 65 data of high-resolution Aqua Moderate-Resolution Imaging Spectroradiometer (MODIS), with a spatial resolution of 4  
 66 km, from 2015 until 2018 (April–September). The water depth data was gained from the ETOP01 (Amante and Eakins  
 67 2009) satellite database. In this study, we used monthly temporal resolution. Furthermore, the SST and SSC averaged  
 68 during southeast monsoon were mapped as shown in Figures 2 and 3, respectively.



69 **Figure 2.** The profiles of SST average during southeast monsoon from 2015 until 2018 overlaid with the skipjack tuna distribution in the  
 70 Bone Gulf waters. The gradient from green (low temperature) to red (high temperature) illustrates variations in SST in the waters. The  
 71 red dot on the maps represents the location of the skipjack tuna fishing coordinates during the study  
 72

**Commented [JB11]:** Was the study signed off by any ethics committees?

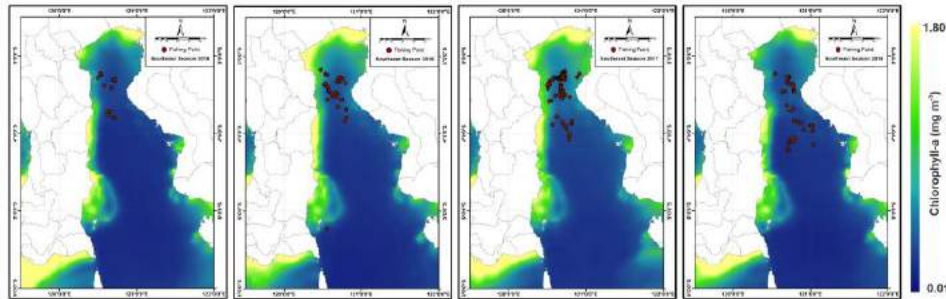
**Commented [S12R11]:** No, this study uses data on skipjack tuna catches in the Bone Gulf, and no experiment is carried out. The method used is a statistical analysis that does not require laboratory treatment. that is why we did not submit to the ethics committee

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73  
74 **Figure 3.** The profiles of SSC average during southeast monsoon from 2015 to 2018 overlaid with the skipjack tuna distribution in the  
75 Bone Gulf waters. The gradient from blue (low concentration) to yellow (high concentration) illustrates variations in SSC in the waters.  
76 The red dot on the maps represents the location of the skipjack tuna fishing coordinates during the study

77 *Data Analysis*

78 To determine the effect of oceanographic parameters on horizontal distributions of skipjack tuna in the sea, statistical  
79 models (Hastie and Tibshirani 1990) were used for the CPUE and oceanographic datasets. The models, such as GAMs and  
80 GLMs, were created using the MGCV package in R-studio (Wood 2006) to predict the spatial patterns of skipjack tuna.  
81 The response variable used skipjack tuna catches (CPUE/fishing trip), and the predictor used oceanographic parameters  
82 (SST, SSC, and depth).

83 The hypothesized interactions between oceanographic parameters and skipjack tuna distribution are most likely non-  
84 linear. GAM was employed as an experimental technique to determine the forms of the associations. The connections  
85 between the skipjack distribution and each predictor (SST, SSC, and depth) were also determined. In a GLM, proper  
86 functions were utilized to identify these forms in the linear model, as indicated in Equations (1) and (2) (Safruddin 2013).

87 
$$g(\mu) = \alpha_0 + s_1(\text{SST}) + s_2(\text{SSC}) + s_3(\text{depth}) + \varepsilon \quad (\text{GAM model}) \quad (1)$$

88 
$$g(\mu) = \beta_0 + \beta_1(\text{SST}) + \beta_2(\text{SSC}) + \beta_3(\text{depth}) + \varepsilon \quad (\text{GLM model}) \quad (2)$$

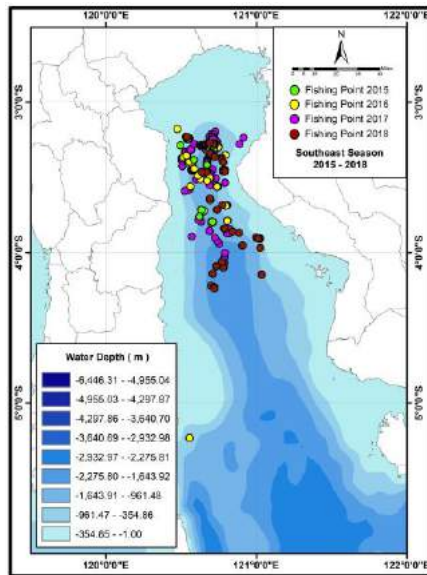
89 where  $g$  is the link function,  $\mu$  is the expected value of the dependent variable for the presence of skipjack tuna  
90 (CPUE),  $\alpha_0$  and  $\beta_0$  are the respective model's constant,  $s_n$  is the predictor variable's smoothing function,  $\varepsilon$  is a random  
91 error term, and  $\beta_n$  is the vector of model coefficients.

92 The Gaussian family with identical link functions was chosen since the skipjack tuna CPUE has a continuous  
93 distribution. Models were created from the ground up, with only one independent component such as SST, and predictor  
94 components were added later. Model selection was influenced by the predictor's significance, Akaike Information  
95 Criterion (AIC) reduction, and the deviance explained value. The best model was chosen from a group of seven to build  
96 the GAMs/GLMs. The GAMs/GLMs model was utilized to compare the results of the prediction models using a statistical  
97 criterion. They were also used to explain all observations with multiple variables, including inter-variable correlations  
98 (Safruddin 2013).

99 **RESULTS AND DISCUSSION**

100 **Skipjack tuna fishing ground**

101 Skipjack tuna fishing grounds were mapped on latitude and longitude scales, with SST, SSC, and depth overlay  
102 (Figures 2–4). CPUE marks the position along the overlay in Figures 2–4, and each school is designated as a single point.  
103 Map contours with high SST, SSC, and depth, or the opposite, were also discovered.



104  
105 **Figure 4.** The profiles of bathymetric overlay with the skipjack tuna distribution during southeast monsoon from 2015 to 2018 in the  
106 Bone Gulf waters.

107 The lowest SST and the highest SSC occur every year during the southeast monsoon period. The reverse happens in the  
108 northwest monsoon season, skipjack tuna was least abundant in the lower SST area (Figure 2) due to changes in water  
109 temperature caused by water currents from the Flores Sea entrance to the Bone Gulf. This could be a strategy in biological  
110 processes related to fish growth under changing oceanographic conditions. Skipjack tuna stock is positively correlated  
111 with oceanographic factors. It is distributed mainly in nearshore areas in the water depth range of 50 to 2,000 m (Figure 4).  
112 The horizontal profiles of the SST and SSC structures for the 2015–2018 southeast monsoon season (Figures 2 and 3) are  
113 warmer near the coast than offshore. Skipjack schools occupy offshore areas where they prefer relatively higher SST and  
114 lower SSC (Figures 2 and 3).

115 The environmental conditions of skipjack tuna fishing grounds were used for four monthly datasets (April–August). As  
116 a result, the preference range suggested a possible association between all examined factors. For example, Figure 2 shows  
117 that skipjack tuna were found in temperatures ranging from 29.5 to 31.05°C. Likewise, the skipjack tuna schools  
118 concentrated in the narrow ranges of 0.15–1.00 mg.m<sup>-3</sup> with respect to SSC (Figure 3). As for the depth of water, skipjack  
119 is found in waters with a depth of 50 – 2,000 meters (Figure 4).

120 **Effects of oceanographic factors on skipjack tuna distribution**

121 The oceanographic conditions of the skipjack tuna schooling coordinates were employed in the current study for  
122 displaying the area and further analysis. Tables 1 and 2 show the models built using GAMs/GLMs on the skipjack tuna  
123 distribution scenarios utilizing predictor parameters (SST, SSC, and depth). Tables 1 and 2 present the results for each of  
124 the seven GAM and GLM models. Each model's predictor component(s) significantly affected the skipjack tuna  
125 distribution in  $p < 0.05$  reference levels, except depth as predictor two and three (Table 1). However, only SST substantially  
126 contributed to a single model predictor, two model predictors, and three model predictors in GLMs (Table 2). For the final  
127 model combination of SST, SSC, and depth, the cumulative deviance explained (CDE) was 21.9% (GAMs) and 12.830%  
128 (GLMs), respectively. Thus, Tables 1 and 2 suggest that the influence of oceanographic conditions may explain the  
129 fluctuation of skipjack tuna abundance distribution. Additionally, GAMs with higher CDE were well-suited to characterize  
130 the influence of oceanographic conditions on skipjack tuna distribution and abundance.

131 Tables 1 and 2 show the results of GAMs and GLMs, respectively. For both statistical models, the SST had the largest  
132 deviance explained among the single variable models. According to AIC (6048.045) and CDE (21.9%), and as the best  
133 model predictor of GAM, the combination of SST and SSC predicted relatively more significant variability in skipjack  
134 tuna catches. The AIC values for the three-parameter models were low (6049.831) and the most significant deviation  
135 explained was 21.9%. SST was the sole predictor model with the lowest AIC (6083.072) and the maximum CDE on the  
136 GLMs model (12.870%) and was also found as a combined two-parameter model between SST and SSC. The three-

## Statistical Model for Skipjack Habitat

137 parameter models had the lowest AIC and the highest CDE overall (12.830%). All results produced by combining  
 138 predictor factors at various levels revealed an increase or decrease in CDE and a higher AIC value of variation.

139 GAMs models were more effective than GLMs in understanding the effect of oceanographic factors on skipjack tuna  
 140 distribution and abundance, as shown in Tables 1 and 2. The result of the GAM plots shows the impact of each predictor  
 141 on schooling density of skipjack tuna as shown in Figures 5. The observed data points are represented by the rug plot on  
 142 the horizontal axis, while the thin line shows the fitted function, and the grey shading represents the 95% confidence  
 143 interval (Safruddin 2013).

144  
 145 **Table 1.** Oceanographic factor influences on the skipjack tuna distribution (n=508), according to the GAMs models. Also included are  
 146 the significant factor, AIC value, and CDE

Model	Oceanographic factor	P-value	AIC	CDE (%)
SST	SST	<0.001 ***	6054.183	20.400
SSC	SSC	<0.001 ***	6121.052	8.400
Depth	Depth	<0.001 ***	6132.647	4.970
SST + SSC	SST	<0.001 ***	6048.045	21.900
	SSC	<0.001 ***		
SST + Depth	SST	<0.001 ***	6067.725	17.300
	Depth	0.296		
SSC + Depth	SSC	<0.001 ***	6121.672	8.350
	Depth	0.236		
SST + SSC + Depth	SST	<0.001 ***	6049.831	21.900
	SSC	<0.001 ***		
	Depth	0.832		

147 Note: Sig. codes: 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*'

148 Figure 5 describes the impact of oceanographic conditions on skipjack tuna distribution. Around 29.5–30.5°C, the SST  
 149 (Figure 5a) had a noticeable positive effect on skipjack tuna distribution. The confidence intervals are broader because  
 150 there are fewer data points at 30.5–31.0°C. In the SSC plot (Figure 5b), there was a beneficial influence on school  
 151 distribution in the SSC ranges of 0.25–0.35 mgm<sup>-3</sup>. A consistent influence on skipjack tuna distribution was seen at a depth  
 152 of 500–1,500 m (Figure 5c). The study also found that models combining SST and SSC produced the most significant  
 153 model prediction, with the lowest AIC and highest CDE (Figure 5d). Skipjack tuna distribution in the Northern Pacific  
 154 Ocean near Japan waters had SST and SSC optimal values of 20.5–26°C and 0.3–0.37 mgm<sup>-3</sup>, respectively, according to  
 155 Mugo (2010). The findings of this study corroborated those of Zainuddin et al. (2017), who discovered that the distribution  
 156 of skipjack tuna in the coastal area was primarily around 50 m depth.

157 **Table 2.** Oceanographic factor influences on the skipjack tuna distribution (n=508), according to the GLMs models. Also included are  
 158 the significant factor, AIC value, and CDE

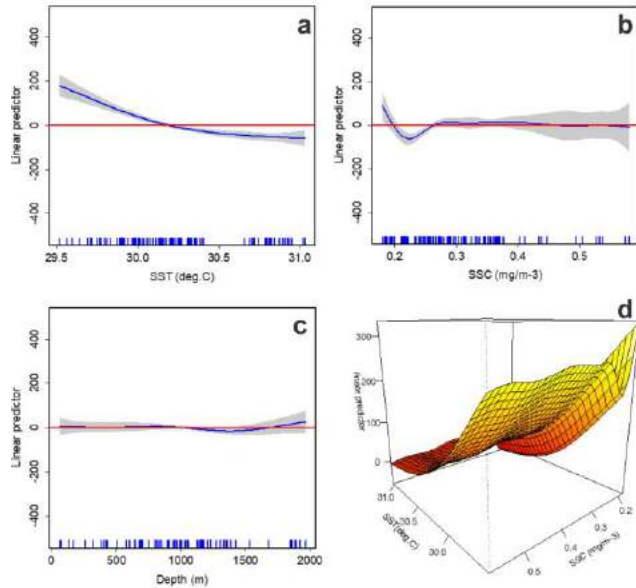
Model	Oceanographic factor	P-value	AIC	CDE (%)
SST	SST	<0.001 ***	6083.072	12.960
SSC	SSC	0.894	6154.549	0.194
Depth	Depth	0.176	6152.724	0.165
SST + SSC	SST	<0.001 ***	6084.600	12.870
	SSC	0.494		
SST + Depth	SST	<0.001 ***	6084.987	12.800
	Depth	0.772		
SSC + Depth	SSC	0.385	6153.966	0.117
	Depth	0.109		
SST + SSC + Depth	SST	<0.001 ***	6085.819	12.830
	SSC	0.282		
	Depth	0.379		

159 Note: Sig. codes: 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*'

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## Statistical Model for Skipjack Habitat



160  
161 **Figure 5.** Skipjack tuna distribution responses of oceanographic factors; (a) SST, (b) SSC, (c) depth, and (d) best model predictor. The shaded  
162 area is the standard error indicating the 95% confidence interval. The stack of blue vertical lines on the x-axis indicates the density or  
163 distribution of the test parameter data. The y-axis is the partial effect of the variable, while the 3D graph depicts a combination model between  
164 significant SST and SSC to be the best predictive model.

## 165 Discussion

166 Oceanographic conditions such as the SST, which have the most significant impact on the growth stages of fish and  
167 their distribution (Yuniarti et al. 2013; Syah et al. 2020), play a main role in the natural oscillations of skipjack tuna stocks.  
168 As a result, SST is a great indicator for the fishing ground of skipjack tuna to have been used by fishermen and researchers  
169 for decades. Furthermore, changes in oceanic (physical and biological) parameters may significantly impact migration  
170 patterns and fish growth (Safruddin et al. 2018).

171 Since the SST in the research region may vary, measurements should be obtained frequently. More samples may be  
172 required to accomplish this goal. Therefore, one of the objectives of this research was to determine how oceanographic  
173 data can be used in research (e.g., correlation between skipjack tuna distribution and abundance). Temperature fluctuations  
174 are often linked to the biological richness (Iskandar et al. 2017; Takarina et al. 2018), such as anchovy distribution and  
175 abundance as the prey for skipjack tuna, and they have an important influence on fish physiology (Kunarso et al. 2011;  
176 Olson et al. 2016; Duffy et al. 2017).

177 Satellite remote sensing imagery directly provides horizontal and large-area information on oceanographic conditions,  
178 which may be utilized to understand oceanographic processes in the surface water better. The combination of satellite data  
179 with acoustic technology will, of course, increase the accuracy of the data. For example, CTD and satellite data are  
180 combined when conducting data observations (Safruddin 2013). As a result, four-year datasets of oceanographic  
181 conditions (SST, SSC, and water depth) on skipjack tuna position were employed, with scattered plots and optimal ranges  
182 indicating a possible association among all variables observed, as shown in Figure 5.

183 Skipjack tuna can be found in coastal areas, sometimes in large numbers, especially in upwelling areas (Sari et al.  
184 2018; Wijaya et al. 2020). This study details the interactions between skipjack tuna and its oceanographic variables taking  
185 into account temporal and spatial scale aspects to understand the various processes involved and how they can be used to  
186 model dynamics and estimate their abundance (Prista et al. 2011; Selvaraj et al. 2020). The catch data used is the  
187 distribution of catches in Bone Bay. Although spatially, several fishing points are located in almost the same area, the  
188 dynamics of different oceanographic parameters each year make the description of the range of SST and SSC at each  
189 skipjack fishing point experience different.

190 Oceanographic conditions are essential variables to assess the abundance of fish in the waters, especially skipjack tuna,  
191 representing the original habitats. The distribution of skipjack tuna observed during the daytime is closely related to the  
192 dynamics of oceanographic variables and fishing operations in the Bone Gulf. As shown in Tables 1 and 2 and Figure 5,

## Statistical Model for Skipjack Habitat

193 the effect of oceanographic parameters on the abundance and distribution of skipjack tuna is also a reference for water  
194 depths. The p-value, AIC, and CDE can all be used to assess the impact of changing oceanographic conditions on skipjack  
195 tuna CPUE. As a result, oceanographic variables connected to skipjack tuna distribution are critical for understanding  
196 skipjack tuna habitat preferences.

197 Oceanographic phenomena in the waters, such as frontal oceanic zones, eddies, and upwelling areas, often occur with  
198 different characteristics as seen in the Bone Gulf and the Flores Sea (Zainuddin et al. 2017, 2019; Hidayat and Zainuddin  
199 2018; Hidayat et al. 2019b). This event makes the waters very dynamic and affects the horizontal distribution of fish in the  
200 Bone Gulf. The dynamic oceanographic parameters in this area produce highly productive habitats and serve as foraging  
201 grounds for various commercially and ecologically important species such as anchovies and skipjack tuna (Safuruddin et al  
202 2018; Hidayat et al 2019b)

203 The results of this study indicate that the SST tolerance value for skipjack tuna is in the range of 29.5–30.5°C and in  
204 the range of 0.25–0.35 mgm<sup>-3</sup> for SSC parameters (Figures 5a and 5b). However, in addition to SST and SSC, Indonesian  
205 Throughflow (ITF) and Asian monsoons also influence the location of the optimum habitat for skipjack tuna (Gordon  
206 2005). Changes in the value of SST in the waters are heavily influenced by the seasonal cycle, in contrast to the SSC,  
207 which is not influenced much by the seasonal cycle. Therefore, the migration of skipjack tuna in the northern waters of the  
208 Bone Gulf is thought to have followed the mass movement of water in the southeast monsoon, occupying relatively warm  
209 areas in offshore waters.

210 Based on the lowest AIC value and the highest CDE, the GAM nonlinear model is the best statistical model to  
211 understand the effect of oceanographic parameters on the distribution and abundance of skipjack tuna. This study is also  
212 supported by previous findings in the Makassar Strait, which reported that the GAM model effectively assessed the effect  
213 of oceanographic parameters on skipjack tuna (Hidayat et al. 2019a) and small pelagic fish such as anchovies in the Bone  
214 Gulf (Safuruddin et al. 2018).

### 216 Conclusion

217 This study concludes that the GAM statistical model has succeeded in explaining the effect of oceanographic  
218 parameters on the distribution of skipjack tuna in the Bone Gulf. This study also shows the vital role of oceanographic  
219 parameters in understanding the habitat of skipjack tuna related to its abundance and distribution in the waters. The  
220 distribution of skipjack tuna in the ocean shows a strong relationship with several parameters such as the SST, SSC, and  
221 water depth. Suitable or optimal conditions for skipjack tuna represented skipjack fishing areas during the study in the  
222 southeast monsoon period. Oceanographic parameters associated with fish catches correspond to the spatial and temporal  
223 distribution of skipjack tuna and have become a hot topic of discussion worldwide (Andrade 2003; Mugo et al. 2010;  
224 Zainuddin et al. 2019). From the results of this study, it can be suggested that management decisions to increase fishery  
225 yields need to consider oceanographic conditions and characteristics in the waters.

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# The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia

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**Abstract.** Safruddin, Hidayat R, Farhum SA, Zainuddin M. 2022. *The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia. Biodiversitas 23: xxxx.* Skipjack tuna (*Katsuwonus pelamis*) is the main fishery product in the Bone Gulf, Indonesia, since it has high economic value and is widely accepted by the market. The migration of skipjack tuna can be described by oceanographic dynamics, influenced by seasonal changes. This study aimed to explore the relationship between the oceanographic factors and the distribution and abundance of skipjack tuna obtained by pole and line fishing in the Bone Gulf, Indonesia. The research was conducted during the southeast monsoon season (April-September) from 2015 until 2018. Three oceanographic parameters were used to understand this relationship, i.e., Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), and water depth. Generalized Additive Models (GAMs) and Generalized Linear Models (GLMs) used to predict the spatial pattern of the skipjack tuna showed that all considered parameters significant influenced the distribution of skipjack tuna in the study area. The fish are mostly distributed from coastal to offshore areas, ranging between 50 to 2000 meters and even wider. The concentration tends to be high within the range of 29.5 to 30.5°C of SST, 0.25 to 0.35 mgm<sup>-3</sup> of SSC, and 500 to 1500 meters of water depth. The research also found that the skipjack tuna migration to the Bone Gulf may have followed the current water interruption during the southeast monsoon, for preferred warmer temperatures and lower primary productivity waters in the offshore areas. This factor may represent the optimal habitat of skipjack tuna during the period and can be the basis for determining the skipjack fishing schedule in the Bone Gulf.

**Keywords:** Fishing schedule, oceanographic factors, satellite data, skipjack tuna habitat, southeast monsoon season

**Abbreviations:** Sea Surface Temperature (SST), Sea Surface Chlorophyll-a (SSC), Catch Per Unit Effort (CPUE), Generalized Additive Models (GAMs), Generalized Linear Models (GLMs), Akaike Information Criterion (AIC), Cumulative Deviance Explained (CDE)

## INTRODUCTION

Skipjack tuna (*Katsuwonus pelamis*) is the most crucial target catch of marine fisheries in the world's oceans (Galland et al. 2016). Large schools of adult skipjack tuna are often associated with juvenile yellowfin (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) (IOTC 2020). Skipjack tuna is a highly migratory pelagic species inhabiting all tropical and subtropical waters (Artetxe-Arrate et al. 2020). However, they are found mainly in the tropical areas of the Atlantic, Indian, and Pacific Oceans, with the most incredible abundance seen near the equator. Since juvenile yellowfin and bigeye tuna often school with adult skipjack tuna, they are caught by purse seine and pole and line vessels whose main target is skipjack tuna (Hidayat et al. 2019; IOTC 2019; Safruddin et al. 2020).

The dynamics of oceanographic factors could affect the natural fluctuations in the distribution and abundance of skipjack tuna in the coastal and offshore areas (Mugo et al. 2010; Tseng et al. 2010; Wang et al. 2016). The distribution could also be influenced by the abundance of small pelagic fish such as anchovy in the same area

(Safruddin et al. 2018). Therefore, there is an urgent need for information on the effects of oceanographic factors on skipjack tuna distribution (Andrade and Garcia 1999) to predict fishing ground potential zones for sustainable skipjack tuna fishery in the study area.

Statistical models such as generalized additive models (GAMs) and generalized linear models (GLMs) can be the most useful methods for determining the fish distribution in relation to oceanographic factors such as the sea surface temperature (SST), sea surface chlorophyll-a (SSC), and water depth (Safruddin 2013; Safruddin et al. 2018; Selao et al. 2019).

The Bone Gulf is one of the best skipjack tuna habitats in Indonesian waters (Zainuddin et al. 2020), with the peak fishing season lasting from early April until the end of September (southeast monsoon). Although skipjack tuna is an iconic species in the Bone Gulf, its local availability is a key factor for the pole and line fishery economy. However, there is a lack of information about its distribution, both spatially and temporally. Hence, this study is an attempt to investigate the availability of skipjack tuna caught using pole and line fishing gear under various oceanographic

conditions and to discuss the oceanographic elements impacting skipjack tuna distribution by applying statistical models.

## MATERIALS AND METHODS

### Study area

The study area was located in the Bone Gulf (3-5°S and 120-122°E), South Sulawesi, Indonesia (Figure 1). The field surveys used the pole and line method (local commercial fisheries) to investigate the fishing ground positions and the number of skipjack tuna catches during the study. Oceanography and bathymetric observations (satellite imagery data) were conducted monthly during the southeast monsoon (April-September) from 2015 until 2018. This study only focuses on fishing activities in the southeast monsoon, which is due to the peak season for skipjack fishing in the Bone Gulf takes place in the southeast monsoon.

### Procedures

#### Data collection

In-situ data were obtained through a scientific survey at the fishing base at Murante fish landing site, Luwu district. We gathered the fishery data from 508 fishing ground positions. A global positioning system (GPS) was used to determine fishing ground coordinates (latitude and longitude). The in-situ field data consisted of the fishing position and catch per unit efforts (CPUEs). The oceanographic parameters (SST, and SSC) were obtained from satellite oceanography imagery data of high-resolution Aqua Moderate-Resolution Imaging Spectroradiometer (MODIS), with a spatial resolution of 4 km, from 2015 until 2018 (April-September). The water depth data was gained from the ETOPO1 (Amante and Eakins 2009) satellite database. In this study, we used monthly temporal resolution. Furthermore, the SST and SSC averaged during southeast monsoon were mapped as shown in Figures 2 and 3, respectively.

### Data analysis

To determine the effect of oceanographic parameters on horizontal distributions of skipjack tuna in the sea, statistical models (Hastie and Tibshirani 1990) were used for the CPUE and oceanographic datasets. The models, such as GAMs and GLMs, were created using the MGCV package in R-studio (Wood 2006) to predict the spatial patterns of skipjack tuna. The response variable used skipjack tuna catches (CPUE/fishing trip), and the predictor used oceanographic parameters (SST, SSC, and depth).

The hypothesized interactions between oceanographic parameters and skipjack tuna distribution are most likely non-linear. GAM was employed as an experimental technique to determine the forms of the associations. The connections between the skipjack distribution and each predictor (SST, SSC, and depth) were also determined. In a GLM, proper functions were utilized to identify these forms in the linear model, as indicated in Equations (1) and (2) (Safruddin 2013).

$$g(\mu_i) = \alpha_0 + s_1(\text{SST}) + s_2(\text{SSC}) + s_3(\text{depth}) + \varepsilon \text{ (GAM model)} \quad (1)$$

$$g(\mu_i) = \beta_0 + \beta_1(\text{SST}) + \beta_2(\text{SSC}) + \beta_3(\text{depth}) + \varepsilon \text{ (GLM model)} \quad (2)$$

Where,  $g$  is the link function,  $\mu_i$  is the expected value of the dependent variable for the presence of skipjack tuna (CPUE),  $\alpha_0$  and  $\beta_0$  are the respective model's constant,  $s_n$  is the predictor variable's smoothing function,  $\varepsilon$  is a random error term, and  $\beta_n$  is the vector of model coefficients.

The Gaussian family with identical link functions was chosen since the skipjack tuna CPUE has a continuous distribution. Models were created from the ground up, with only one independent component such as SST, and predictor components were added later. Model selection was influenced by the predictor's significance, Akaike Information Criterion (AIC) reduction, and the deviance explained value. The best model was chosen from a group of seven to build the GAMs/GLMs. The GAMs/GLMs model was utilized to compare the results of the prediction models using a statistical criterion. They were also used to explain all observations with multiple variables, including inter-variable correlations (Safruddin 2013).

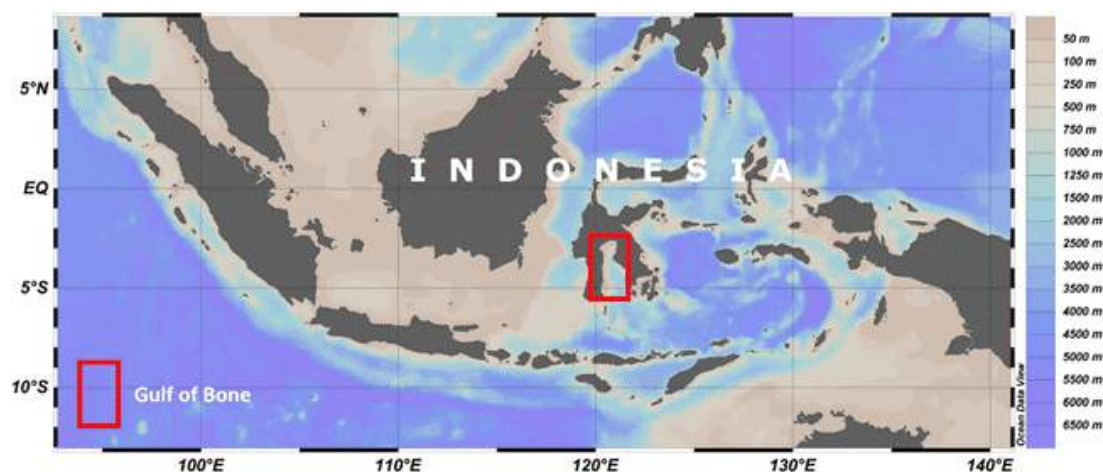
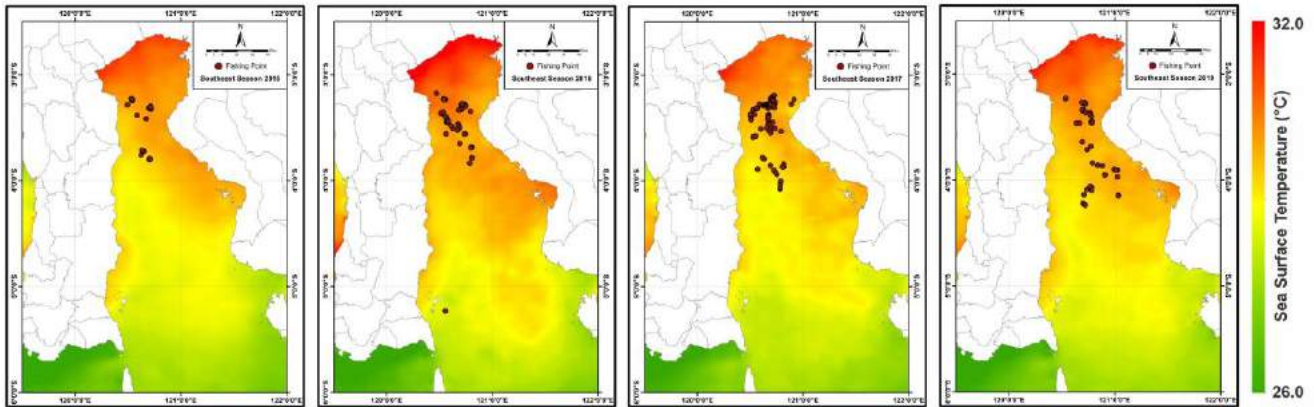
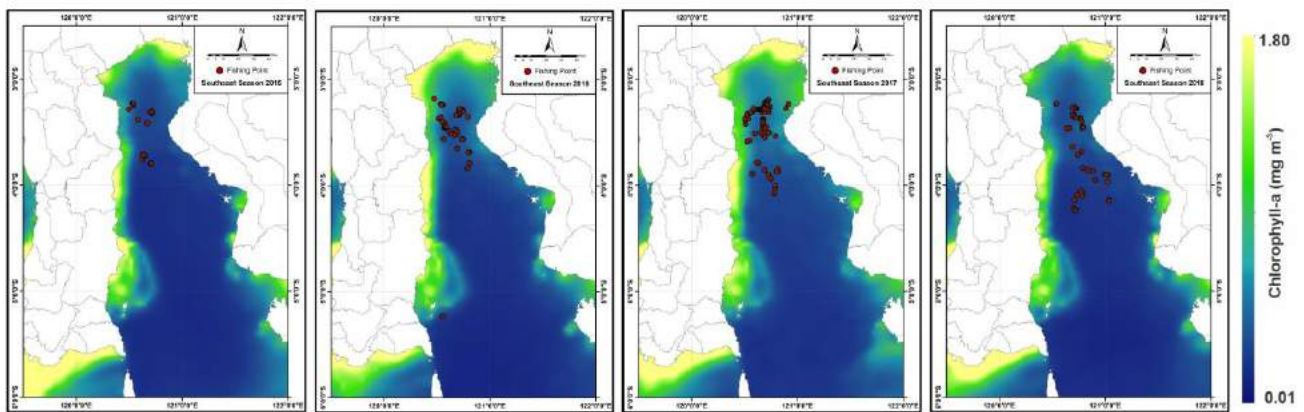


Figure 1. Map of the Indonesian seas with the red box representing the study area



**Figure 2.** The profiles of SST average during southeast monsoon from 2015 until 2018 overlaid with the skipjack tuna distribution in the Bone Gulf waters. The gradient from green (low temperature) to red (high temperature) illustrates variations in SST in the waters. The red dot on the maps represents the location of the skipjack tuna fishing coordinates during the study



**Figure 3.** The profiles of SSC average during southeast monsoon from 2015 to 2018 overlaid with the skipjack tuna distribution in the Bone Gulf waters. The gradient from blue (low concentration) to yellow (high concentration) illustrates variations in SSC in the waters. The red dot on the maps represents the location of the skipjack tuna fishing coordinates during the study

## RESULTS AND DISCUSSION

### Skipjack tuna fishing ground

Skipjack tuna fishing grounds were mapped on latitude and longitude scales, with SST, SSC, and depth overlay (Figures 2-4). CPUE marks the position along the overlay in Figures 2-4, and each school is designated as a single point. Map contours with high SST, SSC, and depth, or the opposite, were also discovered.

The lowest SST and the highest SSC occur every year during the southeast monsoon period. The reverse happens in the northwest monsoon season, skipjack tuna was least abundant in the lower SST area (Figure 2) due to changes in water temperature caused by water currents from the Flores Sea entrance to the Bone Gulf. This could be a strategy in biological processes related to fish growth under changing oceanographic conditions. Skipjack tuna stock is positively correlated with oceanographic factors. It is distributed mainly in nearshore areas in the water depth range of 50 to 2000 m (Figure 4). The horizontal profiles of the SST and SSC structures for the 2015-2018 southeast monsoon season (Figures 2 and 3) are warmer near the

coast than offshore. Skipjack schools occupy offshore areas where they prefer relatively higher SST and lower SSC (Figures 2 and 3).

The environmental conditions of skipjack tuna fishing grounds were used for four monthly datasets (April-August). As a result, the preference range suggested a possible association between all examined factors. For example, Figure 2 shows that skipjack tuna were found in temperatures ranging from 29.5 to 31.05°C. Likewise, the skipjack tuna schools concentrated in the narrow ranges of 0.15-1.00 mg.m<sup>-3</sup> with respect to SSC (Figure 3). As for the depth of water, skipjack is found in waters with a depth of 50-2000 meters (Figure 4).

### Effects of oceanographic factors on skipjack tuna distribution

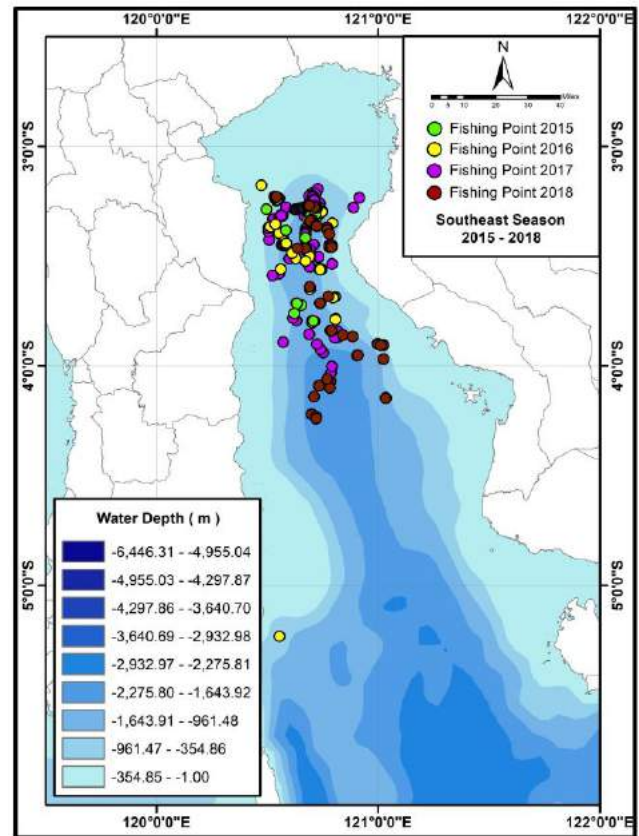
The oceanographic conditions of the skipjack tuna schooling coordinates were employed in the current study for displaying the area and further analysis. Tables 1 and 2 show the models built using GAMs/GLMs on the skipjack tuna distribution scenarios utilizing predictor parameters (SST, SSC, and depth). Tables 1 and 2 present the results

for each of the seven GAM and GLM models. Each model's predictor component(s) significantly affected the skipjack tuna distribution in  $p < 0.05$  reference levels, except depth as predictor two and three (Table 1). However, only SST substantially contributed to a single model predictor, two model predictors, and three model predictors in GLMs (Table 2). For the final model combination of SST, SSC, and depth, the cumulative deviance explained (CDE) was 21.9% (GAMs) and 12.830% (GLMs), respectively. Thus, Tables 1 and 2 suggest that the influence of oceanographic conditions may explain the fluctuation of skipjack tuna abundance distribution. Additionally, GAMs with higher CDE were well-suited to characterize the influence of oceanographic conditions on skipjack tuna distribution and abundance.

Tables 1 and 2 show the results of GAMs and GLMs, respectively. For both statistical models, the SST had the largest deviance explained among the single variable models. According to AIC (6048.045) and CDE (21.9%), and as the best model predictor of GAM, the combination of SST and SSC predicted relatively more significant variability in skipjack tuna catches. The AIC values for the three-parameter models were low (6049.831) and the most significant deviation explained was 21.9%. SST was the sole predictor model with the lowest AIC (6083.072) and the maximum CDE on the GLMs model (12.870%) and was also found as a combined two-parameter model between SST and SSC. The three-parameter models had the lowest AIC and the highest CDE overall (12.830%). All results produced by combining predictor factors at various levels revealed an increase or decrease in CDE and a higher AIC value of variation.

GAMs models were more effective than GLMs in understanding the effect of oceanographic factors on skipjack tuna distribution and abundance, as shown in Tables 1 and 2. The result of the GAM plots shows the impact of each predictor on schooling density of skipjack tuna as shown in Figures 5. The observed data points are

represented by the rug plot on the horizontal axis, while the thin line shows the fitted function, and the grey shading represents the 95% confidence interval (Safuruddin 2013).



**Figure 4.** The profiles of bathymetric overlay with the skipjack tuna distribution during southeast monsoon from 2015 to 2018 in the Bone Gulf waters

**Table 1.** Oceanographic factor influences on the skipjack tuna distribution (n: 508), according to the GAMs models. Also included are the significant factor, AIC value, and CDE

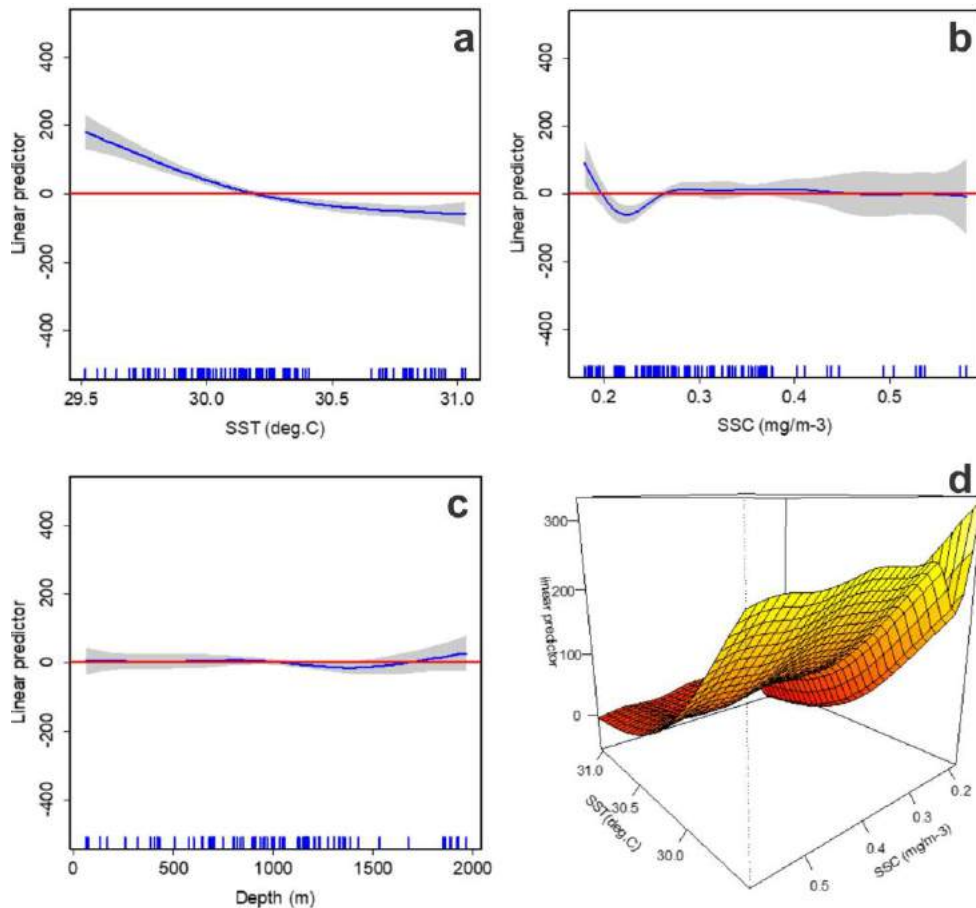
Model	Oceanographic factor	P-value	AIC	CDE (%)
SST	SST	<0.001 ***	6054.183	20.400
SSC	SSC	<0.001 ***	6121.052	8.400
Depth	Depth	<0.001 ***	6132.647	4.970
SST + SSC	SST	<0.001 ***	6048.045	21.900
	SSC	<0.001 ***		
SST + Depth	SST	<0.001 ***	6067.725	17.300
	Depth	0.296		
SSC + Depth	SSC	<0.001 ***	6121.672	8.350
	Depth	0.236		
SST + SSC + Depth	SST	<0.001 ***	6049.831	21.900
	SSC	<0.001 ***		
	Depth	0.832		

Note: Sig. codes: 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*'

**Table 2.** Oceanographic factor influences on the skipjack tuna distribution (n: 508), according to the GLMs models. Also included are the significant factor, AIC value, and CDE

Model	Oceanographic factor	P-value	AIC	CDE (%)
SST	SST	<0.001 ***	6083.072	12.960
SSC	SSC	0.894	6154.549	0.194
Depth	Depth	0.176	6152.724	0.165
SST + SSC	SST	<0.001 ***	6084.600	12.870
	SSC	0.494		
SST + Depth	SST	<0.001 ***	6084.987	12.800
	Depth	0.772		
SSC + Depth	SSC	0.385	6153.966	0.117
	Depth	0.109		
SST + SSC + Depth	SST	<0.001 ***	6085.819	12.830
	SSC	0.282		
	Depth	0.379		

Note: Sig. codes: 0.001 '\*\*\*' 0.01 '\*\*' 0.05 '\*'



**Figure 5.** Skipjack tuna distribution responses of oceanographic factors; (a) SST, (b) SSC, (c) depth, and (d) best model predictor. The shaded area is the standard error indicating the 95% confidence interval. The stack of blue vertical lines on the x-axis indicates the density or distribution of the test parameter data. The y-axis is the partial effect of the variable, while the 3D graph depicts a combination model between significant SST and SSC to be the best predictive model

Figure 5 describes the impact of oceanographic conditions on skipjack tuna distribution. Around 29.5-30.5°C, the SST (Figure 5a) had a noticeable positive effect on skipjack tuna distribution. The confidence intervals are broader because there are fewer data points at 30.5-31.0°C. In the SSC plot (Figure 5b), there was a beneficial influence on school distribution in the SSC ranges of 0.25-0.35 mgm<sup>-3</sup>. A consistent influence on skipjack tuna

distribution was seen at a depth of 500-1500 m (Figure 5c). The study also found that models combining SST and SSC produced the most significant model prediction, with the lowest AIC and highest CDE (Figure 5d). Skipjack tuna distribution in the Northern Pacific Ocean near Japan waters had SST and SSC optimal values of 20.5-26°C and 0.3-0.37 mgm<sup>-3</sup>, respectively, according to Mugo et al. (2010). The findings of this study corroborated those of

Zainuddin et al. (2017), who discovered that the distribution of skipjack tuna in the coastal area was primarily around 50 m depth.

### Discussion

Oceanographic conditions such as the SST, which have the most significant impact on the growth stages of fish and their distribution (Yuniarti et al. 2013; Syah et al. 2020), play a main role in the natural oscillations of skipjack tuna stocks. As a result, SST is a great indicator for the fishing ground of skipjack tuna to have been used by fishermen and researchers for decades. Furthermore, changes in oceanic (physical and biological) parameters may significantly impact migration patterns and fish growth (Safruddin et al. 2018).

Since the SST in the research region may vary, measurements should be obtained frequently. More samples may be required to accomplish this goal. Therefore, one of the objectives of this research was to determine how oceanographic data can be used in research (e.g., correlation between skipjack tuna distribution and abundance). Temperature fluctuations are often linked to the biological richness (Iskandar et al. 2017; Takarina et al. 2018), such as anchovy distribution and abundance as the prey for skipjack tuna, and they have an important influence on fish physiology (Kunarso et al. 2011; Olson et al. 2016; Duffy et al. 2017).

Satellite remote sensing imagery directly provides horizontal and large-area information on oceanographic conditions, which may be utilized to understand oceanographic processes in the surface water better. The combination of satellite data with acoustic technology will, of course, increase the accuracy of the data. For example, CTD and satellite data are combined when conducting data observations (Safruddin 2013). As a result, four-year datasets of oceanographic conditions (SST, SSC, and water depth) on skipjack tuna position were employed, with scattered plots and optimal ranges indicating a possible association among all variables observed, as shown in Figure 5.

Skipjack tuna can be found in coastal areas, sometimes in large numbers, especially in upwelling areas (Sari et al. 2018; Wijaya et al. 2020). This study details the interactions between skipjack tuna and its oceanographic variables taking into account temporal and spatial scale aspects to understand the various processes involved and how they can be used to model dynamics and estimate their abundance (Prista et al. 2011; Selvaraj et al. 2020). The catch data used is the distribution of catches in Bone Bay. Although spatially, several fishing points are located in almost the same area, the dynamics of different oceanographic parameters each year make the description of the range of SST and SSC at each skipjack fishing point experience different.

Oceanographic conditions are essential variables to assess the abundance of fish in the waters, especially skipjack tuna, representing the original habitats. The distribution of skipjack tuna observed during the daytime is closely related to the dynamics of oceanographic variables and fishing operations in the Bone Gulf. As shown in

Tables 1 and 2 and Figure 5, the effect of oceanographic parameters on the abundance and distribution of skipjack tuna is also a reference for water depths. The p-value, AIC, and CDE can all be used to assess the impact of changing oceanographic conditions on skipjack tuna CPUE. As a result, oceanographic variables connected to skipjack tuna distribution are critical for understanding skipjack tuna habitat preferences.

Oceanographic phenomena in the waters, such as frontal oceanic zones, eddies, and upwelling areas, often occur with different characteristics as seen in the Bone Gulf and the Flores Sea (Zainuddin et al. 2017, 2019; Hidayat and Zainuddin 2019; Hidayat et al. 2019b). This event makes the waters very dynamic and affects the horizontal distribution of fish in the Bone Gulf. The dynamic oceanographic parameters in this area produce highly productive habitats and serve as foraging grounds for various commercially and ecologically important species such as anchovies and skipjack tuna (Safruddin et al. 2018; Hidayat et al. 2019b).

The results of this study indicate that the SST tolerance value for skipjack tuna is in the range of 29.5-30.5°C and in the range of 0.25-0.35  $\text{mgm}^{-3}$  for SSC parameters (Figures 5a and 5b). However, in addition to SST and SSC, Indonesian Throughflow (ITF) and Asian monsoons also influence the location of the optimum habitat for skipjack tuna (Gordon 2005). Changes in the value of SST in the waters are heavily influenced by the seasonal cycle, in contrast to the SSC, which is not influenced much by the seasonal cycle. Therefore, the migration of skipjack tuna in the northern waters of the Bone Gulf is thought to have followed the mass movement of water in the southeast monsoon, occupying relatively warm areas in offshore waters.

Based on the lowest AIC value and the highest CDE, the GAM nonlinear model is the best statistical model to understand the effect of oceanographic parameters on the distribution and abundance of skipjack tuna. This study is also supported by previous findings in the Makassar Strait, which reported that the GAM model effectively assessed the effect of oceanographic parameters on skipjack tuna (Hidayat et al. 2019a) and small pelagic fish such as anchovies in the Bone Gulf (Safruddin et al. 2018).

This study concludes that the GAM statistical model has succeeded in explaining the effect of oceanographic parameters on the distribution of skipjack tuna in the Bone Gulf. This study also shows the vital role of oceanographic parameters in understanding the habitat of skipjack tuna related to its abundance and distribution in the waters. The distribution of skipjack tuna in the ocean shows a strong relationship with several parameters such as the SST, SSC, and water depth. Suitable or optimal conditions for skipjack tuna represented skipjack fishing areas during the study in the southeast monsoon period. Oceanographic parameters associated with fish catches correspond to the spatial and temporal distribution of skipjack tuna and have become a hot topic of discussion worldwide (Andrade 2003; Mugo et al. 2010; Zainuddin et al. 2019). From the results of this study, it can be suggested that management decisions to increase fishery yields need to consider oceanographic conditions and characteristics in the waters.

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Safruddin - &lt;safruddin@fisheries.unhas.ac.id&gt;

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**[biodiv] New notification from Biodiversitas Journal of Biological Diversity**

2 messages

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**DEWI NUR PRATIWI** <smujo.id@gmail.com>  
Reply-To: Ahmad Dwi Setyawan <editors@smujo.id>  
To: Safruddin Hasyim <safruddin@fisheries.unhas.ac.id>

Wed, Apr 13, 2022 at 7:08 AM

You have a new notification from Biodiversitas Journal of Biological Diversity:

You have been added to a discussion titled "Uncorrected Proof" regarding the submission "The Use of statistical models in Identifying Skipjack Tuna Habitat Characteristics during the Southeast Monsoon in Bone Gulf, Indonesia".

Link: <https://smujo.id/biodiv/authorDashboard/submission/10023>

Ahmad Dwi Setyawan

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**DEWI NUR PRATIWI** <smujo.id@gmail.com>  
Reply-To: Ahmad Dwi Setyawan <editors@smujo.id>  
To: Safruddin Hasyim <safruddin@fisheries.unhas.ac.id>

Wed, Apr 13, 2022 at 7:13 AM

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#### SAFRUDDIN

Study Program of Capture Fisheries, Faculty of Marine Science and Fisheries, Universitas Hasanuddin.  
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The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia

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## [biodiv] Editor Decision

1 message

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**Ayu Astuti** <smujo.id@gmail.com>

Thu, Apr 14, 2022 at 11:10 PM

To: SAFRUDDIN HASYIM <safruddin@fisheries.unhas.ac.id>, RACHMAT HIDAYAT <rh191993@gmail.com>, "ST. AISJAH FARHUM" <icha\_erick@yahoo.com>, MUKTI ZAINUDDIN <muktizunhas@gmail.com>

SAFRUDDIN HASYIM, RACHMAT HIDAYAT, ST. AISJAH FARHUM, MUKTI ZAINUDDIN:

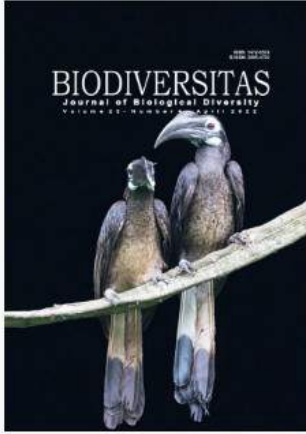
We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia".

Our decision is to: Accept Submission

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# The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia



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DOI

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## Abstract

**Abstract.** *Safruddin, Hidayat R, Farhum SA, Zainuddin M. 2022. The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia. Biodiversitas 23: 2231-2237. Skipjack tuna (*Katsuwonus pelamis*) is the main fishery product in the Bone Gulf, Indonesia, since it has high economic value and is widely accepted by the*

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