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RELATIONSHIP BETWEEN SEA SURFACE TEMPERATURE AND CHLOROPHYLL-A WITH YELLOWFIN TUNA CATCH AT THE CILACAP OCEAN FISHING PORT, INDONESIA

HUBUNGAN SUHU PERMUKAAN LAUT DAN KLOROFIL-A TERHADAP TANGKAPAN TUNA SIRIP KUNING DI PPS CILACAP, INDONESIA

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ABSTRACT

The Cilacap Ocean Fishing Port (PPS) is the main fishing center for yellowfin tuna (*Thunnus albacares*) in Southern Java. The objectives of this study are to map the distribution of sea surface temperature, chlorophyll-a concentration, and fishing ground for yellowfin tuna in the waters of the Cilacap PPS (Indonesian Fisheries Management Area/WPPNRI 573 and the open sea), and to examine the relationship between sea surface temperature and chlorophyll-a with yellowfin tuna catches. Based on the monthly logbook of the Cilacap PPS for 2019 to 2023, the data used included fishing locations and the number of yellowfin tuna caught. Aqua MODIS Level 3 satellite imagery from the same time period provided information on sea surface temperature and chlorophyll-a. The relationship between sea surface temperature and chlorophyll-a, as well as the catch of yellowfin tuna, was investigated using multiple linear regression in Microsoft Excel 365. The results show that yellowfin tuna were caught between 8–15 °S and 100–112 °E, with the highest catch concentrations occurring between 8–11 °S and 108–111 °E. Sea surface temperature ranged from 25 to 30 °C, while chlorophyll-a concentrations ranged from 0.05 to 0.28 mg/m^3. According to the regression model, sea surface temperature and chlorophyll-a combined accounted for only 16% of the variance in catch (R^2 = 0.16), indicating that other variables were more important.

Keywords: chlorophyll-a, Indian Ocean, sea surface temperature, upwelling, yellowfin tuna

ABSTRAK

Pelabuhan Perikanan Laut (PPS) Cilacap merupakan pusat utama penangkapan tuna sirip kuning (*Thunnus albacares*) di Jawa Selatan. Tujuan penelitian ini adalah untuk memetakan distribusi suhu permukaan laut dan konsentrasi klorofil-a, mengidentifikasi area penangkapan tuna sirip kuning di perairan PPS Cilacap (Wilayah Pengelolaan Perikanan Negara Republik Indonesia/ WPPNRI 573 dan laut lepas), dan meneliti hubungan antara suhu permukaan laut dan klorofil-a dengan hasil tangkapan tuna sirip kuning. Berdasarkan buku catatan bulanan PPS Cilacap untuk tahun 2019 hingga 2023, data yang digunakan meliputi lokasi penangkapan dan jumlah tuna sirip kuning yang dihasilkan. Citra satelit Aqua MODIS Level 3 pada periode waktu yang sama memberikan informasi tentang suhu permukaan laut dan klorofil-a. Hubungan antara suhu permukaan laut dan klorofil-a dengan hasil tangkapan tuna sirip kuning diteliti menggunakan regresi linier berganda di Microsoft Excel 365. Hasil penelitian menunjukkan bahwa tuna sirip kuning tertangkap pada kisaran antara 8–15 ºLS dan 100–112 ºBT, dengan konsentrasi tangkapan tertinggi berada pada kisaran antara 8–11 ºLS dan 108–111 ºBT. Suhu permukaan laut berkisar antara 25–30 °C, dengan konsentrasi klorofil-a berkisar antara 0,05–0,28 mg/m^3. Menurut model regresi, suhu permukaan laut dan klorofil-a secara gabungan menyumbang 16% dari varians tangkapan (R^2 = 0,16), menunjukkan bahwa variabel lain lebih penting.

Kata kunci: klorofil-a, Samudera Hindia, suhu permukaan laut, tuna sirip kuning, *upwelling*

INTRODUCTION

Indonesia is one of the world's largest tuna producers, with a total production of 1.39 million tons of tuna, skipjack, and mackerel (in 2021) and 1.49 million tons (in 2022) (KKP 2022). Yellowfin tuna, *Thunnus albacares*, is a highly prized tuna species frequently caught in Indonesian waters. One of the main ports in Java, the Cilacap Sea Fishing Port (PPS) is a popular spot for tuna viewing. In 2022, the port produced 8,846.92 tons of tuna, or approximately 44.33% of its total fisheries production (Azizi *et al.* 2020; Zahra *et al.* 2023). The predominance of the yellowfin tuna landings at the Cilacap PPS demonstrates the importance of studying this region to support tuna fisheries management based on oceanographic conditions.

Lack of knowledge about potential yellowfin tuna fishing locations is a major problem facing local fisheries management in the Cilacap Sea Fishing Port area. A common technique for identifying potential fishing locations is oceanographic parameter analysis (Putra *et al.* 2017; Susilo and Wibawa 2016). Sea surface temperature and chlorophyll-a concentration significantly impact the presence of pelagic species such as yellowfin tuna (Syihab *et al.* 2014; Tangke *et al.* 2015; Munandar *et al.* 2016).

The distribution and reporting of pelagic fish are strongly influenced by oceanographic factors such as sea surface temperature and chlorophyll-a. Fish migration, physiological functions, and habitat preferences are all influenced by temperature (Hendiarti *et al.* 2006; Fathurrahman *et al.* 2015). Chlorophyll-a, on the other hand, indicates the level of primary water productivity that supports the marine food chain, according to Erlina (2006) and Kunarso *et al.* (2011). Consequently, the potential of fishing areas, particularly for yellowfin tuna, is often linked to changes in these two factors.

One useful tool for regularly and extensively monitoring marine parameters is satellite photography (Munthe *et al.* 2018; Safruddin *et al.* 2018). The Aqua Moderate Resolution Imaging Spectroradiometer (Aqua MODIS) is a satellite equipped with sensors to detect sea surface temperature and chlorophyll-a concentration. Sea surface temperature and chlorophyll-a distribution can be used to identify potential fishing locations (Mursyidin and Yuswardi 2017; Kurnianingsih *et al.* 2017; Padmaningrat *et al.* 2017).

The objectives of this study were to map the distribution of sea surface temperature and chlorophyll-a concentration, identify fishing areas for yellowfin tuna in the waters of the Cilacap Fisheries Authority (WPPNRI 573 and the high seas), and analyze the relationship between sea surface temperature, chlorophyll-a, and yellowfin tuna catches. In addition to providing scientific knowledge about the ideal sea conditions for yellowfin tuna in the research area, the findings of this study are expected to be a basis for fishermen in identifying more productive fishing locations and times to increase catch yields.

METHODS

Research location

This research was conducted in May 2024. Padjadjaran University (PSDKU Pangandaran Campus) processed data after it was collected at the Cilacap Sea Fishing Port (PPS). Due to the extensive catch of yellowfin tuna, the Cilacap Fishing Port (PPS) was chosen as the research location.

Materials and equipment

SeaDAS was used to process sea surface temperature and chlorophyll-a satellite imagery from Aqua MODIS Level 3, ArcGIS was used for spatial analysis, and Microsoft Excel 365 was used for statistics. Aqua MODIS Level 3 imagery with a spatial resolution of 4 km and a monthly temporal resolution obtained from the NASA Ocean Color website was used to collect sea surface temperature and chlorophyll-a data from January 2019 to December 2023. Vessel logbooks submitted to the Cilacap Sea Fishing Port (PPS) through the Directorate General of Capture Fisheries reporting system provide information on yellowfin tuna catch and their locations; the captain's GPS coordinates were used to determine the catch location.

Quantitative descriptive approach

This study adopted a quantitative descriptive approach. Descriptive techniques were used to describe similarities, differences, or relationships between different entities (Gayatri 2013; Linarwati *et al.* 2016; Syahrizal and Jailani 2023). The quantitative approach is applied from data collection and processing to the presentation of results using numbers (Baba 2017; Jayusman and Shavab 2020; Dhewy 2022).

Data types and data sources

This study used primary and secondary data. The Cilacap Sea Fishing Port's monthly fishing logbook for 2019–2023 served as the primary data source, which also included interviews with 20 fishermen to verify fishing areas and the number of yellowfin tuna caught. Secondary data consisted of time-series records of sea surface temperature and chlorophyll-a from NASA Ocean Color's Aqua MODIS Level 3 satellite imagery (1996).

Research stages

This research was conducted through a series of planned and systematic steps to obtain appropriate data. Problem discussion, literature review, data collection, and data analysis are all part of the research process. Figure 1 shows the stages of this research.

Data processing

Fishing area data processing from logbooks was carried out using Microsoft Excel 365, then spatially processed using Google Earth and ArcGIS to produce a map of yellowfin tuna fishing areas in Portable Network Graphics (png) format. The results of processing Aqua MODIS satellite imagery using SeaDAS and ArcGIS in the same format produced a map of the distribution of sea surface temperature and chlorophyll-a in the yellowfin tuna fishing zone. Using multiple linear regression, the following equation was used to examine the relationship between sea surface temperature (X_1) and chlorophyll-a (X_2) with yellowfin tuna catch (Y):

$$Y = a + b_1X_1 + b_2X_2$$

Description:
Y = Production (tons/month)
X_1 = Sea surface temperature (°C)
X_2 = Chlorophyll-a (mg/m^3)
a = Constant
b_1 = Sea surface temperature coefficient
b_2 = Chlorophyll-a coefficient

To ensure the simultaneous and partial influence of independent variables on the dependent variable, the results of the regression analysis included the coefficient of determination (R^2), F-test, and t-test at a 95% confidence level (Sutawijaya 2010; Dwiyanti *et al.* 2023; Kuswanto and Syamsuddin 2017; Rodhiyanti *et al.* 2021; Tangke and Deni 2013; Pontoh *et al.* 2019).

The independent variable (X1) significantly influences the dependent variable (Y) if the calculated t-value is higher than the table t-value. Conversely, X1 does not significantly influence Y if the calculated t-value is lower than the table t-value (Tangke 2013; Puspitasari 2017).

Data analysis

Data on the location of tuna fishing grounds were analyzed quantitatively and descriptively to determine which fishing grounds were closest and furthest from the Cilacap Sea Fishing Port (PPS). To identify the highest and lowest values and monthly variations, a descriptive quantitative analysis of sea surface temperature and chlorophyll-a data was conducted. Sea surface temperature and chlorophyll-a in yellowfin tuna fishing were analyzed using multiple linear regression, and the results were determined to be significant or insignificant.

Multiple linear regression models were used to evaluate the combined effects of sea surface temperature (SST) and chlorophyll-a concentration on yellowfin tuna catches. These two oceanographic variables are widely recognized as major factors influencing pelagic fish distribution, reflecting thermal preferences and trophic availability, respectively (Kuswanto and Syamsuddin 2017; Hafiz *et al.* 2017; Dwiyanti *et al.* 2023). This model assumes a linear response of catch to environmental predictors, an approach commonly used in fisheries-oceanography studies to measure the relative contribution of diverse environmental factors, despite the potential for non-linear ecological responses (Tangke *et al.* 2015; Kuswanto and Syamsuddin 2017; Bahri *et al.* 2017).

RESULTS AND DISCUSSION

Fishing grounds for yellowfin tuna (*Thunnus albacares*)

Fishing logbooks showed that several fishing grounds in WPPNRI 573 and the high seas have been used by fishermen for yellowfin tuna fishing operations. Fishermen engaged in yellowfin tuna fishing activities in the areas of 8–15 °S and 100–112 °E; however, many fishing operations were concentrated at 8–11 °S and 108–111 °E, as shown in Figure 2.

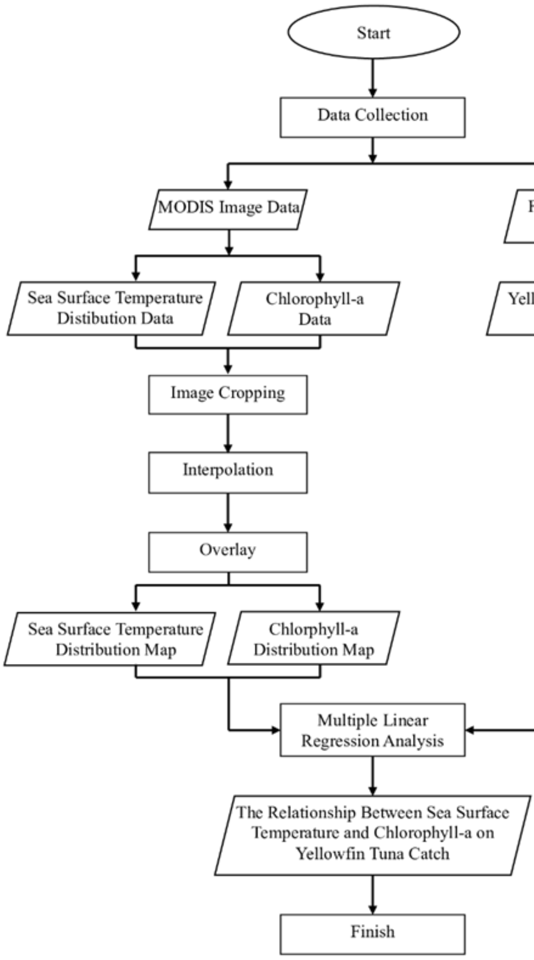

Figure 1. Flowchart of the research stages analyzing the relationship between sea surface temperature and chlorophyll-a on yellowfin tuna catch.

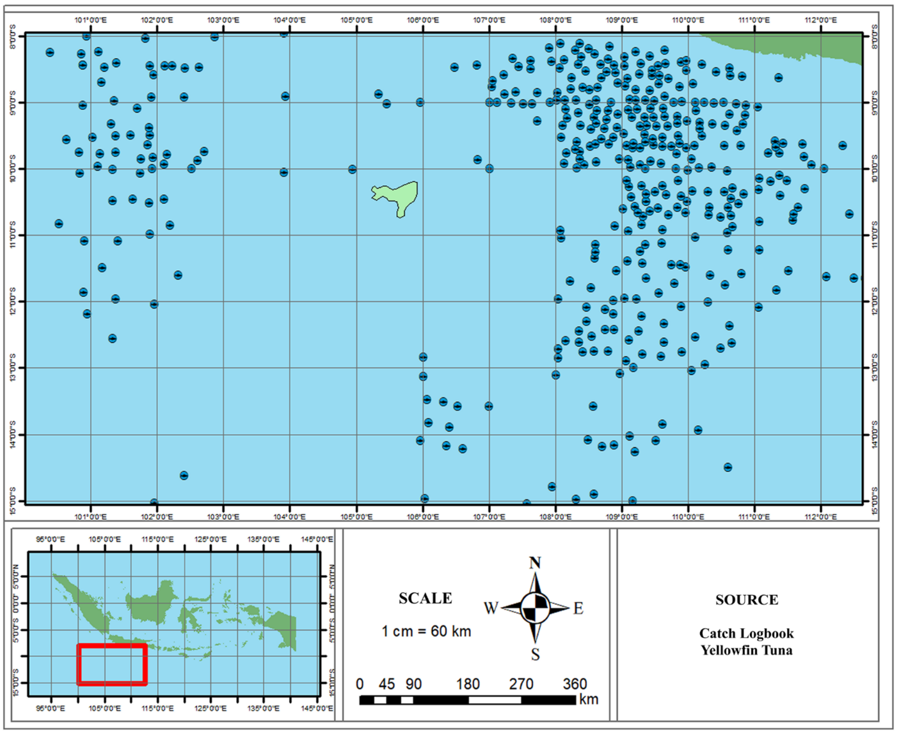

Figure 2. Yellowfin tuna (*Thunnus albacares*) fishing grounds in WPPNRI 573 derived from fishing logbooks.

Yellowfin tuna fishing grounds in the Indian Ocean based on the activities of PPS Cilacap fishermen were generally located in the range of 8–22 °S and 93–112 °E, with the determination of operational locations influenced by vessel size, logistics, number of crew members, and fishing targets (Wudianto *et al*. 2017; Aji *et al*. 2013; Santara *et al*. 2014; Trenggono 2023). Yellowfin tuna were schooling and migrating following suitable habitat conditions, so that distribution and catch results are influenced by aquatic environmental factors, monsoon wind patterns, rainfall, and oceanographic dynamics (Lintang *et al*. 2012; Ekaputra *et al*. 2020; Fajrianti *et al*. 2016).

Seasonal variations in yellowfin tuna catch are closely related to changes in oceanographic conditions caused by the monsoon system. During the east monsoon until the second transitional season (June–October), intensified upwelling increases water productivity and food availability, resulting in yellowfin tuna tending to be more concentrated in fishing grounds and resulting in higher catch. Conversely, during the November–May period, fishing activity generally decreases due to the spawning season and changing environmental conditions, impacting catch fluctuations (Meliza *et al*. 2013; Safruddin *et al*. 2020).

The effectiveness and efficiency of yellowfin tuna fishing operations are increased by the use of FADs (Fish Aggregating Devices) in fishing tactics. According to several studies (Tamarol and Wuaten 2013; Nurani *et al*. 2014; Fuadi *et al*. 2022), yellowfin tuna are caught with longlines in Sangihe waters, North Sulawesi, and handlines assisted by FADs in Aceh waters.

Yellowfin tuna production

The Cilacap PPS produced 9,453.28 tons of yellowfin tuna between 2019 and 2023, with an average production of 157.55 tons per month. The lowest annual production was 418.29 tons in 2019, while the highest annual production was 4,273.17 tons (in 2023). August 2023 had the highest production (674.23 tons), while June 2020 had the lowest production (2.12 tons). Figure 3 shows the amount of yellowfin tuna produced between 2019 and 2023.

Strong southeasterly winds cause upwelling, the movement of ocean masses from lower to upper nutrient-rich layers, during the easterly monsoon (June–August). Higher chlorophyll-a concentrations indicate increased aquatic production, and this may also increase food availability for pelagic species such as tuna. This explains the high catch in August 2023. These results are consistent with research by Savitria *et al*. (2013), which found that several variables, such as shifts in heat flow, air temperature, and wind speed, influence sea surface temperatures in the southern Indian Ocean.

However, from the west monsoon season (December–February) to the first transition season (March–May), winds are often weaker, and sea surface temperatures increase. Seasonal wind fluctuations are caused by winds moving from Asia to Australia during the west monsoon season, which lasts from December to February (Najid *et al*. 2012). Water production is often lower under these conditions because upwelling is less conducive.

June 2020 recorded the lowest production, likely influenced by a combination of suboptimal environmental conditions and other external factors such as the impact of the COVID-19 pandemic, which can disrupt fishing operations and catch distribution. Seasonal water mass exchange significantly impacts the presence and abundance of pelagic fish in Indonesian waters, including southern Java (Priatna and Natsir 2017). Therefore, disease transmission in yellowfin tuna caught at the Cilacap Fishing Port is largely explained by local oceanographic dynamics that influence the seasons, such as variations in sea surface temperature and chlorophyll-a.

Yellowfin tuna fishing boat

The dimensions of yellowfin tuna fishing boats are shown in Figure 4. During the 2019–2023 period, the total number of fishing boats reached 1,026 vessels, dominated by boats measuring 21–35 GT. Boats measuring 30 GT were the most common, with 336 boats. The fishing boat caught yellowfin tuna using a variety of fishing gear.

Fishing activities are carried out using longline, handline, gillnet, dragon net, and purse seine fishing gear. The boat using longline fishing gear consists of 464 units, handline 417 units, gillnet 125 units, dragon net 13 units, and purse seine 7 units. The composition of the fishing boat by fishing gear type is presented in Figure 5.

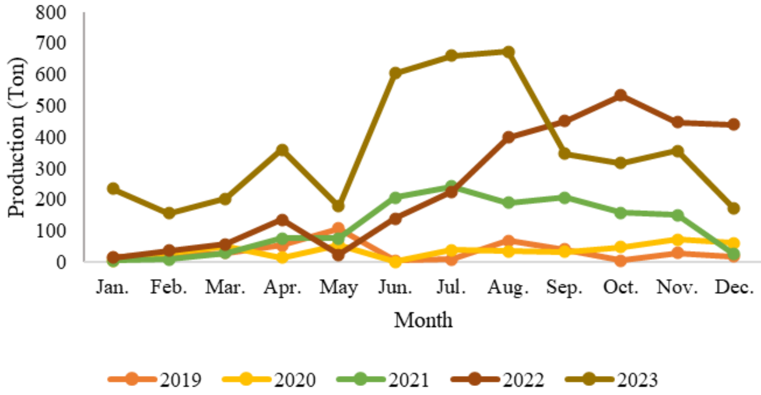

Figure 3. Yellowfin tuna (*Thunnus albacares*) production volume at PPS Cilacap (2019–2023).

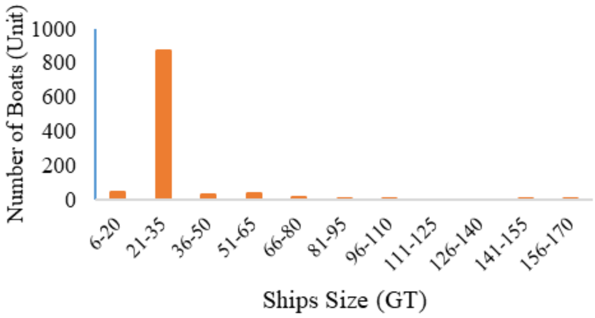

Figure 4. Size distribution of yellowfin tuna (*Thunnus albacares*) fishing vessels.

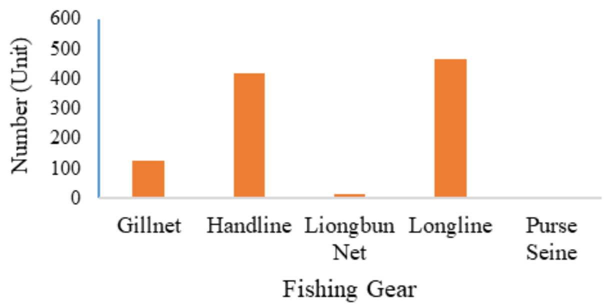

Figure 5. Distribution of fishing gear types used by the yellowfin tuna (*Thunnus albacares*) fleet.

Distribution of sea surface temperature and chlorophyll-a in yellowfin tuna fishing areas

Figure 6 shows the distribution of average monthly sea surface temperatures in the yellowfin tuna fishing ground. This visualization illustrates monthly temperature fluctuations, which could potentially impact the distribution and presence of yellowfin tuna in the study area. This pattern can be used as a guide in selecting more appropriate fishing times and locations.

The monthly average distribution of chlorophyll-a in the yellowfin tuna fishing ground is shown in Figure 7. Monthly fluctuations in chlorophyll-a levels in the study waters are depicted in this graph. The availability of natural food for yellowfin tuna can be affected by variations in chlorophyll-a concentration, which in turn can impact catch and distribution patterns.

The monthly distribution of chlorophyll-a in the yellowfin tuna fishing ground from January 2019 to December 2023 is depicted in Figure 8. According to the results of image interpretation, there were significant fluctuations in chlorophyll-a concentrations between 2019 and 2023. Chlorophyll-a concentrations ranged from 0.05 mg/m^3 (in the open sea) to 0.28 mg/m^3 (in areas near land).

Sea surface temperatures in yellowfin tuna fishing grounds ranged from 25 to 30 °C between 2019 and 2023. January–March 2020 had the maximum temperature (30 °C), while August–September 2019 and September 2023 recorded the lowest temperature (25 °C). Average temperatures peaked at 28 to 30 °C early in the year, decreased to 25 to 27 °C midway through the year, and then increased slightly to 27 to 29 °C later in the year. The highest maximum temperature was recorded in 2020, while the largest temperature fluctuation occurred in 2023. The range of monthly temperature variation was 0.1 to 5 °C. As seen in Figure 9, these data indicate seasonal trends affecting yellowfin tuna distribution and catch.

Month-to-month changes in chlorophyll-a concentrations in yellowfin tuna fishing areas exhibited a fluctuating pattern throughout the 2019–2023 period, with the highest concentrations generally occurring in coastal waters near land. January had the lowest levels (0.05–0.06 mg/m^3), which gradually increased to a maximum in May (0.07–0.21 mg/m^3) and August (0.09–0.24 mg/m^3). Throughout the year, the highest value was 0.28 mg/m^3, while the lowest was 0.05 mg/m^3.

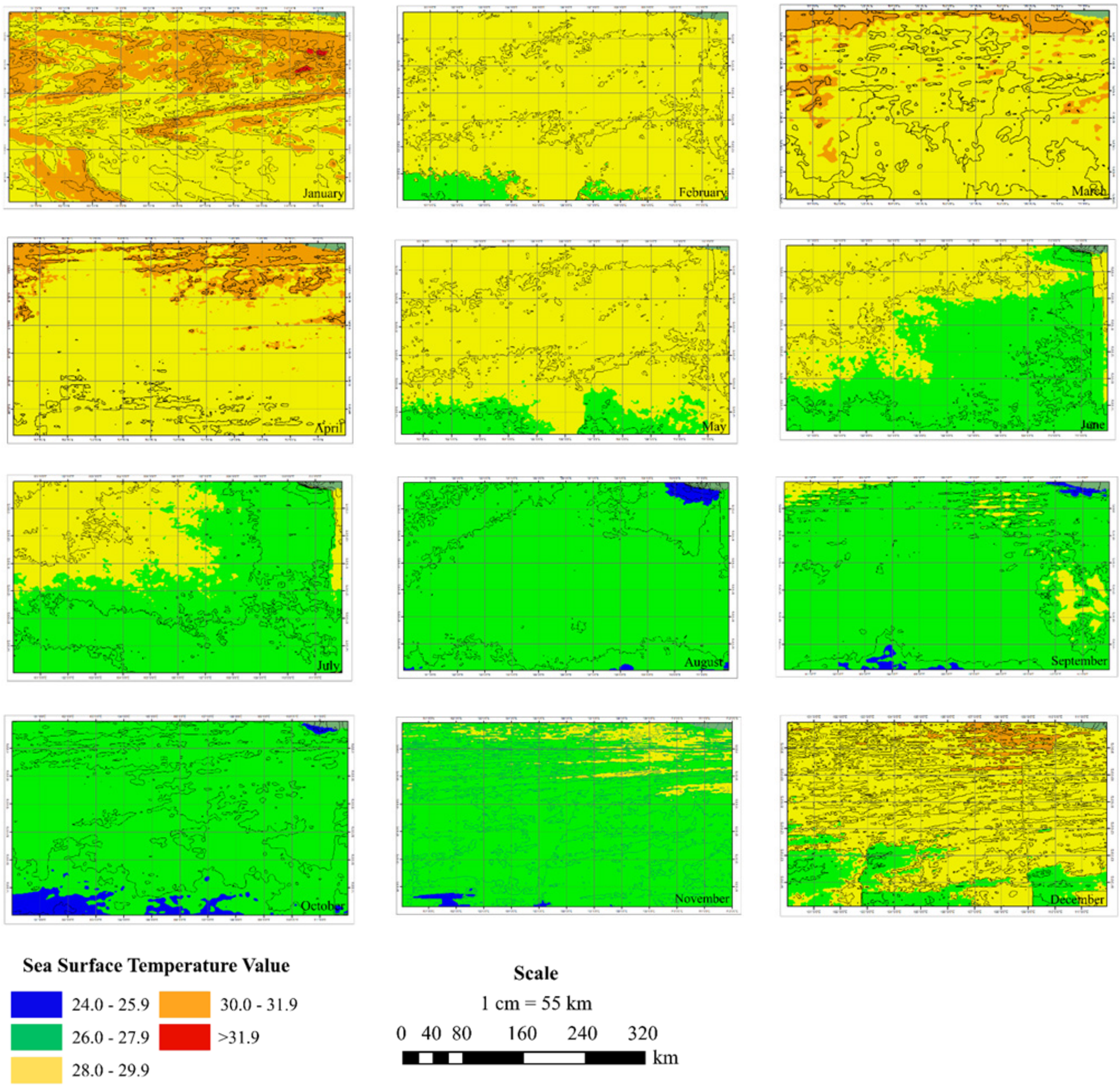

Figure 6. Distribution of average sea surface temperature in 2019–2023.

Concentrations were relatively high from June to September, exceeding 0.10 mg/m³, with September reaching 0.17–0.21 mg/m³. The values then decline steadily from October (0.07–0.13 mg/m³) to December (0.06–0.08 mg/m³). Chlorophyll-a concentrations often peak in the middle of the year, indicating higher primary productivity during this time. The graph of average chlorophyll-a concentrations in Figure 8 makes this trend quite clear.

Relationship between sea surface temperature and chlorophyll-a in yellowfin tuna fishing grounds

Fishery production increased significantly from 2019 to 2023. In 2019 and 2020, most months recorded production below 100 tons, but from 2021 to 2022, the number of months with production above 100 tons increased. 2023 saw a surge, with all months exceeding 100 tons, as shown in Figure 10. Chlorophyll-a concentrations consistently ranged between 0.05 and 0.28 mg/m³ throughout the observation period; July 2019 had the highest value, while January 2022 and January and March 2023 had the lowest. Importantly, the range narrowed from 0.06–0.28 mg/m³ (in 2019) to 0.06–0.17 mg/m³ (in 2023).

Although yellowfin tuna do not directly consume phytoplankton, they are stated to contribute to the food chain that controls aquatic productivity. The increase in chlorophyll-a content and catch of yellowfin tuna from 2021 to 2023 is shown in Figure 11. Conversely, chlorophyll-a concentrations decreased between 2019 and 2020, despite an increase in yellowfin tuna catch. Temporal lags in the aquatic food chain are the cause.

Siregar *et al.* (2016) claimed that a 30-day lag caused catch variations with a decrease in chlorophyll-a concentration. This suggests that higher chlorophyll-a concentrations, which are a better indicator of primary production, may not always translate into higher catch. The availability of yellowfin tuna as a top predator is ultimately influenced by the delay time required for zooplankton to consume phytoplankton, followed by smaller fish. Consequently, the relationship between tuna harvest and chlorophyll-a is indirect and only becomes clear after the trophic chain process in the aquatic ecosystem.

As a vital link in the aquatic ecosystem's food chain, chlorophyll-a is crucial for maintaining catch production. The presence of phytoplankton, the primary producers of higher organisms, is indicated by high levels of chlorophyll-a in the water (Putra *et al.* 2017). Water with high chlorophyll-a levels is ideal for small fish to forage. As a result, small fish congregate, attracting the attention of yellowfin tuna. This process occurs over the next 1–2 months because small fish need time to grow before becoming the primary food source for yellowfin tuna (Hariyanto *et al.* 2008). For this reason, high chlorophyll-a concentrations are not consistent with high yellowfin tuna production.

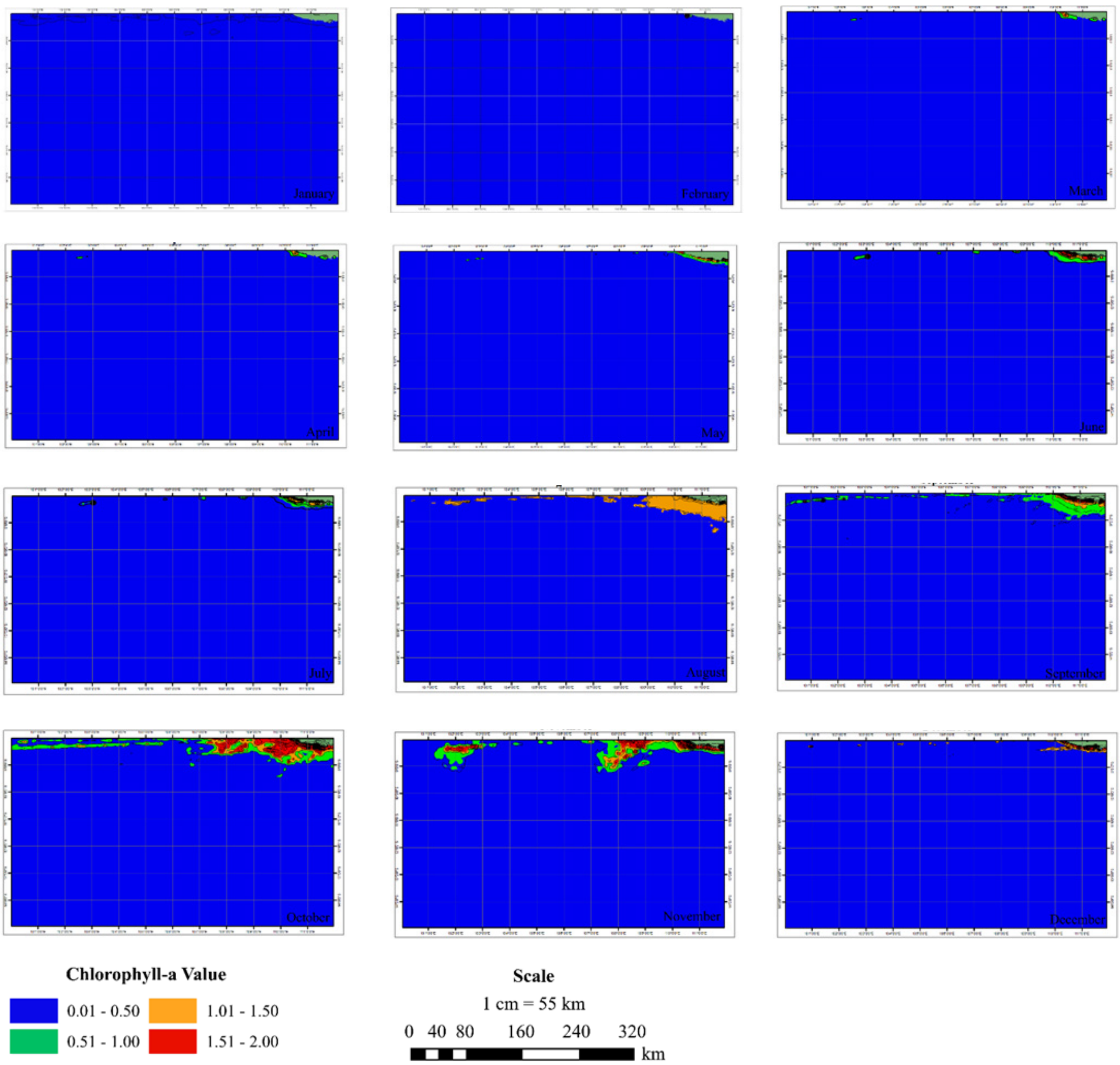

Figure 7. Distribution of average sea surface chlorophyll-a in 2019–2023.

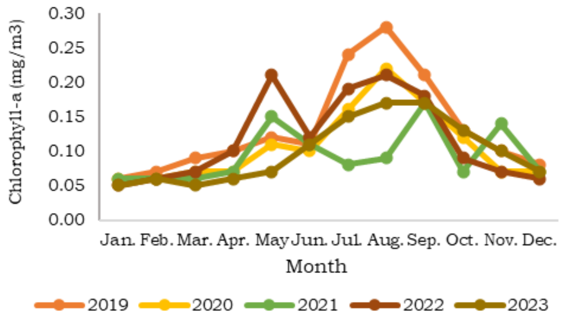

Figure 8. Average chlorophyll-a values for 2019–2023.

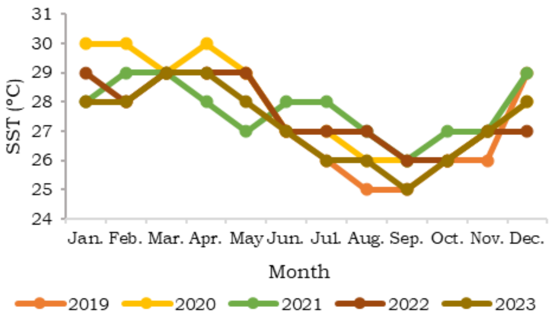

Figure 9. Average sea surface temperature values for 2019–2023.

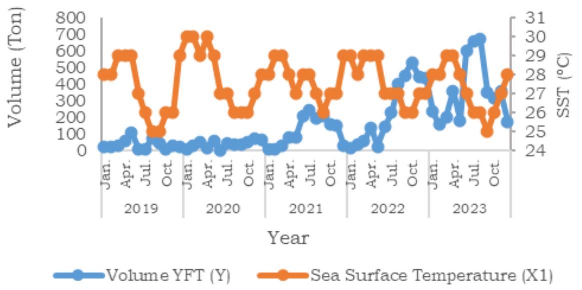

Figure 10. Relationship between sea surface temperature and yellowfin tuna production volume.

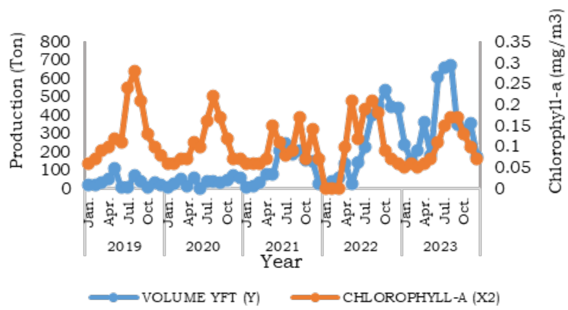

Figure 11. Relationship between chlorophyll-a and yellowfin tuna production volume.

Relationship between sea surface temperature, chlorophyll-a, and yellowfin tuna production

Correlation between variables was examined to determine the extent to which independent factors influence the dependent variable. Multiple linear regression analysis was then used to analyze the data. Table 1 displays the results of the regression analysis performed using Microsoft Excel 365.

Table 1 shows an R^2 of 0.16, meaning that sea surface temperature and chlorophyll-a only explain 16% of the variation in yellowfin tuna production, while 84% is influenced by other factors. These factors can originate from oceanographic conditions such as ocean currents, salinity, and thermocline depth, then ecological aspects such as food availability and spawning season, as well as anthropogenic factors such as the intensity of fishing effort. Research conducted by Fuadi *et al.* (2022) revealed a coefficient of determination (R^2) of 0.18, which is in line with this study. The regression model used in this study was significant at the 95% confidence level, according to the calculated F value of 5.50. This indicates that yellowfin tuna catches are significantly influenced by sea surface temperature, while chlorophyll-a has no statistically significant effect.

The calculated t-value for the sea surface temperature variable is -3.16, according to the t-test findings. It can be stated that sea surface temperature has a significant impact on yellowfin tuna fishing because this figure is higher than the t-table (when considered in absolute terms), which is 3.16 > 2.05. The negative coefficient indicates that catch tends to decrease with increasing sea surface temperatures. Specifically, the average tuna catch is predicted to decrease by 67.20 tons for every 1 °C increase in temperature.

On the other hand, the calculated t-value for the chlorophyll-a variable was -1.29. It was determined that the calculated t-value (1.29) < t-table after comparing it with the t-table value of 2.05. Thus, it can be said that the chlorophyll-a variable did not significantly influence the yellowfin tuna catch in this study. This suggests that the relationship between variations in chlorophyll-a levels and tuna production has not been proven to be significant.

Table 1. Results of multiple linear regression analysis of sea surface temperature (SST) and chlorophyll-a on yellowfin tuna production.

Variable	Coefficient	t value
Constant	2082,03	3,34
SST	-67,20	-3,16
Chlorophyll-a	-664,01	-1,29
R2	0,16	
F value	5,50	

Y = 2082.03 + X1 -67.20 + X2 -664.01
Ln Y = 2082.03 -67.20 Ln X1 -664.01Ln X_2
Y = 2082.03 - 67.20 X1 – 664.01 X2

Description:
Y = Production (tons/month)
X1 = Sea surface temperature (°C)
X2 = Chlorophyll-a (mg/m^3)

CONCLUSION

Yellowfin tuna (*Thunnus albacares*) can be found between 8 °S and 15 °S and 100 °E and 112 °E, but fishing is most popular between 8°S and 11 °S and 108 °E and 111 °E. Sea surface temperature mapping data from 2019 to 2023 shows a temperature range of 25 to 30 °C, with an average of 28 °C. Chlorophyll-a levels were found to range from 0.05 to 0.28 mg/m^3, with an average of 0.11 mg/m^3. Regression analysis shows that yellowfin tuna catches are significantly influenced by sea surface temperature, while chlorophyll-a does not show a significant influence.

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