Effect of Sea Surface Temperature and Chlorophyll-a On the Catch of Yellowfin Tuna (*Thunnus albacares*) in The Waters of North Maluku, Indonesia

Darmiyati Muksin[1], Faizal Rumagia[1]*, Kartina Syukur[1], Salim Abubakar[2], Irwan Abdul Kadir[1], Imran Taeran[1], Darmawaty[1], Bahar Kaidati[1]

[1]Department of Fisheries Resource Utilization, Faculty of Fisheries and Marine Science, Khairun University
[2]Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Khairun University
Jl. Jusuf Abdulrahman, Kampus II Unkhair Gambesi. Kota Ternate Selatan, Indonesia
Email: faizal.rumagia@unkhair.ac.id

Abstract

The waters of North Maluku, abundant in nutrients and ocean currents, provide an ideal habitat for yellowfin tuna (Thunnus albacares), indicating a healthy marine ecosystem. Tuna, an oceanic pelagic species that migrates with ocean currents, is affected by sea surface temperature (SST) and chlorophyll-a plays an important role in determining yellowfin tuna fishing grounds. This study aims to analyze the spatial and temporal distribution of SST and chlorophyll-a concentration in North Maluku waters and analyze the relationship between SST, chlorophyll-a, and tuna catches. The present study employed both descriptive and quantitative analysis methods to examine the relationship between sea surface temperature, chlorophyll-a, and yellowfin tuna catch. The result shows that the temporal fluctuations in the highest recorded SST were seen in the 2021 transitional season, and the lowest in the 2019 East season. Chlorophyll-a concentrations also showed fluctuations, with the highest value recorded in the 2019 East season and the lowest in the 2020 second transitional season. There is an inverse correlation between SST and chlorophyll-a, with low SST tending to be accompanied by high chlorophyll-a concentrations. The decline in chlorophyll-a concentration can be attributed to various factors, including nutrient availability, sunlight intensity, and water temperature. About 17.48% of the catch of yellowfin tuna (Thunnus albacares) in North Maluku waters is influenced by SST and chlorophyll-a while the rest is influenced by other factors. This indicates that other factors play an important role in determining the catch of yellowfin tuna in North Maluku waters.

***Keywords**: Sea surface temperature; chlorophyll-a; fishing ground; yellowfin tuna; North Maluku*

INTRODUCTION

Located on the equator, Indonesia has a tropical climate with two main seasons: the western (December-February) and the eastern (June-August). Monsoon movement is the main cause of these seasonal changes, with the west monsoon occurring when the sun is south of the equator, causing higher air pressure and winds blowing from Asia towards Australia, and vice versa during the east monsoon. In addition to the monsoon circulation, the Indonesian region is also influenced by local and global phenomena such as the Hadley circulation, Walker circulation, ENSO, and IOD, which influence sea surface temperature through the hydrological cycle (Dewi *et al*., 2020; Fadhilah *et al*., 2022; IPCC, 2023; Khan *et al*., 2020; Yuliardi *et al*., 2025).

Tuna resources are one of the important economic species that play a role in the marine ecosystem, which requires special attention to their distribution patterns in order to protect and manage sustainable tuna fisheries resources. Many research results show that marine environmental factors as one of the important external factors, and influence the habitat and distribution patterns of tuna in marine waters (Amri *et* al., 2024; Kalangi *et al*., 2024; Tangke *et al*., 2024; Wiryawan *et al*., 2020; Yang *et al*., 2023). The distribution of yellowfin tuna in Indonesian waters is greatly impacted by a variety of marine environmental factors, including temperature, salinity, ocean currents, and chlorophyll-a (Amri *et al*., 2024; Dimu *et al*., 2024; Suhadha & Asriningrum, 2020; Tangke *et al*., 2024). Furthermore, climate change has a detrimental effect on fishing efforts, particularly in relation to the estimation of fish distribution areas, which are becoming increasingly dispersed and unpredictable (Haruna *et al*., 2018; Istnaeni *et al*., 2024).

*) Corresponding author
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The waters North Maluku which are located in the Coral Triangle region of the world and influenced by currents from the Pacific Warm Pool, have highly dynamic oceanographic conditions influenced by seasonal monsoon winds and El Niño-Southern Oscillation (ENSO) events (De Anda-Montañez *et al*., 2004; Khan *et al*., 2020), which affect sea surface temperature and chlorophyll-a patterns in these waters. Despite the ecological importance of these waters, several studies have shown a relationship between environmental variables and yellowfin tuna fishing (Amri *et al*., 2024; Dimu *et al*., 2024; Tangke *et al*., 2024). Advances in remote sensing and geographic information systems (GIS) (Tong *et al*., 2022) now allow the analysis of high-resolution sea surface temperature and chlorophyll-a data (Auricht *et al*., 2022), providing the opportunity to provide more productive estimation models for the management of capture fisheries (Heltria *et al*., 2024; Issifu *et al*., 2022), especially the yellowfin tuna fishery. The objective of this study is to analyse the spatial and temporal distribution of sea surface temperature and chlorophyll-a concentrations and their relationship with yellowfin tuna (*Thunnus albacares*) catches in North Maluku waters. The results of this study are expected to be a source of information for fishermen in North Maluku to determine the appropriate time to conduct more effective yellowfin tuna (*Thunnus albacares*) fishing activities to improve the fishermen's economy.

MATERIALS AND METHODS

The research was conducted for over four months from November 2024 to February 2025 in the North Maluku waters. The research zone in North Maluku waters is located at geographical coordinates around 3° 8' 52" S - 2° 57' 20" N and 124° 56' 58" - 130° 53' 30" E (Figure 1).

This study collected data on sea surface temperature (SST), chlorophyll-a (Chl-a), and yellowfin tuna catches in North Maluku waters. Fishing location coordinates for yellowfin tuna (*Thunnus albacares*) were obtained by accompanying fishermen during their activities. SST and Chl-a data were sourced as secondary data from Aqua MODIS satellite images available at http://oceancolour.gsf.nasa.gov. The satellite data, provided as numerical values, were analysed

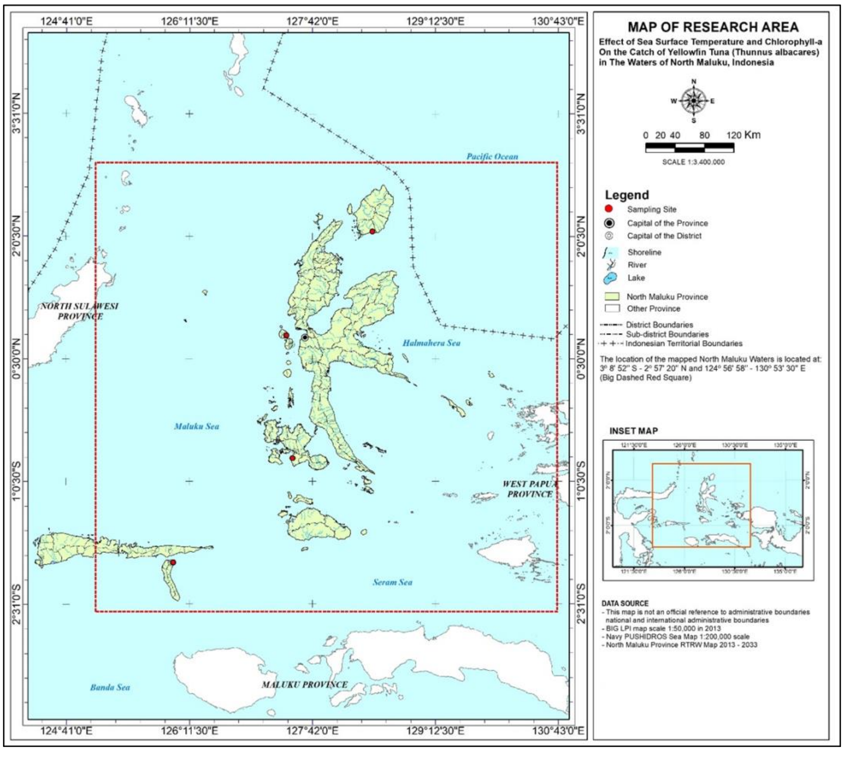


Figure 1. Map of the research location

using the GrADS application to assess the variability of SST and Chl-a. Data collection occurred every three months over a five-year period from 2019 to 2023. The study employed a seasonal observation framework dividing the year into four quarters: DJF (December–February) as the West Season, MAM (March–May) as the First Transitional Season, JJA (June–August) as the East Season, and SON (September–November) as the Second Transitional Season.

Catch data of yellowfin tuna (*Thunnus albacares*) were obtained from the Ternate Nusantara Fishing Port (PPN Ternate) office and the North Maluku branch of MDPI Foundation. Fish catch data was used to analyse the relationship between environmental variables (SST and Chl-a) and yellowfin tuna (*Thunnus albacares*) catch. Fish catch data were obtained over a 5 (five) year period (2019-2023).

The SST data generated from cropping of the study area (North Maluku region) includes longitude, latitude, and spatial value estimation variables. SST data extraction was carried out using channels 31 and 32 on the Aqua MODIS sensor. SST was obtained using the Miami Pathfinder SST (MPFSST) algorithm (Minnett *et al*., 2002). Chl-a data extraction was conducted using channels 31 and 32 of Aqua Modis by applying the OC3M algorithm of O'Reilly *et al*. (1998).

The effect of SST and Chl-a on the catch of yellowfin tuna (*Thunnus albacares*) was analyse using multiple linear regression analysis. Determination of the degree of relationship between yellowfin tuna (*Thunnus albacares*) catch and SST and Chl-a variables using correlation analysis. The higher the correlation value, the closer the relationship between the two coefficients. The statistical analysis was conducted using Microsoft Excel software.

RESULTS AND DISCUSSION

The results of satellite data analysis using the GrADS application show that the distribution of average SST in the waters of North Maluku over the last five years, from 2019 to 2023, was highest during the first transition season (West to East) in March, April, and May (MAM) of 2021, reaching 30.86°C, and the lowest temperature was recorded at 28.77°C during the second transition season (East to West) in September, October and November (SON) in 2019 (Figures 2a and 3a). The highest temperature in this study was found in 2021, reaching 30.86°C, in line with the results of Rosalina *et al*. (2023), which stated that in 2021, SST showed very significant seasonal fluctuations. The highest temperature was recorded in the west monsoon season, peaking in November at around 30.63°C. This increase in temperature is characteristic of tropical coastal waters, which are influenced by strong solar radiation. During the east monsoon season, sea surface temperatures decreased, reaching their lowest point in August with a range of 28.7–30°C. This decrease in temperature was likely caused by strong east monsoon winds, which drove the movement of water masses from the Australian continent towards the Asian continent.

The average Chl-a values in the waters of North Maluku over the past five years (2019 to 2023) based on analysis using the GrADS application indicate that the highest concentrations of Chl-a in the waters of North Maluku are found during the East Season, which occurs in June, July, and August (JJA), with the highest concentration recorded in 2019 at 0.22 mg/m^3, and the lowest at 0.11 mg/m^3 recorded during the second transition season (East to West) occurring in September, October, and November (SON) in 2020 (Figures 2b and 3b).

The distribution of the highest average SST from this study (Figures 2a and 3a) shows results that are almost identical to those in the 2021 IPCC Report, highlighting a significant increase in globalsea level change, a phenomenon that has not occurred in the last 3,000 years. This increase is closely related to global warming, which is driven by increased greenhouse gas emissions. Global warming, in turn, causes SST to rise. Greenhouse gas emissions and ongoing global warming are exacerbating this situation, threatening marine ecosystems, human life and the climate (IPCC, 2023).

The lowest temperature recorded in this study was 28.77°C during the transition season II (East to West) in September, October, November (SON), which is consistent with the findings of Cai *et al*. (2020), which showed that SST in the Eastern Pacific decreased significantly from 33.5°C to 26.5°C between February and September. SST anomaly variables were also detected in the Bacan region, South Halmahera and the waters of Java and Bali, with ranges of 1.8–2.60°C and 1.2–1.30°C, respectively (Karman, 2016).

The highest concentration of Chl-a in the waters of North Maluku, with a value of 0.22 mg/m^3 (Figures 2b and 3b) found in this study, has conditions that are almost the same as those found in the results of the study by Fauziah *et al*. (2020) in the waters of Natuna, which showed that the average Chl-a concentration in Natuna waters is 0.25 mg/m^3. Meanwhile, according to the results of research by Lasut *et al*. (2021), Chl-a concentrations in the waters of North Sulawesi, particularly in the western and eastern regions, tend to be higher during the El Niño period. This is caused by the movement of warm water masses to the east, which causes a void in the waters of Indonesia.

The r value (correlation coefficient) of 0.187 (Table 1) indicates a relatively low positive relationship or little influence on catch results between the dependent and independent variables. The p-value for SST is 0.000395723 (Table 1), indicating a significant relationship between SST and catch results. This is in line with previous research findings which show that SST affects the distribution and abundance of tuna (Bafagih & Laitupa, 2024).

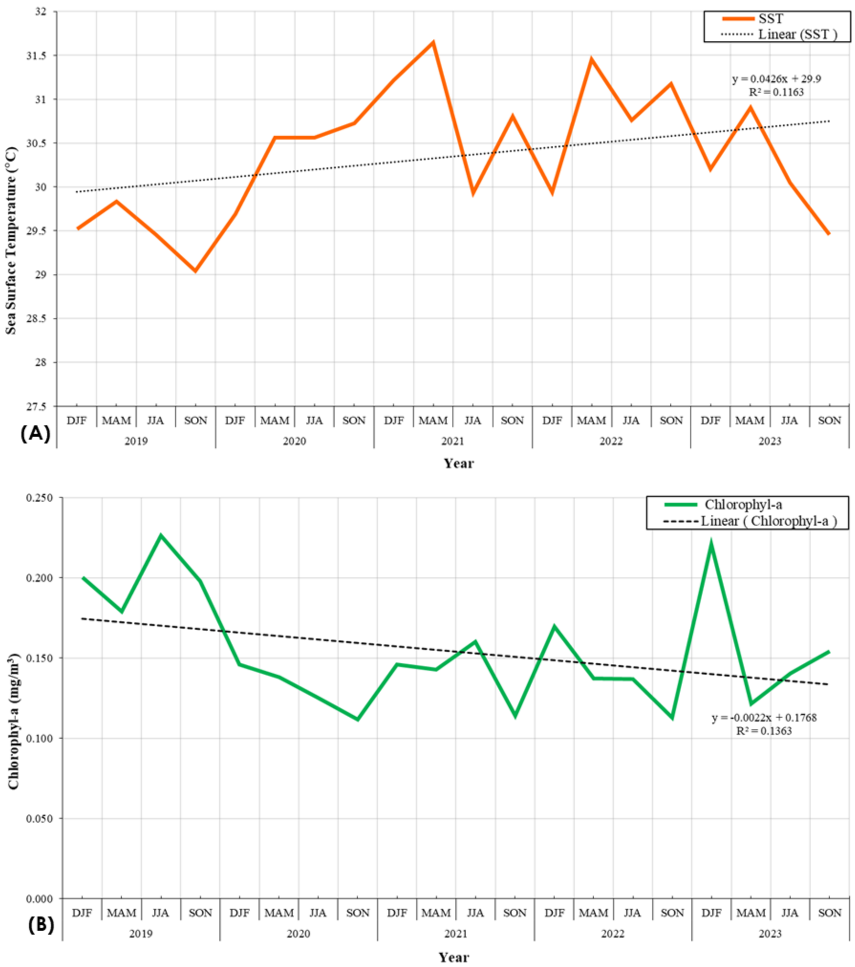
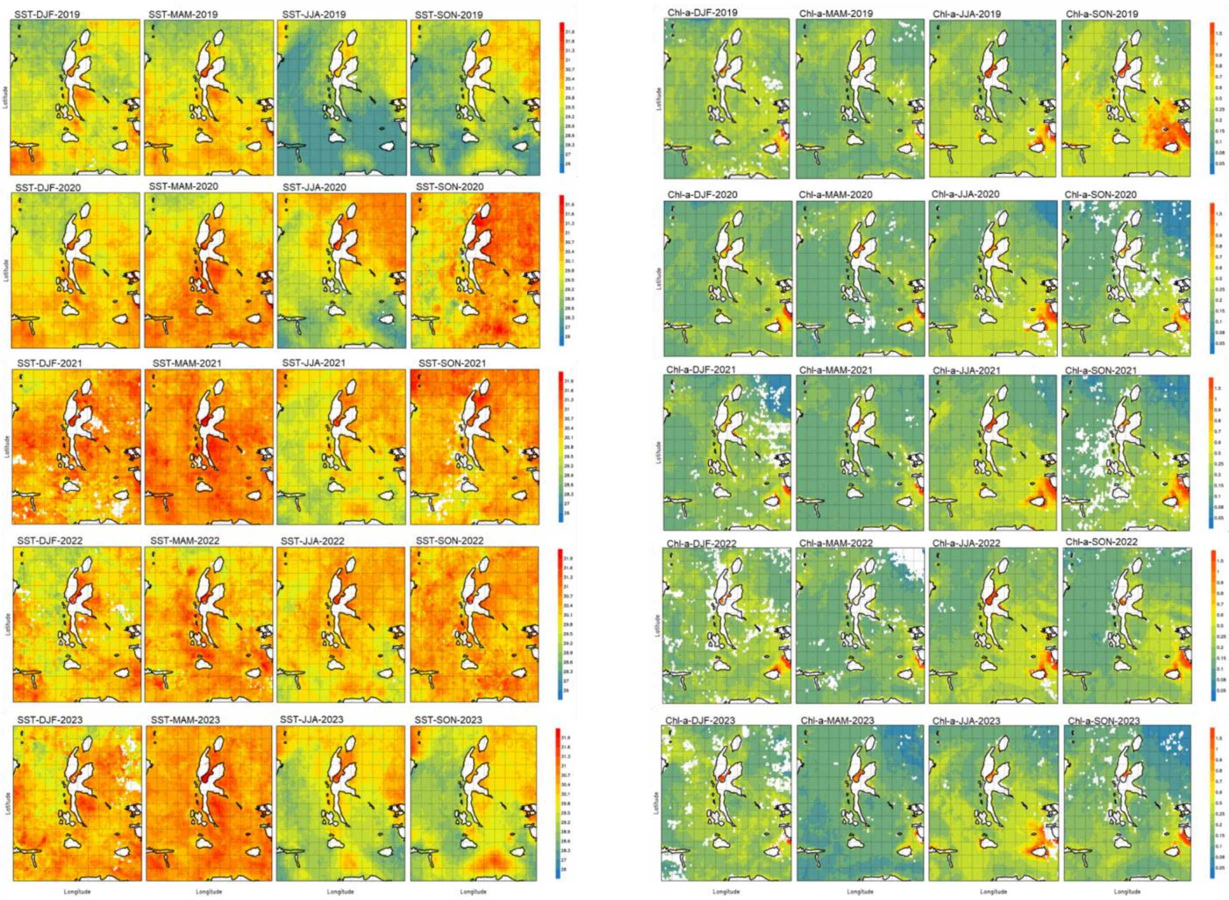


Figure 2. The average plot of SST (A) and concentration of Chl-a (B) in the waters of North Maluku from 2019 to 2023. (DJF = December–January–February; MAM = March–April–May; JJA = June–July–August; SON = September–October–November).

The p-value for Chl-a is 0.209399648 (Table 1), which is greater than 0.05, indicating that there is no relationship between Chl-a concentration and yellowfin tuna catch in this study. The simultaneous or joint effect shows that both variables (SST and Chl-a) affect the catch. Meanwhile, the partial effect ($p < 0.05$ means there is an effect) means that only SST affects the catch, while Chl-a does not affect the catch. The effect of Chl-a on tuna catch is more apparent in the long term. This is because tuna need time to respond to changes in Chl-a concentration (Bafagih & Laitupa, 2024; Cai *et al*., 2020; Tangke *et al*., 2024).

The relationship between SST and tuna catch shows an inverse correlation (Figure 5a), meaning that an increase in SST tends to result in a decrease in catch, and vice versa (De Anda-Montañez *et al*., 2004; Setyaningrum *et al*., 2017). According to Cai *et al*. (2020) found that SST does not directly affect tuna catch because tuna always migrate.

Although some studies show a weak correlation between Chl-a and yellowfin tuna (*Thunnus albacares*) catch yields as found in this study (Figure 5b), other studies show a significant effect between Chl-a and tuna (*Thunnus albacares*) catch yields, with a time lag in its effect (Dimu *et al*., 2024; Tangke *et al*., 2024; Wiryawan *et al*., 2020). This time lag refers to the food chain cycle, in which tuna prey on small mesopelagic fish that feed on phytoplankton. This time lag can reach 3-5 months (Schaefer *et al*., 2014; Tangke *et al*., 2024).



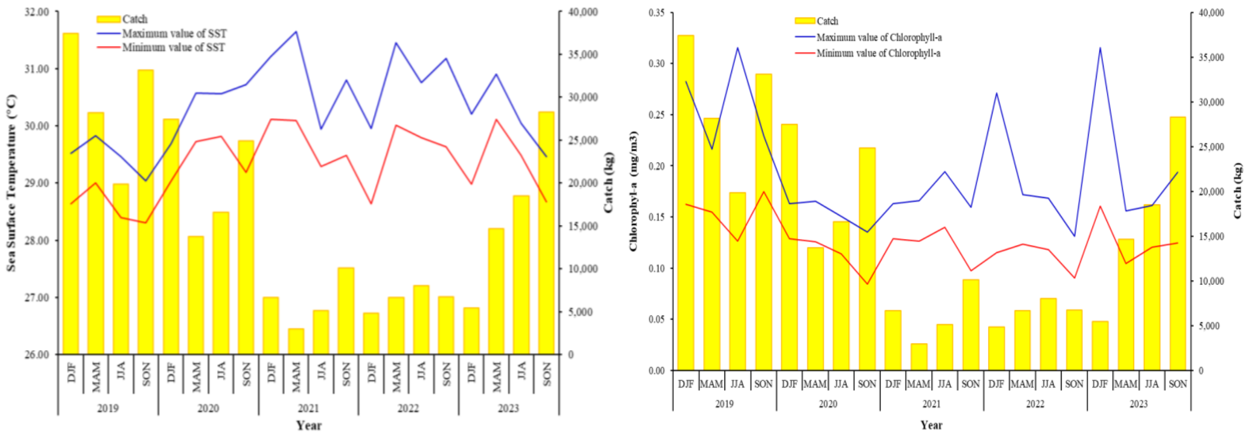
Distribution of SST

Chlorophyll-a concentration

Figure 3. Distribution of SST and chlorophyll-a concentration the waters of North Maluku in 2019–2023. (DJF = December–January–February; MAM = March–April–May; JJA = June–July–August; SON = September–October–November)

Table 1. Results of multiple linear regression equation analysis

Equation Model	R^2	r	*p-value*
SST = -3280.053	0.1749	0.1870	0.000395723
Chlorophyll-a = -23859.128			0.209399648



fluctuations in SST chlorophyll-a concentration

Figure 4. The illustration of the fluctuations in SST with yellowfin tuna catches and changes in chlorophyll-a concentration with yellowfin tuna catches (B) in the waters of North Maluku during the period 2019-2023.

CONCLUSION

Sea surface temperature (SST) fluctuations in the waters of North Maluku during the period 2019-2023 are inversely correlated with Chl-a concentrations. High SST is associated with low Chl-a. The highest SST was found during the first transition season (West to East) in 2021, reaching 30.86°C, and the lowest was recorded at 28.77°C during the second transition season (East to West) 2019. The highest concentrations of Chl-a are found during the East Season in 2019 at 0.22 mg/m^3, and the lowest at 0.11 mg/m^3 recorded during the second transition season (East to West) in 2020. The highest tuna catch of 37,444.92 kg was recorded during the western season in 2019, while the lowest catch of 2,968.68 kg was recorded during the transition season I in 2021. SST has a significant effect on yellowfin tuna (*Thunnus albacares*) catches in the waters of North Maluku, with high SST leading to a decline in tuna catches. Chl-a does not have a significant effect on yellowfin tuna (*Thunnus albacares*) catches. Overall, SST and Chl-a explain approximately 17.48% of the variation in yellowfin tuna (*Thunnus albacares*) catch in North Maluku water.

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