# Seasonal and Spatial Dynamics of Chlorophyll-a Concentrations in Marine Protected FMA 714 in Relation to Yellowfin Tuna (*Thunnus albacares*) Catches

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*Abstract*

*Indonesia's Ministry of Marine Affairs and Fisheries designated Fisheries Management Area 714 (FMA 714) as a tuna conservation area. Research has been conducted on the potential fishing grounds, distribution, and abundance of YFT in FMA 714. Still, a study that analyzes catch productivity and YFT coordinates with YFT conservation area distance has never been done. The objectives of this study are to analyze the seasonal and spatial dynamics of Chl-a concentrations in FMA 714 using temporal spatial analysis with SeaDAS 9.0.1, analyze fishing productivity by season using CPUE analysis, and determine the distance of the fishing ground from the conservation area using point distance geoprocessing analysis in GIS. The data used are logbook data from YFT caught with pole and line in the form of fishing coordinates, several catches, and seasonal Chl-a concentrations from 2019-2021, and catch per unit effort to analyze fishing productivity. The results showed that the highest average Chl-a concentration in FMA 714 was dominated by the eastern monsoon, transition period II, transition period I, and the western monsoon period. Transition period II had the highest CPUE, 19.50 fish/fishing set, and the lowest CPUE was found in the eastern monsoon, 0.36 fish/fish set. The fishing area has a moderate chlorophyll-a concentration but tends to yield a high CPUE and there is a tendency for high CPUE to be relatively far from the tuna conservation area.*

*Keywords: Seasonal spatial chlorophyll-a, FMA 714, fishing grounds, Yellowfin tuna*

## Introduction

Fisheries Management Area 714 (FMA 714) is a deep-water area with depths ranging from 900 to 7400 meters, with a high potential for capturing fisheries, including yellowfin tuna (YFT). IMMAF (2016) states that YFT is a highly mobile fish species. Several studies have shown that FMA 714 is a nursery and spawning ground because many *scombridae* larvae are found, and their abundance and distribution are large (Bailey *et al*., 2012; Gaol *et al*., 2020). Therefore, MMAF has designated the area as a tuna conservation area at coordinates ranging from 126°-132° E and 4°-6°S through Ministerial Regulation of MMAF No. 26 of 2020.

FMA 714 includes fertile waters with dynamic oceanographic conditions (Amri, 2005; Hariati, 2017). Chlorophyll-a (Chl-a), a fertility indicator, plays a significant role in primary productivity in aquatic ecosystems (Nufadilah, 2023). This primary productivity causes high phytoplankton growth and will support more significant fish populations (Kasma, *et al*., 2007; Lee *et al*., 2014). In the ocean, Chl-a concentrations vary seasonally and are influenced by climatic conditions such as El Niño and La Niña phenomena. These changes can affect fish distribution and abundance (Gaol *et al*., 2020).

YFT are predatory fish that feed on small fish, squid, and crustaceans. In areas with high Chl-a concentrations, the food chain will be more productive, increasing the availability of food for YFT, which may attract YFT to the area in large numbers.

Remote sensing satellite technology is often used to map Chl-a concentrations in the ocean; data from this technology can help fishers and fisheries managers to detect the fertility of global waters quickly (Song and Zhou, 2010; Sambah *et al.,* 2016; Marpaung *et al.,* 2021). YFT has both horizontal and vertical migration patterns with variable swimming depths. This behavior makes satellite-derived chlorophyll an ecologically relevant measurement for this study. Chlorophyll a is a primary productivity indicator that reflects phytoplankton concentrations at the ocean surface, which underpins the food chain in tropical marine ecosystems.

Olson *et al*. (1994) demonstrated that tropical tuna, including YFT, frequently aggregate around oceanic fronts and areas of abrupt environmental changes, detectable through surface chlorophyll-a gradients. Polovina (2001) further established a positive correlation between tropical tuna concentrations and satellite-identified marine environmental structures, including chlorophyll-a distribution and thermal fronts, as indicators of potential habitats. In the Banda Sea specifically, Zainuddin *et al*. (2006) found that YFT catch per unit effort (CPUE) increased significantly in areas with chlorophyll-a concentrations between 0.2 and 0.4 $mg.m^{-3}$. While the chlorophyll-a data in this study derives from satellite imagery of surface conditions, these measurements provide a reliable indirect indicator of YFT presence.

Research on the potential fishing grounds, distribution, and abundance of YFT fish in FMA 714 has been widely conducted (see Zainuddin *et al*., 2013; Muhling *et al*., 2015; Tadjuddah, 2018; Hidayat *et al*., 2019). Nevertheless, no research has been conducted that analyzes capture productivity or CPUE and links the points of YFT caught in FMA 714 with the distance of the YFT conservation area. Hence, this study is crucial for formulating strategic measures by policymakers to ensure sustainable management of the YFT conservation area in FMA 714. The objectives of this study are: 1) to analyse the seasonal and spatial dynamics of Chl-a concentrations in FMA 714 from 2019 to 2021, 2) to analyse fishing productivity based on season, and 3) to determine the distance of the closest and furthest fishing areas from the conservation area.

## Materials and Methods

### *Data analysis*

Data collection was conducted at Kendari Ocean Fishing Port (KOFP); this location was chosen because fishers based at KOFP caught FMA 714. The data used in this study includes logbook records of YFT catches from 12 fishing fleet units between 2019 and 2021. This data encompasses catch coordinates, catch amounts, and seasonal Chl-a concentrations for the same period. This research prioritized pole and line fishing gear as the focus of our research due to the observed decline in the number of fishing fleets and fishing gear (KOFP, 2023). The seasons are divided based on (Sartimbul *et al*., 2010; Adi Wijaya *et al*., 2020): the western monsoon period (December, January, and February) and transition period I (March, April, and May). Eastern monsoon period (June, July, and August) and transition period II (September, October, and November).

The research was conducted in several stages. As with the boundaries of the study area, FMA 714 is between the coordinates of 121°.07'44" - 132°.05'41"E and -8°.01'23" -8°.07'16" S are around the waters of the Banda Sea and Tolo Bay (Figure 1).

The initial phase involved collecting data on the coordinates of the processed fishing locations by observers between 2019 and 2021. The fishing position data consists of the coordinates of the fishing position, fishing season, fishing time, and the amount of *catch*. Catch per unit effort (CPUE) analysis is employed to characterize fishing productivity, utilizing the formula of Sparre and Venema (1992) and Sambah *et al.* (2016).

CPUE is commonly used as a parameter to determine the productivity of fishing gear, so that CPUE can be used as an indicator in sustainable fisheries management (Zainuddin *et al.,* 2013; Sambah *et al*., 2016). CPUE was calculated based on YFT catches of the pole and line gear landed at KOFP. A fishing set is defined as the number of pole-and-line fishing gear used at each capture coordinate point. Fishing ground points collected were 41 points. This water area is bounded by 121°07'.44" E to 132.05'41 "E and 01°02'35 "S to 08°07'16" S. The lack of fishing points collected from observers is since currently, the pole and line fishing gear is relatively much less than the purse seine fishing fleet, which is more dominant in operating in KOFP.

The second stage processed monthly, daytime Chl-a concentration data derived from the Aqua-Modis level 3 satellite were downloaded from the NASA Goddard Space Flight Centre (GSFC) through the following website http://oceancolor. gsfc.nasa.gov/cgi. These data are 4-km pixel resolution products. The processed Chl-a concentration data is also from 2019 to 2021. Data processing begins with the download of chlorophyll-a data. The format of chlorophyll-a data is Non-Conformance (.nc). The data was then extracted using the SeaDAS 9.0.1 application and cropped according to the coordinates of the study area. After cropping, the pixel mask was exported and stored as a Text Tab Delimited (txt). The .txt data generated from the SeaDAS processing results were then opened in Microsoft Excel to carry out the cloud cover and land correction process by removing irrelevant pixel values. The following process was visualizing the distribution of Chl-a parameters and seasonal CPUE data using ArcGIS 10.8 to convert the txt data into *a shapefile*, then inputting the capture coordinates and the layout process. During the study, spatial-temporal analysis was conducted to determine the distribution and spread of Chl-a and the phenomenon. Distance analysis of fishing point coordinates with tuna conservation areas was carried out using geoprocessing point distance, calculated with nautical miles. The OC3M algorithm equation was used to estimate Chl-a concentrations using bands nine and 12 (O'Reilly *et al.*, 2000). This algorithm uses the logarithmic ratio of the reflectance values at several specific wavelengths. i.e.:

$$\mathbf{Ca = 10}^{0.283 - 2.753 * R1 + 1.457 * R2 + 0.659 * R3 - 1.403 * R4}$$

$$R = \log_{10}\left(Rrs\left(\frac{443}{551}\right) > Rrs\left(\frac{448}{551}\right)\right)$$

Note: Ca= Chlorophyll-a (mg.m$^{-3}$); R= Reflectance ratio; Rrs= Remote sensing

As an effort to avoid the erroneous estimation of Chl-a data from the impact of suspended particles, baseline reflectance, and case-2 water conditions, valid Sea Surface Chlorophyll-a (SSC) data from MODIS data in 0 < SSC <5 mg.m$^{-3}$ were used. Valid selective scattering (SSC) data were filtered using the initial analysis of MODIS data to produce SSCs within the 0-5 mg.m$^{-3}$ range (Sartimbul *et al.*, 2018; Wijaya *et al.*, 2020).

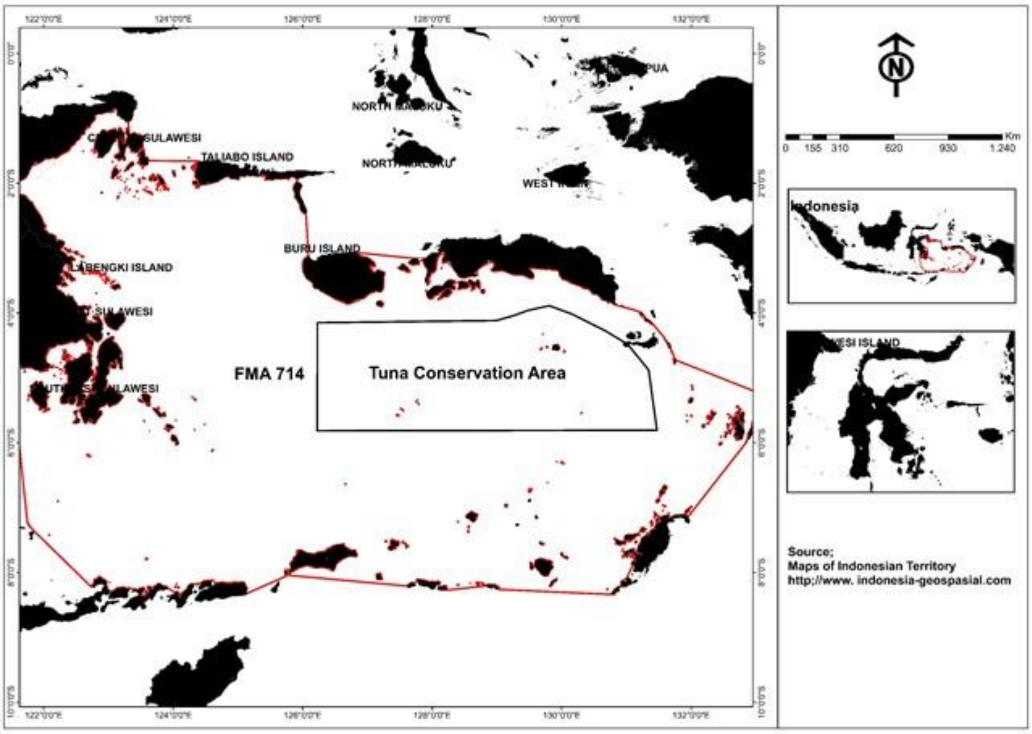


Figure 1. Research Site in Fisheries Management Area 714

## Result and Discussion

### *Seasonal and spatial dynamics of chlorophyll-a concentrations*

Based on the findings of the three-year analysis, it shows that the highest average chl- a concentration in FMA 714 is dominated by the eastern monsoon, which is 0.39 mg.m$^{-3}$ (±0.06) followed by transition period II of 0.30 mg.m$^{-3}$ (±0.13) followed by transition period I of 0.23 mg.m$^{-3}$ (±0.07) and 0.19 mg.m$^{-3}$ (±0.02) in the western monsoon period (Figure 2.). The highest Chl-a concentration in the eastern monsoon occurred in 2019, namely in the northern part of Muna Island, north of Seram Island, and north of the Kei Islands. However, in 2019, the highest Chl-a concentrations spread evenly throughout the waters of FMA 714.

However, in this season, the Chl-a concentration decreased in 2020 and 2021, but the Chl-a concentration was still higher than in the other seasons. This can be caused by the strong eastern monsoon winds that move from mainland Australia to Asia through Indonesian waters, including the waters of FMA 714 (Kunarso *et al*., 2011, 2015; Hariati *et al*., 2017). In general, Chl-a concentrations in the eastern monsoon in 2019, 2020, and 2021 have the same pattern: high Chl-a concentrations spread evenly throughout the waters.

Furthermore, Karman *et al*. (2015) stated that in the Banda Sea and Arafura Sea, which are included in FMA 714 waters during the east or southeast monsoon (June-August), water fertility and phytoplankton abundance will increase due to upwelling, which has an impact on waters that cause the circulation of water masses in these waters to affect the mixing of water masses and the tendency for changes in chlorophyll-a concentrations around higher FMA 714 waters. Masithah *et al*. (2023) also stated that the temporal distribution of Chl-a in a body of water can describe how Chl-a concentrations change over time in the water column. Temporal fluctuations in chlorophyll-a concentrations indicate seasonal patterns in the waters (Figure 2.),

The lowest Chl-a concentrations are mainly in the western monsoon period, especially in 2020. The lowest Chl-a concentrations were 0.04-0.09 $mg.m^{-3}$, as well as in 2019 and 2021. The spots with the lowest concentrations are Buru Island, Taliabo Island, and Seram Island, while slightly greater levels are observed in the southeastern region of the Wakatobi islands. This phenomenon may be linked to the relatively low wind intensity during the western monsoon season, resulting in reduced circulation currents that hinder the provision of essential nutrients required for the proliferation of phytoplankton responsible for Chl-a production. Supporting this claim are the findings of Mercado-Santana *et al*. (2017) and Vallina *et al*. (2017), who assert that the spatial and temporal distribution of chlorophyll-a (Chl-a) concentrations in marine waters is directly affected by the concentration of phytoplankton biomass. These phytoplankton are autotrophic organisms whose temporal distribution is significantly influenced by the annual and daily solar cycles, which impact current circulation.

Within the transition period II, the concentration of Chl-a consistently exceeds that of the west-east transition season for three years. This is due to the continued impact of the eastern monsoon period during this season. Eastern monsoon and transition period II have similar chlorophyll-a concentration patterns throughout the year because similar oceanographic factors influence both seasons in the water area. During transition period II, although seasonal winds appear to be weakening, some areas still experience increased activity in ocean dynamics, including limited upwelling, water mixing, and current-borne nutrient transport. This maintains chlorophyll-a concentration levels similar to the eastern monsoon period (Gao *et al.,* 2018; Wirasatriya *et al.,* 2021). The pattern of variability of Chl-a concentration between seasons can be seen in Figure 2**.**

The spatial distribution of seasonal Chl-a concentrations in FMA 714 appears to be higher in most coastal areas, while low concentrations are in offshore waters. Chlorophyll-a concentration values appear higher in areas close to the coast than in offshore waters. This is due to the greater supply of nutrients from land compared to offshore waters (Nuzapril *et al*., 2017b). Based on the analysis, the concentration of Chl-a for 3 years in FMA 714 fluctuates dynamically, with a visible pattern that the eastern monsoon period and transition period II always have higher concentrations during the study than other seasons while western monsoon period and transition period I always have a lower concentration pattern but western monsoon period has a lower pattern. The details of the average seasonal Chl-a concentration distribution are shown in Figure 3.

### *Catch Per Unit Effort (CPUE)*

The highest catch in the western monsoon period, with a CPUE of 3.16 fish/fishing set, was found at position 122°22'20.46" E and 02°18'63.16" S. In contrast, the lowest CPUE was found at 1.22 fish/fishing set at position 122°20'41.74" E and 02°28'55".14 S. The farthest fishing position from the tuna conservation area was found at position 122°37'09.70" E and 02°45'06".81 S with a distance of 290.60 nautical miles. In contrast, the closest fishing position from the conservation area was detected at position 122°06'83.33" E and 03°35'22".22 S with a distance of 224.84 nautical miles. In the western monsoon period, the spatial distribution of YFT fishing areas in FMA 714 is dominant in Labengki Island and Tolo Bay waters.

The highest CPUE in transition period I of 11.25 fish/fishing set was found at position 125°20'68.01" E and 03°04'73".02 S, while the lowest CPUE was found at 0.71 fish/fishing set at position 122°22'51.35" E and 02°32'29".82 S. The farthest fishing position from the tuna conservation area is at 122°37'24.48" E and 02°44'49".81 S with a distance of 290.20 nautical miles while the closest fishing position from the conservation area is found at 125°60'55.33" E and 03°11'33".33 S with a distance of 83.14 nautical miles. In this transition period I, the spatial distribution of the YFT fishing area is still around Labengki Island waters. However, some fishing positions have tended to be more offshore, namely towards the western part of Buru Island and the southern part of Taliabo Island waters.

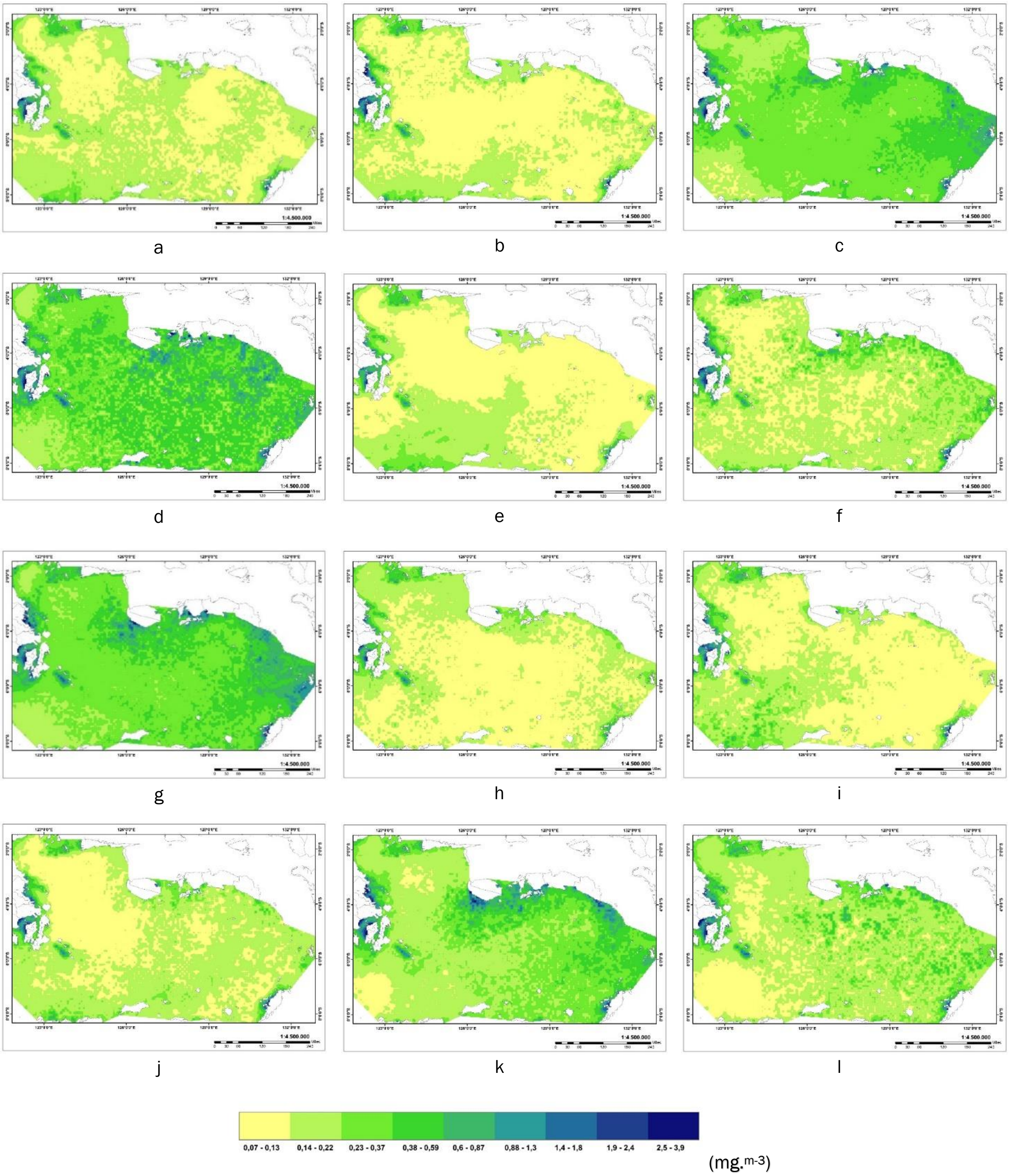


**Figure 2.** Seasonal Chl-a concentrations. 2019: (a) western monsoon, (b) transition period I, (c) eastern monsoon, (d) transition period II. 2020:(e) western monsoon, (f) transition period I, (g) eastern monsoon, (h) transition period II. 2021: (i) western monsoon, (j) transition period I, (k) eastern monsoon, (l) transition period II

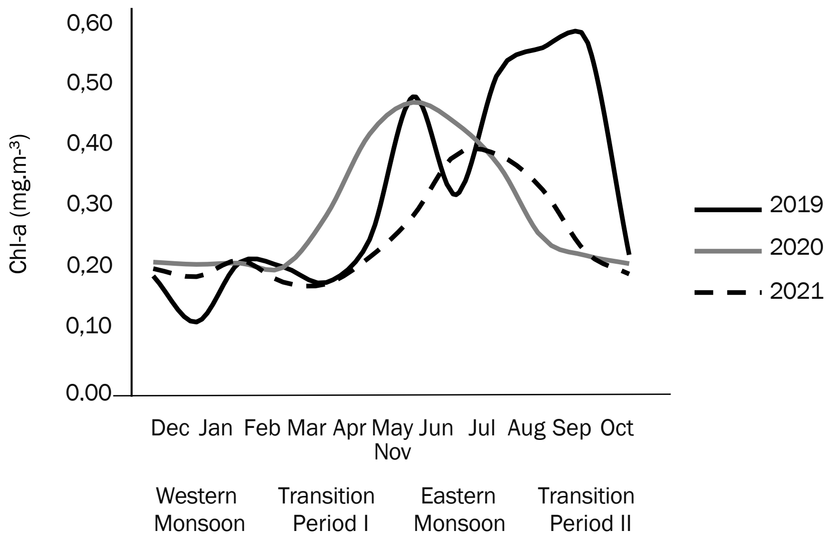


**Figure 3.** Average seasonal distribution of Chl-a concentrations 2019-2021

In the eastern monsoon period, the highest CPUE of 9.60 fish/fishing set was found at position 122°23'42.01" E and 02°19'31".21 S. At the same time, the lowest CPUE was observed at 0.36 fish/fishing set at position 122°38'21.60" E and 02°38'03".18 S. The farthest fishing position from the tuna conservation area was found at position 124°50'33.33" E and 02°17'44".17 S with a distance of 180.63 nautical miles. In contrast, the closest fishing position from the conservation area was found at 124°75'55.56" E and 03°61'88".89 S with a distance of 107.97 nautical miles. In this eastern monsoon period, the spatial distribution of YFT fishing areas in FMA 714 is still seen around the waters of Labengki Island. Although it is evident that several fishing locations have shifted towards the central region of FMA 714 waters and are approaching the conservation area, they are still located outside. The YFT fishing locations have exhibited a diverse pattern in the current season. They are more widely distributed in the southern waters of Taliabo Island and the western waters of Buru Island.

The transition period II season had the highest CPUE of 19.50 fish/fishing set found at 122°23'42.01" E and 02°19'31".20 S, while the lowest CPUE was found at 122°38'32.06" E and 02°38'31".08 S with 0.36 fish/fishing set. The three-year seasonal composite of Chl-a concentration and YFT CPUE points can be seen in Figure 4.

The farthest fishing position from the tuna conservation area is at 122°46'00.01" E and 02°48'11".10 S with a distance of 284.28 nautical miles. In comparison, the closest fishing position from the conservation area is found at 123°21'80.56" E and 02°74'66".70 S with 229.04 nautical miles. In this transition period II, the fishing position is getting further away from the waters of Labengki Island. There are no more fishing points around these waters, but the fishing position is settled and dominant in the southern part of Taliabo Island and the western part of Buru Island. The distribution of Chl-a and CPUE can be seen in Figure 5.

Based on the results of this study, it shows that YFT fishing areas in FMA 714 using pole and line tend to be concentrated in certain areas that are more productive, namely around the waters of Labengki Island, the southern part of Taliabo Island, and the northern part of Buru Island. Figures 4(a-d) indicate that the fishing grounds are at low Chl-a concentrations, and there is a tendency for high CPUE to be relatively far from tuna conservation areas.

Based on the findings of previous studies (Syahailatua *et al*., 2023), it is apparent that the Banda Sea and Seram Sea surrounding Taliabu Island and Buru Island are affected by the Indonesian Throughflow (ITF). These currently transport abundant nutrients from the Pacific Ocean to Indonesian waters and significantly contribute to the primary productivity in the area. Moreover, the findings of Farley *et al*. (2013) and Waas *et al*. (2023) indicate that the marine habitats surrounding Buru Island and Taliabu Island provide suitable conditions for tuna populations due to the presence of robust coral reefs, fluctuating sea depths, and a well-regulated aquatic environment. Furthermore, the findings of Sunoko and Huang (2014) demonstrate that the waters surrounding Buru Island and Taliabu Island exhibit a high level of tuna catch productivity compared to other locations across Indonesia.

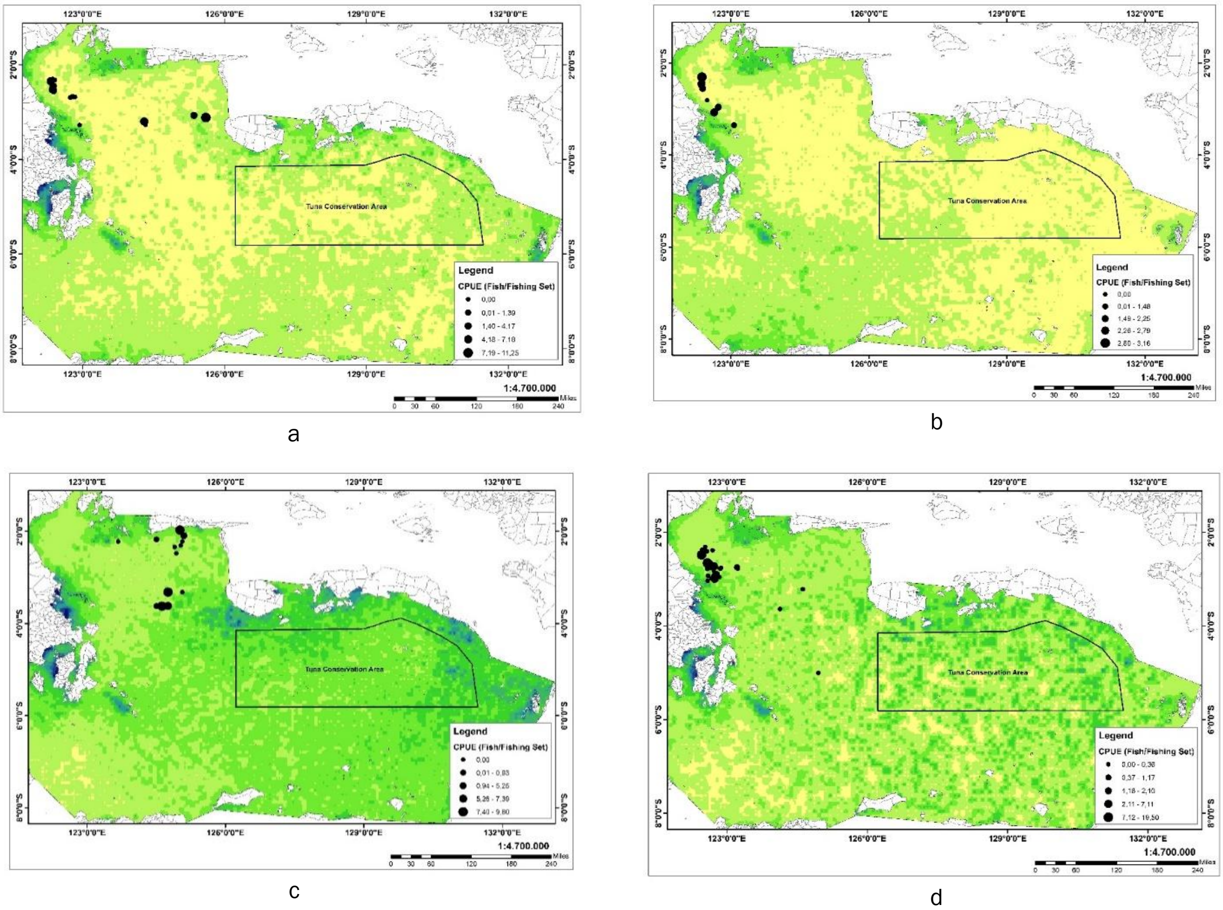


Figure 4. Composite of Chl-a concentration and point CPUE of YFT: (a) western monsoon, (b) transition period I, (c) eastern monsoon, (d) transition period II.

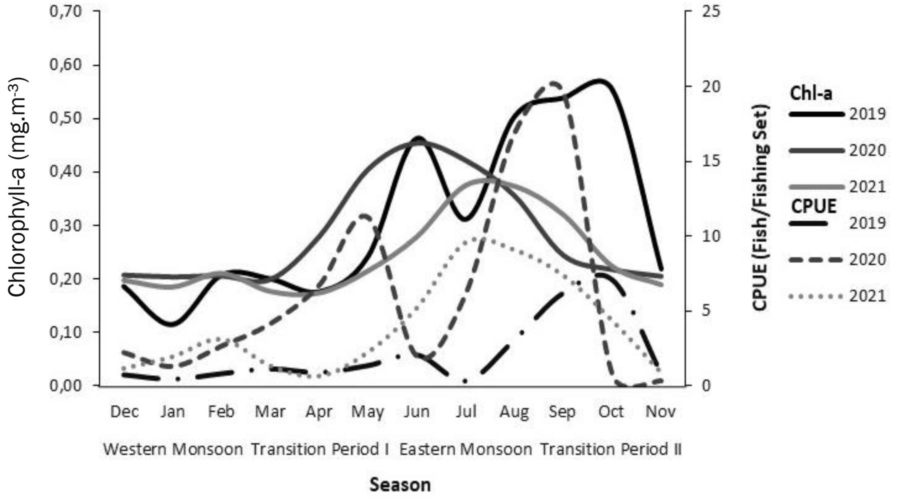


Figure 5. Average seasonal distribution of Chl-a concentrations 2019-2021

## Conclusion

This study concluded that the highest average Chl-a concentration in FMA 714 was dominated by the eastern monsoon, transition period II, transition period I, and the western monsoon period. Transition period II had the highest CPUE, 19.50 fish/fishing set, and the lowest CPUE was found in the eastern monsoon, 0.36 fish/fish set and the fishing area is in a Chl-a concentration that is not too high, and there is a tendency for high CPUE to be relatively far from the tuna conservation area

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