Estimation of the fishing ground potential based on oceanography parameters (GIS-based) of yellowfin tuna (*Thunnus albacares*) in West Sumatra waters

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Abstract. Oceanographic parameters can be used as indicators to estimate potential fishing grounds by utilizing geographic information system (GIS) technology. This study aims to analyze an estimation of potential fishing ground of yellowfin tuna (*Thunnus albacares*) based on oceanographic parameters (sea surface temperature (SST), salinity, and chlorophyll-*a*) using satellite data obtained from Marine Copernicus at West Sumatra waters, within an area of 74.23 mi and 1,189 catchment points. Oceanographic and catches data of yellowfin tuna from 2019 to 2020 (on a fishing catch) were analyzed. The data analysis involved catch per unit effort (CPUE) analysis, multiple linear regression analysis, and indicators for estimating potential fishing ground. Based on the results, yellowfin tuna catches spread throughout the West Sumatra waters, with the average range of SST distribution 29.43-30.93^{o}C, salinity 32.8-33.6 ppt, and chlorophyll-*a* 0.12-0.16 mg m^{-3}. Meanwhile, regression test analysis showed their significant effect by the value of F $8.23 \times 10^{-5} < 0.05$ between oceanography parameters and yellowfin tuna catches. Furthermore, CPUE value was classified as high with the value > average CPUE (163.69 kg $trip^{-1}$ > 159.30 kg $trip^{-1}$). In conclusion, the estimation of yellow fin tuna fishing ground based on the oceanographic parameters revealed that West Sumatra waters was categorized as a potential fishing ground.
Key Words: chlorophyll-*a*, fishing ground, salinity, sea surface temperature, yellowfin tuna (*Thunnus albacares*).

Introduction. West Sumatra waters have several potential pelagic fish resources such as tuna (*Thunnus* sp.), skipjack tuna (*Katsuwonus pelamis*), mackerel tuna (*Euthynnus affinis*), and mackerel (*Scomberomorini* sp.). Among those species, yellowfin tuna (*Thunnus albacares*) is a type of tuna widely caught with a high quality in West Sumatra waters. According to Sitepu et al (2023), yellowfin tuna is a commercial commodity exceedingly demanded in Bungus Ocean Fishing Port (PPS Bungus), West Sumatra. FAO (2018) reported that tuna fishing industry in Indonesia has remarkably grown in 2016 leading Indonesia to be the top country worldwide in terms of tuna landings. However, in the following years based on the statistical report by Bungus Ocean Fishing Port (2020), in the range of 2017-2020, the productions of yellowfin tuna catches showed a declining trend including in 2017 (575.92 tons), 2018 (468.49 tons), 2019 (499.86 tons), and 2020 (275.83 tons). This report indicated that there was a decrease in the yellowfin tuna catches from year to year.

A declining trend in yellowfin tuna catches has been influenced by oceanographic parameters such as sea surface temperature (SST), salinity, and chlorophyll-*a.* Based on existing oceanographic parameters, observations of sea conditions should be carried out effectively without spending large amount of costs and taking a lot of time. Siregar et al (2022) reported that fishermen productivity is linked with fishing results, such as social and economic factors, including costs, number of boats, number of workers, experience, and distance to fishing ground. In addition, oceanography parameters take a profound position to anticipate the cost overruns of fishing activities since it helps the fishermen to comprehend the fishing grounds well. Indeed, comprehending the fishing ground very well gives the fishermen an opportunity to determine an appropriate strategy for obtaining optimal catches and avoiding redundant costs (Siregar et al 2022).

Satellite data visualized by a geographic information system (GIS) can see the distribution of the fishing grounds based on several parameters of oceanographic conditions such as sea surface temperature (SST), salinity, and chlorophyll-*a*. These parameters can be taken from Marine Copernicus website which provides a collection of observational and satellite data involving SST, salinity and chlorophyll-*a* sensors. The utilization of GIS approach, coupled with various spatial analysis methods, can serve a potential solution to address these issues (Nurholis et al 2020). Yellowfin tuna is often found in the distribution of SST of 29.5°C, salinity of 33.7 ppt, and sea surface height (SSH) of 0.89-0.92 cm (Syah et al 2020). Changing in oceanographic parameters affects the existence of fish and the formation of potential fishing grounds. Oceanographic parameters and their fluctuations have a direct impact on various aspects of fish behaviors and growth, including feeding behavior, metabolic rates, spawning activities, and other essential behaviors (Hsu et al 2021).

Based on the discussion above, this study aims to estimate the potential fishing ground of yellowfin tuna based on oceanographic parameters (SST, salinity, chlorophyll-*a*) utilizing GIS in West Sumatra waters and data productions of yellowfin tuna collected from Bungus Oceanic Fishing Port.

Material and Method

Description of the study sites. The study place was located in West Sumatra waters, Padang City. The research area covers 74,23 mi^2 and 1,189 catchment points, with the farthest fishing point of 166.6 miles and the closest fishing point of 14.16 miles (Figure 1). Data were collected from Bungus Ocean Fishing Port.

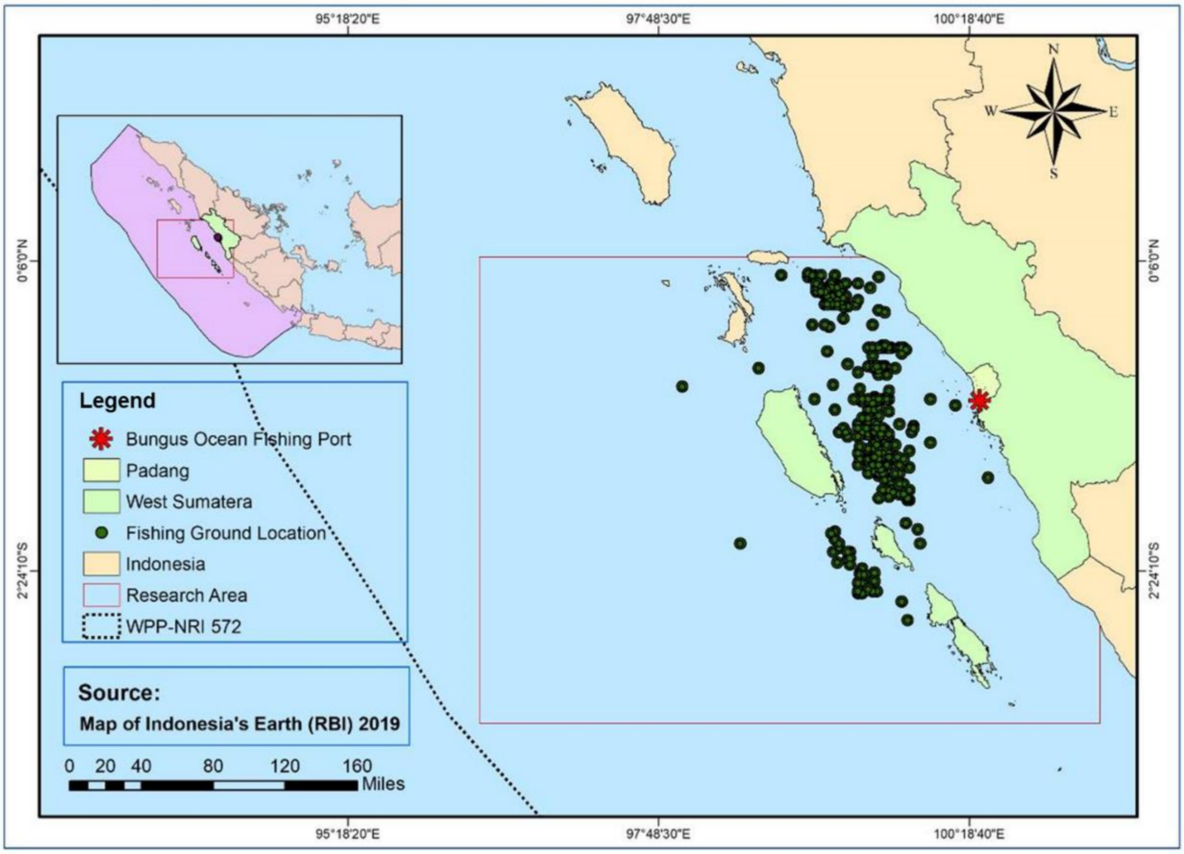


Figure 1. The location of research, West Sumatra waters.

Materials. Data collections consist of primary data and secondary data. The primary data such as oceanographic data (SST, salinity, and chlorophyll-*a*) were based on the 2019-2020 (on a fishing catch) distribution obtained from Marine Data Copernicus (Table 1) and analyzed using software (ArcGIS 10.8 and Microsoft Excel). Meanwhile, the secondary data such as logbook data (time of catch, coordinates point, and amount of yellowfin tuna catches) was obtained from the Bungus Oceanic Fishing Port based on several fishing gears used by local fishermen including boat liftnets, tuna handline, handline, tuna long line, trawl, and troll line.

Table 1

Survey parameters used in research

Parameter	*Unit*	*Information*	*Data size*	*Data source*
Sea surface temperature (SST)	°C	Temperature distribution measurements	0.083° × 0.083°	- Global Ocean Physics Reanalysis; - Global Ocean 1/12°C Physics Analysis and Forecast.
Salinity	ppt	Salinity distribution measurements	0.083° × 0.083°	- Global Ocean Physics Reanalysis; - Global Ocean 1/12°C Physics Analysis and Forecast.
Chlorophyll-*a*	mg m^{-3}	Chlorophyll-*a* distribution measurements	0.25° × 0.25°	- Global Ocean Biogeochemisty Hindcast; - Global Ocean Biogeochemisty Analysis and Forecast.

Data analyses methods. The present research was tested by several analyses, such as catch per unit effort (CPUE) analysis, multiple linear regression analysis, and indicators for estimating potential fishing ground.

Catch per unit effort (CPUE) analysis. The calculation of CPUE aims to determine the abundance and the utilization level of yellowfin tuna landed in Bungus Oceanic Fishing Port. According to Devasa et al (2023), a standardization of fishing gear can be calculated using the following formula:

$$CPUE = \frac{Ci}{Fi}$$

where: CPUE = the amount of catch per capture effort (kg trip^{-1});
Catch (C_i) = catch per fishing gear effort i (kg);
Effort (F_i) = catch per fishing gear effort (trip);

Multiple linear regression analysis. The relationship between oceanographic parameters and yellowfin tuna catch can be analyzed using multiple linear regression. Regression equations were done by applying the following formula (Uyanık & Güler 2013):

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3$$

where: Y = catch of yellowfin tuna (kg);
a = intercept coefficent;
X_1 = sea surface temperature (°C);
X_2 = salinity (ppt);
X_3 = chlorophyll-*a* (mg m^{-3});
b_1 = regression of temperature parameter coefficient;
b_2 = regression of salinity parameter coefficient;
b_3 = regression of chlorophyll-*a* parameter coefficient.

Estimation of the potential fishing ground analysis. Determination of potential fishing ground was assessed by considering several indicators such as CPUE, oceanographic parameters evaluation, scoring estimation of potential fishing ground. According to Bukhari et al (2017), estimation of the potential fishing areas can be done through CPUE indicators (Table 2).

Table 2

Fishing ground assessment with CPUE indicators

No.	*CPUE category*	*Criteria*	*Score*	*Fishing ground category*
1.	High	CPUE > average CPUE	6	Potential
2.	Low	CPUE ≤ average CPUE	4	Less potential

Zen et al (2005) explained the meaning of catch analysis in the fishing ground of yellowfin tuna as follows:

1. If the CPUE value is high, it means that the fishing ground can be categorized as a potential area;
2. If the CPUE value is low, it means that the fishing ground is categorized as a low potential area.

Weight determination available in Tables 3 and 4 will be added in Table 5. According to Bukhari et al (2017), fishing ground identification was made by numbering the scores that were the sum of existing indicators. Potential category is scored by 19 to 22, medium category is 16 to 19, and less potential is 13 to 16.

Table 3

Evaluation Potential Category of the fishing ground based on oceanographic parameters

No.	*Parameter*	*2 (less potential)*	*4 (medium)*	*6 (potential)*
1.	SST (°C)	< 24 and > 30	25-28	29-30
2.	Salinity (ppt)	< 20 and > 35	20-30	30-35
3.	Chlorophyll-*a* (mg m^{-3})	< 0.1	0.1-0.2	> 0.2

Table 4

Assessment of the fishing ground location indicator

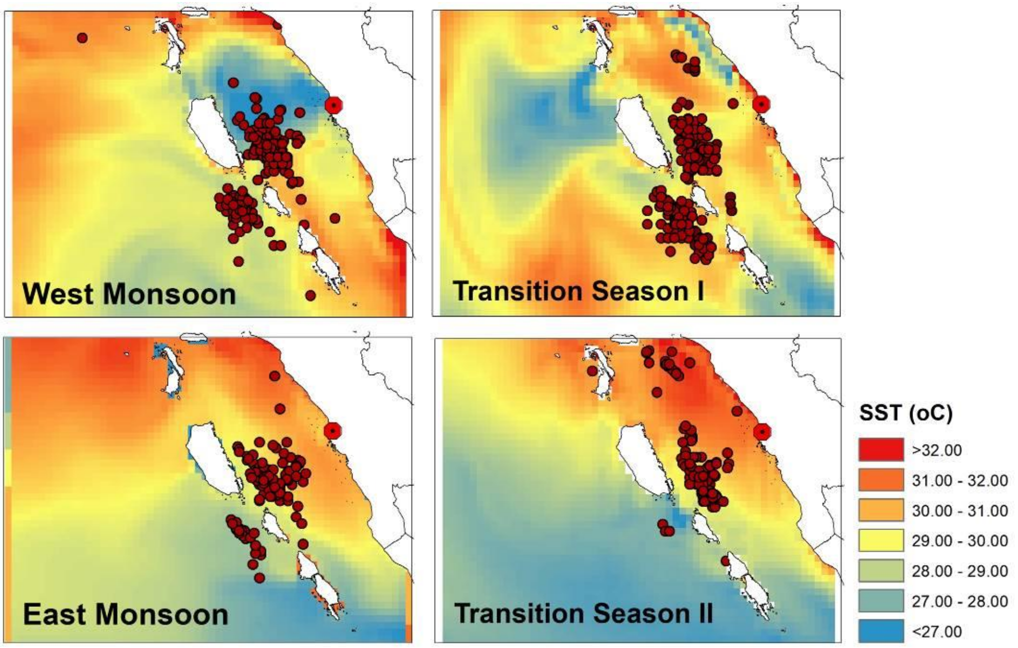
Fishing ground location indicator				*Fishing ground location category*
CPUE (kg $trip^{-1}$)	*SST (°C)*	*Chlorophyll-a (mg m^{-3})*	*Salinity (ppt)*	
Optimum (n = 6)	Optimum (n = 6)	Optimum (n = 6)	Optimum (n = 6)	Potential (n = 19-22)
Medium (n = 4)	Medium (n = 4)	Medium (n = 4)	Medium (n = 4)	Medium (n = 16-19)
Not Optimal (n = 2)	Not optimal (n = 2)	Not optimal (n = 2)	Not optimal (n = 2)	Less potential (n = 13-16)

*n = scoring.

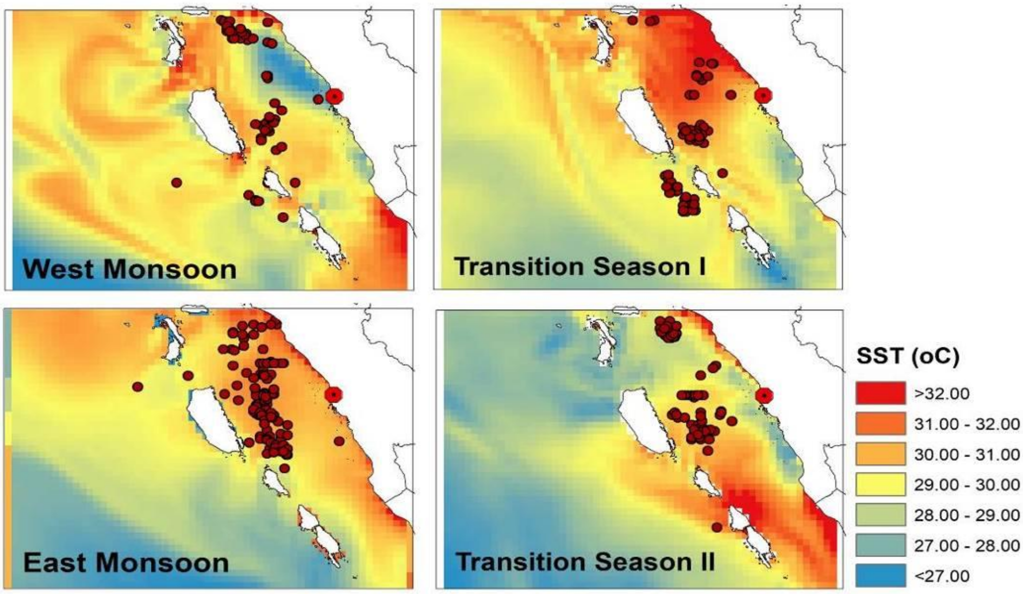
Results and Discussion

Distribution of sea surface temperature. Figure 2 shows the distribution of SST in the waters of West Sumatra during the years 2019-2020 across the west monsoon, east monsoon, transitional season I, and transitional season II. The distribution of SST in these four seasons indicates that the waters of West Sumatra are potentially suitable as a fishing ground. The highest SST occurred during transitional season I (March-May), ranging from 29.99 to 30.95°C. The significant change in SST during transitional season I was influenced by the weakening of the monsoon winds, leading to a reduction in upwelling intensity, which caused the surface water to become relatively warmer (Putra et al 2022). During the east monsoon (June-August), the SST distribution ranged from 29.24 to 30.76°C.

The east monsoon is characterized by low rainfall intensity due to wind patterns blowing from Australia to Asia across Indonesia (Kurniawati et al 2015). Conversely, the lowest SST distribution occurred during transitional season II (September-November), with a range of 29.01 to 30.28 °C. The movement of monsoon winds from the southeast to the northwest over the waters of West Sumatra caused an increase in upwelling intensity, resulting in cooler SST. Additionally, the sun's movement farther from the equator reduced solar radiation in the waters of West Sumatra, thereby decreasing ocean warming (Alfajri et al 2017).



(a)

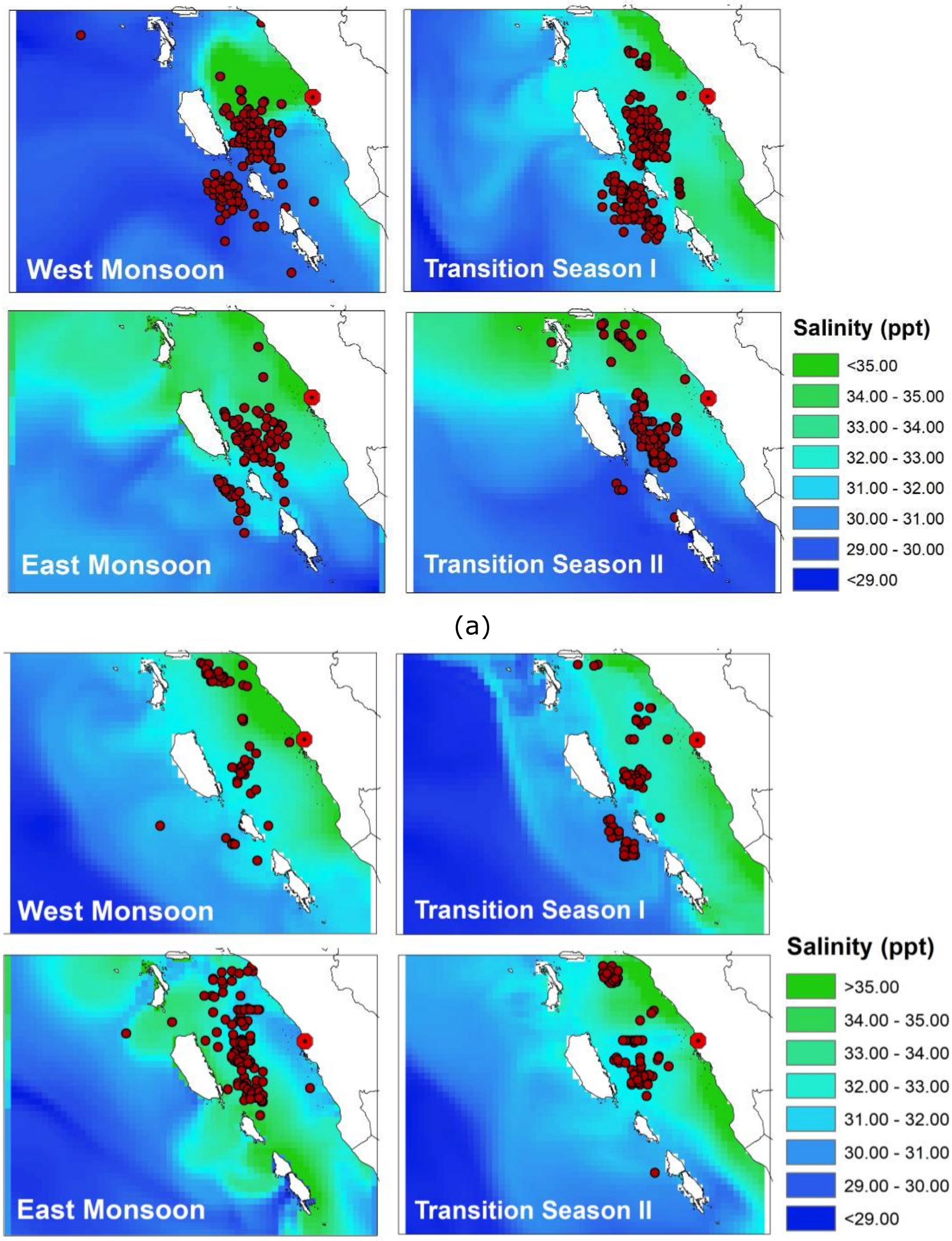


(b)

Figure 2. Distribution of sea surface temperature: a) 2019; b) 2020.

Based on the analysis, it can be indicated that most of yellowfin tuna was caught in the SST distribution ranging from 28.65 to 30.93°C in West Sumatra waters. Weng et al (2017) added that yellowfin tuna is commonly found below and above the thermocline, temperatures of 18-31°C. Meanwhile an effective yellowfin tuna catching is largely obtained in the SST starting from 20°C and also at 28°C where it often lives in groups with dolphins.

Salinity. Yellowfin tuna in West Sumatra waters in Figure 3 were caught within an average distribution of salinity ranging from 30.88 to 34.32 ppt, with the highest average salinity in the east season (June-August) being 33.23 to 34.16 ppt and the lowest average salinity in the west monsoon (December-February) being 30.88 ppt to 33.64 ppt. A decrease in salinity was a result of a high rainfall and luminous intensity during the western season (Syah et al 2020).



(b)

Figure 3. Distribution of salinity: a) 2019; b) 2020.

The distribution of salinity characteristics during transition seasons I and II shows fluctuations. In transition season I, the average distribution of salinity was about 32.85 to

33.62 ppt while in transition season II it ranged from 33.09 to 34.32 ppt. The average distribution of salinity demonstrated the optimal value in catching yellowfin tuna. According to Supadiningsih & Nurul (2004) and Tangke et al (2016), yellowfin tuna is infrequently found at low salinity but it can be easily found in the range of salinity between 32 and 35 ppt. The distribution of salinity in shallow waters tends to be higher since it is primarily influenced by a warmer condition (Rozirwan et al 2020).

Distribution of chlorophyll-a. Chlorophyll-*a* distribution in West Sumatra waters revealed good conditions ranging from 0.08 to 0.34 mg m^{-3}. The highest distribution of chlorophyll-*a* occurred at transition season II (October-November), ranging from 0.09 to 0.34 mg m^{-3}, while the lowest distribution of chlorophyll-*a* occurred in transition season I (March-May) and in east monsoon (June-August) ranging from 0.08 to 0.13 mg m^{-3}. The lowest distribution of chlorophyll-*a* was dominated by the lowest variance value of 0.08 to 0.09 mg m^{-3} (Figure 4). A high chlorophyll-*a* concentration leads to boost a primary productivity since small fish which are the prey for tuna will gather at an abundant chlorophyll-*a* area (Ningsih et al 2021).

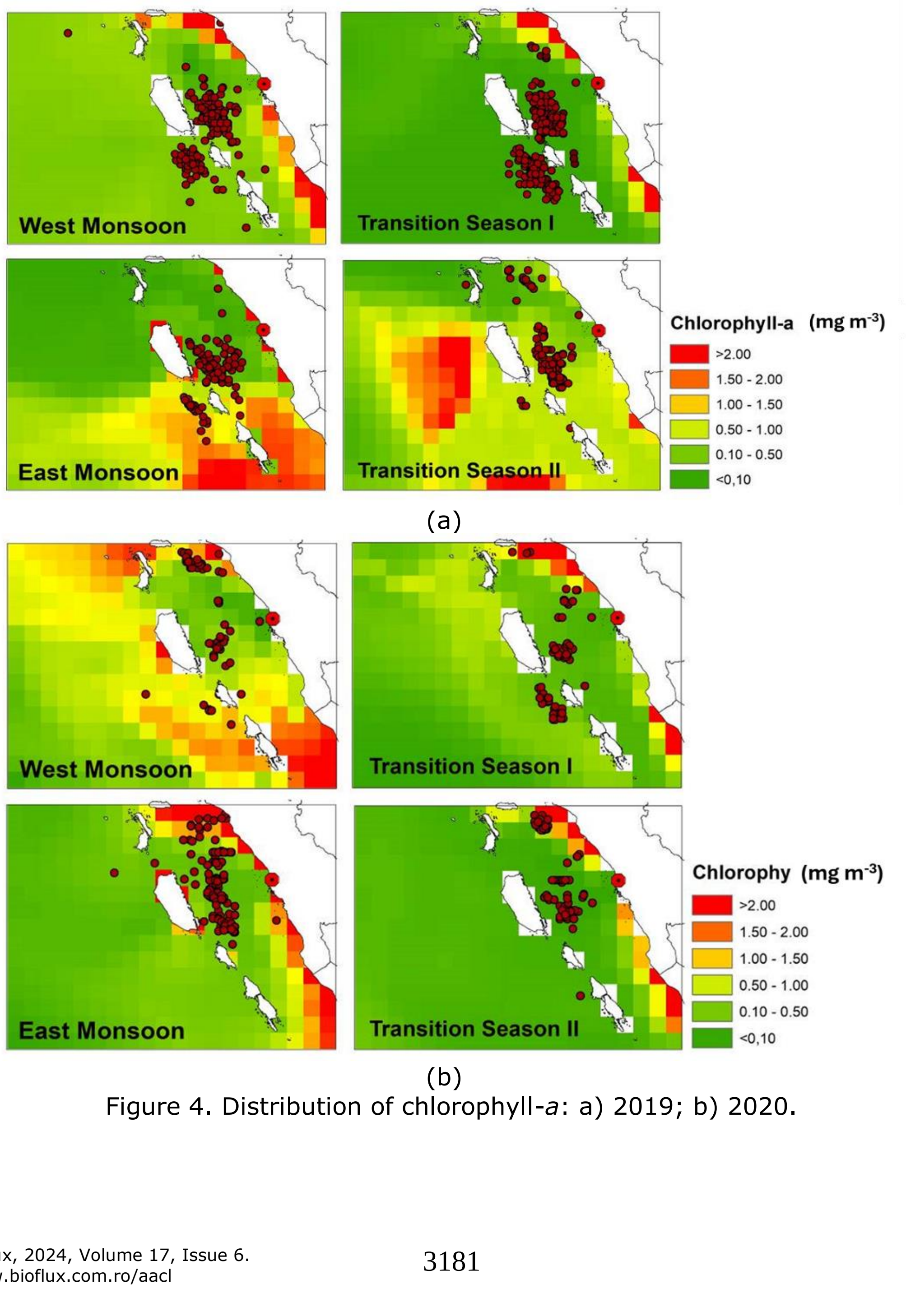


Figure 4. Distribution of chlorophyll-*a*: a) 2019; b) 2020.

In west monsoon (December-February), the average distribution of chlorophyll-*a* ranged from 0.08 to 0.21 mg m^{-3}. A higher rainfall intensity in west monsoon is beneficial to a high chlorophyll-*a* concentration due to plentiful nutrients brought from the mainland to the coast by the river flow (Syah et al 2020).

Catch of yellowfin tuna. The annual catch of yellowfin tuna in the West Sumatra waters during 2019-2021 revealed variability. The highest catch of yellowfin tuna in 2019 was 109,162 kg, with the highest catch in February gaining 13,408 kg and 128 trips. Meanwhile, in 2020 it had a catch of 87,635 kg, with the highest catch in October 2020 reaching 13,937 kg and 47 trips.

On the other hand, the lowest catch occurred in February 2020, where the total catch was 1,400 kg, with only two trips in West Sumatra Waters. Meanwhile, the rest of fishing trips were carried out outside the area of West Sumatra waters (open sea). Indeed, different natural factors influence the capture fisheries production. Indirectly, natural conditions may affect the number of fishing trips deployed by the fishermen as well as their fishing locations. It is very common that the fishermen use the weather condition not only to decide a proper time for conducting fishing activities but also to determine the areas where they will fish (Ridha et al 2013).

Looking at different fishing seasons, fishing activities in west monsoon (December-February) during 2019-2020 accounted for the highest catch value of 54,181 kg and the number of trips was 361 trips. Meanwhile, transition season I (March-May) was determined as the lowest fishing season amounted to 43,597 kg, and the number of trips was 325 trips. The catch in east season (June-August) has reached 50,663 kg, and the number of trips was 333 trips. Meanwhile, in transition season II (October-November) the total catch amounted to 51,330 kg, and the number of trips was 235 trips (Figure 5).

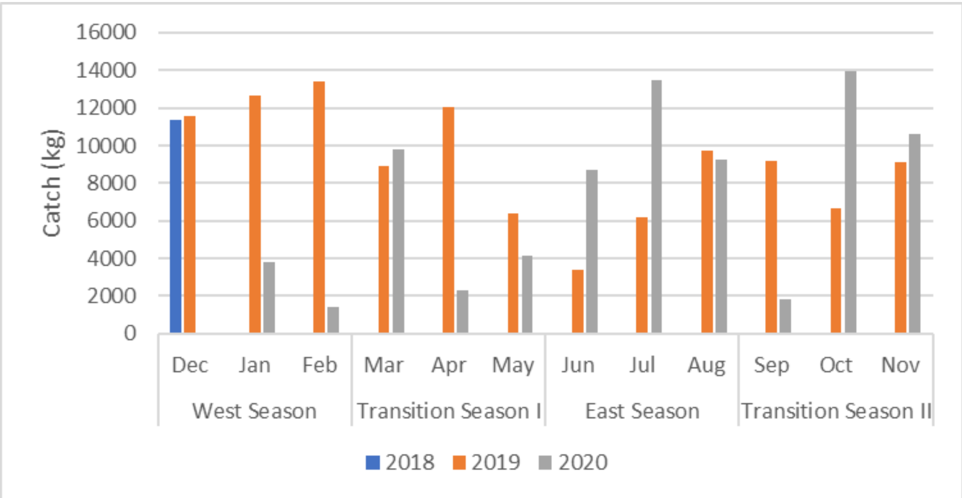


Figure 5. Catch of yellowfin tuna chart.

On the other side, fishing activities during February 2020 accounted for the lowest catch in which the total catch was 1,400 kg, with only two trips in West Sumatra waters. At the same time, other fishing trips were carried out outside the area of the West Sumatra waters (open sea). This finding relates with the characteristic of yellowfin tuna as a highly migratory fish species that can swim long distances throughout the open sea (Tambunan 2021). Moreover, yellowfin tuna can migrate within the economic exclusive zone (EEZ) of one or more countries and the open sea areas across national boundaries (straddling fish stocks). In addition, it cannot be neglected that natural factors also take a significant influence toward the capture fisheries production. Supporting natural conditions may lead to an optimal effort of fishing trips and a higher number of fishing locations. In fact, the local fishermen plan a decision related to when and where they fish by relying on their ability to reckon the circa weather (Ridha et al 2013).

CPUE'S analysis. Yellowfin tuna is one of the main catch commodities landed at Bungus Oceanic Fishing Port. The data from the oceanic fishing port (2016) revealed that the catch production of yellowfin tuna is a leading fish resource in West Sumatra Province reaching 319.58 tonnes in 2016. The CPUE value of yellowfin tuna catches in West Sumatra waters can be seen in Figure 6.

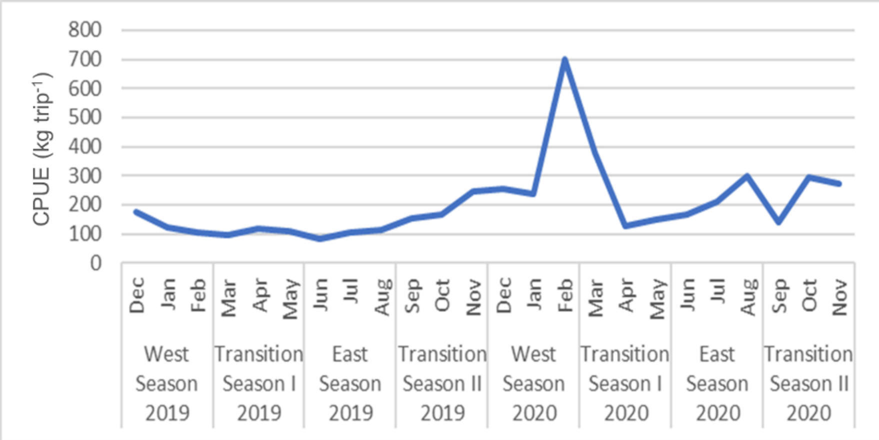


Figure 6. Catch per unit effort (CPUE) analysis chart.

The CPUE value of yellowfin tuna tends to be fluctuated during 2019-2020. The most considerable CPUE value was in February 2020 reaching 700 kg trip^{-1}. While the lowest CPUE value occurred in June 2019 only 82.78 kg trip^{-1}. Referring to the collected data, the fishermen deploying fishing activities in February 2020 only took two trips with the impact point at 0°16'S and 99°20'T (700 kg); 0°15'S 99°24'T (700 kg). The limited number of fishing trips in West Sumatra waters cannot be separated from the weather conditions and natural factors in that month which were not quite friendly for fishing so that the fishermen looked for safer alternative fishing locations on the open sea area.

Previous research (Limbong et al 2017) claimed that the weather condition during western monsoon resulted to unfavorable wave height in a wider area for conducting fishing activities. Therefore, many fishermen tended to operate fishing activities in the areas near small islands since it has a calmer current and wave. At this point, such natural conditions also tightly correlate to several elements supporting the capture fishing productions such as fishing season, number of fishing fleets, and number of fishing trips conducted by the fishermen (Limbong et al 2017).

Relation of catch yellowfin tuna with oceanography parameters. The determination of potential yellowfin tuna fishing grounds needs to involve more representative samples in order to be able to describe the extent of potential yellowfin tuna fishing grounds especially if the data is only based on productivity (Irham et al 2022). Nurani et al (2015) reported that there was a pattern in the relationship between tuna fishing season and water conditions in which the fishing season demonstrates a shift from east to west accompanied by distinct seasonal patterns in different areas. The monthly pattern of relationship between the number of catches and the characteristic of SST was identified assorted during the fishing seasons of 2019-2020 in Bungus Oceanic Fishing Port. The information related to this is depicted in Figure 7. The highest distribution of SST values occurred in March 2020, with an average distribution of SST value of 30.95°C, while the catch of yellowfin tuna was 9,825 kg. The lowest distribution of SST value occurred in October 2019, with an average distribution of SST value of 28.29°C and 6,680 kg of yellowfin tuna were caught.

In east monsoon and transitional monsoon, the occurrence of upwelling events was also consistent with some previous studies (Habibi et al 2010; Atmadipoera & Widyastuti 2014; Nababan et al 2016; Wiryawan et al 2020). Laevastu & Hayes (1981) stated that a slight change in water temperature merely such as 0.02°C can lead to a notable shift in the fish population density within sub-tropical areas. The abundance numbers of tuna populations both seasonally and annually are interconnected and influenced by SST, chlorophyll-*a* levels, as well as upwelling and El Niño phenomenon (Wiryawan et al 2020).

Based on the graphic pattern in Figure 7, it depicts the condition where the distribution of SST was categorized as a potential area between 28-30^{o}C, so that the number of catches was also abundant. The relationship between the distribution of SST and the number of yellowfin tuna catches is multifaceted since the characteristic of yellowfin tuna as a predator in the sea surface makes it closely relying on the oceanographic parameters (Hsu et al 2021). The ideal oceanographic parameters not only serve an abundant number of preys for yellowfin tuna but also support its life cycle and growth including its feeding behaviors, metabolic rates, and spawning activities (Hsu et al 2021).

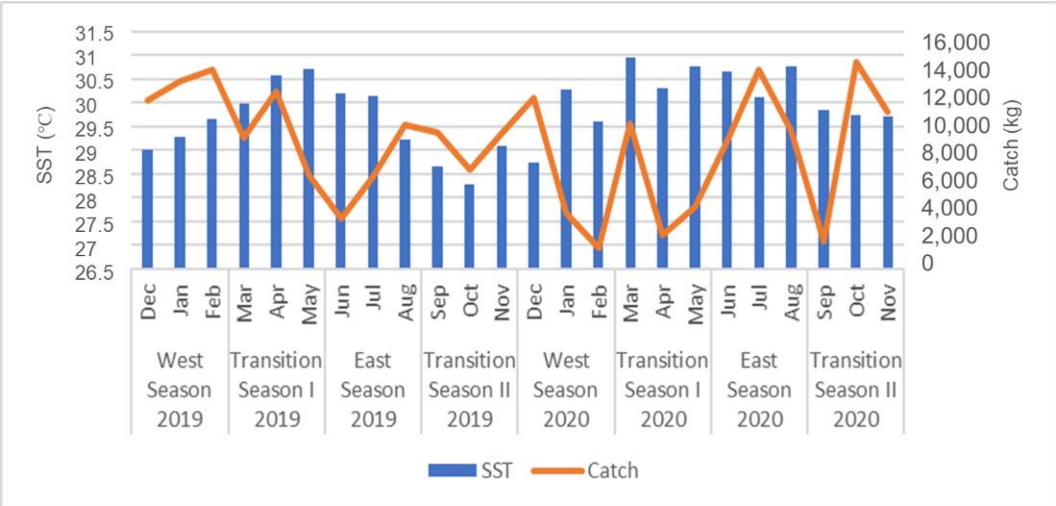


Figure 7. Catch of yellowfin tuna and distribution SST chart.

The distribution of salinity in West Sumatra waters ranged from 32 to 35 ppt, while the average catch of yellowfin tuna in 2019-2020 reached 8,234 kg. Based on the catch and salinity graphs in Figure 8, there were differences between the distribution patterns of salinity and the number of catches of yellowfin tuna in each fishing season. The highest salinity distribution occurred in September 2019, with the average salinity distribution of 34.32 ppt, and the catch of yellowfin tuna was 9,162 kg.

The lowest salinity distribution occurred in February 2020, with the average salinity distribution of 30.88 ppt, and the catch of yellowfin tuna amounted to 1,400 kg. One of the factors influencing the low catches in February was due to limited trips conducted by the fishermen in the West Sumatra waters, only two trips. The weather factors such a high current and waves has restricted the fishermen to conduct their fishing activities in West Sumatra waters. As an alternative to this unexpected natural condition, the fishermen prefer to deploy their fishing activities in several nearby small islands which have a modest characteristic of currents and waves. Therefore, it can be found a drastic decrease in the numbers of fishing fleets and trips in West Sumatra waters during this season (Limbong et al 2017).

Based on the graphic of the relationship between catch and salinity in Figure 8, it shows that the average distribution of salinity in West Sumatra waters is categorized as suitable, supported by satisfactory catches obtained during 2019-2020. Yellowfin tuna was caught in the salinity range of 30-34 ppt which is the optimum salinity for yellowfin tuna life.

The monthly distribution of chlorophyll-*a* values in West Sumatra waters ranged from 0.08 to 0.34 mg m^{-3}. The highest average distribution of chlorophyll-*a* occurred in November 2019 which was 0.34 mg m^{-3} and the catch of yellowfin tuna was 9,121 kg. In contrast, the lowest average distribution of chlorophyll-*a* occurred periodically in December 2018 - May 2019 (west monsoon 2019 - transition season I 2019). The lowest average distribution of chlorophyll-*a* was 0.09 mg m^{-3} and the lowest average catch amounted to 10,792 kg. Chlorophyll-*a* distribution is one of crucial oceanographic parameters for assessing the existence of fish in a fishing ground and it is influenced by several factors such as luminous intensity and nutrient availability (Ningsih et al 2021; Setiawati et al 2021).

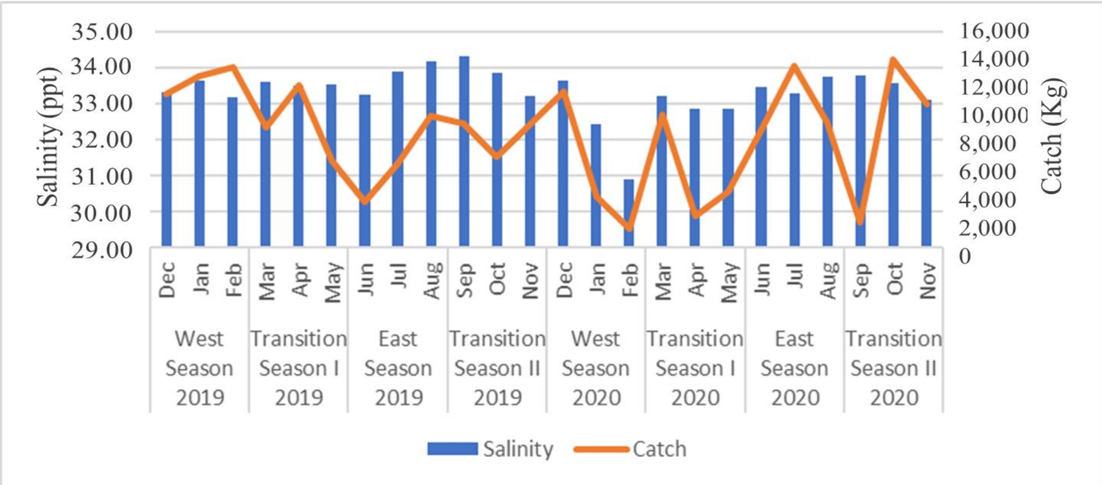


Figure 8. Catch of yellowfin tuna and salinity distribution chart.

Unfortunately, low values of chlorophyll-*a* distribution were also identified in April 2020 until November 2020, with the average distribution of 0.09 mg m^3 and the yellowfin tuna catch of 8,029 kg. According to Nurani et al (2022), a coastal water typically influenced by a range of physical factors exhibits a higher primary productivity compared to the open seas since lack of upwelling on a large scale. Furthermore, the spatial distribution of chlorophyll-*a* found in phytoplankton can be an indicator of water productivity level (Welliken et al 2018; Aulia et al 2021).

Based on the graphic in Figure 9, the monthly distribution of chlorophyll-*a* shows dynamic patterns; the low level of chlorophyll-*a* was in line with a decline in the number of catches. In contrast, if the distribution of chlorophyll-*a* increased reciprocally the catch would increase. Either the high or low distribution of chlorophyll-*a* in West Sumatra waters was influenced by other oceanographic conditions such as the distribution of SST, salinity, depth, currents, and so on.

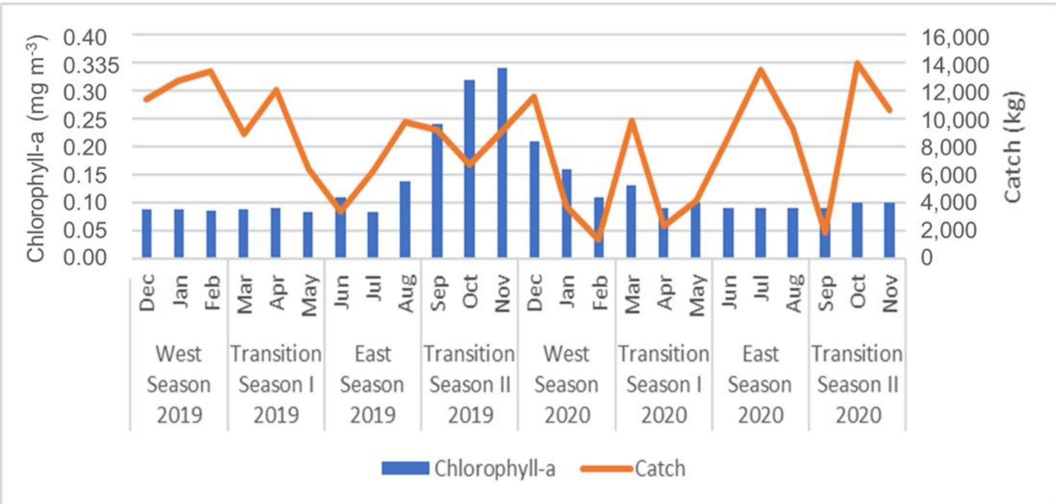


Figure 9. Catch of yellowfin tuna and chlorophyll-a distribution chart.

Results of multiple linear regression anlaysis. This analysis was intended to determine the effect of the independent variables namely SST (X1), salinity (X2), and chlorophyll-a (X3), toward the dependent variable namely the catch of yellowfin tuna (Y). The regression analysis results can be seen in Table 5.

Table 5

Regression analysis of the relationship between oceanography parameters and catch of yellow fin tuna

Variable	*Coefficient*	*P value*
(Constant)	5140.399	0.002869
SST (X1)	0.657265	0.984605
Salinity (X2)	-152.145	3.69×10^{-5}*
Chlorophyll-*a* (X3)	982.7207	0.008454*
R^2	0.650842	
F	12.42	

* Strongly significant.

Based on the results of the t-test in Table 5, the p-value of salinity (X2) and chlorophyll-a (X3) is 3.69×10-5 and 0.08 respectively, which indicates a p-value < 0.05. It can be concluded that changes in the salinity (X2) and chlorophyll-a (X3) have a significant effect on the catch of yellowfin tuna (Y) in West Sumatra waters.

Based on the coefficient value in Table 5 the following equation was obtained:

$$Y = 5140.39 + 0.65\ SST - 152.14\ Salinity + 982.72\ Chlorophyll\text{-}a$$

The regression model in Table 5 shows the effect of the three independent variables on the yellowfin tuna catch. A correlation coefficient (R) of 0.65 was obtained meaning that the relationship between the catch of yellowfin tuna and the independent variables, namely SST, salinity, and chlorophyll-*a*, was equal to 65%. The coefficient of determination (R^2) was 0.65, meaning that 65% of the variables that occurred in the catch of yellowfin tuna were caused by SST, salinity, and chlorophyll-a. While the rest of 35% was influenced by other factors.

The F test results in Table 5 show a significant F value of 8.23×10^{-5} smaller than α (0.05) and F_{count} 12.42 and F_{table} 3.10 ($F_{count} > F_{table}$). Therefore, the regression equation was acceptable, meaning that the oceanographic parameters, namely SST, salinity, and chlorophyll-*a*, significantly contributed to the catch of yellowfin tuna in West Sumatra waters. The relationship between the three variables was assumed to have a strong correlation with the upwelling process.

Analysis of potential fishing ground of yellowfin tuna. To determine the potential fishing ground of yellowfin tuna, a mapping of the suspected fishing ground was carried out based on an assessment of the suspected fishing ground, which can be seen in Table 6.

Table 6

Assessment of potential fishing ground of yellowfin tuna

Fishing season (2019-2021)	*Fishing ground location indicator*								*Total*	*Category*
	CPUE (kg trip^{-1})		*SST (°C)*		*Salinity (ppt)*		*Chlorophyll-a (mg m^{-3})*			
	Value	*Score*	*Value*	*Score*	*Value*	*Score*	*Value*	*Score*		
West	150.08	4	29.4	6	32.8	6	0.12	4	20	P*
Transition I	134.14	4	30.6	6	33.1	6	0.11	4	20	P*
East	152.14	4	30.1	6	33.6	6	0.1	4	20	P*
Transition II	218.42	6	29.4	6	33.5	6	0.16	4	22	P*

*P = potential.

Based on the assessment of yellowfin tuna fishing ground in 2019-2021, the yellowfin tuna fishing ground in West Sumatra waters is classified as a potential location. It can be concluded that the catch of yellowfin tuna spreads not only in the West Sumatra waters but also in the open sea areas. As stated by Trommer et al (2013) in Hastuti et al (2021) that generally the fishing ground of yellowfin tuna tended to move around. Dynamic changes of the environmental conditions lead the fish to move from one place to another finding a suitable habitat which has abundant food sources to maintain their lives.

Conclusions. Based on the oceanographic parameters applied, the annual characteristics distribution of SST, salinity, and chlorophyll-*a* in West Sumatra waters can be described as fluctuating. The multiple regression linear analysis shows that the two oceanographic parameters including salinity and chlorophyll-*a* simultaneously and significantly affect the number of yellowfin tuna catch (*Thunnus albacares*) in West Sumatra waters. Meanwhile, the estimation analysis of potential yellowfin tuna fishing ground based on several indicators identified West Sumatra waters as a potential fishing ground.

Acknowledgements. We are very keen to thank the Head of Bungus Ocean Fishing Port for providing and allowing us to use the fishing port data. A sincere thank also goes to all parties who have contributed to the success of this study.

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

References

Alfajri, Mubarak, Mulyadi A., 2017 Spatial and temporal analysis of sea surface temperature distribution in West Sumatra waters. Dinamika Lingkungan Indonesia 4(1):65-74. [in Indonesian]

Atmadipoera A. S., Widyastuti P., 2014 A numerical modeling study on upwelling mechanism in South of Makassar Strait. Jurnal Ilmu dan Teknologi Kelautan Tropis 6(2):355-371.

Aulia F., Rusdi M., Deli A., Fuadi A., Irham M., Indra I., 2021 The Marxan model for determining no-catch zones based on conservation targets in the north-eastern region of Simeulue District. IOP Conference Series: Earth and Environmental Science 711(1):012024.

Bukhari B., Adi W., Kurniawan K., 2017 [Estimation of mackerel fishing areas based on distribution of sea surface temperature and chlorophyll-*a* in Bangka waters]. Jurnal Perikanan Tangkap: Indonesian Journal of Capture Fisheries 1(3):1-22. [in Indonesian]

Bungus Ocean Fishing Port (PPS Bungus), 2020 [Capture fisheries statistics at Bungus Ocean Harbor]. Laporan Statistik 2020, 175 pp. [in Indonesian]

Devasa R., Azzahra S. B., Nahar A., Maysabila A., Adiara F. A., Akbarsyah N., 2023 Analysis of maximum sustainable yield (MSY) and catch per unit effort (CPUE) multi fishing gear in PP Cikidang, Pangandaran Regency, West Java, Indonesia. World Scientific News 180:14-24.

FAO, 2018 The state of world fisheries and aquaculture (SOFIA) - meeting the sustainable development goals. FAO, Rome, Italy, 227 pp.

Habibi A., Setiawan R. Y., Zuhdy A. Y., 2010 Wind-driven coastal upwelling along South of Sulawesi Island. Ilmu Kelautan: Indonesian Journal of Marine Science 15(2):115-118.

Hastuti H., Wirasatriya A., Maslukah L., Subardjo P., Kunarso K., 2021 [Effect of chlorophyll-*a* factor and sea surface temperature on anchovy (*Stolephorus* sp.) catches in Jepara]. Indonesian Journal of Oceanography 3(2):197-205. [in Indonesian]

Hsu T. Y., Chang Y., Lee M. A., Wu R. F., Hsiao S. C., 2021 Predicting skipjack tuna fishing grounds in the Western and Central Pacific Ocean based on high-spatial-temporal-resolution satellite data. Remote Sensing 13(5):861.

Irham M., Akbar M. W., Mukhli M., Fuadi A., Authar M., Setiawan I., 2022 Catching investigation of yellowfin tuna (*Thunnus albacares*) based on the distribution of chlorophyll-*a* in the North waters of Aceh: a November and December analysis. E3S Web of Conferences 339:02004.

Kurniawati F., Sanjoto T. B., Juhadi, 2015 [Estimation of small pelagic fishing potential zones in Java Sea waters in West and East seasons using Aqua Modis imagery]. Geo-Image 4(2):9-19. [in Indonesian]

Laevastu T., Hayes M. L., 1981 Fisheries oceanography and ecology. Fishing News Books, 199 pp.

Limbong I., Eko S. W., Roza Y., 2017 [Factors influencing production yields of ring purine fishing units in PPN Sibolga, North Sumatra]. Albacore 1(1):89-97. [in Indonesian]
Nababan B., Rosyadi N., Manurung D., Natih N. M., Hakim R., 2016 The seasonal variability of sea surface temperature and chlorophyll-*a* concentration in the south of Makassar Strait. Procedia Environmental Sciences 33:583-599.
Ningsih W. A. L., Lestariningsih W. A., Heltria S., Khaldun M. H. I., 2021 Analysis of the relationship between chlorophyll-*a* and sea surface temperature on marine capture fisheries production in Indonesia: 2018. IOP Conference Series: Earth and Environmental Science 944(1):012057.
Nurani T. W., Wahyuningrum P. I., Wisudo S. H., Arhatin E. R., Komarudin D., 2015 Catch of tuna fish on trolling fishing in Indian Ocean waters, southern coast of East Java related to sea surface temperature variability. Malaysian Applied Biology 44(3):25-28.
Nurani T. W., Wahyuningrum P. I., Iqbal M., Khoerunnisa N., Pratama G. B., Widianti E. A., Kurniawan M. F., 2022 Skipjack tuna fishing season and its relationship with oceanographic conditions in Palabuhanratu waters, West Java. Malaysian Applied Biology 51(1):137-148.
Nurholis, Gaol J. L., Syah A. F., Dewi A. K., 2020 GIS-based spatio-temporal analysis on yellow fin tuna catch in Eastern Indian Ocean off Sumatera. IOP Conference Series: Earth and Environmental Science 429(1):012041.
Putra Y. E., Syarifuddin H., Sumadja W. A., 2022 [The effect of the distribution of sea surface temperature in the Indian Ocean south of Java on the catch of yellowfin tuna (*Thunnus albacares*) using Aqua Modis satellite imagery]. Asian Journal of Aquatic Sciences 5(2):169-175. [in Indonesian]
Ridha U., Hartoko A., Muskanonfola M. R., 2013 [Analysis of the distribution of lemuru (*Sardinella lemuru*) catches based on satellite data on sea surface temperature and chlorophyll-*a* in the waters of the Bali Strait]. Management of Aquatic Resources Journal (MAQUARES) 2(4):53-60. [in Indonesian]
Rozirwan, Apri R., Iskandar I., 2020 Distribution of zooplankton abundance and diversity in the vicinity of Maspari Island, Bangka Strait, South Sumatra, Indonesia. EurAsian Journal of BioSciences 14(2):3571-3579.
Setiawati M. D., Rachman H. A., As-syakur A. R., Syahailatua A., 2021 Identification of commercial tuna hotspot in the southern waters of Java-Bali through satellite remote sensing data. IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2021, July 11-16, Brussels, Belgium, pp. 7434-7437.
Siregar D. F. B., Hanum N., Martahadi, 2022 [Analysis of factors influencing fishermen's income in Islands Nine, Pangkar Susu District, Langkat District]. Jurnal Samudra Ekonomika 6(2):166-172. [in Indonesian]
Sitepu E. D. P., Isnaniah, Bustari, 2023 Productivity of yellow fin tuna (*Thunnus albacares*) catches on handline vessels before the continuation of the Covid-19 pandemic in PPS Bungus West Sumatra Province. Journal of Coastal and Ocean Sciences 4(2):66-72.
Supadiningsih C., Nurul R., 2004 [Determination of tuna and skipjack fishing grounds using remote sensing technology]. Pertemuan Ilmiah Tahunan I. Teknik Geodesi Institur Teknologi Sepuluh November, Surabaya, 16 pp. [in Indonesian]
Syah A. F., Siregar E. S. Y., Siregar V. P., Agus S. B., 2020 Application of remotely sensed data and maximum entropy model in detecting potential fishing zones of yellowfin tuna (*Thunnus albacares*) in the eastern Indian Ocean off Sumatera. Journal of Physics: Conference Series 1569(4):042097.
Tambunan N. Y., 2021 [The role of fisheries management institutions in tuna fisheries in Indonesia]. Jurnal Ilmu Sosial dan Pendidikan 5(2):535-546. [in Indonesian]
Tangke U., Karuwal J. W. C., Mallawa A., Zainuddin M., 2016 [Analysis of the relationship between sea surface temperature, salinity, and currents with tuna catches in the waters of the western part of Halmahera Island]. Jurnal IPTEKS Pemanfaatan Sumberdaya Perikanan 3(5):368-382. [in Indonesian]
Uyanık G. K., Güler N., 2013 A study on multiple linear regression analysis. Procedia - Social and Behavioral Sciences 106:234-240.

Welliken M. A., Melmambessy E. H. P., Merly S. L., Pangaribuan R. D., Lantang B., Hutabarat J., Wirasatriya A., 2018 Variability chlorophyll-*a* and sea surface temperature as the fishing ground basis of mackerel fish in the Arafura Sea. E3S Web of Conferences 73:04004.

Weng J. S., Lee M. A., Liu K. M., Huang H. H., Wu L. J., 2017 Habitat and behaviour of adult yellowfin tuna (*Thunnus albacares*) in the waters off southwestern Taiwan determined by pop-up satellite archival tags. Aquatic Living Resources 30:34.

Wiryawan B., Loneragan N., Mardhiah U., Kleinertz S., Wahyuningrum P. I., Pingkan J., Wildan, Timur P. S., Duggan D., Yulianto J., 2020 Catch per unit effort dynamic of yellowfin tuna related to sea surface temperature and chlorophyll in Southern Indonesia. Fishes 5(3):28.

Zen M., Simbolon D., Gaol J. L., Hartojo W., 2005 [Study of potential zones for catching mackerel (*Rastrelliger* spp.) in Asahan Regency, North Sumatra]. Seminar Nasional Perikanan Tangkap, pp. 303-314. [in Indonesian]

Received: 15 August 2024. Accepted: 06 November 2024. Published online: 30 December 2024.

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How to cite this article:
Lisna, Febryanti H. R., Heltria S., Toni Y., Ramadan F., Ramdhani F., 2024 Estimation of the fishing ground potential based on oceanography parameters (GIS-based) of yellowfin tuna (*Thunnus albacares*) in West Sumatra waters. AACL Bioflux 17(6):3175-3189.