Fisheries Journal, 15 (2), 709-719 (2025)
http://doi.org/10.29303/jp.v15i2.1428

CHLOROPHYLL-A VARIABILITY IN RELATION TO LEMURU FISH (*Sardinella lemuru*) CATCHING SEASON IN THE BALI STRAIT

Variabilitas Klorofil-A Kaitannya Dengan Musim Penangkapan Ikan Lemuru (*Sardinella lemuru*) di Selat Bali

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(Received February 20th 2025; Accepted April 27th 2025)

ABSTRACT

Lemuru fish *(Sardinella lemuru)* is one of the main commodities in the waters of the Bali Strait. As a dynamic water environment, oceanographic conditions in the Bali Strait affect the high and low production of lemuru fish. Upwelling influences the presence of lemuru fish at various times of the year, causing changes in chlorophyll-a concentration. The purpose of this study is to assess the relationship between the lemuru fishing season in the Bali Strait and chlorophyll-a levels. The data used are chlorophyll-a image data and lemuru fish catch data spanning nine years (2014–2022). Chlorophyll-a data were visualized both temporally and spatially. Meanwhile, the catch data was transformed into CPUE values. The season index is used to determine the lemuru fishing season. The northwest season has the highest average CPUE (5,219 - 6,244 kg/trip), whereas the southeast season has the lowest CPUE (2700 - 5,590 kg/trip). Chlorophyll-a concentrations are highest in the southeast season through the second transition season (1 - 1.5 mg/m^3), and lowest in the northwest season (0.2 - 0.3 mg/m^3). The histogram illustrates that the largest CPUE acquisition occurs when chlorophyll-a concentration is low (<0.2 mg/m^3). According to the fishing season index (IMP) of *Sardinella lemuru* fish, the highest fishing season time is in December (158.49%) and the lowest is in May (49.39%). The fishing season occurs when chlorophyll-a concentrations are low.

Keywords: Chlorophyll-a, CPUE, Histogram, Lemuru Fish, Season Index

ABSTRAK

Ikan lemuru *(Sardinella lemuru)* adalah produk sumber daya ikan utama di perairan Selat Bali. Sebagai wilayah perairan yang dinamis, kondisi oseanografi di Selat Bali mempengaruhi tinggi rendahnya jumlah produksi ikan lemuru. Kelimpahan ikan lemuru dipengaruhi oleh adanya *upwelling* pada musim tertentu yang berakibat pada fluktuasi konsentrasi klorofil-a. Penelitian ini bertujuan untuk mengidentifikasi kaitan antara variabilitas klorofil-a di Selat Bali terhadap musim penangkapan lemuru. Data citra klorofil-a dan data hasil tangkap ikan lemuru

digunakan dengan rentang waktu sembilan tahun (2014 – 2022). Dilakukan visualisasi temporal dan spasial bagi data klorofil-a, sementara data hasil tangkap dikonversi menjadi nilai CPUE. Musim penangkapan ikan lemuru dihitung menggunakan indeks musim. Musim barat merupakan periode dengan rata – rata CPUE tertinggi (5,219 – 6,244 kg/trip), sementara CPUE terendah terjadi pada musim timur (2700 – 5,590 kg/trip). Klorofil-a memiliki konsentrasi tinggi pada musim timur hingga musim peralihan II (1 – 1.5 mg/m^3) dan cenderung lebih rendah pada musim barat (0.2 – 0.3 mg/m^3). Histogram menunjukkan bahwa perolehan CPUE tertinggi terjadi ketika klorofil-a memiliki konsentrasi yang rendah yakni < 0.2 mg/m^3. Hasil indeks musim penangkapan (IM) ikan lemuru menunjukkan periode musim penangkapan tertinggi terjadi pada bulan Desember (158,49%) dan terendah pada bulan Mei 49.39%. Musim penangkapan terjadi ketika klorofil-a berada pada konsentrasi yang rendah.

Kata Kunci: CPUE, Histogram, Indeks Musim, Klorofil-a, Lemuru

INTRODUCTION

The Bali Strait is a narrow waterway between Java and Bali with great fishing opportunities, especially lemuru fish (*Sardinella lemuru*) (Rahadian *et al.*, 2019). *Sardinella lemuru* is the main commodity for fishermen at the Muncar Fishing Port, Banyuwangi. Muncar Fishing Port is known as the largest producer of lemuru fish in Java which acts as the main source of income for local fishermen (Simbolon *et al.*, 2017).

In the waters of the Bali Strait, the abundance of lemuru fish is caused by the variability of oceanographic parameters which cause the high and low lemuru catches to differ in each season (Hestiningsih *et al.*, 2017). One of the oceanographic conditions that affects the existence of lemuru fish is productivity which is influenced by chlorophyll-a. The productivity conditions of the Bali Strait waters influenced by the waters of South Java and the Indian Ocean affect the high and low production of lemuru fish (Sartimbul *et al.*, 2010; Sambah *et al.*, 2021).

Chlorophyll-a is associated with the increase and decrease of plankton in waters, the concentration of chlorophyll-a can be used to determine the level of fertility and productivity of waters (Syamsuddin *et al.*, 2024). Thus, chlorophyll-a is a parameter that can be used to determine the area of pelagic fish catch (Adivitasari *et al.*, 2022; Kuswanto *et al.*, 2017). Kunarso *et al.*, (2011) then said, information about chlorophyll-a can be used as a basis for estimating and determining waters that have the potential as fishing areas.

Previous studies on the relationship between chlorophyll-a and pelagic fish catches and fish presence include studies by Nurdin *et al.*, (2018), Ranintyari *et al.*, (2018), Syamsuddin *et al.*, (2018), Nurani *et al.*, (2022), Pata *et al.*, (2021), Pratama *et al.*, (2022), and Adivitasari *et al.*, (2022). This study aims to understand the variability of chlorophyll-a concentration and its relationship to the lemuru (*S. lemuru*) fishing season in the Bali Strait. This research is important for capture fisheries management for both fishermen and policy makers in implementing effective and efficient environmentally-based fishing activities.

RESEARCH METHODS

Location of Research

The research was located in the waters of the Bali Strait with coordinates -8.1°S to -9.43°S and 113.96°E to 115.21°E (Figure 1). The data used include lemuru fish production data and chlorophyll-a data with a time span of nine years (2014 - 2022). Chlorophyll-a data was processed using Matlab R2017B software, while lemuru fish production data was converted into CPUE.

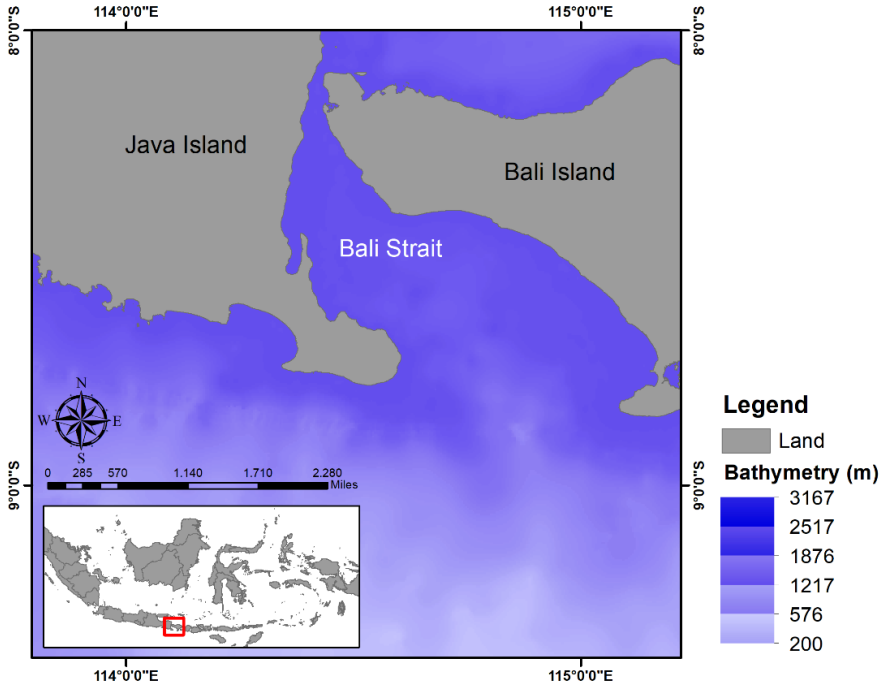

Figure 1. Map of the research area in the Bali Strait

Data

The data consists of chlorophyll-a satellite imagery data obtained through the Marine Copernicus data portal (https://data.marine.copernicus.eu/product) with a spatial resolution of 4 km and monthly temporal resolution and lemuru fish (*S. lemuru*) catch data obtained from Muncar Fishing Port. Muncar, Banyuwangi with a span of nine years (2014 - 2022).

Chlorophyll-a data processing

Chlorophyll-a parameter data were downloaded with monthly temporal resolution in netCDF (.nc) format. After the data was downloaded, Matlab R2017B software was used to perform the spatial visualization process of chlorophyll-a variability in the Bali Strait.

Lemuru fish data processing

Sardinella lemuru fish production data obtained from the PPI Muncar logbook were converted into CPUE (catch per unit effort) which were processed using Microsoft Excel software and presented in the form of an average CPUE bar chart. The calculation of fishing gear standardization was carried out before calculating CPUE, using the equation:

$$FPI_i = \frac{CPUE_i}{CPUE_s}$$

Standard *Effort* = FPI_i × jumlah *effort*

Description:
$CPUE_S$ = catch per standard fishing gear effort
$CPUE_I$ = catch per fishing gear effort i
FPI_i = fishing gear effort i

The Average Percentage Method, based on Time Series Analysis, was used to identify fishing season patterns. Then, the monthly CPUE value (Ui) and the average CPUE per month in a year ($\bar{U}$) were calculated. Fishing season is identified when the Fishing Season Index is more than 100% (Rahmawati *et al.*, 2013; Fadhilah & Simanjuntak, 2024).

$$\bar{U} = \frac{1}{m}\sum U_i$$

$\bar{U}$ = Average monthly CPUE value in a year (kg/trip)
Ui = CPUE value per month (kg/trip)
m = twelve (number of months)

Up is calculated where the Ui ratio is expressed in percentage form:

$$U_p = \frac{U_i}{\bar{U}} \times 100\%$$

Next, calculate the seasonal index as follows:

$$IM_i = \frac{1}{t}\sum U_p$$

Where:
IMi = i-th seasonal index
t = number of years of data

The standardization of fishing gear aims to standardize fishing efforts, especially those catching Sardinella lemuru. To ensure that the catch from a type of fishing gear is the same as the standard fishing gear, standardization is carried out with the aim of equalizing different efforts (Zain *et al.*, 2022).

Standardization of a fishing gear can be done by calculating the fishing power index (FPI) value of each fishing gear used. The fishing season is classified based on the fishing season index (IMP) value which is divided into two categories based on the IMP value, namely the fishing season (IMP>100%) and not the fishing season (IMP<100%). The CPUE value of the fishing gear can be divided by the CPUE of the standard fishing gear. The FPI value for the fishing gear that is used as a standard is one (Zain *et al.*, 2022).

RESULT

CPUE Lemuru Fish

The average monthly CPUE of lemuru fish based on Muncar Fishing Port, Banyuwangi data from 2014 to 2022 is presented in Figure 2.

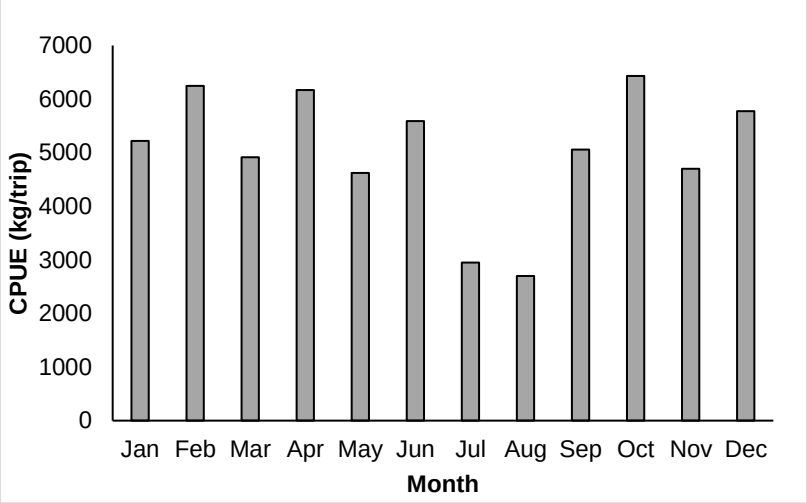

Figure 2. Average CPUE of lemuru fish

Based on the graph in Figure 2, the average CPUE at PPI Muncar has a fluctuating value but still represents a seasonal pattern. In the west season period, the average CPUE ranges from 5,219 - 6,244 kg/trip. Similar results occurred in the transition season I period with a CPUE range of 4,914 - 6,167 kg/trip. This value then decreased in the east season which was the period with the lowest CPUE (2700 - 5,590 kg/trip). In the transition season II, the average CPUE increased again, ranging from 4,701 - 6,430 kg/trip. During the period 2014 - 2022, October was the highest peak of the average CPUE, while August produced the lowest average CPUE. Syah *et al.*, (2019) stated that the high and low CPUE values of lemuru fish in the Bali Strait were influenced by climate variability such as monsoons which affected oceanographic conditions.

Temporal and Spatial Variability of Chlorophyll-a

The variability of chlorophyll-a in the Bali Strait during 2014 to 2022 is presented in Figures 3 and 4. The seasonal pattern of chlorophyll-a is very clear, where the highest peak occurs in September (1.5 mg/m3) and the lowest in January (0.2 mg/m^3).

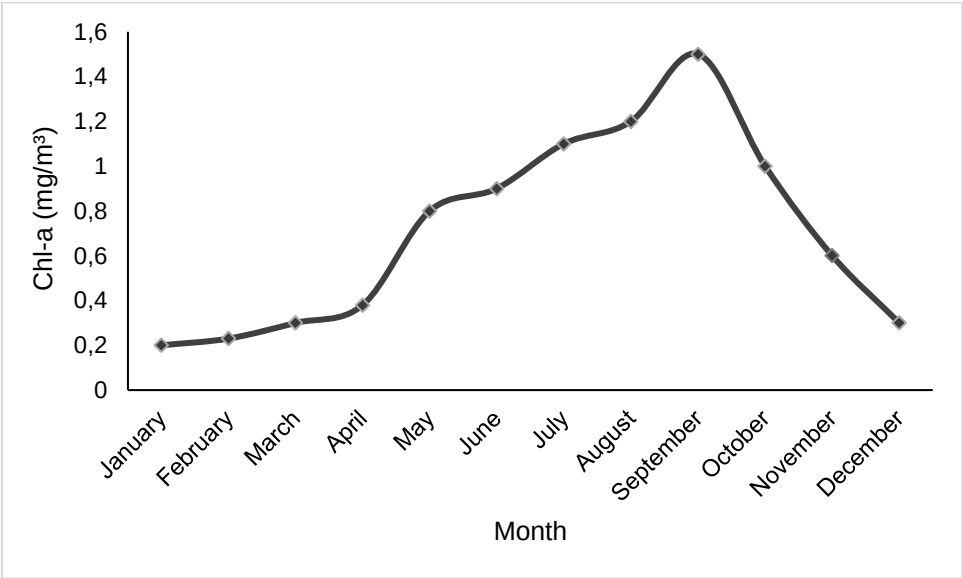

Figure 3. Temporal Variability of Chlorophyll-a 2014 – 2022

The fluctuation of chlorophyll-a concentration values climatologically can be seen in the graph in Figure 3. From January to March, chlorophyll-a conditions were relatively stable and low, ranging from 0.2 to 0.3 mg/m³. There was a gradual increase in April until it peaked in September with a value of 1.5 mg/m³. After reaching its peak, chlorophyll-a decreased again from October to December and returned to a lower level of around 0.3 mg/m³.

Chlorophyll-a generally shows a clear seasonal pattern due to the influence of the monsoon (Sukresno *et al.*, 2018; Harahap *et al.*, 2020), with the highest concentration during the east season (July-September) and the lowest concentration during the west season (January-March). The increase in chlorophyll-a concentration in the east season is caused by the upwelling process that transports nutrients from the underwater column to the surface column, and helps the growth of phytoplankton (Sartimbul *et al.*, 2010). In addition to seasonal factors, the concentration of chlorophyll-a in the Bali Strait is also influenced by the intra-annual phenomenon or El Nino Southern Oscillation (ENSO). Because according to Sambah *et al.* (2021) oceanographic characteristics including chlorophyll-a parameters are not only influenced by seasonal variability, but also by ENSO.

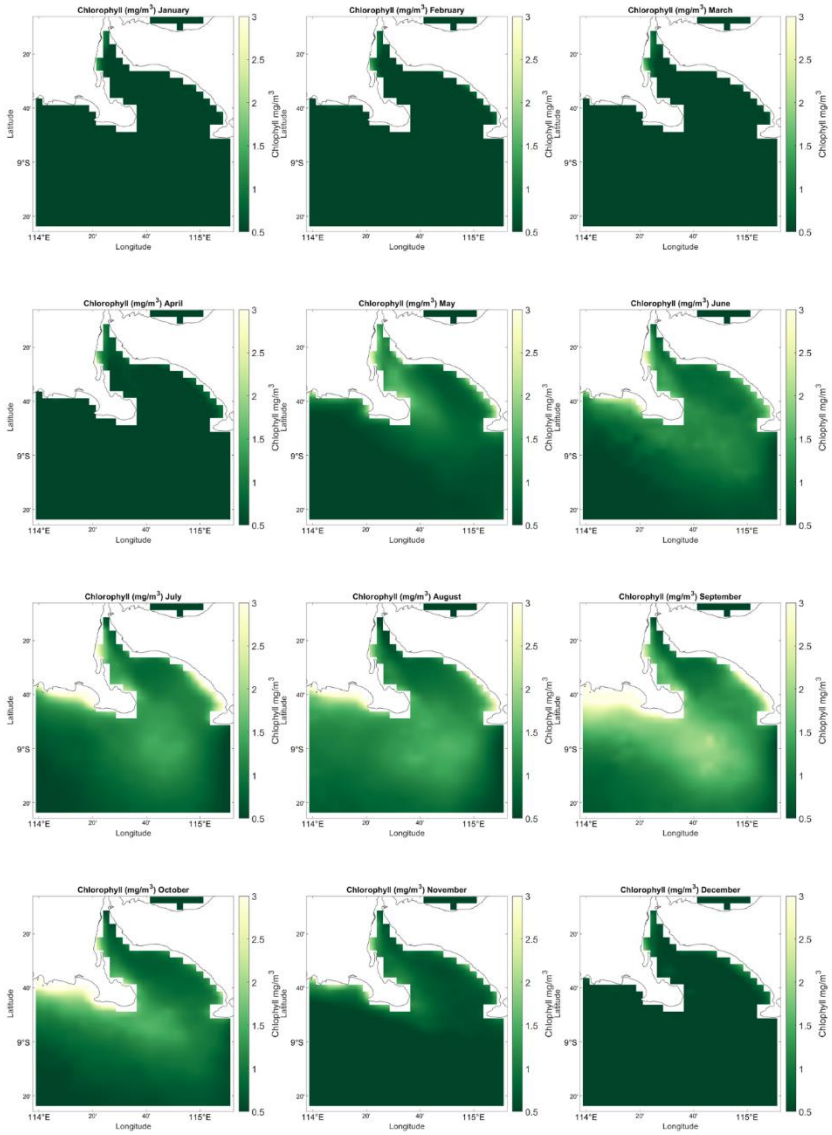

Figure 4. Average climatology of Chlorophyll-a concentration 2014 – 2022

Climatologically, the concentration of chlorophyll-a in the Bali Strait can be seen in Figure 4. At the beginning of the year, the concentration of chlorophyll-a is relatively low, especially in the southern waters, with some increases in the northern coastal areas. This reflects the less productive water conditions during the rainy season. From April to June, there was an increase in the concentration of chlorophyll-a, especially in the northern coastal areas and deep waters of the strait. This indicates an increase in phytoplankton activity, possibly caused by changes in water temperature and increased nutrient input carried by currents. Then from July to September, the concentration of chlorophyll-a peaked. The southern and central areas of the waters experienced a significant increase, indicating high primary productivity. From October to December, the concentration of chlorophyll-a began to decline, especially in the southern waters. However, in the northern area, the concentration remained high. This decrease was caused by changes in currents and seasonal winds that reduced upwelling activity. Furthermore, a histogram was made to determine the relationship between the value of chlorophyll-a concentration and CPUE (Figure 5). It can be seen that the highest average CPUE (> 3000 kg/trip) was obtained at a relatively low chlorophyll-a concentration, namely < 0.2 mg/m^3.

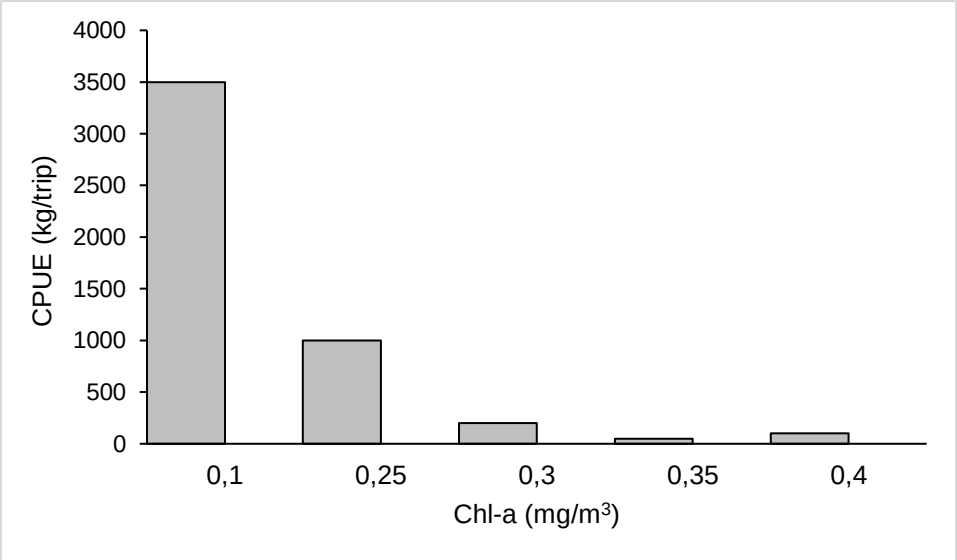

Figure 5. Histogram of chlorophyll-a against CPUE

Indeks Musim Penangkapan Ikan Lemuru

Based on Table 1, the seasonal index obtained from the average CPUE value for 9 years from 2014 to 2022 shows a clear seasonal pattern. The value of the lemuru fishing season index with the lowest fishing season period occurred in May, reaching 49.39%. The fishing time categorized as not a fishing season occurred in January-February (west season) with an IMP value of 98.73% - 99.33% and May-September (east season) with an IMP value ranging from 49.39% - 82.30%.

Table 1. Sardinella lemuru Fishing Season Index Value in the Bali Strait

Month	Season Index (%)
Jan	99.33
Feb	98.73
Mar	122.10

Apr	148.36
May	49.39
Jun	82.30
Jul	60.69
Aug	58.69
Sept	63.65
Oct	131.54
Nov	126.72
Dec	158.49

Description:

Season
Off Season

The lemuru fishing season occurs during Transition Season 1 (March-April) with an IMP range of 122.10-148.36%, Transition Season 2 (October-November) with an IMP range of 126.72%-131.54%, and West Season (December) with an IMP value of 158.49%. The peak fishing season with the highest IMP value occurs in December. A high IM value indicates a high average catch for lemuru fish. The results of the season index analysis indicate that the transition season is the optimal season for fishing activities, when the temperature conditions are warmer.

DISCUSSION

Chlorophyll-a tends to be low in the west season and increases in the east season and lasts until the second transition season. This is in line with Arianto *et al.*, (2014), which states that the equatorial current moves to the waters of South Java due to the Southeast monsoon. Deeper water masses fill the void until upwelling occurs. Khadami & Suprijo (2019) said that upwelling is influenced by the Indian Ocean Dipole (IOD) which causes fluctuations in chlorophyll-a concentration. Upwelling in the Bali Strait often occurs in the second transition season (September-November) followed by an increase in phytoplankton. The catch will increase during this period until it reaches its highest increase in December (Gustantia *et al.*, 2021).

In accordance with the research of Adivitasari *et al.*, (2022), the highest catch occurs in April and October to December. While the lowest catch is obtained at the end of the west season (January-February) and the east season. Seasonal analysis of chlorophyll-a climatology in the lemuru fish catch area in the Bali Strait has a high concentration distribution during the eastern monsoon compared to the western monsoon with a range of chlorophyll-a concentrations ranging from 0-1 mg/m^3.

In a study conducted by Sambah *et al.*, (2021) it was found that the peak of the lemuru fishing season in the Bali Strait occurs in November or transition season II. This is based on the availability of chlorophyll-a concentration which affects the presence of lemuru fish. The increase in chlorophyll-a concentration does not directly affect the number of catches, this occurs due to the time lag so that zooplankton in phytoplankton can utilize chlorophyll as a food source (Putra *et al.*, 2012; Gustantia *et al.*, 2021). Sartimbul *et al.*, (2010) stated that it

takes about three months (3-month lag) between the response of catch results to chlorophyll-a, so that there is a negative correlation between chlorophyll-a and pelagic fish (Setiawan *et al.*, 2024).

CONCLUSION

The highest average CPUE was obtained in the west season with a CPUE value of 5,219 - 6,244 kg/trip. While the lowest average CPUE occurred in the east season (2,700 - 2951 kg/trip). The CPUE value is inversely proportional to the chlorophyll-a concentration value where low chlorophyll-a occurs in the west season and increases in the east season. Histogram analysis shows that the highest CPUE occurs when chlorophyll-a has a low concentration, namely <0.2 mg/m^3. The season index shows that the best season for catching lemuru fish in the Bali Strait occurs in April-May (transition season 1) and October-December (transition season 2 and the beginning of the west season).

ACKNOWLEDGEMENTS

The researcher would like to thank Marine Copernicus (https://data.marine.copernicus.eu/product) for the Aqua-Modis Chlorophyll-a satellite data and the Muncar Fish Landing Base, Banyuwangi for the fish catch production data. The researcher would also like to thank Padjadjaran University for the Unpad Internal Grant (HRU).

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