The spatial pattern relationship between SST and chlorophyll-a in *Lemuru* Bleeker, 1853 catches in Bali Strait, Indonesia

N D Pertami¹,²*, I W Nurjaya³, A Damar⁴ and M F Rahardjo⁴

¹Graduate School of Bogor Agricultural University, Bogor, Indonesia
²Faculty of Marine Sciences and Fishery, Udayana University, Bali, Indonesia
³Department of Marine Technology, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Bogor, Indonesia
⁴Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Bogor, Indonesia

*E-mail: dati_pertami@yahoo.co.id

Abstract. *Lemuru* Bleeker, 1853 is one of the most commonly found species in pelagic fisheries in Bali Strait. Data from the MODIS (*Moderate Resolution Imaging Spectroradiometer*) Terra satellite remote sensing, collected over a period of nine years from 2007 to 2015, were used to observe the spatial relationship between lemuru catches, Sea Surface Temperature (SST), and Chlorophyll-a (chl-a) concentration in the Bali Strait, Indonesia. The purpose of the study was to provide information about the spatial relationship between lemuru catches and both marine environmental parameters. Linear correlation analysis was carried out to determine the level of relationship with the restriction of the analysis of long-term and seasonal relationships. The results showed that during the year of observation, lemuru catches showed a declining trend. Lemuru catches showed a correlation with SST and chl-a concentration, as clearly indicated by high responses in DJF (December-January-February) and SON (September-October-November) months and unclear responses in MAM (March-April-May) months and JJA (June-July-August) months. In DJF, the spatial relationship between both marine environmental parameters and lemuru catches was high in the central part of the strait and in SON in the northwestern part of the strait.

Keywords: chlorophyll-a (chl-a), lemuru, sea surface temperature (SST).

1. Introduction

The Bali Strait is a nutrient rich body of water. It contains a very high level of biomass [1-3] and is rich in nutrient content with high biological and fisheries productivity [4, 5]. The Bali Strait also has unique characteristics. It is geographically classified as semi-closed waters, separating Java and Bali, and it has an area of about 2,500 km. Topographically, the Bali Strait is shallow in the northern parts with a depth of ± 50 meters, while the southern part is deep waters with a depth of more than 200 meters [2]. The water bathymetry in the northern part could result in swift surface currents, while the presence of a river that empties into the eastern part of the strait makes the availability of nutrients in the deeper water column allegedly not come out following the movement of water mass [6].
Determining fish catch areas and the growth and metabolic processes of aquatic organisms strongly depends on temperature parameters. One of the oceanographic parameters that characterize water masses in the ocean is Sea Surface Temperature (SST). The SST has a close relationship with the conditions of the seawater below and plays an important role for marine aquatic organisms [7]. Water phenomena such as two different seawater masses fronts, streams, increasing the mass of seawater in the deep layer which is rich in nutrient content to the surface (upwelling), and biological activity can be determined using SST data [8]. Climate and monsoon also have important roles in the oceanographic characteristics of the Bali Strait waters, namely the upwelling process. During the southeast monsoon (June-August/October), SST is low and chlorophyll-a concentration (chl-a) is high, whereas during the west monsoon (December-February) the opposite applies [4]. Overfishing of lemuru in the Bali Strait waters has been predicted [9]. Lemuru fish caught around the Bali Strait waters from year to year experienced a very significant increase, but starting in 2007 there was a fluctuating catch.

The purpose of this study was to provide information about the spatial relationship between lemuru catches and both marine environmental parameters, namely Sea Surface Temperature (SST) and chlorophyll-a concentration (chl-a), in the Bali Strait, Indonesia, using satellite images of MODIS (Moderate Resolution Imaging Spectroradiometer) taken in 2007-2015.

2. Materials and Methods

The study was carried out around the Bali Strait, especially at the location of lemuru fishing ground around the Bali exposure of Bali Strait waters (figure 1).

![Study area in the lemuru fishing ground around Bali exposure of Bali Strait waters.](image)

**Figure 1.** Study area in the lemuru fishing ground around Bali exposure of Bali Strait waters.

2.1. Materials and data

Data of chlorophyll-a and SST in the study sites were collected from satellite images of MODIS (Moderate Resolution Imaging Spectroradiometer) Terra Level 3 monthly composite with 4 km resolution collected over a period of 9 years (2007-2015). These data were used to observe the spatial relationship between lemuru catches and sea surface temperature (SST) and chlorophyll-a (chl-a) concentration over the Bali Strait, Indonesia. These collections of data were available in the site http://oceancolor.gsfc.nasa.gov/cms/.

2.2. Methodology and data processing

The data used were in the HDF format (Hierarchical Data Format) where the data was a digital compressed data and appearance was flat. The downloaded data must be extracted first before processed further. Data extracts were performed using WinRAR 3.42 software. Image data of MODIS level 3 were data that had been processed, which means that they had been corrected radiometrically and atmospherically. The data included information concerning the latitudes, longitudes, land, coastline, estimated SST and chl-a concentration. The application of algorithms at level 3 was done automatically. MODIS level 3 monthly composites that had been extracted were then processed using
ENVI 4.8 software, beginning with the calling of the extracted data, then cropping with the limit of 8.203211° S - 114.327561° E and 8.878431° S - 115.170293° E. The output of image processing of SST and chl-a concentration using ENVI 4.8 software was in the form of ASCII format, which was then used to obtain information about temporal fluctuation. After that, the data were processed in Microsoft Excel 2010 and imported and saved again in the xlsx extension (*.xlsx) or in other extensions to facilitate the next process. Then, the values of SST and chl-a concentration of the control results of each research location covering 16 x 20 pixels were obtained in full for the sake of further analysis, namely monthly pattern analysis, monthly time-series, and seasonal linear correlation.

2.3. Data analysis
Based on the date form of a monthly pattern, the mean value of SST and chl-a concentration was analysed by averaging the pixel values for the entire study area. Meanwhile, the monthly average data was displayed in the form of time series graphs using Microsoft Excel 2010 to determine fluctuations. Another analysis conducted in this study was linear correlation analysis. The lemuru catch data were treated as the dependent variable and the SST and chl-a concentration as independent variables. Data analysis was performed on each pixel of SST and chl-a concentration with coordinates as identity. Data were extracted from each pixel of the MODIS imaging to get data per point. Each point had information on coordinates, month, year, and value of SST and chl-a content. Then, the data was sorted into a time series. Monthly data on the quantity of lemuru caught were first sorted, and then calculation was done using linear correlation equation (equation 1). The linear correlation analysis was conducted to determine the relationship level by restriction analysis of long-term and seasonal relationships. After obtaining the correlation value, the data point was converted to a raster data format that had the same spatial resolution as the original data (4 x 4 km). These processes were carried out using Microsoft Excel 2010 and ArcGIS 10.2 software.

Linear correlation equation:

$$r = \frac{n \sum XY - (\sum X)(\sum Y)}{\sqrt[n]{\sum X^2 - (\sum X)^2} \sqrt[n]{\sum Y^2 - (\sum Y)^2}}$$

Where:
- $X$ = quantity of lemuru catch
- $Y$ = environmental factors that influence lemuru catches (SST or chl-a concentration)
- $n$ = the amount of data used.

The seasonal analysis was based on monsoon activity [10]. Seasonal analysis was carried out by linking monthly data in the same season with annual observation data. The season was grouped into four periods, namely December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), September-October-November (SON). DJF represented the monsoon peak of Australia-North Asia, while the peak of the monsoon Southeast-Asia Australia was represented by JJA. MAM and SON represented the transition of the rainy season [11]. Seasonal linear correlation analysis was carried out by connecting monthly data in the same season during the annual observation period.

3. Results and Discussion

The seasonal linear correlation analysis of chl-a concentration from MODIS data with the total monthly catches of lemuru from 2007-2015 showed a positive correlation during the SON period. There was no significant correlations in the other periods, namely DJF, MAM, and JJA (figure 2). Wyrtki [10] states that the waters of the Bali Strait are influenced by the East Monsoon (Southeast Monsoon) in April-September and West Monsoon (Northwest Monsoon) in October-March. During the time of the East Monsoon, there is an increase of water mass along the south coast of Java-Sumbawa, where the southern equatorial current extended northward and suppressed the flow of water in the southern coast of Java, which causes the water in the Bali Strait to rise [12]. The lemuru
The fishing season occurs during the West Monsoon season. The volume of lemuru starts to increase in October and reaches its peak around December-January [13, 14].

In the SON months, the East Monsoon season enters a transition period ahead of the Western Monsoon season, where the phenomenon of upwelling takes place, it is predicted that phytoplankton content in the waters will be increased [15]. It was further stated that aquatic environmental factors such as nitrates and phosphates as nutrients that support phytoplankton growth were also high around Bali’s exposure to the Bali Strait waters [16]. Furthermore, [17] adds that the plankton concentration in Bali exposure was higher than the waters in the central part of the strait and Java exposure. The abundance of phytoplankton is very high in the East Monsoon season (August) until the transition season 2 (September) [18, 19].

The lemuru catches responded to SST clearly, as indicated by a high response in DJF (December-January-February) and SON (September-Oktober-November). During MAM, lemuru catches responded to SST clearly around the eastern part of the Bali Strait, while in the JJA there were fewer responses. During the East Monsoon season, the content of chl-a in the part of the Bali Strait that
approaches Bali Island was high to a depth of 23 m, whereas the water temperature was low [20]. Furthermore, the phenomenon of upwelling that occurred during the East Monsoon season (April-October) made the water temperature conditions in the Bali Strait cooler than during the Western season [1, 21-23]. Furthermore, [24] states that oceanographic and climatological factors have a significant effect on the lemuru fish catch. The rising trend of lemuru fish catches occurs when entering the East Monsoon season (August-September) and was seen to reach its maximum point in November [20]. The spatial relationship between both marine environmental parameters and the lemuru catches was high during the DJF period in the central part of the strait and during the SON period around the northwestern part of the strait.

The lemuru catches during a year of observation indicated a declining trend. The Marine and Fisheries Office of Banyuwangi and Jembrana Districts stated that catches of lemuru in 2007 were 67,252 tons/year\(^{-1}\). The following year, there was a very significant decrease in catches, down to 38,656 tons/year\(^{-1}\). The catches of lemuru fish increased slightly in 2009 and dropped again in 2010. The lowest quantity of catches was observed around 2011 until 2013. Lemuru fish catches increased again between 2014 and 2015. The catches of lemuru in the period between 2007 and 2015 are shown in (figure 4). Furthermore, Lemuru fish catches decreased again but not significantly and dropped dramatically in 2017. Monthly lemuru catches in the 2007-2015 period are shown in (figure 5).

During the period of observation, lemuru catches began to increase in the SON months, except in 2010. The highest quantity of catches could be found in DJF (December-January-February) in 2007,
2012, and 2015. Lemuru catches fluctuated significantly from 2007 to 2009 between January/February - August and in 2015 between May and September. The lowest quantity of lemuru catches could be found in the MAM and JJA periods in 2011 to 2014. Environmental factors were one of the factors that could affect the decline of lemuru catches.

4. Conclusion

The lemuru catches indicated a declining trend. The lemuru catches clearly responded to SST and chlorophyll-a concentration, as indicated by a high response during DJF (December-January-February) and SON (September-October-November), while in the MAM (March-April-May) and JJA (June-July-August) periods there were no significant responses. The maximum catches were found in DJF in 2007, 2012, and 2015. The spatial relationship between both marine environmental parameters and the lemuru catches was high in the central part of the strait in the DJF months, and in the northwestern part of a strait in the MAM months.

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