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The Distribution of Oceanographic Parameter Conditions in the Swordfish (*Xiphias gladius*) Fishing Ground in the Southern Indian Ocean off Java

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The Southern Indian Ocean off Java is one of the potential locations for catching swordfish. One crucial factor in improving fishermen's productivity is the availability of information regarding the characteristics of waters related to potential fishing areas. This research aimed to determine the distribution conditions of several oceanographic parameters such as sea surface temperature, salinity, chlorophyll-a, and surface currents using remote sensing data at the swordfish *(Xiphias gladius*) fishing ground in the Southern Indian Ocean off Java. This research was conducted from April 27, 2022, to December 12, 2022, in the Indian Ocean. Data for several oceanographic parameters were obtained from the *data.marine.copernicus.eu* website from April 2022 to December 2022, and the coordinates of the swordfish *(Xiphias gladius)* fishing ground were obtained from KM Lulu Marina 08, which operates in WPPD 57. Data from *data.marine.copernicus.eu* are the result of reanalysis methods developed by the Copernicus

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Marine Service (CMS) using multisensor satellite images data such as MODIS-AQUA, NOAA20-VIIRS, NPP-VIIRS, and Sentinel 3A-OLCI. The spatial resolution of the data was standardized to 0.001 degrees using resampling techniques with B-Spline interpolation. The highest sea surface temperature (SST) at each fishing ground was recorded in April 2022 at the fishing ground ST 1, reaching 27.52°C. The lowest SST was observed in November 2022 at fishing ground ST 6, measuring 21.70°C. The lowest salinity values at each fishing ground were recorded in June 2022 at fishing ground ST 1, measuring 34.09 psu, while the highest salinity values were found in April 2022 at fishing ground ST 6, measuring 35.38 psu. The lowest chlorophyll-a concentration values at each fishing ground were recorded in December 2022 at fishing ground ST 6, measuring 0.062 mg/m^3, while the highest concentration values were found in September 2022 at fishing ground ST 6, measuring 0.357 mg/m^3. The lowest catch was recorded in September 2022, with only 2 fish caught, while the highest catch was recorded in November 2022, with a total of 42 fish caught. The optimal swordfish catch rate falls within the range of SST 23.47-24.74°C, salinity 34.45-34.78 psu, and chlorophyll-a concentration in the range of 0.079-0.124 mg/m^3.

Keywords: Indian ocean; oceanographic parameters; swordfish.

1. INTRODUCTION

The Indian Ocean south of Java is a region where various commercial fish species are captured and have been exploited by fishermen for a long time. Various types of tuna and pelagic tunas (such as skipjack and mackerel) are the primary targets of fishermen in these waters. Another species incidentally caught by tuna fishermen is the swordfish (*Xiphias gladius*). In the tuna fishing industry, swordfish are considered a bycatch of tuna longline fishing [1]. Swordfish are categorized as apex predators distributed in almost all the world's waters. In the Indian Ocean, their exploitation began in the 1950s by the Japanese fleet and was dominated by Taiwan in the 1990s. Indonesian fishermen only started utilizing them in 1983 with the introduction of deep tuna longline fishing [2,3].

The life patterns and existence of fish are inseparable from oceanographic parameters, which include temperature, salinity, currents, and chlorophyll-a content. Oceanographic parameters influence various fish activities such as growth, spawning, metabolism, and other activities [4]. This indicates that the presence of fish and the determination of potential fishing areas are greatly influenced by oceanographic parameters. Furthermore, these oceanographic parameters have a significant relationship with catch results, so at a certain level of accuracy, catch results can be predicted with equations [4].

The fertility level of a water body can be indicated by the chlorophyll-a concentration in the water, making it attractive to pelagic fish species that are plankton feeders. During photosynthesis, phytoplankton produces organic matter beneficial to fish, with phytoplankton serving as primary producers in the aquatic food chain [4]. Abundant chlorophyll-a concentration indicates high primary productivity, where phytoplankton are consumed by zooplankton, which in turn are preyed upon by higher trophic species such as cephalopods and small-sized fish, which become prey for larger fish [5].

The relationship between sea surface temperature and chlorophyll-a conditions concerning potential fishing areas is described, where SST and chlorophyll-a are independent variables, and potential fishing locations are highly associated variables [6]. The swordfish catch in the Indian Ocean has been steadily increasing, starting from less than 10,000 tons in the 1980s and 32,305 tons in early 2000s [7]. Although it is only a bycatch of tuna longline fleets, its contribution to tuna fisheries in Indonesia was quite significant from 2004 to 2007, with an average production of 1,600 tons. The waters of the Indian Ocean south of Java are one of the potential locations for swordfish capture [2,3].

One crucial factor in increasing fishermen's productivity is the availability of information regarding the characteristics of waters related to potential fishing areas. Various research results have shown that the presence of fish resources in the waters is closely related to oceanographic conditions, making oceanographic information highly important [4]. Furthermore, the dynamic nature of the sea necessitates monitoring oceanographic parameters using remote sensing technology (spatial and temporal) to analyze their relationship with the presence of fish resources as a basis for developing a fishing area information system [4]. The research aimed to determine the distribution conditions of several hydro-oceanographic parameters such as sea surface temperature, salinity, chlorophyll-a, and surface currents using remote sensing data at the swordfish (*Xiphias gladius)* fishing ground in the Southern Indian Ocean off Java.

2. MATERIALS AND METHODS

2.1 Location

This research was conducted from April 27, 2022, to December 12, 2022, in the Indian Ocean (Fig. 1). Six coordinate points for the swordfish (Xiphias gladius) fishing locations were obtained using KM. Lulu Marina 08 - PT. Golden Tuna Benoa, Bali Province, operating in the World Fisheries Management Area 57 (WPPD 57).

2.2 Data Analysis

Data for several oceanographic parameters such as sea surface temperature, salinity, chlorophyll-a, and surface currents were obtained from the *data.marine.copernicus.eu* website during the period from April 2022 to December 2022. Coordinate points for swordfish (*Xiphias gladius*) fishing ground and catch results were acquired from KM Lulu Marina 08, which operates in WPPD 57. The types and specifications of the oceanographic parameter data can be found in Table 1. Subsequently, this data was processed using QGIS 3.32 LIMA software to visualize its distribution and extract values at the swordfish fishing locations (*Xiphias gladius*). The data sourced from *data.marine.copernicus.eu* is the result of a reanalysis method developed by the Copernicus Marine Service (CMS) using multi-sensor satellite image data, including MODIS-AQUA, NOAA20-VIIRS, NPP-VIIRS, and Sentinel 3A-OLCI. The equations for this method can be seen in Table 1. Furthermore, all data were standardized to a spatial resolution of 0.001 degrees using resampling techniques with the B-Spline interpolation method.

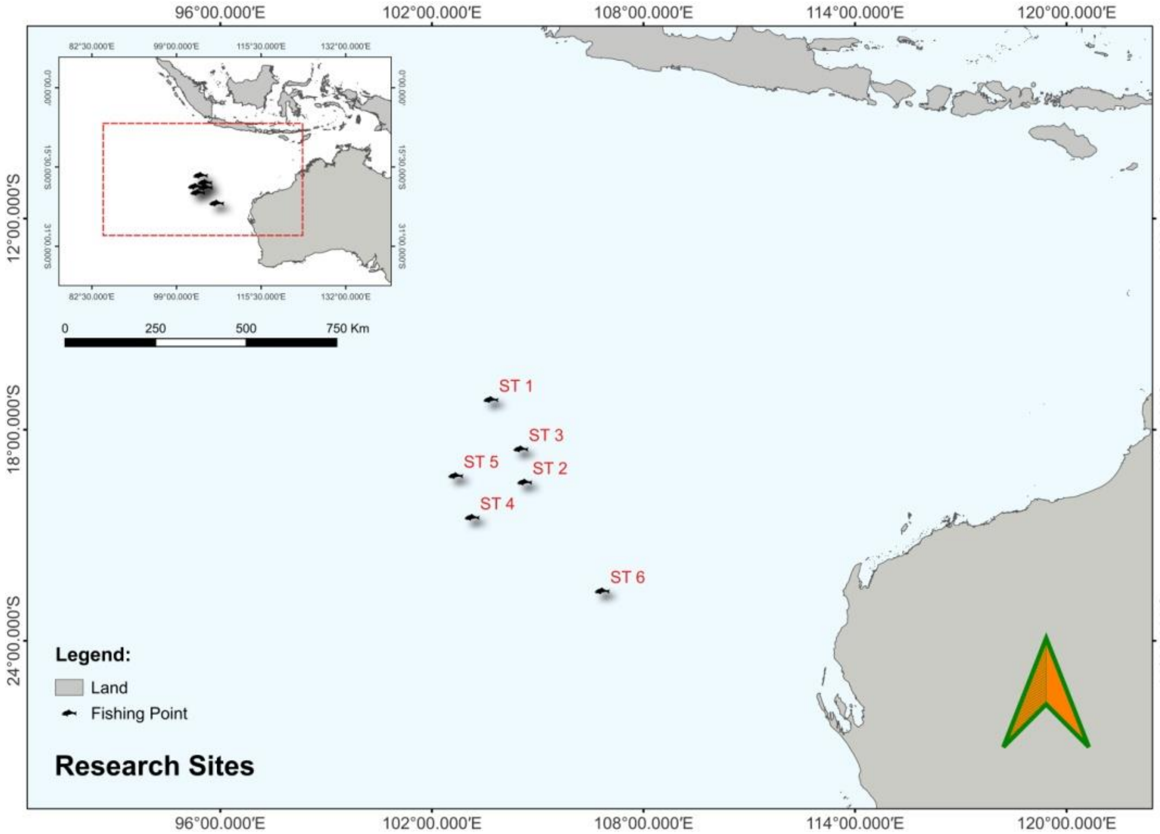

Fig. 1. Research Location Map

Table 1. Types and specifications of data

No	Data Type	Unit	Spatial Resolution	Temporal Resolution	Algorithm	Reference
1	sea surface temperature	^{0}C	1/12 derajat	- Rata-rata Harian	NEMO3.6 [8]	*data.marine.copernicus.eu/products*
2	Salinity	psu	1/12 derajat	- Rata-rata mingguan	NEMO3.6 [8]	*data.marine.copernicus.eu/products*
3	Chlorophyll-a	mg/ m^3	1/4 derajat	- Rata-rata bulanan	NEMO3.6-PISCES	*data.marine.copernicus.eu/products*
4	Ocean Surface Currents	m/s	1/12 derajat		NEMO3.6 [8]	*data.marine.copernicus.eu/products*

3. RESULTS AND DISCUSSION

3.1 Sea Surface Temperature

The distribution of sea surface temperature (SST) from April 2022 to December 2022 does not vary significantly and forms a stratified pattern, with temperatures becoming warmer as you move towards the equator and tending to be cooler towards the southern waters of South Australia (Fig. 2). The average temperature variability throughout the months ranges from 19.73°C to 32.29°C. The lowest temperature range occurred in August 2022, ranging from 16.51°C to 31.57°C. Meanwhile, the highest temperature range was observed in April 2022, from 21.02°C to 32.29°C (Fig. 2).

The distribution of sea surface temperature (SST) during the transitional season I, which occurs in March, April, and May in the tropical Indian Ocean, becomes warmer with an average range of 29°C. In contrast, in the southern part of the Indian Ocean, it is cooler and extends northward [9]. SST during the Eastern season, which occurs in June, July, and August, is generally cooler in the Indian Ocean than during the Western season and the Transitional season because the surface wind circulation patterns in both the northern and southern hemispheres exhibit regular patterns [9]. During the transitional season II in September, October, and November, the SST distribution in the northern hemisphere of the Indian Ocean starts to warm due to weakened wind circulation, while the northern equatorial current remains stationary, causing the SST distribution in the southern hemisphere of the Indian Ocean to be cooler [10].

Based on the distribution pattern of sea surface temperature, there is a horizontal temperature change pattern in the region around 160 degrees South latitude (S) where higher temperatures in the waters south of Java meet lower temperatures in the waters of southern Australia. This is one of the indicators of the presence of a front in that area, where fronts typically create horizontal temperature gradients that can be observed from oceanographic variables like temperature [11].

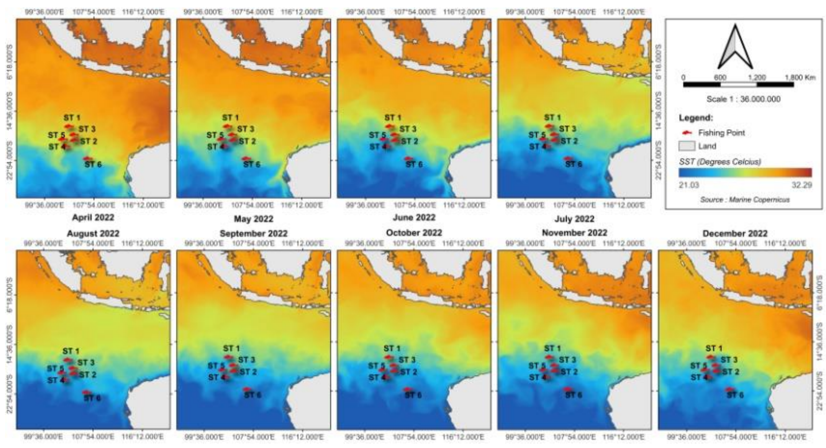

Fig. 2. Distribution of Sea Surface Temperature for April 2022-December 2022

3.2 Salinity

Salinity plays a crucial role in the marine ecological system. The distribution of aquatic biota is closely intertwined with salinity because several biota species can withstand significant changes in salinity levels [12]. The range of average salinity values from April 2022 to December 2022 is from 21.95 psu to 42.06 psu (Fig. 4). Based on this distribution pattern, monthly salinity variability indicates that salinity levels increase as you move offshore and decrease towards the coast due to the influence of land-based intrusions.

Fish tend to select environments with salinity levels that are more suitable for their body's osmotic pressure. If the concentration of a fish's body is not in balance with its surroundings, it will experience stress, which can ultimately lead to death because the fish cannot control the osmoregulation process (the regulation of osmosis within the fish's body). The salinity levels in the waters of the Indian Ocean during the Eastern season are higher compared to the Western season, ranging from 33.4 psu to 34.8 psu [13]

3.3 Chlorofil-a

Fertile waters contain high concentrations of chlorophyll-a, as chlorophyll-a is one of the indicators of water fertility. The average distribution of surface chlorophyll-a concentrations from April 2022 to December 2022 ranged from 0.03 mg/m3 to 3.51 mg/m3. The highest chlorophyll-a concentrations were found in June-August 2022 (Eastern season) and were located around the waters south of Java to the Bali Strait, as well as the northern waters of Australia (Fig. 4.).

High chlorophyll-a concentrations during the period from June to August are found offshore Java [14]. Several factors influence chlorophyll-a abundance, one of which is the upwelling process caused by monsoonal winds. During the Eastern Monsoon, chlorophyll-a concentrations increase, indicating abundant phytoplankton in the waters due to upwelling off the south of Java [15]. On the other hand, low chlorophyll-a concentrations are influenced by a lack of nutrient concentration, which is caused by the absence of significant upwelling events [16].

3.4 Distribution of Oceanographic Parameter Variability

The variability of sea surface temperature (SST) at the swordfish fishing locations from April 2022 to December 2022 ranged from 21.7°C to 27.52°C (Fig. 5). The highest SST at each fishing location was recorded in April 2022 at fishing location ST 1, reaching 27.52°C. Conversely, the lowest SST was observed in November 2022 at fishing location ST 6, registering 21.7°C (Fig. 5).

The range of salinity values at the swordfish fishing locations from April 2022 to December 2022 fluctuated between 34.09 psu and 35.38 psu (Fig. 5). The lowest salinity values at each fishing location were recorded in June 2022 at fishing location ST 1, measuring 34.09 psu. In contrast, the highest values were found in April 2022 at fishing location ST 6, measuring 35.38 psu (Fig. 5).

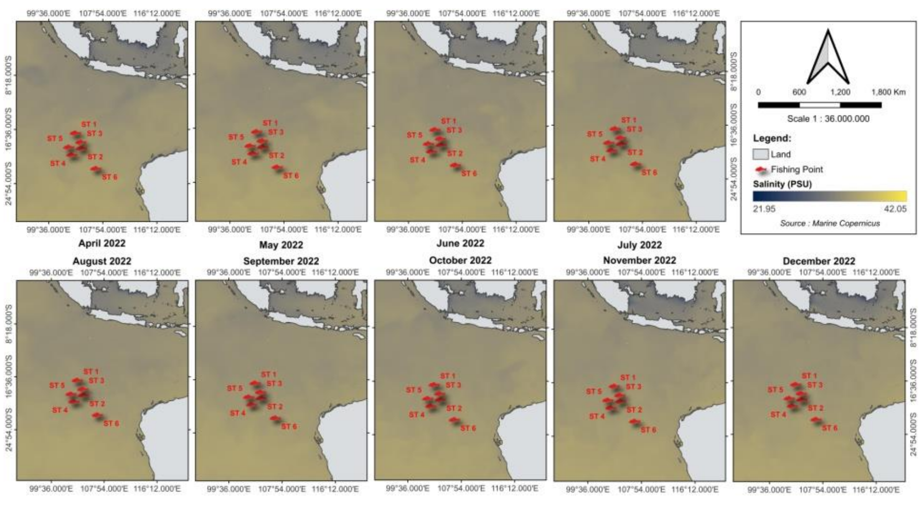

Fig. 3. Distribution of Salinity for the Period April 2022 – December 2022

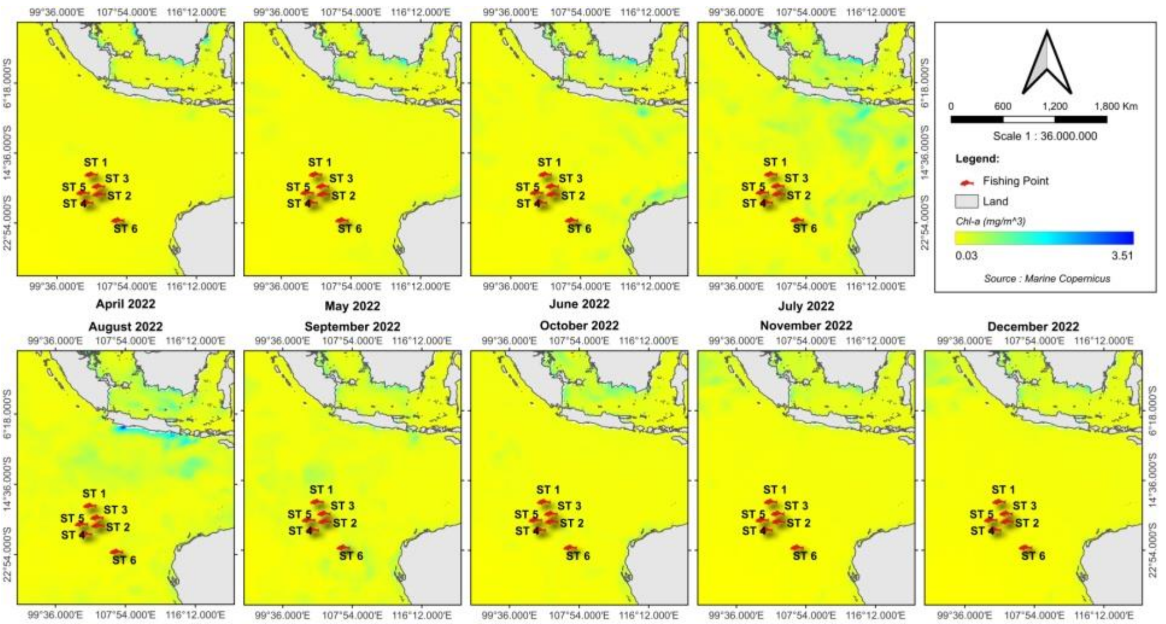

Fig. 4. Distribution of Chlorophyll-a from April 2022 to December 2022

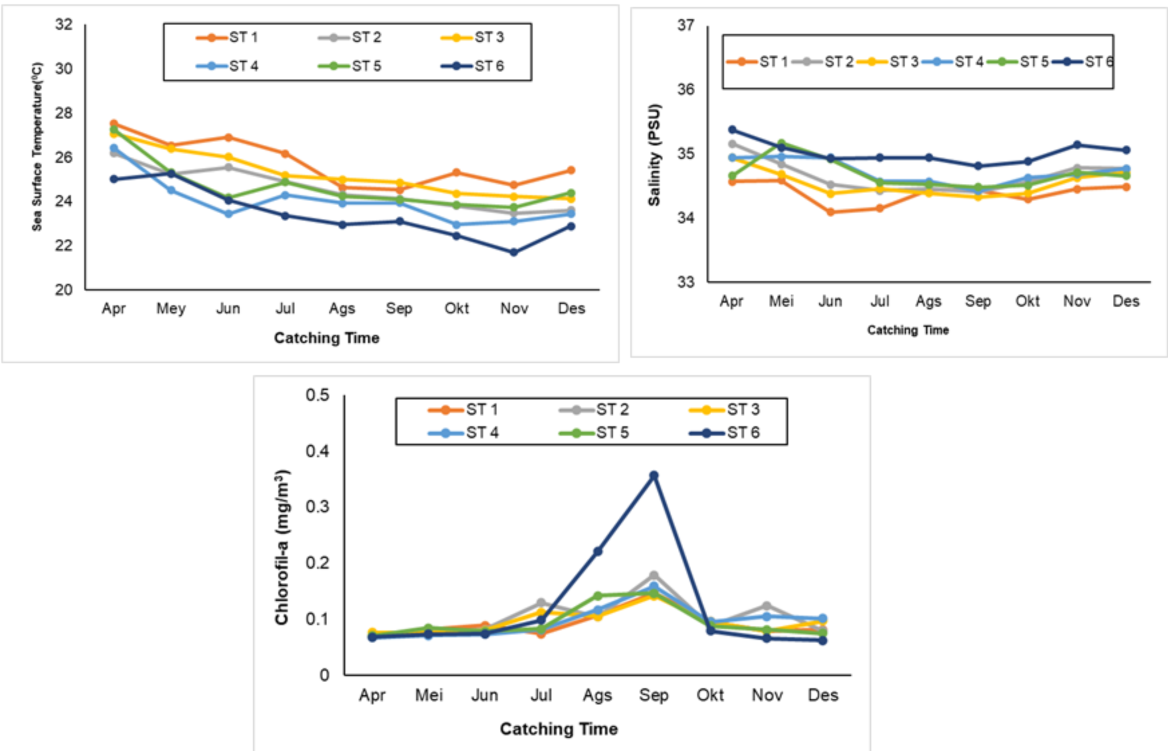

Fig. 5. Graph of Distribution of SST, Salinity, and Chlorophyll-a at fishing points

The range of chlorophyll-a concentration values at the swordfish fishing locations from April 2022 to December 2022 fluctuated between 0.062 mg/m3 to 0.357 mg/m3 (Fig. 5). The lowest chlorophyll-a concentrations at each fishing location were observed in December 2022 at fishing location ST 6, measuring 0.062 mg/m3. Conversely, the highest concentration values were found in September 2022 at fishing location ST 6, measuring 0.357 mg/m3. During that

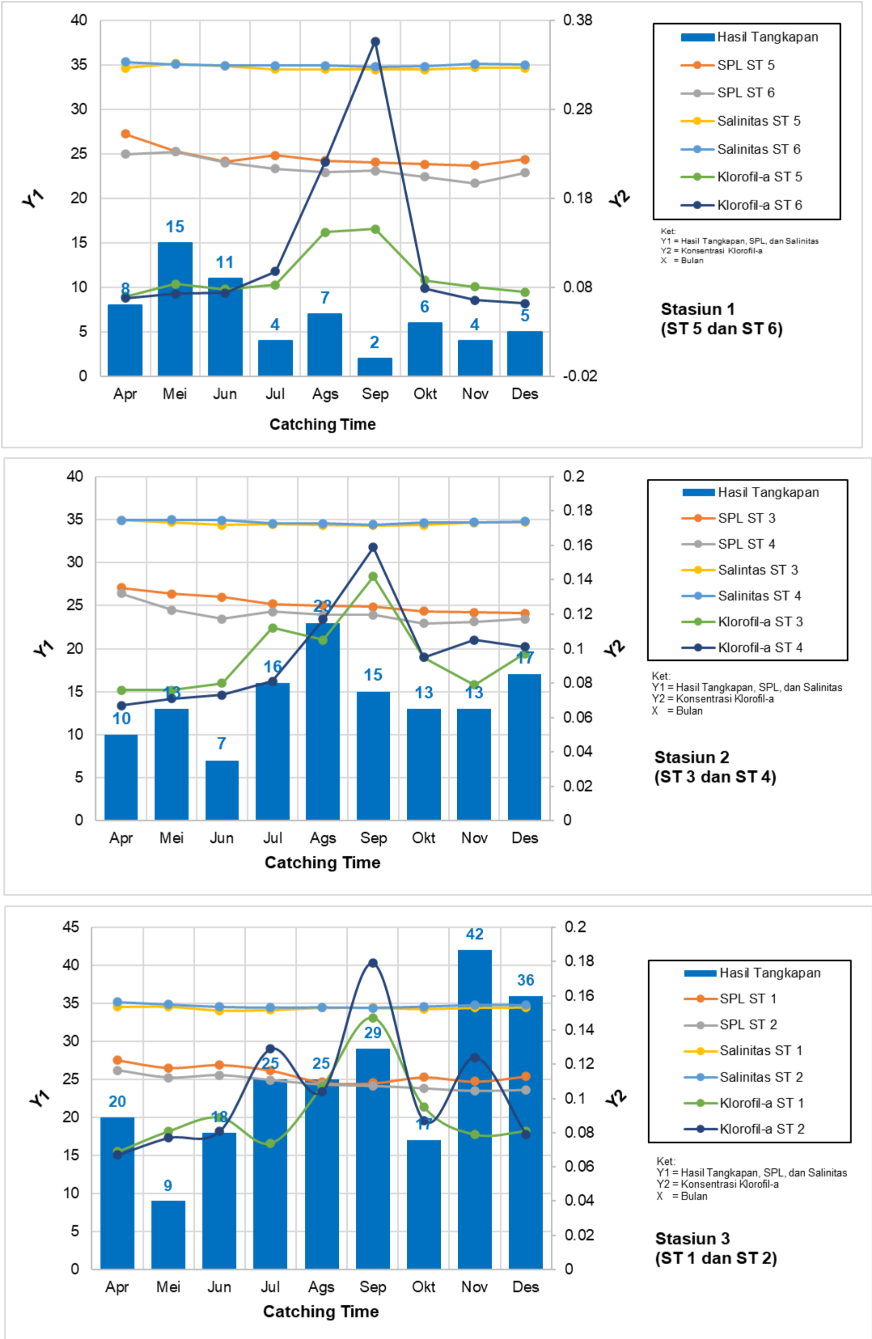

Fig. 6. Graph of catches with oceanographic parameters

month, chlorophyll-a concentrations reached their peak at every fishing location compared to other months (Fig. 5).

3.5 Conditions of SST, Salinity, and Chlorophyll-a on Catches

The catch of swordfish concerning the oceanographic parameters, specifically SST, salinity, and chlorophyll-a, is presented in Fig. 6, where "stations" represent the cumulative catch results from two swordfish fishing points. The highest catch results at Station 1 (ST 5 and ST 6) were recorded in May 2022, with a catch of 15 individuals, while the lowest catch was observed in September 2022, with a catch of 2 individuals. At Station 2 (ST 3 and ST 4), the highest catch was in August 2022, totaling 23 individuals, and the lowest catch occurred in June 2022, with a total of 7 tails.

Meanwhile, at Station 3 (ST 1 and ST 2), the highest catch was recorded in November 2022, with a total of 42 individuals, which represents the optimum catch within the SST range of 23.47°C to 24.74°C. The lowest catch occurred in May 2022, with a total of 9 individuals. This indicates that Station 1 had the highest cumulative catch results every month (from April 2022 to December 2022) when compared to the other two stations.

Among the oceanographic parameters used, chlorophyll-a is the most influential factor. However, this differs from other studies in the same location, where sea surface temperature has a more significant impact among other parameters [17,18] (Setiawan et al. 2015). This condition can also be observed in the results shown in Fig. 6, where high chlorophyll-a values do not significantly affect the increase in swordfish catch results at each fishing location. The highest chlorophyll-a concentrations were observed in September 2022 at each station, but it did not result in the highest swordfish catch.

The distribution of swordfish CPUE (Catch Per Unit Effort) shows a similar concentration pattern to Blue Marlin, which means both are caught at the same time and location [19]. This occurs because both have similar vertical movement characteristics, tending to stay near the surface at night and swimming deeper during the day [1]. Factors influencing Bigeye Tuna, apart from oceanographic parameters, include eddy kinetic energy (EKE) and dissolved oxygen levels, which also affect swordfish distribution [20,21].

Climate anomalies in the Indian Ocean (South of Java), such as El Niño, La Niña, and Dipole Mode (positive or negative), affect the dynamics of oceanographic parameters like SST, upwelling intensity, and chlorophyll-a enrichment [15]. These conditions also influence the distribution and abundance of resources, fluctuations in swordfish catch results, and the composition of neritic tuna catch results [2,3].

4. CONCLUSION

The oceanographic parameter conditions in the Indian Ocean exhibit varying patterns each month, with SST experiencing an increase in April 2022. The highest chlorophyll-a concentration was recorded in September 2022, while the salinity level ranged from 34 to 36 PSU. Chlorophyll-a concentration did not influence the high catch numbers. The optimal swordfish catch rate occurs within the SST range of 23.47-24.74°C, salinity range of 34.45-34.78 psu, and chlorophyll-a concentration range of 0.079-0.124 mg/m3.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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