Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 28(6): 2531 – 2550 (2024)
www.ejabf.journals.ekb.eg

Distribution of Chlorophyll-a Concentration in Biak Numfor Waters and Its Impact on Bullet Tuna Catch (*Auxis rochei* Risso, 1810)

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ARTICLE INFO
Article History:
Received: Sept. 5, 2024
Accepted: Nov. 27, 2024
Online: Dec. 30, 2024

Keywords:
Chlorophyll-a,
GIS,
Bullet tuna,
Auxis rochei.
GAM

ABSTRACT

This study was conducted with the aim of examining the distribution of chlorophyll-a concentration and its effect on the production of tuna catch to achieve optimum fish catch in the waters of Biak Numfor Regency. This study employed experimental fishing techniques from April to July 2023, collecting data on catch volumes and satellite imagery to assess the distribution of chlorophyll-a concentration based on fishing position plots. The data analysis commenced with GIS techniques to extract and map the temporal distribution of chlorophyll-a in the study area, followed by a composition analysis of the catch. Statistical analyses were then performed to explore the effects and relationships between chlorophyll-a concentration and bullet tuna catch volumes. The findings revealed significant fluctuations in chlorophyll-a concentrations in the waters of Biak Numfor from April to July 2023, with minimum and maximum values of 0.16 and 0.42mg m^{-3}, respectively, and an average concentration of 0.32mg m^{-3}. Regression analysis demonstrated a significant impact of chlorophyll-a concentration on bullet tuna catch, with an F-value of 82.834 and a significance level of 0.00. The coefficient of determination (R^2) was calculated at 0.58, while GAM analysis confirmed a highly significant relationship between the two variables (P<0.0001). Correlation analysis further supported these findings, yielding an r-value of 0.762, indicating a strong positive correlation between chlorophyll-a concentration and bullet tuna catch. Notably, cross-correlation analysis showed that the presence and increase in bullet tuna production in the waters of Biak Numfor were particularly pronounced during the 17th fishing trip.

INTRODUCTION

Biak Numfor Regency is situated within Fisheries Management Area 717 of the Republic of Indonesia, which encompasses the Northern Pacific Ocean and Cenderawasih Bay in Papua and West Papua **(Bona *et al.*, 2017)**. This region boasts extensive waters that are rich in fishery resources, with bullet tuna (*Auxis rochei* Risso, 1810) being one of the most commonly caught species. According to **Nybakken (1992)**, **Nelwan *et al.***

(2015), and **Panggabean and Nazzal (2020)**, the potential of pelagic fish represents a significant economic resource, residing in surface and mid-water layers, and plays a vital role in the utilization of fishery resources in Indonesia. Bullet tuna (Fig. 1) is a small, economically significant pelagic fish that schools near the surface down to depths of approximately 100 meters **(Muklis *et al*., 2009)**. Morphologically, it is characterized by a streamlined, torpedo-shaped body, short pectoral fins that do not extend to the anterior edge's vertical line, a bluish dorsal coloration, and a white belly **(Fishbase, 2024)**. In Biak Numfor Regency, the bullet tuna is primarily harvested using various fishing gear, with purse seines and longline fishing being the predominant methods **(DKP Kabupaten Biak Numfor, 2022)**.

Currently, bullet tuna production in the waters of Biak Numfor Regency is approximately 659.10 tons, which accounts for about 40% of the total fishery potential (approximately 1,647.75 tons per year). Therefore, efforts are needed to boost production to 80%, or around 1,318.20 tons annually. Various initiatives have been undertaken to enhance production, including increasing the number of fishing gear units and fishing trips. However, these efforts have not produced optimal results, as fishermen continue to depend on traditional methods for identifying fishing areas based on their experience or instincts. This reliance on instinct does not yield the best outcomes, highlighting the importance of accurately identifying fishing zones before operations commence. According to **Tangke *et al*. (2020)** and **Tangke *et al*. (2023)**, fishing grounds are defined as areas where fishing gear is deployed to exploit fishery resources, and their distribution is influenced by a range of factors, one of which is the oceanographic characteristics of the waters.

Elasari *et al.* (2022) emphasized the importance of oceanographic factors as key indicators for identifying fishing areas, noting that changes in these parameters can significantly influence fish movement patterns. Fish typically seek out environments that are conducive to their habitats. According to **Pratama *et al*. (2022)**, seasonal fishing patterns and the abundance of pelagic fish are affected by oceanographic dynamics, including chlorophyll-a concentration and sea surface temperature. Understanding these seasonal patterns and their connection to oceanographic factors can help fishermen improve their catch efficiency. Environmental suitability, which impacts the availability of fish resources, encompasses factors such as sea surface temperature, salinity, and chlorophyll-a concentration. These elements affect water productivity and can be measured through phytoplankton content **(Akhlak *et al*. 2015)**. Chlorophyll-a, a photosynthetic pigment found in phytoplankton, serves as an indicator of water fertility, as it is associated with microscopic single-celled organisms inhabiting aquatic environments **(Makmur, 2008; Subama, 2014)**. Moreover, **Mahabror *et al*. (2017)** postulated that chlorophyll-a concentration can be used to assess fish resources, as there is a correlation between primary productivity and fishery resources. Consequently, regions with elevated chlorophyll-a concentrations are likely to support higher fish populations. Recent advancements in science and technology have enabled the detection of chlorophyll-a concentration using the Terra and Aqua satellites equipped with the Moderate Resolution Imaging Spectroradiometer (MODIS). These data can be collected in a time series format and can be utilized to identify fishing areas through remote sensing technologies. The use of Aqua-MODIS satellite imagery for monitoring chlorophyll-a concentrations can greatly enhance the identification of potential fishing zones **(Tangke *et al*., 2016; Tangke *et al*., 2021)**. **Kurniawati *et al*. (2015)** successfully predicted fishing zones based on chlorophyll-a distribution in the waters of North Aceh and West Aceh using high-precision remote sensing data from Aqua MODIS satellite imagery.

Given the significant potential of bullet tuna resources in the waters of Biak Numfor Regency and the currently low level of exploitation, there is a pressing need for information regarding the temporal distribution of bullet tuna fishing areas based on oceanographic parameters, particularly chlorophyll-a concentration. This information, supported by technological advancements, can enhance the reliability of catch outcomes, ultimately optimizing fishing efforts and promoting the sustainable use of bullet tuna resources. Therefore, this study aimed to investigate the distribution of chlorophyll-a concentration and its effect on bullet tuna catch production to achieve optimal fishing results in the waters of Biak Numfor Regency.

MATERIALS AND METHODS

This study is an experimental fishing research project conducted from April to July 2023 in the waters of Biak Numfor Regency, Papua Province (Fig. 1). The data collected included the total weight of bullet tuna catches from fishermen for each fishing trip, catch position data, and time series data on chlorophyll-a concentration from April to July 2023, which was obtained from the website https://oceancolor.gsfc.nasa.gov/. Data processing began with the extraction of satellite imagery using SeaDAS 4.7 software to acquire the coordinates and the spatial and temporal distribution of chlorophyll-a concentration in the study area, formatted as *.CSV files. The chlorophyll-a concentration data were then analyzed using Microsoft Excel 2010 for statistical and GIS analysis. The steps for data collection and processing are illustrated in Fig. (2).

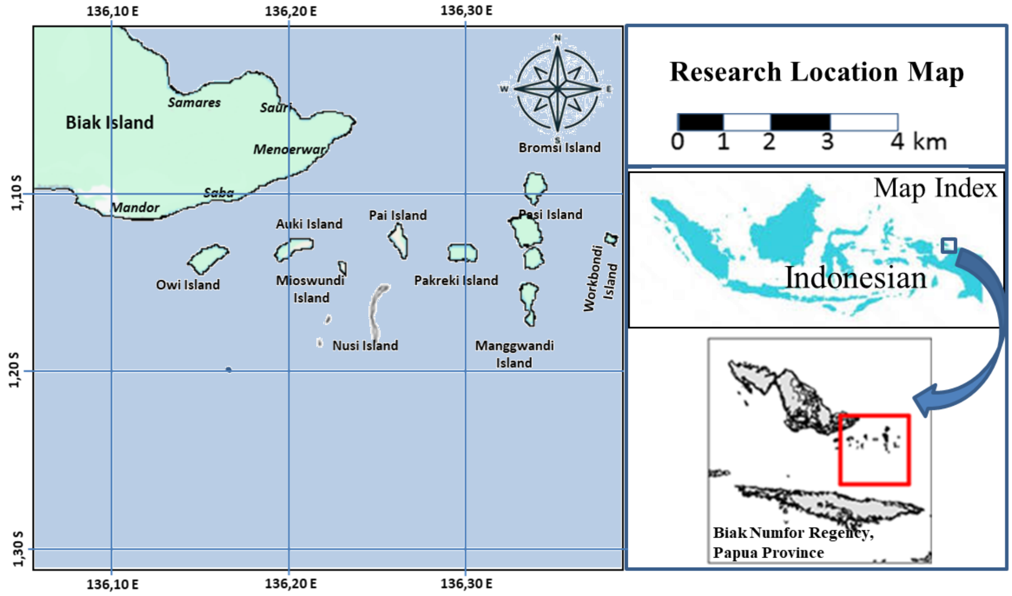

Fig. 1. Study location (Waters between the Padaido Islands and Yapen Island, Biak Numfor Regency, Papua Province)

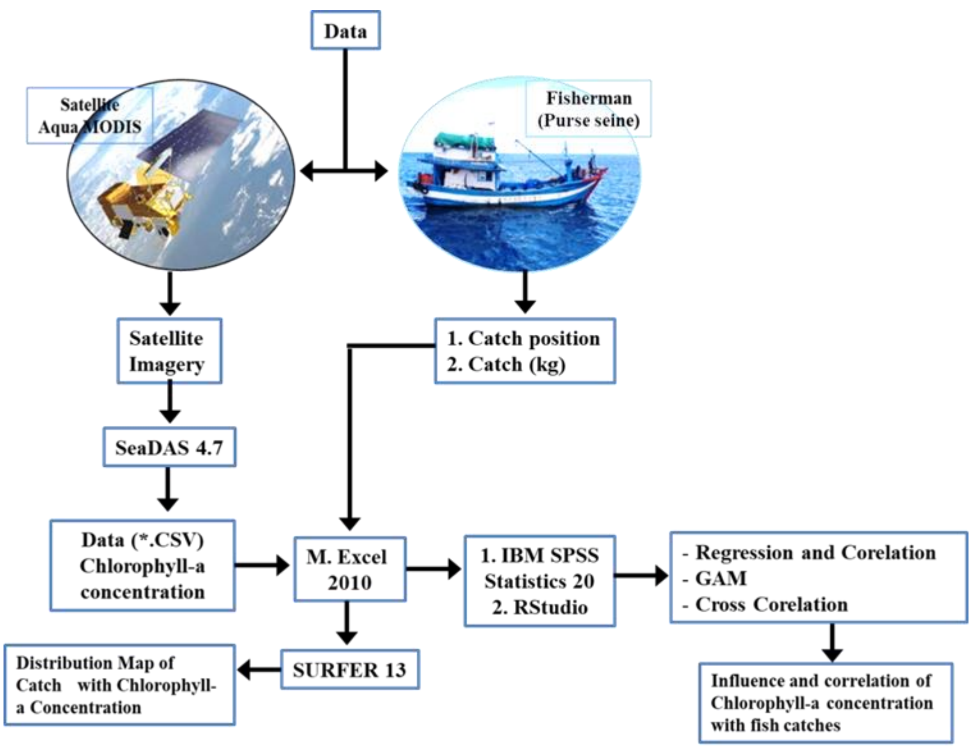

Fig. 2. Flowchart of data collection and processing procedures

The research data comprised both *in situ* and imagery data. The imagery data were extracted from Aqua MODIS Level 2 images using SeaDAS 4.7 software in *.CSV format. Both data sets were then processed using Microsoft Excel 2010 for further analysis. Statistical analyses, including regression, correlation, Generalized Additive Models (GAM), and cross-correlation, were conducted using IBM SPSS Statistics 20 and RStudio to compare different catch types and quantities. Specifically, regression analysis, correlation, and GAM were employed to assess the influence and relationship between chlorophyll-a concentration and bullet tuna catch volumes. For GIS analysis, data were processed using SURFER 13 software to map the distribution of chlorophyll-a concentration alongside bullet tuna catches.

The data analysis procedure commenced with the extraction of satellite imagery using SeaDAS 4.7, followed by GIS analysis with SURFER 13 to create maps and graphs depicting the spatial and temporal distribution of chlorophyll-a concentration from April to July 2023. Following this, the composition of the catch was analyzed, with catches sorted and weighed by species prior to analysis using the formula **(Salim & Kelen, 2017; Mauliddin *et al*., 2022; Tumion *et al*., 2023)**:

$$Xi(\%) = \frac{\sum \quad ni}{\sum \quad N} \; x \; 100$$

Where, Xi = percentage of species (i); ni = total weight of species (i) (kg); and N = total weight of the catch (kg).

To assess the impact of chlorophyll-a concentration on bullet tuna catch, a linear regression analysis was performed using IBM SPSS Statistics 20, based on the formula provided by **Walpole and Myers (1995)**:

Y = a + bX + e

Where, Y = bullet tuna catch (kg); a = intercept; b = slope; X = chlorophyll-a concentration; and e = error.

Subsequently, to explore the relationship between chlorophyll-a concentration and bullet tuna catch, Pearson correlation analysis was conducted using the formula from **Walpole and Myers (1995)**:

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

Where, $r\varkappa y$ = correlation coefficient between variables (x) and (y), $\varkappa$ = deviation from the mean for chlorophyll-a values, y = deviation from the mean for catch values

To evaluate the relationship between the response variable (μi), representing catch volume) and predictor variables (oceanographic parameters), a non-linear Generalized Additive Model (GAM) analysis was conducted, following the methodologies of **Hastie and Tibshirani (1986)**, **Safruddin and Zainuddin (2007)** and **Wood (2017)**:

$G(\mu i) = \alpha_0 + s_1$ (Const. chl-a) $+ \varepsilon$

Where, g = spline smooth function; μi = response variable; α_0 = constant coefficient; sn = smoothing function of predictor variable; and ε = standard error.

The final step involved cross-correlation analysis to predict the relationship between chlorophyll-a concentration and bullet tuna catch, utilizing time series data to identify any time lag associated with the presence of bullet tuna in fishing areas. This analysis was performed using the formula referenced by **Shumway and Stoffer (2006)**, **Cowpertwait and Metcalfe (2009)** and **Thomas (2010)**:

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

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

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

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

Where, Y = bullet catch tuna, and X = chlorophyll-a concentration

RESULTS AND DISCUSSION

1. Distribution of chlorophyll-a concentration in Biak Numfor waters

Chlorophyll-a is a photosynthetic pigment present in phytoplankton, which are microscopic single-celled organisms found in both freshwater and marine environments. The concentration of chlorophyll-a serves as an indicator of primary productivity or the fertility of the waters **(Makmur, 2008; Subama, 2014)**. The chlorophyll-a produced by phytoplankton reflects water fertility, and these organisms play a critical role as primary producers in aquatic food chains. Consequently, fluctuations in phytoplankton populations can significantly affect the seasonal availability of bullet tuna, as noted by **Simbolon and Girsang (2009)**. The temporal distribution of chlorophyll-a concentration in the waters of Biak Numfor is depicted in Fig. (4a-d).

Fig. (3a-d) presents the results of chlorophyll-a concentration extraction from Aqua-MODIS satellite imagery for the period from April to July 2023 in the waters of Biak Numfor Regency, located at coordinates 136°06’ E - 136°38’ E; 0°2’ S - 1°29’ S. The images indicate that the distribution of chlorophyll-a concentration is quite dynamic, with monthly values fluctuating between 0.19 and 1.3mg m^{-3} in April, 0.15 to 0.89mg m^{-3} in May, 0.12 to 0.95mg m^{-3} in June, and 0.14 to 1.1mg m^{-3} in July. **Shtraikhert and**

Zakharkov (2002) and **Gaol *et al*., (2004)** observed that chlorophyll-a levels tend to vary seasonally, suggesting that water fertility also changes with seasons.

The monthly fluctuations in chlorophyll-a distribution are believed to be influenced by seasonal conditions and the geographic location of Biak Numfor, situated between two major islands (Biak Island and Papua Island), which facilitates nutrient input from the land. According to **Nontji (2008)**, chlorophyll-a concentration in aquatic environments is closely linked to nutrient supply from land runoff, which enters through river flows. Furthermore, **Wahyudi (2019)** noted that from April to July, the region transitions from the first transition season to the eastern season, characterized by varying conditions of warm temperatures and moderate rainfall, resulting in runoff and direct nutrient influx from the land via rivers. The optimal temperature range for plankton development in tropical regions, which is suitable for aquatic organisms, typically falls between 25 and 32°C **(Efendi, 2003)**. Additionally, **Zulhaniarta *et al*. (2015)** indicated that phytoplankton growth is supported by the availability of nutrients and light intensity in the water.

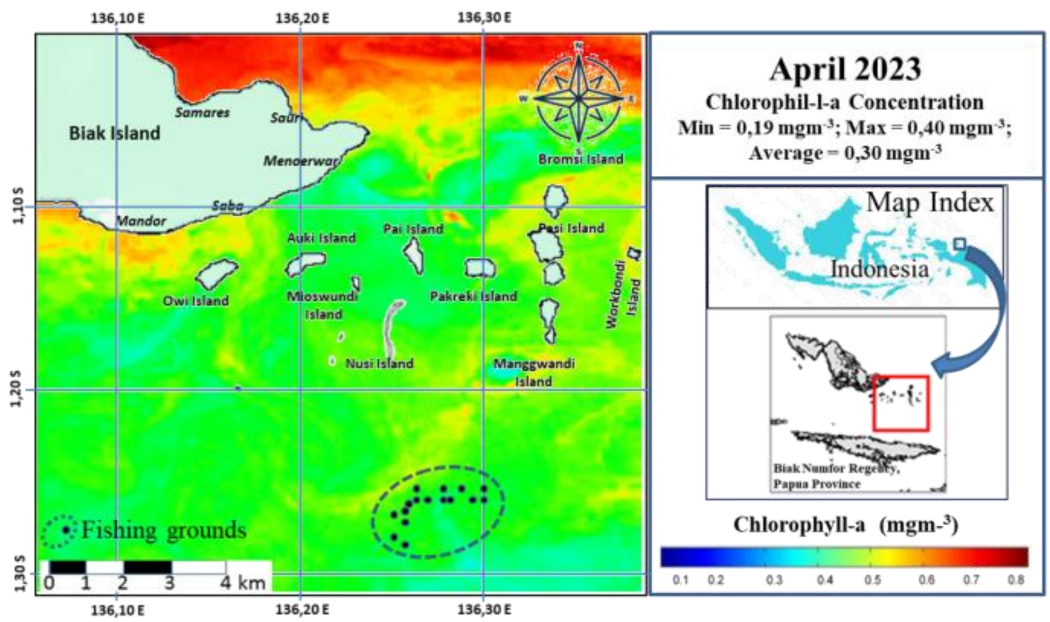

Fig. 3a. Distribution of chlorophyll-a concentration in April 2023

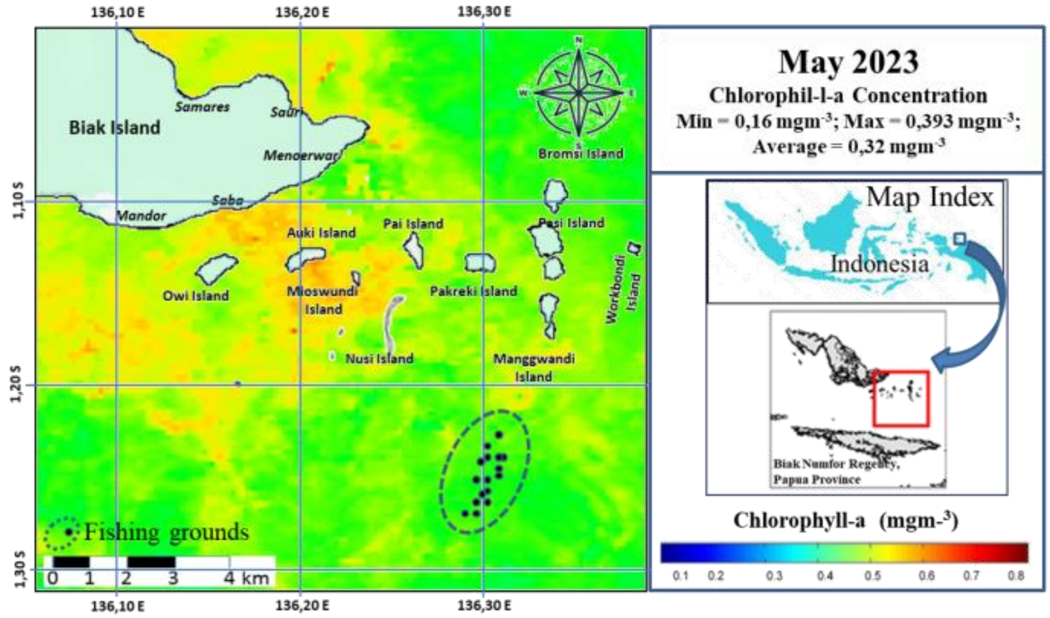

Fig. 3b. Distribution of chlorophyll-a concentration in May 2023

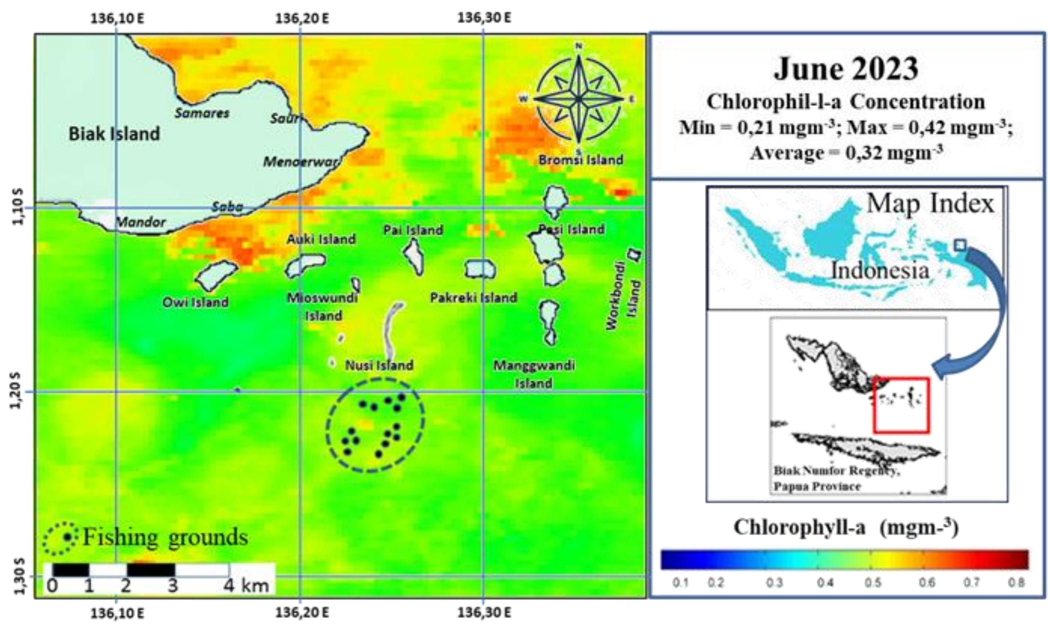

Fig. 3c. Distribution of chlorophyll-a concentration in June 2023

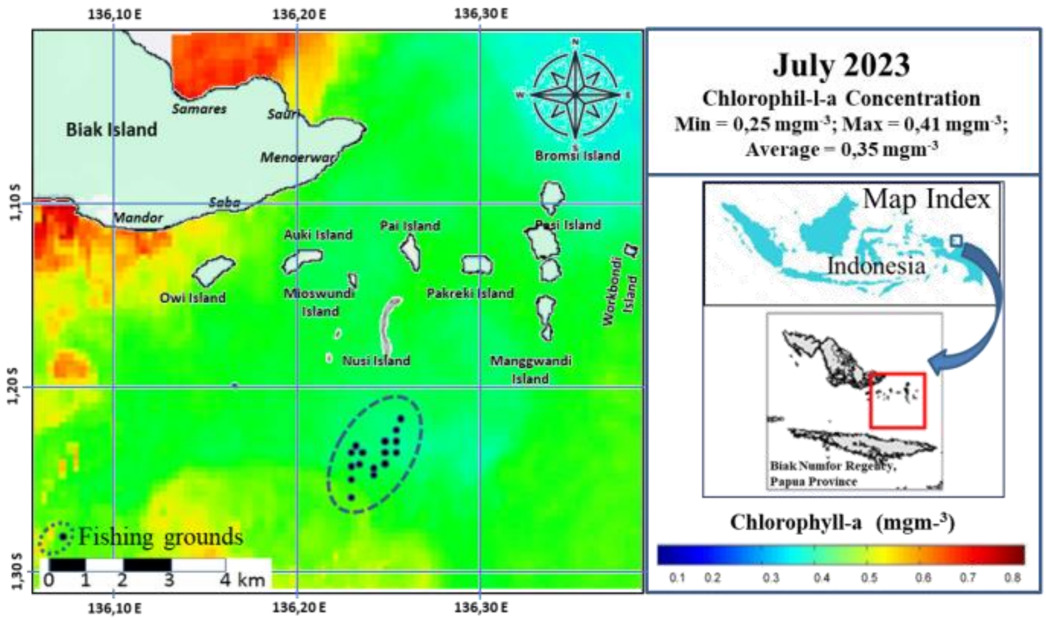

Fig. 3d. Distribution of chlorophyll-a concentration in July 2023

Fig. (3a-d) also depicts the distribution of fishing areas, which are primarily situated in the southeastern part of Biak Island. The average travel time to these areas is between 6 to 9 hours, with speeds ranging from 5 to 7 miles per hour. The chlorophyll-a concentration in these fishing zones, as indicated by the catch position data collected during the study, shows that in April 2023, the fishing area was located at coordinates 136°3'45"E - 136°24'21"E; 1°25'19"S - 1°28'27"S. The chlorophyll-a concentrations during this period ranged from 0.19 to 0.40mg m^{-3}, with an average of 0.30mg m^{-3}. In May, the fishing area shifted to coordinates 136°28'E - 136°33'E; 1°23'S - 1°27'19"S, where chlorophyll-a concentrations decreased compared to April, recording a minimum of 0.16mg m^{-3} and a maximum of 0.393mg m^{-3}, resulting in an average of 0.32mg m^{-3}. In June 2023, the fishing area was found at coordinates 136°23'41"E - 136°26'27"E; 1°20'35"S - 1°24'17"S, where chlorophyll-a concentrations slightly increased, ranging from a minimum of 0.21mg m^{-3} to a maximum of 0.42mg m^{-3}, with an average of 0.32mg m^{-3}. By July 2023, the fishing area was located at coordinates 136°23'32"E - 136°26'17"E; 1°2'34"S - 1°26'25"S, exhibiting stable chlorophyll-a concentrations with a minimum of 0.25mg m^{-3} and a maximum of 0.41mg m^{-3}, leading to an average of 0.35mg m^{-3}. Overall, the average chlorophyll-a concentration in the fishing area suggests that it is quite productive, as the concentrations range between 0.2 and 0.6mg m^{-3}, which is classified as abundant **(Simbolon & Girsang, 2009)**. Additionally, **Gower (1972)**, as cited in **Kristiyani *et al*. (2012)**, asserted that chlorophyll-a concentrations exceeding 0.2mg m^{-3} indicate the presence of phytoplankton, signaling suitable habitats for fish.

The variations in chlorophyll-a concentration data based on satellite imagery from April to July 2023 in the fishing area are illustrated in the graph (Fig. 4). This graph shows significant fluctuations in chlorophyll-a concentrations with each fishing trip, recording minimum and maximum values of 0.16 and 0.42mg m^{-3}, respectively, with an average of 0.32mg m^{-3}. The trends depicted in Fig. (5) also indicate an upward trajectory in chlorophyll-a levels from April to July 2023, consistent with the average concentrations shown in Fig. (3a-d).

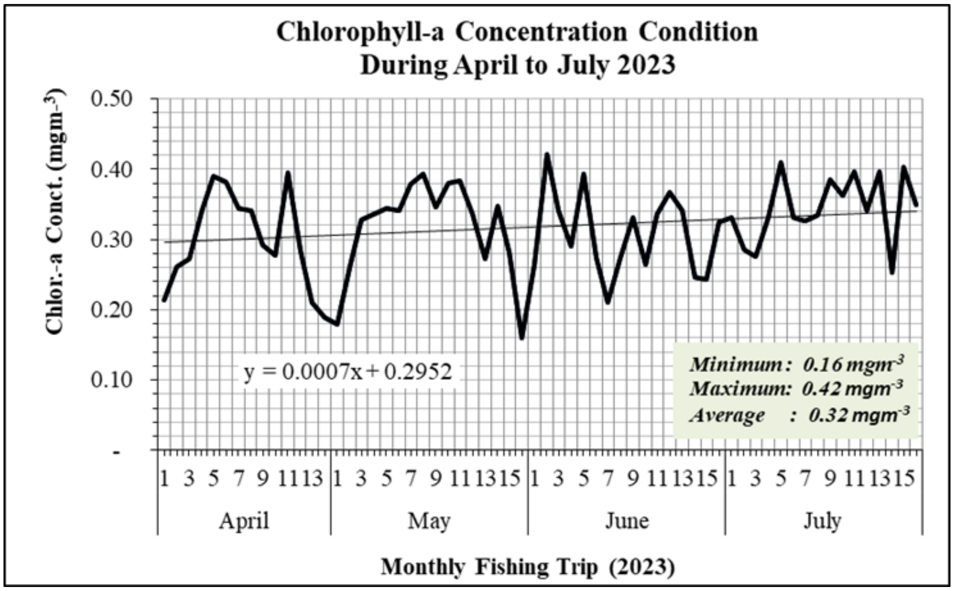

Fig. 4. Fluctuations in chlorophyll-a concentrations in the fishing area from April to July 2023

2. Fish catch results

The primary catches from purse seine and longline fishing vessels operating in the waters of Biak Numfor consist of various pelagic fish species, including the skipjack tuna, yellowfin tuna, mackerel fish, and bullet tuna (Fig. 5). An analysis of catch composition from April to July 2023 indicates that the bullet tuna is the most prevalent species, with a total catch of 1,279.7kg, representing approximately 58.5% of the overall catch (Fig. 6). In the waters of Biak Numfor Regency, Papua Province, the bullet tuna is primarily harvested using several types of fishing gear, such as purse seines, longlines, surface gill nets, and fishing bags. Among these, purse seines and longlines are the most commonly employed methods for capturing the bullet tuna. Fig. (7) illustrates the production of the bullet tuna in Biak Numfor Regency from April to July 2023.

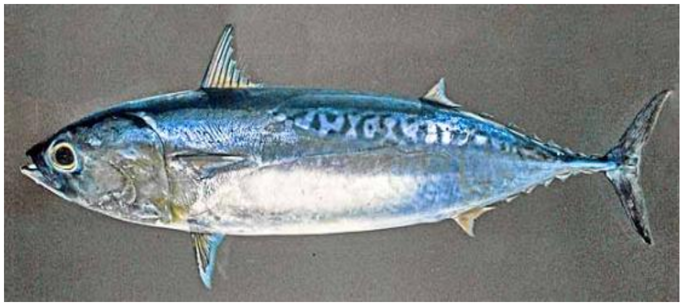

Fig. 5. Bullet tuna (*Auxis rochei* Risso, 181)
(Research data, 2023)

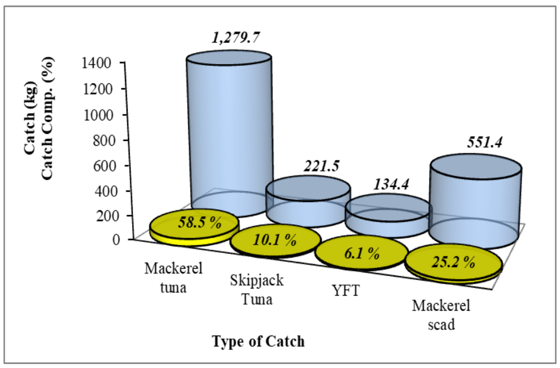

Fig. 6. Quantity and composition of catches from April to July 2023

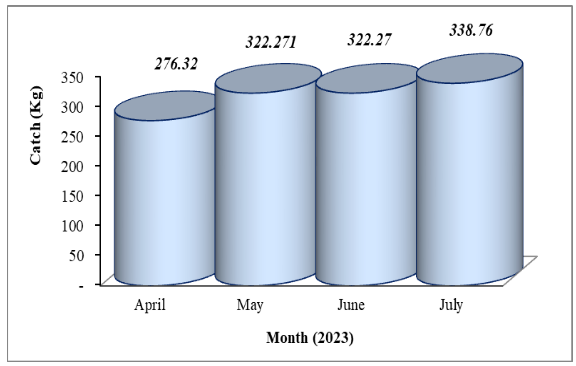

Fig. 7. The bullet tuna production from April to July 2023

As shown in Fig. (6), the total production of the bullet tuna from April to July 2023 amounted to 1,279.7kg, resulting in an average monthly production of 319.92kg. The fluctuations in bullet tuna production during this period are depicted in Fig. (7), which reveals that production was at its lowest in April 2023 and peaked in July 2023, demonstrating a consistent upward trend each month. These variations in productivity and catch volume are believed to be influenced by several factors, including the number of fishing trips and the technical aspects of gear operation. In April 2023, there were 14 fishing trips, which increased to 16 trips the following month. The technical aspects of gear operation are heavily reliant on the skills of the fishermen, the use of fishing aids, and the techniques employed during gear operation. According to **Nelwan *et al*. (2015)**, catch productivity refers to the efficiency of fishing gear in yielding a specific amount of catch per unit of effort, which is closely related to these technical aspects. Furthermore, **Oktavia *et al*. (2018)** highlighted that technical considerations significantly influence the effectiveness of gear operation, emphasizing that attention to these details is beneficial for practitioners in the fishing industry.

Another factor believed to affect catch production is the fluctuation of oceanographic parameters. **Pratama *et al*. (2022)** noticed that seasonal fishing patterns and the abundance of pelagic fish are influenced by the dynamics of oceanographic conditions, including chlorophyll-a concentration and sea surface temperature. The waters of Biak

Numfor represent a dynamic ecosystem where fish populations are affected by these oceanographic factors. Researchers such as **Simbolon and Girsang (2009)**, **Gaol *et al.* (2010)**, **Mujib *et al.* 2013b**, **Tangke *et al.* (2021)** and **Tangke *et al.* (2022)** have observed that fishing areas with high resource potential are significantly influenced by oceanographic conditions. **Nurani *et al.* 2022)** emphasized that the success of fishermen in utilizing fish resources depends on oceanographic conditions, seasonal variations, and specific fishing locations. **Zainuddin *et al.* (2017)** and **Safruddin *et al.* (2022)** noted that oceanographic parameters such as water depth and processes like upwelling or chlorophyll-a fronts **(Hidayat *et al.*, 2019)** can serve as indicators for identifying potential areas for economically significant fish catches. **Freon *et al.* (2005)**, as cited in **Nelwan *et al.* (2015)**, highlighted that variations in fish catch quantities are related to the feeding patterns and behaviors of pelagic fish species. Additionally, **Rizwan *et al.* (2014)**, as referenced in **Apriliani *et al.* (2018)** and **Tangke *et al.* (2023)**, indicated that the volume of fish caught is influenced by food availability, with chlorophyll-a concentration being a critical factor in determining the abundance and health of fish in a given aquatic environment.

3. Fluctuations in chlorophyll-a concentration and bullet tuna catch

The bullet tuna is a pelagic species that schools near the surface down to depths of approximately 100 meters. As a carnivorous fish, its primary diet consists of small pelagic fish, supplemented by squid, making its presence closely linked to the food chain, particularly phytoplankton, which serve as primary producers in marine ecosystems. Daily fluctuations in bullet tuna populations and chlorophyll-a concentrations are illustrated in Fig. (9).

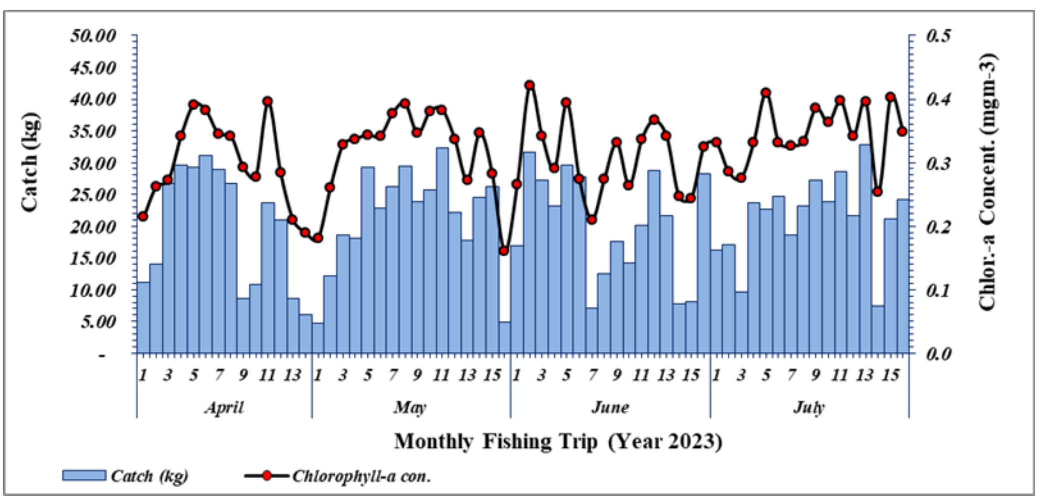

Fig. 9. Daily fluctuations of bullet tuna and chlorophyll-a concentrations from April to July 2023

Fig. (9) illustrates that the conditions of bullet tuna catches and chlorophyll-a concentration from April to July 2023 follow a similar trend: as chlorophyll-a concentration increases, bullet tuna production also rises. Conversely, a decrease in chlorophyll-a concentration typically results in lower tuna catches. The results from the linear regression analysis (Fig. 10) show that chlorophyll-a concentration has a significant partial effect on catch distribution, with an F¬count value (Fhit) of 82.834 and a significance level (Sig.) of 0.00. The established regression equation is as follows: Y = 0.22 + 0.005*Catch (kg). The coefficient of determination (R^2) is 0.58, indicating that 58% of the presence of the bullet tuna in the fishing area is influenced by chlorophyll-a concentration, assuming other oceanographic parameters remain constant. Research by **Putra *et al*. (2012)** found that fluctuations in chlorophyll-a concentration between 0.22 and 1.15mg m^{-3} significantly impacted the catches of small pelagic fish in the Java Sea.

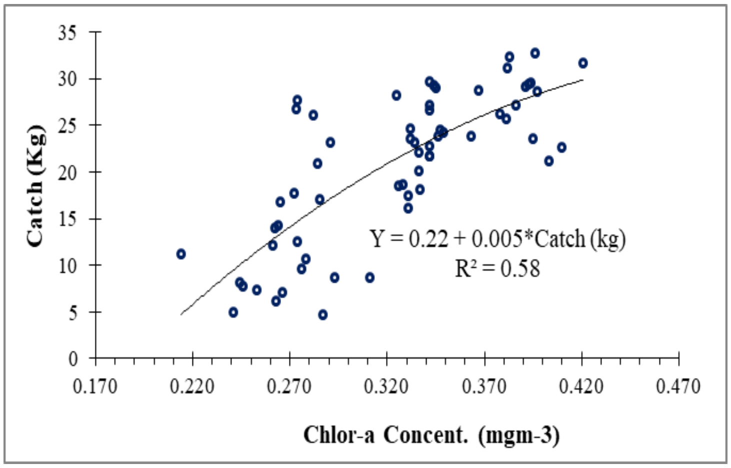

Fig. 10. The effect of chlorophyll-a concentration on the bullet tuna distribution

The correlation analysis revealed a correlation coefficient (r) of 0.762 between chlorophyll-a concentration and bullet tuna catch. This strong positive correlation suggests that increases in chlorophyll-a concentration are associated with increased bullet tuna catches. This relationship is further illustrated in Fig. (11), which indicates that at low chlorophyll-a concentrations (0.1-0.2mg m^{-3}), the bullet tuna catches averages 35.5kg. As chlorophyll-a concentration rises, the catch amount also increases, as shown by the upward trend line corresponding to higher chlorophyll-a levels.

Adnan (2010) noted that an increase in chlorophyll-a in the waters leads to greater pelagic catches, while a decrease in chlorophyll-a results in reduced catches. According to **Ningsih *et al*. (2022)** and **Sukardi *et al*. (2024)** chlorophyll-a significantly influences pelagic fish catches, with higher chlorophyll-a concentrations likely resulting in greater fish production, and lower concentrations leading to reduced catches. Additionally, **Nurani *et al*. (2022)** and **Nurdin *et al*. (2018)** found that catches of pelagic fish, such as bullet, tuna, and mackerel, tend to increase when sea surface temperatures are low and chlorophyll-a is abundant. **Hidayat *et al*. (2019)** observed that chlorophyll-a concentrations of 0.2mg m^{-3} are significantly related to pelagic fish catches. Furthermore, **Safruddin and Zainuddin (2007)** indicated that average monthly chlorophyll-a concentrations exceeding 2.0mg m^{-3} in a body of water suggest sufficient plankton availability to support the survival of pelagic fish.

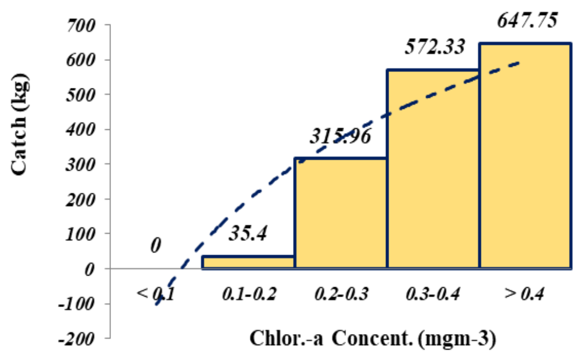

Fig. 11. Distribution of bullet tuna in relation to chlorophyll-a concentration

The results of the Generalized Additive Model (GAM) analysis presented in Table (1) indicate a strong and highly significant relationship between bullet tuna catch and chlorophyll-a concentration, with a significance value (Sig.) of less than 0.0001. The density distribution of the catches shown in Fig. (11) further supports the robust correlation between chlorophyll-a concentration and the bullet tuna catch. It can be concluded that the optimal potential fishing areas for small pelagic fish, particularly bullet tuna, in the waters of Biak Numfor are found within a chlorophyll-a concentration range of 0.2 to over 0.4mg m^{-3}.

Table 1. Results of GAM analysis (Non-parametric ANOVA) on the effect of chlorophyll-a concentration on bullet tuna catch

Variable	Pr (F)	Sig.
Chlor.-a Concentration	0.000264	< 0.0001

The bullet tuna is a pelagic fish species classified as carnivorous. It does not rely directly on chlorophyll-a **(Tarigan *et al*., 2021)**. Nevertheless, its presence in a given aquatic environment is indirectly influenced by phytoplankton **(Kuswanto *et al*., 2017)**. In this context, the presence of the bullet tuna in a fishing area requires a specific time interval, known as the correlation distance or time lag. Cross-correlation analysis revealed that in the waters of Biak Numfor, this time lag for the bullet tuna was observed during the 17th fishing trip. This finding is supported by Fig. (12), which shows that the bullet tuna catches begin to increase significantly starting with the 17^{th} trip, despite substantial catches being recorded in earlier trips.

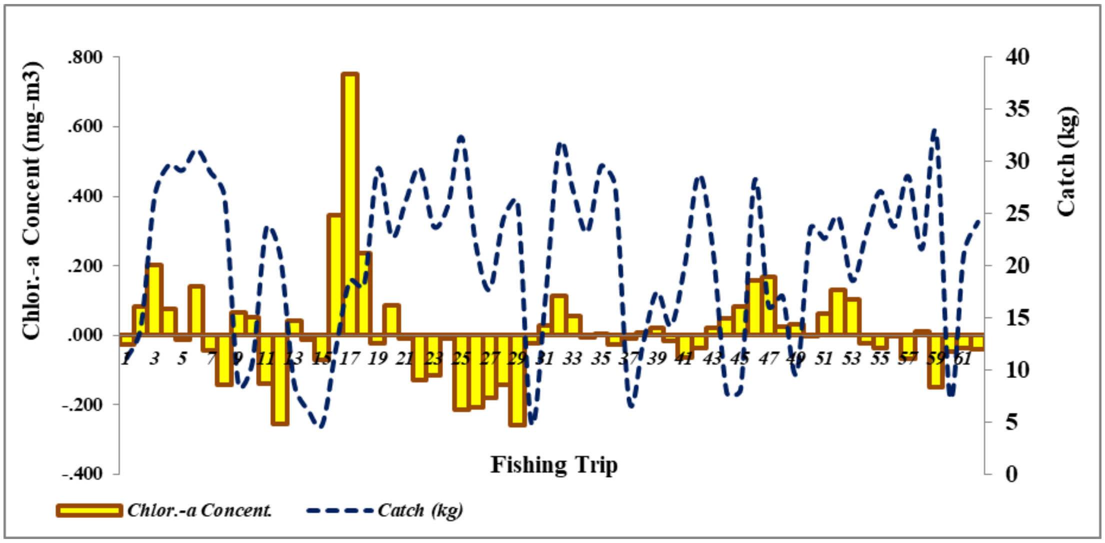

Fig. 12. Time lag of chlorophyll-a concentration and bullet tuna catch

CONCLUSION

From April to July 2023, the chlorophyll-a concentration in the waters of Biak Numfor exhibited considerable variability, with minimum, maximum, and average values of 0.16mg m^{-3}, 0.42mg m^{-3}, and 0.32mg m^{-3}, respectively. Regression and GAM analyses indicate that chlorophyll-a concentration has a significant and strong effect on tuna catch, with an F-value of 82.834, a significance level of 0.00, and a correlation coefficient of 0.762. The GAM analysis further revealed a highly significant relationship between the two variables (P< 0.0001). Correlation analysis also shows a strong positive correlation (r= 0.762). Additionally, cross-correlation analysis confirms that the presence and increased production of the bullet tuna in Biak Numfor waters are notably observed during the 17th trip.

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