Analysis of small pelagic fishing grounds using a generalized additive model in the Makassar Strait

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Abstract. Spatial and temporal studies on the distribution of small pelagic fish by applying oceanographic parameters are essential for fisheries management. An understanding of the spatial characteristics of small pelagic fish distributions is important to optimize the sustainability of marine resource utilization. This study examined the characteristics of small pelagic fish fishing grounds through the analysis of oceanographic parameters using remote sensing satellite data and generalized additive model. Remote sensing satellite data (SST and chlorophyll-a) covering the area of Makassar Strait were obtained from NASA databases with a spatial resolution of 4 km and monthly temporal resolution. Data on the geographical location and catch volume of small pelagic fish were obtained from a fisheries survey in the Makassar Strait. Remote sensing satellite data and fisheries survey data were plotted graphically to determine the environmental conditions at the sites where the small pelagic fish were caught. Catch volume and catch positions were mapped to show fish distribution. The results show that the highest point was around Baru waters with a catch of 30.70 kg - 36.75 kg. Small pelagic fish were caught in the SST range between 29.82 °C - 31.32 °C and mostly caught in chlorophyll-a between 0.34 mg/m³ - 0.62 mg/m³.

1. Introduction

Fisheries are an important source of food and livelihoods worldwide [1]. Small pelagic fish are an important economic resource and a major ecological component in various marine ecosystems [2]. Small pelagic fish contribute significantly and are a crucial component of aquatic ecosystems [3,4]. Small pelagic fish have a variety of species in their population and play a role in ecology and socio-economic development [5]. Overexploitation for both commercial and consumption purposes has resulted in the reduction of several species of aquatic species [6,7]. Estimation of fish distribution spatially and temporally is essential information in the management of marine ecosystems [8].

The use of remote sensing methods is one of the effective techniques in fisheries assessment. Remote sensing methods are increasingly being used in identifying the relationship between...
environmental parameters and species abundance [9,10]. Besides the study of [11] also used remote sensing techniques to map the characteristics of fish habitats. Habitat is key in studying fishery resources and can be an appropriate criterion for management decisions [12]. Fish habitat and distribution can be observed and mapped using remote sensing technology [13].

Distribution of small pelagic fish is influenced by oceanographic parameters of the waters spatially and temporally. Oceanographic dynamics of the waters affect the distribution of small pelagic fish [14]. The distribution of small pelagic fish is influenced by environmental conditions [15]. The main feeding target for small pelagic fish is plankton so its abundance is strongly influenced by the conditions of its aquatic environment [16]. Food availability significantly affects the presence of pelagic fish and is associated with the food chain.

An understanding of the relationship between the distribution of small pelagic fish and oceanographic parameters is essential to know to conserve its resources [14]. SST and chlorophyll-a content are important variables for the existence and abundance of pelagic fish populations. One of the efforts that can be made in optimizing the catch is by conducting various studies to determine the characteristics of the target catchment area through oceanographic parameters. This paper aimed to provide an up-to-date overview of oceanographic parameters and analysis of small pelagic fishing grounds in the Makassar Strait to provide information in fisheries management.

2. Methods

2.1. Study Area

The Makassar Strait is known as one of the waters rich in small pelagic fish resources in Indonesian waters. The Makassar Strait is a strait between the islands of Kalimantan and Sulawesi in Indonesia. This strait also connects the Sulawesi Sea in the north with the Java Sea in the south. The map of the research location is shown in Figure 1.
2.2. Purse Seine Fishery Data
The data used in this study are purse seine catch data in March-May 2020 in the form of small pelagic fish in the Makassar Strait waters. The catches that were the target of this study were Indian mackerel (*Rastrelliger kanagurta*) Short mackerel (*Rastrelliger brachysoma*) and Sardine (*Sardinella sp.*) which were the highest average catch on purse seine fishing gear. Purse seines are designed to catch schooling fish. A purse seine is made of a long wall of netting framed with a lead line and a floating line. The purse seine is set from one or two boats to surround a detected school of fish. A purse line threaded through purse rings spaced along the bottom of the net is drawn tight (pursed) to stop the school of fish escaping downwards under the net [17].

2.3. Satellite Remote Sensing Data
Oceanographic data in the form of Sea Surface Temperature (SST) and chlorophyll-a in March-May 2020 were obtained from the AQUA satellite with a MODIS (Moderate-Resolution Imaging Spectroradiometer) sensor with a spatial resolution of 4 km and a monthly temporal resolution (monthly). Satellite images are the result of remote sensing observations. SST and chlorophyll-a values were obtained through the extraction process of remote sensing satellite data. Satellite or
airborne measurement of spectral reflectance (ocean color) is an effective method for monitoring phytoplankton by its proxy concentration of chlorophyll-a the green pigment [18].

Remote sensing is a method of recording an object on the earth's surface without physical contact with that object. Sustainable use of marine resources requires effective monitoring and management. Since the advent of the satellite remote sensing method it is possible to retrieve oceanographic parameter data with acceptable spatial and temporal resolution [19]. The same research was conducted by [14] regarding the detection of potential fishing locations using remote sensing data. Also [20] studied fish distribution using oceanographic data in the form of SST and chlorophyll-a. Image cutting process uses SEADAS software (SeaWiFS Data Analysis System) and processing uses ArcGIS 10.1 software. These data were analyzed using an overlay technique using a Geographical Information System (GIS) to determine the distribution of oceanographic parameters in the form of SST and chlorophyll-a spatially and temporally and plotted with small pelagic fishing production data.

2.4. Analysis of the Generalized Additive Model (GAM)

GAM analysis is a non-parametric analysis so it can be used even if the sample does not spread normally. GAM analysis has a high degree of accuracy so it is often used in the study of the relationship between the two variables. This study attempts to use GAM analysis to determine the relationship between SST and chlorophyll-a with small pelagic fish catches in the Makassar Strait. This analysis has been used in previous studies that studied the relationship between pelagic fish and oceanographic parameters in the waters of the Gulf of Bone [20].

3. Results and Discussion

3.1. Environmental Conditions of Makassar Strait Waters

Fish stocks are a crucial high protein food source for humanity but the world's fisheries are under increasing pressure related to human population growth. About 80% of the world's fish stocks are now fully exploited or overexploited [1]. The use of fish resources in the waters must still be controlled so that it can be balanced with the growth rate [21]. The distribution of variations in environmental conditions affects the distribution abundance and availability of fish [22]. The most frequently measured environmental parameters in studying fish habitats are SST and chlorophyll-a. Information about these parameters helps in predicting the location distribution and behaviour of fish [23].

Small pelagic fish are generally found in areas around coastal waters. The main prey of these fish is plankton so its existence is likely to be significantly influenced by environmental conditions [16]. Information on the oceanographic conditions of the waters can be used as a reference for estimating the presence of fish mostly small pelagic fish which are highly influenced by SST and chlorophyll-a. In general the distribution of oceanographic conditions in the Makassar Strait in March-May 2020 is very volatile in the form of SST ranging from 25.51°C - 32.50°C (Figure 2) and chlorophyll-a ranging from 0.01 mg/m³ - 1.60 mg/m³ (Figure 3).

The distribution of SST in the Makassar Strait in March 2020 looks higher with a range of 27.51°C - 32.50°C and in May 2020 the spatial distribution is cooler with a range of 25.51°C - 30.51°C can be seen in Figure 2. Small pelagic fish were found to respond to temperature changes in the water [24].

Based on Figure 3 it can be seen that the chlorophyll-a concentration is higher in areas near land such as research by [20,25] showed higher chlorophyll-a concentrations in areas near mainland Sulawesi. The distribution of chlorophyll-a in the Makassar Strait ranges from 0.01 mg/m³ - 1.60mg/m³. Chlorophyll-a is an important factor in the study of the characteristics of potential small pelagic fish areas. [26] stated that environmental parameters are important for estimating marine fishery resources apart from temperature namely chlorophyll-a because it is a source of food for aquatic biota. Primary productivity is a critical index in phytoplankton production and is associated with fishing [27,28]. The concentration of chlorophyll-a is a phytoplankton photosynthetic pigment which is considered as an index of biological productivity [29].
Figure 2. Satellite ocean color showing SST distribution March – May 2020 in the Makassar Strait
Figure 3. Satellite ocean color showing chlorophyll-a distribution March-May 2020 in the Makassar Strait

Figure 4 showed a graph of the relationship between SST and chlorophyll-a on the catch of small pelagic fish in the Makassar Strait. The graph showed that the highest catch of small pelagic fish in the Makassar Strait is in the SST range of 30.5°C - 30.75°C as much as 517.48 kg and the lowest is 31.26°C - 31.50°C with a catch of 31.32 kg. Changes in temperature appear to be contributing to dynamic ecological processes such as foraging for pelagic fish [30]. During the study the highest catch was in the range of chlorophyll-a 0.21 mg/m³ -0.40 mg/m³ as much as 699.65 kg and the lowest was in the chlorophyll-a range of 0.01 mg/m³ - 0.20 mg/m³ as much as 116.12 kg.
Figure 4. The histogram of the catch distribution over the SST range and chlorophyll-$a$

The map of the distribution of small pelagic fish catches in the Makassar Strait waters shows that the catchment points are spread from Barru waters to Makassar City and it can be seen that the catching points around Barru Waters or the northern part are denser. The highest catch was at point $119^\circ32'55"E$ and $4^\circ28'6"S$ as much as 36.9 kg and the lowest was at point $119^\circ20'43"E$ and $4^\circ42'53"S$ as much as 4.6 kg.

3.2. Analysis of the Generalized Additive Model (GAM)

The results of the GAM analysis are shown in Table 1 and Figure 5. Table 1 shows that the environmental parameter that most influences the catch of small pelagic fish is chlorophyll-$a$. According to [31] that chlorophyll-$a$ is not eaten directly by fish but high chlorophyll-$a$ concentrations increase the chances of feeding opportunities for fish so that fish gather in the area.

Figure 5 shows that small pelagic fish were caught in the SST range between 29.82°C - 31.32°C and chlorophyll-$a$ between 0.27 mg/m³ - 0.93 mg/m³. Based on Figure 5 small pelagic fish are mostly caught in chlorophyll-$a$ between 0.34 mg/m³ - 0.62 mg/m³. Previous studies mention the same result that the chlorophyll-$a$ preference of small pelagic fish is in the range of 0.31 mg/m³ - 0.10 mg/m³ [25].

| Variable | Df | Sum Sq | Mean Sq | F value | Pr(>F) |
|----------|----|--------|---------|---------|--------|
| s(SST)   | 1  | 50.8   | 50.8    | 0.6997  | 0.40685|
| s(Chl)   | 1  | 413.5  | 413.5   | 5.6957  | 0.02083*|

Signif. Codes: 0 ‘****’ 0.001 ‘***’ 0.01 ‘**’ 0.05 ‘*’ 0.1 ‘.’ 1
Figure 5. Relationship between small pelagic fish catches and SST and chlorophyll-a

3.3. Spatial distribution of small pelagic fish catches

Figure 6 shows that the catching points for small pelagic fish in the Makassar Strait are spread along the Barru waters to the Makassar Waters. However on the map it can be seen that during the research period the catchment points were gathered in the area around the Barru waters. The most catches are around Barru waters namely 30.70 kg - 36.75 kg per catch point.

Figure 6. Spatial distribution of points and catches of small pelagic fish
4. Conclusion
The most points are around Barru waters with catches of 30.70kg - 36.75kg. Small pelagic fish were caught in the SST range between 29.82°C - 31.32°C and mostly caught in chlorophyll-a between 0.34 mg/m³ - 0.62 mg/m³.

Acknowledgements
The author would like to thank the Ministry of Research and Technology / National Agency for Research and Technology for financial assistance for the Beginner Lecturer Research scheme with contract number: 231 / SP2H / LT / DRPM / 2019 on behalf of A.Rini Sahni Putri S.Pi. M.Si. We would also like to thank an anonymous reviewers and the editor for their suggestions to improve this manuscript.

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