HISTORICAL STUDY OF UPWELLING IN BANGGAI WATERS BASED ON REMOTE SENSING DATA

Ulfa Fitriyan[1], Masita Dwi Mandini Manessa[2]*, Faisal Hamzah[3], Marsya J Rugebregt[3], Rina Zuraida[3], Agus S Atmadipoera[4], Supriatna[2]

Article History: Received: 02.10.2022 **Revised:** 23.12.2022 **Accepted:** 17.01.2023

Abstract

The Banda Sea and the Maluku Sea affect the Banggai waters which have a lot of life in them. Because of this, the waters around Banggai are one of the best places for fishing in the world. The productivity of Banggai waters cannot be separated from the influence of the sea, such as the phenomenon of upwelling. Upwelling is an important process that transports nutrients to biological systems connected to food webs in the water column. There are many areas with indications of upwelling in Indonesia, one of which is in the western Maluku Sea near Banggai. This study intends to investigate the characteristics of the upwelling phenomenon by analyzing the historical fertility of Banggai waters through two main indicators, namely sea surface temperature (SST) and chlorophyll-a, using satellite imagery data. Analysis was performed using 4 kilometers SST spatial resolution data (NOAA AVHRR Pathfinder Version 5.3 Collated Global) and chlorophyll concentration (SMI Warna Laut). The results of chlorophyll-a dispersion patterns from 1998 to 2022 were collected in August 2004, 2006 and 2015 at 23 -24°C. This is related to the El-Nino period; El-Nino showed a value of 0.6 in 2004, 0.5 in 2006, and 2.2 in 2015. Based on this study, the distribution of chlorophyll-a in Banggai was greatest during the El Nino period.

***Keywords**: Remote sensing, Upwelling, chlorophyll a*

[1]Department of Marine Science, Faculty of math and Science, University of Indonesia, Depok, Indonesia.
[2]Department of Geography, Faculty of Math and Science, University of Indonesia, Depok, Indonesia
[3]Research Center for Climate and Atmosphere, Research Organization for Earth Sciences and Maritime (ORKM), National Research and Innovation Agency (BRIN), Indonesia
[4]Department of Marine Science and Technology IPB University
Corresponding Email: manessa@ui.ac.id

1. Introduction

Banggai waters is one of the productive areas in Indonesia where its waters are influenced by the Banda Sea and Maluku Sea, causing the waters in the Banggai region to have abundant fishery potential and are rich in fertile ecosystems (Thoha & Rachman, 2013). The location of Banggai waters is in the path of the Indonesian Cross Flow (ARLINDO) or it can also be called the Indonesian Througflow System (ITF). This then affects the mass of water and nutrient levels in Banggai waters originating from the Indian Ocean and the Pacific Ocean (Sprintall et al., 2009; Baars et al., 1990). The monsoon wind system that affects the Banda Sea and Maluku Sea can also affect the condition of the water parameters in Banggai. The mixing of water masses from the Banda Sea and Maluku Sea affects the structure of the zooplankton community and the spatial distribution of the Banggai Sea (Rachman & Asniariati., 2012). This condition creates high productive water thereby creating several areas known as fishery hot spots in Banggai waters.

Several conditions in Banggai waters indicate high potential in the field of fisheries in several seasons. High capture fisheries yields can be characterized by the productivity of the aquatic environment in the region. The presence of complex ecosystems, dynamic flow patterns between islands, and various activities in the archipelago affect nutrient levels, dissolved oxygen and pH, indicators of water fertility and distribution patterns (Simanjuntak, 2012). The productivity of the waters in Banggai is inseparable from the presence of oceanographic factors, one of which is the Upwelling phenomenon. Studies on the distribution of upwelling are very useful for the field of capture fisheries in particular. Several research results show that fishing ground areas in Indonesia that have great potential are areas where there is an upwelling phenomenon (Swara, 2021). As one of them is in the waters of the island of Java in the research of Syamsuddin et al., (2016) which states that the southern waters of the island of Java are a very productive area as a tuna fishing ground due to the upwelling phenomenon. Various upwelling events in the world that are ecologically and economically valuable (Shute et al., 2022a). The seasonal coastal upwelling system in the eastern Great Australian Bight (GAB), which is referenced in valuable research by Shute et al., (2022) supports Australia's largest fishery.

Upwelling is an important phenomenon in the oceans that plays an important role in marine hydrology and marine ecological systems (Zhang et al., 2022). This phenomenon occurs when most of the seawater rises from the base layer to the surface layer (Nybakken, 1988; Rahman & Kunarso, 2022). Ascending cold water makes nutrients available for primary production in the euphotic zone, where mass and energy are transferred through trophic nets resulting in areas rich in terms of biological abundance (Picado et al., 2023) (Dey & Sil, 2023). As a result of the rising mass of seawater from the bottom to the surface, the surrounding waters become fertile and rich in nutrients and support from sufficient sunlight will trigger an increase in phytoplankton (Putra et al., 2017) (Hsiao et al., 2011). Upwelling can occur in the open ocean or in coastal waters, having a different process, where in the open sea upwelling is influenced by the movement of ocean currents which spread from the mass of bottom water rising to the surface to fill the surface and then fill in the empty gaps. While the process of upwelling in coastal waters, namely the occurrence of Ekman divergence due to wind blowing parallel to the coast (Anam & Iskandar, 2022; Kunarso & Ningsih, 2014).

Knowledge of the characteristics of upwelling is very important for the development of better fisheries management, action planning, strategy and protection, fishery resources and coastal environment (Afzal et al., 2023). Moreover, the coastal upwelling zone accommodates most of the fishing grounds worldwide (Wang et al., 2023). Many of the world's upwelling systems are ecologically and economically valuable (Kampf & Chapman, 2016 ; Shute et al., 2022) (Huang & Shi, 2021). Upwelling ecosystems produce more than 20% of the world's fish catch, with less than 3% of the total global ocean area (Benazzouz et al., 2014). Despite covering only 1% of global sea level, upwelling systems contribute ~7% of global primary production and >20% of global fish catch (Varela et al., 2018) this is disputable because upwelling can affect biosynthetic ability and expression of growth-related genes in fish (Zuloaga, 2018). The resulting upwelling phenomenon is usually characterized by low sea surface temperatures and increased distribution of chlorophyll-a. Not a few studies on upwelling with two parameters of temperature and chlorophyll have been carried out in Indonesia, but there is still very little discussion of this issue in Banggai waters.

Regarding the explanation above, it is important to study the phenomenon of upwelling in the Banggai waters of the Maluku Sea by studying the historical fertility of the Banggai waters by looking at the parameters of sea surface temperature and chlorophyll-a. In the narrative of water fertility, chlorophyll-a and sea surface temperature play an important role in the primary productivity of waters. The effect of sea surface temperature on the growth of phytoplankton indirectly affects the concentration of chlorophyll-a in the waters (Sidik et al., 2015). This study was conducted using NOAA AVHRR Pathfinder version 5.3 collated global (SST) for the last 40 years and Ocean Color SMI image data (chlorophyll-a concentration) for the last 24 years, both of which have a spatial resolution of 4 km. The existing image data was then validated with field data related to the distribution of chlorophyll-a and sea surface temperature in Banggai-Maluku.

2. Methods

Location and time of research

The location of this research is in the waters of Banggai - West Maluku Sea, the southern part of Taliabu waters, and around the Peleng Strait. In this study, the data collected was field data of water samples using the CTD (Conductivity Temperature Depth) tool to determine the distribution of Chlorophyll-a and Sea Surface Temperature which were used to validate the image data taken. Field data was conducted from 4 September to 17 September 2022, using the Baruna Jaya VIII research vessel. This research is part of the Expedition "Banggai Upwelling Dynamic Ecosystem Experiment" organized by the National Innovation Research Agency (BRIN).

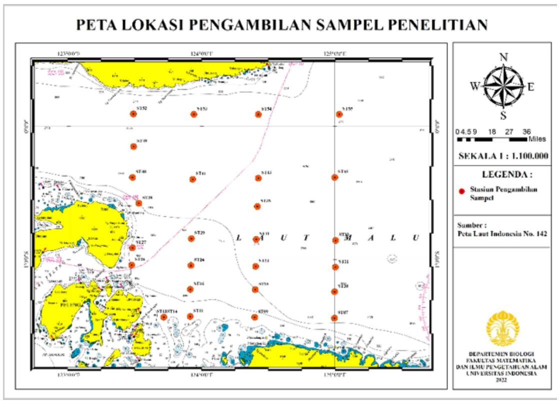

Figure 1. Map of Research Locations, red dots represent observation stations.

Research Variables

The variables used in this study can be seen in the following table:

Table 1. Research Variables

No	Variable	Definition	Focus
1.	Chlorophyll-a	Chlorophyll-a is a leaf green substance found in all plants plays a role in the process of converting light energy into chemical energy, this process known as photosynthesis is closely related to phytoplankton abundance (Hestiningsih *et al.*, 2017; Nybakken, 1992)	Distribution and concentration of chlorophyll-a
2.	Sea Surface Temperature	Sea surface temperatures can affect the oceanic atmospheric system globally (Z. Xu et al., 2021). So that the parameter of sea surface temperature is widely referred to as one of the important factors in the life of marine life.	Sea surface temperature variability
3.	*Upwelling*	Upwelling is defined simply as a physical oceanographic process in which warmer surface water is replaced by cooler, nutrient-rich water flowing from deeper layers (Atmadipoera *et al.*, 2020; Arhan *et al.*, 2000)	Historical Upwelling

Data Acquisition

Data acquisition in this study is divided into 3, namely image data acquisition, field data acquisition as a ground check, and supporting data.

Acquisition of Image Data

Image data acquisition is used to determine the distribution of chlorophyll-a and to determine sea surface temperature variability. The process used in performing image processing, namely

Acquisition of Field Data

During the ground check, environmental parameters such as physical and chemical parameters were measured. The data collection process for measuring environmental parameters for water sampling uses a CTD tool which consists of 8 rosette bottles, and each bottle has a water sample that can be taken from different depths in the range of 100 m – 5m. By using this CTD tool, we have obtained some data that has been recorded via computer, such as: Depth Chl max, sea surface temperature, salinity, and current speed.

Supporting Data

Oceanic Nino Index or ONI Index data is used to view La Nino and El Nino climate periods, climate anomaly phenomena on a global scale.

Data Processing

Image Data Processing:

Processing of sea surface temperature image data using NOAA AVHRR Pathfinder version 5.3 collated global (SPL) for the last 40 years and Ocean Color SMI image data (chlorophyll-a concentration) for the last 24 years, both of which have a spatial resolution of 4 km. The two data were processed using Google Earth Engine.

Field Data Processing:

Field data processing of chlorophyll-a concentration (Hutagalung et al., 1997)

Work procedures:

1. The process of taking water samples using a CTD tool consisting of eight rosette bottles. In each rosette bottle the water samples taken have different depths. In taking water samples to obtain chlorophyll-a content, we need water samples from a depth of 100 m – 5 m. then for the number of water samples required is as much as 3 – 4 liters. This is because the water sampling location is offshore where the oceanic waters contain relatively little phytoplankton.
2. After the sampling process, 4 liters of water samples were filtered using a vacuum pump, starting by placing 0.2 mm filter paper.
3. Rinse with a solution of magnesium carbonate into the filter holder ± 10 ml and then suck back the distilled water until the filter looks dry.
4. Take the filter results (filter paper) and wrap it using aluminum foil then label it and put it in the freezer if the next analysis process is not carried out.
5. Add 10 ml of 90% acetone into a 15 ml centrifuge tube containing the sample (filter results) then store in a light-tight room for 6 hours until the sample dissolves.
6. Grind the dissolved sample until smooth into a centrifuge grinder with a rotation of 4000 rpm for 30-60 minutes.
7. 7Check the crushed clear liquid by pouring the liquid into a 1 cm cuvette (10 cm, 15 cm) and check the absorbance with a spectrophotometer at wavelengths of 750, 664, 647 and 630 nm.
8. The process of taking water samples using a CTD tool consisting of eight rosette bottles. In each rosette bottle the water samples taken have different depths. In taking water samples to obtain chlorophyll-a content, we need water samples from a depth of 100 m – 5 m. then for the number of water samples required is as much as 3 – 4 liters. This is because the water sampling location is offshore where the oceanic waters contain relatively little phytoplankton.
9. After the sampling process, 4 liters of water samples were filtered using a vacuum pump, starting by placing 0.2 mm filter paper.
10. Rinse with a solution of magnesium carbonate into the filter holder ± 10 ml and then suck back the distilled water until the filter looks dry.
11. Take the filter filter results (filter paper) and wrap it using aluminum foil then label it and put it in the freezer if the next analysis process is not carried out
12. Add 10 ml of 90% acetone into a 15 ml centrifuge tube containing the sample (filter results) then store in a light-tight room for 6 hours until the sample dissolves.
13. Grind the dissolved sample until smooth into a centrifuge grinder with a rotation of 4000 rpm for 30-60 minutes.
14. Check the crushed clear liquid by pouring the liquid into a 1 cm cuvette (10 cm, 15 cm) and check the absorbance with a spectrophotometer at wavelengths of 750, 664, 647 and 630 nm.

Data Analysis

Remote Sensing Data Analysis:

Monthly SST and chlorophyll-a images are displayed using application software. The SST and chlorophyll-a data are then displayed to determine the spatial and temporal distribution (in graphical form) of the SST data and chlorophyll-a concentration. Areas where upwelling occurs have temperature indicators <27 °C and chlorophyll-a concentrations >0.4 mg/m3.

Field Data Analysis of Chlorophyll-a Concentration (Hutagalung et al., 1997):

To calculate the chlorophyll concentration, the absorbance of the measured wavelengths (664,647 and 630 nm) is reduced by the absorbance at the wavelength of 750 nm. Absorbance reduction at each wavelength is carried out to obtain the absorbance value carried out by chlorophyll, because at a wavelength of 750 nm there is no absorption carried out by chlorophyll (only the sample turbidity factor). Chlorophyll content is calculated using the following formula:

$$\frac{\{(11,85\, x\, E664) - (1,54\, x\, E647) - (0,08 x E630)\}\, x\, Ve}{Vs\, x\, d}$$

Information:

E664 : Absorbance 664 nm - Absorbance 750 nm

E647 : Absorbance 647 nm - Absorbance 750 nm

E630 : Absorbance 630 nm - Absorbance 750 nm

Ve : Acetone Volume = 10 ,mL

Vs : V filtered water sample = 4 L

D : cuvette diameter width = 4 cm

Correlation Test Analysis

Statistical tests were conducted to obtain a correlation between *upwelling parameters and to obtain the relationship* of upwelling phenomena with the ENSO period and the number of fish catches. The relationship between SPL, chlorophyll-a and *upwelling* area with ENSO or catch amount is calculated using the Pearson Correlation equation technique (Pearson, 1895).

$$r_{XY} = \frac{n\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{\{n\Sigma X^2 - (\Sigma X)^2\}\{n\Sigma Y^2 - (\Sigma Y)^2\}}}$$

Information:

r : Pearson correlation coefficient

x : Variable SPL, Chlorophyll-a, *Upwelling*

y: Enso variable

n : Number of samples

The interpretation of the strength of the relationship between two variables is divided into several criteria based on the value of the correlation coefficient in (Table 1).

Table 2. The value of the strength of the relationship results from the Pearson correlation coefficient

Correlation Coefficient	Relationship Interpretation
0	No Correlation
0.00-0.25	Very weak correlation
0.25-0.50	Correlation is sufficient
0.50-0.75	Strong correlation
0.75-0.99	Very high correlation
1	Perfect

3. Results and Discussion

Sea Surface Temperature

Temperature is one of the determining factors in the metabolic process of organisms in the waters. Water temperature can change according to the season, the latitude of an area, the location of the place in relation to the sun's orbit, air circulation, cloud cover, water flow, time of measurement, and water depth (Schaduw et al., 2013). According to Setiadi et al., (2020), Indonesian waters are generally heavily influenced by the west monsoon which occurs from December to February and is followed by the first transitional season, namely March to May, and the east monsoon which occurs from June to August and followed by a second transitional season, from September to November. In general, sea surface temperature conditions (Figure 2) in Banggai waters for the last 40 years have shown varying results. Changes in sea surface temperature that occur at different places and times during the study may be caused by seasonal patterns, and these changes result in differences in biological activity in the sea (N. Xu et al., 2010). So that it does not show the same pattern every year, this difference is thought to be due to the IOD and ENSO phenomena in these waters every year (Hestiningsih et al., 2017). According to Kida & Richards (2009), sea surface temperature variations can be influenced by oceanographic factors, namely currents, tides, meteorological factors, and local factors such as seabed topography, as well as by meteorological factors such as monsoons and air temperature.

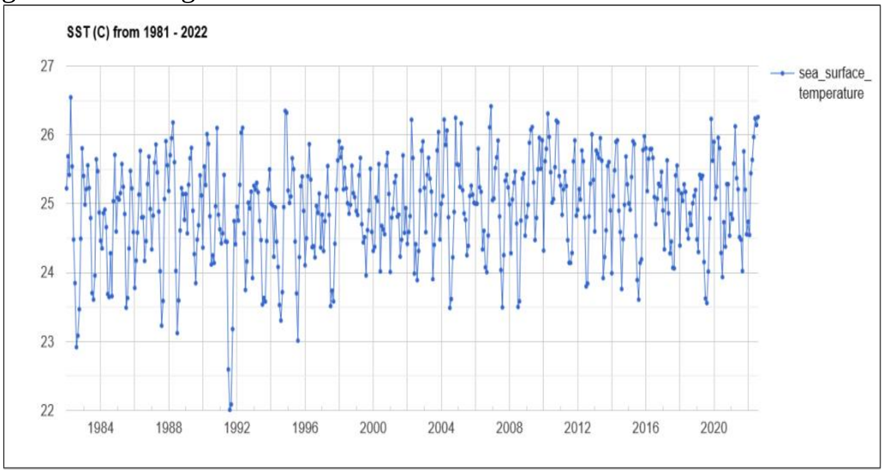

Figure 2. Graph of the distribution of sea surface temperatures in Banggai-Maluku waters in 1984-2022

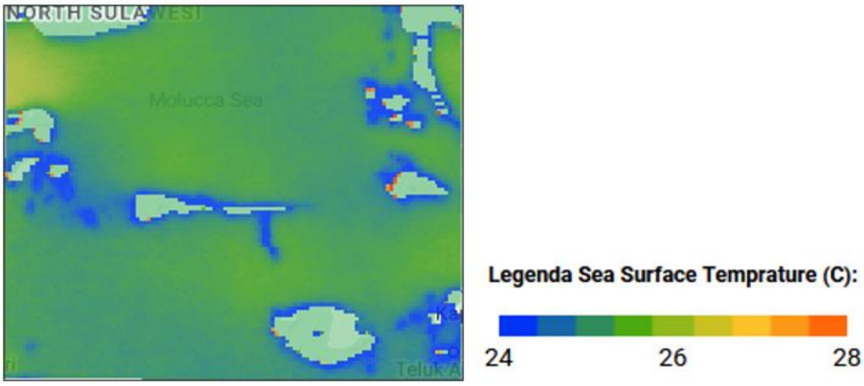

Figure 3. Sea Surface Temperature Spatial Data

In Figure 2 is a graph of the distribution of sea surface temperature in the long term where each month has a different temperature intensity. From the prediction of the intensity of sea surface temperature generated in the last 40 years, this can be a way to see the characteristics or dynamics of upwelling in the future and will make it easier to make policy decisions easier (Alonso Del Rosalio et al., 2019). Then in Figure 3 shows the spatial data of sea surface temperature where we can find out which water areas have high or low intensity. The closer to the land area or it can be called the coastal area the lower the sea surface temperature. This can occur due to the wind that moves the water masses in Banggai waters. Coastal upwelling flows are major oceanographic features driven primarily by wind (Huang et al., 2023). The movement of the wind with a sufficiently strong intensity can result in mixing of the bottom water mass with the top layer water mass so that the intensity of the temperature distribution becomes homogeneous (Tubalawony, 2008). The main drivers behind upwelling are wind interactions, the Coriolis Effect, and Ekman transport (Fallah & Mansoury, 2022; Patel et al., 2020) (Ito et al., 2023).

Distribution of Chlorophyll-a in Banggai-Maluku Waters

The upwelling process can be inferred from the spatial and temporal distribution of chlorophyll-a concentrations. Kristiyani et al., (2020) said that chlorophyll-a is an important part of how the main producers in the marine environment are made. Based on the graph of the distribution of chlorophyll-a in Figure 4, it can be seen that the highest concentration value of chlorophyll-a was found in 2004 with a concentration value of 0.52 mg/m3, in 2006 with a concentration value of 0.47 mg/m3, and in 2015 with a concentration value of 0.49. In those years, the highest chlorophyll-a peak occurred in August. The average amount of chlorophyll-a in Banggai waters was quite stable from January to May. It doesn't go up or down. The distribution of chlorophyll-a then increased gradually from June to August until it reached a peak of 0.49 mg/m3. again in September to December. The distribution of the highest average chlorophyll-a values occurred in August due to a change in the dominant wind direction from Asia to Australia, so that the maximum average chlorophyll-a values occurred in August. Upwelling occurs in the summer from June to August due to the southwest monsoon (Jing et al., 2011; Zeng et al., 2014).

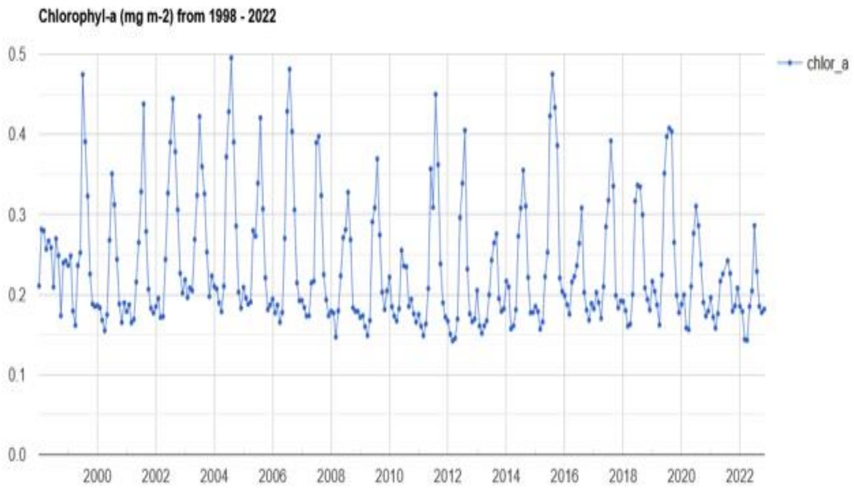

Figure 4. Graph of Distribution of Chlorophyll-a in Banggai-Maluku Waters in 2000-2022

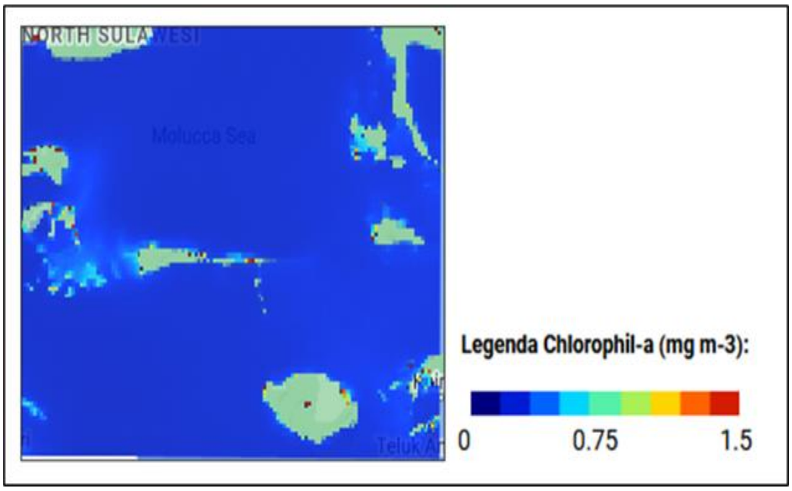

Figure 5. Spatial Data of Chlorophyll-a

The results of field measurements conducted in September 2022 at 27 observation stations showed that the distribution of chlorophyll-a concentrations (Figure 6) showed the highest concentration, namely 0.65-0.82 mg/m3. The highest concentration of chlorophyll-a was found at stations 7 and 54 which were near islands or the mainland. This happens because of the large supply of nutrients from the mainland. Whereas in open water, the value of chlorophyll concentration is lower due to the lack of direct nutrient supply from the land, so that the value of addition to nutrients originating from land, nutrients also accumulate in the surface layer along with the increase in deep water mass. This means that the high productivity of the high seas is growing en masse. Higher nutrient levels lead to higher primary productivity, followed by higher chlorophyll a concentrations as well. When upwelling occurs, sea surface temperatures decrease and surface chlorophyll and nutrient concentrations increase.

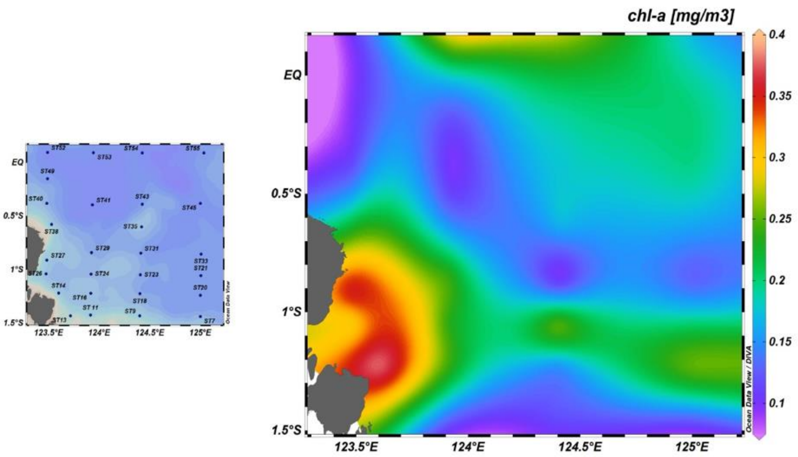

Figure 6. Spatial interpolation of chlorophyll-a value observations based on ground check on September 4 – 17, 2022

Based on the results of image distribution of chlorophyll-a distribution patterns from 1998 to 2022, it was collected in August 2004, 2006 and 2015 at a temperature range of 23-24°C. This is related to the El-Nino period; El-Nino showed a value of 0.6 in 2004, 0.5 in 2006, and 2.2 in 2015. In these years there was an El-Nino period from July to December. Based on this study, the greatest distribution of chlorophyll-a in Banggai occurred during the El Nino period. When El Nino occurs, the temperature in Indonesian waters is lower than the normal year, and when La Nina occurs, the temperature in Indonesian waters is warmer than the normal year. Due to changes in SST, the concentration of chlorophyll-a in Indonesian waters also fluctuates. During El-Nino, chlorophyll-a conditions are higher than normal years, whereas during La Nina events, chlorophyll-a in Indonesian waters is lower than normal years (Pratama, 2014). When SST and chlorophyll-a change during different global climate events, the upwelling intensity and duration will be different. In El Nino events, upwelling develops more widely than normal years, whereas in La Nina events, upwelling events last shorter, and the area is narrower than normal years. Upwelling occurs during summer, bringing cold, salty, and nutrient-rich water to the surface and thus resulting in high marine productivity (Shi et al., 2019). In research (Putri et al., 2021) states that upwelling is strong during El-Nino times and weak during La-Nina times. So it can be said that the effect of ENSO is very significant on the characteristics and dynamics of upwelling (Gao et al., 2022). The interannual variability of upwelling has shown a close relationship with climate change and El Niño events (Sydeman et al., 2014; Wang et al., 2015).

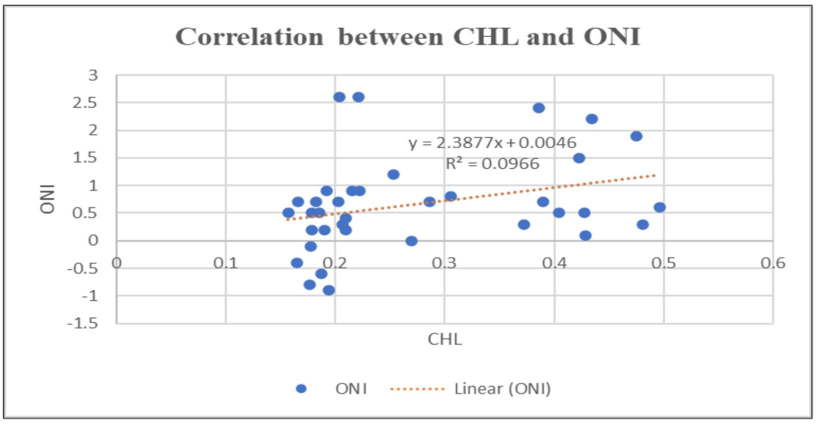

Figure 7. Correlation of Chlorophyll-a and ONI Index

The Pearson correlation test was used in this study to obtain correlation results between the SST variables and Chlorophyll-a which showed a correlation strength value of -0.822. This value is included in the category of "strong correlation". While the negative sign on the correlation value indicates the opposite direction of correlation between the two variables, the lower the SST value, the higher the chlorophyll-a value. As for the chlorophyll-a variable with the ONI index, it shows a correlation value of 0.31, meaning that the interpretation of the correlation relationship is sufficient.

4. Conclusion

Results of chlorophyll-a dispersion patterns from 1998 to 2022 were collected in August 2004, 2006, and 2015, with an average chlorophyll concentration of 0.49 mg/m3 and a sea surface temperature range of 23–24°C. This is related to the El-Nino period; El-Nino showed a value of 0.6 in 2004, 0.5 in 2006, and 2.2 in 2015. Based on this study, the distribution of chlorophyll-a in Banggai was greatest during the El Nino period.

References

Afzal, F. G., Hasanlou, M., & Rajabi-Kiasari, S. (2023). Monitoring and estimating coastal upwelling using Sentinel-3 satellite imagery (case study: The Caspian Sea). *Continental Shelf Research*, *261*, 105010.

Alonso Del Rosario, J. J., Vidal Pérez, J. M., & Blázquez Gómez, E. (2019). On the Prediction of *Upwelling* Events at the Colombian Caribbean Coasts from Modis-SST Imagery. *Sensors (Basel, Switzerland)*, *19*(13). https://doi.org/10.3390/s19132861

Anam, K., & Iskandar, I. (2022). Analisis Dinamika Upwelling Di Selatan Jawa Dan Barat Sumatera Pada Kejadian Iod Positif Tahun 2019 (*Doctoral Dissertation*, Sriwijaya University).

Benazzouz, A., Mordane, S., Orbi, A., Chagdali, M., Hilmi, K., Atillah, A., ... & Hervé, D. (2014). An improved coastal upwelling index from sea surface temperature using satellite-based approach–The case of the Canary Current upwelling system. *Continental Shelf Research*, *81*, 38-54.

Dey, S., & Sil, S. (2023). Spatio-temporal variability of coastal upwelling using high resolution remote sensing observations in the Bay of Bengal. *Estuarine, Coastal and Shelf Science*, 108228.

Fallah, F., Mansoury, D., 2022. Coastal upwelling by wind-driven forcing in the Caspian Sea: a numerical analysis. Oceanologia. https://doi.org/10.1016/j.oceano.2022.01.003.

Gao, W., Wang, Z. Y., Zhang, R. H., & Huang, H. J. (2022). Variability of the Mindanao Dome upwelling system during ENSO event from 2010 to 2015. *Deep Sea Research Part I: Oceanographic Research Papers*, *189*, 103875.

Hestiningsih Yudo Prasetyo, B. S. A. W. (N.D.). *Identifikasi Kawasan*

Upwelling Berdasarkan Variabilitas Klorofil-A, Suhu Permukaan Laut Dari Data Citra Aqua Modis Tahun 2003-2015 Dan Arus (Studi Kasus: Perairan Nusa Tenggara Timur). Jurnal Geodesi Undip, 6(1), 189-198.

Hsiao, S. H., Kâ, S., Fang, T. H., & Hwang, J. S. (2011). Zooplankton assemblages as indicators of seasonal changes in water masses in the boundary waters between the East China Sea and the Taiwan Strait. *Hydrobiologia*, *666*, 317-330.

Huang, C., Yang, Y., Chen, F., Kong, D., Xu, J., Chen, C., ... & Huang, X. (2023). External forcing mechanisms controlling the Qiongdong upwelling in the northern South China Sea during the Holocene. *Global and Planetary Change*, *220*, 104021.

Huang, Z., Hu, J., & Shi, W. (2021). Mapping the coastal upwelling east of Taiwan using geostationary satellite data. *Remote Sensing*, *13*(2), 170.

Ito, W., Nakayama, K., & Shintani, T. (2023). Coriolis effects on wind-driven upwelling in enclosed basins. *Continental Shelf Research*, *256*, 104956.

Jing, Z., Qi, Y., & Du, Y. (2011). Upwelling in the continental shelf of northern South China Sea associated with 1997–1998 El Niño. *Journal of Geophysical Research: Oceans*, *116*(C2).

Kida, S., & Richards, K. J. (2009). Seasonal Sea Surface Temperature Variability In The Indonesian Seas. *Journal Of Geophysical Research: Oceans*, *114*(6). Https://Doi.Org/10.1029/2008jc005150

Kristiyani, H. N., Jayanto, B. B., & Setyawan, H. A. (2020). Analisis Hubungan Parameter Suhu Permukaan Laut Dan Klorofil-A Terhadap Hasil Tangkapan Ikan Teri (Stolephorus Sp) pada Alat Tangkap Bundes (Danish Seine) di Perairan Kota Tegal Jawa Tengah. *Journal of Fisheries Resources Utilization Management and Technology*, *9*(1), 13-24.

Picado, A., Vaz, N., Alvarez, I., & Dias, J. M. (2023). Modelling coastal upwelling off NW Iberian Peninsula: New insights on the fate of phytoplankton blooms. *Science of The Total Environment*, *874*, 162416.

Pradana Putra, D., Amin, T., & Putri Asri, D. (2017). Analisis Pengaruh Iod Dan Enso Terhadap Distribusi Klorofil-A Pada Periode Upwelling Di Perairan Sumbawa Selatan. In *Jurnal Meteorologi Klimatologi Dan Geofisika* (Vol. 4, Issue 2). Http://Www.Cpc.Ncep.Noaa.Gov.

Pratama, I. , & K. N. (2014). (N.D.). *Aplikasi Penginderaan Jauh Multitemporal Untuk Monitoring Kejadian Upwelling Di Perairan Bagian Selatan Pulau Jawa-Laut Timor. Jurnal Bumi Indonesia, 3(3).*

Putra, D., Amin, T., & Putri Asri, D. (2017). Analisis Pengaruh Iod Dan Enso Terhadap Distribusi Klorofil-A Pada Periode Upwelling Di Perairan Sumbawa Selatan. In *Jurnal Meteorologi Klimatologi Dan Geofisika* (Vol. 4, Issue 2). Http://Www.Cpc.Ncep.Noaa.Gov.

Putri, I. W., Wirasatriya, A., Kunarso, Ramdani, F., Jalil, A. R., & Prasetyawan, I. B. (2021). The El Nio Southern Oscillation (ENSO) Effect on *Upwelling* in the North Maluku Sea. *IOP Conference Series: Earth and Environmental*

Rachman, A., & Asniariati, E. (2012). Zooplankton Spatial Distribution and Community Structure in Banggai Sea. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, *4*(2).

Rachman, A., Asniariati, E., Pasir, J., Timur, A., & Utara, J. (2012). Zooplankton Spatial Distribution And Community Structure In Banggai Sea. In *Jurnal Ilmu Dan Teknologi Kelautan Tropis* (Vol. 4, Issue 2). Http://Itk.Fpik.Ipb.Ac.Id/Ej_Itkt42

Rahman, I., Studi Ilmu Kelautan, P., Perikanan Dan Ilmu Kelautan, J., & Pertanian, F. (N.D.). *Keterkaitan Antara Fenomena Upwelling Dan Jumlah Tangkapan (Hook Rate) Tuna Di Perairan Selatan Pulau Jawa-Bali*. *2*(1), 20–28. Http://Oceancolor.Gsfc.Nasa.Gov/.

Ramansyah, (2009). Penentuan Pola Sebaran Konsentrasi Klorofil-A Di Selat Sunda Dan Perairan Sekitarnya Dengan Menggunakan Data Inderaan Aqua Modis. *Agris.Fao.Org*.

Schaduw, J. N. W., Ngangi, E. L. A., & Mudeng, J. D. (2013). Land Suitability Of Seaweed Farming In Minahasa Regency, North Sulawesi Province Kesesuaian Lahan Budidaya Rumput Laut Di Kabupaten Minahasa, Provinsi Sulawesi Utara. *Aquatic Science & Management*, *1*(1), 72–81. Http://Ejournal.Unsrat.Ac.Id/Index.Php/Jasm/Index

Setiadi, N. L., Schaduw, J. N. W., Luasunaung, A., Tilaar, F. F., Manoppo, L., Tumbol, R. A., & Sumilat, D. A. (2020). Analysis Of Upwelling Event Based On Satellite Imagery In Fishery Management Area (FMA) 716. *Jurnal Ilmiah PLATAX*, *8*(2), 242-250.

Shi, R., Cai, Q., Dong, L., Guo, X., & Wang, D. (2019). Response of the diurnal cycle of summer rainfall to large-scale circulation and coastal upwelling at hainan, south China. *Journal of Geophysical Research: Atmospheres*, *124*(7), 3702-3725.

Shute, A., Kämpf, J., Doubell, M., Rodriguez, A. R., Möller, L., Baring, R., & Newman, M. (2022). Variability Of Surface And Subsurface Phytoplankton Blooms In A Seasonal Coastal Upwelling System. *Continental Shelf Research*, *246*. Https://Doi.Org/10.1016/J.Csr.2022.104832

Sidik, A., Agussalim, A., & Moh Rasyid Ridho, (2015). Registrasi: 21 Mei 2013; Diterima Setelah Perbaikan. In *Juni* (Vol. 7, Issue 2).

Simanjuntak Bidang Dinamika Laut, M., & Oseanografi-Lipi, P. (2012). Sea Water Quality Observed From Nutrient Aspect, Dissolved Oxygen And Ph In The Banggai Waters, Central Sulawesi. In *Jurnal Ilmu Dan Teknologi Kelautan Tropis* (Vol. 4, Issue 2). Http://Itk.Fpik.Ipb.Ac.Id/Ej_Itkt42

Sprintall, J., Wijffels, S. E., Molcard, R., & Jaya, I. (2009). Direct estimates of the Indonesian Throughflow entering the Indian Ocean: 2004–2006. *Journal of Geophysical Research: Oceans*, *114*(C7).

Sugiyono. 2003. Metode Penelitian Administrasi. Bandung : Alfabeta

Supyan, S., Susanto, A. N., & Malik, F. R. (2020). Hubungan Sebaran Suhu Permukaan Laut Dan Klorofil-A Dengan Hasil Tangkapan Ikan Cakalang Di Daerah Fishing Ground Bagian Barat Pulau Halmahera. *Jurnal Ilmu Kelautan Kepulauan*, *3*(1).

Swaraa, I. G. M. A., Karanga, I. W. G. A., & Indrawana, G. S. (2021). Analisis Pola Sebaran Area Upwelling di Selatan Indonesia Menggunakan Citra Modis Level 2. Journal of Marine Research and Technology, 4(1), 56-71.

Syamsuddin, M., Saitoh, S. I., Hirawake, T., Syamsudin, F., & Zainuddin, M. (2016). Interannual Variation Of Bigeye Tuna (Thunnus Obesus) Hotspots In The Eastern Indian Ocean Off Java. *International Journal Of Remote Sensing*, *37*(9), 2087–2100. Https://Doi.Org/10.1080/01431161.2015.1136451

Sydeman, W. J., García-Reyes, M., Schoeman, D. S., Rykaczewski, R. R., Thompson, S. A., Black, B. A., & Bograd, S. J. (2014). Climate change and wind intensification in coastal upwelling ecosystems. *Science*, *345*(6192), 77-80.

Thoha, H., & Rachman, A. (2013). The Abundance and Spatial Distribution of Plankton Communities in Banggai Islands Waters. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, *5*(1).

Tubalawony, S. (2008). Dinamika Massa Air Lapisan Ekman Perairan Selatan Jawa--Sumbawa Selama Muson Tenggara. *Torani*, *17*(2), 140–150.

Varela, R., Lima, F. P., Seabra, R., Meneghesso, C., & Gómez-Gesteira, M. (2018). Coastal warming and wind-driven upwelling: a global analysis. *Science of the Total Environment*, *639*, 1501-1511.

Wang, F., Wu, Y., Chen, Z., & Zhang, J. (2023). Nitrogen supply in the upwelling of mid-west region of the South China Sea: The case of mesopelagic fishes. *Ecological Indicators*, *153*, 110427.

Wang, X. L., Cai, X. D., Su, Z. E., Chen, M. C., Wu, D., Li, L., ... & Pan, J. W. (2015). Quantum teleportation of multiple degrees of freedom of a single photon. *Nature*, *518*(7540), 516-519.

Xu, N., Duan, S., Li, A., Zhang, C., Cai, Z., & Hu, Z. (2010). Effects of temperature, salinity and irradiance on the growth of the harmful dinoflagellate Prorocentrum donghaiense Lu. *Harmful Algae*, *9*(1), 13–17. https://doi.org/10.1016/j.hal.2009.06.002

Zeng, X., Belkin, I. M., Peng, S., & Li, Y. (2014). East Hainan upwelling fronts detected by remote sensing and modelled in summer. *International Journal of Remote Sensing*, *35*(11-12), 4441-4451.

Zhang, R., Song, J., Polonsky, A. B., Wang, L., Guo, J., Fu, Y., & Zhang, R. (2022). The spring–neap variability and mechanisms of long-term variations in the upwelling at the tip of Liaodong Peninsula, China. *Regional Studies in Marine Science*, *55*, 102574.

Zuloaga, R., Almarza, O., Vald´es, J.A., Molina, A., Pulgar, J., 2018. Oceanographic upwelling conditions influence signaling pathways involved in muscle growth of intertidal fish. Comp. Biochem. Physiol. B 218, 37–43. https://doi.org/10.1016/j. cbpb.2018.02.001..