Dynamics of Chlorophyll-a Concentration in Ternate Island Waters and Its Effect on Yellowfin Tuna Production

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Abstract. This research was conducted from May to August 2023, with the aim of assessing the distribution of chlorophyll-a concentration and its effect on yellowfin tuna production in Ternate Island waters. The use of experimental fishing methods in collecting research data and data analysis in the form of abundance analysis, exponential regression, cross correlation, and General Additive Models is expected to answer the research objectives. The results showed that the fluctuation of yellowfin tuna fish catch was similar to the abundance of fish stocks with the highest catch in June (14 229 kg) followed by July (11 142 kg), August (10 764 kg) and May (8 001 kg). The catch of yellowfin tuna fish is spread over a range of chlorophyll-a concentrations between 0.06 mg m⁻³ to 0.32 mg m⁻³, with an average monthly chlorophyll-a concentration of 0.22 mg m⁻³. Chlorophyll-a conditions in Ternate Island waters are quite fluctuating and significantly affect the catch of yellowfin tuna fish with a very strong correlation coefficient of 0.87. The results of General Additive Models analysis found that the chlorophyll-a concentration value for potential yellowfin tuna fishing areas is > 0.01 mg m⁻³ with a correlation distance or time lag is in week 15.

Keywords: Biophysical environment, madidiang, oseanography factor, phytoplankton, Thunnus albacares (Bonnaterre, 1788)
1 Introduction

The waters of Ternate Island, which is located in the Indonesian cross-current area (Arus Lintas Indonesia - ARLINDO), certainly has considerable fisheries potential, one of which is yellowfin tuna (Figure 1) from the scombridae family which is an economically important large pelagic fish species. Yellowfin tuna (YFT) with the scientific name *Thunnus albacares* (Bonnaterre, 1788) is the highest export commodity after shrimp and seaweed [1]. Yellowfin tuna live in clusters in the pelagic zone in tropical and sub-tropical waters and are a type of fast swimming fish whose spatial and temporal existence is strongly influenced by environmental factors, especially foraging grounds [2]. According to Kurota *et al.* [3], Pamungkas *et al.* [4], environmental conditions are an important factor in the growth and development of fish, especially pelagic fish. According to researchers [5–7], the concentration of the distribution of environmental or oceanographic parameters in a body of water can affect the distribution and abundance of a biological resource in the waters, especially in fishing areas, further by Putri *et al.* [8], suggesting that the presence of fish is influenced by the water conditions favored by the target fish catch, and according to Nataniel *et al.* [9], that the condition of the aquatic environment affects the availability of fish schooling.

![Fig. 1. Yellowfin tuna/YFT (Thunnus albacares).](image)

Environmental parameters that play a role in fish distribution, especially yellowfin tuna, are biophysical parameters including sea surface temperature, chlorophyll-a concentration, salinity, and currents [10]. Biophysical environmental conditions play an active role in the potential and distribution and also have a major influence on the seasonal pattern of yellowfin tuna fishing. The influence of the biophysical environment is also on the availability of food both in quantity and quality which affects predation rates and is an important variable for yellowfin tuna populations. Food availability is related to the food chain, where phytoplankton with chlorophyll-a pigment, which is the primary producer and the basic chain, will then be utilized by herbivorous animals to carnivorous animals so that it will form a fishing area. Yellowfin tuna as a carnivorous animal that is present in the fishing area is not a consumer that utilizes chlorophyll-a as a food source but as a food chain in a fishing area.

Chlorophyll-a is a photosynthetic pigment that is the most common pigment found in phytoplankton so that the content of phytoplankton concentration is often expressed in chlorophyll-a concentration [11]. Yusop and Mustapha [12], stated that one of the parameters
of environmental conditions that can determine the distribution of fish resources is chlorophyll-a concentration so that it can be used to estimate the habitat of fish resources. Phytoplankton holds important waters as primary producers; therefore, chlorophyll-a phytoplankton is often expressed as an index of biological productivity in the oceanic environment which is then associated with fish production. According to several researchers [13–15], the concentration of chlorophyll-a values has a significant effect on increasing fish catches. Based on the description above, this study was conducted to examine the distribution of chlorophyll-a concentration and its effect on yellowfin tuna production in Ternate Island waters.

2 Material and method

This research was conducted from May to August 2023, in the waters of Ternate Island at coordinates 0°44' N - 1°10' N and 127°8' E - 127°24' E (Figure 2) with experimental fishing method. The tools used consisted of one unit of computer with software consisting of SeaDAS 7.4, R version 4.0.2 for GAM modeling and statistical analysis, as well as ArcGIS 10.4 for making maps of research locations and maps of potential fishing areas. Research materials in the form of yellowfin tuna catch weight data per fishing trip and fishing area position plots, then chlorophyll-a concentration data during May to August 2023 were obtained from https://oceancolor.gsfc.nasa.gov/l3/.

![Research location](https://example.com/fig2.png)

Fig. 2. Research location.
The research data were then analyzed to determine the abundance using the formula according to Nugraha and Hufiadi [16] in the Equation (1).

\[ LP = \frac{E}{P} \times 100 \]  

(1)

Where,
LP = Hook rate
E = Number of YFT fish caught (kg)
P = Number of fishing lines used

To see the effect between chlorophyll-a concentration and YFT fish catch, an exponential regression analysis was conducted with the mathematical model in the Equation (2) [17, 18].

\[ y = a^{bx} \]  

(2)

Where,
y = YFT fish catch
x = Chlorophyll-a variable value
a and b = Constants

The analysis was then continued using the General Additive Model with R software version 4.0.2. GAM is a non-linear model, used to examine the relationship between the response variable \( \mu_i \) (total catch of YFT fish) and the predictor variable (chlorophyll-a concentration), which is formulated with mathematical Equation (3) [19, 20].

\[ G(\mu_i) = \alpha 0 + s1 (\text{Const. chlorophyll a}) + \epsilon \]  

(3)

Where,
g = spline smoothing function
\( \mu_i \) = response variable
\( \alpha 0 \) = constant coefficient
s = smoothing function of the predictor variable
\( \epsilon \) = standard error

3 Result and discussion

3.1 Catch results

Yellowfin tuna (YFT) is an economically important large pelagic fish species with a fairly high production level in Ternate Island waters, where the total catch during May to August 2023 was 44 136 kg with an average catch per month of 11 034 kg mo\(^{-1}\). The catch of YFT fish during May to August 2023 was quite fluctuating, where the highest catch was in June while the lowest was in May (Figure 3a). This fluctuation in catch is similar to the fishing rate (Figure 3b), which indicates that the abundance of YFT fish stock in June is higher than the abundance of YFT fish stock in May, July and August 2023.
3.2 Characteristics and values of chlorophyll-a concentration in Ternate Island area

Chlorophyll-a is phytoplankton biomass which is an index of the level of biological productivity of a body of water [19, 5], where the distribution of chlorophyll-a concentration can be related to fish production or catch [21]. Determining the level of fertility and the quality of a body of water can be seen from the value of chlorophyll-a contained in these waters. The weekly chlorophyll-a concentration fluctuation during May to August 2023 can be seen in Figure 4 and Figure 5, while the distribution of chlorophyll-a concentration in Ternate Island waters can be seen in Figure 6.
Figure 4 and Figure 5, it can be seen that the weekly fluctuation of chlorophyll-a concentration during May to August in Ternate Island waters is in the range of 0.06 mg m$^{-3}$ to 0.32 mg m$^{-3}$, with an average chlorophyll-a concentration of 0.22 mg m$^{-3}$. The dynamics of chlorophyll-a concentration during May to August 2023 is thought to be influenced by nutrient availability and sunlight intensity [22]. In addition to these two factors, fluctuations in chlorophyll-a concentrations in offshore waters such as the current research area can be explained by the influence of monsoon winds that result in circulation patterns and raising water masses or mixing processes that bring nutrients from the bottom of the water to the surface of the sea water, causing an increase in chlorophyll-a content in the surface layer of water [23, 13].

Another influence that is thought to play a role in fluctuations in chlorophyll-a concentration in Ternate Island waters is the influence of Pacific Ocean water masses crossing these waters to the Indian Ocean through the Indonesian cross-current system that mixes and will increase nutrient concentrations which cause an increase in chlorophyll-a
content in Ternate Island waters [24]. According to Agung et al. [25], that the distribution of chlorophyll-a concentrations in shore areas is also largely influenced by wind factors, the mechanism of influence is that the wind blowing in these waters is thought to result in a mixing process so that chlorophyll-a concentrations in these waters vary greatly [25].

![Fig. 6. Distribution of chlorophyll-a concentration in May to August 2023 in Ternate Island waters.](image)

Chlorophyll-a in May (Figure 6a) looks lower in the western and southern parts of Ternate Island and tends to be high in the northern part of Ternate Island. In general, the condition of chlorophyll-a concentration in the fishing area during May is in the range of 0.06 mg m\(^{-3}\) to 0.26 mg m\(^{-3}\) with an average value of 0.19 mg m\(^{-3}\) (Figure 5). In June the chlorophyll-a concentration was in the range of 0.19 mg m\(^{-3}\) to 0.32 mg m\(^{-3}\) with an average value of 0.225 mg m\(^{-3}\) and almost evenly distributed in the fishing area (Figure 6b). In June (Figure 6c) the distribution of chlorophyll-a concentrations tended to be high in the western and southern areas of Ternate Island with minimum, maximum and average values of 0.1 mg m\(^{-3}\), 0.32 mg m\(^{-3}\), and 0.245 mg m\(^{-3}\), respectively. In August (Figure 6d) chlorophyll-a concentration conditions tend to be high in the northern part of Ternate Island and some areas in the west and south of Ternate Island and in general the chlorophyll-a concentration value in August is in the range of 0.1 mg m\(^{-3}\) to 0.32 mg m\(^{-3}\) with an average value of 0.22 mg m\(^{-3}\).

The condition of the average value of chlorophyll-a concentration in May to August 2023 in the waters of Ternate Island which is at a value greater than 0.19 (0.2) mg m\(^{-3}\) can indicate the presence of sufficient plankton to maintain fish survival [11]. According to Putra et al.
[26], that phytoplankton abundance has a correlation with chlorophyll-a, because it is known that phytoplankton contains chlorophyll-a so that the high and low abundance of phytoplankton can affect the size of the chlorophyll-a content. The content of chlorophyll-a concentration in a water body is closely related to the food chain. High chlorophyll-a content in the waters will increase the productivity of zoo plankton, thus creating a food chain that supports the productivity of fish in the waters [26].

3.3 Relationship between chlorophyll-a concentration and YFT fish catches

Chlorophyll-a content in a body of water is closely related to the food chain and will increase the productivity of plankton, especially zoo plankton, thus creating a food chain that supports fish productivity in waters [27, 28]. Chlorophyll-a is used as a measure of the amount of phytoplankton in certain waters and can be used as a guide to water productivity. YFT fish is a type of pelagic fish whose existence is influenced by the food chain process, where the existence of YFT fish is influenced by phytoplankton, although not directly. The graph of YFT fish fluctuation and chlorophyll-a concentration can be seen in Figure 7.

![Figure 7](https://example.com/image7.png)

Fig. 7. Distribution graph of chlorophyll-a concentration with YFT fish catches.

Figure 7 shows the weekly fluctuation of YFT fish catch and chlorophyll-a concentration during May to August 2023, where it can be seen that when the YFT fish catch increases, the chlorophyll-a concentration conditions also increase, and if the chlorophyll-a concentration decreases, it will affect the trend of YFT fish production which also decreases. The results of the exponential regression analysis between chlorophyll-a and YFT fish catches (Figure 8), found that chlorophyll-a concentration in Ternate Island waters is closely related to chlorophyll-a concentration, with a determination coefficient value \( r^2 \) of 0.755 or individually 75.5% of the presence of YFT fish is influenced by chlorophyll-a concentration. The correlation coefficient obtained from the results of data analysis is 0.87, meaning that the relationship between the two variables is very strong with a positive correlation value, that is, if the concentration of chlorophyll-a increases, the catch of YFT fish will also increase as shown in the linear trendline in Figure 8.

Other research results by Tangke et al. [11], found that chlorophyll-a in the Maluku Sea has a close relationship with chlorophyll-a in the range of 0.042 mg m\(^{-3}\) to 0.78 mg m\(^{-3}\), [24],
chlorophyll-a fluctuations in Java sea waters range from 0.22 mg m\(^{-3}\) to 1.15 mg m\(^{-3}\) and significantly affect the catch of small pelagic fish [2], chlorophyll-a is in the range of 0.2086 mg m\(^{-3}\) to 7.4654 mg m\(^{-3}\) and 0.20 mg m\(^{-3}\) to 0.40 mg m\(^{-3}\). The average value of monthly chlorophyll-a concentration greater than 2.0 indicates the presence of sufficient plankton to maintain fish survival, especially small pelagic fish [2]. High concentrations of chlorophyll-a in the waters contain high nutrients that cause the formation of potential fishing grounds [30]. According to Hidayat et al. [31], the distribution of large pelagic fish, especially skipjack tuna in Makassar strait, is influenced by chlorophyll-a and sea surface temperature, further by Tan et al. [32], the number of pelagic fish in the waters of the Bali strait is thought to be due to the large availability of food in the waters, further by Nugraha and Hufiadi [16], that chlorophyll-a concentration and sea surface temperature are parameters that can be used to detect potential areas for fishing.

The results of the analysis with the General Aditive Model can be seen that the chlorophyll-a concentration for potential fishing areas in May to August 2023 in Ternate Island waters is at a value > 0.1 mg m\(^{-3}\) (Figure 8 and Figure 9). Furthermore, the results of the cross-correlation analysis between chlorophyll-a concentration and the number of...
mackerel catches are presented in Figure 10, where it can be seen that the time lag or correlation distance occurs in week 15. The results of this test are reinforced by the descriptive analysis in Figure 11, which shows that the catch of YFT fish began to increase significantly in week 7 even though the value of chlorophyll-a concentration and YFT fish catch was already high in previous trips.

Chlorophyll-a content also affects the catch of tuna because chlorophyll-a acts as the main link in the food chain [33, 11]. The concentration of chlorophyll in the waters does not directly affect the number of fish in the area. There is a time when the chlorophyll concentration in the water area is first eaten by herbivorous organism structures, for example zooplankton, or small crustaceans (juveniles), and then eaten by the trophic level above [34, 35]. The time-lag between environmental parameters and tuna fishing data can be explained through the food chain process. The food chain process takes time, where producers (chlorophyll-a) in phytoplankton are consumed by zooplankton and small fish, until they become food for larger tuna [36, 11].

Fig. 10. Cross-correlation between chlorophyll-a and YFT fish catches.
Fig. 11. Chlorophyll-a showed a significant effect on Trip 15.

4 Conclusion

The concentration of chlorophyll-a in the waters of Ternate Island is quite fluctuating from May to August 2023 and is in the range of values 0.06 mg m$^{-3}$ to 0.32 mg m$^{-3}$, with an average value of 0.22 mg m$^{-3}$, where this value indicates the presence of sufficient plankton to maintain the continuity of fish resources so that the value of chlorophyll-a concentration exponentially gives a real influence on the distribution of YFT fish with potential fishing areas at a chlorophyll-a value $> 0.1$ mg m$^{-3}$ and an increase in the yield of YFT fish can be seen significantly in the time leg or correlation distance at week 15.

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