Prediction of potential fishing zones for mackerel tuna (Euthynnus sp) in Bali Strait using remotely sensed data

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Abstract. Mackerel tuna (Euthynnus sp.) is one of the pelagic fish species that has become the export commodity of Indonesia. This species is a carnivorous marine biota that forms a group with rapid swimming abilities. Mackerel tuna is scattered throughout Indonesian waters, including the waters of the Bali Strait. This study aims to predict Mackerel tuna fishing zone in the Bali Strait by using remotely sensed data. Sea surface temperature (SST) and sea surface chlorophyll-a (chl-a) were downloaded from the ocean colour website meanwhile the fishing catches obtained from nusantara fisheries port (pelabuhan perikanan nusantara) Pangembangan, Bali and the fishing lane from marine research and observation agency (balai riset dan observasi laut), Bali. The results showed that the highest of fishing catches occurred in September and October with SST value of 26 – 28 °C and chl-a value of 0.4 – 2.6 mg/m3. Based on the SST and chl-a value, the results revealed the potential fishing zone of Mackerel tuna mostly occurred during south monsoon (April - September). In general, the distribution of Mackerel tuna, based on the overlaid SST and chl-a, showed moderate spatial correlation with actual fishing locations from local fisherman. Integration in situ data and oceanographic condition generated from remotely sensed data could form the basis for fisheries management and information system, such as Mackerel in Bali Strait.

1. Introduction

Bali Strait waters are unique and dynamic waters [1]. The Bali Strait waters are influenced by Indonesia Throughflow, which carries a mass of warm water from the Pacific Ocean to the Indian Ocean through Indonesian waters [2]. These currents have an effect on regional circulation in Indonesian waters and the temperature structure of Indonesian sea waters, both vertically and horizontally [3].

Bali Strait waters are located between Java Island in the west and Bali Island in the east. Funnel-shaped Bali Strait waters with an area of around 2,500 km². The northern part is a narrow area with a width of about 2.5 km while the width in the south region is around 55 km. The depth in the middle of the strait is about 300 meters and deeper in the southern part of the strait, which is around 1,300 meters [4]. The main types of potential fish resources in pelagic fishing activities in the waters of Bali Strait are mackerel, flying fish, lemuru, and tuna fish [5].

Mackerel tuna (Euthynnus sp) is one of the dominant fishery resources and has a high economic value. Mackerel tuna is a pelagic fish of Indonesia's main export commodities [6]. The catch of tuna in the
waters of the Bali Strait reached 1,632,383 kg in 2015 [7]. Previous studies indicate that oceanographic parameters such as sea surface temperature, salinity, chlorophyll-a concentration, upwelling, eddies are related to fish existence [8-10]. Furthermore, production and distribution of Mackerel tuna (*Euthynnus sp*) are believed strongly influenced by oceanographic conditions of waters such as sea-surface chlorophyll-a (SSC) and sea surface temperature (SST) [6, 11]. SST is closely related to the suitability of physiological conditions and morphological adaptation of fish. In addition, SST becomes an indirect indicator of biological productivity or the presence of fish food [12]. Meanwhile SSC is a factor that can provide a direct indication of the existence of fish food and the pathways of fish migration areas [13].

Information on oceanographic condition is strongly influenced by the role of current technology. Advanced technology is believed to be able to provide extensive information in a relatively short time. One alternative technology that can be used to determine the oceanographic condition is to utilize geographic information system capabilities and remote sensing. Therefore, the objective of this study is to elucidate how oceanographic conditions affect the distribution of Mackerel Tuna (*Euthynnus sp*) in Bali Strait based on remotely sensed data.

2. Method
One of fishing activities area for Mackerel tuna in Indonesia is Bali Strait (Figure 1). Bali Strait is located between Java Island and Bali Island. This study area is influenced by both Indonesian through flow and mixing in the Pacific Ocean [14].

![Figure 1. Study Area, Bali Strait, located between Bali and Java Islands.](image)

2.1. Satellite-derived environment variable
Sea-surface chlorophyll-a (SSC) and sea-surface temperature (SST) data for period of January – December, 2016 – 2018 (3 years) were analyzed to understand the oceanographic condition in Bali Strait. Both monthly data have level 3 and spatial resolution of 4 km. SSC and SST data were generated from satellite images from the Moderate Resolution Imaging Spectroradiometer (MODIS)-Aqua mission and were downloaded from ocean color website ([http://oceancolor.gsfc.nasa.gov/](http://oceancolor.gsfc.nasa.gov/)). These data were processed with SeaDas package ver. 7.4 and ArcGIS 10.2.

2.2. Fishing lane and catch data
Catch data for Mackerel tuna were obtained from PT Perikanan Nusantara an incorporated company of the Indonesian government, at Benoa, Bali. Data included fish weight (in tones) per month during 2016 – 2018. In addition, the fishing lane was obtained from marine research and observation agency (Balai Riset dan Observasi Laut), Bali. The fishing lane data only for period of July 2018. The data were used to validate the potential fishing zones of Mackerel tuna.

2.3. Relationship between Mackerel and oceanographic conditions
Multiple linear regression was used to express the association between oceanographic condition of SSC and SST and Mackerel tuna catch. Regression is one of the data analysis techniques in statistics,
which is often used to examine the relationship between several variables and predict a variable. The relationship or influence of two or more independent variables on non-independent variables are called the multiple linear regression model [15]. Graphic relation between oceanography parameters and the fishing catch was created to decide the favored oceanographic conditions of Mackerel tuna. The dependent variable used in this study is monthly catch data from 2016 - 2018, while for the independent variables were SST and SSC, consequences the equation used was:

$$Y = a + b_1X_1 + b_2X_2$$

$$r = \frac{n \sum_{i=1}^{n} X_i Y_i - \sum_{i=1}^{n} X_i \sum_{i=1}^{n} Y_i}{\sqrt{n \sum_{i=1}^{n} X_i^2 - (\sum_{i=1}^{n} X_i)^2} \sqrt{n \sum_{i=1}^{n} Y_i^2 - (\sum_{i=1}^{n} Y_i)^2}}$$

where:

$Y =$ Mackerel catch data (tones)

$a =$ Konstanta

$X_1 =$ sea-surface temperature ($^\circ$C)

$X_i =$ Sea-surface chlorophyll-a (mg/m$^3$)

$b_1 =$ Regression coefficient of sea-surface temperature

$b_2 =$ Regression coefficient of sea-surface chlorophyll-a (mg/m$^3$)

$r =$ correlation coefficient

3. Result

3.1. Fisheries and environmental data

Figure 2 showed the variation catch of Mackerel tuna during 2016 – 2018. The total catch during this period was 7,693 tones with the highest catch occurred during September – October. The highest catch of Mackerel tuna occurred in 2018 with a total catch of 5,542 tones, meanwhile the lowest catch of 155 tones occurred in 2016.

Figure 2. The value of tuna fish production in 2016 - 2018 in the Bali Strait waters.

The monthly averaged time series of environmental data for the period 2016 – 2018 are shown in Figure 3. SST of 2017 almost has same pattern and value with SST of 2018. During 2017 and 2018 SST have a value of 24.08 – 33.01 and 23.76 – 33.29 $^\circ$C, respectively. However, during 2016, the pattern and values of SST are slightly different, especially from May – November. In general, during
2016, the water condition is warmer than 2017 and 2018. During 2016 SST has a value between of 26.96 – 33.60 °C.

In addition, mean of SSC during 2017 also showed the same pattern with mean of SSC in 2018. In 2018, mean of SSC started increasing in May with value of 1.55 mg/m³ and reached the highest value of 4.05 mg/m³ in September. During this year the mean value of SSC during October – November still remained high. Contrast condition was shown in 2016. During 2016, the mean of SSC from January – December have low value.

![Mean value of (A) sea surface temperature and (B) sea surface chlorophyll-α in 2016 – 2018.](image)

Pearson correlation results (-0.835) showed the strong negative relationship between SST and SSC. This unique relationship indicates that SSC will increase when the SST decline (Figure 4). This condition demonstrates that the increase in SSC is strongly influenced by upwelling processes such as during ENSO and IOD events [5, 16]. The upwelling event clearly seen in 2017 and 2018. During this two year, especially May – September, the SSC has high value when the SST was low.

![Figure 4: Mean value of SST and Chl-a in 2016 – 2018.](image)
3.2. Regression and potential habitat

We employed monthly catch data for Mackerel tuna and oceanographic factors in multiple regression model analysis. The results showed that correlation coefficient, \( r = 0.620 \), indicates that there was moderate relationship between SST and SSC with Mackerel tuna catch. In addition, the result also showed the significant value of < 0.05. This outcome illustrates that the SST and SSC together affect the Mackerel tuna catch. Multiple linear regression can also provide partial information on the influence of each independent variable on the dependent variable. T-test result revealed that SST was not given actual effect on the Mackerel tuna catch (significant value of > 0.05). In contrast, SSC gave actual effect on the Mackerel tuna catch data (significant value of < 0.05). These results indicate that SSC has high impact on the Mackerel tuna catch compared with SST in Bali Strait.

Figure 5 showed the relationship between time series of environmental and catch data of Mackerel tuna during 2016 – 2018. The figure showed that, in general, high catch was occurred in SST value of 26 – 28°C and SSC value of 0.47 – 2.6 mg/m³. These environmental values were then used to understand the potential fishing zones for Mackerel tuna.
Figure 5. Relationship between time series of environmental and catch data of Mackerel tuna during in (A) 2016, (B) 2017 and (C) 2018.

Maps of predicted for 2018 are shown in Figure 6. The predicted feasibility of incident of Mackerel tuna in the Bali Strait mostly occurred during southeast monsoon (May – September) and the beginning of northeast monsoon (October - November). The high potential of habitat in the southeast monsoon and the beginning of the northeast monsoon is thought to be related to the increase or high concentration of SSC. During southeast monsoon the predicted probability of occurrence of Mackerel tuna almost covered the entire Bali Strait, especially in May and July. The predicted probability of occurrence decrease in August, but going up again in September – November. In general, the distribution of Mackerel tuna based on the predicted probability of occurrence revealed moderate spatial with the fishing lane in May – November, except in August (Figure 7).
Figure 6. Potential fishing zone of Mackerel tuna from January – December 2018.

Figure 7. Fishing lane overlain on potential fishing zone for Mackerel tuna from May – November 2018.
4. Discussion
Mackerel tuna is a highly migratory species and has a widespread area. This species can be found in the tropical waters of the Indo-Pacific. Mackerel prefers to stay close to the beach when spawning and juvenile sizes are found in bays and ports. This species often forms a large group when looking for food together with the family of Scombridae and has rapid swimming ability in the waters [17-19]. Mackerel tuna is a carnivorous marine biota, prey on other small fish, crustacean, mollusca, annelida, anthephyta, squid and some small pelagic fish (Stolephorus sp, Sardinella sp, and Selar sp) [17]. Although sexually mature fish may be encountered throughout the year, the seasonal spawning peaks of this species varied according to region, for example March-May in Philippine waters; during the Northeast Monsoon period (October-November and April-May) around Seychelles; from the middle of the Northeast Monsoon to the beginning of the Southeast Monsoon (January-July) in East Africa; and from August to October in Indonesia [20]. In addition, Mackerel is a pelagic fish species that many spread along the Asian continent including Indonesian waters such as in the Bali Strait water. The Bali Strait is waters with considerable fisheries resources. The catch is dominated by pelagic and demersal fish species. Mackerel tuna (Euthynnus sp) is one of the biggest catches in Bali Strait besides Sardinella lemuru, Decapterus spp. and Rastrelliger kanagurta [5].

Productivity, migration pattern and fish distribution are influenced by changes in the environment evident from the variations in temperature, chlorophyll-a concentration, currents, salinity, and wind field [21-23]. In this study, in general, high catch of Mackerel tuna mostly occurred during southeast monsoon (May – September) and at the beginning of northeast monsoon (October - November) (Figure 2), when the SSC has high value. [7] reported that SSC in the waters of the Bali Strait reaches the highest peak in the southeast monsoon. During this period, upwelling generally occurs which is characterized by a decrease of SST value and an increase in SSC value [24]. Therefore, we believed that the increase catches of Mackerel during southeast monsoon were mostly correlated with upwelling event (Figure 5). Our results are consistent with the findings of [11] and [25], who reported that SSC have significant impact on CPUE of pelagic fish and Mackerel tuna catch in Bali Strait. The abundance of SSC in the waters will increase the productivity of plankton so that the feeding chain can support fish productivity in the waters [26, 27]. In the southeast monsoon the water flows from the South of the Bali Strait to the north of the Bali Strait. Fertility rates are higher during the southeast monsoon due to the upwelling process in the Indian Ocean, which contains more nutrients entering the Bali Strait [28]. In addition, [29] reported that the elevated of SSC will be followed by Mackerel tuna catch. However, the increase in the value of SSC was not simultaneously followed by an increase in Mackerel tuna catches [7]. This is due to the time lag between SSC and the catch of large fish [30].

Figure 5 showed that high catches of Mackerel tuna occurred in the prior six – seven months from elevated SSC. Besides SSC, SST also has a large role in the distribution of tuna in the Bali Strait. In this study, most of high catch was occurred in SST value of 26 – 28°C. Our results are supported by previous research, in which SST value of 20 – 28°C is optimum condition for Mackerel tuna activities and consequences they can be found in the surface until a depth of 40 m [11]. They also reported that Mackerel tuna catch will decrease at warmer conditions because the tuna will swim deeper when the water temperature ranges between 31°C and 32°C, so the fishing gear will not be able to reach it. In general, the variability of SST in the Bali Strait is small. In contrast, the variability of SST in the tropical eastern Pacific is high due to a lack of strong equatorial upwelling. However, higher variability (>4.0°C) occurs along and offshore of the Java (including Bali Strait) and Sumatra Coasts, reflected of strong remote effect of the equatorial Indian Ocean integrated with local upwelling [31].
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6. References
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