Spatial-temporal habitat suitability for lemuru fish (*Sardinella lemuru*) using the Second-generation Global Imager (SGLI) and Maximum Entropy model in the Bali Strait, Indonesia

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Abstract. Lemuru fish (*Sardinella lemuru*), the most dominant fishery resource, has economic values for the fisherman fishing activities in the Bali Strait (between Jawa and Bali islands), Indonesia. Spatial and temporal prediction for the fishing location is essential information for effective fisheries management. The high spatial resolution of sea surface temperature (SST) and Chlorophyll-a (Chl-a) by the second-generation global imager (SGLI) on the global change observation mission (GCOM-C) satellite was employed for the input of the Maximum Entropy Model (MaxEnt) to predict the potential fishing area of lemuru fish in 2020. This study analyzed SST and Chl-a using the SGLI data and shows the variability of SST and Chl-a for lemuru fish-catching data. The MaxEnt model performance to predict the habitat suitability for lemuru fish in the Bali Strait has been shown in this study. As a result, the maximum average Chl-a estimated in August 2020 was around 1.62 mg m$^{-3}$ and maximum SST in March 2020 around 28.12°C. The correlation between SST and Chl-a with total lemuru fish-catching were -0.209 and 0.375 for SST and Chl-a, respectively. The prediction of lemuru fishing areas using the MaxEnt model showed excellent model evaluations with a correlation value higher than 0.80.

Keywords: Chlorophyll-a, GCOM-C, MaxEnt Model, *Sardinella lemuru*, Sea Surface Temperature

1. Introduction
The Bali Strait is one of Indonesia's territorial waters that have high natural resource potential. The Area is only about 2,500 km$^2$, but has great potential for fishing. The Bali Strait has unique and dynamic waters that can cause fluctuations in fish production amount each year. According to [1], the most significant type of fish caught in the Bali Strait is the lemuru (*Sardinella lemuru*), a fish that can only be found in the Bali Strait [2]. This fish plays a significant role in the economy of fishers in the Bali Strait. Each year the catch of lemuru has fluctuated, making fishing locations challenging to predict. Sea Surface Temperature (SST) and Chlorophyll-a (Chl-a) are oceanographic conditions that can affect the oceans' condition of resources [3].
Apart from environmental conditions, the condition of fish resources can also be influenced by oceanographic phenomena, such as upwelling [4]. Therefore, understanding the relationship between these factors is essential for effective fisheries management [5]. Observing oceanographic factors in the oceans is complicated if conducted by direct observation due to time and cost limitations. Remote sensing technology was used to facilitate observation at sea [6].

Various studies using remote sensing have been carried out to manage fisheries potential [7] using the Moderate Resolution Imaging Spectroradiometer (MODIS), which has a resolution of 1–4 km; this resolution is not suitable for the location of the Bali Strait. In 2017 the new GCOM-C optical satellite was launched, monitoring marine productivity better than MODIS. GCOM-C resolution is about 250 m². Remote sensing technology is being developed with various models to estimate marine fishing areas, such as the Maximum Entropy (MaxEnt) model. The MaxEnt model is a model that estimates the maximum probability distribution with approximate data [8].

Predicting the fishing area’s potential helps fishers save costs and efficiency in fishing time. The existence of a prediction of fish catchment areas supports and facilitates the management of fishery resources. Management plays an essential role in optimizing total fish catch production.

2. Materials and methods

The research location is in the Bali Strait, which is located at 114.41° East – 8.177° South (Fig. 1). The Bali Strait in the west has bounded the mainland of Java, while Bali’s island in the east limits it. The Bali Strait is the water that connects the Flores Sea and the Madura Strait in the north and the Indian Ocean in the south.

![Figure 1. Research location.](image-url)
2.1. Second-generation Global Imager (SGLI)
SST and Chl-a images were obtained from the Global Change Observation Mission-climate (GCOM-C) satellite with the product type level 2. The daily temporal resolution of the GCOM-C satellite has a spatial resolution of 250 m. The daily temporal resolution of the GCOM-C satellite has a spatial resolution of 250 m on January 2019 - December 2019, and is available at https://gportal.jaxa.jp/.

2.2. In-situ data
In-situ data in this study is data on the coordinates point of lemuru catch in the Bali Strait. This data was obtained from the Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia. This data is in the form of daily coordinates point for lemuru fish catch locations in the Bali Strait from January to December 2019.

2.3. Processing data
Level 2 remote sensing Chl-a and SST data from the GCOM-C satellite were collected and then cropping based on the Bali Strait AOI. After the cropping, proceed with the data extraction.

The in situ and remote sensing data will be devided into 4 groups. Each groups contain of 3-month data based on the season such as December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON), thats all data the data is then interpolated and modified to an .ASC extension and processed in the Maxent software.

The MaxEnt model was one of the Species Data Modeling (SDM) methods used to predict fish occurrence. The MaxEnt model looks at the closeness between the spatial data of lemuru available from the Prefectural Public Safety Commissions (PPSC) logbook data/fish catch coordinate point and correlated with the sea surface temperature and Chl-a parameters. The MaxEnt model results are evaluation models in Area Under the Curve (AUC) graphs, response curves, analysis of the contribution of parameters in the form of Jackknife test, map prediction of lemuru distribution opportunities, and raw data output, and control parameters. The first data prepared for the MaxEnt Model processing was the location of lemuru fishing, which was contained in an extension (.xls) containing information on lemuru and its coordinates. The data storage extension in the form (.xls) was also made in the extension (.csv). The following data needed were Chl-a and SST in extension (.asc) images. After that, the work was done in Maximum Entropy software version 3.4.1. The process begins by entering the coordinates of the lemuru extension point (.csv) data in the Samples tab and entering the environment parameter (.asc) data in the Environment Layers tab. Next, a checklist creates response curves and jackknife variables of importance and fills the iteration column of 500 with a random test percentage of 25%. The results have been obtained and stored following the destination output folder.

2.4. Analysis data
MaxEnt Modeling was a method of predicting the distribution of lemuru fish in Java's southern waters. The MaxEnt model generally estimates lemuru distribution opportunity by determining the maximum entropy probability (most spread, uniform, and closest) [7]. According to [9], the problem with modeling the distribution of species was estimating density. The MaxEnt model explains the estimated density represented by the probability of presence over environmental data variables. Thus, P (x | y = 1) gives a non-negative value for each SST (x) value and the total value of P (x | y = 1) is 1. If the lemuru fish was assumed to be y, then P (y = 1 | x) was the presence probability. According to Bayes, the equation of the probability of presence was as follows [10]:

\[ P (y = 1 | x) = \frac{P (x | y = 1) p (y = 1)}{p (x)} = \pi (x) P (y = 1) | X | \]  

Where \( P (x | y = 1) \) is the likelihood, \( P (y = 1 | x) \) represents the probability of presence (conditioned on the environments), \( P (x) \) is the prior evidence, and \( P (y = 1) \) represents the prior target.

Probability was obtained from sample data made into training data, which was data in 1 year (12 data) be affected by environmental parameters, which will become a probability of presence (conditioned on the environments). Comparative Probability data are SST and Chl-a data, which are
environmental parameters that affect lemuru fish's presence. The probability of the species was the likelihood that the fish will appear but was not affected by environmental parameters.

The quantity $P(y=1|x)$ was the probability that the species was present at point $x$ with a probability between 0 and 1 for the scattered organisms. Equation 1 shows that $\pi$ was proportional to probability of presence. However, if only presence data cannot determine the species' prevalence [10]. To see closeness does not only require attendance data [11]. The next step that must be done was to use the Gibbs Distribution theorem [7]. The Gibbs distribution was an exponential distribution defined by the feature vector. The Gibbs Distribution formula is as follows:

$$q(x) = \frac{\exp(\sum_{j=1}^{n} \lambda_j f_j(x))}{z_{\lambda}}$$

(2)

$\lambda_j$ is the weight of $x$ on variable $j$, $f_j$ represents the $x$ value on variable $j$, $z_{\lambda}$ is the exponential sum of the features weight vector of set $X$, and $q(x) = \text{Estimation } P(x \mid y = 1)$.

With presence-absence data, the definition of the response variable should naturally be consistent with the sampling method. For example, if the available data are surveys of 1-m$^2$, then $y = 1$ should correspond to the species being present in a 1-m$^2$. The available data do not usually describe the survey method with presence-only data, so the modeler has considerable leeway in defining the response variable.

After obtaining an estimate from $P(x \mid y = 1)$, then calculate the entropy of $q(x)$, the formula is as follows [10].

$$H(x) = \sum_{x=1}^{n} q(x) \ln q(x)$$

(3)

Furthermore, to obtain the distribution of the probability of presence (estimation opportunities), as follows:

$$P(y = 1 \mid x) = \frac{e^{Hq(x)}}{1+e^{Hq(x)}}$$

(4)

3. Results and discussion

3.1. Performance of the maximum entropy model in determining lemuru fishing habitat

The maxent model uses a model evaluation method in the form of Receiver Operating Characteristics (ROC), displayed with the Area Under Curve (AUC). The x-axis AUC curve describes sensitivity as to how well the model predicts attendance, and the y-axis describes specificity how well the model predicts absence data. On the curve, there was a red line showing the suitability of the model to the training data (75% of the total data), the blue line showing the suitability of the model to the test data (25% of the data), and the black or turquoise line explaining how well the model data being tested is. The blue line was below the black line, indicating that the model was not doing well.

The MaxEnt algorithm used in this study produces good to excellent predictive ability in predicting potential seasonal fishing areas, at least sufficiently sampled locations in the basic model. In this study, the AUC value is higher than 0.80, which indicates that the regional base model has good to outstanding suitability (Figures 2-5). This is under the statement of [16], which states that the performance of the model is seen based on the AUC value, where AUC values of 0.6 - 0.7 are considered low, 0.7 - 0.8 are considered moderate, 0.8 - 0.9 are considered acceptable, and more than 0.9 indicate very high accuracy for measure the presence and absence of the resulting model.

Analysis of the contribution of environmental variables using the Jackknife test. The Jackknife test was used to see each environmental variable's contribution and effect on the model building process. The blue bar chart indicates the contribution of environmental variables to the AUC value. The Tosca bar chart defines the contribution of environmental variables when not in use. The red diagram indicates the contribution of all variables to the chance of lemuru fish presence.
From the analysis of the contribution of environmental variables, it can be concluded that the variable that has a contribution and was considered necessary in SON and DJF months was chl-a, while in MAM and JJA months, it was sea surface temperature (Figures 6-9). SON month was a transitional period II, namely the East Monsoon season, which enters a transition period before the West Monsoon season where the upwelling phenomenon occurs; it was estimated that the phytoplankton content in the waters would increase (17) supported by the research of [18] and [19] that the lemuru fishing season occurs during the West Season. Lemuru volume starts to increase in October and reaches a peak around December – January.
Figure 7. The Jackknife test on MAM (SST has a contribution value of 83.9%, and Chl-a has 16.1%).

Figure 8. The Jackknife test on JJA (SST has a contribution value of 100%, and Chl-a has 0%).

Figure 9. The Jackknife test on SON (Chl-a concentration has a contribution value of 69.6%, and SST has a contribution value of 30.4%).

Figures 10 to 11 show the response curve results for each season; the x-axis response curve explains the value of the distribution of parameters, and the y-axis explains the relationship between the index value of the chance of lemuru's presence with the parameter. The index value was close to the value of 1, then the probability of lemuru fish with a high parameter.
Figure 10. The response curve of the SST parameter related to the lemuru presence index value in (a) DJF has the highest probability of appearance at 27.5°C-28.7°C; (b) MAM, the highest probability of appearance is at 27.65°C-28.4°C; (c) JJA the highest probability of appearance at 24.2°C-25.05°C; (d) SON the highest probability of appearance at 24.37°C-26.5°C.

Figure 11. The response curve of the Chl-a parameter related to the lemuru presence index value in (a) DJF has the highest probability of appearance at 0.25-0.54 mg/m³; (b) MAM the highest probability of appearance is at 0.33-0.8 mg/m³; (c) JJA, the highest probability of appearance is at 0.2-5.28 mg/m³; (d) SON the highest probability of appearance at 0.25-0.93 mg/m³.

3.2. Prediction map of lemuru fish habitat in the Bali strait

The index value on the response curve was close to the value 1, then the probability of closeness of the presence of lemuru with high parameters. The response curve was at the optimum value when it moved to its peak [20]. Based on the results obtained, the highest index value of Chl-a was in the low Chl-a concentration. Furthermore, the SST parameter response curve results associated with the highest chance index value for lemuru are in the range of 24º - 28º C. According to [21], the lemuru fishing area in the Bali Strait in each season was generally in the temperature range of 25º C - 29.5º C; this was
following [3] research that around 70% of lemuru fishing activity in the Bali Strait occurs at temperatures of 25.5° - 26.5° C.

Prediction maps are generated from various analyzes contained in the Maximum Entropy Model. The prediction map is shown in Figure 12.

![Figure 12. Map of prediction of lemuru fish habitat in the Bali strait on DJF with values is at 0.40-0.67, when MAM the values are around 0.45-0.67, JJA the values are around 0.48 - 0.55, and at SON the values are around 0.47-0.56.](image)

The HSI value in the months of DJF and MAM was better than in JJA and SON months. With the fish habitat's prediction map layout combined with the average fish catch in 2019, the habitat prediction map results do not always match the average fish catch. This does not agree with the research of [22], which states that areas with high phytoplankton and zooplankton tend to have a high volume of pelagic fish. The nature of the fish, which was always in motion, was suspected to be the cause. If an area of water has suitable conditions and supports fish, fish was not sure there are fish in the Area. Fish need time to adjust and move to a suitable location and support their lives [23].

4. Conclusion
The maximum average Chl-a concentration occurs in August (Dry season) at 1.62 mg/m³, and the lowest concentration occurs in January (Wet season) 0.45 mg/m³. Furthermore, the average SST began to be high in January, reaching a maximum temperature in March (Wet season) with a value of 28.12° C; It began to decline the minimum temperature in August (Dry season) a value of 22.40° C.

Prediction of lemuru fishing areas using the MaxEnt Model results in good to outstanding model evaluations. The results of the AUC value in each season are DJF = 0.806, MAM = 0.930, JJA = 0.968, and SON = 0.856. The percentage contribution of parameters during SON and DJ months that
contributed was Chl-a, while during MAM and JJA the contribution was SST. The HSI index values on DJF is 0.40 - 0.67, in MAM is 0.45 - 0.67, in JJA is 0.48 - 0.55, and SON is 0.47–0.56.

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