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Sensitivity and Dynamic of *Sardinella Lemuru* in Bali Strait Indonesia

Abu Bakar Sambah[1,2,*], Adi Wijaya[3,4], Nurin Hidayati[1,2], Feni Iranawati[1,2]

[1] Department of Fisheries and Marine Resources Utilization, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang, East Java 65145, Indonesia

[2] Marine Resources Exploration and Management Research Group, Universitas Brawijaya, Malang, East Java, 65145 Indonesia

[3] Doctoral Student, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang, East Java 65145, Indonesia

[4] Institute for Marine Research and Observation, Ministry of Marine Affairs and Fisheries, Perancak, Jembrana, Bali, Indonesia

Abstract: The study of the oceanographic parameters related to the fish habitat is important in predicting the fishing season dynamics for sustainable fisheries management. The characterization of *Sardinella lemuru* was analyzed to study the sensitivity and dynamic of *S. lemuru* to the oceanographic factors in the Bali Strait, Indonesia. The study aims to analyze the sensitivity and fishing season dynamic of *S. lemuru* to the oceanographic factors, ENSO, and IOD in the Bali Strait, Indonesia. Dataset was obtained from the MODIS Aqua/Terra satellite images for 2000-2020, *S. lemuru* catch from the fishing logbook, and fishing ground point data. They were analyzed using the GAM approach for the habitat suitability model prediction of *S. lemuru*. The study described that the Fishing Season Index (FSI) was increased and followed by the decrease of SST (the highest value of SST was in December, and the lowest was in September). The increase of SSC was influenced by the El-Nino phenomena and followed by the increasing number of FSI. The SST and SSC have an inverse pattern. The upwelling phenomenon causes a decrease in SST and high nutrient content in the water surface. GAM analysis illustrated three alternative models for the habitat prediction with oceanographic parameters as predictors, in which the combinations of SST and SSC in the model described the best model. Habitat suitability prediction of *S. Lemuru* generated from the spatial data overlay process based on the GAM analysis value was described monthly potential fishing ground of *S. lemuru*. The potential fishing ground described that during the end of the transition season-2 to the west season indicated as suitable habitat mostly in the study area. This study made important contributions for sustainable lemuru fish management in the Bali Strait, especially in support of the regulation of fishing activities based on seasons or based on catch quotas and fishing ground.

Keywords: *Sardinella lemuru*, oceanographic parameters, habitat mapping, fishing ground.

印度尼西亚巴厘岛海峡沙丁鱼的敏感性和动态

摘要：与鱼类栖息地有关的海洋学参数研究对于预测捕捞季节动态以实现可持续渔业管理至关重要。分析了撒丁藻的特征，以研究柠檬猴对印度尼西亚巴厘岛海峡海洋因素的敏感性和动态。这项研究的目的是分析印尼蓝嘴猴对海洋因素，ENSO 和碘酒在印度尼西亚巴厘岛海峡的敏感性和捕鱼季节动态。数据集是从 2000-2020 年的方式水/ 兵马俑卫星图像，捕捞日志中的莱姆。 莱姆鲁捕捞以及捕捞地面点数据获得的。使用 GAM 方法对它们进行了分析，以预测柠檬草的生境适应性模型。研究表明，捕鱼季节指数（FSI）先上升后下降。SST 的最高值出现在 12 月，最低的是 9 月。南南合作的增加受到厄尔尼诺现象的影响，其次是 FSI 数量的增加。SST 和 SSC 有具有相反的模式。上升现象导致水面 SST 降低和营养成分

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About the authors: Abu Bakar Sambah, Nurin Hidayati, Feni Iranawati - Department of Fisheries and Marine Resources Utilization, Faculty of Fisheries and Marine Science, Marine Resources Exploration and Management Research Group, Universitas Brawijaya, Malang, Indonesia; Adi Wijaya - Doctoral Student, Faculty of Fisheries and Marine Science, Universitas Brawijaya, Malang, Indonesia; Institute for Marine Research and Observation, Ministry of Marine Affairs and Fisheries, Bali, Indonesia

Corresponding author Abu Bakar Sambah, absambah@ub.ac.id

高。 GAM 分析以海洋参数作为预测因子，说明了三种用于生境预测的替代模型，其中模型中 SST 和 SSC 的组合描述了最佳模型。描述了基于 GAM 分析值从空间数据叠加过程中生成的勒穆鲁的生境适宜性预测，描述了勒穆鲁的每月潜在捕鱼场。潜在的渔场描述，在第 2 季到西季的过渡期结束时，表明这是大多数研究区域的合适栖息地。这项研究为巴厘岛海峡可持续的蓝鳍金枪鱼管理做出了重要贡献，特别是支持基于季节或基于捕捞配额和渔场的捕鱼活动的监管。

关键词：沙丁鱼，海洋学参数，栖息地图，渔场。

1. Introduction

Oceanographic conditions and variations have an important role in various energy transfer processes from the Pacific Ocean to the Indian Ocean within the framework of Indonesian Through Flow (ITF) [1], [2], [3]. ITF is part of the global thermohaline circulation. It is closely related to regional climate dynamics such as the Asian Monsoon or globally, such as ENSO in the Pacific Ocean and IODM in the Indian Ocean, which affects the Indonesian waters [4], [5].

The impact of climate change can also be seen from the ENSO phenomenon, which affects sea level. During an El Niño, the trade winds weaken, followed by a warm mass of water moving eastward, causing a sea-level decrease. The opposite occurs during La Niña. ITF plays an important role in the ENSO phenomenon, as evidenced by the fluctuations that occur in ITF. As a result of these fluctuations, the water mass being carried can be colder or warmer than usual (sea surface temperature anomaly) to affect seawater temperature stratification in the Indian Ocean. Climate change also affects fish migration. Fish have a high sensitivity to temperature changes [6].

S.lemuru catch in the Bali strait varies between seasons. High capture of *S. lemuru* is inseparable from the high-water productivity conditions due to the upwelling phenomenon that occurs seasonally in the southern waters of Java, which are associated with the Indian Ocean [1], [7], [8]. The hydro-acoustic surveys in September 1998 and August 2000 in the Bali strait reported that lemuru fish were concentrated in the Java and Bali waters at a depth of 50 to 60 meters. Lemuru juveniles are in shallow waters [9], [10]. The movement of lemuru fish in the water column to find the optimum range of environmental factors used in their metabolic processes [1], [8], [10].

During the fishing period of 2007-2017, the catch tended to decline [9], [10]. The decline in fishing today is influenced by fishing pressure and is associated with climate change and variability also [11]. Changes and variability in the climate on the coast and the sea impact the uncertainty of the potential fishing's time and location [12].

Determining the fishing season is part of the fishing strategy related to climate anomalies. Standard fishing season procedures need to be compiled and developed by examining oceanographic dynamics that often occur or are always affected by ENSO, IOD, and fishermen's adaptation to the incidence of these two phenomena so that new and informative Standard Operating Procedures can be developed. This study analyzes the sensitivity and fishing season dynamic of *S. lemuru* to the oceanographic factors, ENSO, and IOD in the Bali Strait, Indonesia. This study has a new contribution in relating the influence of oceanography and climatological phenomena to the sensitivity and season dynamics of *S. lemuru* by using long time-series data, where spatial modeling is also carried out to estimate the potential habitat of *S. lemuru*. Previous research has analyzed the relationship only on the relationship between oceanographic parameters and *S. lemuru* catches, as well as the influence of climatological phenomena on oceanography.

By combining spatial and temporal information, it is hoped that the shifting of environmental conditions in the *S. lemuru* area can be determined with better accuracy. The research results will contribute to the basic theory of fish habitat and migration and the estimation of *S. lemuru* fishing season in the Bali Strait. Besides, it also contributes to the *S. lemuru* habitat suitability model through integrated analysis between oceanographic factors and climate change, which can also be used as a basis for determining fishing areas and is useful in supporting the government in this case, the Ministry of Marine Affairs and Fisheries in preparing an alternative approach to predict potential fishing ground specifically for the Bali strait for sustainable capture fisheries management in responding to the challenge of the measurable goals of SDGs (Sustainable Development Goals) point 14, namely life below water.

2. Methods

2.1. Research Location

The research area included the Bali strait separated by Java island in the west and Bali islands in the east (Fig. 1). The Bali strait has specific oceanographic characteristics. With relatively shallow bathymetry in the north and flanked by the *Blambangan* peninsula and *Tanjung Benoa* in the southern part, it forms the Bali Strait as semi-closed waters. This condition has caused relatively low oceanographic dynamics in the Bali Strait to change significantly. This is also in line with the fertility of its waters. The Bali Strait has relatively high fertility throughout the year, with a tendency to be higher in the eastern monsoon [13].

The Bali Strait waters are fertile waters characterized by nitrate content between 0.174 - 1.825 mg/l with a horizontal distribution that tends to be higher in the southern part. The phosphate content in the Bali Strait ranges from 0.023 - 0.066 mg/l. The dissolved oxygen (DO) content ranges from 4.7 - 4.83 mg/l, and the pH ranges from 8.41 to 9.49 [14].

At the research location, during the western season between October and February, there was an increase in the catch of *S. lemuru*, while in the east season between March and September, there was a decrease. *S. lemuru* catch fluctuation is also associated with the number of fishing trips in the west season tends to be higher than the fishing trips in the east season.

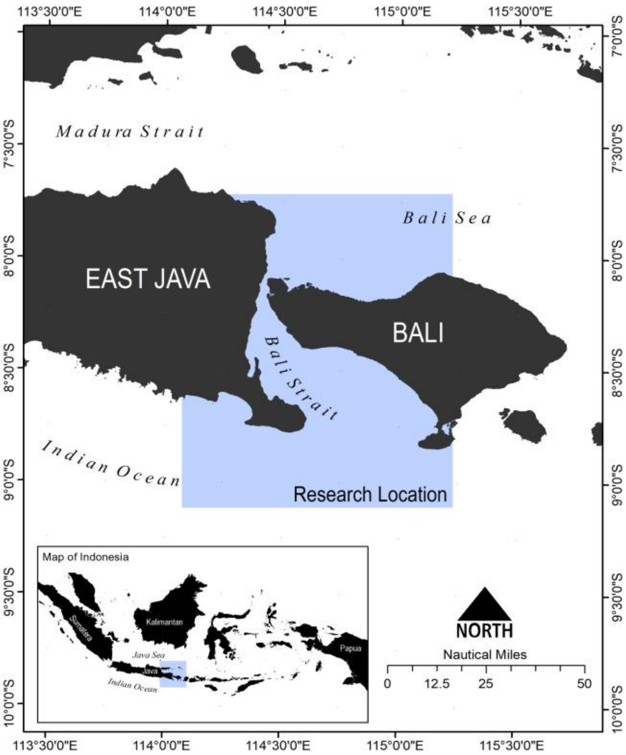


Fig. 1 Research location

2.2. Dataset

Data on Sea Surface Chlorophyll-a/SSC and Sea Surface Temperature/SST and fishing production series data from 2000 to 2020 was taken from fishing ports in the Bali Strait. The SST index for NINO 3.4 was obtained from the website http://www.cpc.ncep.noaa.gov/. Indian Ocean Dipole (IOD) data expressed in Dipole Mode Index (DMI) was obtained from the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) website http://www.jamstec.go.jp/frsgc/research/d1/lod.

Oceanographic variables were obtained from the MODIS Aqua/Terra sensor. These variables include SST (°C) and SSC (mg.m^{-3}). Oceanographic variable data with a spatial resolution of 1 km and a Global Equidistant Cylindrical geometric projection. The data was obtained by downloading from the Ocean Color Homepage (http://oceancolor.gsfc.nasa.gov/).

The MODIS Aqua/Terra sensor was carried out by utilizing the embedded IDL (Interactive Data Language) command-line in the SeaDAS program. Processing MODIS Aqua/Terra data into SST distribution data applied the ATBD-25 v.2 algorithms (Algorithm Theoretical Basic Document). Meanwhile, the data for SSC concentration used the OCM4 algorithm. For the overlay process, all variable data were converted to raster data with geometric projection WGS1984.

Moreover, *S. lemuru* catch data also collected from the fishing logbook of the lemuru catch in the fishing ground of Bali Strait. The data included fish catch production, composition, and the fishing ground based on fishing season. Catch data was collected from the participatory mapping during the fishing trip, and the catch data reported from the fishing port (*Muncar* fishing port of East Java and *Pengambengan* fishing port in Bali).

2.3. Data Analysis

2.3.1. Sea Surface Temperature

The data was calculated using the following Formula.

$$dBT = BT39 – BT40 \quad (1)$$

dBT is the brightness level of the color temperature. The value of BT39 = 3.959 μm, and the value of BT40 = 4050 μm. Formula (2) calculates the SST value.

$$SST4 = a0+a1xBT39+a2xdBT+a3x1.0/\mu-1.0 \quad (2)$$

μ is the Zenith angle level while the values a0, a1, a2, and a3 are in accordance with the values set by Rosenstiel School of Marine and Atmospheric Science (RSMAS) based on the values or brightness levels that have been obtained.

2.3.2. Sea Surface Chlorophyll-a

Chlorophyll-a concentration can be calculated using an algorithm in data processing software [15]. This value was calculated using Formula (3).

$$Ca = 10^{(a0+a1R+a1R2+a2R2+a3R3+a4R4)}$$

$$Ca = \log_{10} \frac{R_{rs443} > R_{rs488}}{R_{rs551}} \quad (3)$$

Ca = chlorophyll-a concentration (mg.m^{-3}), R = Reflectance Ratio, and Rrs = Remote Sensing Reflectance.

Rrs has wavelengths ranging from 440 and 70 nm. This study's data used Rrs (blue) with a range of 443 and Rrs (green) with a range of 488, while Rrs551 was defined as a surface reflectance value at a wavelength of 551 nm. The values a0 = 547, and a1 = 0.2424.

2.3.3. Correlation Analysis

Analysis of SST anomalies in the Pacific Equator (ENSO), in the Indian Ocean (IOD), and fishery production anomalies was carried out in the same year between 2000-2020. The relationship was observed in the following periods: December-February, March-May, June-August, and September-November. The level of correlation was determined based on the confidence level of strong (99%), moderate (95%), and weak (90%). Based on the Significance of a Correlation Coefficient analysis, the correlation level was strong (15-0.54), moderate (-0.41 or 2-0.53), and weak (-0.392 or 2- 0.33). Meanwhile, the areas that were not affected had a value (2-0.32).

2.3.4. Potential Fishing Ground Mapping

The potential fishing ground was created using the research parameters. The map was illustrated the suitability area predicted as the habitat of *S. lemuru*. This is also defined in the term of Habitat Suitability Index (HIS). HSI is a numerical index that represents the habitat suitability capacity for a particular species. Functionally, HSI is a combination of habitat factors and additive priority functions as the following Formula.

$$H = \sum_{i=1}^{m} a_i . w_i \quad (4)$$

where H is the habitat suitability value, m is the number of factors, and ai is a relatively important factor of SST and SSC and *w*as the weighted value of each variable.

The score of each parameter is based on the frequency with which it appears in the fishing trip's total data. The order of the scores is based on the order of frequencies that appear. Each parameter's weight has been calculated in the estimator of the proportion of fish habitat based on a Generalized Additive Model (GAM), a generalized linear model in which the linear response variable depends linearly on unknown smooth functions of some predictor variables. Interest focuses on inference about these smooth functions.

2.3.5. Catch Sensitivity and Dynamic

The catch season dynamics shows the variability of the response time of the shift in the production of the catch to climatic conditions. Meanwhile, the sensitivity of the fishing period shows how many days the peak shift occurred. The dynamics and sensitivity determinations were obtained from the overlaying process of maps of existing fishing locations with ENSO and IOD impact areas' delineation. Research steps as described in Fig. 2.

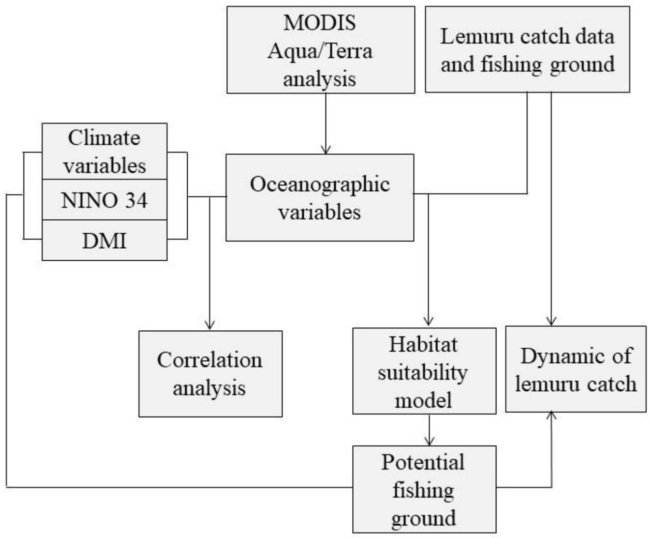


Fig. 2 Research flow diagram

This study applies oceanographic parameter data obtained through satellite observation, then relates it to climatological phenomena and caught fish. The research method used was a descriptive approach by integrating all data in a spatial-based with geographical references. GIS was applied in analyzing and presenting habitat suitability and mapping potential lemuru fishing areas around the research area. The statistical approach was also carried out through correlation analysis between research parameters.

3. Result and Discussion

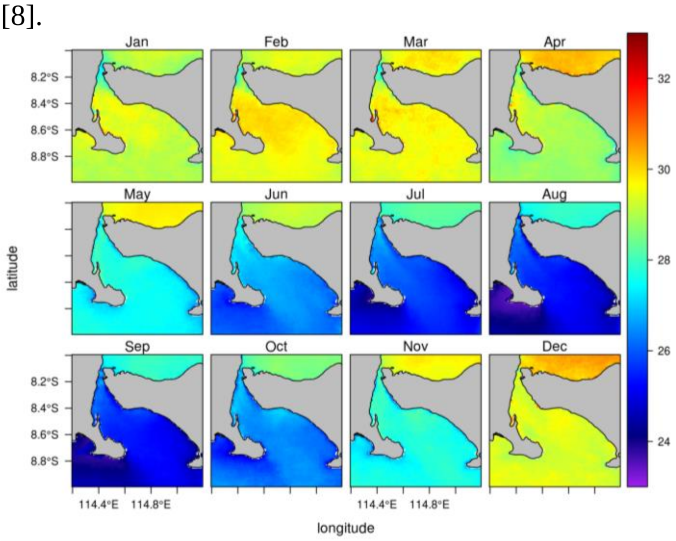
3.1. Oceanographic Variability

The Bali Strait is one of the waters that separate the islands of Java and Bali and has a fairly high fertility rate. The highest water fertility level in the Bali Strait occurs during the eastern monsoon, where upwelling occurs. The dominant nutrients consisting of phosphate and nitrate in the waters are quite high and abundant of phytoplankton.

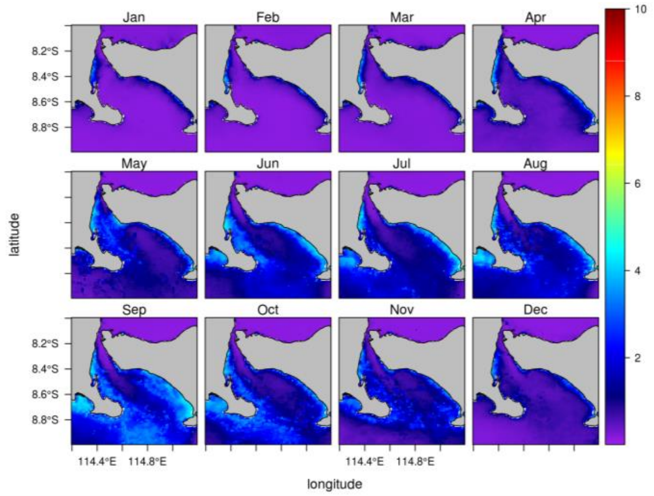
The surface temperature needs to be known because it is an important indicator in monitoring oceanographic conditions, knowledge of sea surface temperature variability and can be used to determine the location of fronts, upwelling, and potential distribution of fish. Water temperature varies greatly. This variation impacts the growth process, swimming velocity, reproduction, distribution, and biota mortality [8]. The spatial distribution of SST and SSC in the last 20 years is presented in Fig. 3. The variation in SST values changes every year. It shows that the highest value was in December (30.29 °C), and the lowest was in September (28.23 °C). The difference in SST can be influenced by unequal sunlight, season, and latitude. Temperature greatly affects fish migration, spawning, feeding activities, and others.

The average SST obtained varied each month. In November, the SST value showed a relatively higher in the northern part of the study area (Bali Sea) than the Bali Strait waters, which tended to be cooler. In December, the SST value seemed to move from the northern part to the Bali strait waters, which caused the temperature to be warmer, which happened until April. The same pattern occurred during November again in May, where the shelters began to fall in the Bali Strait until they reached their lowest value during June to October. Based on the Fishing Seasonal Index (FSI) during 1993-2019 reported by [16], it is known that in September, the FSI value began to increase until it reached the highest value in November, or during the transition season 2 (from east to west season), and at the time of SST values tend to be low.

Temperature is an indication of the presence of fish groups in an area. However, sea surface temperature is strongly influenced by changes in other environmental waters, including currents, winds, and direct sunlight exposure. At the same time, lemuru is a type of fish sensitive to environmental changes [17]. Research by [18] described that based on the El Nino 3.4 index from May 2015 to April 2016, the El Nino 3.4 index in Indonesian waters shows a high positive, namely>1. The El Nino index shows high positive values for six consecutive months indicates a strong El Nino phenomenon causes the waters around Indonesia to become colder than the normal average. This was confirmed by [19], which states that the El Nino phenomenon in the Pacific Ocean causes SST anomaly in the Indian Ocean south of Java, including the waters of the Bali Strait. Furthermore, during the El Nino period, the SST in the Bali strait experienced a lower decline than the average SST in the non-El Nino period [8].



(a)



(b)

Fig. 3 Oceanographic variability during 2000-2020 in the Bali strait: (a) SST (in °C), and (b) SSC (in $mg.m^{-3}$)

The concentration of chlorophyll-a in the waters of the Bali Strait is influenced by the mass of water that enters and leaves the strait, where the mass of water comes from the surface water mass so that the availability of nutrients in the deeper water column does not come out following the movement of the water mass [13].

S. lemuru caught in the Bali Strait is a small pelagic species whose main food source is plankton, so the dynamics of chlorophyll-a concentration will influence *S. lemuru* in the Bali Strait. Chlorophyll-a is one of the most important parameters that determine primary productivity at sea.

The highest SSC was found in September (1.58 mg $.m^{-3}$), and the lowest was in January (0.26 $mg.m^{-3}$). In September, there was an east monsoon where there was an uplift of the water mass to the surface so that the SSC value was quite high. High SSC in the waters was identified close to the mainland, but some were offshore, precisely in the southern waters, directly adjacent to the Indian Ocean. This was due to the occurrence of nutrient transport from the land through rivers; besides, the Bali Strait's southern waters get water input, which has high nutrient levels [20].

Chlorophyll can be measured by utilizing its incandescent nature when stimulated by a certain wavelength of light or extracting chlorophyll from plants using acetone to calculate its primary productivity [21]. The value of SSC in the Bali strait in 2000-2020 was quite stable, but in 2015 it experienced a high enough increase due to the influence of El-Nino, which caused the water temperature in the Bali Strait to be quite low.

Research by [8] found that concentration chlorophyll-a experienced a significant increase and reached its peak in December and then decreased to the lowest concentration in February. The increase in chlorophyll-a concentration in the Bali strait was a response to the upwelling phenomenon. In the ENSO positive index period, chlorophyll-a in the Bali strait will increase compared to the negative ENSO period. The same thing happened in the positive IOD period, where the chlorophyll-a concentration in the Bali Strait experienced enhancement. This is in accordance with research conducted by [8], who found that the El Nino period and the IOD period were positive, SST in the Bali Strait has decreased, and SSC has increased. This influence occurs through the upwelling mechanism, which carries the water mass cool and rich in nutrients from the bottom layer to the surface, so then triggers an increase in chlorophyll-a.

Based on the FSI analysis, it is also described that the highest SSC in September was followed by the increasing number of FSI from September to November [16]. The Bali Strait's SSC concentration affects the lemuru population with a time lag of approximately three months [8].

The correlation of SST and SSC can be categorized as a negative linear correlation, which was sufficient. It can be described that SSC's distribution value will be high if the SST value decreases and vice versa [22]. The negative correlation value indicates that the lower the thermocline layer's upper limit, the higher the maximum SSC concentration will be, and vice versa [23]. The results explained that the SST values in the Bali Strait ranged from 27.63 °C to 30.65 °C, while the SSC values ranged from 0.25 to 0.64 $mg.m^{-3}$.

The study found that SST and SSC had the same relationship pattern over the 20 years of data analyzed. The relationship between these two oceanographic parameters has an inverse pattern. Namely, an increase in SST values tends to be followed by a decrease in SSC value, and vice versa. Statistical calculations were used to investigate the relationship between parameters. The more real the linear relationship, the stronger or higher the degree of the relationship between the two variables or more. Pearson correlation is a simple correlation involving only the independent and dependent variables [24].

The high and low SST and SSC are influenced by the upwelling phenomenon, which causes a decrease in SST and high nutrient content, which is rich in nutrients (nitrate and phosphate) towards the surface of the water so that high amounts of nutrients will be followed by an increase in chlorophyll-a content in the area [25]. The SST and SSC have a very strong correlation with a correlation value of 0.748, and the form of the relationship was negative, meaning that the higher the SST value, the lower the SSC value. The relationship was found to be inversely related to the results of the study. It was found that the relationship between SST and SSC had an R2 value of 0.54.

3.2. ENSO and IOD Analysis to SST, SSC, and *S. Lemuru* Catch

In the La Nina period (2000 and 2007), SSC concentrations increased, especially during the transition season (March-April-May). Meanwhile, during El Nino (2002, 2004, and 2009), SSC increased in May and October. The combination between the El Nino and IOD (+) periods (2006, 2015, 2018, and 2019) shows that SSC increased from May to September. Furthermore, the combination between the La Nina and IOD (+) periods (2008, 2011, and 2017) shows that SSC increased from May to September. The increase in SSC concentration in the Bali strait and surrounding waters during 2006-2007 was associated with a weak El-Nino period marked by positive IOD.

Moreover, in the El Nino and IOD positive periods, SSC anomalies were higher than during normal years. The weak El Nino period occurred in 2004-2005, 2006-2007; was happening in 2002-2003 and 2009-2010; very strong happened in 2015-2016. Positive IOD occurred simultaneously in this El Nino period. In 2016, when there was an increase in SST, it was also marked by a decrease in SSC value and low ONI and DMI indices. Likewise, in 2008, the ONI and DMI indices were indicated to increase and marked by a decrease in the SST value and an increase in SSC value at the Bali strait. The relationship between the SST anomaly, SSC anomaly, ONI and DMI indices, and *S. lemuru* catch in the Bali Strait is presented in Fig. 4.

The phenomenon, which is the interaction between the sea and the atmosphere above it in the Indian Ocean, is called the Indian Ocean Dipole (IOD). Dipole Mode Index (DMI) is used to determine the IOD condition. DMI measures the change between SST in the eastern Indian Ocean (90° East Longitude - 110° East Longitude, and 10° South Latitude - 0° South Latitude) and the western part of the Indian Ocean (50° East Longitude - 70° Longitude East, and 10° South Latitude - 10° North Latitude).

The DMI value can be positive (+) or negative (-) used as a reference for the presence of extreme symptoms. A positive DMI value (+) indicates that the SST in the eastern part of the Indian Ocean, including the western part of Indonesia, is in cold conditions. There is not much evaporation that can produce rain clouds. Meanwhile, SST in the western part of the Indian Ocean (close to the African continent) is in hot conditions. Much evaporation occurs and produces rain-producing clouds.

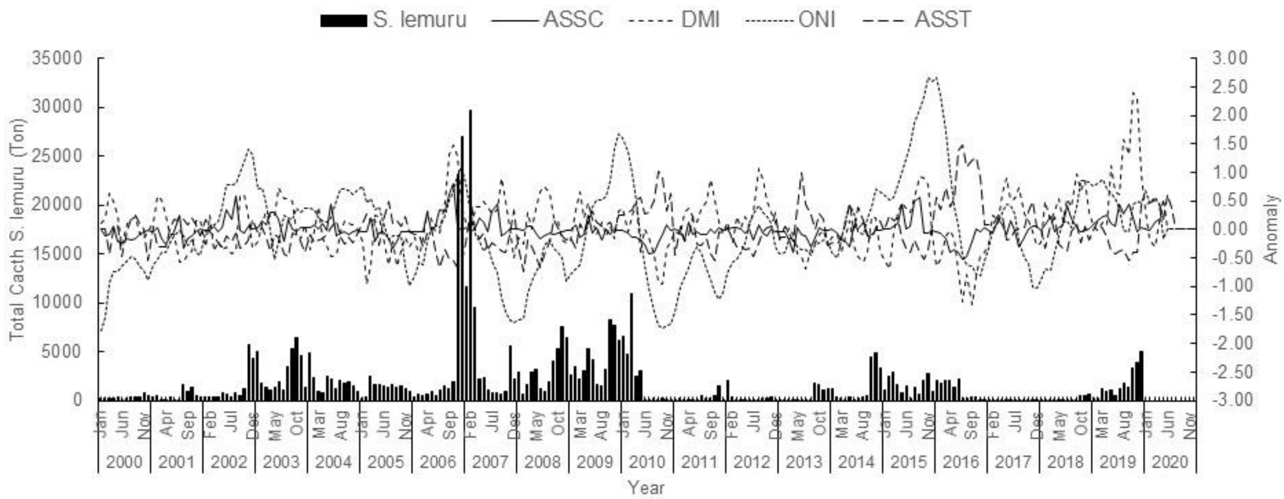


Fig. 4 The relationship between the SST anomaly, SSC anomaly, ONI and DMI indices, and *S. lemuru* catch in the Bali strait

A positive DMI value (+) causes a decrease in rainfall in the western part of Indonesia. Conversely, suppose the DMI is negative (-). In that case, the SST in the eastern part of the Indian Ocean, including the western part of Indonesia, will increase so that there is much evaporation and produces lots of rain clouds. In a negative DMI condition, it rains a lot in the western part of Indonesia. Regarding the drought, it is necessary to pay close attention to the positive DMI if it coincides with the El Nino phenomenon. The positive DMI phenomenon affects the western part of Indonesia. In contrast, El Nino affects the rainfall in Indonesia's eastern, central, and southeastern parts. It can be indicated that there is a potential for drought in almost all regions of Indonesia due to decreased rainfall during that period [26]. The Oceanic Nino Index (ONI) has become a standard index by the National Oceanic and Atmospheric Administration (NOAA) to monitor, identify, and predict ENSO based on deviation data from sea surface temperatures in the Niño 3.4 region (5° N-5° S, 120° - 170° W).

Fig. 4 explains that during 2010 and 2016, the SST increased and was followed by a decrease in the value of SSC and the low ONI and DMI index values. *S. lemuru* catch during this period shows an increase only at the beginning of the year and decreases from April to December. Likewise, in 2016, the condition of the *S. lemuru* catch experienced the same dynamics. During the period 2000 to 2020, the highest *S. lemuru* catch occurred in late 2006 to early 2007 when SSC's value tended to increase, and SST values decreased. *S. lemuru* was caught at SST between 26 –27 °C, with the highest frequency at 26.5°C. The SSC range for the lemuru fishing was 0–4 mg.m^{-3}, and the preferable concentration ranged from 0–0.5mg.m^{-3}.

3.3. Suitability Habitat Analysis of *S. Lemuru*

S. lemuru catch was collected from the fishing base around the Bali Strait (*Muncar* fishing port of East Java and *Pangembengan* fishing port of Bali). The collected data include catch number and geographical information of fishing ground, in addition to the oceanographic parameter data. These data were applied in the modeling process of suitability habitat mapping using Formula (4).

Collected *S. lemuru* catch data described that the highest production of lemuru catch occurred in 2016, where the catch was 928.5 tons while the lowest production was in 2011, which was 125.2 tons. During the last 20 years, the highest SST value was in 2012, namely 30.60 °C, while the lowest SST value was in 2017, namely 27.63 °C. It can be explained that in a period of almost every five years, there was a similar pattern of relationship between the SST value and the catch of *S. lemuru* in the Bali Strait, namely a decrease in SST value followed by an increase in the value of the catch, and also SSC value. This occurred during the period 2010 to the end of 2014 and from mid-2016 to 2018. In 2015 the same pattern occurred in mid-2018, namely the value of SST and catch had almost the same pattern, wherein the SST range of 29 °C.

The peak season for lemuru fishing occurs in November (the East-West transitional season). The trend of fishing season patterns indicates the most appropriate time or season to catch lemuru [27]. The fishing area is based on the amount of catch, SST, and SSC. Modeling of potential fishing areas is carried out based on the assumptions of several oceanographic parameters. The analysis model was based on the average oceanographic parameter values in the study area collected from 2000 to 2020.

Variations in oceanographic, environmental conditions play an important role in natural fluctuations in fish stocks. SST and SSC have the greatest impact on the distribution of small pelagic fish. SST is a good indicator of fishing area and has been used for decades by fishers and researchers. Besides, changes in environmental factors (physical and biological) may have profound effects on fish migration and growth patterns [28].

Lemuru is a type of pelagic fish whose existence depends on the concentration of SSC. The increase in the SSC concentration of the waters will be accompanied by an increase in the catch value. The increase in the value of SSC concentration does not directly affect the increase in the catch value, but it takes some time so that the existing chlorophyll has been used by zooplankton as a food source [29]. Lemuru fish is a filter feeder with the main food being phytoplankton and zooplankton and can live at 26°C - 29°C [30]. Research conducted by [31] explains that lemuru prefers water areas with low temperatures, namely 23 ºC - 26 ºC. Based on the analysis of the relationship between SSC and *S. lemuru* catches in the east and west monsoons, it shows that the correlation coefficient value in the eastern monsoon is 0.745 with an SSC value range of 0.09 - 3.9 mg/l lower than the west season with a correlation coefficient value of 0.771, and SSC value range of 0.01 - 0.9 mg/l [32].

The analysis of predictor models (oceanographic factors) on the *S. lemuru* catch was carried out to determine how much influence oceanographic variations have on the fish catch. The parameter was analyzed based on the unit model of each parameter and a combination of all parameters to find the best model, which will then be used in analyzing the suitability of habitat mapping in the Bali Strait. The results of the model through GAM analysis as described in Table 1.

Table 1 list the model variable, P-value, DE, AIC, and EDF for some models. The predictor variables were highly significant (P < 0.00) for all of the models. High significance was indicated from the highest DE. DE has the same meaning as the determination value in linear regression. SST showed the highest DE among the single-parameter models (DE=6.05%).

Table 1 GAM model (Sig. codes: 0(***)0.001(**) 0.01(*) 0.05'.')

Model	**Parameters**	**EDF**	**AIC**	**P-value**	**DE (%)**	**N**
Model 1	SST	3.09	426.41	$< 2 \times 10^{-16}$ ***	6.05	175
Model 2	SSC	1.00	431.84	$< 2 \times 10^{-16}$ ***	0.75	175
Model 3	SST	3.10	428.31	$< 2 \times 10^{-16}$ ***	6.11	175
	SSC	1.00				

There are three alternative models with elements of oceanographic parameters as predictors. It can be seen that the best model in Model-3, which is a combination model of the two oceanographic parameters as predictors, SST and SSC. The best model is the highest DE value (6.11%) with significance for each of the predictors. Models developed from the combination of two parameters had the highest DE, which indicated that the combination of two parameters generated the best models. These models were evaluated based on the significance level of predictors (P-value), deviance explained (DE), and the Akaike Information Criterion (AIC) value [33]. AIC and DE were used to determine the best model. The smallest value of AIC and the highest value of DE were selected as the best model. GAM plots were developed to interpret each predictor variable's effect on the catch of *S. lemuru*.

SST and SSC's effect on the catch of *S. lemuru* is described in Fig. 5a–b. A negative effect of SST on the catch of *S. lemuru* was observed at temperatures <25.8 °C and >27 °C, while the positive effect of temperature on the catch of *S. lemuru* was from 25.8 to 27 °C. There was an indication that the high catch of *S. lemuru* at lower SSTs.

Meanwhile, for SSC parameters, with a pattern similar to SST, a positive effect occurred on the abundance of SSC<0.53 and >0.57 $mg.m^{-3}$ and negatively affected the abundance of 0.53 – 0.57 $mg.m^{-3}$. Based on the model of the relationship between oceanographic parameters and *S. lemuru* catches in the waters of the Bali Strait and its surroundings, a fish habitat suitability map was created, which can also be used as information on potential fishing ground. Spatially and temporally, the modeling results use a weighted overlay approach through the Geographic Information System process. The overlay process was carried out on raster data of each oceanographic parameter that has been reclassified according to the suitability criteria for SST and SSC for fish species according to their behavior. The weights used in this raster overlay operation are the same, assuming the two parameters have the same effect on fish habitat.

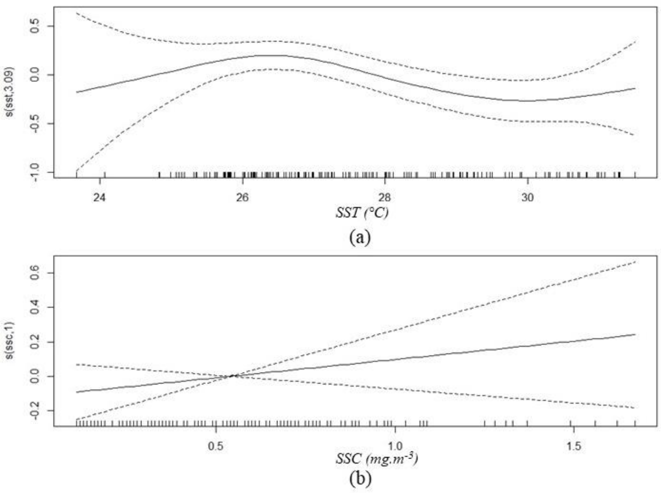


Fig. 5 Effect of the oceanographic variables on the catch of *S. lemuru*: (a) SST, and (b) SSC. Tick marks at the abscissa axis represent the observed data, and the full line is the GAMs function

3.4. Habitat Prediction of *S. Lemuru*

A randomly selected value of observed catch data in the Bali Strait and predicted values generated by the GAM was applied to investigate the oceanographic variable's combined model for habitat prediction of *S. lemuru*. A total of175 samples were selected from the *S. lemuru* catch in the different fishing seasons. Catch data were stratified and classified based on the catch production includes high catches, medium catches, low catches, and null catches. GAM re*sult illustrated* the parametric coefficients as described in Table 2. We collected observational data from the daily catch of *S. lemuru* in Bali Strait adjusted to the time of acquisition of satellite image data that produces oceanographic parameter values.

Table 2 GAM parametric coefficients

Formula:
ln(sl) ~ s(sst) + s(ssc)
Parametric coefficients:

	Estimate	Std. Error	t-value	Pr(>|t|)
(Intercept)	7.699	0.061	126.3	<2e-16*

Approximate significance of smooth term:

	edf	Ref.df	F	p-value
s(sst)	3.095	3.896	1.977	0.099
s(ssc)	1.000	1.000	0.065	0.799

Signif. codes: 0 '*' 0.001 '*' 0.01 '' 0.05 '.' 0.1 ' ' 1
R-sq.(adj) = 0.0385
Deviance explained = 6.11%

Mapping of the *S. lemuru* habitat to predict the potential fishing ground in Bali Strait was carried out through an overlaying environmental parameters model that affects fish distribution using a weight-based overlay approach. The map in Fig. 6 illustrates the percentage of *S. lemuru* habitat suitability in each month based on predictive models of oceanographic parameters (for 20 years) with field observation data related to *S. lemuru* catches in the Bali Strait.

The percentage of habitat suitability for *S. lemuru* starts to increase from October to February (end of the transition season-2 to the west season). The highest concentration is more in coastal areas, both in Java and Bali islands side equally. The concentration of *S. lemuru* habitat suitability is more evenly distributed, with almost the same percentage in all parts of the Bali Strait waters in April or at the middle of the transition season-1 (average 60%). During the east to the middle of the transition season-2, the percentage of *S. lemuru* habitat suitability looks low, especially in the southern part of the Bali Strait or directly facing the Indian Ocean (June, July August). Based on the FSI analysis [16], it can be seen that the FSI of *S. lemuru* began to increase in September and reached its peak in November. On the other hand, June and July are the periods with the lowest FSI. In general, this has the same pattern as the map of the *S. lemuru* suitability model.

The research of [34] related to the spatial variability of *Sardinella aurita* off the southeastern Caribbean Sea described that during transition conditions, high sardine biomass also occurred and that during upwelling conditions (December-April), this species was broadly distributed within upwelling plumes that extended from the coast across the continental shelf. During the warm season (September-October), *Sardinella aurita* was concentrated close to the coast within the first 10 km, and GAM analysis of the SST-gradient effects on sardine-NASC/Nautical Area Scattering Coefficient and Schools did not show any significance for any of the upwelling conditions.

In the habitat modeling for other pelagic species, [35] reported the significant relationship between observed fish catch and predicted from GAM analysis was R^2 = 0.51 for yellowfin tuna in the equatorial Atlantic Ocean and 0.64 for skipjack tuna in the western part of the North Pacific Ocean [33]. Our research explained 6,11% (Table 2) of variability in *S. lemuru* habitat based on oceanographic variables only. The model generated by [33] explained 13.3% of variability, and research by [36] was 8.39%. SST and SSC are important to predicting the *S. lemuru* habitat. However, perhaps many other environmental factors also play a role in influencing the dynamics of this species' habitat.

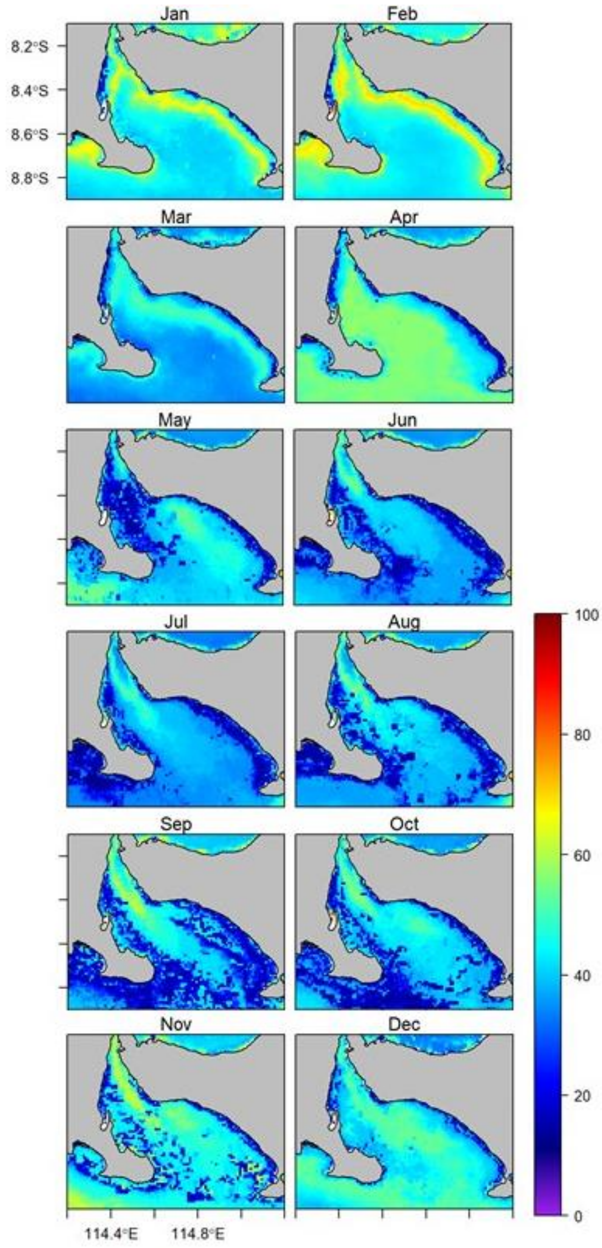


Fig. 6 Habitat suitability map of *S. lemuru* in Bali strait (in %)

This research's limitation was the low spatial resolution due to oceanographic satellite data, which has not too high spatial resolution. Some water areas that approach the land or coastal areas were not detected in the value of the oceanographic parameter. Besides, due to the oceanographic parameters used for the sea surface area, there were limitations in connecting these parameters with the presence of fish that were indicated to move to deeper layers of water in certain months. For this reason, as future work, the use of depth data and marine acoustic recording is needed.

4. Conclusion

This study tried to analyze *S. lemuru* by analyzing the sensitivity and fishing season dynamic of *S. lemuru* to the oceanographic factors, ENSO, and IOD in the Bali Strait Indonesia. Oceanographic parameters of SST and SSC were obtained from the MODIS Aqua/Terra sensor. *S. lemuru* catch data were collected from the fishing logbook and observation data. The research parameters were analyzed using the GAM approach to determine the suitability model for predicting the suitability habitat of *S. lemuru*.

By analyzing the oceanographic parameters, it can be concluded that during September, the FSI value increased and was followed by the decrease of SST. During 2000-2020, the highest value of SST was in December, and the lowest was in September. The highest SSC was found in September, and the lowest was in January. El-Nino affected the increase of SSC and was followed by the increasing number of FSI. The relationship between these two oceanographic parameters has an inverse pattern. The high and low value of SST and SSC were also is influenced by the upwelling phenomenon, which causes a decrease in SST and high nutrient content, which is rich in nutrients to the water surface. The phenomenon, which is the interaction between the sea and the atmosphere above it also analyzed in this study. DMI was applied to determine the IOD condition. The study illustrated that during 2010 and 2016, the SST was increased and was followed by a decrease of SSC and the low ONI and DMI index values. *S. lemuru* catches during this period increased only at the beginning of the year and decreases from April to December.

In the habitat suitability model of *S. lemuru* in the Bali strait based on GAM analysis, it can be informed that there were three alternative models with elements of oceanographic parameters as predictors. The combination of SST and SSC in the model described the best model. The model was applied in the mapping process. The Geographical Information System approach was used to create a potential fishing ground map of *S. Lemuru* as another habitat suitability prediction term. The monthly potential fishing ground of *S. lemuru* described that during the end of the transition season-2 to the west season, Bali Strait's area showed a trend towards suitable habitat and was mostly a potential lemuru fishing ground, especially in January to April.

This result is important information for sustainable lemuru fish management in the Bali Strait. One of them is to regulate fishing activities based on seasons or based on catch quotas and fishing grounds. The sustainability of fish resources in the Bali Strait can be maintained. The use of other oceanographic parameters such as Photosynthetically Active Radiation (PAR), depth, Sea Surface Height, and increasing the number of observation data will be future work.

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