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Analysis of the relationship between the ENSO phenomenon, Net Primary Productivity and catches of yellowfin tuna in Sibolga Waters, Indonesia

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Abstract. *Fadhilah A, Leidonald R, Susetya IE, Dewinta AF. 2022. Analysis of the relationship between the ENSO phenomenon, Net Primary Productivity and catches of yellowfin tuna in Sibolga Waters, Indonesia. Biodiversitas 23: 4440-4447.* The eastern Indian Ocean includes the western seas off of North Sumatra. They have a high potential for catching fish, which is a measure of their degree of primary production. Numerous factors, including oceanic conditions and the El Niño Southern Oscillation (ENSO) phenomena, frequently have an impact on its potential. Additionally, ENSO has an influence on the availability of nutrients that generate chlorophyll, a component of primary production, as well as water mass. It is also responsible for anomalies of sea surface temperature (SST) that occur in the Pacific Ocean. Therefore, this study aims to determine the effect of the ENSO phenomenon on primary productivity as well as the abundance of yellowfin tuna (*Thunnus albacares*) in the western waters of North Sumatra. Data were obtained from the Aqua MODIS level 3 satellite for analysis of net primary productivity (NPP) using various parameters, namely Vertically Generalized Production Model (VGPM), Ocean Niño Index (ONI), yellowfin tuna catch, winds from ERDDAP, and currents from AVISO. Its relationship with the abundance of yellowfin tuna, and ENSO was then determined using the Pearson correlation. The VGPM calculation showed that NPP for 2016-2020 ranged from 275.169 mgC/m^2 to 994.898 mgC/m^2. The study also revealed that the ENSO phenomenon has a weak relationship with primary productivity and the abundance of yellowfin tuna with correlation values of 0.262 and -0.191, respectively.

Keywords: Abundance, El Niño, Indian Ocean, La Niña, *Thunnus albacares*, western waters of Nias Island

Abbreviations: ENSO: El Niño Southern Oscillation; NPP: net primary productivity; ONI: Ocean Niño Index; SST: sea surface temperature; VGPM: Vertically Generalized Production Model

INTRODUCTION

The eastern portion of the Indian Ocean is where the western seas of Sumatra are situated. They were included in the Fisheries Management Area of Indonesia 572, according to Indonesian Regulation Number 18 of 2014 issued by the Minister of Maritime Affairs and Fisheries (WPP-RI 572). Furthermore, the waters have a fish resource potential of 1.228 million/year, which accounts for 12% of the total resources in Indonesia, which are dominated by small pelagic fish groups (Prasetyo 2020).

Climate change affects populations, communities, and entire ecosystems, as well as the survival, growth, reproduction, recruitment, and distribution of individuals within a species (Pillai and Satheeshkumar 2013). According to Coll and Libralato (2012), these species have a substantial influence over the structure and functioning of marine ecosystems and disturbing these species - for instance, habitat alterations or overexploitation may lead to trophic cascades that affect the ecosystem's general structure. Over-capturing is proven to lead a slow growth in certain fish species (Manangkalangi et al. 2022).

The fishery products in North Sumatra are produced from Sibolga City on the west coast of Sumatra. The city has a relief area at an altitude between 0-150 meters above sea level, hence, it has a coastal area topography and fishing is the major source of livelihood. Since the bulk of the population is concentrated in the fishing industry, the city's fisheries have made good progress and are now one of the main producers of pelagic fish in the seas of west Sumatra (Nasution 2017).

Waters with high net primary productivity (NPP) produce high and abundant marine resources. It should be noted that nutrient is strongly related to the part of the primary productivity component (Setiawan and Kawamura 2011). Furthermore, productivity is strongly influenced by the presence of nutrients, light, chlorophyll-a, Photosynthetically Active Radiation (PAR), and sea surface temperature (SST). It is also influenced by oceanographic factors, such as seasons, the Indonesian traffic flow (arlindo) affecting water mass, the occurrence of mixing processes in the sea, as well as the El-Niño South Oscillation (ENSO). One aspect of climate variability related to sea surface temperature is the ENSO, where ENSO is an anomaly of sea surface temperature at the equator of the Pacific Ocean (Puryajati et al. 2021).

According to the findings, the ENSO has a greater effect on the interannual variability of total chlorophyll-a than the Indian Ocean Dipole (Sari 2018). Climate change presents an emerging challenge to the sustainable management of tuna fisheries, and robust information is essential to ensure future sustainability (Nicol et al. 2013). There are challenges in utilizing marine resources in Indonesia and one of them is environmental changes caused by ENSO phenomenon (Handayani et al. 2019). This indicates that the influence of ENSO on SST and chlorophyll-a variability only happens during the summer. As mentioned previously, the ENSO plays a significant role in enhancing the magnitude of Chl-a blooming and SST cooling but not altering their seasonal variation. During the El Niño (La Niña) event, the magnitudes of summertime Chl-a bloom and SST cooling are enhanced (reduced) by about 0.1 mg/m3 and 0.5 °C, respectively. This implies that the El Niño event is an advantage for summertime fisheries activity (Wirasatriya et al. 2017). One of the satellite images that can be used to estimate NPP in waters is the Aqua MODIS satellite with a moderate resolution imaging spectroradiometer (Aryanti et al. 2019).

The high demand for yellowfin tuna is an important economic lifeline for these communities. Unfortunately, the yellowfin population can no longer sustain the pressures of fishing. Tuna distribution and abundance are primarily determined by seawater temperature. However, detailed information on climate change and its impact on Indian Ocean tuna stocks are very sparse. Recent studies have found that tuna population dynamics are influenced by the ENSO phenomenon. The El Niño phenomenon is a great opportunity to observe and evaluate how microhabitats are changing and such changes are influencing tuna distribution. A better understanding of the relationships between the marine environments, distribution and fishing conditions can make the use of tuna resources more efficient, profitable and sustainable. However, further studies are needed to determine the role of his ENSO in tuna distribution in the Indian Ocean. Therefore, this study aims to determine the primary productivity and yellowfin tuna (*Thunnus albacares*) catches in Sibolga waters using oceanographic parameters from Aqua MODIS satellite imagery data for 2016-2020 as well as to analyze their relationship.

MATERIALS AND METHODS

Study area

This study was conducted from July to August 2021 at the Sibolga Fisheries Port (01° 43’ 12” N, 98° 47’ 44” E), Gatot Subroto st., Pondok Batu, Sarudik, Central Tapanuli District, North Sumatra Province, Indonesia.

Procedures

Data collection

Primary and secondary resources were used as records for this investigation. The major statistics came from conversations with fishermen and information on fishing grounds that were gathered from fishing vessels’ logbooks. Additionally, the observe became equipped with purse seine fishing equipment for shooting pelagic species like yellowfin tuna. The secondary data includes seizing information for every month from 2016 to 2020 from ring seines from the fishing base in PPN Sibolga. Subsequently, records on vessel loading and unloading tracking operations, in addition to auctions, have been used to decide the ring trawling trap. Then, the use of Aqua MODIS degree 3 scans downloaded from "http://oceancolor.gsfc.nasa.gov," a monthly composite of records on chlorophyll-a concentration, SST, PAR, and euphotic depth (Zeu) become compiled. The month-to-month ENSO index (ONI) from NOAA turned into retrieved from https://www.cpc.ncep.noaa.gov/facts/indices/oni.ascii.txt, in which statistics for the ENSO phenomena from January 2016 to December 2020 have been received as index values.

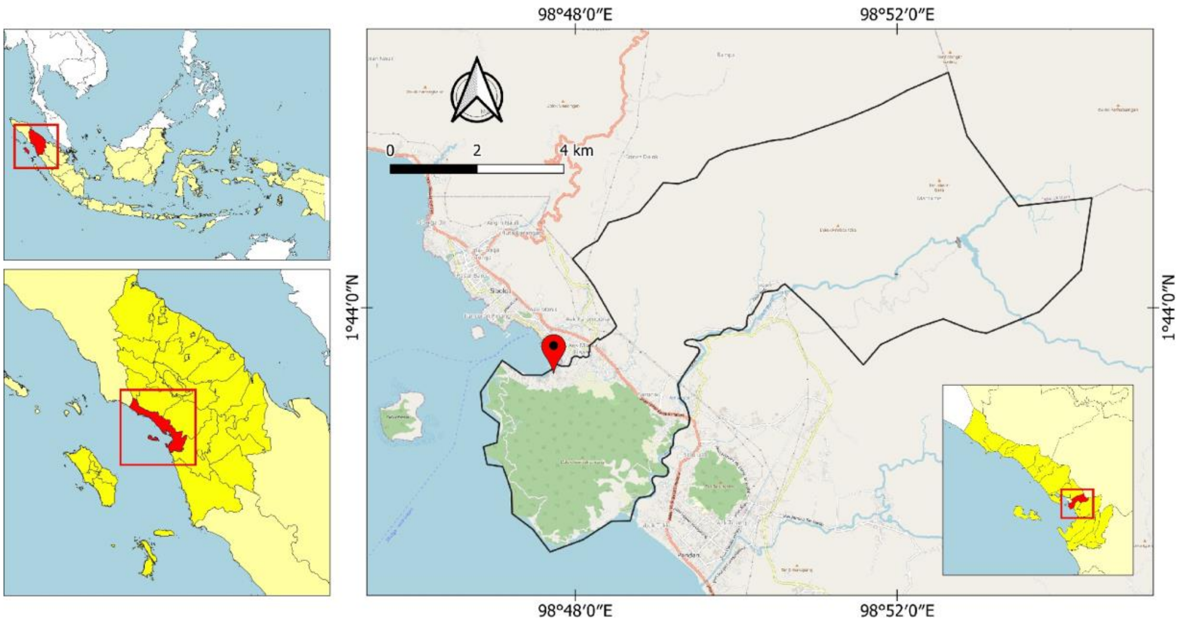

Figure 1. Study location of Sibolga Fishery Port in Central Tapanuli District, North Sumatra Province, Indonesia

Determination of observation location

The observation location was selected using the purposive sampling method by determining the point that represents the fishing area of the local fishermen.

Data analysis

Aqua MODIS satellite image data processing

Data on chlorophyll-a and SST concentrations were obtained from the monthly level composite data of the Aqua MODIS satellite images, which were recorded for 5 years (2016 - 2020), available at the National Aeronautics and Space Administration (NASA) website http://oceancolor.gsfc.nasa. Subsequently, government SST, chlorophyll-a, PAR, and Zeu data were projected back into a GeoTIFF file in the SeaDAS (SeaWiFS Data Analysis System) application for further processing using ArcMap. The ArcMap, SST, chlorophyll-a, PAR, and Zeu data were then clipped to the extent of the study location.

Primary productivity with VGPM

NPP was calculated using the Vertically Generalized Production Model (VGPM) as a function of surface chlorophyll concentration, SST, sunshine duration, PAR, and the depth of the euphotic zone estimated from the chlorophyll concentration. The VGPM equation was further developed as follows (Behrenfeld and Falkowski 1997; Hu et al. 2014):

$$PP = 0.66125 \times P^{B}{}_{opt} \times \frac{Eo}{Eo+4.1} \times C_{SAT} \times Zeu \times D_{IRR}$$

Where:

PP : Integrated daily carbon fixation from surface to euphotic zone (Zeu) (mgC/m^2/day);

PB_{Opt}: The optimal rate of daily carbon fixation occurring in the water column [mgC(mg Chl)$^{-1}$ h^{-1}]. PB_{Opt} can be modeled based on the relationship of temperature variation

Catch per Unit Effort (CPUE)

Yellowfin tuna (*T. albacares*) production/catch statistics for the five years between 2016 and 2020 were categorized based on the quantity of fish caught and fishing efforts in the form of trips using conventional fishing gear. The productivity of the gear was then calculated from the data using the Catch per Unit Effort (CPUE) analysis. The Gulland (1983) equation was then used to get the CPUE value:

$$CPUE = \frac{Ci}{fi}$$

Where:

CPUE : Total catch per fishing effort
Catch (Ci) : The catch of the i-th fishing gear (tons)
Effort (fi) : Attempt to catch in year i-th (trip)

RESULTS AND DISCUSSION

Oceanographic parameter variability in waters

The oceanographic parameters variability in the western waters of Nias Island consists of the SST and chlorophyll-a variables. SST anomaly tends to fluctuate significantly compared to the chlorophyll-a anomaly between 2016 - 2020. As seen in Figure 2, both parameters contradict with one another, indicating a negative correlation. Furthermore, positive and negative SST anomalies are often accompanied by negative and positive chlorophyll-a anomalies, respectively. The highest SST anomaly was observed in December 2020 at 1.592, while the lowest was observed in May 2018 at -2.079. The highest chlorophyll-a anomaly was observed in January 2019 at 0.0746, while the lowest was observed in November 2020 at -0.133.

SST anomaly at the end of 2016 was negative with the graph pointing downwards. Furthermore, the ONI index value for ENSO events was negative, which indicates the occurrence of a La-Niña phase, which had an impact on the warming of SST (on an average 30.60 °C in 2016). This finding is consistent with Jamili (2018) which linked a positive anomaly with the occurrence of EL-Niño. The La-Niña phenomenon was indicated by the negative SST anomaly in the Niño 3.4 zone.

The graph also showed that the minimum SST and the maximum chlorophyll-a value indicated the occurrence of upwelling and El Niño phenomena in 2019. The ONI index in 2019 was positive, which implies that there was an El Niño phase. During that phase climatic anomalies in the Indian Ocean in the form of El-Nino-La-Nina and Dipole Mode (positive/negative) affect the dynamics of oceanographic parameters such as SST, upwelling intensity and chlorophyll-a enrichment (Amri et al. 2013) and in this study a clear disparity is seen. The difference in the value of the distribution of these parameters (Figure 2). Such conditions also affect the distribution and abundance of small pelagic fish resources in southern Java (Hendiarti 2008); as well as fluctuations in catches of bigeye tuna (Syamsuddin et al. 2013); and the composition of neritic tuna catch (Amri and Satria 2013). Climatic anomalies in the Indian Ocean in the form of El-Nino-La-Nina and Dipole Mode (positive/negative) affect the dynamics of oceanographic parameters such as SST, upwelling intensity and chlorophyll-a enrichment. (Amri et al. 2013) and in this study, it is clear that the disparity in the value of the distribution of these parameters is clear (Figure 2). Such conditions also affect the distribution and abundance of small pelagic fish as well as fluctuations in catches of bigeye tuna (Syamsuddin et al. 2013); and the composition of the type of neritic tuna catch (Amri and Satria 2013). The inter-annual variability of the entire chlorophyll-a is strongly stimulated by using ENSO rather than the Indian Ocean Dipole (Sari 2018).

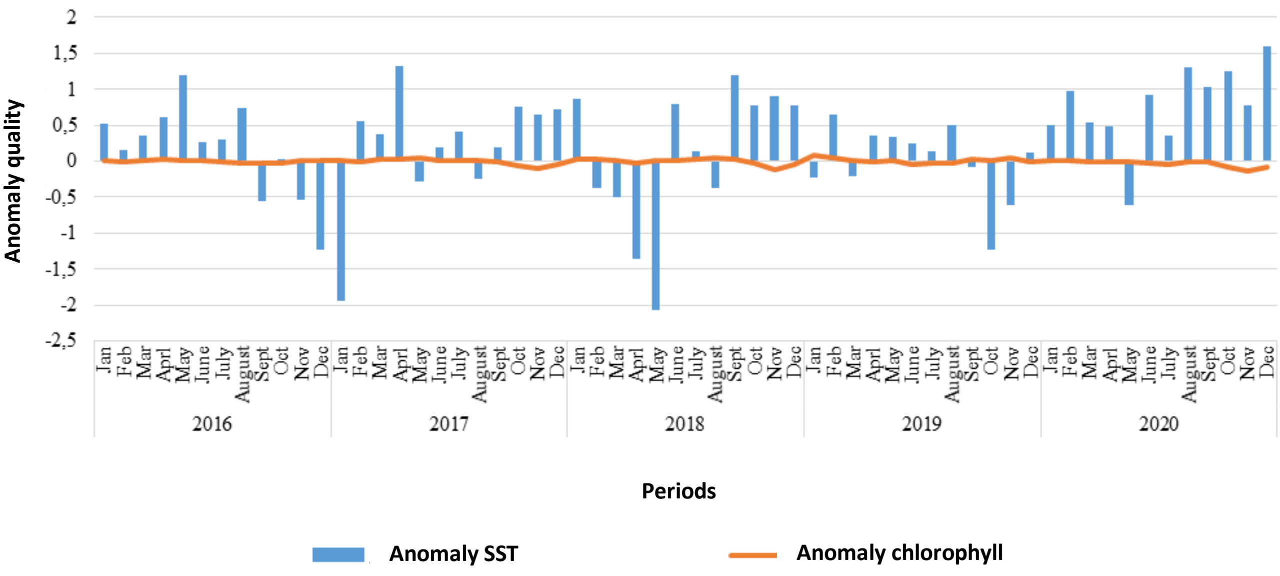

Figure 2. Anomalies of SST and Chlorophyll-a in the western waters of Nias Island during 2016-2020

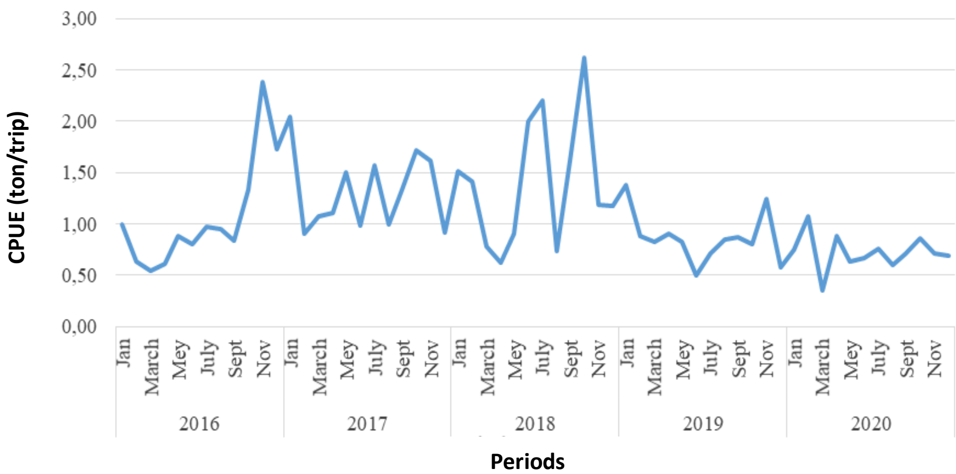

Figure 3. Net Primary Productivity (NPP) in the western waters of Nias Island during 2016-2020

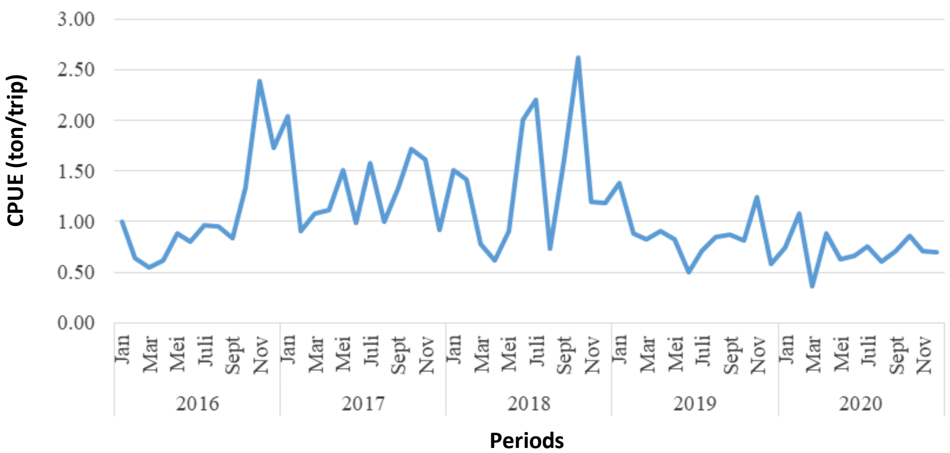

Figure 4. Seasonal trend of yellowfin tuna (*Thunnus albacares*) CPUE Fluctuations during 2016-2020 at the Sibolga Nusantara Fisheries Port

Net Primary Productivity (NPP) west waters of Nias

NPP value for the western waters of Nias Island in 2016-2020 was calculated with the VGPM (Vertically Generalized Production Model) formula developed by Behrenfeld and Falkowski (1997). Furthermore, the data used were obtained from the analysis of Aqua MODIS satellite imagery in the form of SST data, chlorophyll-a concentration, PAR, and euphotic depth data (Zeu). The NPP value in the area ranged from 306,679 MgC/m^2 to 573,718 MgC/m^2. The highest annual NPP value of 431.519 MgC/m^2 was recorded in November 2016, while the lowest value of 348.348 MgC/m^2 was obtained in August 2020. These values were found to fluctuate every year, and they were influenced by oceanography and several other factors. The SST parameters and chlorophyll-a from the waters also affected the rate of primary productivity (Nuzapril et al. 2019). Kemili and Putri (2012) reported that the average NPP of Indonesian waters increases every year.

Figure 3 revealed that the primary productivity value tends to fluctuate every year. The highest NPP between 2016-2020 in the western waters of Nias Island occurred in November 2019, while the lowest value was recorded in July 2020. These values were calculated with the secondary data obtained from the Aqua MODIS satellite image. The data were collected in the form of chlorophyll-a concentration, SST, PAR, as well as the euphotic depth, which represents the areas that sunlight can penetrate to enable phytoplankton to carry out photosynthesis. This finding is consistent with Aryanti et al. (2019) that NPP in waters is strongly influenced by the presence of nutrient factors, light, chlorophyll-a, PAR, and SST.

The average value of chlorophyll-a concentration was low because some satellite image data were covered by clouds. Furthermore, the satellite sensors were not able to detect the concentration up to a light penetration depth of 1%, hence, the value obtained does not fully represent the area's NPP. This is in line with Nuzapril et al. (2017) that one of the problems faced during imaging is the inability of the satellite sensors to detect beyond sea level depth. The surface concentration obtained can only account for approximately 30% of the primary productivity of the sea, while NPP spanned 4.6 times the attenuation/ compensation depth.

CPUE yellowfin tuna (*Thunnus albacares*)

Figure 4 shows the overall catch per unit effort of yellowfin tuna (*T. albacares*) obtained for 5 years (2016-2020) at the Sibolga Nusantara Fisheries Port, which tends to fluctuate every month. The recorded CPUE value (*T. albacares*) ranged from 0.358 tons/trip in March 2020 to 2.625 tons/trip in September 2018, and the highest 5 years average value of 1.323 tons/trip was obtained during the transitional season II (September, October, and November).

Relationship between ENSO index, NPP, and catch of yellowfin tuna (*Thunnus albacares*)

Analysis of the relationship between the ENSO index, NPP, and catch of yellowfin tuna (*T. albacares*) was carried out using the Pearson correlation analysis. Table 1 shows the correlation values of the three parameters.

Relationship between ENSO and Catch

The catch of yellowfin tuna at PPN Sibolga has a very low correlation with the effect of ENSO. A low correlation value of -0.191 was obtained along with a significance of 0.143, which indicates that the values were greater than the 5% significance level, indicating the lack of a link between the two variables. The relationship between ENSO and catch has been demonstrated in Figure 5.

Figure 5 shows that there is a positive correlation between the ENSO phenomenon and the catch of yellowfin tuna (*T. albacares*) where a decrease in the ENSO index is accompanied by a decrease in the number of catches. Furthermore, the negative directional decrease in the index indicates the occurrence of a weak La Niña phenomenon. The distribution of the foremost market tuna species, populace, and recruitment of the tuna inventory is motivated with the aid of the ENSO variability and modifications in oceanic parameters such as sea surface temperature, salinity and DO (dissolved oxygen). But, as those species are greater widely disbursed and feature extended spawning grounds in both east and the western Indian Ocean, the connection with ENSO is more complicated (Pillai and Satheeshkumar 2013).

In the La Niña phase, there was a decrease in the concentration of chlorophyll, which led to the occurrence of a low NPP value. The low NPP in turn, led to a decrease in the number of fish catches in 2017 with a total volume of 953.3 tons when the phase lasted for the most part of the year. This finding is in line with Aryanti et al. (2019) that an increase in the La Niña value is often accompanied by a decrease in NPP and this decrease causes an inadequate supply of chlorophyll, which leads to a reduction in fish catches. Current observations of ENSO have proven that the Indian Ocean is continuously heating and its warm pool is increasing, mainly within the current period (Achuthavarier et al. 2012). Kumar et al. (2014) have highlighted the need for a detailed investigation of the position of ENSO within the distribution of Tunas inside the Indian Ocean.

Relationship between NPP and Catch

Table 1 shows the result of the Pearson correlation analysis, which revealed that there was a strong correlation between NPP and catch with a value of 0.605. This finding indicates that NPP was positively related to the number of yellowfin tuna (*T. albacares*) caught between 2016-2020. A significance value of 0.000 (< 0.05) was obtained, which revealed that there is a relationship between both parameters. Furthermore, the graph of their relationship tends to be unidirectional and directly proportional, but some were not in the same direction. The graph level gap was assumed to be related to the small coverage and fishing areas outside the study location. It is also related to the fishermen's social factors as well as the water's oceanography, such as currents and winds. Chlorophyll-a is a component or proxy for primary productivity, and it has a strong and linear relationship with fish catches. Howell et al. (2013) reported that climate change, as well as a 10% decrease in the NPP of the total ecosystem biomass, affected the low trophic levels.

Table 1. Relationship between ENSO Index, NPP and yellowfin tuna (*Thunnus albacares*) catch

Correlation table				
		ENSO Index	**Net Primary Productivity (mg/m^3)**	**Catch of yellowfin tuna (tons)**
ENSO Index	*Pearson Correlation*	1	0.262	-0.191**
	Sig. (2-*tailed*)		0.043	0.143
	N	60	60	60
Primary Productivity (mg/m^3)	*Pearson Correlation*	0.262	1	0.605**
	Sig. (2-*tailed*)	0.043		0.000
	N	60	60	60
Catch (tons)	*Pearson Correlation*	-0.191**	0.605**	1
	Sig. (2-*tailed*)	0.143	0.000	
	N	60	60	60

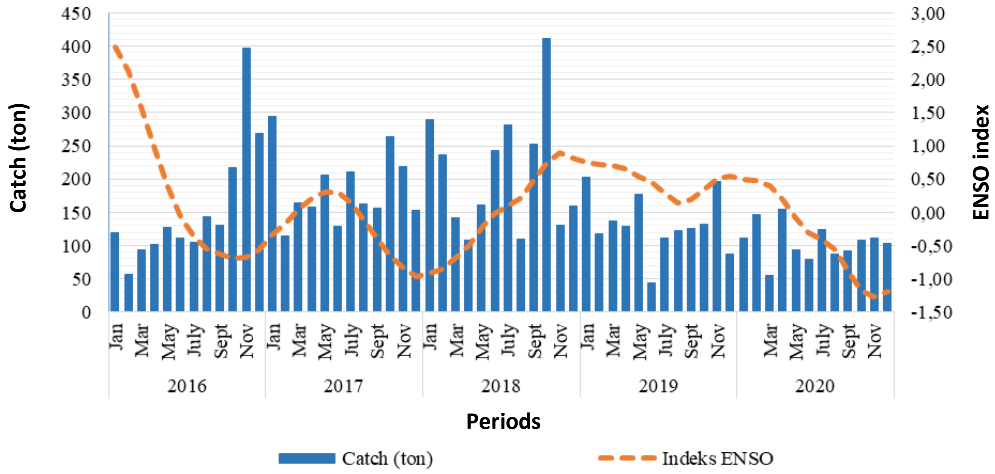

Figure 5. Relationship between ENSO Index and Catch of yellowfin tuna during 2016-2020

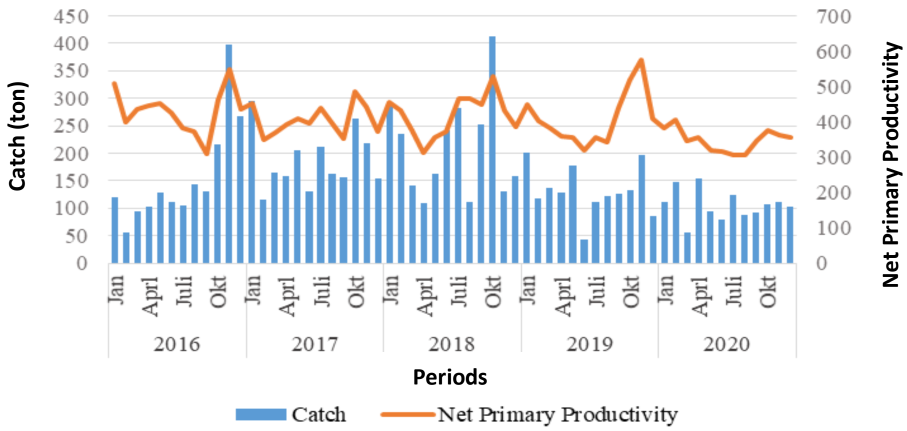

Figure 6. Relationship of Net Primary Productivity (NPP) with catches of yellowfin tuna

Discussion

Based on oceanographic characteristics from Aqua MODIS satellite imagery data, from the current study for the dynamics of net primary productivity in Sibolga seas at yellowfin tuna (*T. albacares*) fishing locations during the period of 2016-2020 showed that the lowest NPP in September 2016 and the maximum NPP in November 2019. Measurement of primary productivity is a basic requirement for studying the structure and function of aquatic ecosystems (Tamire and Mengistou 2014; Xiao et al. 2015). In other words, water productivity can also be used in water resource management and water quality monitoring (Zhang and Han 2015; Mercado-Santana et al. 2017). In relation to fish production (stock) and aquaculture, it is important to study aquatic productivity (Rahayu et al. 2017; Mercado-Santana et al. 2017; Chen et al. 2017).

During the said period, the ENSO phenomenon was found to weakly affect the catch of yellowfin tuna in the western waters of Nias Island. This was because the phenomenon itself occurred in the Eastern Pacific Ocean, while the study was conducted in the Eastern Indian Ocean. This is in line with Khasanah and Sastra (2017) that ENSO affected the water condition in the Indian Ocean. The El-Niño phenomena, which caused a decline in the water conditions, made this influence clear and it was also evident when water conditions improved during the occurrence of the La-Niña phenomena. This oceanic feature may be used to anticipate (a few months ahead of the tuna forecast) the location of the greatest tuna abundance within the tuna fishing ground extending across the Indian Ocean.

The value of primary productivity in Sibolga waters (west waters of Nias Islands) in yellowfin tuna (*T. albacares*) catching areas based on oceanographic parameters from Aqua MODIS satellite imagery data in 2016-2020 obtained the lowest NPP value occurred in September 2016 and the highest NPP occurred in November 2019. Though the ENSO phenomenon had an influence on the primary productivity of waters and the abundance of yellowfin tuna, the correlation value between the ENSO index, net primary productivity and abundance of yellowfin tuna was found to be weak. The management of tuna resources should be more effective, lucrative, and sustainable with a better knowledge of the interactions between ocean environments, distribution, and fishing conditions. However, a detailed long-term investigation is needed to examine the relationship between ENSO, NPP and the distribution of Tuna inside the Indian Ocean.

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