Short Research Article

Impact of Oceanographic Variability on Chlorophyll-a Concentration and Sea Surface Temperature in North Maluku Waters and its Influence on Fish Abundance

ABSTRACT

The waters of North Maluku are rich in fisheries resources, which are important for the local economy and marine biodiversity. The variability of oceanographic conditions, such as chlorophyll-a and sea surface temperature, plays a significant role in determining fish abundance in this region. This study analyzes the seasonal variations of chlorophyll-a and sea surface temperature during 2021, as well as their impact on the productivity of the waters. Satellite imagery data of chlorophyll-a and sea surface temperature were analyzed using spatial interpolation. The results show seasonal fluctuations in chlorophyll-a concentration and sea surface temperature, where higher chlorophyll-a concentrations support primary productivity and fish abundance during mid-year. The highest chlorophyll-a concentration occurred in June (0.212 mg/m³) and the lowest in February (0.103 mg/m³). The negative phase of the Indian Ocean Dipole (IOD) reduces upwelling intensity, decreases nutrient availability, and impacts the decline in primary productivity. The highest sea surface temperature was recorded in November (30.99°C) and the lowest in August (29.87°C). These oceanographic variations affect the availability of phytoplankton, which is crucial in the marine food chain, and have implications for sustainable fisheries management in North Maluku. The results of this study can also serve as a reference for fish distribution or abundance modeling, such as with the maximum entropy method, to better understand the factors influencing fish distribution patterns in the region.

Keyword : Chlorophyll-a, Fish Abundance, Indian Ocean Dipole, Oceanography, Sea Surface Temperature

1. INTRODUCTION

The North Maluku Sea is part of Fisheries Management Area (WPP) 715, known for its high biodiversity and abundance of fishery resources (Albasri and Pratama 2019). The richness of fish resources in this region is supported by its location within the Coral Triangle, a region with the world's highest coral reef biodiversity. Fishing activities in these waters yield various economically valuable pelagic fish, such as tuna, skipjack, and mackerel, as well as demersal fish, which are the primary catch (DKP 2023). This vast potential not only supports the local economy but also makes a significant contribution to national fishery production.

Fish abundance in a particular area is strongly influenced by oceanographic conditions, including chlorophyll-a concentration, sea surface temperature (SST), and salinity (Pratama et al. 2022). According to Gaol et al. (2014) and Setyaningrum et al. (2017), the presence of fish resources in a water body is not only affected by sea surface temperature but also by chlorophyll-a concentration. These oceanographic factors play an important role in determining the distribution and abundance of fish in specific waters (Saifudin et al. 2014; Wang et al. 2016). Chlorophyll-a, as an indicator of primary productivity, provides phytoplankton, which serves as the primary food source in the marine food chain (Simbolon and Girsang 2009). SST influences fish metabolism, distribution, and migration, making it one of the main factors in determining fish habitats (Azwar et al. 2016).

The relationship between fish abundance and oceanographic conditions is highly interconnected. Optimal environments, such as high chlorophyll-a concentration, suitable temperatures, and stable salinity levels, support marine productivity and fish availability. Conversely, significant changes in oceanographic conditions, such as a decline in chlorophyll-a concentration or an increase in sea surface temperature, can negatively impact fish populations by reducing primary productivity or altering habitat distribution (Sadly and Awaludin 2017). Seasonal dynamics and global climate change also influence these oceanographic factors, making a deeper understanding of their variability essential to support sustainable fisheries.Pratama et al. (2022) successfully modeled the relationship between oceanographic factors, such as chlorophyll-a, sea surface temperature, salinity, and current velocity, and the formation of optimal fish habitats using the Maximum Entropy method. Their findings showed that the combination of these oceanographic factors significantly affects fish distribution and abundance.

Based on this background, it is crucial to analyze the variations in oceanographic conditions, including chlorophyll-a and sea surface temperaturein the waters of North Maluku. This analysis is expected to provide deeper insights into the relationship between oceanographic factors and fish resource abundance in the region. Furthermore, the findings are anticipated to support sustainable fishery resource management, particularly through a better understanding of marine environmental dynamics in the waters around North Maluku.

2. MATERIALANDMETHODS

This study was conducted using secondary data processing, including satellite imagery data on chlorophyll-a, sea surface temperature (SST), and salinity throughout 2021. Chlorophyll-a and SST data were downloaded from the website www.oceancolor.gsfc, while salinity data were obtained from https://marine.copernicus.eu/. The imagery data were downloaded in Non-Conformance (.nc) format. Subsequently, the data underwent several processing procedures.

The process began with data extraction using the SeaDAS 7.5.3 application, followed by spatial clipping to focus on the study area. After the clipping process, the data were exported into a tab-delimited text format (.txt). The .txt files were then processed using Microsoft Excel to remove unnecessary or irrelevant data and to correct for cloud cover issues.

The cleaned .txt data were further processed using ArcGIS software to perform advanced processing, such as data interpolation using the Inverse Distance Weighted (IDW) method. The IDW interpolation method is advantageous due to its adjustable characteristics, allowing for the restriction of input points used in the interpolation process. Additionally, this method facilitates the removal of points that are distant from samples or have low to no spatial correlation (Pasaribu and Haryani 2012).Once the interpolation process using IDW was completed, raster data for the oceanographic parameters were obtained. These raster data were then used to create map layouts, which facilitated the analysis of spatial distribution.

3. RESULTS AND DISCUSSION

3.1 Chlorophyll-aVariation in the Waters Around North Maluku

The monthly average variations in chlorophyll-a concentration in the waters around North Maluku during 2021 are shown in Figure 1. The average chlorophyll-a concentrations from January to December were 0.145 mg/m³, 0.103 mg/m³, 0.131 mg/m³, 0.147 mg/m³, 0.172 mg/m³, 0.212 mg/m³, 0.207 mg/m³, 0.187 mg/m³, 0.136 mg/m³, 0.157 mg/m³, 0.162 mg/m³, and 0.141 mg/m³, respectively. The highest chlorophyll-a concentration occurred in June, with a value of 0.212 mg/m³, while the lowest concentration was recorded in February at 0.103 mg/m³.

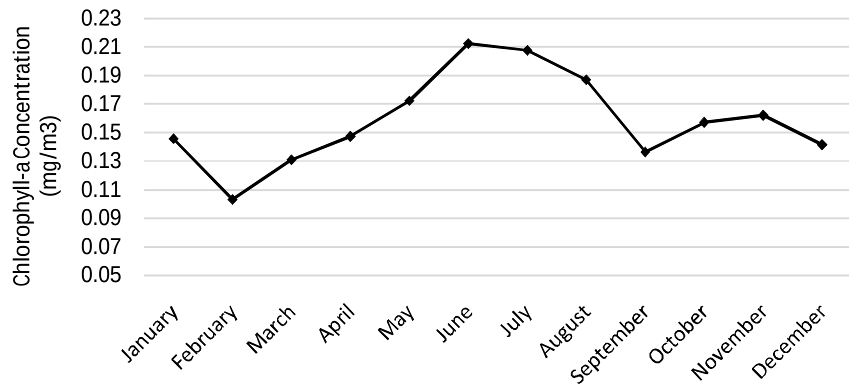

Figure 1. Monthly average fluctuations in chlorophyll-a concentration in the Waters around North Maluku

Figure 1 shows significant seasonal variations, where chlorophyll-a concentrations tend to increase in the middle of the year (May to August) and decrease at the beginning and end of the year (December to February). The rise in chlorophyll-a concentration from June to August indicates that this period was marked by relatively optimal primary productivity in 2021, supporting the abundance of phytoplankton, which forms the base of the marine food chain. This condition is typically followed by an increase in the abundance of pelagic fish such as skipjack tuna, due to a significant positive correlation between chlorophyll-a concentration and skipjack tuna catch production (Pratama et al., 2022). Conversely, the low chlorophyll-a concentrations at the beginning of the year may indicate oceanographic conditions that are less favorable for primary productivity.

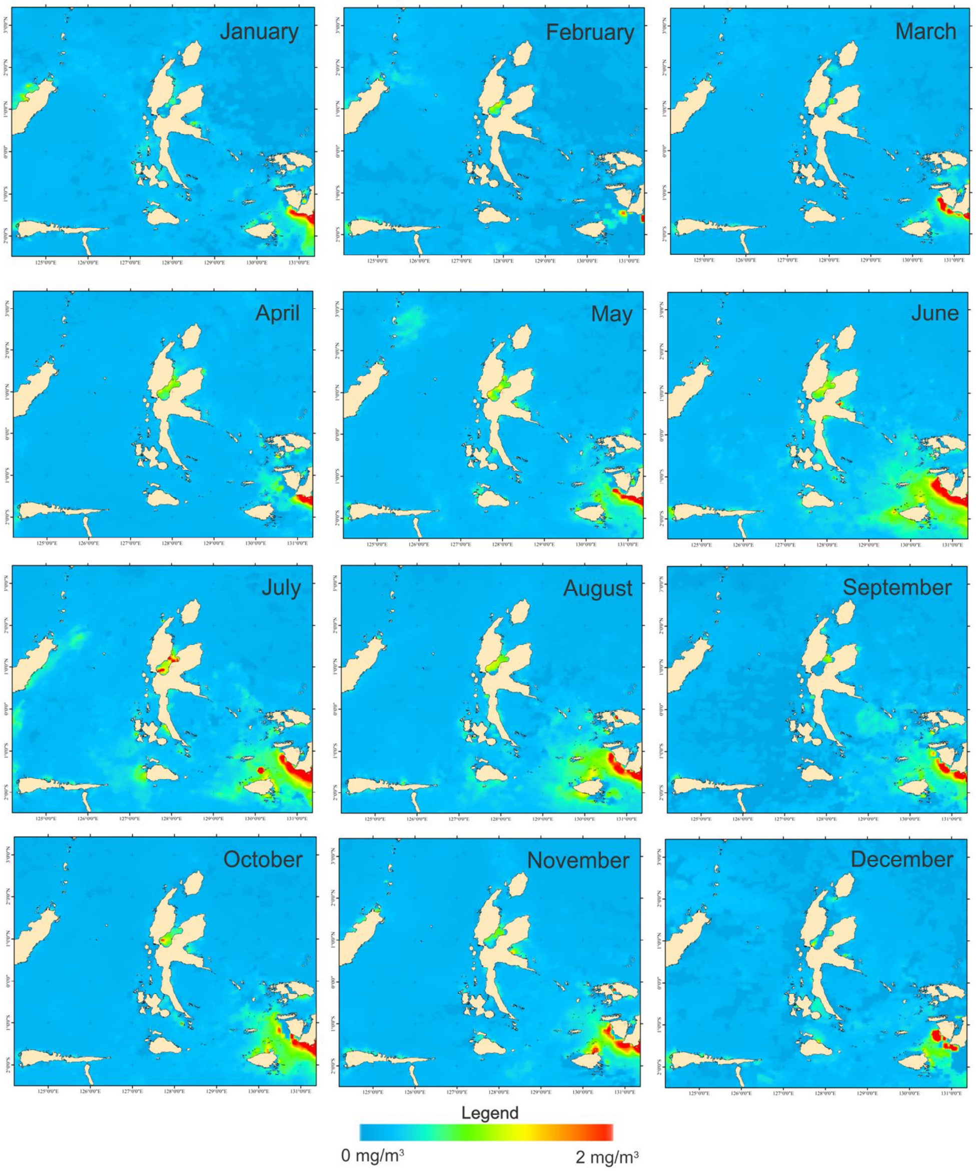

Figure 2. Spatial map of chlorophyll-a concentration distribution in the waters around North Maluku.

Based on the spatial and temporal distribution map of chlorophyll-a concentration in Figure 2, it can be observed that coastal areas or waters near the land tend to have higher chlorophyll-a concentration values. This aligns with the findings of Nurani et al. (2021), which state that waters near the land will have higher chlorophyll-a concentrations compared to waters farther from the land. Higher chlorophyll-a concentrations tend to result in higher fish production, meaning that fish abundance in the waters tends to be high (Ningsih et al., 2021).

The average distribution of chlorophyll-a values this year tends to be low. Based on the Dipole Mode Index (DMI) from the Meteorology, Climatology, and Geophysics Agency (BMKG), a negative Indian Ocean Dipole (IOD) phase occurred in June 2021, indicated by a DMI value of less than -0.4. BMKG predicts that the negative IOD phase will continue until November 2021. This phenomenon caused an increase in sea surface temperature, which led to a decrease in chlorophyll-a concentration. Sea surface temperature significantly influences chlorophyll-a concentration (Gao et al., 2022). According to Nurani et al. (2021), low chlorophyll-a concentrations in waters may be caused by the negative IOD phase, which reduces upwelling intensity. Upwelling is the process of cold, nutrient-rich water rising from the seabed to the surface, which typically increases primary productivity in waters. Without sufficient upwelling, the availability of nutrients in the surface layer decreases, thus hindering the growth of phytoplankton, which is a key component of chlorophyll-a.

The IOD itself is an ocean-atmosphere phenomenon occurring along the equator that affects the climate of countries surrounding the Indian Ocean (Saji et al., 1999). With the decrease in chlorophyll-a concentrations, primary productivity in the waters becomes lower because phytoplankton, the primary producer in the marine food chain, cannot develop optimally. This directly impacts the availability of food for zooplankton and other organisms that serve as prey for fish. Consequently, fish abundance in the waters also declines due to the reduced food supply. Small pelagic fish, such as mackerel and anchovies, are highly dependent on phytoplankton abundance since they are directly or indirectly at the base of the food chain starting with phytoplankton. The decline in small fish populations also affects predator fish at higher trophic levels, such as tuna and skipjack.

3.2 Sea Surface Temperature Variation in the Waters Around North Maluku

The fluctuations in the average sea surface temperature in the waters around North Maluku in 2021 are shown in Figure 3. The monthly average sea surface temperatures for January, February, March, April, May, June, July, August, September, October, November, and December are 30.43°C, 30.27°C, 30.73°C, 30.68°C, 30.31°C, 30.06°C, 29.89°C, 29.87°C, 29.93°C, 30.82°C, 30.99°C, and 30.29°C, respectively. The highest value was recorded in November at 30.99°C, while the lowest value occurred in August at 29.87°C.

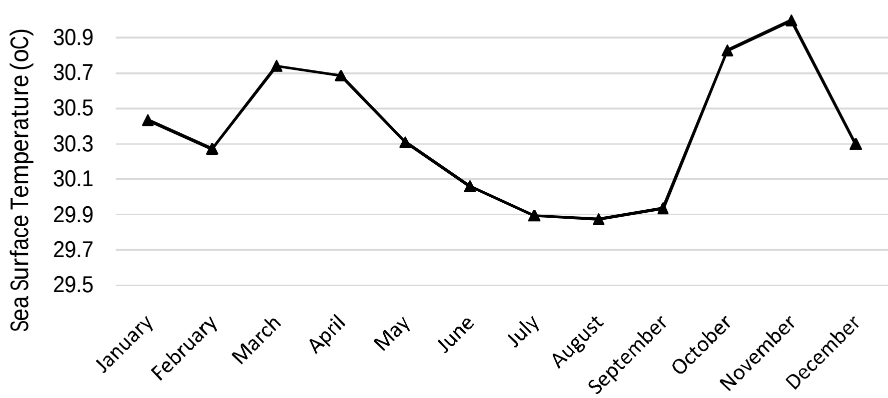

Figure 3. Monthly average fluctuations in sea surface temperature in the waters around North Maluku

Based on Figure 3, it is evident that sea surface temperature (SST) ranges from 29.87°C to 30.99°C throughout the year. SST tends to be higher in October and November, with values reaching 30.82°C and 30.99°C, respectively. Meanwhile, the lowest SST values occur in July and August, at 29.89°C and 29.87°C, respectively. Overall, the temperature pattern indicates that these waters remain relatively warm year-round, with a slight temperature decrease during mid-year (eastern season) and an increase towards the end of the year (western season).

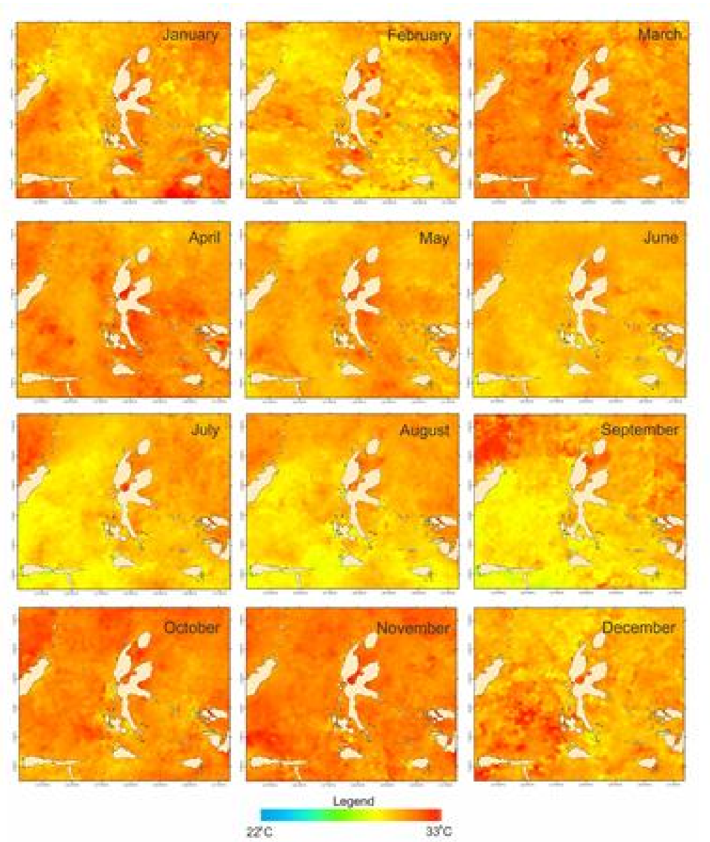

Figure 4. Spatial map of sea surface temperature distribution in the waters around North Maluku.

Based on the temporal spatial map of sea surface temperature (SST) in the waters around North Maluku shown in Figure 4, the average SST in 2021 is considered high. This elevated SST distribution is attributed to the negative IOD phase and La Niña phenomenon (BMKG, 2021). During the negative IOD phase, waters tend to warm compared to other phases (Malau et al., 2021). The negative IOD phase increases SST in the eastern Indian Ocean (including Indonesia and Australia), leading to an intensification of downwelling. Downwelling is the sinking of warm, nutrient-poor water, which hampers the distribution of nutrients from deeper layers to the surface. This phenomenon is suspected to contribute to the elevated SST in the waters around North Maluku during the eastern season. The IOD phase (positive/negative) in a region can be identified using the Dipole Mode Index (DMI), which is the difference in sea surface temperature anomalies between the Western Tropical Indian Ocean (WTIO) and the Southern Tropical Indian Ocean (STIO).

Similar to the decline in chlorophyll-a concentration, an increase in SST also negatively affects fish abundance in the waters. Warmer temperatures tend to reduce the intensity of upwelling, the process by which nutrient-rich water rises from the ocean depths. With reduced upwelling, the amount of nutrients in the surface layer decreases significantly. As a result, primary productivity, marked by phytoplankton growth at the base of the food chain, also declines. Phytoplankton plays a crucial role as a primary food source for zooplankton, which, in turn, serves as food for various fish species.

The results of this study can significantly inform local fisheries management strategies by providing a deeper understanding of the seasonal patterns of chlorophyll-a and sea surface temperature variations, which influence fish abundance. This knowledge can guide the optimal timing for fishing activities, ensuring they align with periods of higher primary productivity when fish abundance is typically greater. Furthermore, recognizing the impact of oceanographic conditions like the Indian Ocean Dipole (IOD) and La Niña events allows fisheries managers to anticipate changes in marine conditions and biodiversity, enabling proactive management decisions. The study's findings can also be utilized in habitat suitability modeling or fish abundance forecasting through techniques like maximum entropy, improving predictions of fish distribution and supporting more effective conservation measures. Ultimately, these insights can aid in the development of sustainable fisheries practices and help mitigate the effects of environmental variability and climate change on marine ecosystems.

4. CONCLUSION

The seasonal variation in chlorophyll-a concentration and sea surface temperature (SST) in the waters around the Halmahera Sea, North Maluku, exhibited significant patterns throughout 2021. The highest chlorophyll-a concentration was recorded in June (0.212 mg/m³), indicating optimal primary productivity driven by increased phytoplankton growth. Conversely, the lowest chlorophyll-a concentration occurred in February (0.103 mg/m³) due to the negative Indian Ocean Dipole (IOD) phase. The negative IOD phase reduces upwelling intensity, thereby limiting nutrient availability in the ocean's surface layer. The SST pattern revealed the highest temperature in November (30.99°C) and the lowest in August (29.87°C). Elevated SST was influenced by the negative IOD phase, which caused an increase in downwelling intensity, reducing the distribution of nutrients from the deeper ocean layers to the surface.

5. DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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