Yellowfin Tuna Fishing Dynamic During Low IOD Positive and Negative at Eastern Indian Ocean; Study Case at Western Waters of Sumatera

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Abstract: Effect of Indian Ocean Dipole (IOD) was highly significant on term of environments parameter variabilities at the Indian Ocean. Variation in the abundance and distribution of yellowfin tuna have been well known associated with environment parameters that drive by large-scale climatic indices such us Indian Ocean Dipole. To better understanding on yellowfin tuna fishing activities at the Western waters of Sumatera, we investigated hand line fishing catch during 2016 and 2017 as the IOD negative and positive events representation. Our result showed significant different fishing variabilities between year with negative and positive indices. Mean annual yellowfin tuna catch significantly higher during positive IOD both of abundance and weight, following by mean annual catch per unit effort (CPUE). During positive IOD hand line fishing trips were significantly lower compare than negative IOD. We also evaluated the geographic distribution of hand line fishing activities, we found that fishing activities cover significant wider area during positive IOD. In the opposite, during negative IOD yellowfin tuna fishing activities became centralized. This study gave us new perception on large-scale climatic events effect on yellowfin tuna fishing activities at a narrow study area.

1. Introduction
Population abundances and distribution of many species has been reported that affected by climatic oscillations, anomalies and change. Climatic events also affect many ecological processes in marine ecosystem that alternate natural process of species distribution [1, 2, 3]. Yellowfin tuna is one of large pelagic fish species that has oceanic migration path (highly migratory species), distributed over the Atlantic, Indian and Pacific Oceans [4]. Yellowfin tuna that one of important pelagic tuna species have been observed that clearly linked to large-scale climatic events such as El Nino Southern Oscillation (ENSO) at the Pacific Ocean [5] and Indian Ocean Dipole at Indian Ocean [3].

Large-scale climatic event which happen at Indian Ocean called with Indian Ocean Dipole (IOD), driven mostly by inter-annual variability pattern in sea-surface and subsurface temperatures that produce an alteration of wind and precipitation anomalies at two mainland which are Australia and Asia [6]. During positive phase of IOD anomalous upwelling occur along the Sumatera-java Coast (mostly at the South Java Sea) that enhance cooling sea surface temperatures in the eastern Indian Ocean including west Sumatera Waters and south Java Sea. Decreasing of SST coincidence with a westward wind anomaly that occur along equator, it pushed the thermocline deeper and warmer SST in the western Indian Ocean [6, 7, 8, 9]. Warmer SST and deeper MLD at the west part associated with increasing primary productivity in the east as a result of eventual upwelling and shallower MLD. Some of IOD events were coincided with ENSO events at the pacific ocean [10], but not all IOD events co-occurred with the ENSO events [11, 9].

Yellowfin tuna catch rate at Indian Ocean has been associated with IOD, it was observed to be negatively correlated with a periodicity center around 4 years. During IOD
positive, SST became higher, primary production was lower, CPUE decreased and the
distributions were restricted to the western and northern of the West Indian Ocean [3].
Negative IOD events has different impact with positive IOD, lower SST and higher primary
production associated with higher CPUE mostly at the Arabian Sea and Madagascar Sea [3].
Thus, large scale climatic events mostly studied at the west part of Indian Ocean. There are
no clear information regarding the impact of IOD event on yellowfin tuna at the eastern
Indian Ocean especially at the west Sumatera Waters as a local part of eastern Indian Ocean.

The purpose of this study is to understand how the IOD events associate to environment
variables that linked to the yellowfin tuna abundance. This study also to observe the
relationship of yellowfin tuna distribution to the environment parameters during different
IOD events. Thus, it will improve our understanding regarding yellowfin tuna habitat
preferences during different IOD events. It will helpful to add information on large scale
climatic oscillations impact to yellowfin tuna abundance on local spatial scale such as west
Sumatera Waters.

2. Material and Method

2.1. Study Area

![Figure 1. The Study Area of Eastern Indian Ocean (Western Waters of Sumatera)](image)

Our study area was at western waters of Sumatera (WWS) which is located in the Eastern
Hindian Ocean (Figure 1). Western waters of Sumatera in Indonesia also included in Wilayah
Pengelolaan Perikanan Republik Indonesia (WPP-RJ) 572 which is part of Indian Ocean
Tuna Commission (IOTC) competence area. Characteristically, WWS affected by Indonesian
through flow (ITF) through Sunda Strait [12, 11]. Nutrient transfer at WWS highly affected
by South Java Current (SJC) that flow through at tropical Indian Ocean along west coast of
Sumatera, south of Java, cross the Sawu sea until Ombay strait [13]. Nutrient variability is
also strongly influenced by oceanographic events such as Indian Ocean Dipole (IOD) which
drains water masses from the Bay of Bengal in the southwest of the Indian Ocean towards
the west coast of Sumatra [14]. Other main of water circulation that happen at this AOI South
Equatorial Current (SEC) which transported low salinity water from the east and recirculated
westward at East Gyral Current (EGC) [12].
2.2. Data Collection

Yellowfin tuna fishing data collected from daily hand line fishermen’s logbooks and organized into a spatial database. The data collected from 2016 to 2017 which based at Bungus fishing port. Environment dataset also collected within fishing data time line that use to assess the relationship of yellowfin tuna distribution with environment variables. We performed six environment variables to more understand the interaction among them to the yellowfin tuna distribution and preferences. Those six environment variables including the sources namely sea surface temperature (SST), sea surface height (SSH), mix layer depth (MLD) and sea surface salinity (SSS) that we compiled from open access data website http://marine.copernicus.eu and extracted from Global ARMOR 3D L4 dataset by monthly basis and has 0.25°x0.25° spatial resolution. Chlorophyll-a concentration dataset we compiled from the same source but extracted from different dataset which is PISCES biogeochemical model dataset by monthly basis with 0.25°x0.25° grid. We also performed bathymetry data from https://www.gebco.net which gridded bathymetry model dataset with 15 arc-second grid spatial resolution.

2.3. Data Analysis

Data management aimed to compile the dataset based on specific fishing catch and fishing fleet which are yellowfin tuna and/or hand line fishing fleets. We also applied spatial filtering on the fishing position data based on following criterions: a. excluded fishing points that overlapped with land; b. excluded fishing points at the coastal waters; and c. exclude fishing points which out from area of interest. We used the dataset to calculate Catch per Unit Effort (CPUE) that represent of fish abundance per fishing effort. We performed the CPUE calculation using approach that explained by [15, 16]:

$$ CPUE = \frac{Catch_i}{Effort_i} = 1,2,3 \ldots n \quad (1) $$

Where:

- CPUE = Catch per unit effort (kg and/or weight per day) day-1
- Catch$_i$ = Catch (kg and/or weight) day-1
- Effort$_i$ = fishing effort (days) day-1

The calculation of the geographical distribution was carried out using the GIS-based model to determine 4 spatial indicators, namely central tendency, spatial dispersion, directional dispersion, and directional trends [17, 18, 19]. The central tendency is the geographical center distribution of the yellowfin tuna catch data, or the average x and y coordinates of the total coordinates in the study area. The alteration of central tendency reflects variations in the distribution of fishing activity both spatially and temporally. The spatial dispersion is representing the area of spatial concentration and distribution of the coordinates around the central tendency. Directional dispersion and directional trend were calculated using the "standard deviational ellipses tool". The directional distribution calculated the standard distance from the direction of the x and y coordinates distributions that were represented by oval visualization containing 95% of the total data input. In general, the description of the spatial indicators used in this study is shown in Table 1.
Table 1. Spatial indicators used in this study

| Spatial Indicators         | Equations                                                                 | Spatial Scale | Time Scale | Ecological Explanation                      |
|----------------------------|---------------------------------------------------------------------------|---------------|------------|---------------------------------------------|
| Central Tendency           | \( \bar{X} = \frac{1}{n} \sum_{i=1}^{n} X_i \) \( \bar{Y} = \frac{1}{n} \sum_{i=1}^{n} Y_i \) | Global        | Annual     | Centre of the fishing fleet concentration   |
| Spatial Dispersion         | \( SD = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (X_i - \bar{X})^2} \) \( SD = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (Y_i - \bar{Y})^2} \) | Global        | Annual     | Spatial dispersion of lights fishing fleets |
| Directional Dispersion     | \( SD_x = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2} \) \( SD_y = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \bar{y})^2} \) | Global        | Annual     | Directional distribution of \( x \) and \( y \) axis |
| Directional Trend          | \( \tan \theta = \frac{A + B}{C} \)                                      | Global        | Annual     | Directional tendency of light fishing fleets spatial distribution |
| Catch Per Unit Effort density | \( CPUE = \frac{\sum_{i=1}^{n} (\text{N or kg})}{\sum_{i=1}^{n} \text{(days and CPUE analysis per 4 km²)}} \) | Global        | Annual     | Fishing catch (N or kg), effort (days and CPUE analysis per 4 km²) |

Source: [17, 18, 19].

Furthermore, directional trends were the calculation of degree \( A, B, \) and \( C \). Clear brief of this equation explained as follow:

\[
A = \left( \sum_{i=1}^{n} \bar{x}_i^2 - \sum_{i=1}^{n} \bar{y}_i^2 \right) \quad B = \left( \sum_{i=1}^{n} \bar{x}_i^2 - \sum_{i=1}^{n} \bar{y}_i^2 \right)^2 + 4 \left( \sum_{i=1}^{n} \bar{x}_i \bar{y}_i \right)^2 \quad C = 2 \sum_{i=1}^{n} \bar{x}_i \bar{y}_i
\]

\( \bar{x}_i \) and \( \bar{y}_i \) are the deviations for the \( x \)-\( y \) coordinates from the mean center calculation.

Environment parameters data extracted at the fishing points by performing a tools “extract value to point” at the GIS platform, this data prepared as the data input on GAM model. Daily fishing points data used as the basis for oceanographic parameters data extraction on monthly scale. This dataset was the main data on building correlation between fish abundance (CPUE) and oceanographic parameters, at the end smoothing curve was the final result to determine the habitat preferences of yellowfin tuna at the different fishing years which are 2016 and 2017. GAM formula that carried by mgcv package (https://cran.r-project.org/web/packages/mgcv/index.html) at R platform gave us a practical solution on linked the environment parameters with the yellowfin tuna abundance.

Generalized Additive Model established by Hastie and Tibshirani in 1986 [20]. GAM is the expansion of additive model by modelling \( y \) as univariate additive function from free variables. Specifically, GAM using the smoothing curve factor to build relationship model between independence variable (fish abundance or CPUE) and dependence variables (oceanographic parameters) [21]. Prediction variable selection process are based on lowest Akaike’s Information Criterion (AIC) values, deviance explained and the highest confidence level (\( p\)-value \( < 0.05 \)) from each builded model [22]. Basic formulation of GAM from mgcv packages “predict gam” as follow:

\[
y = e + s(SST) + s(Chl-a) + s(SSH) + s(SSS) + s(MLD) + s(bathymetry) + ....s(n(xn))
\]

Fishing catch which represented as CPUE expressed as \( y \) at the equations above, \( e \) is random error and \( xn \) is the explanatory variables that drive the fishing abundance that expressed as CPUE. Spline smooth factor on each predictor variables expressed as \( s \), this smooth factor has bigger impact to explain the relationship on fish abundance and explanatory variables. The best model selected based on the best \( p\)-value and Akaike
Information Criterion (AIC) value. Predictor variables considered as a significance variance explanatory of CPUE if residual value and AIC value decrease as additional of total predictor variables were used. Final probability shall be lower than 0.01 \((p\text{-value} < 0.01)\) \([23, 24, 25, 26, 18]\).

To better understand on distinguish of the IOD event on fishing activities between different years at the study area, we performed unpaired two samples Wilcoxon test to our two population data which were 2016 and 2017 dataset. This test was performed due to non-normally distributed on the dataset. We used 0.05 of significant level as the base line of accepting the assumption. When the \(p\text{-value}\) higher than 0.05 it considering there are no significance different between the populations and vice versa.

3. Result and Discussion

3.1. Fishing Activities Analysis

Climatic event seem to have significant impact to the fishing dynamic on high spatial location such us Indian Ocean. \([3]\) has been studied the effect of IOD event to the yellowfin tuna fishing activities in the Indian ocean, particularly at the western Indian Ocean. His study found that during positive IOD events, SST and primary productivity associated with the decreasing CPUE. Inversely, during the negative IOD events SST and primary productivity supported to the higher CPUE. The annual yellowfin tuna fishing activities guide us to understand what exactly the impact of the year with the significant negative IOD events and year with the positive IOD events. Yellowfin tuna fishing catch (kg) found that not significant different between two year which are 2016 with mean annual value 113.4 ± 89.19 kg and 2017 with mean annual value 123.35 ± 108.16 kg. Number of catch at 2017 were significantly higher with mean annual value almost 2 times higher (3.57 ± 5.29) compare than 2016 with mean annual value only 2.82 ± 1.97.

![Figure 2. Annual yellowfin tuna fishing activities data variations during 2016 and 2017](image)

Fishing catch data during these two years (2016 and 2017) revealed the fact that IOD events seem to have impact to the yellowfin tuna distribution at the study area. We suspect that there is possibility during 2016 and 2017 yellowfin tuna with different certain size was dominated at these location. In 2017 with the number of catch almost two times higher, we found the mean annual weight of catch were not significantly higher. It could be mean that fish with smaller size dominantly distributed in the study area. This can be reasonable
considering yellowfin tuna was migrate by the same age of schooling [27, 28]. During negative IOD such as 2016, SST became warmer at the east part of the Indian Ocean, this condition is ideal for bigger fish during the spawning period. It also consider that WWS is quite protect water area that will support to provide comfortable spawning ground for yellowfin tuna.

Mean Annual fishing trip shown that during negative IOD events the fishing trip were significantly higher compare that with the year with positive IOD events. During 2016 (negative IOD) fishing trip almost 2 times higher (42.88 ± 22.4 days) compare that in the 2017 with the mean annual fishing trip of 28.44 ± 21.02 days. Those data gave us an information that during negative IOD events yellowfin tuna fisherman has been experienced hard fishing season. Long period fishing at the sea and the low fishing catch were enough to justify that during negative IOD events became hard fishing season. Hard fishing season push more effort to the fisherman to get more fishing catch from the sea.

Catch per unit effort also shown same trend with the fishing trip, CPUE both by the number of catch and by weight during positive IOD events has significantly higher compare that during negative IOD event. Mean annual value of CPUE by number of catch in 2016 was 0.066 ± 2.41, it was 2 times lower compare that in the 2017 with the mean value 0.126 ± 2.92. Likewise, CPUE by weight of catch in the 2016 gives mean value 2.644 ± 0.06 and also two times lower compare than in the 2017 that has mean value 4.337 ± 0.16. All those numbers clearly compile and shown at the Table 1 and Figure 1 respectively. Catch per unit effort as the abundance and fishing productivity indicator shown clearly that year with the positive IOD could be declared more productive in term of fishing productivity and abundance compare than years with negative IOD events.

| Year | Catch (N) | Catch (Kg) | Trip (T) | CPUE (N) | CPUE (Kg) |
|------|-----------|------------|----------|---------|----------|
| 2016 | 2.82 ± 1.97<sup>a</sup> | 113.4 ± 89.19<sup>a</sup> | 42.88 ± 22.4<sup>a</sup> | 0.066 ± 2.41<sup>a</sup> | 2.644 ± 0.06<sup>a</sup> |
| 2017 | 3.57 ± 5.29<sup>b</sup> | 123.35 ± 108.16<sup>b</sup> | 28.44 ± 21.02<sup>b</sup> | 0.126 ± 2.92<sup>b</sup> | 4.337 ± 0.16<sup>b</sup> |

Note: different letters in the table indicate a significant difference

Dipole Mode Index has shown a significant negative IOD events pattern during 2016 and insignificants positive IOD events during 2017. Catch per unit effort seem to have a correlation to the IOD. Lowest IOD event during 2016 to 2017 found at July 2016 (-1.18) and coincidence with the CPUE as high as 2.14 kg days<sup>-1</sup>. The highest DMI monitored at August 2017 that coincidence with significant high value of CPUE, the value of DMI and CPUE at August 2017 were 0.3 and 4.36 kg days<sup>-1</sup> respectively. Linier correlation on DMI and CPUE was performed to identify more clear how the DMI impact on the fish abundance and fishing productivity. Due to the limited dataset (n=24) linier fit on DMI and CPUE shown low r<sup>2</sup> = 0.0706, nevertheless it still proper to justify how the DMI act to the CPUE, from those linier fitting we observed that CPUE were increase as increasing of DMI at the study area. This information could be really important as the preliminary study how the IOD events effect on yellowfin tuna fishing dynamic on a local study area especially WWS. Time series DMI and CPUE and linier fit both of them clearly shown at the Figure 3.
3.2. Spatial Distribution Analysis

The pattern of spatial fishing catches points, days at sea and CPUE were observed accumulated at the certain study area, dominant distribution location is in Mentawai strait and in the off west coast of Sipora island. Mentawai strait and Mentawai surrounding waters has been known as the traditional tuna fishing ground for the local fishermen that dominantly home based at the three closest fishing port which are Bungus fishing port in west Sumatera, Sibolga fishing port in north Sumatera and Nizam Zachman fishing port in Jakarta [19]. Sum of total catch (kg \(4 \text{ km}^{-2}\)) in 2016 has minimum and maximum range between 13 to 1.681 kg \(4 \text{ km}^{-2}\) respectively, those number were significantly lower compare to 2017 that has minimum and maximum range value between 20 to 3.327 kg \(4 \text{ km}^{-2}\). Different thing on total effort (days per \(4 \text{ km}^{-2}\)), spatially 2017 has significant lower range of value which are around 4 to 592 days at sea per \(4 \text{ km}^{-2}\) but has double significant higher of CPUE value in range between 0 to 131 kg per days. The total effort in 2016 became 2 times higher than 2017 which is around 7 to 1.067 days per \(4 \text{ km}^{-2}\) but almost 2 times lower in CPUE that has value in between 0 to 59 kg per days per \(4 \text{ km}^{-2}\).

This spatial variation shows to us how the IOD event both of positive and negative affected to the fishing dynamic especially in yellowfin tuna. Spatially in 2016 fishing activities dominantly accumulated at the Mentawai strait and the western part of Sipora island, but during 2017 fishing activities became less accumulated in the west part of Sipora island. Fishing activities in 2017 centralized at the Mentawai strait that became most productive fishing area and has the highest abundance of fish during year with positive IOD events. Figure 4 revealed the fact that fishing activities in WWS has been affected not only on term of temporal productivity but also on spatial distribution. Change on the spatial distribution could be an indicator and sign on how fishing activities reacted to the environmental condition alteration during different climatic event such as IOD events. Spatial distribution of fishing activities at WWS during 2016 and 2017 clearly explained at the Figure 4. To get more understanding on how the IOD events impacted to the yellowfin tuna fishing activities spatially and quantitatively. We employed some spatial indicator to calculate geographical distribution of fishing activities in the study area, technically this calculation base on previous study that have been done by [18, 19, 17].
Figure 4. Spatial distribution of catches (kg per 4 km²), total effort (days at sea per 4 km²), and CPUE (kg days⁻¹ per 4 km²) during 2016 and 2017

Figure 5 shows the distribution of yellowfin tuna catches (red dots) in 2016 and 2017 with spatial indicators such as spatial dispersion (circle), directional dispersion x and y (ellipse) and directional trends. In the 2017 fishing activities monitored covered widest distribution compare than 2016. Spatial dispersion value in 2016 was 86.88 km that seem significantly lower compare than in 2017 that has value of spatial distribution 148.43 km. Directional dispersion on longitude (x) in 2016 has higher value compare that in 2017, but not directional dispersion on y where in 2016 the value was lower than in 2017. Directional trend in 2016 was 117.45 degrees and in 2017 was 75.85 degrees, these trend represent the rotation of spatial and directional dispersion in the study area. During 2017 fishing season it seem the fishermen explored wider area in the WWS that cause wider distribution, it also indicate that fishing activity became more dynamic in term of spatial distribution. Table 3 and figure 5 clearly exposed the value of spatial indicator of geographical distribution both temporally and spatially.

Table 3. Geographic distribution indicator values in 2016 & 2017

| Year | Spatial Dispersion | Directional Dispersion (x) | Directional Dispersion (y) | Directional Trends (°) |
|------|--------------------|---------------------------|---------------------------|------------------------|
| 2016 | 86.88              | 94.73                     | 78.24                     | 117.45                 |
| 2017 | 148.43             | 86.22                     | 191.38                    | 75.85                  |

The results of this study show that temporal and spatial distributions of yellowfin tuna hand line catches are linked to climatic oscillations in the Indian Ocean. Previous study has been reported on relationship of yellowfin tuna to the fish abundance. Catch rates increased in association with decreases in SST and increases in NPP during negative IOD events from January to June in the western Indian Ocean and decreased in association with increases in SSTs and decreases in NPP during positive IOD events [3]. Catch rates of yellowfin tuna in the purse seine fishery have also been observed to increase and or decrease with negative and or positive IOD events [29].
3.3. Environment Variables Relationship Dynamic

The relationship between environment variables and catch rates that represent by CPUE produced by statistical approach of GAM (Figure 6). Generally, x-axis shows explanatory variable data variances, the y-axis shows the contribution of explanatory variables to the dependence variable in this case was catch rates of yellowfin tuna (CPUE). Thick lines show statistically appropriate functionalities, while dashed lines show 95% confidence intervals. The horizontal lines provide a high or low boundary relationship between CPUE of yellowfin tuna and oceanographic variables. GAM function line that intersects exactly on the zero horizontal line, shows there is no relationship between parameters. A high relationship justified by GAM functional line that fall at the positive area or vice versa.

The single variable significances of environment variable at different years shown at the Table 1, it clearly explain how the IOD event have been affected the fishing activities trough the differences of numbers of variables with significance value under 5 percent. During 2016 that represent negative IOD events seem the most significant variables was SSH where the fishing activities predominantly happen at SSH value bigger than 0.95 m. SSH range during 2017 seem to be lower at the value 0.92 m (Figure 6) considering of the upwelling event that dominantly happen at the eastern Indian Ocean during positive IOD and downweling during negative IOD events [10, 31, 3], our result was consistent on that argumentation.

Three variables that has best significance values were SSH, MLD and CHL, that variable are always associated on climatic events oscillation. Warm and cold water transport events in the Indian Ocean caused by the IOD drive changes in the marine environment variables such as primary production, mixed layer depth and sea surface height [32]. The southwestern monsoon events associated with negative IOD events generates extensive coastal upwelling over the margin of continental areas in the northwestern Indian Ocean, driving an increase in primary production which effects on higher order productivity in the region [29, 32]. During positive IOD events, shifting trade winds increase convergence in the west reducing wind speeds and convection that resulting warmer of surface temperature, a reduction of coastal upwelling and lower productivity in the west part or Indian Ocean while the opposite event happen in the eatern Indian Ocean. The deepening of thermocline further disperses productivity into subsurface layers [33, 3].

Figure 5. Annual maps of yellowfin tuna catches distribution from 2016 to 2017 (red dots), Spatial Dispersion (circle), Directional Dispersion and Trends (ellipses)
In the 2007 positive IOD event, water temperatures were relatively lower in the eastern Indian Ocean compared to the western Indian Ocean that has SST value >29.5 °C with low productivity < 220 mg C m$^{-2}$ d$^{-1}$ [3]. The variabilities on SST during positive IOD events were associated with highly significant SSH, MLD and CHL during 2017 over the catch rates. SST preferences shown to have higher range value in 2016 compared to the 2017, where salinity has lower preferences during negative IOD events compared to the positive IOD events. Mix layer depth show consistent behaviour where during 2016 it became lower in preferences compared to the 2017. Upwelling event during positive IOD in the eastern Indian Ocean drive increasing of vertical mixing at the coastal area and increasing primary production [10, 31, 8]. Upwelling event during positive IOD events clearly associated with the high value of CHL preferences that significantly relate to the higher catch rates while 2016 monitored have lower range preferences value. High CHL values predominantly occurs in the coastal waters, thus became make sense considering fishing activities during 2016 dominantly associated with deeper water compared to the fishing activities at 2017.

| No | Variables | GAM p-value 2016 | GAM p-value 2017 |
|----|-----------|------------------|------------------|
| 1  | SST       | 0.54237          | 0.2564344        |
| 2  | SSH       | 0.04894 *        | 0.0046820 **     |
| 3  | SSS       | 0.74103          | 0.428989         |
| 4  | MLD       | 0.43903          | 0.0127827 *      |
| 5  | CHL       | 0.9236           | 0.0002343 ***    |
| 6  | Bathymetry | 0.60788          | 0.3977458        |

Figure 6. Modelled effect of environment variables on CPUE. The solid line shows the fitted GAM function and the black-dotted line indicates 95 % confidence intervals. Relative density of data points are indicated by the rug plot on the x-axis (col 1-2 for 2016 and col 3-4 for 2017 dataset)
4. Conclusion

This study provides preliminary information regarding some of the key environment variables that drive the variation on the temporal and spatial distribution of yellowfin tuna fishing activities during different IOD events. This study give new perception on how different IOD events impact to the yellowfin tuna fishing catch rate associated with the environment variables. Climatic oscillation seem to give an impact to the fishing activities both spatially and temporally. In addition, the relationship between catch rates and IOD indexes might not simply be determined by linear model, due to lack of dataset it performed only to identify the trend of catch rates over IOD events. Longer dataset and more robust non-liner model must be applied on the way forward to better identification of climatic oscillation impact to the fishing activities. Finally, the associations between six variables including SST, SSH, SSS, MLD, CHL and bathymetry were presented quantitatively and remained explain that different IOD event gives distinguish impact to the fishing activities at the local study area such as western waters of Sumatera.

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