Changes in potential distribution and abundance of skipjack tuna (*Katsuwonus pelamis*) in the southern waters of West Java, Indonesia

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Abstract. Skipjack tuna (*Katsuwonus pelamis*) is the main export commodity of Indonesian marine fisheries. The spatial distribution of skipjack tuna is strongly influenced by oceanographic conditions. This research was conducted to determine the changes of potential distribution and abundance of skipjack tuna in the southern waters of West Java. The data analyzed are skipjack catch, fishing location, chlorophyll-a concentration and sea surface temperature. Linear regression analysis was used to determine the trend of skipjack catch. The maximum entropy (Maxent) model was used for analyzing changes in skipjack's potential distribution. The results showed that the seasonal variation in skipjack catch was influenced by the monsoon system and the inter-annual variation was influenced by the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) phenomena. When there is a positive phase of IOD and El Nino, the catch increases significantly. On the other hand, it decreases significantly when there is a negative phase of IOD and La Nina. In the 2010-2020 period, skipjack catches experienced a downward trend. The Maxent model can predict the potential distribution of skipjack tuna in the southern waters of West Java well. The potential distribution of skipjack tuna in the southern waters of West Java is increasingly shifting to the south. The potential distribution shifted from 7.2°-9°S in 2010 to 8.2°-10° S in 2020.
Key Words: ENSO, IOD, Maxent, skipjack tuna, spread potential.

Introduction. Skipjack tuna (*Katsuwonus pelamis*) is one of the pelagic fish species that migrate long distances and spread throughout global tropical and subtropical waters (Arai et al 2004). Skipjack tuna has high economic value and contributes greatly to the global fishing industry, making it the main catch target (Yen et al 2016; Zainuddin et al 2017; Hidayat et al 2021). The spatial distribution pattern and abundance of skipjack tuna are influenced by oceanographic conditions (Desianty et al 2020; Putri et al 2021). The concentration of chlorophyll-a and sea surface temperature are oceanographic parameters that have a major influence on the distribution of fish (Lanz et al 2009).

Indonesia's territory, which is almost 70% oceans, has abundant potential for fishery resources with very high economic value (Sari & Muslimah 2020). Skipjack tuna is the dominant marine fishery resource in Indonesian waters (Apriliani et al 2019). The potential distribution of skipjack tuna is throughout Indonesian waters except in the Java Sea. With abundant potential and high economic value, skipjack is one of the main export commodities of the Indonesian marine fishery resources (Sepri et al 2020). Nevertheless, unfortunately, from year to year, skipjack catches in Indonesian waters have decreased (Novianto et al 2018).

Climate change as a result of global warming caused by increased greenhouse gases emitted into the atmosphere by human activities has a negative impact on oceanographic environmental conditions, which, in turn, affects the habitat, distribution and abundance of fish (Hoegh-Guldberg & Bruno 2010; Muhling et al 2015; Johnson et al

2018; Monnier et al 2020; Rubio et al 2020). The impact of climate change causes a decrease in fish catches in the tropics (Townhill et al 2021). The spatial distribution of skipjack tuna is also strongly influenced by the Indian Ocean Dipole (IOD) and El Nino Southern Oscillation (ENSO) phenomena (Dueri 2017).

The southern waters of West Java, which are part of the Indian Ocean, are known to have high skipjack tuna potential (Irianto et al 2015; Jatmiko et al 2019; Artetxe-Arrate et al 2021). Oceanographic conditions in the southern waters of Java are influenced by the monsoon system, IOD and ENSO (Wyrtki 1961; Webster et al 1999; Susanto et al 2001). Changes in oceanographic conditions due to climate change, changes in the monsoon system, the occurrence of IOD and ENSO phenomena are indicated to greatly affect the spatial distribution and abundance of skipjack tuna in these waters. Based on these aspects, the purpose of this study was to determine the potential changes in the spatial distribution of skipjack tuna in the southern waters of West Java. The results of this study can be used in the context of sustainable management of fisheries resources in the southern waters of West Java.

Material and Method

Research location. The location of this research was the southern waters of West Java, located at 105–109°E and 7–10°S (Figure 1).

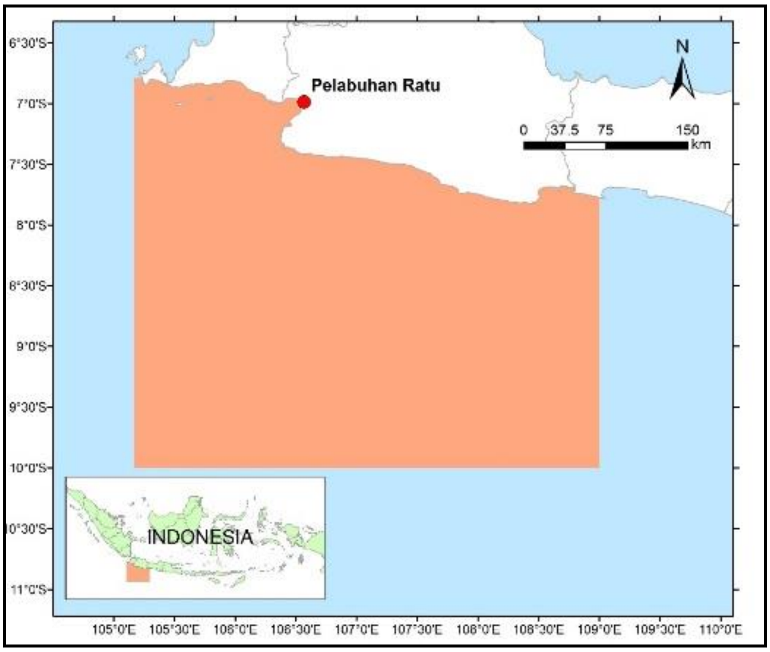

Figure 1. Research location.

Data. The data used consisted of sea surface temperature, chlorophyll-a concentration, fishing locations, and skipjack catch. Data on sea surface temperature and chlorophyll-a concentration were obtained from Aqua MODIS satellite imagery with monthly temporal resolution from December 2002 to November 2020. These data have a spatial resolution of 4x4 km^2. Data on sea surface temperature and chlorophyll-a concentrations were also obtained from Ocean Color NASA (https://oceancolor.gsfc.nasa.gov). Skipjack tuna catch data from January 2010 to December 2020 and data on fishing locations in 2010 and 2020 were obtained from the Palabuhanratu Nusantara Fisheries Port, West Java.

Methods. This study uses several methods including: seasonal analysis, divided into 4 seasons (DJF, MAM, JJA, and SON), interannual analysis, and spatial distribution modeling with maximum entropy (Maxent) model.

In this study, seasonal and inter-annual variations were analyzed. Seasonal variations consist of DJF (average December, January, February), MAM (average March, April, May), JJA (average June, July, August) and SON (average September, October, November). Analysis of seasonal variation is closely related to the influence of the Asian and Australian monsoons on the distribution and abundance of skipjack tuna in the southern waters of West Java. Meanwhile, the inter-annual analysis determined the effect of IOD, ENSO and the impact of climate change on skipjack catches. Trends in changes in oceanographic conditions and skipjack catch were analyzed using the trend analysis method.

The analysis of the spatial distribution of skipjack tuna in the southern waters of West Java uses the maximum entropy (Maxent) model. The Maxent model can predict the spatial distribution of skipjack tuna in the western waters of Sumatra, which is part of the Indian Ocean (Syah et al 2019). Oceanographic parameters used are sea surface temperature and chlorophyll-a. The model simulation area covers the southern waters of West Java (105–109°E and 7–10°S) with a grid size of 4x4 km^2. The Maxent model was run with 500 iterations with 75% of data used to build the model, and 25% of data used as model validation. Analysis of changes in potential distribution of skipjack tuna was carried out by comparing the results of the 2010 Maxent model output with 2020 Maxent model output.

Results and Discussion. Figure 2 shows seasonal and inter-annual variations in skipjack catches in the southern waters of West Java in the 2010-2020 period. The number of skipjack catches varied from season to season. The lowest catch occurred in DJF, with 32 tons. Then, in MAM, the catch increased slightly to 35 tons. In JJA and SON, the catch increased to 61 tons and 63 tons, respectively. Meanwhile, the inter-annual variation in skipjack catches experienced high fluctuations. The decrease in skipjack catch coincided with the occurrence of negative phase IOD and La Nina, whereas an increase in catch coincided with the occurrence of positive phase IOD and El Nino. In general, in the 2010-2020 period, skipjack catches in the southern waters of West Java experienced a downward trend.

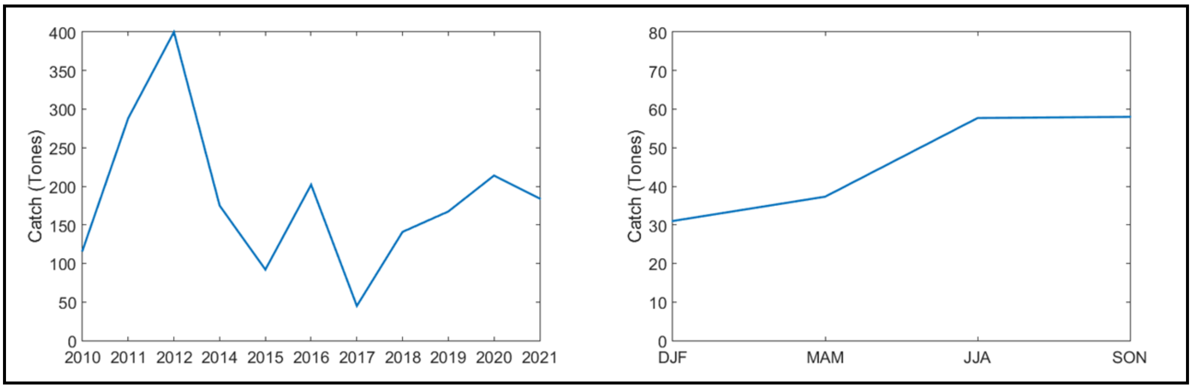

Figure 2. Seasonal and inter-annual variations in skipjack (*Katsuwonus pelamis*) catch.

Figure 3 shows the seasonal variation of the potential spatial distribution of skipjack tuna in the southern waters of West Java in 2010 and 2020. The high potential distribution is presented in red. The potential area for skipjack distribution in the DJF season is concentrated in the western part between 7.5-8°S and 105–106.5°E. In the MAM season, the potential area for skipjack distribution is wider, concentrated in the middle to the east, between 8-9°S and 107.3-109°E. The area of potential distribution of skipjack tuna is wider in the JJA season, concentrated in the western part, 7.2-9°S and 105–107.2°E. In the SON season, the potential area for skipjack distribution is spread along the southern coast of West Java between 7.5–8.5°S. Compared to 2010, the potential distribution of skipjack tuna in 2020 has changed. At DJF, the potential for distribution is increasingly shifting to the south, between 8.3–10^{o}S. The potential for distribution in MAM also shifts to the south and is concentrated between 8.2–9.6^{o}S and 105–106.75^{o}E. The potential distribution area in JJA and SON also shifts to the south up to 10^{o}S, with smaller coverage. In general, the potential distribution of skipjack tuna in 2020 is shifting to the south and tends to decrease.

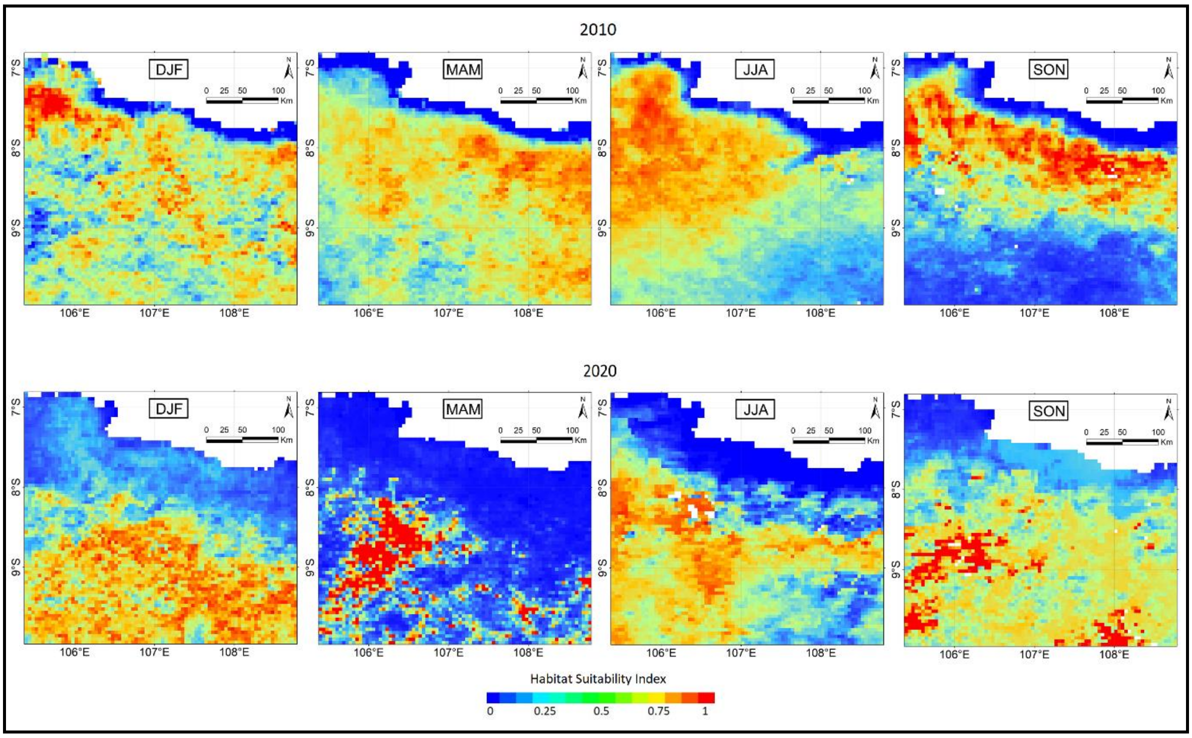

Figure 3. Seasonal variation of skipjack tuna (*Katsuwonus pelamis*) spatial distribution potential in 2010 (top) and 2020 (bottom).

Figure 4 shows the receiver operating characteristic (ROC) curve for the Maxent model output in 2010 and 2020. The fit between the model and the experimental data is presented by the red line, while the fit between the model and the test data is shown by the blue line. The area under the curve (AUC) values for the 2010 model were 0.6 in MAM, 0.7 in DJF and JJA and 0.8 in SON. Meanwhile, the AUC values in 2020 is 0.7 in SON, 0.8 in DJF and JJA and 0.9 in MAM. The criteria for AUC values between 0.5<ROC<0.7 are not good, 0.7<ROC<0.8 are good, and 0.8<ROC<0.9 are very good (Hosmer et al 2013). Based on the AUC value of the model results, it can be concluded that the Maxent model can predict the potential distribution of skipjack tuna in the southern waters of West Java well.

Based on the results, it is known that the number of skipjack catches in the southern waters of West Java varies each season. In the JJA and SON seasons, the skipjack catches are much higher than in the DJF and MAM seasons. Meanwhile, the inter-annual variation in skipjack catches experienced high fluctuations, especially in the JJA and SON seasons. In the 2010-2020 period, skipjack catches in the southern waters of West Java experienced a downward trend. This shows that the potential distribution of skipjack tuna in the southern waters of West Java is closely related to the monsoon system, ENSO and IOD phenomena, and changes in oceanographic environmental conditions due to the impact of climate change.

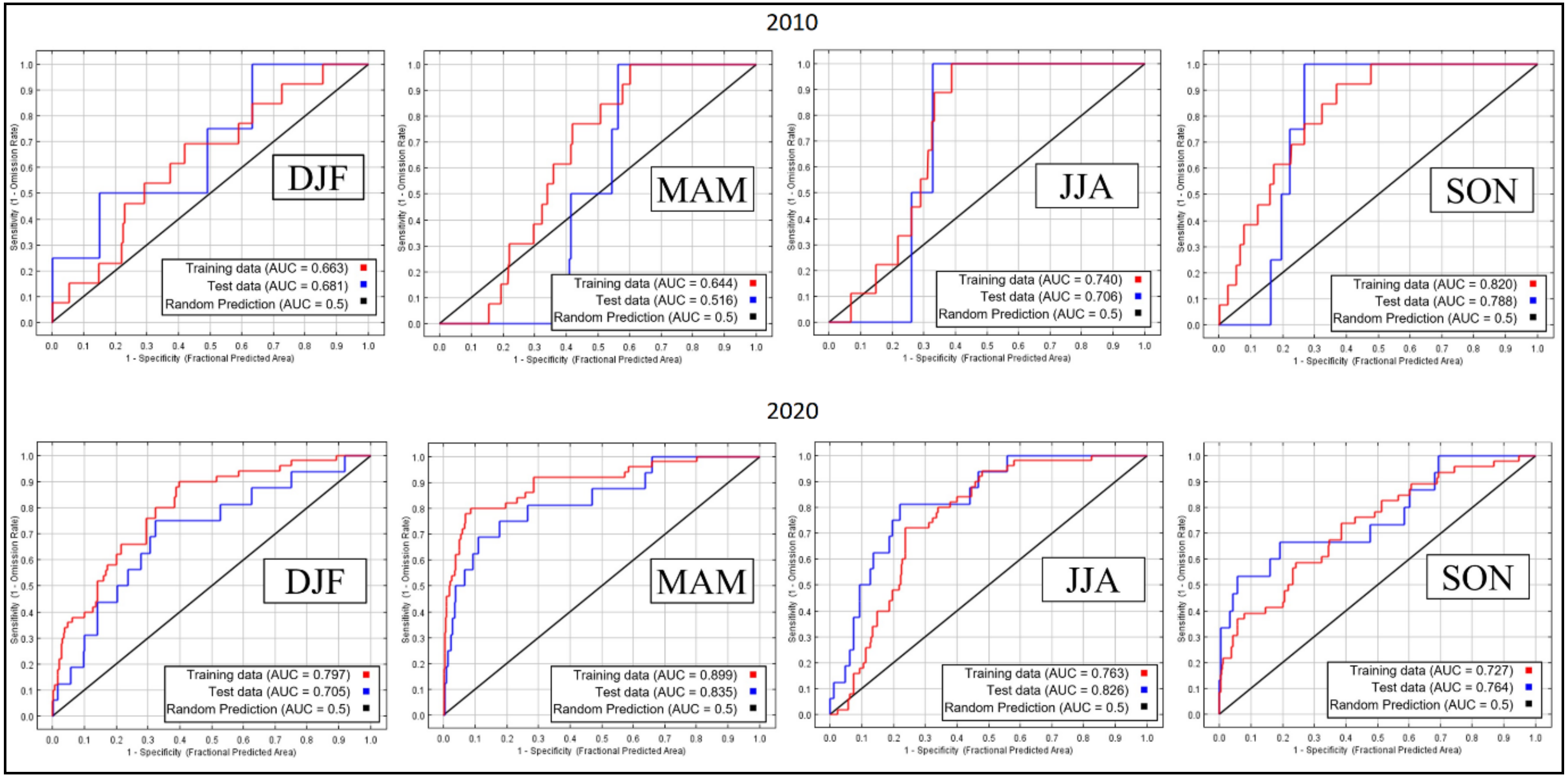

Figure 4. ROC curves for 2010 (top) and 2020 (bottom).

The influence of the monsoon system on the potential distribution of skipjack tuna is closely related to changes in its oceanographic environmental conditions. Figure 5 shows the circulation of seasonal surface winds over the southern waters of Java during the Asian and Australian monsoons. During the Asian monsoon (DJF), the surface wind moves eastward, and conversely the surface wind moves to northwest, parallel to the coastline during the Australian monsoon (MAM to SON). In the Australian monsoon, there was an increase in surface wind speed from 2.6 m s^{-1} to 7 m s^{-1} in JJA m s^{-1}, and 5.4 m s^{-1} in SON. Because the location is in the southern hemisphere, surface wind gusts to the northwest parallel to the coast cause the formation of Ekman transport to offshore, resulting in an upwelling process in the southern waters of Java (Susanto & Marra 2005). This upwelling process takes place between June-October (Susanto et al 2001).

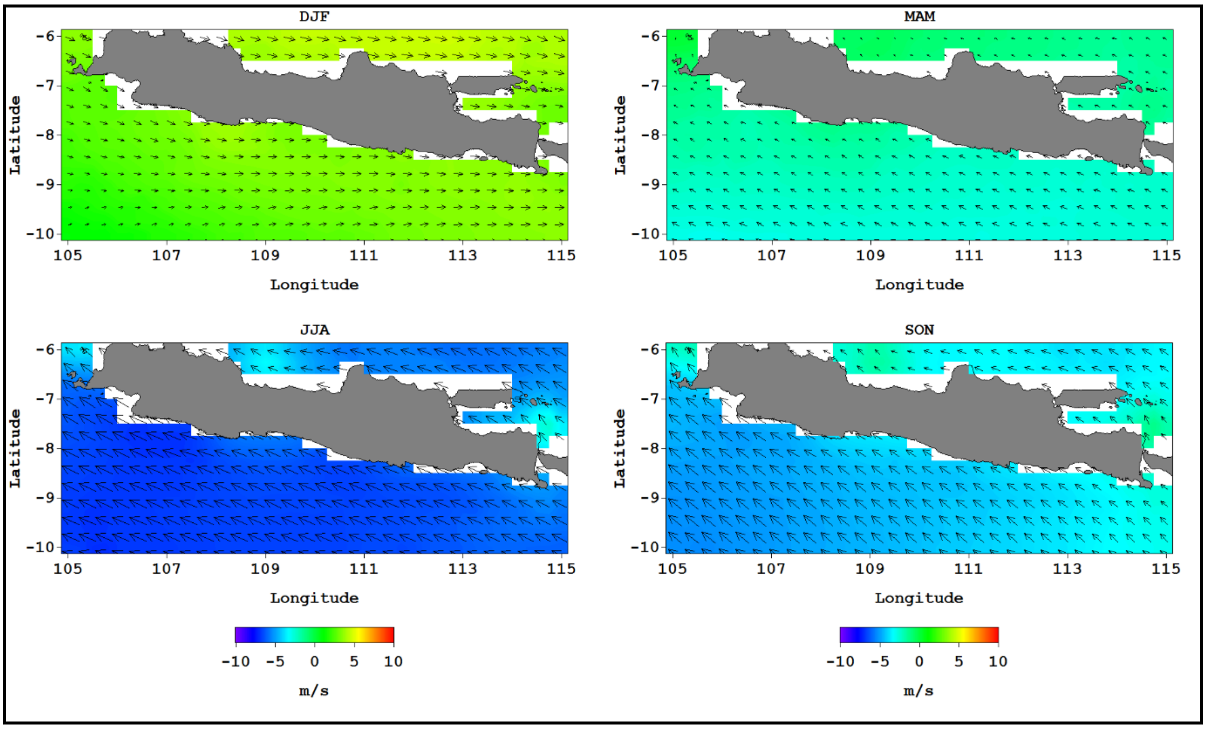

Figure 5. Surface wind seasonal pattern.

The upwelling process changes the conditions of sea surface temperature and chlorophyll-a concentration in the southern waters of West Java (Figure 6). In the JJA and SON seasons, there is an increase in the concentration of chlorophyll-a and a significant decrease in sea surface temperature. The increase in chlorophyll-a concentration was more than 250% from 0.16 mg m^{-3} to 0.4 mg m^{-3} in MAM and became 0.6 mg m^{-3} in JJA. Meanwhile, the decrease in sea surface temperature was more than 2°C from 29.47°C to 27.21°C in MAM and became 27.02°C in JJA. A very high increase in chlorophyll-a concentration indicates an increase in water fertility (Hendiarti et al 2005; Diana et al 2021). Aquatic environments with high fertility levels are indicated as areas with high seawater potential (Dutta et al 2016; Titaheluw et al 2020; Yu et al 2021; Sambah et al 2021). This mechanism causes skipjack catches in JJA and SON seasons to be much higher than in DJF and MAM.

The effect of ENSO and IOD events on skipjack catches is closely related to the upwelling and downwelling processes in the waters of South Java. Figure 7 shows the pattern of surface current circulation during the 2015 El Nino and the negative phase of the 2016 IOD. El Nino and IOD events affect the circulation pattern of sea surface currents in the south of West Java. At the time of the El Nino event, there was an increase in the speed of sea surface currents. This increase in current velocity causes a reduction in the mass of the surface water resulting in a shallowing of the thermocline, which in turn increases the intensity of the upwelling. On the other hand, during the positive phase of 2016 IOD, there was a change in the direction of the sea surface currents moving east. The movement of the surface current that moves eastward meets the South Equatorial Current, resulting in a convergence process causing the formation of a downwelling process.

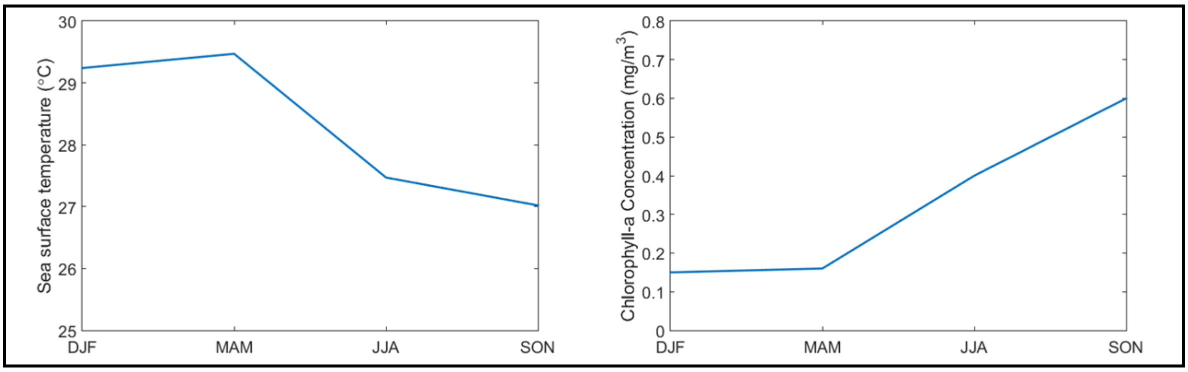

Figure 6. Seasonal variation of sea surface temperature and chlorophyll-a concentration.

The intensity of upwelling is getting stronger when there is a positive phase of IOD and El Nino, so that there is an increase in the concentration of chlorophyll-a. On the contrary, the downwelling process is formed when there is a negative phase of IOD and La Nina. These events cause a significant decrease in the concentration of chlorophyll-a (Currie et al 2013; Wijaya et al 2020; Setyohadi et al 2021). Increase and decrease in the concentration of chlorophyll-a changes the level of water fertility, which in turn affects the abundance of potential fisheries. Thus, when the positive phase of El Nino and IOD occurs, the catch of skipjack tuna tends to increase. Vice versa, when La Nina and IOD in the negative phase occur, skipjack tuna catch tends to decrease.

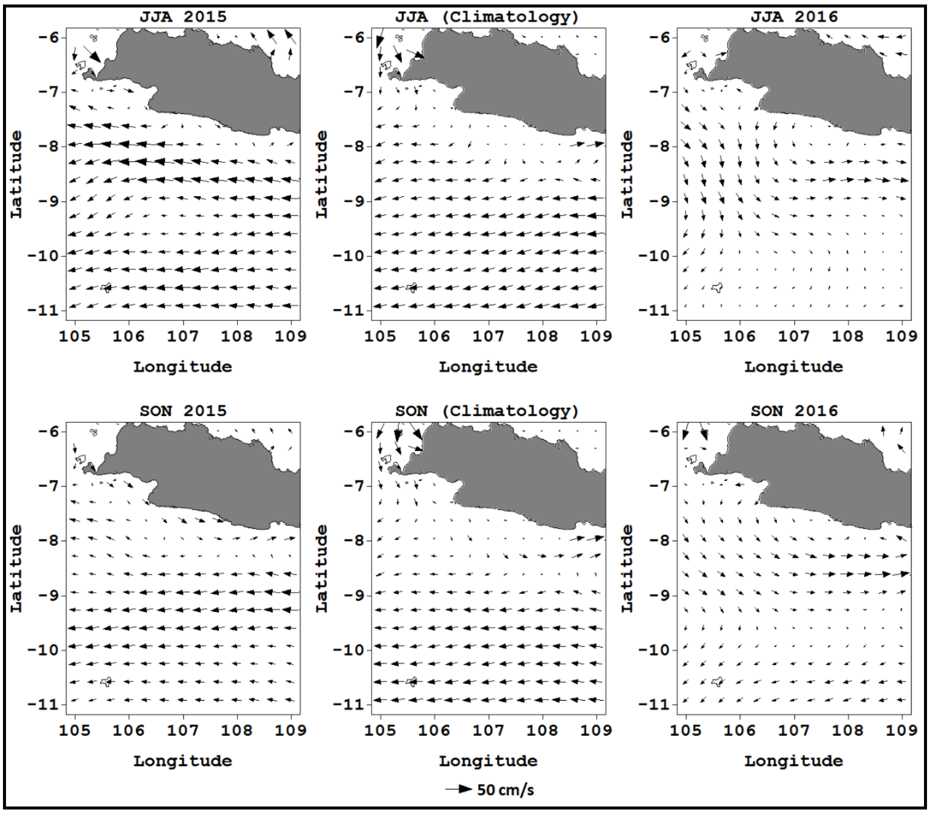

Figure 7. Surface ocean current circulation pattern.

Rising sea temperature is the main factor causing skipjack tuna to migrate in search of suitable habitat (Andrade 2003; Dueri et al 2014; Monnereau & Oxenford 2017; Mugo & Saitoh 2020). Figure 8 shows the spatial distribution of sea surface temperatures in the southern waters of West Java in 2010 and 2020. Based on Figure 8, the sea surface temperature in the southern waters of Java has increased. In the 2010-2020 period, sea surface temperatures from the southern coast of West Java have increased with 0.51°C. Skipjack tuna responds to rising sea temperatures in the tropics by migrating to higher latitudes (Lehodey et al 2012; Monllor-Hurtado et al 2017; Mediodia et al 2020). This high sea surface temperature increase is indicated as one of the causes of decline in skipjack catches in the southern waters of Java and changes in the potential spatial distribution of skipjack tuna, which is increasingly shifting to the south from 7.2-9°S in 2010 to 8.2-10°S in 2020.

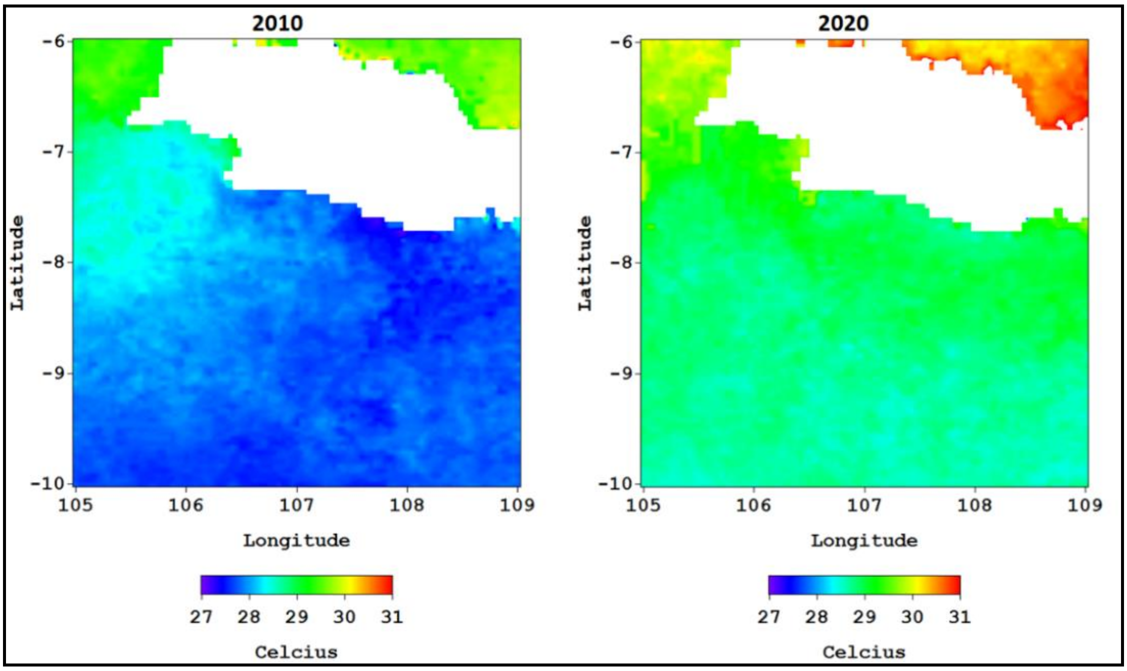

Figure 8. Distribution of sea surface temperatures in 2010 (left) and 2020 (right).

Conclusions. Based on the results, it can be concluded that the seasonal variation in the distribution and abundance of skipjack tuna in the southern waters of West Java is influenced by the monsoon system and the inter-annual variation is influenced by IOD and ENSO. Skipjack catches are maximum during the Australian monsoon (JJA and SON). When there is a positive phase of IOD and El Nino, skipjack catches increase. Vice versa, they decrease when there is a negative phase of IOD and La Nina. Skipjack catches have a downward trend. Maxent model can predict the potential distribution and abundance of skipjack tuna well. The potential for the spatial distribution and abundance of skipjack tuna in the southern waters of West Java is increasingly shifting to the south from 7.2-9°S in 2010 to 8.2-10°S in 2020. The results of this study may be used in planning skipjack fisheries management in the waters of South Java, considering the effects of climate change.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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