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Impact of Climate Variability to Aquatic Productivity and Fisheries Resources in Jepara Waters

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Abstract. Annual climate variability which is monsoon and inter-annual climate variabilities which are ENSO (El Niño Southern Oscillation) and IOD (Indian Ocean Dipole) affect the processes of aquatic productivity in the sea. Enrichment processes such as upwelling, river runoff, and mixing that occurs in the waters area cannot be separated from the influence of climate variability. Each of these waters has different responses to climate variability. Enrichment variability on the marine areas has affected to the fluctuations of fisheries abundance of both seasonal and inter-annual, so there are times in a given year occurred season and abundance of fish in another famine fish. This study aimed to assess the effect of climate variability (monsoon, ENSO, and IOD) on aquatic productivity, fish catches, and time of fish season in the waters of Jepara using descriptive methods. Variability of aquatic productivity was determined based on indicators of chlorophyll-a MODIS satellite imagery. The results of the study showed that the monsoon is the most influence on aquatic productivity and Sea Surface Temperature (SST) in Jepara waters. High productivity occurs in the west and east season. In particular, the highest productivity generally occurs in the east. Harvesting of fish in the waters of Jepara occur in transitional season I (March-May) and Transition II season (September-November), there are lag time 1-3 month after highest peak of chlorophyll-a. The fish lean season occurs in the west, generally months from December to January. Interannual climate variability ENSO and IOD showed that significant affect to SST and fish productivity. When El Nino-positive IOD event impact decrase of SST and highest fisheries productivity.

1. Introduction

Jepara waters in Central Java, Indonesia has a significant fisheries resources located at west and northern including around of Karimunjawa Islands. Economical fisheries resources are pelagic and demersal fish. The areas of pelagic and demersal catches are 1555.2 km^2 and 1360.8 m^2, respectively. There are 23 species which are ariid catfish, *caesionidae sp*, selar, giant trevally, sardinella, anchovy, pony fishes, northern red snapper, blue-spot mullet, mackerel tuna, chub mackerels, spanish mackerel, humpback grouper, *Plectropomus leopardus*, *Siganus sp*, cutlassfish, cucut, milkfish, ray fish, *Panaeus merguiensis*, *Panaeus semisulcatusde*, *Portunidae sp* and squid. In 2012, fisheries catches production has a significant value that is 6991.6 tons. Recently, lowest fish catches and potential catches areas have become the major problem for fishing industries [1]. There is anomaly in lemuru fish catches [2]. The anomaly occurred in lemuru fish catches is affected by annual climate variability condition that is not predicted. Due to the limitation of understanding about those problems, fish catches activity still has some drawbacks, such as ineffectiveness, inefficiency, also time and fuel consuming.

A number of researchers have studied about the relation among monsoon, ENSO, and IOD to physical and biological aspect of the ocean [3], [4], [5], [6], [7], [8]. In physical aspect, annual climate variation generally can change several oceanographic parameters, such as temperature, thermocline depth, location and intensity of upwelling, ocean current, and location of front catches [3], [4], [5], [6], [7], [8]. In the biological aspect, [5] shows that monsoon variability, ENSO, and IOD can trigger the change of aquatic productivity, for example the change of chlorophyll-a intensity. The pattern changes of chlorophyll due to ENSO and IOD has been also studied by [7]. Moreover, the change in physical and biological aspect have affected the fisheries productivity, such as little pelagic fish, particularly lemuru fish catches [2]. However, a major problem with this kind of topics is the different response of waters to monsoon, ENSO, and IOD. No previous study has investigated the effect of climate variability, such as monsoon, ENSO, and IOD in Jepara waters. Therefore, the main purpose of the study is to investigated the response of Jepara waters to climate variability.

The different responses of each waters to monsoon, ENSO and IOD variability become the problem of this research. In Jepara Waters, there were not researchers studying the responses of this waters to monsoon, ENSO and IOD variability. Therefore, this research was focused to investigate Jepara Regency waters responses to monsoon, ENSO and IOD variability. The reseach area at Jepara Regency waters and its round are described in Figure 1.

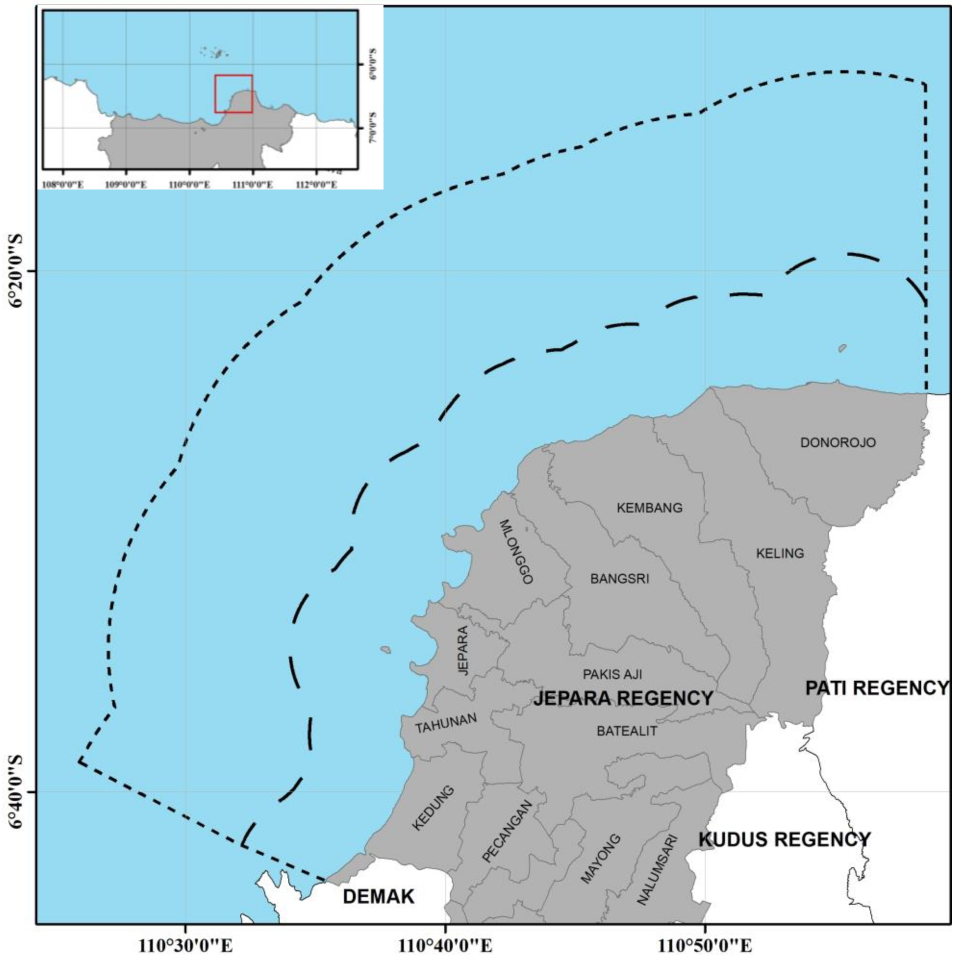

Figure 1. The research location at Jepara Regency waters. The waters bound 4 mile and 12 mile are marked by long dashed line and short dashed line, respectively.

2. Research methods

The data for this study were MODIS data that collected from Aqua and Terra Satellite which are monthly spatial distribution of chlorophyll-a and sea surface temperature (SST). Climate variability data consist wind speed and direction, SST Anomaly at NINO3.4 that are ENSO index, Dipole Mode Index (DMI), and IOD. Monthly research data are chosen because global climate variability, ENSO and IOD, are considered.

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Descriptive and statistical methods are used in this study. Descriptive method was done by describing temporal and spatial variability of productivity in Jepara waters based on chlorophyll-a indicator. In addition, the method is used to analyze source of that aquatic productivity, SST variability and precipitation occurred in that area. Statistical analysis was done by calculating the mean of SST and chlorophyll-a in monthly time series and calculating the correlation and coherence coefficient to monthly mean of wind speed (monsoon indicator), ENSO, and IOD. Then, abundance and scarcity of fish seasons are analyzed based on monthly time series fish landing data. Coherence analysis is used to calculate time lag between productivity period and fish season.

In particular, the method of this research divided into five steps which were collecting primary and secondary data, graphical analysis of the trend of ENSO and IOD, analyzing chlorophyll-a and SST data from MODIS images, analyzing wind speed and direction, and analyzing precipitation data.

1. Collecting primary and secondary data
    - Climate variability data that contain ENSO index which is SST anomaly at NINO3.4 and IOD index which is DMI were collected from: http://www.bom.gov.au/climate/current/soihtml.shtm1; http://www.jamstec.go.jp/frcgs/research/d1/iod/DATA/dmi_HadISST.txt.
    - Monsoon data, wind speed and direction, were collected from http://www.ecmwf.int. These data that is from ECMWF (European Centre for Medium-Range Weather Forecasts) have 1/12 degree (9.17 km) spatial resolution. Then, the data were analyzed using ODV (Ocean Data View)
    - Monthly SST and chlorophyll-a data were collected from MODIS images that is downloaded from http://www.oceancolor.gfc.nasa.gov in HDF (Hierarchical Data Format). The data with 4 km spatial resolution were analyzed in SeaDAS 7.0.
    - Temporal precipitation data downloaded from http://www.esrl.noaa.gov/psd/data/gridded/data.html were reanalyzed then extracted in ODV.
    - Time series fish landing data between 2010 and 2015 were collected from Department of Marine and Fisheries, Jepara.
2. Graphical analysis of the trend of ENSO and IOD

    Trend making was done by plotting on graph between ENSO index which is SST anomaly at NINO3.4 and IOD index which is DMI. As can be seen from the plotting, extreme climate variability occurred was divided into:
    1. El Niño-IOD(-), between June 2004 and Mei 2005 (Case I)
    2. El Niño-IOD(+), between July 2002 and June 2003 (Case II)
    3. La Niña-IOD(-), between June 2010 and January 2011 (Case III)
    4. La Niña-IOD(+), between October 2007 and September 2008; June 2011 and December 2011 (Case IV)
    5. Normal, between September 2003 and March 2004; April and July 2010.

    The study uses these periods because in order to gain insight into months which are ENSO and IOD variability occurred. In addition, Oceanography data were available that periods.
3. Analyzing chlorophyll-a and SST data from MODIS images

    MODIS images were used to describe the data which are chlorophyll-a and SST. Furthermore, MODIS images can produce accurate data and it is used internationally also it is downloaded for free. Chlorophyll-a and SST data collected were Level-3 data in HDF format. The data which are monthly mean are resulted from imaging processes of Terra and Aqua Satellite. SeaDAS 7.0 are used to collect text file (.txt) format data and to analyze spatial distribution of chlorophyll-a and SST. Then, chlorophyll-a and SST data were analyzed the correlation and coherence with another data.
4. Analyzing wind speed and direction

    Wind data collected from ECMWF were Net-CDF format. ODV were used to collect the data, wind vector in u direction (west-east) and v direction (north-south) at research region in txt format. These data were used to calculate total wind speed and direction. Then, wind direction dominant was analyzed using Wind-Rose.

5. Analyzing precipitation data

   Precipitation data collected in netCDF format file were analyzed using Ferret NOAA 6.93 resulting mm/month precipitation data in txt format. Statistical analysis was used to analyze the data.

3. Results and discussions

3.1. The Impact of monsoon to aquatic productivity, SST, and fisheries productivity

Temporal Variability

Figure 2 represents the relation between the monsoon, which is wind speed and chlorophyll-a concentration in Jepara waters from 2002 to 2015. Annually, there was twice in increasing of wind speed. The first period was happened in January or February, and the second period was happened in June or July. The chlorophyll-a increasing in west and east season was influenced by the rising of wind speed. In fact, chlorophyll-a concentration peak was happened together with maximum wind speed in those periods. This global relationship, winds and surface chlorophyll-a, had been reported by [9]. that there is high correlation in shallow mixed layer. Moreover, as shown in Figure 3, there was correlation between aquatic productivity and precipitation. In the first period, the increase of precipitation is the cause of river runoff containing high concentration of nutrients to the sea which are taken for advantage of phytoplankton growth. Similarly, other authors [10], found that significant increase of nutrients strengthens phytoplankton growth. Increasing of chlorophyll-a in east season is expected correlating with mixing of water mass because the rising wind speed. The mixing process will raise nutrients from inner layer to the surface layer. The high nutrients, supported by the highwater brightness in the east season, its triggers high photosynthesis process, so as to produce a high chlorophyll-a value (as an indicator of the high primary productivity of waters). Correlation analysis was used to predict the relationship between wind speed and chlorophyll-a which shown the r value of 0.55, meaning that both have intermediate correlation.

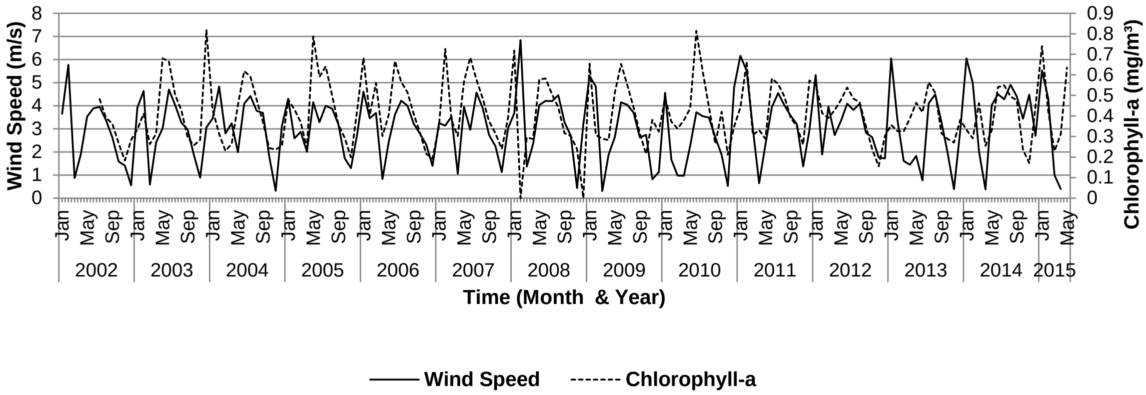

Figure 2. Variability of wind speed and chlorophyll-a intensity in Jepara waters from 2002 to 2015

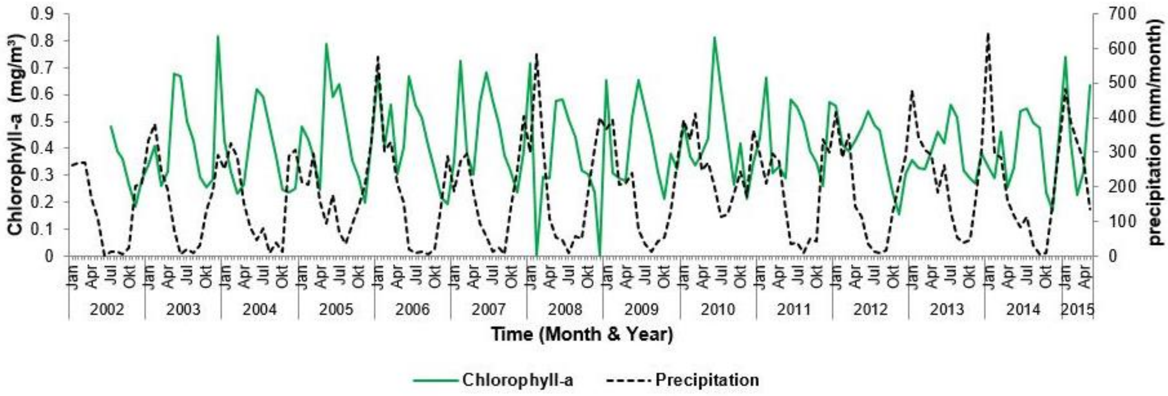

Figure 3. Variability of chlorophyll-a and precipitation intensity in Jepara waters from 2002 to 2015

Monthly maximum wind speed in west and east season ranged from 3.4-6.83 m/s and 3.4-6.8 m/s with a mean of 5.1 m/s and 4.3 m/s respectively. Also, Monthly maximum chlorophyll-a concentration in these seasons ranged from 0.38-0.82 mg/m^3 and 0.48-0.81 mg/m^3 with a mean of 0.59 mg/m^3 and 0.62 mg/m^3 respectively. According to these data, primary productivity at Jepara waters in east season is higher than west season and it can be seen from the value of chlorophyll-a concentration. There are three possible explanations why east season has higher primary productivity than west season. Firstly, it is caused by mixing process that rises along with wind speed getting faster and it, in the same vein, is also stated by [11][12]. Secondly, it might be expected that the current in east season is more steady than west season. At these conditions, there is an advantage for phytoplankton to grow faster. Thirdly, the east season might have turbidity so low that waters has significant light intensity into it, this is in accordance with the statement of [1], thus, chlorophyll-a concentration is higher in east season than west season.

Increasing aquatic productivity in west season that the highest season either in January or February and in east season occurred either in June or July are followed by increasing of fisheries productivity in one through three months after the highest peak of chlorophyll-a (Figure 4). This finding was unexpected and suggest that fish season generally occur in one through three after the highest peak of chlorophyll-a both in transitional season I (March-May) and transitional season II (September-November). As a result, the highest fish season occur in May and September. This finding is supported by [13], which suggest that fish catches in the Java Sea increase during period of March to June and October to November.

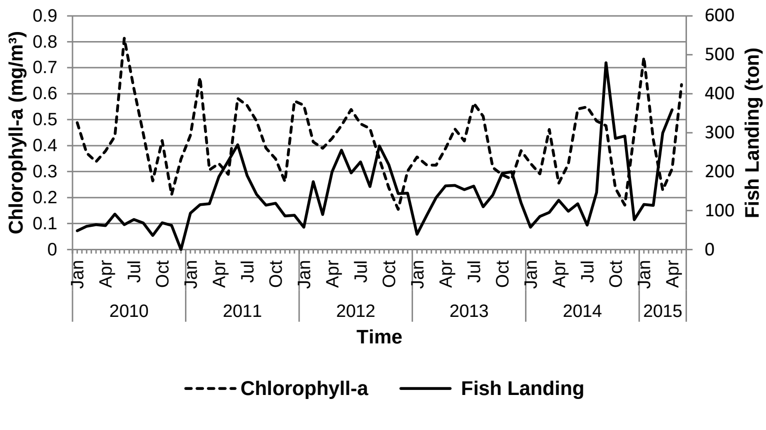

Figure 4. Variability of chlorophyll-a intensity and fish landing at Jepara waters between 2010 and 2015

Figure 5 shows that the lowest fish catches correlate with wind speed. When wind speed at high point, fish catches productivity shows at low point. The explanation for this is that fisherman do not sail to the sea when the wind is very strong. So, the lowest catches fish in Jepara regency generally occur in west season (December or January). Moreover, when the highest wind speed occurs in east season, fish catches is generally decreasing no more than west season.

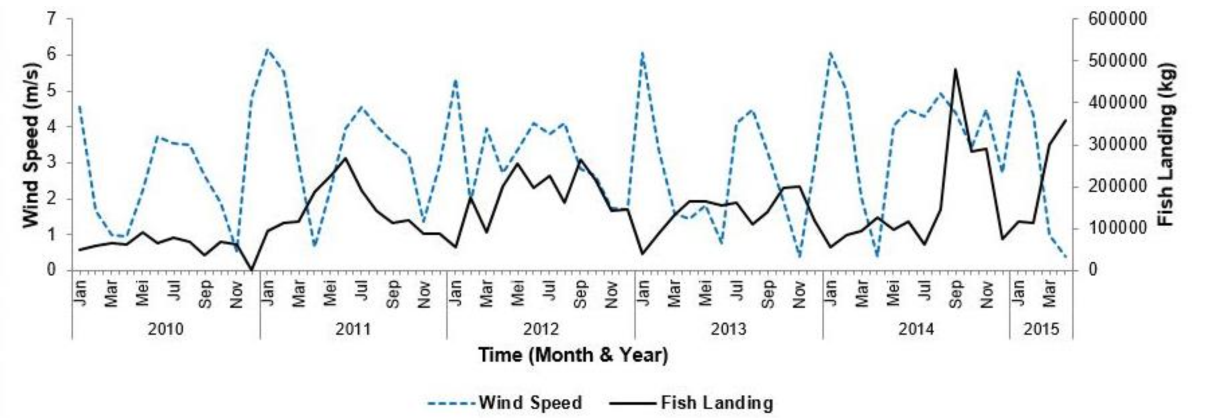

Figure 5. Variability of wind speed and fish landing at Jepara waters between 2010 and 2015

Spatial Variability

Based on Figure 6, it was found that there were three Jepara coastal waters that had high primary productivity, first at north of Donorojo Sub-District Waters, second west of Kedung Sub-District Waters, and third at west of Tahunan Sub-District Waters (the red cicles at Figure 6). Base on the indicator chlorophyll-a concentration show value at the tree location abaut 3-5 mg/m^3. The high primary productivity in the tree locations is thought to be related to the existence of river. The runoff of the river carries a high nutrient that triggers a high primary productivity process which is evident from the high value of chlorophyll-a. [10] also mentioned the effect of the presence of river runoff will cause increased phytoplankton concentration (primary productivity). In the area northern waters of Donorojo, Tahunan and western Kedung Sub-District have high chlorophyll-a levels for most of the year, so from year to year the locations become potential fishing ground. This is according to [14], statement, that area with high chlorophyll-a levels generally have good fishery potential.

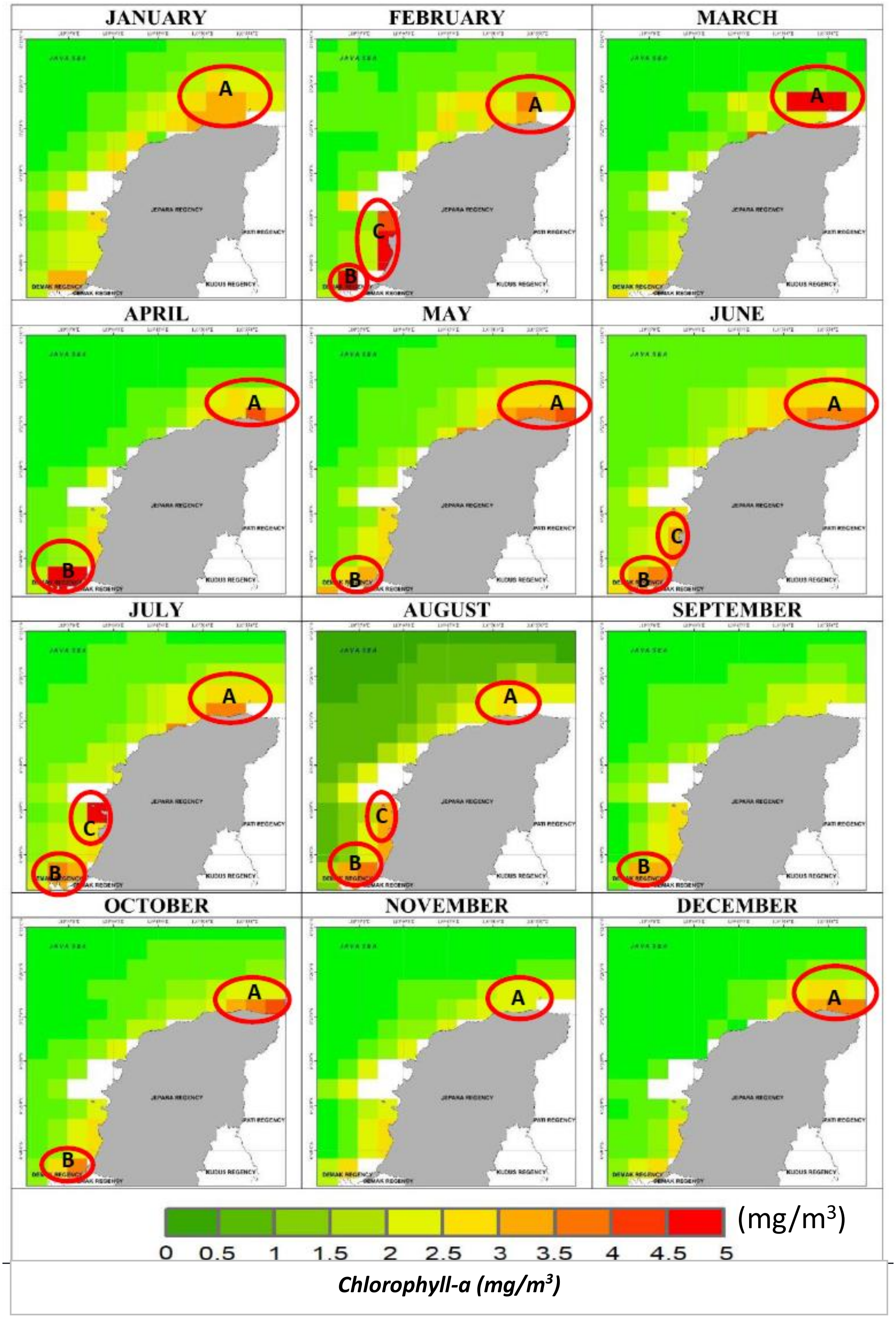

Figure 6. Montly chlorophyll-a distribution (mg/m^3) at Jepara Regency Waters, the climatologis data from 2002-2015, (A) North of Donorojo, (B) West of Kedung, and (C) West of Tahunan

3.2. The Impact of ENSO and IOD to Aquatic Productivity, SST, and Fisheries Productivity

As illustrate in Figure 7- 9, ENSO and IOD have significant influence especially for SST and fish landing in Jepara Regency Waters. The result of data analysis for 14 years shows ENSO has more influence on Jepara waters than IOD ENSO and SST in Jepara waters appear to have high coherence with range from 0.8-0.9 (red colour curve in the Figure 7). The direction of the arrow in the coherence analysis cup shows to the right (Figure 7), this means that the two parameters that are coherently has proportional fluctuation, in terms of an increase or decrease in the ENSO index (the SST anomaly in NINO3.4) will be followed by an increase or decrease of SST in Jepara Regency Waters, within a 32-monthly cycle period. The direction of the arrow inclines up means that the ENSO index parameter (first parameter) first rises or falls and followed by an increase or decrease of SST in Jepara waters. The coherence of IOD and SST in Jepara District Waters shows that not continuity and it tends to be the opposite (the direction of the arrow to the left in Figure 8).

The effect of ENSO on the Jepara waters appears to be larger than IOD. This can occur allegedly related to spatial condition where is the waters of Jepara Regency which is part of Java Sea directly connected without an island barrier with the Pacific Ocean through the Makassar Strait and Sulawesi Sea. The respond of the waters of Jepara Regency to ENSO through changes of monsoon wind variability against the ENSO index when the anomaly in SST di NINO 3,4 positive (El Nino phenomenon), then the wind speed above Jepara waters increased (Figure 2). This is in accordance with [7], that ENSO and IOD are related to the variability of the monsoon wind velocity. This is thought to cause the mixing process in the waters to increase, this can to be seen from the SST indicator which decreases because the water from the lower layer rises (Figure 7a), This is also illustrated by [14], this process is followed by an increase of nutrient in the surface layer. Increasing nutrients in the surface layer with sufficient light support causes an increase of water primary productivity. The opposite condition occurs when a negative SST anomaly occurs in NINO3,4 (La Nina phenomenon).

The high increase in primary productivity during El Nino in the waters of Jepara Regency was followed by an increase in fishery productivity (Figure 8). El Nino events appear to occur in 2011, 2012 and 2014. Based on the graph in Figure 8a, shows an increase / decrease in SST anomalies in NINO3,4, followed by an increase or decrease in landing of fish in the waters of Jepara Regency. Judging from the coherence value, the values ranged from 0.6-0.7 (yellow curve in cup analysis), the right arrow showed the relationship between the two parameters was directly proportional, with a high period of linkage in the 16 months cycle. Increased fishery productivity occurs when sea surface temperatures tend to decrease. There is a correlation between the high increase in primary productivity with the landing of fish is supported by [1].

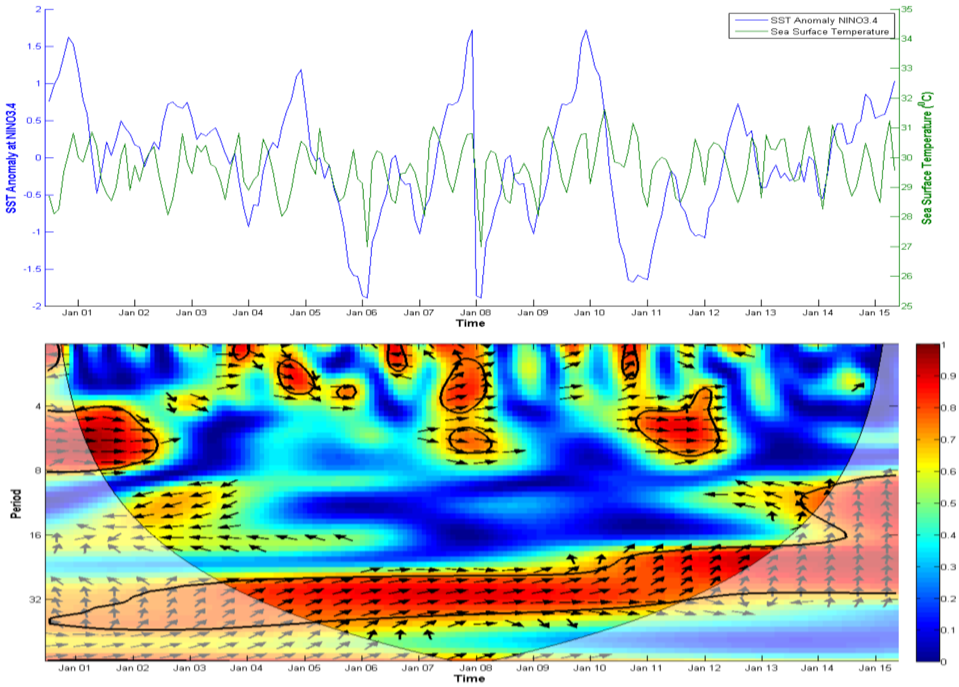

Figure 7. Coherence between SST anomaly at NINO3.4 (ENSO index) and fish landing at Jepara waters, the range of coherence value from 0.6-0.7 for a cycle period 1-2 years, the arrow to the right shows a graph of two parameters in one phase (yellow polygon curve in the analysis cup)

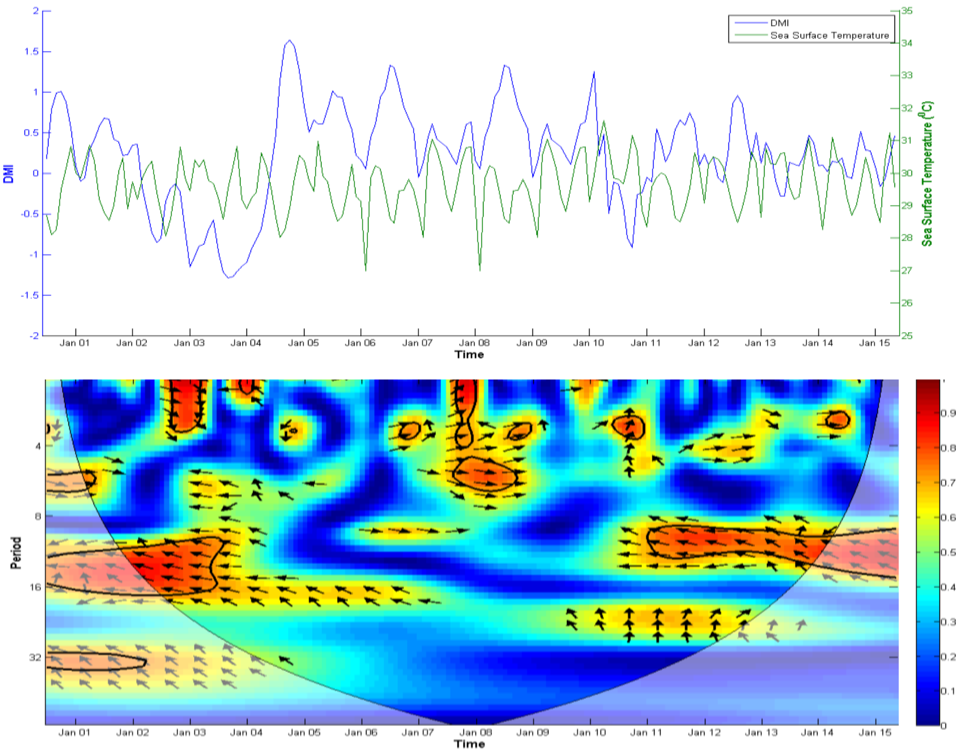

Figure 8. Coherence between DMI (IOD index) and SST at Jepara waters, the range of coherence value from 07-0.8 for a cycle period 16 months, but coherence not continue, the arrow to the left shows a graph of two parameters in opposite (yellow-red polygon curve in the analysis cup)

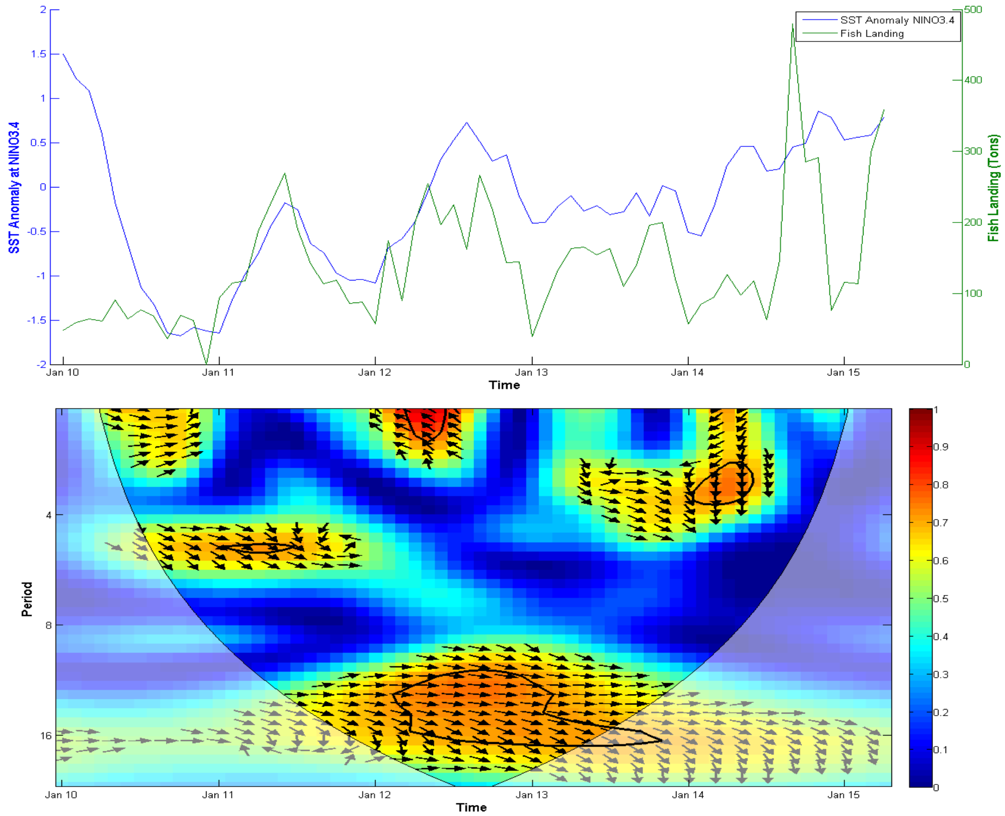

Figure 9. Coherence between SST anomaly at $NINO_{3,4}$ (ENSO Index) and fish landing at Jepara waters, the range of coherence value from 0.6-0.7 for a cycle period 1-16 month, the arrow to the right shows a graph of two parameters in one phase (yellow-red polygon curve in the analysis cup)

4. Conclusions

The study has shown that monsoon has significant correlation to aquatic productivity and SST in Jepara waters. The highest fertilization occurs in two seasons which are west and east season. One of the more significant findings to emerge from this study is that fish season occurs in transitional season I (March-May) and transitional season II (September-November), there are lag time 1-3 month after highest peak of chlorophyll-a. In other hand, the lowest catches generally occur in December through January.

Inter-annual climate variability shows that ENSO is more influent in the waters of Jepara Regency than IOD. The coherence between ENSO and SST in Jepara waters shows range value of 0.8-0.9. ENSO coherence and fish landing showed range value of 0.6-0.6. In addition, the finding of this study indicate that the highest fish landing occurs when El Niño-IOD(+), in contrary, the lowest fish landing occurs when La Nina-IOD (-).

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