

## Spatial-Temporal Variability of Chlorophyll-a Concentration in Cenderawasih Bay and Surrounding Waters

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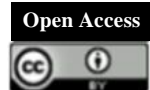
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### Abstract

Chlorophyll-a is one of the parameters determining the primary productivity of water. In the fisheries sector, information on chlorophyll-a concentration in marine waters is very important for the prediction of fishing grounds. This study aims to analyze the variability of chlorophyll-a concentrations in Cenderawasih Bay and the surrounding waters, both spatial and temporal variability. Data from the Aqua-MODIS Level 3 monthly composite period from January to December 2019 was used to determine the concentration of chlorophyll-a. Time-series data are used to determine fluctuations of chlorophyll-a concentrations, while interpolation with the kriging method is used to determine the spatial distribution of chlorophyll-a. The analysis showed that the monthly average value of chlorophyll-a concentration in the study area ranged from 0.1988 – 0.3415 mg.m<sup>-3</sup>. The average value of chlorophyll-a concentration increases from March to June and then decreases in July or August. The highest average chlorophyll-a concentration was in March and the lowest in January. The maximum chlorophyll-a concentration in April and the minimum in August, which is around 9.1089 mg.m<sup>-3</sup> and 0.0975 mg.m<sup>-3</sup>, respectively. The concentration of chlorophyll-a in Cenderawasih Bay and its surrounding waters is dominated by a low concentration, which ranges 0.1482 – 0.3158 mg.m<sup>-3</sup>. Generally, the variability of chlorophyll-a concentrations in the study area is influenced by seasons. The average chlorophyll-a concentration is high in the Transition I (West-east) and East seasons and will decrease in Transition II (East-West) until the West season. Spatially, chlorophyll-a concentrations in coastal areas are higher than in offshore waters. High chlorophyll-a concentrations are found around the border between Nabire Regency and Waropen Regency. The amount of run-off flow that supplies nutrients from the mainland greatly affects the high concentration of chlorophyll-a in the coastal area.

**Keywords:** Chlorophyll-a concentration, Spatial distribution, Aqua-MODIS, Monthly composite, Cenderawasih Bay

### 1. Introduction

In marine waters, chlorophyll-a is identical to the presence of phytoplankton which is the primary food source for marine organisms. All phytoplankton in waters has chlorophyll pigments, especially chlorophyll-a (Castro and Huber, 2007). Therefore, chlorophyll-a is an indicator of the abundance of phytoplankton in waters that is very important in the process of photosynthesis (Zhang and Han, 2015). Ecologically, the chlorophyll of phytoplankton plays an important role as a measure of phytoplankton standing-stock and photosynthetic potential of water (Darecki *et al.*, 2005). Measurement of chlorophyll-a

concentration is one of the fertility parameters of water expressed in primary productivity (Anderson, 2005; Boyer *et al.*, 2009). Therefore, the abundance of phytoplankton as a major producer is very important in the fisheries sector, especially capture fisheries.

At present, monitoring of chlorophyll-a concentrations in marine waters can be done by utilizing remote sensing technology. Chlorophyll-a remote sensing is one way to determine the state of the sea and the processes that occur therein based on the value of the concentration of water-leaving radiance which is the result of interactions between

sunlight and waters received by satellites. The characteristics of chlorophyll-a that can absorb and reflect certain light spectrums are used to detect the distribution of phytoplankton chlorophyll at sea level from satellites. The spectrum of sunlight reaching the sea surface consists of all visible spectra with wavelengths between 400-700 nm (Van Der Woerd and Pasterkamp, 2008). The maximum chlorophyll-a absorbs in the range of 400-500 nm wavelengths, and the maximum reflects in the range of wavelengths 500-600 nm (O'Reilly *et al.*, 1998).

One of the satellite images that can be used to monitor chlorophyll-a concentrations in ocean waters is the Aqua-MODIS (Moderate Resolution Imaging Spectroradiometer) satellite image. The use of Aqua-MODIS satellite data is very good for monitoring the dynamics of chlorophyll-a concentrations in waters because it has a high temporal resolution so that it can be observed periodically and continuously and its distribution patterns can be analyzed (Hamuna *et al.*, 2015). Various studies that have utilized Aqua-MODIS satellite imagery for monitoring chlorophyll-a concentrations, such as Tarigan and Wiadnyana (2013) who observed chlorophyll-a concentrations in Jakarta Bay. Ha *et al.* (2014) and Abbas *et al.* (2019) estimated the concentration of chlorophyll-a in shallow coastal waters. Ali *et al.* (2016) modeling Aqua MODIS data to estimate chlorophyll-a concentrations in the turbid waters of Lake Erie. Wishu and Khoirunnisa (2018) estimating the variability of chlorophyll-a distribution in Belitung Island waters. Abbas *et al.* (2019) estimated the concentration of chlorophyll-a shallow waters in the Chesapeake Bay. Trijayanto and Sukojo (2015) compared chlorophyll-a concentrations using MODIS, VIIRS, and in situ data. Whereas Hanintyo and Susilo (2016) compared chlorophyll-a concentrations of Aqua-Terra MODIS, Landsat-8, and INDES0 satellites.

This study aims to analyze the variability of chlorophyll-a concentrations in Cenderawasih Bay and its surrounding waters, both spatially and temporally, using Aqua-MODIS satellite data. The results of this study can provide information about the distribution pattern of chlorophyll-a concentration in the waters of Cenderawasih Bay and can be used as a basis for further research in the field of marine and fisheries, considering the waters of the Cenderawasih Bay are very potential areas for fishing ground.

## 2. Research Methods

### 2.1 Study Area Description

Cenderawasih Bay is one of the gulf waters located on the border between Papua Province and West Papua Province, Indonesia. Cenderawasih Bay was established as the Cenderawasih Bay National Park, which was definitively determined by Minister of Forestry Decree No. 8009/Kpts-II/2002 on August 29, 2002, with an area of 1,453,500 Ha (Suraji *et al.*, 2015). Administratively, Cenderawasih Bay National Park is located in Teluk Wondama Regency (West Papua Province) and Nabire Regency (Papua Province). Cenderawasih Bay is the largest bay in Indonesia which has a high potential for water resources (BBTNTC, 2009). As a marine national park, most of the biological potential that exists is a diversity of coastal and marine resources.

The waters of the Cenderawasih Bay and the surrounding waters used as the study area are presented in Figure 1. Generally, there are five districts covered by the study area, namely Nabire Regency, Yapen Islands Regency, and Waropen Regency in Papua Province and Teluk Wondama Regency and South Manokwari Regency in West Papua Province.

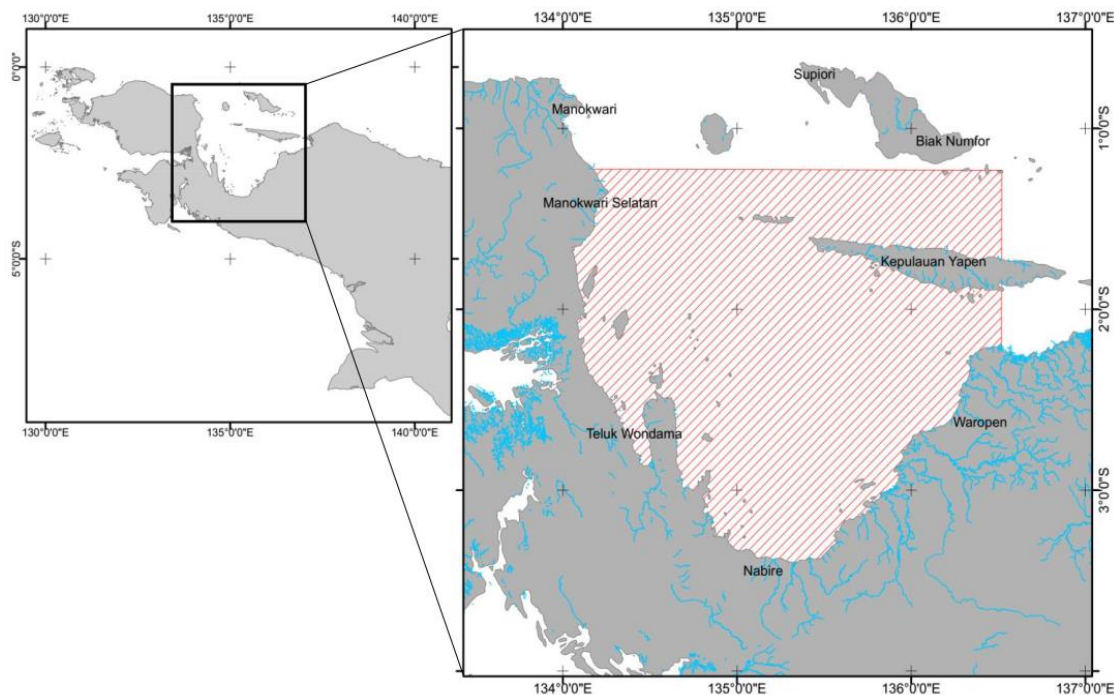


Fig. 1. Map of the study area in Cenderawasih Bay and surrounding waters (Map source: Map of Topographical Indonesia, scale 1:50,000; <https://tanahair.indonesia.go.id/portal-web/>)

## 2.2 Data Acquisition

Data in this study used chlorophyll-a images from the Aqua-MODIS (Moderate Resolution Imaging Spectroradiometer) Level 3 monthly composite from January to December 2019. The chlorophyll-a image downloaded is spatial resolution 4km x 4km in the Hierarchical Data Format (HDF) from the NASA website (<https://oceancolor.gsfc.nasa.gov/l3/>).

## 2.3 Data Processing and Analysis

Image data processing is a way to manipulate image data into the desired output. The chlorophyll-a concentration of Aqua-MODIS Level 3 monthly composites from January to December 2019 obtained is a chlorophyll-a image that has been processed according to the following OC3M algorithm (O'Reilly *et al.*, 2000):

$$C_a = 10^{0.283-2.753R+1.457R^2+0.659R^3-1.403R^4}$$

$$R = \log_{10} \left( \frac{Rrs(443)}{Rrs(550)} > \frac{Rrs(490)}{Rrs(550)} \right)$$

where,  $C_a$  is the concentration of chlorophyll-a ( $\text{mg.m}^{-3}$ ),  $R$  is the reflectance ratio, and  $Rrs$  is the remote sensing reflectance.

The extracted chlorophyll-a image can be displayed in the SeaDAS version 7.2 (SeaWiFS Data Analysis System) software. The stages of image processing carried out begins with cropping according to the research location. The chlorophyll-a image that has been cut according to the location of the study is then carried out the Export Mask Pixels process to obtain the concentration of chlorophyll-a. The chlorophyll-a concentration of each pixel based on the latitude and longitude of the process is obtained in the ASCII (American Standard Code for Information Interchange) format. Furthermore, monthly chlorophyll-a concentration data is tabulated using Microsoft Excel to determine the maximum, minimum, and average monthly chlorophyll-a concentration and then displayed in a time-series graph.

Although the Aqua-MODIS satellite image data used is Level 3, there are still blank pixels (no value) due to cloud cover so they do not have chlorophyll-a concentration values. Therefore, interpolation is needed to get the value of chlorophyll-a concentration in these pixels (Mursyidin *et al.*, 2015). In this study, the interpolation process was carried out using Surfer 11 software. The kriging method was used to interpolate the concentration of chlorophyll-a and to produce a spatial distribution map of chlorophyll-a concentration. Maps of the average distribution of monthly chlorophyll-a concentrations obtained are stored in JPEG format so that they are easily observed visually.

Analysis of chlorophyll-a concentration used in this study is a descriptive analysis that includes temporal and spatial analysis. The temporal analysis was carried out based on the time-series of chlorophyll-a concentrations to determine the temporal fluctuation of chlorophyll-a concentrations in 2019. Spatial analysis was carried out to determine the spatial distribution of chlorophyll-a concentrations in the study area. Spatial analysis was carried out based on

the color degradation of the chlorophyll-a concentration on the map.

## 3. Result and Discussion

### 3.1 Temporal Variability of Chlorophyll-a Concentration

Chlorophyll-a concentrations in Cenderawasih Bay and surrounding waters are shown in Figure 2. There are variations in chlorophyll concentration in the study area, both monthly and seasonal chlorophyll-a concentrations. Monthly average chlorophyll-a concentration ranges from  $0.1988 - 0.3415 \text{ mg.m}^{-3}$ . The highest average chlorophyll-a concentration was in March and the lowest in January. The maximum chlorophyll-a concentration in April and the minimum in August, which is around  $9.1089 \text{ mg.m}^{-3}$  and  $0.0975 \text{ mg.m}^{-3}$ , respectively. Generally, the concentration of chlorophyll-a in Cenderawasih Bay and its surrounding waters is dominated by a low concentration, which ranges  $0.1482 - 0.3158 \text{ mg.m}^{-3}$ . The average chlorophyll-a concentration in the Transition I (West-East) and East Seasons ranged from  $0.2391 - 0.3415 \text{ mg.m}^{-3}$  and decreased in the Transition II Season (East-West) to the West Season with a range of  $0.1988 - 0.2822 \text{ mg.m}^{-3}$ .

The chlorophyll-a concentration obtained in this study was relatively the same as the chlorophyll-a concentration in the waters around the study area. The concentration of chlorophyll-a in-situ in the waters of Teluk Wondama Regency, Manokwari Regency, Biak Numfor Regency, and Tambrauw Regency ranged from  $0.24 - 0.36 \mu\text{g.L}^{-1}$  ( $0.24 - 0.36 \text{ mg.m}^{-3}$ ) (Alianto *et al.*, 2016) and in Doreri Bay, Manokwari Regency ranged from  $0.23 - 3.77 \mu\text{g.L}^{-1}$  ( $0.23 - 3.77 \text{ mg.m}^{-3}$ ) (Alianto *et al.*, 2020). However, it is lower than the chlorophyll-a concentration in Jayapura waters using Landsat 8 data which ranges from  $1.306 - 15.072 \text{ mg.m}^{-3}$  with an average concentration of around  $3.22185 \text{ mg.m}^{-3}$  (Hamuna and Dimara, 2017).

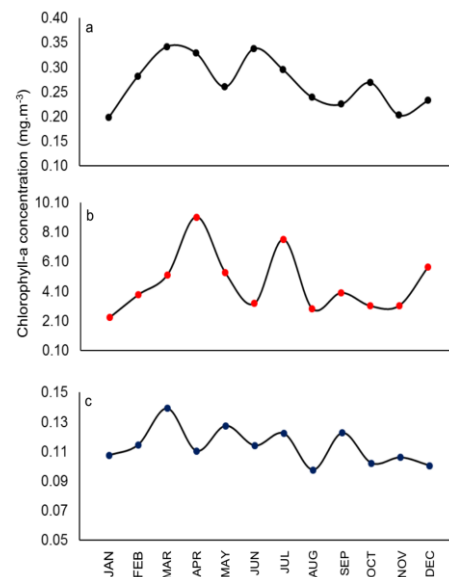


Fig. 2. Temporal variability graph of chlorophyll-a concentration; (a) average concentration, (b) maximum concentration, and (c) minimum concentration



Various research results on the concentration of chlorophyll-a in Indonesian waters using Aqua-MODIS satellite data show a range of varying values. Chlorophyll-a concentrations in southern waters of West Java using Aqua-MODIS Level 3 data ranged from 0.1434 – 1.3689 mg.m<sup>-3</sup> with a dominant range between 0.4 – 1.0 mg.m<sup>-3</sup> (Fitriah and Nahib, 2009). Chlorophyll-a concentrations in the waters of the Madura Strait using Aqua-MODIS data ranged from 2.001 – 3.00 mg.m<sup>-3</sup> (Trijayanto and Sukojo, 2015). Based on the season, the concentration of chlorophyll-a obtained in this study was relatively the same as the concentration of chlorophyll-a in several marine waters in Indonesia. Chlorophyll-a concentrations in the Seram Sea and the Banda Sea are lower in the West Season and Transition I Season, ranging from 0.15 – 0.30 mg.m<sup>-3</sup>, while the concentration of chlorophyll-a in the East and East-West Transition Season ranges between 0.30 – 0.60 mg.m<sup>-3</sup> (Manery, 2014). The research results of Putra *et al.* (2017) showed a higher concentration of chlorophyll-a in August (East Season) compared to the chlorophyll-a concentration in Transition Season II (September – November). Likewise, the results research of Mahabor and Zaky (2016) that the concentration of chlorophyll-a in the southern waters of Aru decreased dramatically in the West Season compared to the previous season.

Based on the trophic status criteria of marine waters referring to Hakanson and Bryann (2008), the Cenderawasih Bay and surrounding waters are dominantly classified as oligotrophic and mesotrophic categories (chlorophyll-a concentration < 6 mg.m<sup>-3</sup>). Besides, the concentration of chlorophyll-a can also be used as an indicator of the fishing ground area. According to Arifin (2009) that the concentration of chlorophyll-a range between 0.26 – 0.29 mg.m<sup>-3</sup> is a good water condition for fishing activities. Specifically, the results of research by Manery (2014) showed that the concentration of chlorophyll-a in areas of high potential, medium potential, low potential, and very low potential for skipjack tuna ranged from 0.40-0.60 mg.m<sup>-3</sup>, 0.20 – 0.40 mg.m<sup>-3</sup>, 0.10 – 0.20 mg.m<sup>-3</sup>, and 0.00 – 0.10 mg.m<sup>-3</sup>, respectively. Based on the dominant chlorophyll-a concentration, the Cenderawasih Bay and its surroundings are in the low to the high potential category for skipjack tuna fishing.

### 3.2 Spatial Distribution of Chlorophyll-a Concentration

Spatially, the distribution of chlorophyll-a concentrations in Cenderawasih Bay and surrounding waters differs between coastal waters and offshore

waters, where coastal waters tend to have higher chlorophyll-a concentrations than offshore waters (Figure 3). The distribution of chlorophyll-a concentrations is almost evenly distributed in offshore waters. While the concentration of chlorophyll-a in coastal waters tends to vary each month, especially in coastal waters around the border between Nabire Regency and Waropen Regency because many large rivers flow around the coastal waters. High concentrations of chlorophyll-a in these waters occur in April, May, July, and August. The maximum and minimum chlorophyll-a concentrations from the interpolation results are presented in Table 1. There are differences in the chlorophyll-a concentration between the data obtained from the Aqua-MODIS satellite imagery and the interpolation results. However, the interpolation results show that the root mean square error (RMSE) is relatively small, ranging from 0.47101 to 1.80772. This shows that the results of the interpolation of chlorophyll-a concentration are quite accurate.

Various research results show that the distribution of chlorophyll-a is relatively the same as the results of this study (Tarigan and Wiadnyana, 2013; Syahdan *et al.*, 2014; Samad *et al.*, 2016; Hamuna and Dimara, 2017). The high distribution of chlorophyll-a concentrations in coastal waters is caused by the presence of a large supply of nutrients through run-off from the mainland, while the low concentration of chlorophyll-a in offshore waters due to the absence of direct nutrient supply from the mainland (Hartuti *et al.*, 2004). The abundance of phytoplankton chlorophyll in a network is highly dependent on the availability of ammonia, nitrates, and silicates (Alianto *et al.*, 2018). The ecological impact of the entry of organic waste from land to estuary causes the waters to become more fertile and an increase in nutrients which is a very important substance in the life of organisms such as phytoplankton (Wang *et al.*, 2015; Wisha and Maslukah, 2017).

The distribution of chlorophyll-a concentrations is also highly correlated with oceanographic conditions (Mann and Lazier, 2006). The abundance and distribution of phytoplankton in the sea as an indicator of chlorophyll-a concentration are not only influenced by nutrients but also the physical conditions of waters such as light penetration, temperature, salinity, and surface currents (Lo *et al.*, 2004; Djumanto *et al.*, 2009), so that abundance is very volatile according to season and location of water (Arinardi *et al.*, 1997). High and low sea surface temperature will affect the intensity of upwelling and chlorophyll-a concentration, especially in offshore waters (Putra *et al.*, 2017).

Table 1. Comparison of chlorophyll-a concentrations between Aqua-MODIS data with the results of interpolation and the RMSE

Data period	Aqua-MODIS L3		Interpolation results		RMSE
	Maximum	Minimum	Maximum	Minimum	
January	2.32029	0.10730	2.32151	0.11060	0.56481
February	3.87149	0.11446	3.98623	0.10899	0.92759
March	5.20729	0.13913	5.20729	0.14325	1.03186
April	9.10892	0.11036	8.74291	0.06953	1.80772
May	5.34494	0.12737	5.26804	0.13106	0.81172
June	3.26698	0.11396	3.07999	0.13288	0.76265
July	7.58811	0.12215	6.33920	0.12514	0.72601
August	2.92509	0.09751	2.78020	0.09410	0.52041
September	3.99518	0.12253	3.78177	0.12314	0.71556
October	3.11472	0.10208	2.93205	0.10682	0.75989
November	3.13050	0.10594	2.87591	0.10579	0.47101
December	5.74047	0.10037	6.92632	0.07853	1.40027

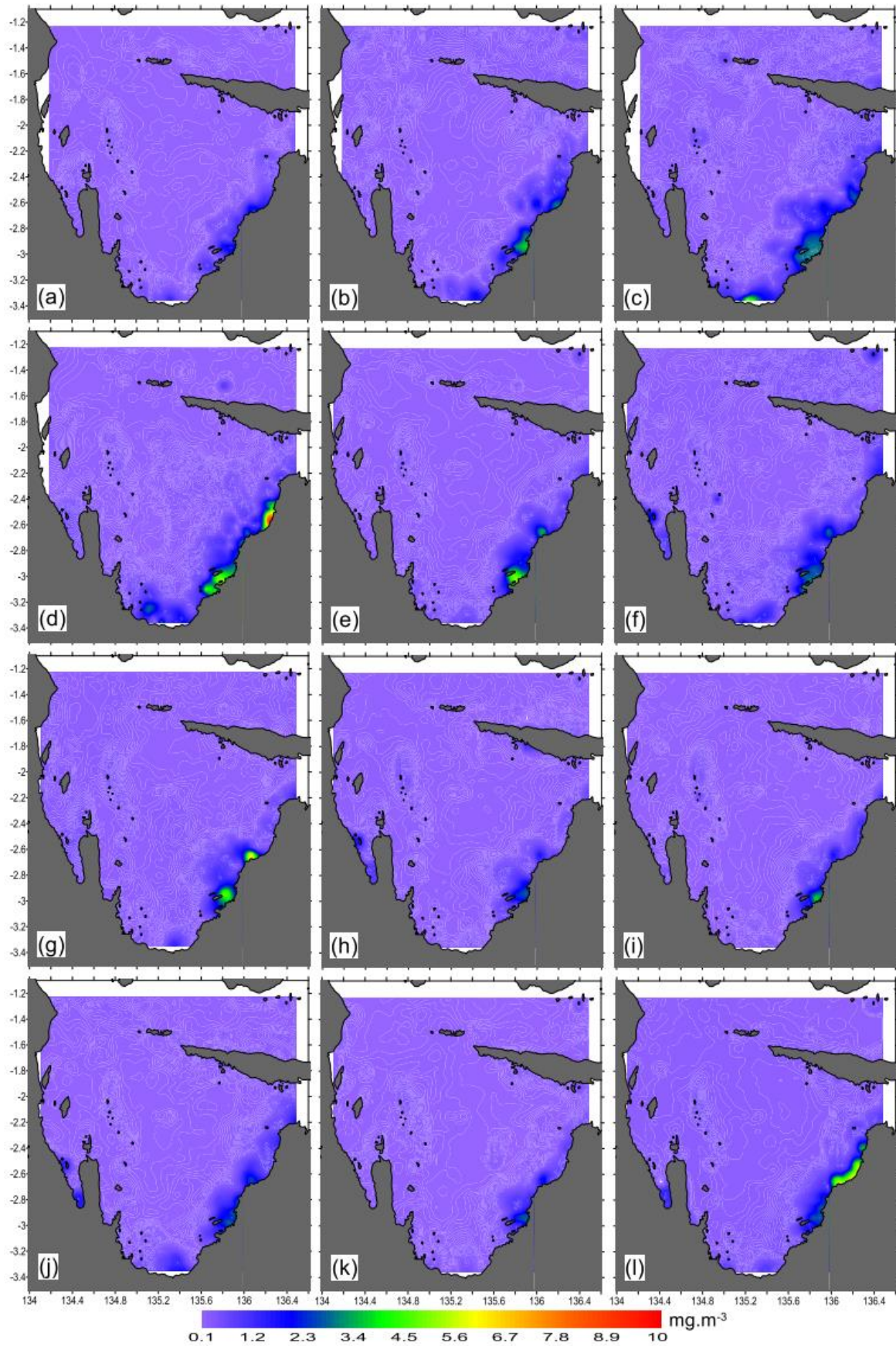


Fig. 3. Spatial distribution of chlorophyll-a concentration in Cenderawasih Bay and surrounding waters; (a) to (l) indicates the period January to December



#### 4. Conclusion

In this study, information has been produced about the variability of chlorophyll-a concentrations in Cenderawasih Bay and surrounding waters, both spatial and temporal variability. The average value of chlorophyll-a concentration increases from March to June and then decreases in July or August. The average value of chlorophyll-a concentration ranged from 0.1988 – 0.3415 mg.m<sup>-3</sup>. The highest average chlorophyll-a concentration was in March and the lowest in January. The concentration of chlorophyll-a in Cenderawasih Bay and its surrounding waters is dominated by a low concentration, which ranges 0.1482 – 0.3158 mg.m<sup>-3</sup>. Generally, the variability of chlorophyll-a concentrations in the study area is influenced by seasons. The average chlorophyll-a concentration is high in the Transition I (West-east) and East seasons and will decrease in Transition II (East-West) until the West season. Spatially, chlorophyll-a concentrations in coastal areas are higher than in offshore waters. High chlorophyll-a concentrations are found around the border between Nabire Regency and Waropen Regency, especially in April, May, July, and December. The amount of run-off flow that supplies nutrients from the mainland greatly affects the high concentration of chlorophyll-a in the coastal area.

#### References

- Abbas, M. M., Melesse, A. M., Scinto, L. J., & Rehage, J. S. (2019). Satellite Estimation of Chlorophyll-a Using Moderate Resolution Imaging Spectroradiometer (MODIS) Sensor in Shallow Coastal Water Bodies: Validation and Improvement. *Water*, 11, 1621.
- Ali, K. A., Ortiz, J., Bonini, N., Shuman, M., & Sydow, C. (2016). Application of Aqua MODIS Sensor Data for Estimating Chlorophyll-a in the Turbid Case 2 Waters of Lake Erie Using Bio-Optical Models. *GIScience & Remote Sensing*, 53(4), 483-505.
- Alianto, Hendri, & Suhaemi. (2018). Kelimpahan dan Kelompok Fitoplankton di Perairan Luar Teluk Wondama, Provinsi Papua Barat. *Jurnal Ilmu dan Teknologi Kelautan Tropis*, 10(3), 683-697.
- Alianto, Kambanussy, Y., Sembel, L., & Hamuna, B. (2020). Akumulasi Biomasa Fitoplankton yang Diukur sebagai Klorofil-a di Perairan Teluk Doreri, Provinsi Papua Barat. *Jurnal Kelautan Tropis*, 23(2), 247-254.
- Alianto, Saleh, F. I. E., Hendri, Suhaemi, Gaité, T., Awak, N. V., & Rumbewas, H. S. R. (2016). Sebaran Klorofil-a di Daerah Fishing Ground Ikan Pelagis Besar Perairan Kepala Burung Pulau Papua. In *Prosiding Seminar Nasional Tahunan XIII Hasil Penelitian Perikanan dan Kelautan: Universitas Gadjah Mada* (pp. PI-11).
- Anderson, T. R. (2005). Plankton Functional Type Modelling: Running Before We Can Walk. *Journal of Plankton Research*, 27(11), 1073-1081.
- Arifin, R. (2009). Distribusi Spasial dan Temporal Biomassa Fitoplankton (Klorofil-a) dan Keterkaitannya dengan Kesuburan Perairan Estuari Sungai Brantas, Jawa Timur. (skripsi).
- Arinardi, O. H., Trimaningsih, Sudirdjo, Sugestingsih, & Riyono, S. H. (1997). *Kisaran Kelimpahan dan Komposisi Plankton Predominan di Perairan Kawasan Timur Indonesia*. Jakarta: Pusat Penelitian dan Pengembangan Oseanologi, LIPI.
- BBTNTC [Balai Besar Taman Nasional Teluk Cenderawasih]. (2009). *Buku Data dan Analisa Zonasi Kawasan Taman Nasional Teluk Cenderawasih*. Balai Besar TNTC, Manokwari.
- Boyer, J. N., Kelbe, C. R., Ortner, P. B., & Rudnick, D. T. (2009). Phytoplankton Bloom Status: Chlorophyll-a Biomass as an Indicator of Water Quality Condition in the Southern Estuaries of Florida, USA. *Ecological Indicators*, 9(6), S56-S67.
- Castro, P., & Huber, M. E. (2007). *Marine Biology*. McGraw-Hill Companies Inc., New York.
- Darecki, M., Kaczmarek, S., & Olszewski, J. (2005). SeaWiFS Chlorophyll Algorithms for the Southern Baltic. *International Journal of Remote Sensing*, 26(2), 247-260.
- Djumanto, Sidabutar, T., Pontororing, H., & Leipary R. (2009). Pola Sebaran Horizontal dan Kerapatan Plankton di Perairan Bawean. *Jurnal Perikanan*, 11(1), 146-161.
- Fitriah, N., & Nahib, I. (2009). Aplikasi Data Inderaja Multi Spektral Untuk Estimasi Kondisi Perairan dan Hasil Tangkapan Ikan Pelagis di Selatan Jawa Barat. *Jurnal Ilmiah Geomatika*, 15(2), 17-31.
- Ha, N. T. T., Koike, K., & Nhuan, M. T. (2014). Improved Accuracy of Chlorophyll-a Concentration Estimates from MODIS Imagery Using a Two-Band Ratio Algorithm and Geostatistics: As Applied to the Monitoring of Eutrophication Processes over Tien Yen Bay (Northern Vietnam). *Remote Sensing*, 6, 421-442.
- Hakanson, L., & Bryann, A. C. (2008). Eutrophication in the Baltic Sea Present Situation, Nutrien Transport Processes, Remedial Strategies. Springer-Verlag, Heidelberg.
- Hamuna, B., & Dimara, L. (2017). Pendugaan Konsentrasi Klorofil-a Dari Citra Satelit Landsat 8 di Perairan Kota Jayapura. *Maspari Journal*, 9(2), 137-146.
- Hamuna, B., Paulangan, Y. P., & Dimara, L. (2015). Kajian Suhu Permukaan Laut Menggunakan Data Satelit Aqua-MODIS di Perairan Jayapura, Papua. *Depik*, 4(3), 160-167.
- Hanintyo, R., & Susilo, E. (2016). Comparison of Chlorophyll-a Measurement Using Multi Spatial Imagery and Numerical Model in Bali Strait. *IOP Conf. Series: Earth and Environmental Science*, 47(2016), 012010.

- Hartuti, M., Prayogi, W., Mulyaningsih, & Manoppo, A. (2004). Implementasi dan Pembinaan Aplikasi Informasi Zona Potensi Penangkapan Ikan di Situbondo dan Makasar. Jakarta: Pusat Pengembangan Pemanfaatan dan Teknologi Penginderaan Jauh, LAPAN.
- Lo, W. T., Hwang, J. J., Hsu, P. K., Hsieh, H. Y., Tu, Y. Y., Fang, T. H., & Hwang, J. J. (2004). Seasonal and Spatial Distribution of Phytoplankton in the Waters off Nuclear Power Plant, North of Taiwan. *Journal of Marine Science and Technology*, 12(5), 372-379.
- Mahabrord, D., & Zaky, A. R. (2016). Analisis Spasial dan Temporal Kesuburan Perairan yang Berpengaruh pada Aktivitas Kapal Ikan di Fishing Ground Selatan Aru dengan Menggunakan Citra MODIS dan RADARSAT-2. *Jurnal Kelautan: Indonesian Journal of Marine Science and Technology*, 9(2), 155-163.
- Manery, M. (2014). Pemetaan Daerah Potensial Penangkapan Ikan Cakalang (*Katsuwonus pelamis*) di Laut Seram dan Laut Banda. (tesis).
- Mann, K. H., & Lazier, J. R. N. (2006). *Dynamics of Marine Ecosystems: Biological-Physical Interactions in the Oceans*. 3rd Edition. Blackwell Publishing Ltd.
- Mursyidin, Munadi, K., & Muchlisin, Z. A. (2015). Prediksi Zona Tangkapan Ikan Menggunakan Citra Klorofil-a dan Citra Suhu Permukaan Laut Satelit Aqua MODIS di Perairan Pulo Aceh. *Jurnal Rekayasa Elektrika*, 11(5), 176-182.
- O'Reilly, J. E., Maritorena, S., Mueller, J. L., O'Brien, M. C., Siegel, D. A., Toole, D., Mitchell, B. G., Kahru, M., Chaves, F. P., Strutton, P., Cota, G. F., Hooker, S. B., McClain, C. R., Carder, K. L., Cargier, F. M., Harding, L., Magnuson, A., Phinney, D., Moore, G. F., Aiken, J., Arrigo, K. R., Letelier, R., & Culver, M. (2000). SeaWiFS Postlaunch Calibration and Validation Analyses, Part 3. NASA Technical Memorandum.
- O'Reilly, J. E., Maritorena, S., Mitchell, B. G., Siegel, D. A., Carder, K. L., Garver, S. A., Kahru, M., & McClain, C. (1998). Ocean Color Chlorophyll Algorithms for SeaWiFS. *Journal of Geophysical Research*, 103(C11), 24937-24953.
- Putra, D. P., Amin, T., & Asri, D. P. (2017). Analisis Pengaruh IOD dan ENSO Terhadap Distribusi Klorofil-a Pada Periode Upwelling di Perairan Sumbawa Selatan. *Jurnal Meteorologi Klimatologi dan Geofisika*, 4(2), 7-15.
- Samad, W., Amran, M. A., Muhiddin, A. H., & Tambaru, R. (2016). Dinamika Spasial Temporal Sebaran Klorofil-a Perairan Selat Makassar Kaitannya dengan Lokasi Penangkapan Ikan. In *Prosiding Seminar Nasional Pengelolaan Perikanan Pelagis di Indonesia: Universitas Brawijaya* (pp. 35-39).
- Suraji, Rasyid, N., Kenyo, A. S. H., Jannah, A. R., Wulandari, D. R., Saefudin, M., Ashari, M., Widiastutik, R., Kuhaja, T., Juliyanto, E., Afandi, A. B., Wiyono, B., Syafrie, H., Handayani, S. N., & Soemodinoto, A. (2015). Profil Kawasan Konservasi Provinsi Papua-Papua Barat. Direktorat Jenderal Kelautan, Pesisir dan Pulau-Pulau Kecil, Kementerian Kelautan dan Perikanan, Jakarta.
- Syahdan, M., Atmadipoera, A. S., Susilo, S. B., & Gaol, J. L. (2014). Variability of surface Chlorophyll-a in the Makassar Strait-Java Sea, Indonesia. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, 14(2), 103-116.
- Tarigan, M. S., & Wiadnyana, N. N. (2013). Pemantauan Konsentrasi Klorofil-a Menggunakan Citra Satelit Terra-Aqua Modis di Teluk Jakarta. *Jurnal Kelautan Nasional*, 8(2), 81-89.
- Trijayanto, D. P., & Sukojo, B. M. (2015). Analisa Nilai Klorofil dengan Menggunakan Data MODIS, VIIRS, dan In Situ (Studi Kasus: Selat Madura). *Geoid*, 11(1), 34-39.
- Van Der Woerd, H. J., & Pasterkamp, R. (2008). HYDROPT: A Fast and Flexible Method to Retrieve Chlorophyll-a from Multispectral Satellite Observations of Optically Complex Coastal Waters. *Remote Sensing of Environment*, 112, 1795-1807.
- Wang, Y., Jiang, H., Jin, J., Zhang, X., Lu, X., & Wang, Y. (2015). Spatial-Temporal Variations of Chlorophyll-a in the Adjacent Sea Area of the Yangtze River Estuary Influenced by Yangtze River Discharge. *International Journal of Environmental Research and Public Health* 12(5), 5420-5438.
- Wisha, U. J., & Khoirunnisa, H. (2018). Variability of Chlorophyll-a Distribution Around Belitung Island Waters Observed by Aqua-MODIS Satellite Data. *Majalah Ilmiah Globè*, 20(2), 77-86.
- Wisha, U. J., & Maslukah, L. (2017). Nutrient Condition of Kampar Big River Estuary: Distribution of N and P Concentrations Drifted by Tidal Bore "Bono". *ILMU KELAUTAN: Indonesian Journal of Marine Science*, 22(3), 137-146.
- Zhang, C., & Han, M. (2015). Mapping Chlorophyll-a Concentration in Laizhou Bay Using Landsat 8 OLI Data. In *Proceedings of the 36th IAHR World Congress: Netherland*.