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Identification Of Upwelling In The Transition Season As A Basis For Estimating Potential Areas For Fishing Mackerel In West Sumatra

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Abstract— The upwelling phenomenon can be utilized in determining potential fishing grounds, which can be identified through oceanographic phenomena such as sea surface temperature, chlorophyll-a, and ocean currents. This study aims to analyze the occurrence of upwelling as a basis for estimating potential macarel fishing grounds in the waters of West Sumatra. The results indicate variability in sea surface temperature, chlorophyll-a concentration, and currents, fluctuating between 2nd Transitional Season and 1st Transitional Season, with upwelling identified as low to very low. Multiple linear regression analysis reveals that sea surface temperature, chlorophyll-a, and currents significantly influence macarel catch rates, with a strong correlation between sea surface temperature and chlorophyll-a in relation to potential fishing areas. In conclusion, upwelling in the waters of West Sumatra is influenced by the variability of these oceanographic parameters, and a strong relationship exists between sea surface temperature and chlorophyll-a with the potential for macarel fishing.

Keywords— Upwelling; Fishing Seasons; Oceanography; Seasonal Variability

I.Introduction

The western coast of Sumatra serves as the location for one of the significant coastal upwelling systems in the Indian Ocean, which is integrated with the coastal upwelling system south of Java. The complexity of this system lies in the interaction between seasonal variability influenced by local atmospheric conditions and modulation by global climate phenomena such as the Indian Ocean Dipole and the El Niño Southern Oscillation, given its proximity to the equator (1). The significant contribution of upwelling regions to global capture fisheries is undeniable. Nearly 90% of the world's fish catches are harvested from highly limited areas, covering only about 2–3% of the ocean's surface, most of which are upwelling regions (2). One of the most widely produced fish species in West Sumatra, according to the Central Statistics Agency, is mackerel, with a production volume of 23,977 tons in 2021.

Fishing grounds are influenced by seasonal variations (3). while the transitional season is characterized by optimal fishing activity, with peak catches occurring in September and October (4). Fishing areas generally shift following environmental changes, affecting fish in selecting suitable habitats. Sea surface temperature and chlorophyll-a are physical factors that influence water productivity and are associated with fish distribution patterns (5). By understanding variations in sea surface temperature, chlorophyll-a, and ocean currents, it is possible to identify key locations such as oceanic fronts and upwelling zones and predict potential fish distribution (6).

Temporal and spatial variations in each parameter are linked to water fertility and flow patterns such as mixing processes and upwelling (7). Information on fishing seasons, including timing and fish presence, can assist fishermen in maximizing their catch (8). The period from July to December marks the fishing season for mackerel, with peak catches recorded in October (9). Previous studies on the upwelling phenomenon in West Sumatra have indicated that upwelling occurs during the East Monsoon and the 2nd Transitional Season (10). Therefore, this study aims to update and expand the existing information on the upwelling phenomenon in the waters of West Sumatra by analyzing sea surface temperature, chlorophyll-a, and ocean currents.

II. Research Method

A.Place and Time

This study was conducted at the Bungus Oceanic Fishing Port, located in Padang City, West Sumatra Province. The research was carried out from November 4, 2024, to November 22, 2024. The selected research period was intended to ensure adequate and representative data collection.

B.Materials and Equipment

The materials used in this study consist of oceanographic parameter data sourced from the Copernicus Marine Environment Service (CMES), accessible at http://marine.copernicus.eu/. The data utilized in this research include sea surface temperature, chlorophyll-a concentration, and ocean currents during the 2nd Transitional Season (September 1 – November 30, 2022) and 1st Transitional Season (March 1 – May 31, 2023). These periods were selected to capture the seasonal variations occurring in the waters of West Sumatra.

C.Research Methods

This research is a qualitative study employing a survey approach. The survey method will utilize ArcGIS 10.8 as a data processing and layout application to obtain the analytical results.

D.Data Analysis

a.Variability of sea surface temperature distribution, chlorophyll-a, and currents

The analysis of sea surface temperature changes, chlorophyll-a concentration, and current patterns can be conducted through the following procedures: Relevant data are downloaded from the website https://data.marine.copernicus.eu and then transferred into ArcGIS software in raster format. The data are subsequently processed to eliminate any potential disturbances or anomalies. Following this, the raster data are converted into contour maps for clearer visualization. Finally, the distribution of these parameters is visualized with additional essential information, such as a legend, to facilitate interpretation.

b. Determination of Upweling Districts

The process of identifying upwelling areas is conducted using the overlay technique, which involves superimposing chlorophyll-a data onto a sea surface temperature map. The upwelling criteria used in this study align with the following category (11).

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Table 1. Category Upweling

Category	**Sea Surface Temperature (°C)**	**Chlorophyll-a (mg/m^3)**
Upwelling Very Low (UVL)	>29,008	< 0,147
Upwelling Low (UL)	28,033 ≤ UL≤ 29,008	0,147 ≤ UL ≤ 0,353
Upwelling Strong (US)	27,058≤ US ≤ 28,033	0,353 ≤US ≤ 0,560
Upwelling Very Strong (UVS)	< 27,058	> 0,560

c. Regresi Linear Berganda

The multiple linear regression analysis is used to measure the influence of variables such as sea surface temperature, chlorophyll-a, and currents on the occurrence of upwelling, as well as its impact on areas considered potential for fish capture.

$$Y = a + b1X1 + b2X2 + b3X3$$

Information:

Y : Macarel catch	A: Constanta
X1: Sea surface temperature	b1: Regression coefficient for the sea surface temperature parameter
X2: Chlorophil-a	b2: Regression coefficient for the chlorophyll-a parameter
X3: Current	b3: Regression coefficient for the current parameter

d. Analysis of Potential Fishing Areas

The next stage of this research is to conduct a correlation analysis to determine the strength of the relationship between potential fishing areas, sea surface temperature, and chlorophyll-a. Subsequently, the suitability of this relationship will be identified based on the interpretation of the correlation analysis (12).

$$r = \frac{N(\sum XY)-(\sum X \sum XY)}{\sqrt{(N(\sum X^2-(\sum X)^2)-(N(\sum Y^2)-(\sum Y)^2)}}$$

r : Potential fishing area	y : Nilai Chlorophyll-a
x : Sea surface temperature value	N : Amount of data

Table 2. Upwelling Categories

Correlation Coefficient	**Relationship Interpretation**
0,80 – 1,00	Very strong
0,60 – 0,79	Strong
0,40 – 0,59	Moderate
0,20 – 0,39	Low
0,00 – 0,19	Very Low

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III. Results And Discussion

On the western coast of West Sumatra, specifically in Bungus Bay, Padang City, there is the Bungus Ocean Fishing Port (PPS). One of the common fishing gear used at this port is the bagan perahu (boat lift net), which specifically targets macarel as the main catch and operates for seven days each fishing trip.

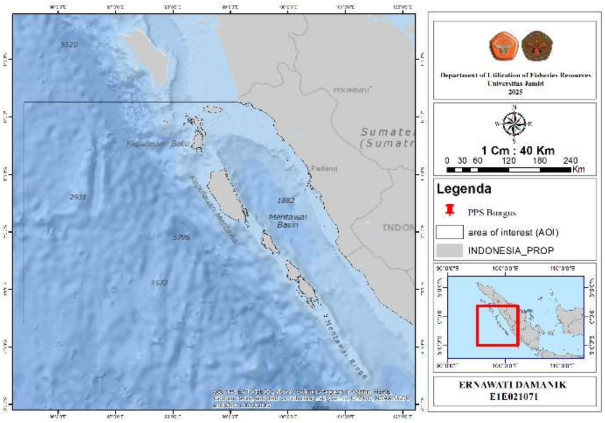

Figure 1. Map of the Research Location

A. Temporal Spatial Distribution of Sea Surface Temperature, Chlorophyll-a, and Current.

Water productivity and fishing location are greatly influenced by the distribution of sea surface temperature, chlorophyll-a, and ocean currents. Spatial-temporal analysis allows us to map the changes and distribution of each parameter, as well as understand the reciprocal relationships among the three.

a. Sea Surface Temperature

Based on the data analysis conducted, the monthly sea surface temperature in the waters of West Sumatra fluctuated from June 1, 2022, to May 31, 2023. The highest value occurred in May 2023, during 1st Transitional Season, as shown in Figure 2 with a dark blue color. The sea surface temperature in that month reached 31°C, while the lowest sea surface temperatures occurred in September 2022, during 2nd Transitional Season, and in March 2023, during the 1st Transitional Season, as shown in Figure 2 with a light blue color, both at 29°C.

The sea surface temperature in West Sumatra peaks during 1st Transitional Season, ranging from 29.99°C to 30.95°C. This temperature increase is caused by significant changes in sea surface temperature that occur during 1st Transitional Season. These changes are influenced by the weakening of the monsoon winds, which leads to a reduction in upwelling intensity. As a result, the sea surface temperature becomes relatively warmer (13).

In Figure 2, it can be observed that the coastal areas have a sea surface temperature in nearshore waters that tends to be darker blue compared to the sea surface temperature in offshore or open waters, which appear lighter blue. This indicates that the sea surface temperature in nearshore waters is generally higher than that in offshore or open waters (14). The relatively high temperatures in coastal waters are likely due to the penetration of sunlight, which can maximally irradiate the waters. This is supported by the shallower waters in coastal areas, allowing the sun to penetrate more effectively.

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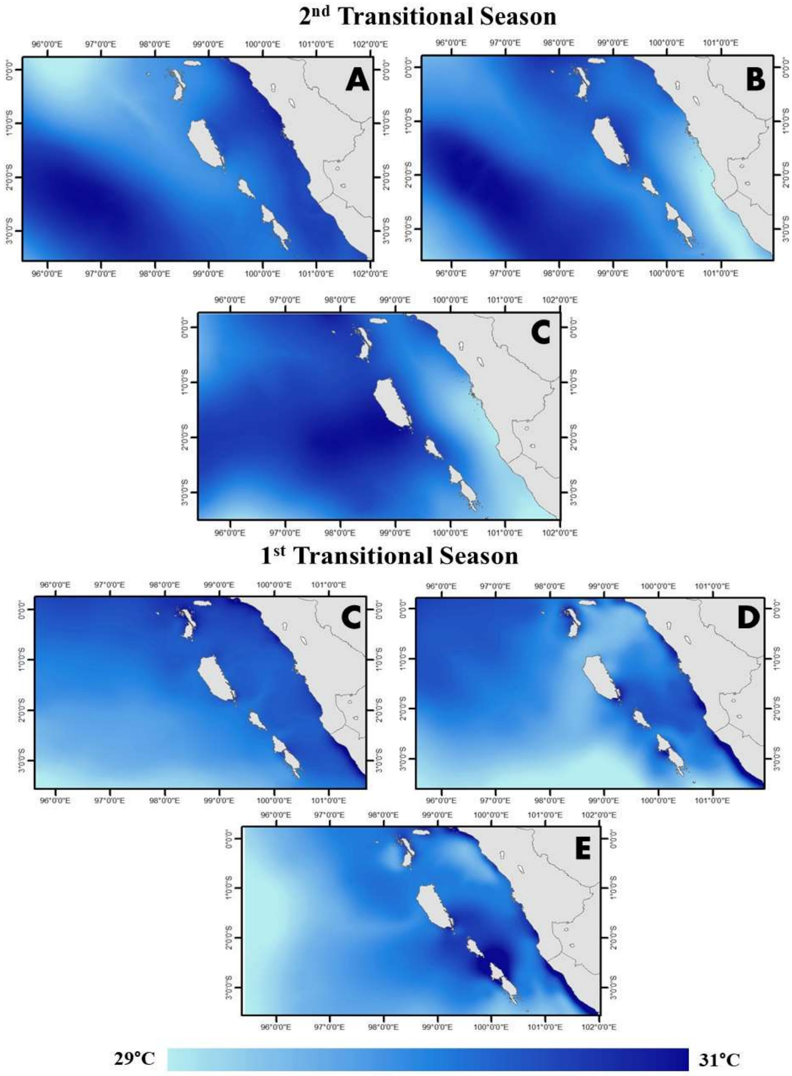

Figure 2. Distribution of Sea Surface Temperature in West Sumatra in the period 1 September 2022 - 30 November and 1 March - 31 May 2023

A.) September B.) October C.) November d.) Maret A.) April F.) May

The decrease in sea surface temperature from the 1st Transitional Season to the West Monsoon is caused by an increase in wind speed from July to December (15). In general, based on the average sea surface temperature, an increase in the monthly average sea surface temperature was observed during the 1st Transitional Season (16).

b. Chlorophyll-a

The distribution of chlorophyll-a concentration, as shown in Figure 3, indicates that the highest concentration occurred in May 2023, during 1st Transitional Season, with a concentration of 0.41 mg/m³. In contrast, the lowest concentration, recorded at 0.10 mg/m³, was observed in April and May 2023, also during the 1st Transitional Season. The average chlorophyll-a concentration during 1st Transitional Season remained consistent at 0.14 mg/m³ (17). Based on this value, the waters of West Sumatra meet the criteria for the optimal conditions for the viability of small pelagic fish, which range from 0.3 mg/m³ to 2.5 mg/m³ (18).

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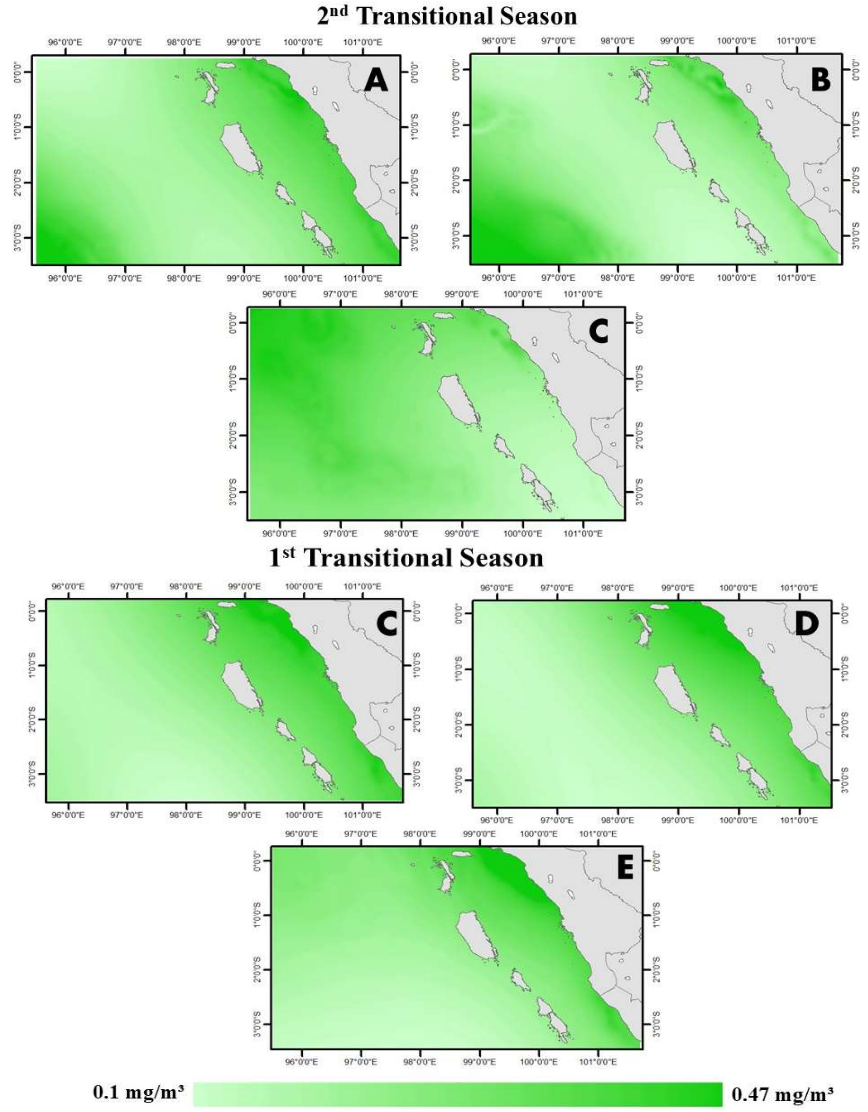


Figure 3 Distribution of Chlorophyll-a in West Sumatra in the period 1 September 2022 - 30 November and 1 March - 31 May

a.) September B.) October C.) November d.) Maret A.) April F.) May

The chlorophyll-a concentration fluctuated across different seasons. During the 2nd Transitional Season the concentration ranged between 0.11 and 0.38 mg/m³, while during the 1st Transitional Season, it varied between 0.10 and 0.47 mg/m³. These fluctuations can be observed particularly in the 2nd Transitional Season, where in September, the lowest concentration was recorded at 0.11 mg/m³, which then increased to 0.12 mg/m³ in October and further to 0.16 mg/m³ in November.

The highest chlorophyll-a concentration during 2nd Transitional Season was recorded in September at 0.26 mg/m³, increasing to 0.28 mg/m³ in October and peaking at 0.38 mg/m³ in November. In the 1st Transitional Season, the lowest chlorophyll-a concentrations remained stable between 0.10 and 0.11 mg/m³. However, the highest concentrations showed an increasing trend, reaching 0.25 mg/m³ in March, rising to 0.37 mg/m³ in April, and peaking at 0.47 mg/m³ in May. When compared to previous studies conducted in West Sumatra using data samples from 2019 to 2023, the highest chlorophyll-a concentration was his finding suggests that in 2023, the waters of West Sumatra experienced a decline in chlorophyll-a concentration compared to previous years.

Based on the distribution of chlorophyll-a concentrations obtained, the trophic status of the waters in West Sumatra is classified as oligotrophic, with chlorophyll-a concentrations ranging from 0-2 mg/m³ (20). In Figure 3, dark green coloration can be observed along the coastline of West Sumatra. The presence of dark green chlorophyll-a concentrations along the coast indicates that, spatially, chlorophyll-a concentrations are higher in coastal areas and gradually decrease toward offshore regions (21). During the 2nd Transitional Season, areas with high chlorophyll-a concentrations can be observed in offshore waters, as indicated by the dark green coloration. This phenomenon may be attributed to the accumulation of nutrients transported from land and human activities, which contribute to increased nutrient concentrations, thereby stimulating phytoplankton growth (22).

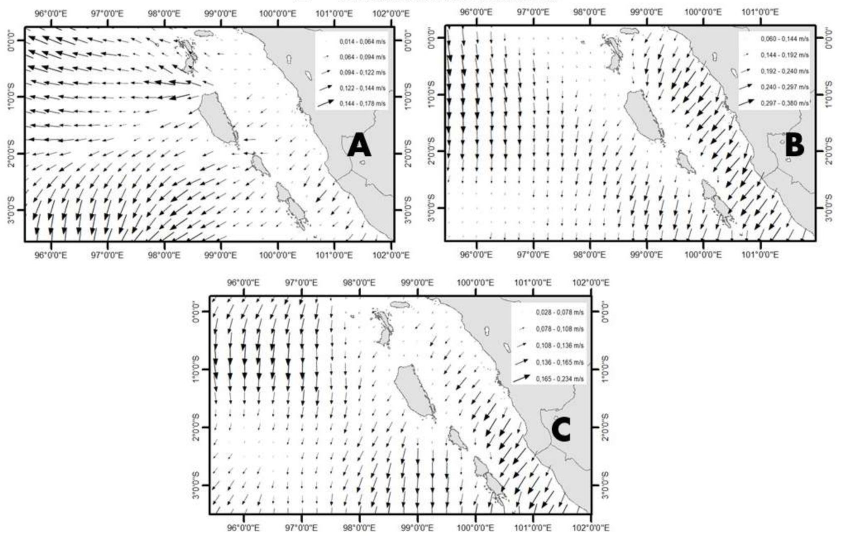
c. Current

Based on the data analysis conducted on current parameters over the period from June 1, 2022, to May 31, 2023, the current speed in the waters of West Sumatra was found to range from 0.001 to 0.34 m/s during the 2nd Transitional Season and from 0.001 to 0.51 m/s during the 1st Transitional Season. According to the current speed classification (23), the currents during the 2nd Transitional Season fall into the moderate category, with a range of 0.20–0.39 m/s, while the currents during the 1st Transitional Season are classified as strong, with a speed of ≥0.40 m/s.

It can be observed that there is an increase in current speed during the transition seasons. In the 2nd Transitional Season, the lowest recorded current speed was 0.001 m/s, occurring in every month. However, the strongest current speed showed a continuous increase, reaching 0.227 m/s in September, rising to 0.307 m/s in October, and peaking at 0.546 m/s in November. The high current speed during the 2nd Transitional Season is attributed to the increased intensity of rainfall, which significantly influences current velocity (24).

During the 1st Transitional Season, the lowest recorded current speed occurred in March at 0.001 m/s, increasing slightly in October and November to 0.003 m/s. The highest current speed in the 1st Transitional Season was recorded in September at 0.343 m/s, then decreased to 0.293 m/s in April before rising again to 0.321 m/s in May. The current speed in the waters of West Sumatra generally ranges between 0.9 and 1.5 m/s (25). As shown in Figure 4, offshore waters in the Indian Ocean exhibit high current speeds, indicated by longer arrow sizes. This phenomenon is primarily driven by wind blowing over the sea surface, which plays a major role in surface current movement, particularly in the central ocean, where the relationship between wind and currents is strong (26). The direction of these currents is then deflected by the Coriolis force, which results from the movement of water from high-pressure to low-pressure regions.

2nd Transitional Season



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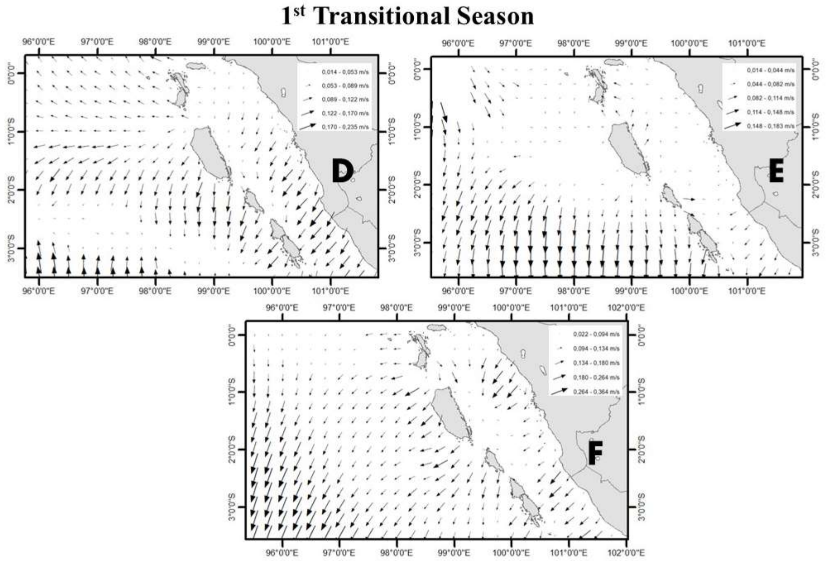

Figure 4. Distribution of Currents in West Sumatra in the period 1 September 2022 - 30 November and 1 March - 31 May 2023 based on (TII) Transitional Season II and (TI) Transitional Season I.

A.) September B.) Oct C.) November d.) Maret A.) April F.) May

B. Upweling

The distribution of upwelling events can be observed in Figure 5, where upwelling is categorized into four levels: very low, low, strong, and very strong. The upwelling phenomenon occurring in the waters of West Sumatra falls into the low and very low categories, with chlorophyll-a concentrations reaching 0.47 mg/m³ and sea surface temperatures of 29°C. According to the upwelling classification (11), West Sumatra is categorized as experiencing very low and low upwelling, with sea surface temperature distribution ranging from 28.033°C to 29.008°C and chlorophyll-a concentrations between 0.147 mg/m³ and 0.353 mg/m³.

Upwelling events were observed in the waters of West Sumatra during both the 2nd Transitional Season and 1st Transitional Season. However, in November 2022 and April 2023, no upwelling occurred. This finding is consistent with previous studies, which indicate that upwelling in West Sumatra typically begins in June, peaks in August, and ends in September (27). Even in periods without upwelling, macarel catches were still obtained. This can be attributed to the fact that the waters of West Sumatra are classified as moderately potential fishing grounds based on their sea surface temperature (27–32°C) and chlorophyll-a concentration (0.1–0.2 mg/m³) (6). Therefore, despite fishing activities not being concentrated in upwelling zones, abundant macarel catches were still recorded due to the moderate fishing potential of the West Sumatra waters.

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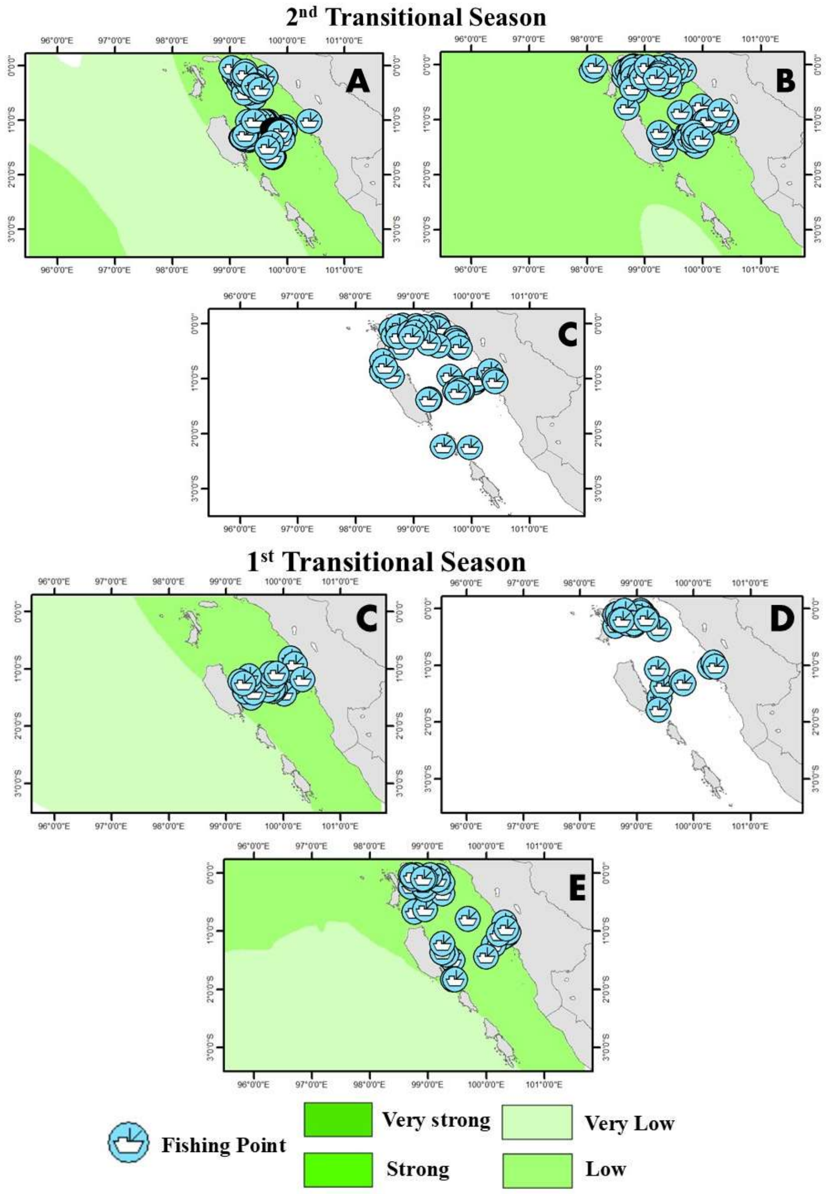

Figure 5. The distribution of Upwelling in West Sumatra in the period of September 1, 2022 - November 30 and March 1 - May 31, 2023 is based on (TII) Transitional Season II and (TI) Transitional Season I.

A.) September B.) Oct C.) November d.) Maret A.) April F.) May

The abundance of macarel is typically caught in waters with a sea surface temperature range of 27 - 29°C (9). In Figure 2, during the 2nd Transitional Season, the upwelling location can be correlated with the previous figure, which shows the sea surface temperature (Figure 2) transitioning from dark blue to light blue and Chlorophyll-a (Figure 3) in light green. During 1st Transitional Season, the sea surface temperature (Figure 2) exhibits a distribution of light blue color offshore, while Chlorophyll-a (Figure 3) is indicated by dark green near the coast.

Regions characterized by dark blue sea surface temperatures and light green chlorophyll-a concentrations indicate that these areas are not classified as upwelling zones. Even though some areas exhibit light green chlorophyll-a concentrations, upwelling does not occur if the sea surface temperature remains light blue. This pattern was also observed in November (1st

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Transitional Season) and April (2nd Transitional Season), where upwelling did not occur because either sea surface temperature or chlorophyll-a concentration did not meet the threshold for upwelling formation. Upwelling does not occur everywhere but is restricted to specific locations where environmental conditions are favorable for this phenomenon (28). In this study, upwelling was observed in offshore areas due to lower sea surface temperatures resulting from deeper waters and sufficient chlorophyll-a concentrations.

It can be observed that the fishing areas during upwelling events consistently remain in the same regions, with the highest catch recorded in October, totaling 67.375 ton macarel. This finding is supported by previous studies (29), which indicate that areas near upwelling zones exhibit significantly higher water productivity compared to other regions. Therefore, efforts should be made to optimize the utilization of these areas through targeted fishing operations in upwelling zones.

B. Relationship Analysis

Based on the analysis conducted, the results of multiple linear regression analysis were obtained to understand how three independent variables (Sea Surface Temperature, Chlorophyll-a, and Currents) influence a dependent variable (Catch Yield). According to the regression statistics, the relationship between the dependent variable and the three independent variables is relatively strong, with a multiple correlation coefficient (Multiple R) of 0.607. This regression model explains approximately 36.9% of the variation in the dependent variable or catch yield, as indicated by the coefficient of determination (R Square) of 0.369. The remaining 30.4% is influenced by other factors. The analysis of variance (ANOVA) indicates that the regression model is statistically significant overall ($p < 0.05$).

Table 1. The results of the analysis of factors that affect the catch.

Variable	**Coefficient**	**t Stat**	**P-value**
Constant	42.705,572	3.614	0.001
Sea Surface Temperature	-1.423,450	-3.547	0.002*
Chlorophyll-a	-3.212,219	-2.739	0.011*
Current	4.889,025	3.338	0.003*

Remarks: * Significantly affects the catch of mackerel
Multiple R : 0.607
R Square : 0.369
Adjusted R Square : 0.296
F count : 5.063
F table : 0.007

Y= 42.705,572 – 1.423,450 X1 – 3.212,219 X2 + 4.889,025X3

The regression coefficients indicate that Sea Surface Temperature (X1) has a significant negative effect on the dependent variable ($p < 0.05$). For every one-unit increase in Sea Surface Temperature (X1), the dependent variable is estimated to decrease by 1,423.450 units. Similarly, Chlorophyll-a (X2) also exhibits a significant negative effect on the dependent variable ($p < 0.05$), where a one-unit increase in Chlorophyll-a (X2) is expected to decrease the dependent variable by 3,212.219 units. However, Current (X3) shows a significant positive effect on the dependent variable ($p < 0.05$), indicating that for every one-unit increase in Current (X3), the catch yield is expected to increase by 4,889.025 units. Overall, this regression analysis confirms that Sea Surface Temperature (X1), Chlorophyll-a (X2), and Current (X3) are significant predictors of the dependent variable, or catch yield.

C. Correlation Analysis

Based on the correlation analysis conducted, a correlation value of 0.085 was obtained. Referring to the correlation category, it can be concluded that the relationship between sea surface temperature and chlorophyll-a with potential fishing grounds exhibits a very strong correlation. The correlation table, which presents the relationship between sea surface temperature and

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chlorophyll-a, provides valuable insights into the potential fishing areas. A correlation value of 0.085 indicates a very strong positive correlation between these two variables. This suggests a tendency for an increase in sea surface temperature to be followed by a rise in chlorophyll-a concentration, and vice versa.

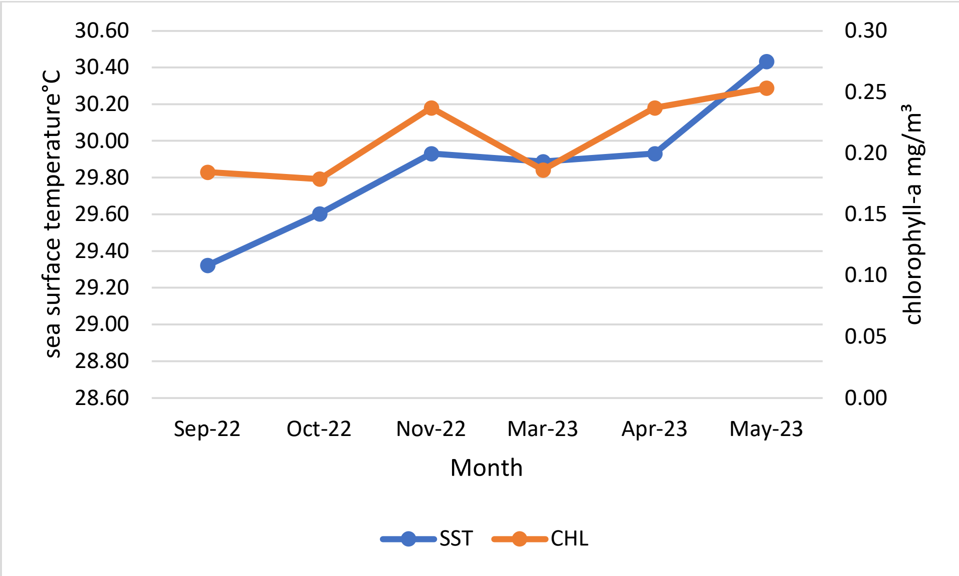

Figure 6. Graph Correlation of sea surface temperature and chlorophyll-a to potential fishing areas

In the context of fishing activities, this relationship indicates that areas with warmer sea surface temperatures tend to have higher concentrations of chlorophyll-a, which serves as an indicator of primary productivity in marine ecosystems. Chlorophyll-a is a pigment used by phytoplankton for photosynthesis, and phytoplankton forms the base of the marine food chain. Therefore, high concentrations of chlorophyll-a indicate an abundance of phytoplankton, which in turn can attract small fish and predator fish, including macarel.

However, it is essential to note that correlation does not always imply causation. While there is a positive relationship between sea surface temperature and chlorophyll-a concentration, this does not necessarily mean that sea surface temperature directly causes an increase in chlorophyll-a levels. Other factors, such as nutrient availability, sunlight intensity, and ocean current patterns, also play a role in influencing chlorophyll-a concentration. Additionally, the moderate correlation observed suggests that the relationship between sea surface temperature and chlorophyll-a concentration is not particularly strong. This implies that other factors also influence chlorophyll-a concentration and fish presence. Therefore, in determining potential fishing grounds, it is crucial to consider additional factors such as ocean depth, substrate type, and fish migration patterns.

IV. Conclusion

Based on the research conducted in the waters of West Sumatra, it can be concluded that upwelling in this region is influenced by the variability of sea surface temperature, chlorophyll-a concentration, and ocean currents. The upwelling occurring in the waters of West Sumatra during 2nd Transitional Season and 1st Transitional Season falls into the low and very low categories. The analysis results indicate that sea surface temperature, chlorophyll-a concentration, and ocean currents have a significant influence on macarel catch yields in West Sumatra waters during the periods of September 1 – November 30, 2022, and March 1 –

May 31, 2023. Additionally, a strong correlation is observed between sea surface temperature and chlorophyll-a in relation to potential fishing zones for macarel.

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