Journal of Hunan University

(Natural Sciences)

Vol. 51 No. 12

December 2024

Available online at

http://jonuns.com/index.php/journal/index

Open Access Article https://doi.org/10.55463/issn.1674-2974.51.12.1

Distribution of Chlorophyll-a Concentrations in Ternate Island Waters Influencing the Productivity of Yellowfin Tuna (*Thunnus albacares*)

Umar Tangke [1]*, Ahmad Talilb [1], Syahnul S. Titaheluw [1], Ruslan Laisouw [2], Muh. Askar Laitupa [3], Djabaluddin Namsa [4], Hamdan Bakari [5], Srifani Jainudin [5], Martina Suasa [5] and M. Faisal Sigui [5]

([1] Department of Fisheries Product Technology, Faculty of Agriculture and Fisheries, Muhammadiyah Maluku Utara University, Ternate, Indonesia

[2] Department of Mathematics and Natural Sciences, Faculty of Engineering, Muhammadiyah Maluku Utara University, Ternate, Indonesia

[3] World Conservation Society (WCS), Ternate, Indonesia

[4] Marine and Fisheries Service of North Maluku Province, Ternate, Indonesia

[5] Fisheries Product Technology student, Faculty of Agriculture and Fisheries, Muhammadiyah Maluku Utara University, Ternate, Indonesia)

* Corresponding author: umbakhaka@gmail.com

Article History:

Received: October 4, 2024
Revised: October 29, 2024
Accepted: November 11, 2024
Published: December 30, 2024

Abstract: Temporal determination of fishing areas can be predicted by utilizing remote sensing and GIS technology, which is both new and growing, one of which is by analyzing the distribution of chlorophyll-a concentrations in time series. Based on this, this research was carried out from May to August 2024 in Ternate Island waters with the aim of examining the distribution of chlorophyll-a concentration and its influence and relationship with the catch of yellowfin tuna, which is the leading commodity in the export sector of capture fisheries in Ternate City. This study was conducted using an experimental fishing method with data collected in the form of fish catch data and satellite images of chlorophyll-a concentration distribution based on catch position plots. The data analysis began with GIS analysis to extract and map the temporal distribution of chlorophyll-a concentration in the study area followed by analysis of catch composition. Furthermore, statistical analysis was conducted to determine the relationship between chlorophyll-a concentration and the number of yellowfin tuna caught. The results showed that the value of chlorophyll-a concentration in Ternate Island waters fluctuated from May to August 2023, with a minimum value of 0.21-0.56 mg m-3 maximum 0.33 mg m-3 and an average of 0.34 mg m3. Furthermore, the results of the regression analysis showed that chlorophyll-a concentration significantly influenced the catch of yellowfin tuna with the value of $F_{count.}$ = 82.834 and Sig. = 0.00, with the coefficient of determination (R^2) being 0.58, and the results of GAM analysis finding that the relationship between the two variables is very very real ($P < 0.0001$), which is reinforced by the results of correlation analysis with an r value of 0.762, which indicates that the correlation between the two variables is strong and positive, with a cross-correlation value indicating the presence and increased production of yellowfin tuna in Ternate Island waters significantly is on trip 13.

Keywords: Yellowfin tuna (YFT), chlorophyll-a, general additive model (GAM), geographic information system (GIS), Ternate Island.

特尔纳特岛水域叶绿素 a 浓度分布对黄鳍金枪鱼（黄鳍金枪鱼）生产力的影响

摘要：利用遥感和 GIS 技术可以预测捕鱼区的时间确定，这两种技术既新颖又不断发展，其中之一就是分析叶绿素 a 浓度的时间序列分布。基于此，这项研究于 2024 年 5 月至 8 月在特尔纳特岛海域进行，旨在研究叶绿素 a 浓度的分布及其与黄鳍金枪鱼捕捞量的影响和关系，黄鳍金枪鱼是特尔纳特市捕捞渔业出口部门的主要商品。这项研究采用实验性捕捞方法，数据以鱼类捕捞数据和基于捕捞位置图的叶绿素 a 浓度分布卫星图像的形式收集。数据分析从 GIS 分析开始，以提取和绘制研究区域叶绿素 a 浓度的时间分布，然后分析捕捞量构成。此外，还进行了统计分析，以确定叶绿素 a 浓度与捕获的黄鳍金枪鱼数量之间的关系。结果表明，2023年5月至8月特尔纳特岛海域叶绿素a浓度值波动较大，最小值为 0.21-0.56mgm-3，最大值为0.33mgm-3，平均值为0.34mgm3。 此外，回归分析的结果表明，叶绿素a浓度对黄鳍金枪鱼的捕捞量有显著影响，Fcount值为82.834，Sig值为1. = 0.00，判定系数（R2）为0.58，GAM分析的结果发现两个变量之间的关系非常真实（P <0.0001），相关性分析的结果也证实了这一点，r值为0.762，这表明两个变量之间的相关性很强，并且是正相关的，互相关值表明特尔纳特岛海域黄鳍金枪鱼的存在和产量的增加在第13次航次中显着。

关键词： 黄鳍金枪鱼（YFT）、叶绿素-a、广义可加模型（GAM）、地理信息系统（GIS）、特尔纳特岛

1. Introduction

The potential of capture fisheries in Ternate Island waters is quite large due to its geographical location in the Maluku Sea and WPP714 with variability in oceanographic parameters that are directly influenced by the movement of water masses in the form of the Indonesian Throughflow (Arlindo) from the Pacific Ocean, which enters through the Maluku Sea to the western Banda Sea and then to the Indian Ocean [1]. The presence of these water masses is thought to provide seasonal variation in fishing patterns. Madidihang fish, also known as yellowfin tuna, is one of the economically important leading export commodity capture fisheries resources from Ternate Island [2]. According to [3], yellowfin tuna is a type of pelagic fish that likes i and often associates with floating objects in the water. The distribution of yellowfin tuna resources in forming fishing grounds by conducting horizontal and vertical migration, to find an environment that suits physiological capabilities and areas rich in food [4, 5], fishing grounds are water areas where fishing gear is operated to exploit fish resources, and their distribution is influenced by various factors, one of which is aquatic oceanographic factors.

The presence of tuna can be assessed using oceanographic parameters, including sea surface temperature, chlorophyll a concentration, and upwelling [6, 7]. According to [8], oceanographic factors play an important role in determining fishing grounds because changes in oceanographic parameter conditions can affect movement patterns as fish tend to look for water conditions that suit their living environment. Fishing season patterns and pelagic fish abundance are influenced by oceanographic dynamics, including chlorophyll-a concentration and sea surface temperature, where information on fishing season patterns and their relationship to oceanographic parameters can help fishermen improve fishing efficiency [9]. The suitability of the aquatic environment that can affect the presence of fish resources includes sea surface temperature, salinity, and chlorophyll-a concentration, whose presence affects water productivity and is measured by the phytoplankton content [10]. Chlorophyll-a is a photosynthetic pigment in phytoplankton and is a microscopic one-cell organism that lives in water; its abundance indicates the level of water fertility [11]. Furthermore, according to [12], chlorophyll-a concentration is also used as information to assess fish resources because there is a relationship between primary productivity and fishery resources, so areas that have high chlorophyll-a concentrations have high concentrations of fish as well.

Along with the advancement of science and technology, the distribution of chlorophyll-a concentrations is currently detected using the Terra and Aqua satellites with Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. The chlorophyll-a concentration distribution can be obtained from time series data and used to determine yellowfin tuna fishing areas using remote sensing technology. The use of sensing technology through Aqua-MODIS satellite imagery to determine chlorophyll-a concentrations can provide significant results for determining potential yellowfin tuna fishing areas [[13, 14]. It is possible to predict fish catch zones based on chlorophyll-a distribution in North and West Aceh waters using remote sensing data in the form of Aqua Modis satellite images with a high level of accuracy [15]. Based on these findings, the research was conducted with the aim of assessing the distribution of chlorophyll-a concentrations and their effects on yellowfin tuna productivity in Ternate Island waters.

2. Materials and Methods

This research is a type of experimental fishing research conducted in the waters of Ternate Island (Figure 1) from May to August 2024, with research equipment and materials consisting of 4 units of vessels and hand line tuna fishing gear, Global Positioning System (GPS), a fish finder, a compass, and scales. The research materials consisted of yellowfin tuna catches that were weighed, ice for cooling, digital maps of Ternate Island from the National Coordination and Mapping Agency (Bakosurtanal) and Aqua MODIS level 2 satellite images.

The process of collecting research data was carried out directly by participating in fishing activities with fishermen, and the data collected were plots of fishing positions, yellowfin tuna catch weight, and chlorophyll-a concentration data in situ. Subsequently, the satellite image data from May to August of 2024 was downloaded from the WEB page https://oceancolor.gsfc.nasa.gov/. The data were then processed to achieve the research objectives, as shown in the flow chart (Figure 2).

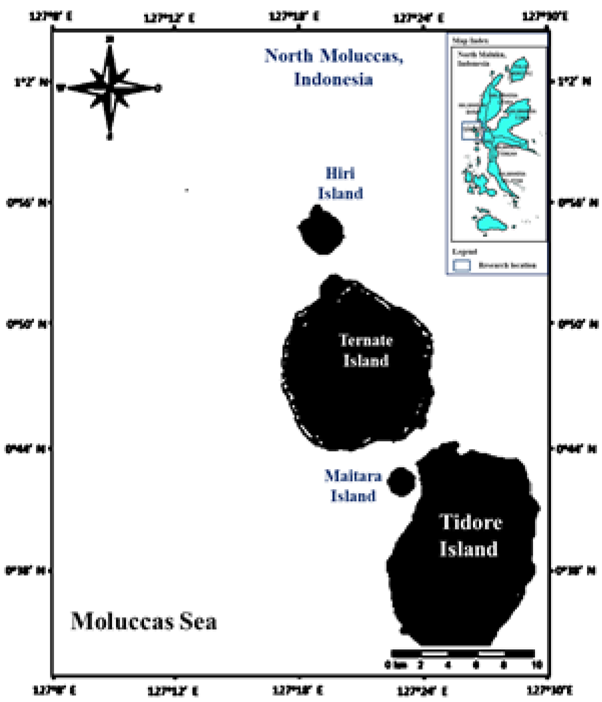

Figure 1. Research location: Ternate Island Waters, North Maluku Province, Indonesia (*Source: Author elaboration, 2024*)

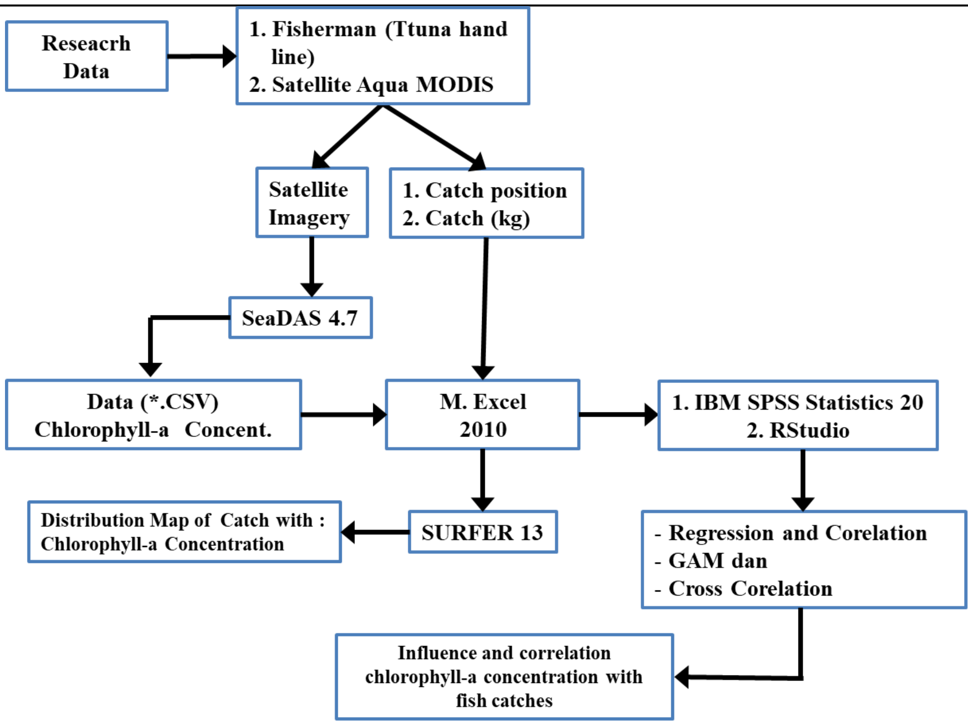

Figure 2. Data processing procedure (*Source: Author elaboration, 2024*)

The research data processed in this study consisted of in situ data, namely the weight of fish catches, plots of the fishing positions, and chlorophyll-a concentration values extracted from the Aqua MODIS level 2 images. The data were then analyzed to achieve the research objectives with statistical analysis in the form of regression analysis, correlation analysis, GAM analysis, and cross-correlation analysis conducted with IBM SPSS Statistics 20 and RStudio, while to map the distribution of chlorophyll-a concentrations in Ternate Island waters, the data were processed using SURFER 13 software. Data analysis began with the extraction of satellite images using SeaDAS 4.7 software and then GIS analysis with SURFER 13 software to map and graph the spatial and temporal distribution of chlorophyll-a concentration and yellowfin tuna catch from May to August 2024. The next step evaluates the condition of the distribution of chlorophyll-a concentration values and fish catches in each fishing area based on its level (low, medium, and high) based on the scoring values in Tables 1 and 2 [15].

Table 1. Scoring values based on chlorophyll-a concentration (modification of *Simbolong and Girsang, 2009*)

No	Chlorophyll-a Concentration (mgm-3)	Scoring
1	< 0.1	Low
2	0.1 - 0.2	Medium
3	> 0.2	High

Table 2. Scoring values based on catch weight (modification of *Simbolong and Girsang, 2009*)

No	Catch (kg/Trip) (cm)	Scoring*
1	< 500	Low
2	500–1.000	Medium
3	> 1.000	High

To analyze the effect of chlorophyll-a concentration on catch, a linear regression analysis was conducted using IBM SPSS Statistics 20 with the following formula [16]:

$$Y = a + bX + e,$$

where: Y = Yellowfin tuna catch (kg), a = intercept, b = slope X = chlorophyll-a concentration value and e = error.

Furthermore, for the relationship between yellowfin tuna catch and chlorophyll-a concentration, Pearson correlation analysis was conducted, with the formula [16]:

$$r_{xy} = \frac{\sum xy}{\sqrt{(x^2)(\sum y^2)}},$$

where: r_{xy} = correlation coefficient between x and y variables, x = deviation from the mean for chlorophyll-a variable values, y = deviation from the mean for y variable values.

To analyze the relationship between the response variable μi (total catch) and the predictor variables (oceanographic parameters), a non-linear analysis of the general additive model (GAM) was performed according to [17, 18] using the following formula:

$$G(\mu i) = \alpha_{0+s_1}(Const.chl - a) + \varepsilon,$$

where: G = spline smooth function, μi = response variable, α_0 = constant coefficient, s_n = smoothing function of the predictor variable and ε = standard error.

The last step was a cross-correlation analysis to predict the relationship between yellowfin tuna catch and chlorophyll-a concentration using time series data to determine the time lag of yellowfin tuna presence in the fishing area. The cross-correlation analysis was conducted using the following formula [19]:

$$R_{XY}(K) = \frac{C_{xy}(k)}{\sqrt{C_x^2(0)C_y^2(0)}}$$

$$C_{XY}(k) = \frac{1}{n}\sum_{t=1}^{n-k} (x_t - \underline{x})\left(y_{tt+k} - \underline{y}\right)$$

$$C_x(0) = \frac{1}{n}\sum_{t=1}^{n} (x_t - \underline{x})$$

$$C_y(0) = \frac{1}{n}\sum_{t=1}^{n} \left(y_t - \underline{y}\right)$$

where: Y = yellowfin tuna catches and X = chlorophyll-a concentration value.

3. Results and Discussion

Yellowfin tuna is a leading fishery resource for fishermen in Ternate Island waters. In the fishing process, fishermen use long boats 0.5-3 GT with 15 PK outboard engines and fishing gear in the form of tuna hand lines. Yellowfin tuna fishing operations in Ternate Island are carried out in groups of 6-10 fishing vessels with a one-day fishing model, where fishermen start leaving for the fishing area in the morning and return to the fishing base in the afternoon. The fishing operation begins with the collection of bait consisting of small pelagic fish species (swallowfish, tuna, flying fish and other fish species) or squid. After the bait collection process, the fishermen will immediately leave for the fishing area with a distance of 7-13 km and a travel time of 1-2 hours at a boat speed of 4-7 knots.

3.1. Fishing Ground

Yellowfin tuna fishing grounds in Ternate Island waters are located in the Maluku Sea and are spread from north to southwest of Terante Island. According to [5], fishing grounds are water areas where fishing gear is used to exploit fish resources. The fishing grounds from May to August 2024 are shown in Figure 3. Figure 3 shows that in May (Figure 3a), yellowfin tuna fishing grounds were scattered in the northwest at coordinates 127°8'23''E - 127°11'30''E; 0°52'13''N - 1°0'26''N, with a distance of ±11-13 km from Ternate Island. In June (Figure 3b) and July (Figure 3c), the yellowfin tuna fishing grounds were in the western region at coordinates 127°7'23''E - 127°12'26''E; 0°44'00''N - 0°53'11''N, and 127°7'43''E - 127°11'51''E; 0°43'42''N - 0°52'37''N, with a distance of ±8-10 km from Ternate Island. In August (Figure 3d), the capture area began to shift northward and was in the west to northwest region at coordinates 127°9'41''E - 127°12'37''E; 0°48'35''N - 1°00'12''N, with a distance of 8-13 km from Ternate Island.

The movement of the fishing grounds during the study from May to August 2024 was based on a plot of the position of the fishing grounds during fishing operations, with the determination of the fishing grounds following the movement of dolphins (Stenella sp) with the assumption and experience of fishermen that the yellowfin tuna group always migrates with dolphins in the surface area so that the presence of dolphins in the sea surface area is an indicator of the presence of yellowfin tuna below. According to [20] in [26], yellowfin tuna with relatively large sizes are found associated with dolphins, namely a total length of 55 - 125 cm and comparative bioenergetic models of yellowfin tuna and dolphins show the tendency of yellowfin tuna to swim following dolphins, and the strength of this association is often used as an indicator of fishing areas by fishermen, which is also likely to be related to the condition of oceanographic parameters that affect the distribution and abundance of prey fish.

3.2. Chlorophyll-a Concentration Distribution

Chlorophyll-a is a photosynthetic pigment found in phytoplankton, which are single-cell and microscopic organisms that live in water; its abundance indicates the level of fertility or primary productivity in a body of water [10, 22]. The chlorophyll-a content produced by phytoplankton is an indicator of the fertility of waters, and phytoplankton are very important as primary producers in the food chain; thus, the distribution and fluctuations of phytoplankton play a role in determining the presence of aquatic fish resources [15]. Figure 3a shows that the distribution of chlorophyll-a concentration in May ranged from 0.21 to 0.56 mg m-3, with an average chlorophyll-a concentration of 0.33 mg m3. In June (Figure 3b), chlorophyll-a concentrations were in the range of 0.16 - 0.50 mg m-3, with an average value of 0.34 mg m3. The chlorophyll-a concentrations in July and August (Figures 3c and 3d) the range of chlorophyll-a concentrations were 0.17 - 0.51 mg m-3 and 0.16- 0.45 mg m-3, respectively, with average values of 0.35 mg m3 and 0.35 mg m3.

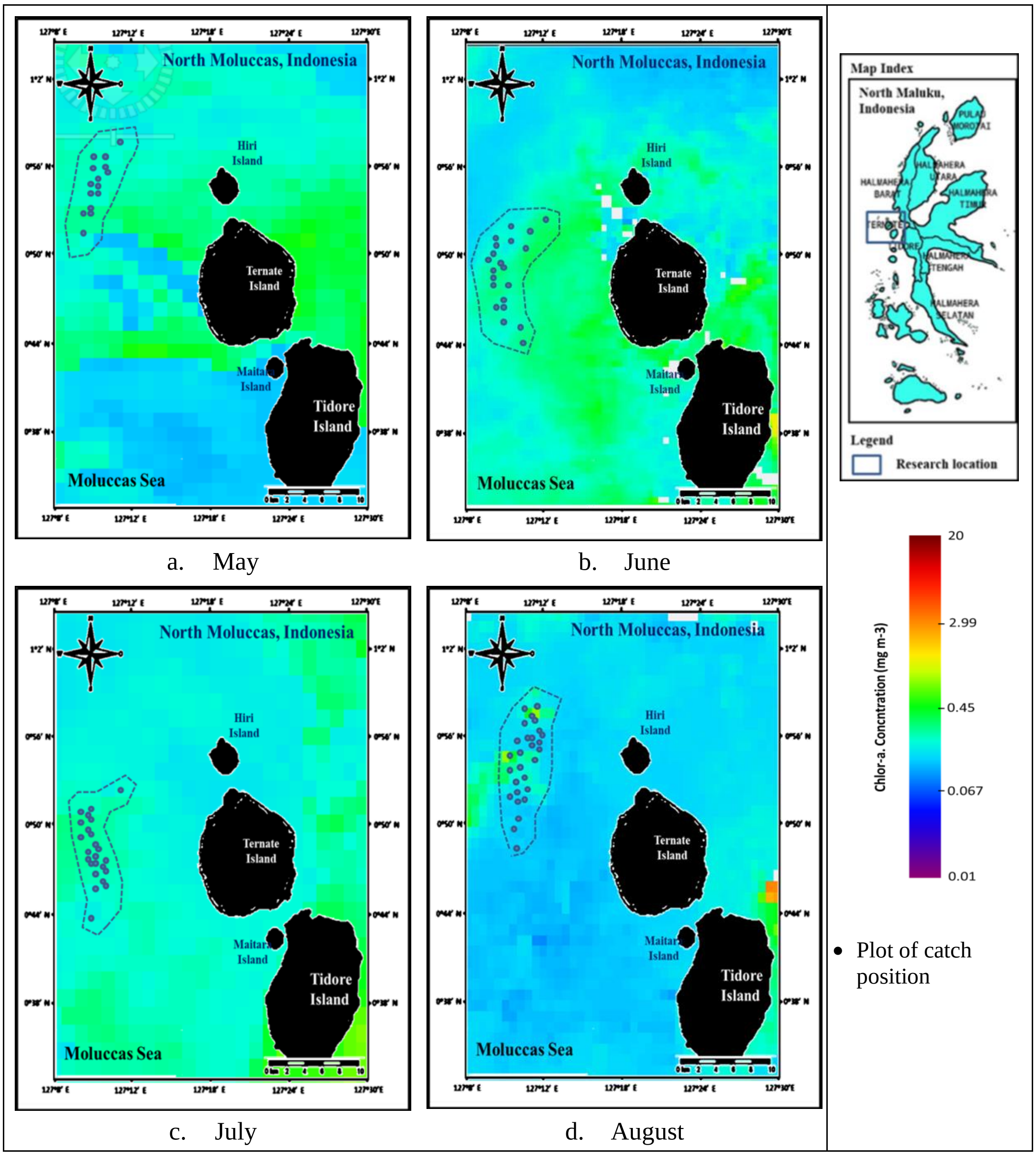

Figure 3. Regional distribution and chlorophyll-a concentration in Pualu Ternate Waters (*Source: Author elaboration, 2024)*)

Figure 4 shows the condition of chlorophyll-a concentration from May to August based on the fishing trip, which continues to fluctuate and vary every fishing trip, with the minimum and maximum chlorophyll-a concentration values recorded are 0.16 mg m-3 and 0.56 mg m-3, respectively, with an average value of 0.33 mg m-3. The condition of chlorophyll-a concentration in Figure 4 also shows an increasing trend, indicating an increase in the value of chlorophyll-a concentration from May to August 2024, which is also the same as the average value of chlorophyll-a concentration in Figures 3(a) to 3(d). The fluctuation of monthly chlorophyll-a concentration values is thought to be influenced by seasonal conditions and the geographical location of Ternate Island waters between two large islands (Halmahera Island) so that there is a supply of nutrients from the mainland.

According to [23], chlorophyll-a content tends to fluctuate seasonally, so that the fertility of the waters will also tend to vary seasonally. In addition to seasonal factors, the high concentration of chlorophyll-a in the waters of Ternate Island is also thought to be caused by the Indonesian Cross Current (ARLINDO).

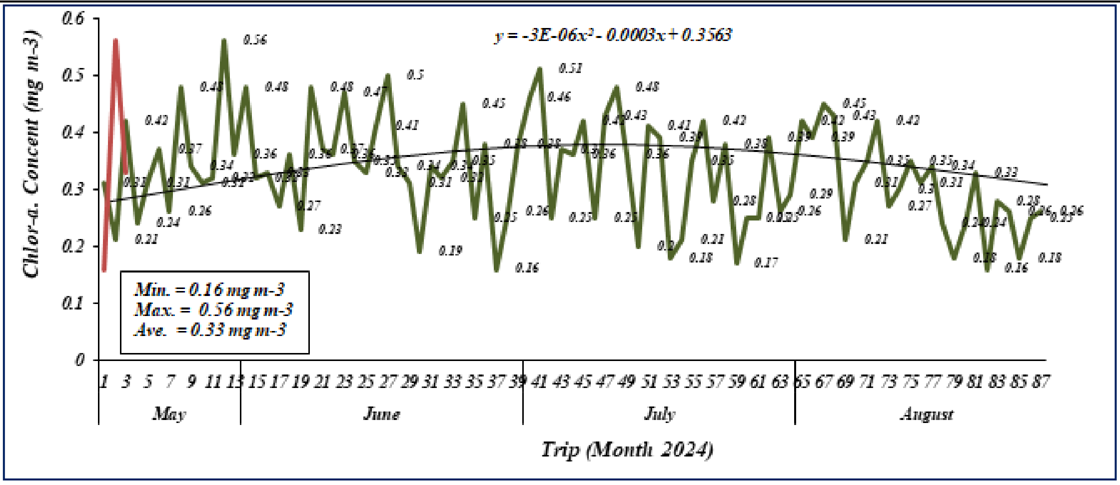

Figure 4. Chlorophyll-a concentration values during the fishing trip (*Source: Author elaboration, 2024*.

According to [24], the high concentration of chlorophyll-a in the waters of Ternate Island is also caused by the Indonesian Cross Current (ARLINDO), the high concentration of chlorophyll-a in the Maluku sea is caused by the Indonesian Throughflow (ITF), which is a system of current movement from the Pacific Ocean to the Indian Ocean that passes through the Maluku sea by carrying water mass temperature, chlorophyll-a concentration, salinity, oxygen, and other tracers that can be used as indicators of water fertility. As suggested in [37], the waters through which ARLINDO passes are generally rich in nutrients that are important for phytoplankton life.

Based on the average value of the concentration in the capture area from May to August 2024 (Figure 5), the condition of chlorophyll-a concentration in Ternate Island waters was categorized as quite high because the distribution was greater than 0.2 mg m3 (Table 1), which indicates that there is high phytoplankton life so that it can be identified as a fish habitat and this area is quite productive.

Figure 5. Yellowfin tuna (*Thunnus albacares*) (*Source: Author elaboration, 2024*)

Furthermore, according to [25], the average monthly chlorophyll-a concentration value in a water body above 2.0 mg m3 indicates the presence of sufficient plankton to maintain the survival of pelagic fish. Chlorophyll-a content produced by phytoplankton is an indication of water fertility, and phytoplankton are very important as a primary producer in the food chain process; thus, fluctuating phytoplankton will play a role in determining the presence of fish in the water [14]. Furthermore, according to [10], chlorophyll-a concentration is also used as information to assess fish resources because there is a relationship between primary productivity and fishery resources, so areas that have high chlorophyll-a concentrations have high concentrations of fish as well.

3.3. Yellowfin Tuna Production

Yellowfin tuna (Figure 5) from the local community, known as madding fish, is the catch of hand-lined tuna fishers. The production of yellowfin tuna in Ternate Island waters using tuna hand line gear from May to August was 49,778.1 kg, with the average catch per month and per trip being 12,444.5 kg and 565.7 kg, respectively. The graph of the number and percentage of yellowfin tuna catches from May to August 2024 is shown in Figure 6.

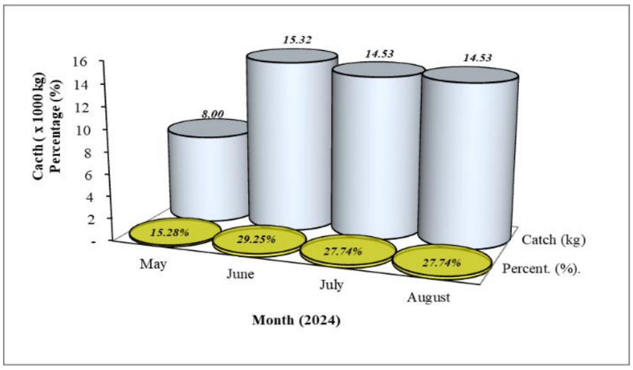

Figure 6. Number and composition of catches during May-August 2024 (*Source: Author elaboration, 2024*)

Figure 6 shows fluctuations in yellowfin tuna production from May to August 2024, with the lowest production in May 2024 and the highest production in June 2024, with a tendency to increase production from May to June and then slightly decrease from June to July and August 2024. Based on the number of catches per month, it can be seen that the level of yellowfin tuna production per month is high because the number of catches per month is more than 1,000 kg (Table 2) and tends to fluctuate. The tendency to fluctuate in the amount of production is thought to be caused by various factors, including the number of fishing trips and technical aspects in operating fishing gear. The number of fishing trips in May 2022 was 14 and increased to 24-26 trips in the following months. Technical aspects are highly dependent on the skill of the fishermen, the use of fishing aids, and fishing gear operation techniques. As stated in [26], fishing productivity is the ability to operate a fishing gear to get a catch in one unit of effort and is closely related to the technical aspects of fishing, while according to [27], technical aspects affect the effectiveness of fishing gear operation, so that accuracy in determining technical aspects will be useful for fishermen in the fishing business.

Another factor that is thought to affect catch production is the dynamics of sonographic factor parameters. As suggested in [8], the fishing season pattern and the abundance of pelagic fish are influenced by the dynamics of oceanographic parameters, including chlorophyll a value and sea surface temperature. Ternate Island waters are dynamic ecosystems; thus, the existence of fish populations is influenced by the conditions of oceanographic parameters. According to [15, 23, 28], fishing grounds are waters with high potential fish resources, where the area is influenced by oceanographic factors. The success of fishermen in utilizing fish resources depends on oceanographic conditions, seasons, and fishing grounds [29]. As stated in [25, 17], oceanographic parameters such as water depth, oceanographic parameter processes such as upwelling or chlorophyll-a front [30] can be used as indicators in determining potential areas of economically important fishing. As reported in [31], the difference in the number of fish catches is related to the patterns and eating habits of pelagic fish groups. Furthermore, according to Rizwan et al. in [5], the number of fish catches is also influenced by food availability and chlorophyll-a concentration, which are important factors that determine population abundance and fish conditions in a body of water.

3.4. Fluctuations in Chlorophyll-a Concentration Affecting the YFT Catch

Yellowfin tuna is a type of pelagic fish that lives in groups in areas near the surface of the water to a depth of ± 100 meters and is classified as a type of carnivorous fish whose main food is small pelagic fish and squid, so the presence of yellowfin tuna in a body of water is influenced by the food chain, especially by the concentration of chlorophyll-a or phytoplankton, which is the primary producer in marine waters. The daily fluctuations of yellowfin tuna and chlorophyll-a concentrations are shown in Figure 7.

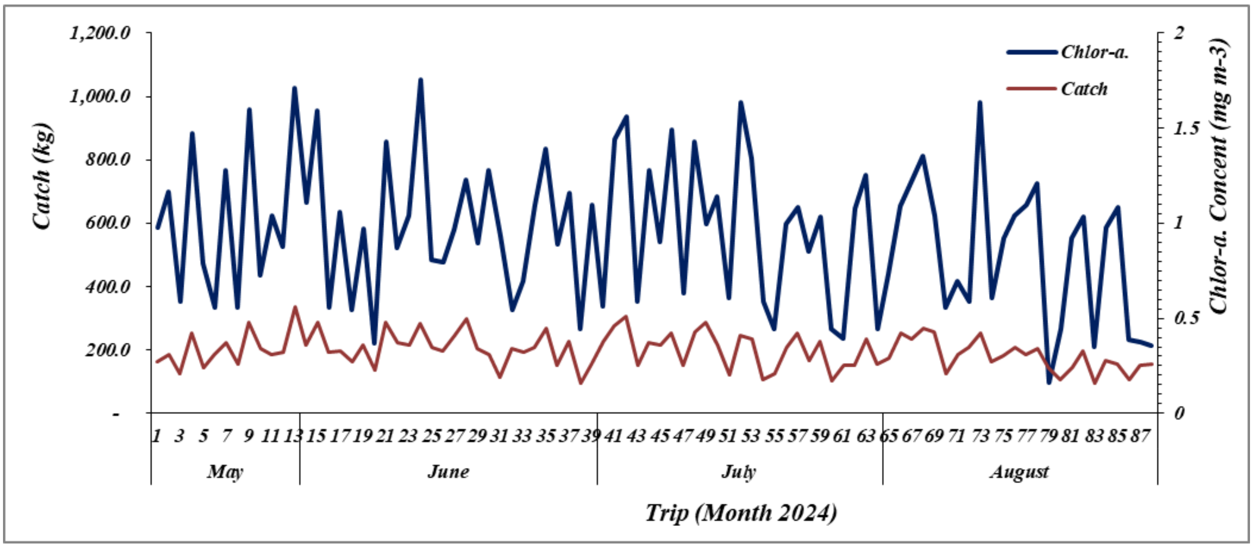

Figure 7. Daily fluctuation of yellowfin tuna and chlorophyll-a concentrations from May to August 2024 (*Source: Author elaboration, 2024*)

Figure 8 shows a graph of fluctuations in yellowfin tuna catch and chlorophyll-a concentration values from May to August 2024, where it can be seen that the conditions of the two variables have almost the same fluctuation tendency, where when the chlorophyll-a concentration rises, it affects the increase in yellowfin tuna catch, and vice versa the same thing also happens when the chlorophyll-a concentration value drops, the yellowfin tuna catch also decreases. The results of linear regression analysis (Figure 8) showed that chlorophyll-a concentration had a partial significant effect on the amount of yellowfin tuna catch with F_{count} = 1,603.157 and significance value (Sig.) = 0.00, and the regression formula formed was y = 1974.1* Catch (kg) 84.891. The coefficient of determination (R^2) = 0.6325 which indicates that 63.25% of yellowfin tuna presence on fishing grounds is influenced by chlorophyll-a concentration, assuming that other oceanographic parameters are constant.

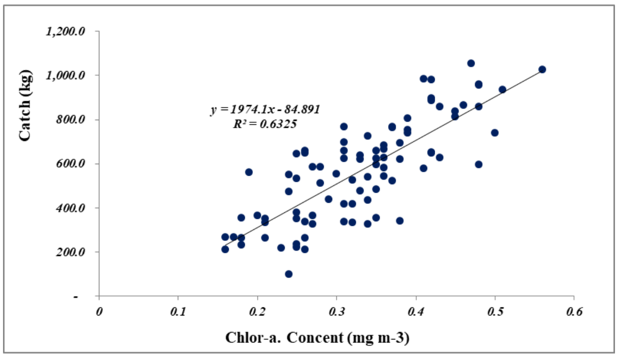

Figure 8. Effect of chlorophyll-a concentrations on yellowfin tuna catch (*Source: Author elaboration, 2024*)

The results of the correlation analysis showed that the correlation (r) between chlorophyll-a concentration and yellowfin tuna catch was 0.762, which based on this value indicates that the correlation relationship between the two variables is strong and positive, where if there is an increase in chlorophyll-a concentration, yellowfin tuna catch tends to increase as well. This can be further explained in Figure 9, which illustrates that at low values of chlorophyll-a concentration (0.1-0.2 mg m-3) the amount of yellowfin tuna catch is 35.5 kg, and the amount of catch further increases as the value of chlorophyll-a concentration increases, as shown in the trend line that increases with increasing chlorophyll-a concentration.

As reported in [36], an increase in chlorophyll-a in waters will increase pelagic catches, whereas a decrease in chlorophyll-a will reduce catches. According to [33], chlorophyll-a significantly affects pelagic fish catches, where higher chlorophyll-a concentrations have the possibility of producing high fish production and conversely lower chlorophyll-a concentrations will provide low catches as well. Furthermore, as revealed by [29] and [10], pelagic fish catches (yellowfin tuna, skipjack, tuna and mackerel) tend to increase when sea surface temperatures are low and chlorophyll-a is abundant. According to [30], chlorophyll-a concentrations with a chlorophyll-a value of 0.2 mg m-3 has a significant relationship with pelagic fish catches, further by [17], the average monthly chlorophyll-a concentration value in a water body above 2.0 mg m-3 indicates the presence of sufficient plankton to maintain the survival of pelagic fish.

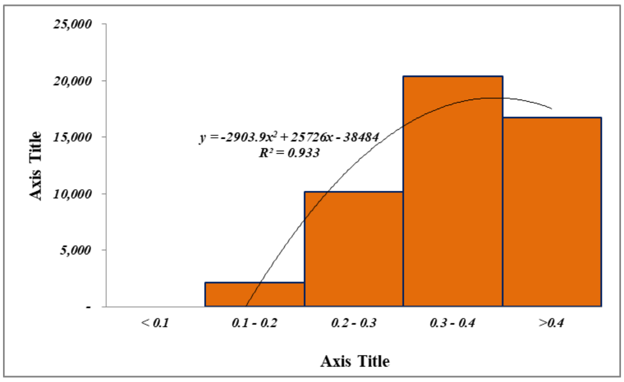

Figure 9. Relationship between yellowfin tuna catch and chlorophyll-a concentration (*Source: Author elaboration, 2024*)

The results of the General Additive Model analysis in Table 3 show that there is a strong and very real relationship between yellowfin tuna catch and chlorophyll-a with Sig value < 0,000. The strong relationship between chlorophyll-a concentration and yellowfin tuna catch is shown by the density of the distribution of catches in Figure 10, so that it can be said that the potential areas of small pelagic fish fishing, especially yellowfin tuna in Ternate Island waters, are good in the range of chlorophyll-a concentrations of 0.2 - > 0.4 mg m-3.

Table 3. Results of general additive model analysis of the effect of chlorophyll-a concentration on yellowfin tuna catch (*Source: Author elaboration, 2024*)

Variable	Pr (F)	Sig.
Chlorophyll-a Concentration	0.000321	< 0.000

Yellowfin tuna is a type of pelagic fish that is classified as a carnivore, and its life does not depend directly on chlorophyll-a [34]. However, in the food chain, the presence of yellowfin tuna in a body of water is also influenced by phytoplankton, although not directly [35]. Based on these findings, the presence of yellowfin tuna in a fishing area requires a certain time. The time interval for the presence of tuna in the fishing area is known as the correlation distance or time lag, so based on the results of the cross-correlation analysis seen below in the waters of Ternate Island, the correlation distance or time lag required by yellowfin tuna is on the 13th trip. Test results This is reinforced by the graph in Figure 10, which shows that the catch of yellowfin tuna began to increase significantly on the 13th trip even though the catch of yellowfin tuna was already high on the previous trips.

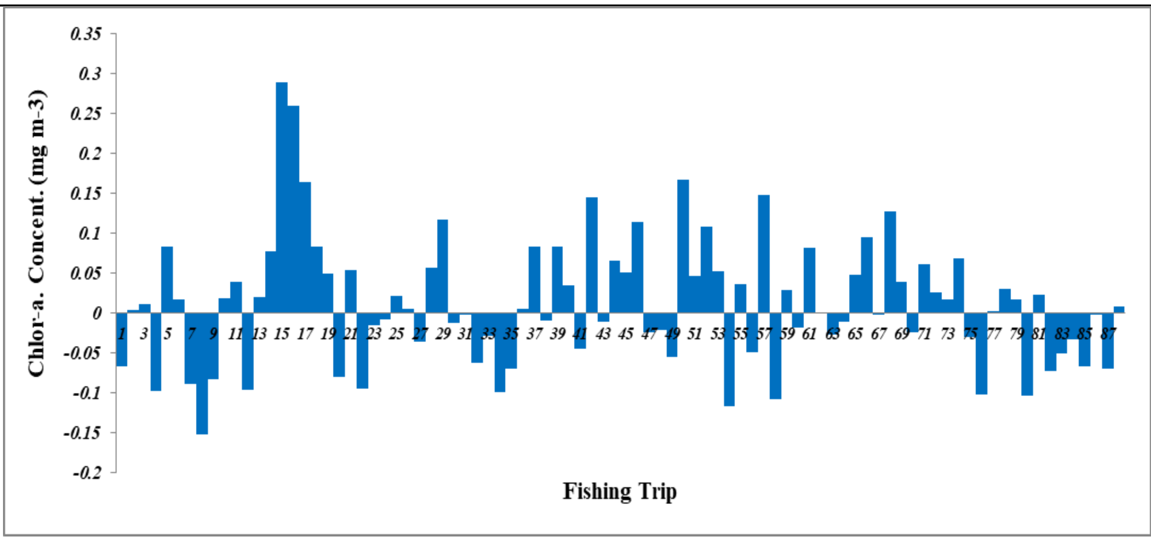

Figure 10. Time lag of yellowfin tuna catch and chlorophyll-a concentration in Ternate Island Waters (*Source: Author elaboration, 2024*)

4. Conclusion

The variability of chlorophyll-a concentrations in the waters of Ternate Island appears to be quite fluctuating from May to August 2023, with minimum, maximum, and average values of 0.16 mg m3, 0.42 mg m3, and 0.32 mg m-3 respectively. 3. Based on the regression analysis, which was strengthened by the GAM analysis, chlorophyll-a concentration had a significant effect on yellowfin tuna catches, with a value of F = 82.834 and Sig. = 0.00, with the influence given based on the coefficient of determination (R2) being 0.58 or 58% of the presence of yellowfin tuna in the fishing area influenced by the presence of chlorophyll-a concentration and 42% influenced by other factors. Furthermore, the results of the GAM analysis show that the relationship between these two variables is very real (P <0.0001), which is strengthened by correlation analysis with a correlation coefficient (r) of 0.762, which indicates that the correlation relationship between the two variables is strong and has a positive value. The cross-correlation, which indicates the presence and real increase in yellowfin tuna production in the waters of Ternate Island is on the 13th trip.

The results of the study indicate that individual concentrations of chlorophyll-a have a real effect on the presence of ikan in fishing areas, so these results are expected to be used as reference and teaching materials in the development of science, especially fisheries catch.

Declarations

Author Contibutions

Conceptualization, U.T., A.T., S.S.T., and R.L.; methodology, U.T., S.S.T, and R.L.; data collection, M.A.L., D.N., H.B., S.J., M.S., and M.F.S.; data analysis, U.T., A.T., R.L., H.B., S.J., M.S., and M.F.S.; writing—original draft preparation, all authors contributed equally; writing—review and editing, U.T., A.T., S.S.T., and R.L.; visualization, M.S., and M.F.S.; supervision, U.T.; project administration, U.T. All authors have read and agreed to the published version of the manuscript.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

Acknowledgements

The researchers would like to thank the Ministry of Education, Culture, Research and Technology, especially the Directorate General of Higher Education, Research and Technology, for providing research funds, enabling the research to be carried out properly. Special thanks to LLDIKTI 12 and the Rector of Muhammadiyah University of North Maluku, who facilitated the smooth implementation of the research according to the plan.

Conflicts of Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

References

[1] GIU L.M., ATMADIPOERA A. S., NAULITA Y., & NUGROHO D. Struktur Vertikal Dan Variabilitas Arlindo Yang Masuk Ke Tepi Barat Laut Banda. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, 2020, 12(2): 457-472.
[2] DKP North Maluku Province. Capture fisheries statistics North Maluku. Indonesina, 2023.
[3] NURDIN E. *Rumpon sebagai alat perikanan tuna berkelanjutan, Sirip kuning (Thunnus albacares)*. IPB. Sekolah Pascasarjana Bogor, 2017.
[4] TANGKE U., SILOOY F. D., ROCHMADY, and SAING Z. Sea Surface Temperature and Chlorophyll-A Condition of Skipjack Tuna (Katsuwonus Pelamis) Catching

Area in Ternate Island Marine Waters. *Journal of Physics: Conference Series*. 2020, 1517: 012039. https://doi.org/10.1088/1742-6596/1517/1/012039

[5] TANGKE U. Estimation of Pelagic Fishing Areas Based on Sea Surface Temperature and Chlorophyll-A Approach in the Maluku Sea. *Agrikan Jurnal Agribisnis Perikanan*, 2023, 16(1): 291-296. https://doi.org/10.52046/agrikan.v16i1.1927.

[6] CAHYA C. N., SETYOHADI D., & SURINATI D. Pengaruh parameter oseanografi terhadap distribusi ikan. *Jurnal Oseana*, 2016, 41(4): 1-14.

[7] ELASARI N., PERDANAWATI R. A., & MAULUDIYAH. Correlation Analysis of Oceanographic Parameters to Catching of Purse Seine Nets in Kranji Waters, Paciran District, Lamongan Regency. *Jurnal Perikanan dan Kelautan*, 2022, 27(3): 371-381.

[8] PRATAMA G. B., TRI W.N., MUSTARUDDIN, & YENI H. Relationship of Oceanographic Parameters to Pelagis Fishing Season in Palabuhanratu Waters. *Jurnal Teknologi Perikanan dan Kelautan*, 2022, 13 (1): 67-78.

[9] AKHLAK, AHSANUL M., SUPRIHARYONO, and HARTOKO A. Hubungan Variabel Suhu Permukaan Laut, Klorofil-a dan Hasil Tangkapan Kapal Purse Seine yang Didaratkan di TPI Bajomulyo Juwana. *Diponegoro Journal of Maquares*, 2015, 4(4): 128-35.

[10] MAKMUR M. Pengaruh Upwelling terhadap Ledakan Alga (Blooming Algae) di Lingkungan Perairan Laut. *Prosiding Seminar. Pusat Teknologi Limbah Radioaktif-BATAN*, 2008 (pp. 240-245).

[11] MAHABROR D., ABDUL R.Z., & JEJEN J.H. Analisis Spasial dan Temporal Musim Tangkap Ikan dengan Data Penginderaan Jauh dan Vessel Monitoring System di Perairan Kepulauan Riau. *Prosiding Seminar Nasional Kelautan dan Perikanan III*, UTM. Madura, 2017 (pp. 131-140).

[12] TANGKE U., LAISOUW R., UMAGAP W. A., and DARMAWATY. Variability of Chlorophyll-a Concentration Relation to Fish Catch of Indian Mackerel in West Halmahera Waters. IOP Conf. Series: *Earth and Environmental Science*, 2021, 777. 012006, https://doi.org/10.1088/1755-1315/777/1/012006

[13] TANGKE U., KARUWAL J.W.C., MALLAWA A., & ZAINUDDIN M. Analisis Parameter Oseanografi Hubungannya dengan Hasil Tangkapan Ikan Tuna Sirip Kuning di Perairan Maluku Utara. *Jurnal "Amanisal" PSP FPIK Unpatti-Ambon*, 2016, 5(1): 1-9.

[14] PANGGABEAN D., & RAUZATUL N. Distribusi dan Kelimpahan Ikan Pelagis di Laut Flores Bagian Barat. *Jurnal Penelitian Perikanan Indonesia*, 2020, 28(2): 61-75.

[15] SIMBOLONG D., & GIRSANG H. S. Hubungan antara Kandungan Klorofil-a. A dengan Hasil Tangkapan Tongkol di Daerah Penangkapan Ikan Perairan Pelabuhanratu. *Jurnal Penelitian Perikanan Indonesia*, 2009, 15(4): 297-305. http://doi.org/10.15578/jppi.15.4.2009.297-305

[16] WALPOLE, R.E., & MYERS R.H. Ilmu Peluang dan Statistika untuk Insinyur dan Ilmuawan. Penerbit ITB, Bandung, 1995.

[17] SAFRUDDIN & ZAINUDDIN M. Mapping Scads Fishing Ground Based on the Relationship between Catch Data and Oceanographic Factors in Bone Coastal Waters. *Torani Jurnal*, 2007, 17(5): 192-200.

[18] WOOD S.N. Generalized Additive Models. An Introduction with R, 2nd Edition. Imprint Chapman and Hall/CRC, 2017. https://doi.org/10.1201/9781315370279.

[19] THOMAS B.C. Comparison of Two Physically-Based Spatially Distributed Hydrology Models in Contrasting GeoClimatic Settings. Thesis. Faculty of Geoinformation Science and Earth Observation (ITC), 2010.

[20] EDWARDS EF. Energetics of Associated Tunas and Dolphins in the Eastern Tropical Pacific Ocean: A Basis for the Bond. *Fishery Bulletin*, 1992, 90: 678-690

[21] TANGKE U., ACHMAR M., & ZAINUDDIN M. Analisis Hubungan Karakteristik Oseanografi Dan Hasil Tangkapan Yellowfin Tuna (Thunnus albacares) Di Perairan Laut Banda. *Jurnal Ilmiah agribisnis dan Perikanan (agrikan UMMU-Ternate)*, 2011, 4(2): 1-14.

[22] HERMAWAN I., SETIAWAN A., & PUSPARIN, N. The Distribution Pattern of Chlorophyll-A Concentration in the Maluku Sea Based on in Situ Observation from Indeso Joint Expedition Program 2016 and Remote Sensing Data. *Jurnal Segara*, 2017, 13(3): 149-157. http://doi.org/10.15578/segara.v13i3.6494

[23] GAOL J. L., WUDIANTO B., PASARIBU D., MANURUNG, & ENDRIANI R. The fluctuation of chlorophyll-a concentration derived from satellite imagery and catch of oily sardine (Sardinella lemuru) in Bali Strait. *International Journal of Remote Sensing and Earth Sciences*, 2004, 1(1): 24-30.

[24] SETIAWAN A. N., DHAHIYAT Y., & PURBA N. P. Variation of temperature and chlorophyll-a due to Indonesian throughflow on skipjack distribution in Lombok Strait. *Jurnal Depik*, 2013, 2(2): 58-69

[25] ZAINUDDIN M, FARHUM A., SAFRUDDIN S., SELAMAT M. B., SUDIRMAN S, NURDIN N, Mega SYAMSUDDIN M., RIDWAN M., & SAITOH S.-I. Detection of pelagic habitat hotspots for skipjack tuna in the Gulf of Bone-Flores Sea, southwestern Coral Triangle tuna, Indonesia. *PLoS ONE*, 2017, 12(10): e0185601. https://doi.org/10.1371/journal.pone.0185601.

[26] NELWAN A.F.P., NURSAM M., & IHSAN M.N. Analisis Produktivitas Bagan Perahu di Perairan Kabupaten Polewali Mandar. *Jurnal Ipteks PSP*, 2015, 2(4): 345-356.

[27] MUKLIS J., LUMBON D., & SIMBOLON. Potensial Fishing Ground Mapping of Skipjack and Frigate Tuna in North Nanggroe Aceh Darussalam waters. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, 2009, 1(1): 24-32, https://doi.org/10.28930/jitkt.v1i1.7935

[28] MUJIB, Z., BOESONO, H. and FITRI, A.D.P.F. Pemetaan sebaran ikan tongkol (*Euthynnus* sp.) dengan data klorofil-a citra modis pada alat tangkap payang (Danish-seine). *Journal of Fisheries Resources Utilization Management and Technology*, 2013, 2(2): 150-160.

[29] NURANI T.W, WAHYUNINGRUM PI, IQBAL M, KHOERUNNISA N, PRATAMA GB, & WIDIANTI EA. Skipjack Tuna Fishing Season and its Relationship with Oceanographic Conditions in Palabuhanratu Waters, West Java. *Malaysian Applied Biology*, 2022, 51(1): 137-148. https://doi.org/10.55230/mabjournal.v51i1.2151

[30] HIDAYAT R., ZAINUDDIN M., PUTRI A. R., & SAFRUDDIN S. Skipjack tuna (*Katsuwonus pelamis*) catches in relation to chlorophyll-a front in Bone Gulf during the southeast monsoon. *AACL Bioflux*, 2019, 12(1): 209-218.

[31] NELWAN A.F.P, SUDIRMAN, MUH N., & YUNUS M. ABD. Produktivitas Penangkapan Ikan Pelagis di Perairan Kabupaten Sinjai Pada Musim Peralihan Barat-Timur. *Jurnal Perikanan*, 2015, 17 (1): 18-25.

[32] ADNAN. Analisis Suhu Permukaan Laut dan Klorofil-a Data Inderaja Hubungannya dengan Hasil Tangkapan Ikan Tongkol (*Euthynnus affinis*) di Perairan Kalimantan Timur. *Jurnal Amanisal*, 2010, 1: 1-12.

[33] NINGSIH W.A.L., LESTARININGSIH W. A., HELTRIA S., and KHALDUN M.H.I. Analysis of the relationship between chlorophyll-a and sea surface temperature on marine capture fisheries production in Indonesia: 2018. *IOP Conference Series: Earth and Environmental Science,* 2022, 944(1): 012057. https://doi.org/10.1088/1755-1315/944/1/012057.

[34] TARIGAN D.J., AGUNG S.S., BELLA D.R., & YANTO A. Potential Fishing Zones Assesment on Euthynnus affinis in Sunda Strait. *Jurnal Teknologi Perikanan dan Kelautan*, 2021, 12 (1): 73-84.

[35] KUSWANTO T. D., SYAMSUDDIN M. L., and SUNARTO. Hubungan suhu permukaan laut dan klorofil-a terhadap hasil tangkapan ikan tongkol di teluk lampung. *Jurnal Perikanan dan Kelautan*, 2017, 8 (2): 90-102

[36] SAFRUDDIN, HIDAYAT R., FARHUM S. A., & ZAINUDDIN M. The use of statistical models in identifying skipjack tuna habitat characteristics during the Southeast Monsoon in the Bone Gulf, Indonesia. *Biodiversity Journal of Biological Diversity,* 2022, 23(4): 2231-2237. https://doi.org/10.13057/biodiv/d230459.

[37] GORDON A. L., and FINE R. A. (1996). Pathways of water between the pacific and Indian oceans in the Indonesian seas. *Nature*, 379: 146–149. https://doi.org/10.1038/379146a0

参考文:

[1] GIU L.M., ATMADIPOERA A. S., NAULITA Y., 和 NUGROHO D. 进入班达西北岸的阿林多的垂直结构和变异性。 热带海洋科学与技术, 2020, 12(2): 457-472.

[2] DKP 北马鲁古省。 获取北马鲁古渔业统计数据。印度尼西亚，2023。

[3] NURDIN E. FADs 作为可持续金枪鱼渔业、 黄鳍金枪鱼（Thunnus albacares）的工具。 IPB。茂物研究生院，2017。

[4] TANGKE U.、SILOOY F. D.、ROCHMADY 和 SAING Z. 特尔纳特岛海水中鲣鱼 (Katsuwonus Pelamis) 捕捞区的海面温度和叶绿素 A 状况。物理学杂志： 会议系列。 2020， 1517： 012039。 https://doi.org/10.1088/1742-6596/1517/1/012039

[5] TANGKE U. 马鲁古海基于海面温度和叶绿素-A 方法的远洋捕捞区估算。农业综合渔业杂志，2023, 16(1): 291-296。 https://doi.org/10.52046/agrikan.v16i1.1927。

[6] CAHYA C. N., SETYOHADI D., 和 SURINATI D. 海洋学参数对鱼类分布的影响。海洋杂志，2016，41(4)：1-14。

[7] ELASARI N.、PERDANAWATI R.A. 和 MAULUDYAH。 拉蒙岸县帕西兰县克兰芝水域海洋学参数与围网捕捞的相关性分析。渔业海事学报， 2022, 27(3): 371-381。

[8] PRATAMA G. B.、TRI W. N.、MUSTARUDDIN 和 YENI H. 海洋学参数与 Palabuhanratu 水域中上层捕鱼季节的关系。渔业与海洋技术学报, 2022, 13 (1): 67-78。

[9] AKHLAK、AHSANUL M.、SUPRIHARYONO 和 HARTOKO A。海面温度变量、叶绿素-a 和 TPI Bajomulyo Juwana 围网渔获量结果之间的关系。迪博内哥罗《马夸尔斯杂志》，2015，4(4)：128-35。

[10] MAKMUR M. 上升流对海洋环境中藻类繁殖的影响。 研讨会论文集。放射性废物技术中心-BATAN，2008（第 240-245 页）。

[11] MAHABROR D.、ABDUL R.Z. 和 JEJEN J.H. 利用遥感数据和廖内群岛水域船舶监测系统对捕鱼季节进行时空分析。国家海洋和渔业研讨会 III，UTM 论文集。马杜拉，2017（第 131-140 页）。

[12] TANGKE U.、LAISOUW R.、UMAGAP W.A. 和 DARMAWATY。叶绿素的变异性 - 浓度与西哈马黑拉水域印度鲭鱼渔获量的关系。 IOP 会议系列：地球与环境科学，2021，777.012006，https://doi.org/10.1088/1755-1315/777/1/012006

[13] TANGKE U., KARUWAL J.W.C., MALLAWA A., 和 ZAINUDDIN M. 与北马鲁古水域黄鳍金枪鱼捕捞结果相关的 海洋学参数分析。 《Amanisal》期刊 PSP FPIK Unpatti-Ambon，2016, 5(1): 1-9。

[14] PANGGABEAN D., 和 RAUZATUL N. 西弗洛勒斯海中上层鱼类的分布和丰富度。印度尼西亚渔业研究杂志, 2020, 28(2): 61-75。

[15] SIMBOLONG D., 和 GIRSANG H.S. 叶绿素 a 含量之间的关系。 A 为 Pelabuhanratu 水上垂钓区金枪鱼的捕获结果。印度尼西亚渔业研究杂志，2009，15(4)：297-305。 http://doi.org/10.15578/jppi.15.4.2009.297-305

[16] WALPOLE, R.E., 和 MYERS R.H. 工程师和科学家的概率与统计科学。 ITB 出版社，万隆，1995。

[17] SAFRUDDIN 和 ZAINUDDIN M. 基于 Bone 沿海水域渔获量数据与海洋学因素之间的关系绘制 Scads 渔场。托拉尼杂志， 2007， 17(5)： 192-200。

[18] WOOD S.N. 广义加性模型。 R 简介，第二版。版权信息 Chapman 和 Hall/CRC，2017。 https://doi.org/10.1201/9781315370279。

[19] THOMAS B.C. 对比地理气候环境下两种基于物理的空间分布水文模型的比较。论文。地理信息科学与地球观测学院（ITC），2010。

[20] EDWARDS EF. 东热带太平洋相关金枪鱼和海豚的能量：债券的基础。渔业公报，1992，90：678-690

[21] TANGKE U., ACHMAR M., 和 ZAINUDDIN M. 班达海域海洋学特征与黄鳍金枪鱼 (Thunnus albacares) 捕捞结果关系分析。农业综合企业和渔业科学杂志（UMMU-特尔纳特农业综合企业），2011，4(2)：1-14。

[22] HERMAWAN I., SETIAWAN A., 和 PUSPARIN, N. 基于 2016 年 Indeso 联合考察计划现场观测和遥感数据的马鲁古海叶绿素 A 浓度分布模式。塞加拉杂志，2017，13(3)：149-157。 http://doi.org/10.15578/segara.v13i3.6494

[23] GAOL J. L.、WUDIANTO B.、PASARIBU D.、MANURUNG 和 ENDRIANI R. 来自卫星图像和巴厘岛海

峡油性沙丁鱼 (Sardinella lemuru) 捕获量的叶绿素 a 浓度波动。国际遥感与地球科学杂志，2004，1(1)：24-30。
[24] SETIAWAN A. N., DHAHIYAT Y., 和 PURBA N. P. 由于印尼流入龙目海峡鲣鱼分布造成的温度和叶绿素-a 的变化。德皮学报, 2013, 2(2): 58-69
[25] ZAINUDDIN M、FARHUM A.、SAFRUDDIN S.、SELAMAT M.B.、SUDIRMAN S、NURDIN N、Mega SYAMSUDDIN M.、RIDWAN M. 和 SAITOH S.-I。 印度尼西亚珊瑚三角金枪鱼西南部骨弗洛勒斯海湾鲣鱼中上层栖息地热点的检测。 《公共图书馆一号》，2017，12(10)：e0185601。
https://doi.org/10.1371/journal.pone.0185601。
[26] NELWAN A.F.P.、NURSAM M. 和 IHSAN M.N. Polewali Mandar 摄政水域蒲甘船只生产力分析。 PSP科技学报，2015，2(4)：345-356。
[27] MUKLIS J.、LUMBON D. 和 SIMBOLON。北南格罗亚齐达鲁萨兰水域鲣鱼和护卫舰金枪鱼的潜在渔场测绘。热带海洋科学与技术, 2009, 1(1): 24-32, https://doi.org/10.28930/jitkt.v1i1.7935
[28] MUJIB, Z.、BOESONO, H. 和 FITRI, A.D.P.F.使用叶绿素 - 帕扬 （丹麦塞纳河） 渔具上时尚图像的数据绘制鲭鱼 (Euthynnus sp.) 的分布图。渔业资源利用管理与技术, 2013, 2(2): 150-160.
[29] NURANI T.W.、WAHYUNINGRUM PI、IQBAL M、KHOERUNNISA N、PRATAMA GB 和 WIDIANTI EA。西爪哇帕拉布汉拉图水域鲣鱼捕捞季节及其与海洋条件的关系。马来西亚应用生物学，2022，51（1）：137-148。 https://doi.org/10.55230/mabjournal.v51i1.2151
[30] HIDAYAT R., ZAINUDDIN M., PUTRI A. R., 和 SAFRUDDIN S. 东南季风期间骨湾金枪鱼 (Katsuwonus pelamis) 捕获量与叶绿素锋的关系。 AACL 生物通量，2019，12(1)：209-218。
[31] NELWAN A.F.P、SUDIRMAN、MUH N. 和 YUNUS M. ABD。 东西过渡季节辛贾摄政水域的远洋捕捞生产力。渔业杂志，2015，17（1）：18-25。
[32] ADNAN.与东加里曼丹水域金枪鱼 (Euthynnus affinis) 捕获量相关的海面温度和叶绿素 a 感官数据分析。阿马尼萨尔杂志，2010，1：1-12。
[33] NINGSIH W.A.L.、 LESTARININGSIH W.A.、HELTRIA S. 和 KHALDUN M.H.I. 印度尼西亚海洋捕捞渔业生产中叶绿素-a 与海面温度关系分析：2018. IOP 会议系列：地球与环境科学, 2022, 944(1): 012057. https://doi.org/10.1088/ 1755-1315/944/1/012057。
[34] TARIGAN D.J., AGUNG S.S., BELLA D.R., 和 YANTO A. 巽他海峡 Euthynnus affinis 潜在捕捞区评估。渔业与海洋技术学报, 2021, 12 (1): 73-84。
[35] KUSWANTO T.D.、SYAMSUDDIN M.L., 和 SUNARTO。楠榜湾金枪鱼捕获量的海面温度与叶绿素a之间的关系。渔业海事杂志, 2017, 8(2): 90-102
[36] SAFRUDDIN, HIDAYAT R., FARHUM S. A., 和 ZAINUDDIN M. 使用统计模型识别印度尼西亚骨湾东南季风期间鲣鱼栖息地特征。生物多样性 生物多样性杂志, 2022, 23(4): 2231-2237. https://doi.org/10.13057/biodiv/d230459。
[37] GORDON A. L. 和 FINE R. A. 印度尼西亚海域太平洋和印度洋之间的水道。自然，1996, 379：146-149。 https://doi.org/10.1038/379146a0