

Trophic Status Monitoring for the Bangka Strait in Indonesia during the COVID-19 Period Using MODIS Data

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Abstract

Many surface waters in the world are impounded by eutrophication due to the global warming phenomenon. This study analyzed the trophic level in the Bangka Strait, a busy pathway that connects two provinces (Bangka and South Sumatra) of Indonesia, using MODIS-Terra chlorophyll-a (Chl-a) data from the 2020 year. We applied the GIS analysis to generate Chl-a concentration and trophic state maps over the study area. The results of the study revealed that the mesotrophic, eutrophic, and oligotrophic status encompass 50%, 43%, and 7% of the Bangka Strait region, respectively. The highest concentration of Chl-a was observed in May (5.38 g/L), while the lowest was observed in September (3.02 g/L). Our study revealed that the high Chl-a concentration was primarily due to nutrient contributions from South Sumatra rivers. On the other hand, the COVID-19 restriction policy significantly reduced Chl-a from July to October. The trophic state of the Bangka Strait was at a mesotrophic level, and the major contributors to the trophic condition in the strait came from the coasts of South Sumatra, which mostly consisted of agricultural and aquacultural activities. These findings will be useful in developing an effective policy for monitoring and protecting surface waters from eutrophication events.

Keywords

Bangka Strait, Chlorophyll-A, Eutrophication, MODIS, Trophic State

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1. INTRODUCTION

Eutrophication phenomena impend nearly half of the earth's surface, encompassing around 71% of surface waters (Moza-fari et al., 2023). Eutrophication is defined as algal blooms that the aquatic ecosystem attributes to a high number of nutrient emissions (Zhou et al., 2022). This situation led to a change in dissolved oxygen, an increase in fish death, and phytoplankton growth, which finally deteriorated aquatic ecosystem quality and tourism opportunities (Sidabutar et al., 2020). In spite of the significance of aquatic ecosystem function for supporting human life, extensive insight into the eutrophication of seawater is still limited, primarily due to the complications and inadequate data needed to study the large area coverage. Furthermore, in order to improve seawater quality and its ecological services, knowledge of eutrophication variation must be obtained through regular monitoring activities.

Chlorophyll-a (Chl-a) is the most prominent photosynthetic pigment in phytoplankton organisms. It is also known as a useful benchmark for the enrichment of nutrients (Wagle et al., 2019). Therefore, we can use Chl-a to determine

the trophic condition in surface water (Scofield et al., 2020). The usual technique for calculating the Chl-a concentration is to use data from in situ measurements and laboratory analysis (Deng et al., 2019). However, the high cost, laboriousness, and time consumption of this technique make it unsuitable for assessing large water area coverage (Ouma et al., 2020). Therefore, to address this issue, we employ the remote sensing technique, which has the capability to gauge Chl-a levels in extensive water regions. The remote sensing technique can calculate the surface water features that interact with light and transform into an energy spectrum (Gürsoy and Atun, 2019). Several sensors on satellites have shown good performance in calculating the Chl-a based on remote sensing technology, such as the operational land imager, the coastal zone color scanner experiment, the moderate resolution imaging spectroradiometer (MODIS), multi-spectral instrument, and seaviewing wide field of view sensors (Ivanda et al., 2021; Tilstone et al., 2021; Zhang et al., 2024). According to Li et al. (2024), and Wilson et al. (2024), these sensors can measure Chl-a from daily to every two weeks with high temporal resolution and spatial

resolution.

Many studies have focused on Chl-a estimation based on satellite data. Barraza-Moraga et al. (2022) have used the Sentinel-2 satellite to estimate Chl-a concentration in Llanhue Lake, Chile. Bu et al. (2022) used GF-4 data to monitor Chl-a distribution over the Yangtze River, China. Despite the notable results, several questions remain unanswered. For instance, one of the most crucial research gaps was associated with the application of MODIS-Terra satellite data to detect Chl-a variation. Several studies have revealed that the Chl-a data from the MODIS sensor in Aqua and Terra satellites showed an admissible spatial and temporal resolution, so it can be a good indicator to substitute the usual technique for Chl-a observation to estimate eutrophication in large seawater regions (Zhang et al., 2021). In this current study, we aim to examine the spatial and temporal changes in the concentration of Chl-a using the MODIS-Terra data in one of the busiest straits in the Indonesian region, namely the Bangka Strait, from January to December 2020. The Bangka Strait is the most important pathway that connects two developed provinces (South Sumatra and Bangka Belitung). The high migration flow, resource trading, and urban growth in both provinces have made this strait prominent for social and economic roles. Furthermore, our findings can assist authorities in mitigating the rising levels of Chl-a in seawater areas, which are still in their early stages and could potentially exacerbate eutrophication and jeopardize the quality of the aquatic ecosystem in the future.

2. EXPERIMENTAL SECTION

2.1 Study Area

The Bangka Strait is a strait that separates Sumatra Island from Bangka Island, which is located in the waters west of the Java Sea (Figure 1).

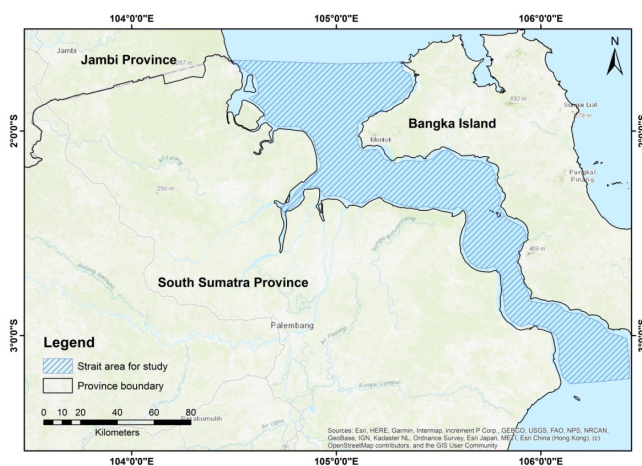


Figure 1. Location of the Study Area.

It has a maximum length of around 216 km and a water depth of about 27 m. This strait serves as the estuary for

several major rivers in the South Sumatra region. Among those major rivers, the Musi River, which is the largest river in South Sumatra, is the primary source of freshwater that enters the Bangka Strait. Currently, due to intense development activities, many coastal areas in South Sumatra are filled with various human activities such as aquaculture and agriculture, which contribute to water pollution. The Bangka Strait is considered a vital region between South Sumatra and Bangka Provinces. For many years, vessels carrying passengers, resources, and daily needs between the two provinces have used the Bangka Strait as their main route, in addition to its use for fisheries. In addition, the Indonesian government is planning to carry out a feasibility study for the construction of a bridge that will cross this strait in early 2029. Therefore, it is important to carry out a study to collect background ecosystem data and monitor present state pollution before the bridge construction takes place. This will monitor the deterioration of the ecosystem due to human activities. A previous study by Napitu et al. (2016) indicated that the south of the Strait region and near Bangka Island show a higher surface temperature and salinity with values of 30-35°C and 31-31.2 psu, respectively. The Bangka Strait is more susceptible to natural and anthropogenic pollution because of its semi-landlocked environment. Over the past decade, the Bangka Strait has witnessed an increase in human pollution activities, posing a significant threat to the marine ecosystem. An increase in population growth and rapid development activities around the Tanjung Api-api port area in South Sumatra for various uses such as aquaculture, settlements, and port development plans implicate more pollution loads on the strait. Furthermore, the increase in urbanization, industrial, and agricultural activities in the Bangka Strait basin was unsustainable, attributing to the discharge of a high number of pollutants into the water, predominantly from the north to the south coasts of Sumatra.

2.2 Data Collection

This study used the MODIS-Terra data from the NASA Ocean Biology Processing Group (<https://oceancolor.gsfc.nasa.gov>) to obtain Chl-a concentrations over the Bangka Strait. This study applied the monthly Level-3 standard mapped images from MODIS-Terra for the study period (Jan-Dec 2020), which included the COVID-19 period. We combined the satellite images into a 9-kilometer grid and made them available online on the NASA Ocean Biology website. We conducted the spatial analysis of Chl-a concentration over the study area using a combination of SeaDas 8.3 and ArcGIS 10 software. Firstly, we clipped the study area using the subset tool and created a polygon of the study area to extract Chl-a values and coordinates from each pixel using SeaDas software. We then processed the Chl-a values in ArcGIS software using the Kriging interpolation technique to create the Chl-a raster map. We produced the Chl-a raster map for each month in the 2020 year. As a

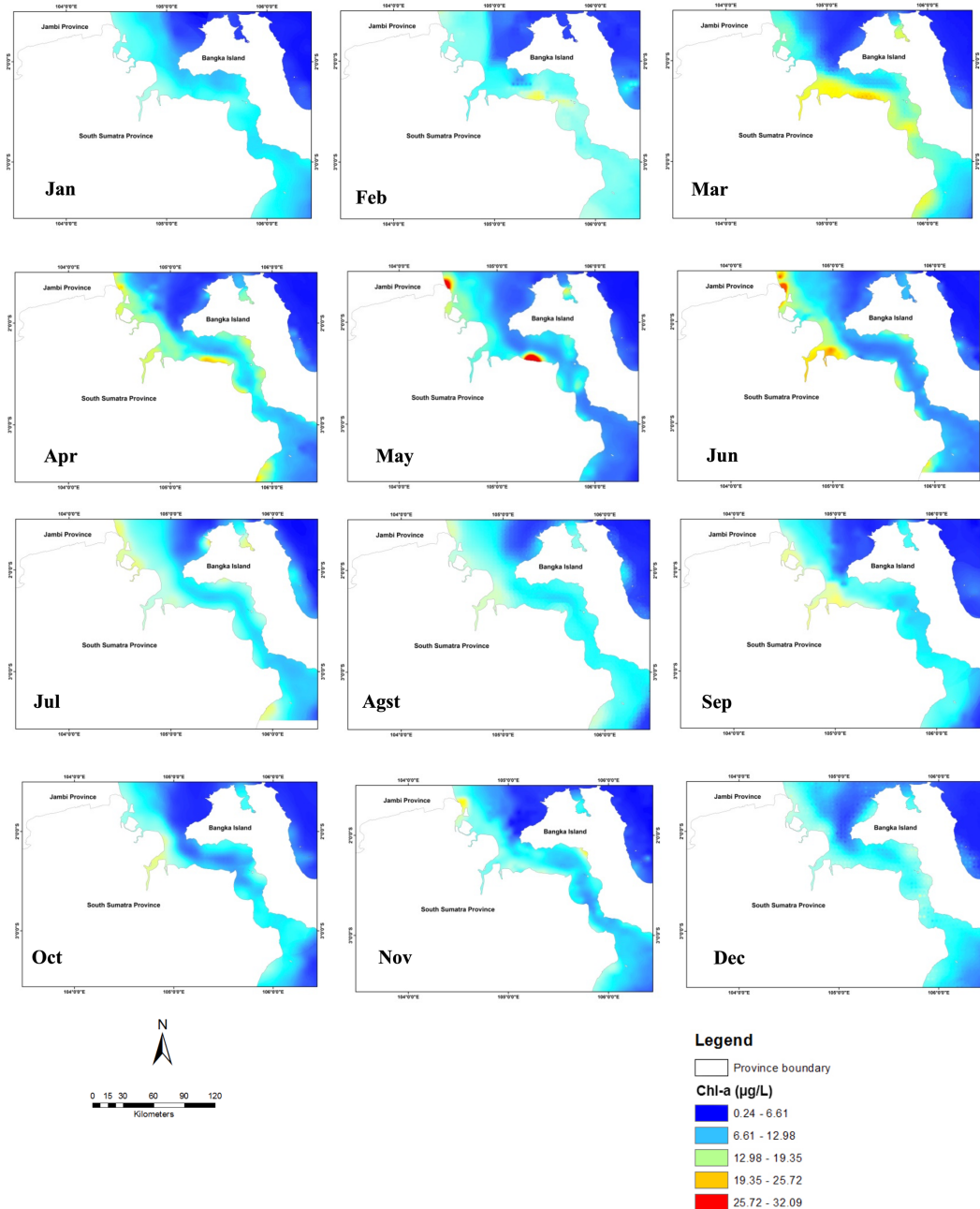


Figure 2. Spatial Variation of Monthly Concentration of Chl-a in the Bangka Strait in 2020

whole, we used the mean monthly data to investigate the change in Chl-a concentration in the distinct areas of the Bangka Strait.

2.3 Estimation of the Trophic State Index (TSI)

In general, there are some indices to estimate the trophic condition of the surface water (Gómez et al., 2021). One of the most used methods is the Trophic State Index (TSI), proposed by Carlson (1977). The TSI calculates algal biomass

according to three water quality variables, such as Chl-a, phosphorus, and depth. Additionally, we can compute the TSI using one of those variables to present the trophic condition in water. Carlson suggested this approach for conditions where only limited in-situ data is available for all the above variables. Many studies have highlighted the Chl-a concentration as the most prominent variable of eutrophication (Xu et al., 2022), so we considered it to analyze the trophic condition in the Bangka Strait. We calculated the TSI using

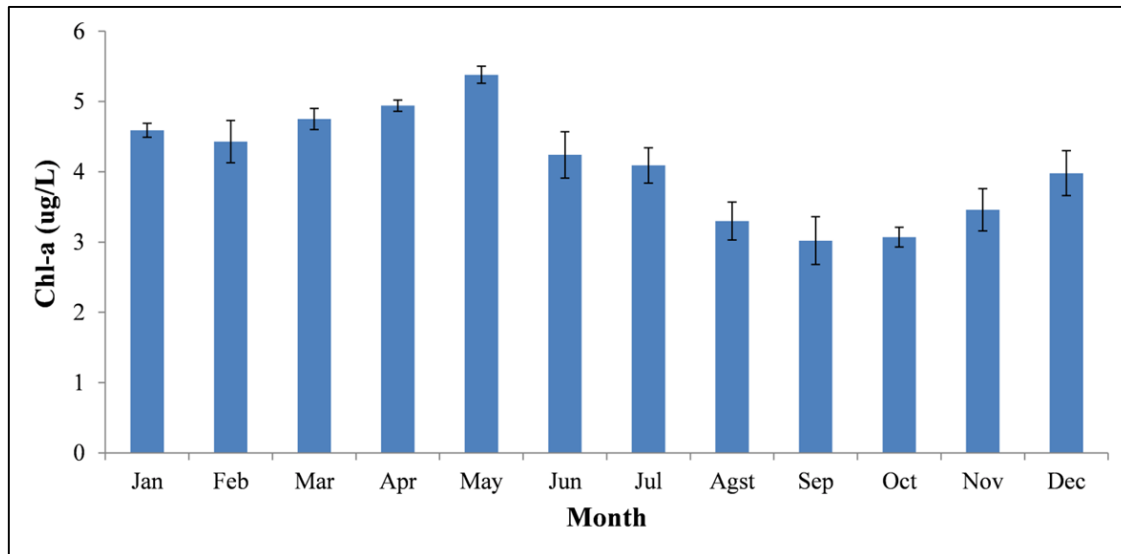


Figure 3. Monthly Mean Concentration of Chl-a in the Bangka Strait in 2020. Blue Bar Chart Indicates January to December 2020

the Chl-a concentration from the MODIS-Terra, as shown in Equation (1).

$$TSI (Chl-a) = 10 \times \left(6 - \frac{2.04 - 0.68 \times \ln (Chl-a)}{\ln (2)} \right) \quad (1)$$

Generally, the TSI ranges from 0 to ∞ . $0 < TSI < 40$ indicates the oligotrophic status in surface water; $40 \leq TSI < 50$ indicates mesotrophic status; $50 \leq TSI < 70$ indicates eutrophic status; and $70 \geq TSI$ indicates hypereutrophic status (Carlson and Simpson, 1996).

3. RESULT AND DISCUSSION

3.1 Spatial and Temporal Changes in Chl-a Concentration

The monthly mean of Chl-a concentration in the Bangka Strait was assessed using spatial analysis throughout the year 2020. The west Bangka Strait, with areas adjacent to the coast of South Sumatra, especially labeled the Musi River Delta in the map, has continuously had a high Chl-a concentration during the study period (Figure 2). The Musi River basin is inhabited by most of the South Sumatra population and has important ports that were used to transport resources such as coal and daily needs from the South Sumatra province to Bangka Island. The river basin is affected by high pollution of surface water in this region and carries a high amount of organic and non-organic materials to the Bangka Strait. Previous studies reveal that total organic compounds and nutrients originated from the coast of Sumatra. It is good to put the amount of organic and inorganic compounds stated by Mueller et al. (2022) in this sentence. Based on our study, the coast of Sumatra showed higher nutrient loads than the coast of Bangka. In addition,

the region from the north to the south of the Bangka Strait, which faced the Sumatra Coast, showed a high concentration of Chl-a. The map procession during the study period indicated that the main contributor of nutrients to the strait is the Musi River.

Figure 3 shows an increase in the mean concentration of Chl-a in the Musi River delta from February to May. According to Rahutami et al. (2022), the increase in total nutrients entering the Bangka Strait comes from non-point sources of contamination in the Musi River basin during the dry season and agricultural season. The aggressive nutrient emissions from the western rivers to the sea contribute immensely to the increment of the Chl-a concentration on the west coast of the Bangka Strait, resulting in the increase of Chl-a in the region, which peaks in May. In contrast, the water current from the south of the Bangka Strait tended to move northward across the west shorelines, acting as a primary driver. This movement redistributed the concentrated nutrients and diluted their concentration, leading to a decrease in Chl-a from June to August. The east monsoon wind, which blows from Australia to Asia, affected this condition (Widyastuti et al., 2010).

High Chl-a concentrations were also found in the coastal area of Jambi Province and the shoreline of the northern Bangka Island in May, but they were lower than the coastal areas of South Sumatra Province. The MODIS data revealed a high Chl-a concentration in the Sungsang area, situated in the coastal part of South Sumatra. Despite the high Chl-a concentrations in a large area of South Sumatra's coastal parts from March to June, the region experienced low Chl-a concentrations from July to December (Figure 2). The South Sumatra Province's application of the COVID-19 movement control order period may have contributed to

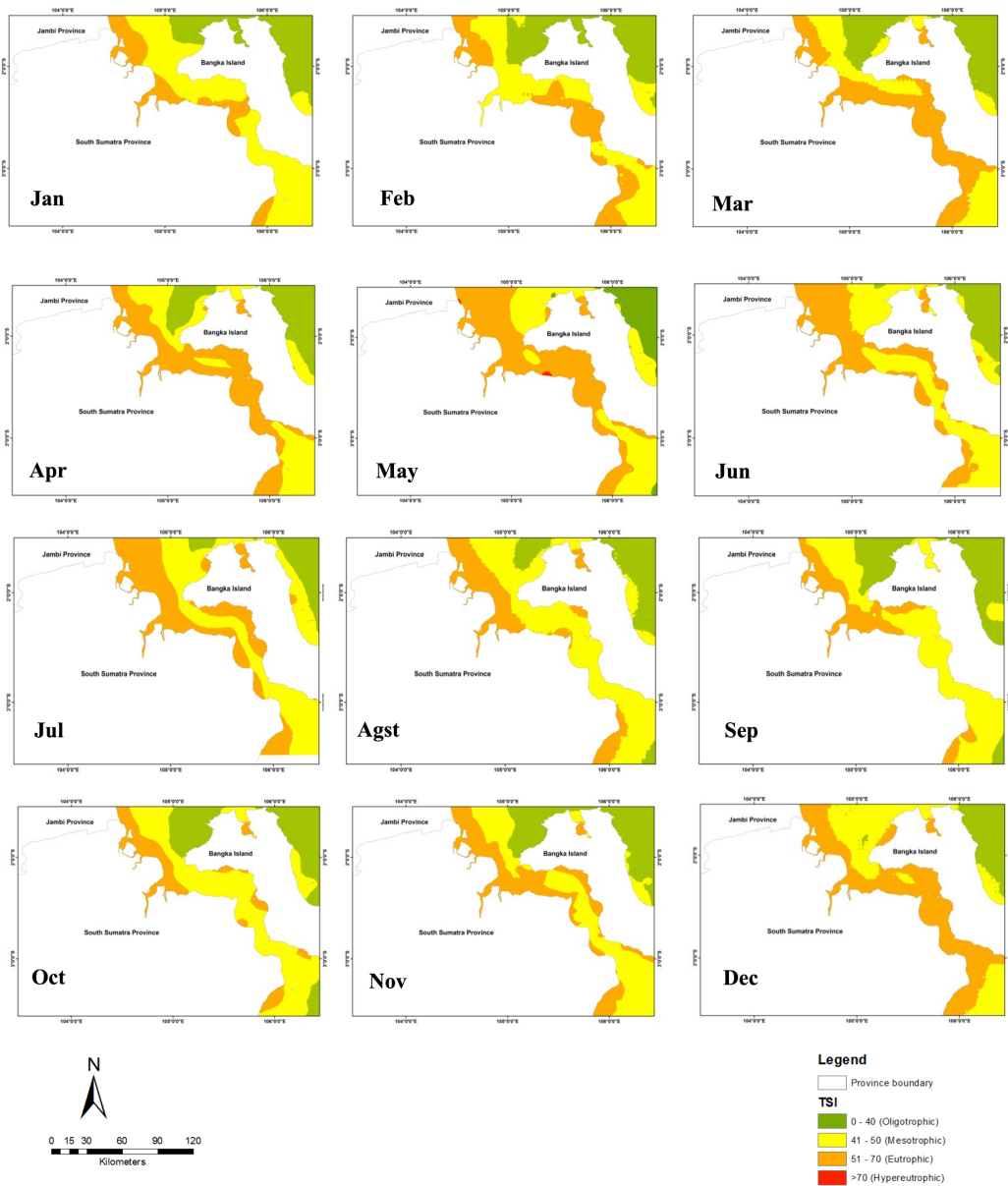


Figure 4. Spatial Variation of Monthly Trophic State Index in the Bangka Strait in 2020

this. This policy has halted most human activities in the province, including those in the industrial, agricultural, and transportation sectors. Tanjung Api-Api Port, located in the northeast part of the province, was a busy port before the COVID-19 virus exposed it. Many vessels sailed through this river every day, releasing a large number of pollutants into the water. Moreover, the pollutants could also result from the cold nutrient circulation from the discharge of Sumatran rivers into the Bangka Strait. The major hydrodynamic properties in the Bangka Strait led to greater Chl-a concentrations on the coasts of Sumatra than on the coasts

of Bangka; they redistributed the algae to the west and middle areas of the strait.

The peak of monthly average Chl-a concentration ($5.38 \mu\text{g/L}$) occurs in May, followed by April ($4.94 \mu\text{g/L}$) on the coasts of South Sumatra province (north and middle regions) (Figure 2). There are many settlements along the coast at the Musi River's mouth. Domestic household activities such as cooking, washing, and bathing use a lot of water from the Musi River. The disposal of household waste directly into the river has an impact on the river, leading to environmental pollution and subsequently lowering the water's quality. The

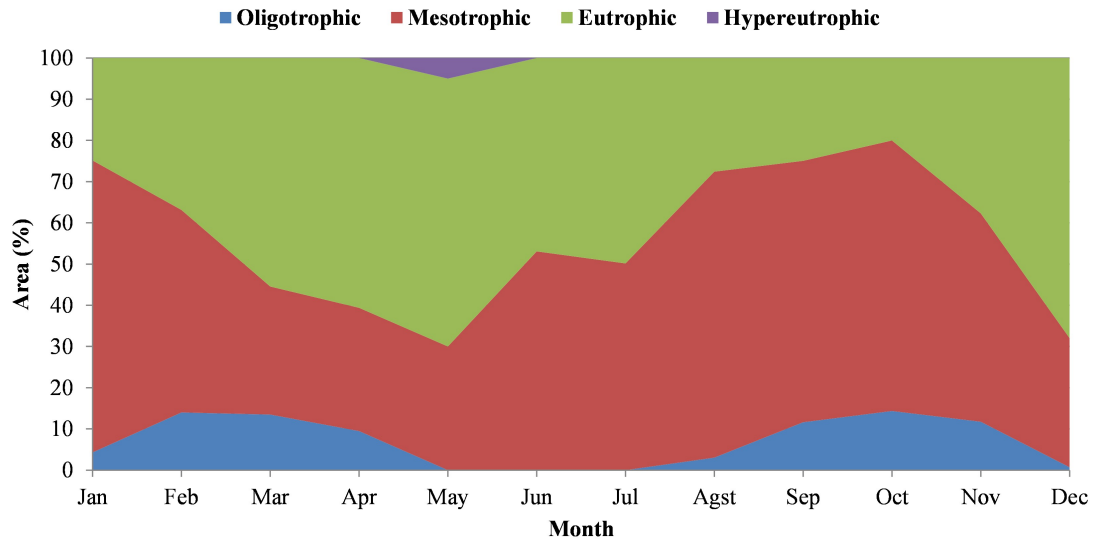


Figure 5. Percentage of Area of the Bangka Strait Encompassed by Oligotrophic (Light Blue Color), Mesotrophic (Red Color), Eutrophic (Green Color), and Hypereutrophic (Purple Color) Circumstances in a Monthly Time Scale

wind conditions, sea surface temperature, and solar radiation could also affect the concentration of Chl-a during the study period. This result was consistent with the previous study on algal blooms found in the west of the Bangka Strait, in which, on that occasion, the algal bloom covered a large area in the River Musi estuary. The eastern Bangka Strait near the coast of Bangka Island is less impacted by high Chl-a concentrations during the study period (less than $4 \mu\text{g/L}$) (Figure 2). Low nutrient input and unsuitable environmental conditions, such as light and temperature, may be the cause. Overall, the pattern of monthly changes in Chl-a concentration in that region was nearly identical.

3.2 Status Over the Bangka Strait

We analyzed the spatial variation map of the trophic status index (TSI) over the Bangka Strait from January to December 2020 using the monthly average Chl-a from the MODIS-Terra product. The TSI analysis classified the strait into oligotrophic, mesotrophic, eutrophic, and hypereutrophic conditions (Figure 4). The distribution of monthly average TSI revealed that around 65%, 61%, and 55% of the strait area were at a bad trophic level, such as eutrophic status, during May, April, and March, respectively. May recorded the worst trophic condition, with 5% of the strait areas being hypereutrophic. August to October recorded the best trophic status, significantly reducing eutrophic waters to less than 30% of the strait area. The COVID-19 movement control order, which suspends all human activities, enables the achievement of this condition. December is the turning point when the eutrophic waters cover up to 68% of the strait area. The loosening of the COVID-19 restriction measure has contributed to the large nutrient loads in the strait

from human activities and increased the eutrophic water areas.

From August to October, the mesotrophic status was the major trophic category in the Bangka Strait (51-69% of the strait area), whereas January showed the highest percentage of mesotrophic waters, which covered up to 70% of the strait area. Low sunlight exposure and low temperatures, which suppressed alga growth in the strait, may have contributed to the increase in good trophic status that occurred at the beginning of the year (during the wet season). This finding was in line with the previous study by Dalu et al. (2019), who recorded that eutrophic water coverage increased in the dry season and decreased in the wet season. Global warming could exacerbate the increase in eutrophication events, thereby impairing the strait ecosystem. The TSI's annual distribution showed that approximately 43% of the strait area was in eutrophic condition throughout the 2020 year. Furthermore, we estimated there was a significant change from oligotrophic waters to mesotrophic waters during the study period. Specifically, mesotrophic and eutrophic waters cover most of the strait areas from May to July (Figure 5).

4. CONCLUSIONS

In this study, we analyzed the spatial and temporal change in Chl-a concentration using MODIS-Terra data over the Bangka Strait in 2020 to examine the trophic status that could deteriorate the marine ecosystem. Our results suggested that the west Bangka Strait, specifically along the coasts of the South Sumatra region, sustained a higher Chl-a concentration as compared with the eastern regions, primarily because of the large number of nutrients from the Musi River. The TSI indicated that the eutrophic water covered

more zones of the strait monthly, particularly in April and May, compared to other months. Our study suggested that when eutrophic water areas increase in the future, the authorities must regularly monitor the quantity of nutrient inputs to the river. In addition, we recommended further studies to improve our understanding of the marine ecosystem's response to human activities (for example, unsustainable construction in the basin and estuary areas) and natural hazards that could contribute to eutrophication and impair the marine ecosystem's health.

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