

ANALYSIS OF WATER PRODUCTIVITY IN THE BANDA SEA BASED ON REMOTE SENSING SATELLITE DATA

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Abstract. This study examines the density of potential fishing zone (PFZ) points and chlorophyll-a concentration in the Banda Sea. The data used are those on chlorophyll-a from the Aqua MODIS satellite, PFZ points from ZAP and the monthly southern oscillation index. The methods used are single image edge detection, polygon center of mass, density function and a Hovmoller diagram. The result of the analysis show that productivity of chlorophyll-a in the Banda Sea is influenced by seasonal factors (dry season and wet season) and ENSO phenomena (El Niño and La Niña). High productivity of chlorophyll-a occurs during in the dry season with the peak in August, while low productivity occurs in the wet season and the transition period, with the lowest levels in April and December. The variability in chlorophyll-a production is influenced by the global El Niño and La Niña phenomena; production increases during El Niño and decreases during La Niña. Tuna conservation areas have as lower productivity of chlorophyll-a and PFZ point density compared to the northern and southern parts of the Banda Sea. High density PFZ point regions are associated with regions that have higher productivity of chlorophyll-a, namely the southern part of the Banda Sea, while low density PFZ point areas are associated with regions that have a low productivity of chlorophyll-a, namely tuna conservation areas. The effect of the El Niño phenomenon in increasing chlorophyll-a concentration is stronger in the southern part of study area than in the tuna conservation area. On the other hand, the effect of La Niña phenomenon in decreasing chlorophyll-a concentration is stronger in the tuna conservation area than in the southern and northern parts of the study area.

Keywords: *PFZ point, density, chlorophyll-a, water productivity, Hovmoller diagram, Banda Sea*

1 INTRODUCTION

Daily PFZ information has become a routine service for users in Indonesia. The information is generated automatically from ZPPI Auto Processing (ZAP) software with sea surface temperature satellite image data input. The distribution of PFZ information has densities that vary spatially and temporally. There are several factors that have an influence on density, namely: water productivity factors, seasonal factors and global phenomenon factors.

Sea waters that have high productivity rates are identified as potential fishing grounds or indicators of predicting fishing locations (Kasma, Osawa & Adnyana, 2007). Productivity of waters can be analysed through oceanographic parameters; for example, the concentration of chlorophyll-a. Chlorophyll-a is an active pigment in phytoplankton which plays an important role in the process of photosynthesis in seawaters and is a major food source for marine organisms (Hatta, 2014).

Chlorophyll-a has spatial and temporal variability. The spatial variation in the distribution of chlorophyll-a in the ocean depends on the geographical location and depth of water. This variation is caused by differences in sunlight intensity and nutrient concentrations in the waters. In addition, variations in chlorophyll-a concentration at sea level are closely related to upwelling events, seasonal changes and global phenomena in the ocean such as the El Niño Southern Oscillation (ENSO) (Kunarso, Hadi, Ningsih & Baskoro, 2011). Chlorophyll-a variability over the years is influenced by the ENSO phenomenon and the Indian Ocean Dipole (IOD) (Hottua, Kunarso & Rifai, 2015). However, the ENSO factor does not have a large influence (correlation of 0.33) on primary productivity in the Banda Sea (Sukresno & Iwan, 2008).

With the development of remote sensing technology, oceanographic parameter data are easily obtained and widely used in research. Nowadays remote sensing technology is an important instrument in obtaining overall sea water measurement data (Semedi & Hadiyanto, 2013). The advantage of using satellites for monitoring chlorophyll-a is because they can record data with a sweep width or a very wide area coverage. Research on the use of chlorophyll-a data from Aqua MODIS (Moderate Resolution Imaging Spectroradiometer) has been conducted by researchers in the marine field. Based on the results of research using chlorophyll-a data from MODIS, its concentration in the seas relates to the number of phytoplankton; more phytoplankton will increase chlorophyll-a concentration. High concentrations of chlorophyll-a can be found in coastal zones, and low concentrations in the open ocean (Winarso & Marini, 2014). Variations in chlorophyll-a and sea

surface temperature during the period 2002-2017 were significantly influenced by the monsoon and Indian Ocean Dipole phenomena (Mashita & Lumban-Gaol, 2019).

This research aims to analyse the density of PFZ points and their relationship with water productivity based on chlorophyll-a parameters. Subsequently, certain factors that affect the productivity of chlorophyll-a spatially and temporally in the Banda Sea are analysed.

2 MATERIAL AND METHODOLOGY

The data used in this study consisted of chlorophyll-a, PFZ points and the southern oscillation index. The chlorophyll-a data from the Aqua MODIS satellites had a spatial resolution of 4 kilometers and a mostly temporal resolution. The chlorophyll-a data period was used from January 2003 to December 2018 (16 years), with data sourced from <https://oceancolor.gsfc.nasa.gov/>. PFZ point data were obtained from ZAP software, with daily sea surface temperature data from Aqua MODIS and S-NPP VIIRS satellites. The PFZ point data covered the period 2016 to 2018. The supporting data for the research were monthly data from the southern oscillation index, used as an indicator of the ENSO phenomenon. These data were sourced from Bureau of Meteorology Australian Government, <http://www.bom.gov.au/climate/>. The region of interest for the research was the Banda Sea and surrounding areas, at longitude 124°E to 132°E and latitude 2.5°S to 7°S, as shown in Figure 2-1. The sea area that is restricted by the red dashed line is a tuna conservation area. This area has been declared as a spawning and breeding ground for tuna fish and it is prohibited to conduct fishing operations there during the three months of October, November and

December (Menteri Kelautan dan Perikanan, 2015).

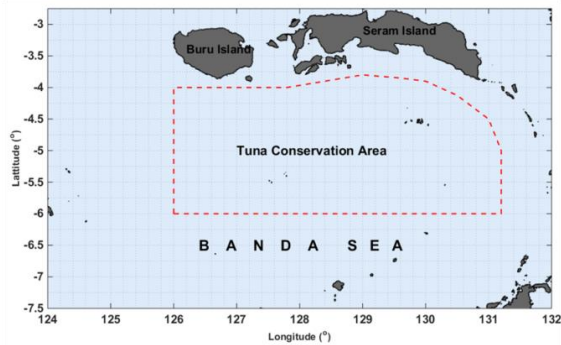


Figure 2-1: Region of interest

To achieve optimal research results and well-structured research implementation, the study was conducted based on the flow chart shown in Figure 2-2. The method used to detect thermal front events from sea surface temperature data was the single image edge detection (SIED) method (Cayula & Cornillon, 1995). From the results of the front detection, the polygon centre point was determined as the PFZ point, using the centre of mass of the polygon area (Hamzah et al., 2016). The annual distribution of PFZ points in the study area represented the PFZ point density. The spatially distributed PFZ point were placed into gridboxes sized $0.25^\circ \times 0.25^\circ$ to produce density of PFZ. Each gridbox contained a number of PFZ points that could be calculated using the counts of points in the polygon function. The purpose of producing PFZ points in the form of density is to facilitate analysis and to determine areas that have high or low density. To analyse the chlorophyll-a data, the statistical average composite method was used (the same month was averaged). To further develop the chlorophyll-a analysis, the Hovmoller diagram method was used. The Hovmoller diagram is a diagram that presents meteorological data or oceanographic parameters in form of xy coordinates; longitude versus time or

time versus latitude (Hovmoller, 1949). In a Hovmoller diagram, the data are averaged for the same latitude or longitude over time. The application of a diagram aims to temporarily examine variations in the distribution of chlorophyll-a data based on latitude or longitude. From these variations, areas that have high or low water productivity can be determined. In this study, averaging of chlorophyll-a for the same longitude with respect to time was conducted to produce a plot of chlorophyll-a distribution data based on the time series versus latitude. In this way, variations in the distribution of chlorophyll-a data based on spatial latitude temporally can be analysed.

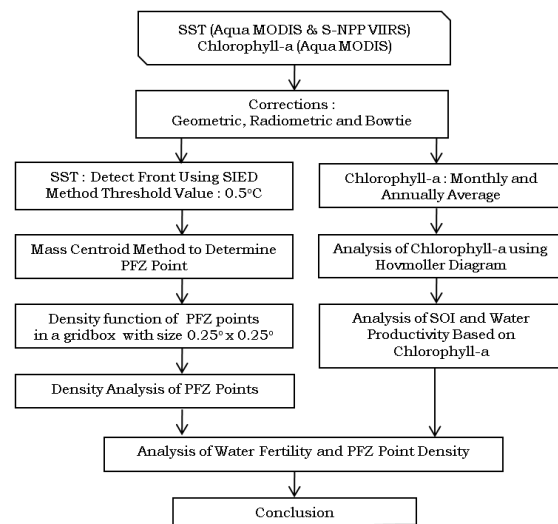


Figure 2-2: Research flowchart

3 RESULTS AND DISCUSSION

Daily PFZ information based on sea surface temperature from satellite data was generated automatically from the ZAP software. The annual spatial distribution of PFZ points per year for the study area from 2016 to 2018 was arranged in the form of a grid box sized $0.25^\circ \times 0.25^\circ$ as shown in Figure 3-1. In 2016, there were no PFZ points in some regions, while most had an information density of 1-6 PFZ point per year. In 2017, there was an increase in PFZ point

information density compared to 2016. The study areas lacking PFZ point information steadily decreased, while those with an information density of 16-21 PFZ points or more significantly increased. In 2018, there was a further increase in PFZ point information density compared to 2016 and 2017. Temporally, there was an increase in PFZ point information density from 2016 to 2018, with the highest density occurring in 2018. Cases of low density and regions without PFZ point information in 2016 were likely due to the operation of the ZAP software which was not optimal that year. However, in 2017 and 2018 the ZAP operation was optimal. In general, the information density of PFZ points in the Banda Sea varied. Spatially, high PFZ point information density is found in the southern part of the Banda Sea, outside the tuna conservation area. Low information density is found in the tuna conservation area. In this study the results of the analysis of the information density of the PFZ points will be linked to the analysis of water productivity based on the chlorophyll-a parameter in the Banda Sea.

The results of the monthly chlorophyll-a data processing from the Aqua MODIS satellite from January 2003 to December 2018, namely the monthly composite average, is shown in Figure 3-2. Chlorophyll-a concentration ranges from 0.05 mg/m³ to 5 mg/m³ it has both spatial and temporal variability. Temporally, high chlorophyll-a concentrations occur from May to October (6 months), with the highest concentrations occurring in July and August. Low concentrations occur from November to April (6 months), with the lowest concentrations occurring in April

and December. Periodically, there is an increase or decrease in the concentration of chlorophyll-a in the Banda Sea. This shows that the seasons, namely the wet season, dry season and the transition period have a strong influence on the variability (increase or decrease) of chlorophyll-a concentration in the Banda Sea. Spatially, the higher concentrations of chlorophyll-a were found in the southern part of the study area and the lower concentrations in the tuna conservation area. This result is very similar to the PFZ point density. A high density of PFZ points is found in the southern part of the study area and a low density in the tuna conservation area. To complete this analysis, follow-up analysis using the Hovmoller diagram was performed.

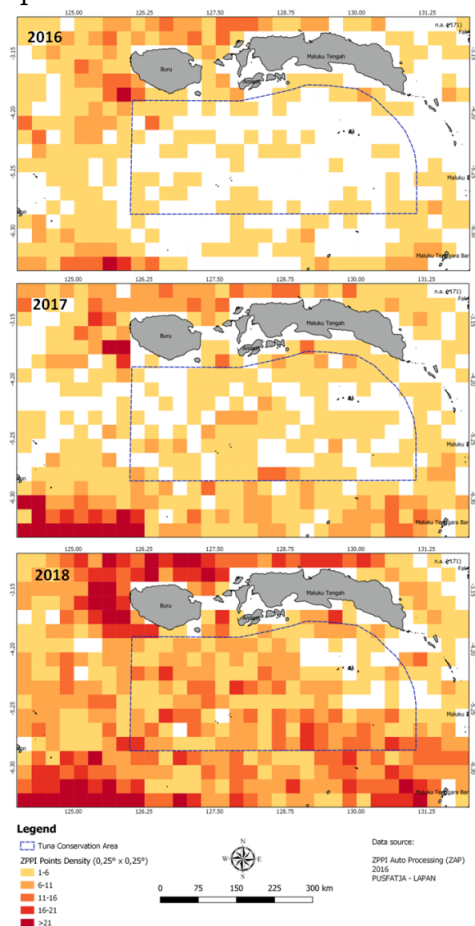


Figure 3-1: Density of PFZ points per year from 2016 to 2018

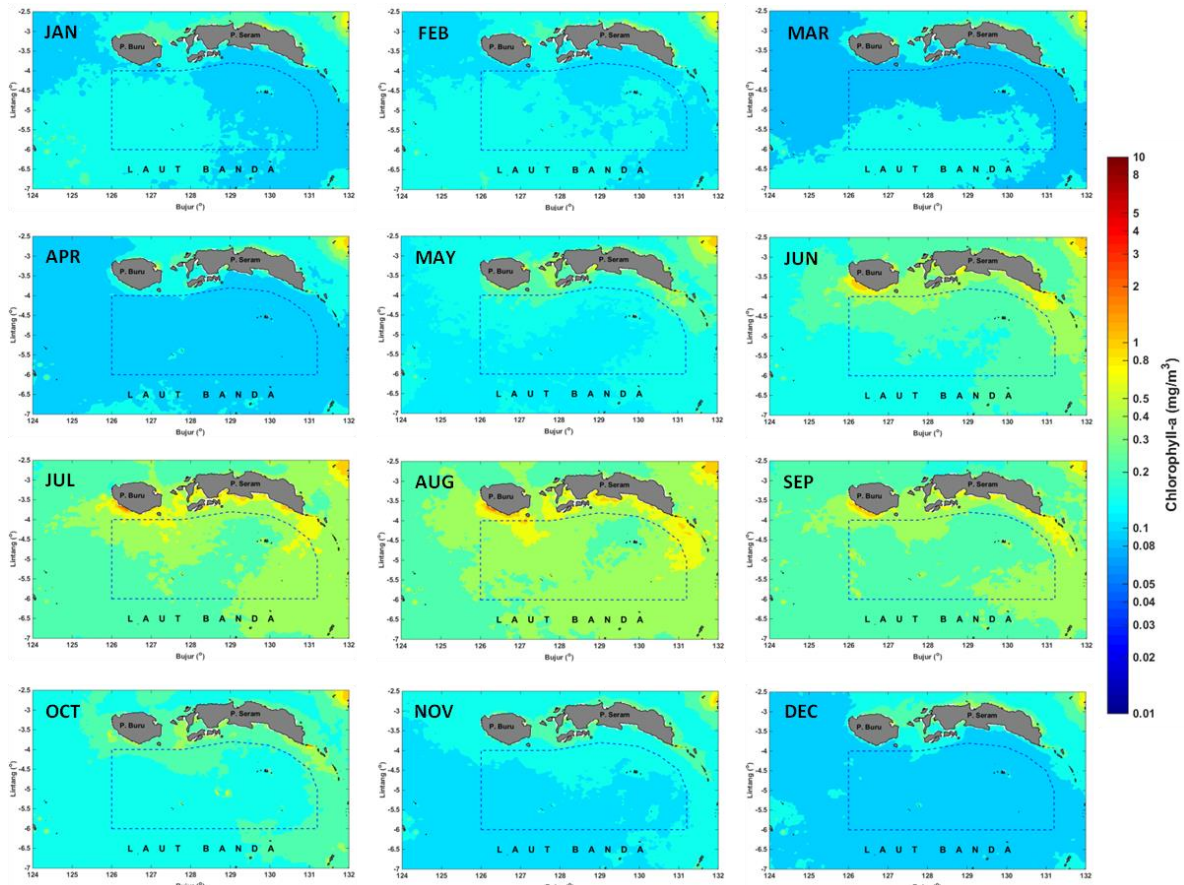


Figure 3-2: Monthly composite average of chlorophyll-a

After applying the Hovmoller diagram, the results of the distribution of chlorophyll-a were obtained in the form of xy coordinates; time (month) versus latitude as shown in Figure 3-3. In the Hovmoller diagram, chlorophyll-a averaging between pixels in the same longitude was performed to research the variability of chlorophyll-a based on latitude. On the basis of this, the tuna conservation area is located 4°S to 6°S (dashed red line). Chlorophyll-a concentration values range from 0.1 mg/m³ to 0.7 mg/m³. Based on the latitude of the study area, the coastal areas of Buru and Seram Islands (2.5°S to 4°S) have higher chlorophyll-a concentrations than in the tuna conservation area (4°S to 6°S) or the southern part of the study area (6°S to 7°S). In general, coastal areas have higher chlorophyll-a concentrations compared to the high seas. Temporally, low chlorophyll-a concentrations occur

from January to April and from November to December. The lowest concentrations occur in April, November and December. High concentrations occur in May to October. The highest chlorophyll-a concentrations occur in July and August. The results of this analysis corroborate those shown in Figure 3-2. The monsoon system that occurs in Indonesia, or seasonal change factors, has a strong influence on the chlorophyll-a variability in the Banda Sea. In the dry season, which occurs in June, July and August (JJA), the concentration of chlorophyll-a increases significantly and reaches its peak in July and August. Increased chlorophyll-a is due to the influence of increased upwelling events in the dry season, which causes nutrients to rise to the surface. In wet season, in December, January and February (DJF) and in the transition period, the concentration of chlorophyll-a is lower than in the dry

season. The decrease in concentration is thought to be due to a fall in the intensity of upwelling events and an increase in the volume of seawater from rainfall. The overall results show that water productivity based on chlorophyll-a concentration is high in the east monsoon (dry season) and low in the west monsoon (wet season) and transition period due to the influence of seasonal factors.

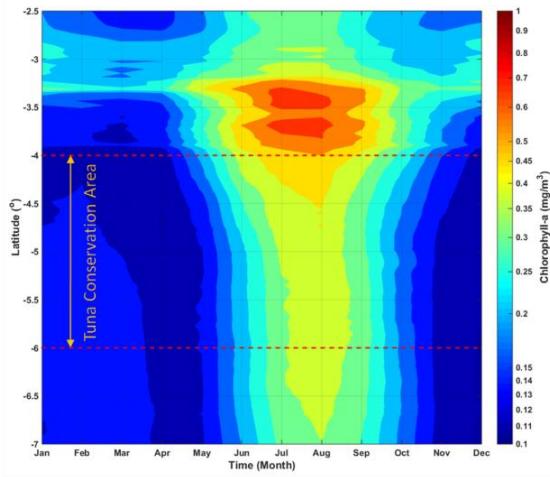


Figure 3-3: A Hovmoller diagram of monthly chlorophyll-a concentration (time vs latitude)

The monthly chlorophyll-a average shows the relationship between the influence of seasons on productivity variation between months and seasons (temporal). The following analysis examined the annual variability of chlorophyll-a from 2003 to 2018, as shown in Figure 3-4. From these results variations in chlorophyll-a over the years can be investigated, namely the increases and decreases in chlorophyll-a concentration. The results show that the average chlorophyll-a concentration per year varied in value between 0.1 mg/m³ to 3 mg/m³. In general, chlorophyll-a is higher on the southern coasts of Buru and Seram Islands, and in the southern part of the study area. Chlorophyll-a concentration showed an increase in 2006 and 2015. The lowest chlorophyll-a concentration during the observation period occurred was in 2010. For more detailed analysis, a Hovmoller diagram and El Niño Southern Oscillation (ENSO) index data were analysed during the period of observation.

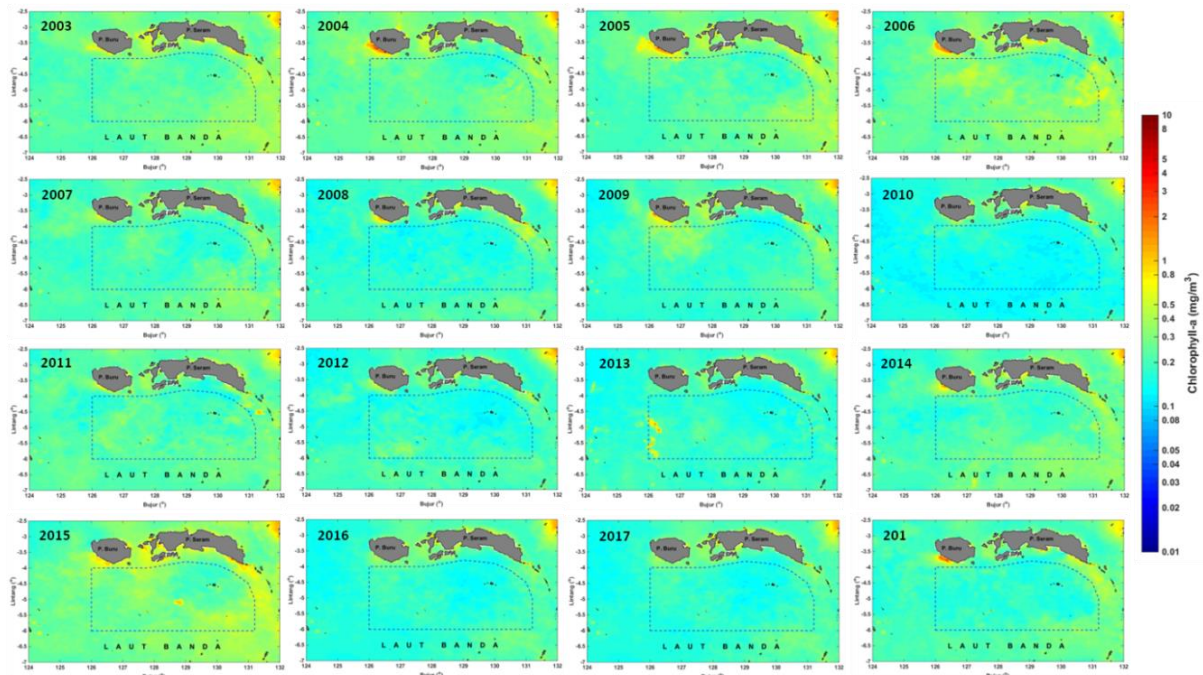


Figure 3-4: Average annual levels of chlorophyll-a from 2003 to 2018

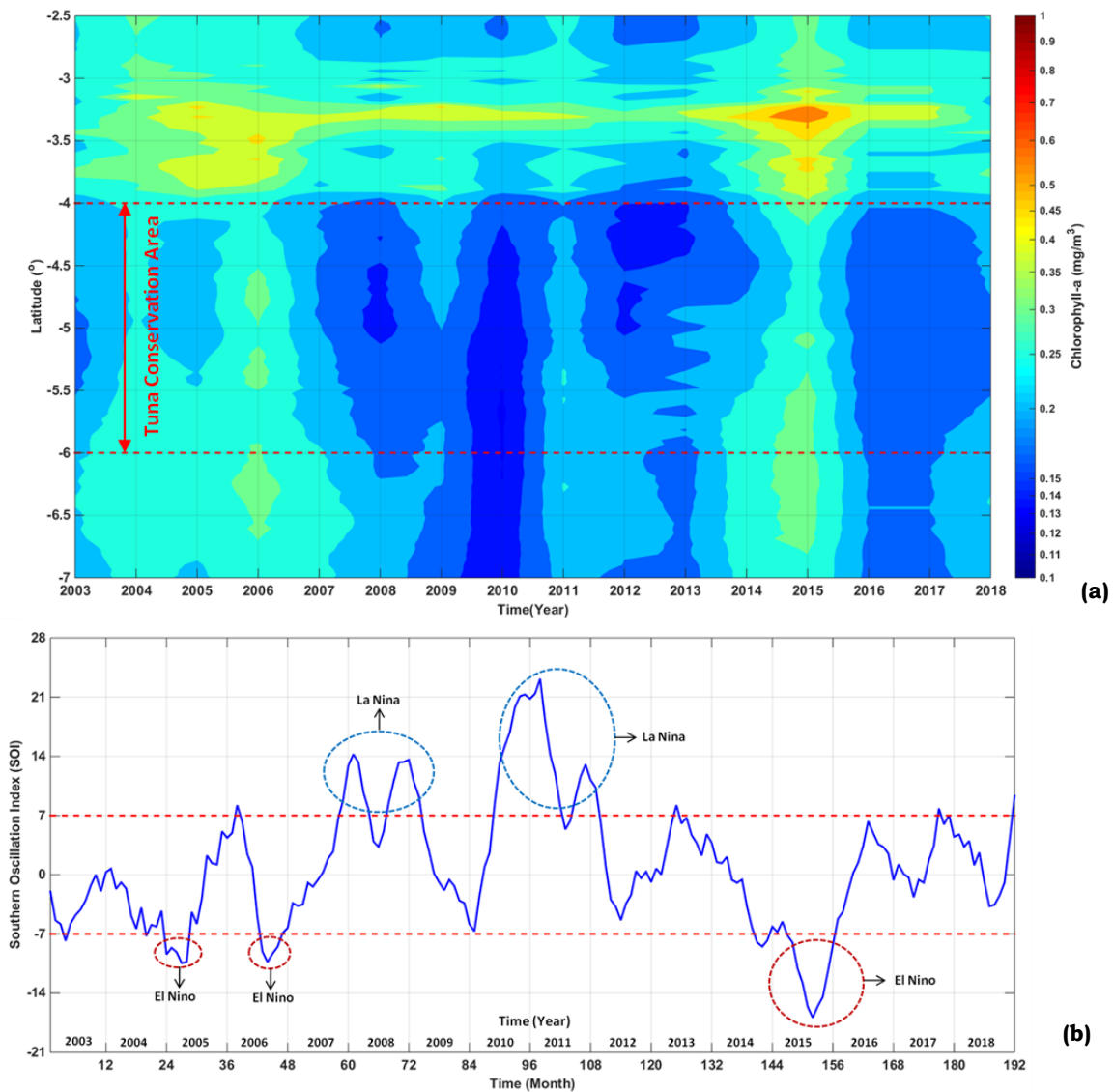


Figure 3-5: (a) Hovmoller diagram of annual chlorophyll-a from 2003 to 2018; (b) Time series of southern oscillation index from 2003 to 2018

The application of the Hovmoller diagram method aimed to analysed the variability in chlorophyll-a between latitudes and years (years versus latitudes) and their relation to ENSO phenomena. The results from applying the Hovmoller diagram and the southern oscillation index values of ENSO phenome are shown in Figure 3-5. Spatially based on latitude, the lowest chlorophyll-a concentration is found in the tuna conservation area with higher chlorophyll-a concentrations in the southern part of the study area and the highest ones in the north. Temporally,

the concentration of chlorophyll-a increased in 2005, 2006 and 2015. During these year, there were El Niño events (shown by red dashed lines), resulting in an increase in chlorophyll-a in the study area. The effect of El Niño phenomena in increasing chlorophyll-a concentration is stronger in the southern part of study area than in the tuna conservation area. In 2008 and 2010 there were the La Niña events (shown by blue dashed lines), which resulted in a decrease in chlorophyll-a concentration in the study area. The biggest decrease in chlorophyll-a concentration occurred

with the La Niña event of 2010, with the highest SOI value. The effect of La Niña phenomena in decreasing chlorophyll-a concentration was stronger in the tuna conservation area than in the southern and northern parts of the study area. The results of the analysis also show that the tuna conservation area had lower water productivity based on chlorophyll-a concentration compared to the northern and southern parts. Water productivity in the Banda Sea is strongly influenced by the ENSO phenomenon. El Niño events result in an increase in upwelling whereas during La Niña events there is a decrease. In upwelling events, there occurs a movement of seawater mass from the bottom layer to surface of the sea bringing nutrients or phytoplankton up to the surface (Ramansyah, 2009; Putra, 2012; Ratnawati, 2017). This causes the concentration of chlorophyll-a to rise at the sea surface.

The results of the analysis show that the high density PFZ point regions were associated with those with higher water productivity based on chlorophyll-a concentration, namely in the southern part of the study site. The low density PFZ point regions corresponds to those with low water productivity/ chlorophyll-a concentration, namely in the tuna conservation area. Seasonal factors, namely the wet season (west monsoon) and the dry season (east monsoon) have a strong influence on the variability of chlorophyll-a concentration/water productivity in the Banda Sea. In the east season, the productivity of chlorophyll-a increases significantly and reaching its peak value in August. In the wet season, chlorophyll-a decreases in productivity, with the lowest levels occurring in December. During the transition from the wet season to the dry season and from the dry season to the wet season, the value of chlorophyll-a

concentration varies (either increasing or decreasing). Chlorophyll-a levels are lowest in April and November. The global phenomena of El Niño and La Niña have a strong influence on productivity variability in the Banda Sea. The El Niño phenomenon results in increased chlorophyll-a concentrations while La Niña events result in decreased chlorophyll-a concentrations. The increases occurring during El Niño are due to the increase in upwelling events which bring nutrients or phytoplankton to the surface of the sea. On the other hand during La Niña events upwelling events decreases due to lower sea surface temperatures than in the layers below.

4 CONCLUSION

The variability of water productivity based on chlorophyll-a concentration in the Banda Sea is influenced by seasonal factors (dry season and wet season) and ENSO phenomena (El Niño and La Niña). In the dry season the water productivity of chlorophyll-a increases and peaks in August. During the wet season and transition period, productivity decreases with the lowest levels occurring in April and December. Water productivity of chlorophyll-a is influenced by global phenomena, namely El Niño and La Niña. In El Niño events chlorophyll-a increases, and in La Niña event it decreases. The high density PFZ point regions were associated with higher water productivity of chlorophyll-a concentration, namely in the southern part of the study area. The low density PFZ point regions corresponded to areas of low chlorophyll-a productivity, namely in the tuna conservation area. The effect of the El Niño phenomenon in increasing chlorophyll-a concentration is stronger in the southern part of study area than in the tuna conservation area while the effect of La Niña in decreasing

chlorophyll-a concentration is stronger in the tuna conservation area than in the southern and northern parts of the study area.

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AUTHOR CONTRIBUTIONS

Analysis of Water Productivity In The Banda Sea Based On Remote Sensing Satellite Data. Lead Author: Sartono Marpaung, Co-Author: Rizky Faristyawan, Anang Dwi Purwanto, Wikanti Asriningrum, Argo Galih Suhadha, Teguh Prayogo, and Jansen Sitorus.

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