The Fishing Ground of Large Pelagic Fish during the Southeast Monsoon in Indonesian Fisheries Management Area-713

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The Fishing Ground of Large Pelagic Fish during the Southeast Monsoon in Indonesian Fisheries Management Area-713

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Abstract. Large pelagic fish (LPF hereafter) is an important group of fishes targeted by local fishermen in the Indonesian Fisheries Management Area-713 (IFMA-713). This IFMA includes the Makassar Strait, Flores Sea, Bali Sea, and Gulf of Bone. The objective of this study was to identify the preferred oceanographic conditions based on LPF fishing grounds in the study area. The experimental fishing was conducted from April to September 2018 by using local commercial fisheries (pole and line and purse seine). The fishing base of pole and line vessels operating in the Gulf of Bone was at Murante fish landing site, Luwu Regency, South Sulawesi. On the other hand, the fishing base of purse seine vessels operating in the Makassar Strait was at Siddo fish landing site, Barru Regency, also in South Sulawesi. Oceanographic factors such as sea surface temperature (SST), sea surface chlorophyll-a (SSC) concentration, and depth were derived from satellite data. The LPF fishing grounds were analysed and visualize using Geographic Infomation System (GIS) techniques. Based on the results, LPF distributions tended to be the highest in specific oceanographic conditions, including SST of 30.0 - 31.0 °C and SSC of 0.20 - 0.30 mg.m^{-3}. They were mostly found in nearshore and offshore areas (maximum depth of about 2,000 m). The selected oceanographic factors played an important role in explaining the LPF fishing grounds. This information could be used for spatial prediction of potential LPF fishing zones in relation to the fish distribution and abundance during the Southeast monsoon in the IFMA-713.

1. Introduction

The ecosystem approach to fisheries framework has been developed on the founding principles and conceptual goals emerging from the decades-long process of elaboration of the foundation for sustainable development, aiming at both human and ecosystem well-being. Furthermore, to organize these as an integrated framework for fisheries, a process of selection and reformulation matured in the 1995 FAO Code of Conduct for Responsible Fisheries [1]. Marine fisheries sustainable management concepts in Indonesia are applied in regions known as Indonesian Fisheries Management Areas (IFMA). The marine waters of Indonesia have been divided into 11 Fisheries Management Areas based on the characteristics of the fish resources and the marine environment. These are: Malacca Strait and Andaman Sea (IFMA-571); Indian Ocean of Western Sumatera and Sunda Strait (IFMA-

572); Indian Ocean of Southern Java, Southern Nusa Tenggara, Sawu Sea, and Western of Timor Sea (IFMA-573); Karimata Strait, Natuna Sea and South China Sea (IFMA-711); Java Sea (IFMA-712); Makassar Sea, Gulf of Bone, Flores Sea and Bali Sea (IFMA-713); Tolo Bay and Banda Sea (IFMA-714); Tomini Bay, Maluku Sea, Halmahera Sea, Seram Sea and Berau Bay (IFMA-715); Sulawesi Sea and Northern sea of Halmahera Island (IFMA-716); Cendrawasih Bay and Pacific Ocean (IFMA-717); and Aru Bay, Arafuru Sea, and Eastern Timor Sea (IFMA-718). IFMA-713 is shown in Figure 1.

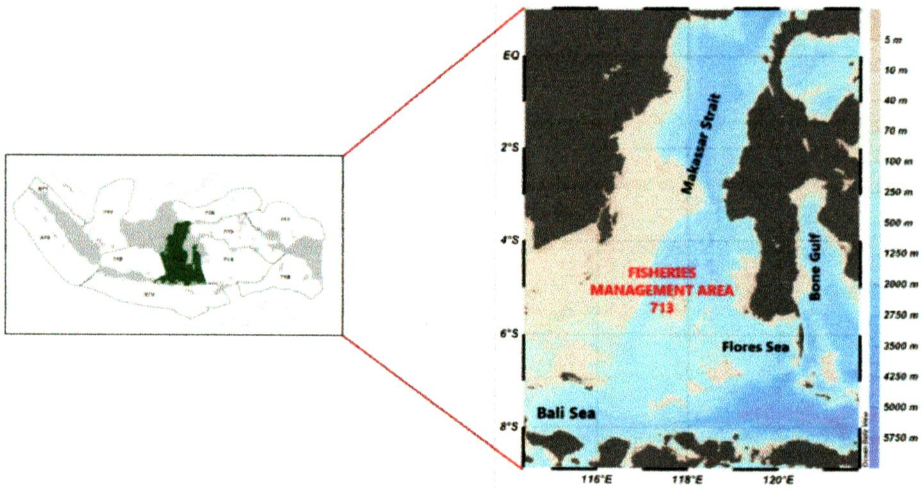

Figure 1. Fisheries Management Area 713 (FMA-713) in Indonesia Fisheries Management Areas. Figure Modified from [2].

The Maximum sustainable yield of large pelagic fish (LPF hereafter) in Indonesian Fisheries Management Area (IFMA) 713 is estimated at 17,058 tons/year, with an optimum effort equal to 14,134 standardised purse seine units [2]. The IFMA-713 is considered one of the best places of LPF fisheries in Indonesia waters, because of the oceanographic conditions in this area which are highly influenced by the Indonesian Throughflow (ITC) and monsoonal patterns [3,4]. The pattern of fish distribution is greatly influenced by oceanographic factors such as sea surface temperature (SST), sea surface chlorophyll-a (SSC) and fishing depth [5–7].

Large pelagic fishes such as yellowfin tuna, skipjack tuna, or little tuna are important species targeted by local commercial fisheries in IFMA 713. The abundance and distribution estimates of LPF in relation to oceanographic conditions are vital information for fisheries management and also for the understanding of ecosystem dynamics. The distribution and abundance of these species tends to aggregate to the preferred bio-physical environments. However, little is known about the real abundance and distribution of LPF in this area, especially in the Southeast Monsoon. A combined satellite remote and geographic information system approach can provide a powerful tool to detect potential fishing grounds particularly for highly migratory fish such as the tuna family [8].

Previous studies suggested that oceanographic factors such as SST, SSC and depth play a role in determining LPF geographical distribution and abundance [5,9]. However, the oceanographic factors that control the distribution and abundance of LPF in IFMA 713 are still unclear. This study was undertaken to address this question. The aim of the study was to understand the oceanographic conditions in the fishing grounds of large pelagic fish (LPF) in IFMA-713 during the southeast monsoon. This information will be useful for many purposes, in particular for sustainable resource management in the LPF fishery.

2. Research methods

This study gathered information about the most important tuna species in the IFMA-713, mainly yellowfin tuna, skipjack tuna, and little tuna, related to their spatial distribution, ranges of SST, SSC, and fishing depth. The research was conducted during the southeast monsoon from April to September 2018 in IFMA-713 (Gulf of Bone and Makassar Strait), Indonesia. The study focused on a pole and line fishery operated in the Gulf of Bone (Murante fishing landing site, Luwu Regency) and a purse seine fishery in the Makassar Strait (Siddo fish leading site, Barru Regency), both in South Sulawesi Province.

2.1. In-situ and ex-situ data collection

The fisheries data (*in-situ* data) were collected during April to September 2018, comprising 241 fishing ground points with coordinates determined using global positioning system (GPS), and catch data from counting the number of large pelagic fish (LPF) caught per hauling. *Ex-situ* data on sea surface temperature (SST) and sea surface chlorophyll-a (SST) were derived from Aqua/MODIS (Moderate Resolution Imaging Spectroradiometer) data obtained from the National Oceanic and Atmospheric Administration (NOAA). These were Standard Mapped Image (SMI) level 3 binary data sets using HDF files with a monthly mean temporal resolution and 0.04 degree (4 km) of longitude and latitude spatial resolution. Meanwhile, bathymetric profiles were derived from the ETOPO2 data base.

The derived SST and SSC and depth were selected to correspond with the time of *in-situ* data. The SeaWiFS Data Analysis System (SeaDAS 5.3) was used to extract monthly SST and SSC that corresponded to latitude and longitude positions of the study area. The SST, SSC and depth data were visualized using inverse distance weighted (IDW) interpolation in ESRI, ArcGIS 10.3. The ArcGIS tools were used to describe the SST, SSC and depth variation during the experimental fishing, and explicitly model the spatial autocorrelation. This study used histogram graphs of catch volume data to describe and compare the relationship between oceanographic conditions of SST, SSC and depth in the study area.

2.2. Construction of Statistical Model

Statistical models [10] were applied to the large pelagic fish fishing grounds and oceanographic datasets to evaluate the effects of oceanographic factors on the LPF distribution in the IFMA 713. The generalized additive models (GAMs) were constructed in R program version 3.6.0 [11] using the GAM function of the mgcv package [12] to predict the distribution of LPF as the response variable and the candidate predictor factors were the oceanographic factors (SST, SSC and depth). The datasets were then used to develop the statistical predictive models. The appropriate function was used to identify these shapes in the linear model respectively as shown in the applied equation (1):

$$g(\mu i) = \alpha 0 + s1\ (\text{temperature}) + s3\ (\text{salinity}) + s3\ (\text{depth}) + \varepsilon \qquad (1)$$

where g is link function, μi is the expected value of the dependent variable for number of LPF (in individuals), α and β0 are the model constant, sn is a smoothing function of the predictor variables and ε is a random error term, βn is the vector of model coefficients.

The abundance of LPF followed a continuous distribution hence the Gaussian family which is associated with the identity link functions was chosen. The Binomial family with logit link function was used for LPF distribution. Models were constructed from the simplest form using one independent factor e.g. SST only, with subsequent addition of predictor factors. Model selection was based on significance of predictor terms, and deviance explained value. Constructed GAMs were made from the best model selected from a set of 7 models. GAMs were employed to compare the resulting model's prediction based on the statistical criterion and furthermore, they were used to explain all observed variables as well as the relationship between variables.

3. Results and discussion

The Fisheries management area 713 comprises three main areas, namely the Makassar Strait in the western area, the Flores Sea and Bali Sea in the southern area and Gulf of Bone in the eastern area. Based on commercial fisheries catches, the production of large pelagic fish (LPF) in these three areas in IFMA713 during 2017 is shown in Figure 2. During the southeast monsoon, landings of LPF in IFMA 713 were highest in the Gulf of Bone, and the species caught were mostly yellowfin tuna (*Thunnus albacares*), skipjack tuna (*Katsuwonus pelamis*), and little tuna (*Auxis* sp).

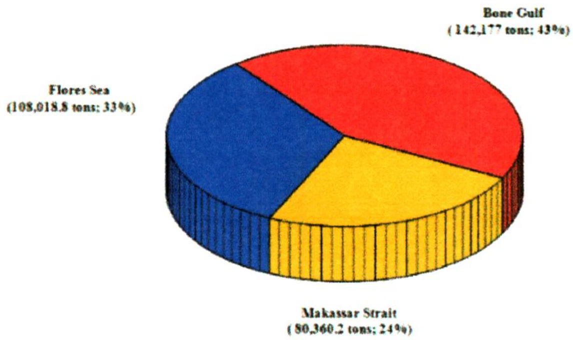

Figure 2. Production of Large Pelagic Fish in MFA 713 [13].

3.1. Fishing Grounds

The satellite images of SST and SSC (Figs. 3 and 4) were used to observe the fishing ground of large pelagic fish in the Indonesia Management Fisheries Area 713. The horizontal profiles of SST and SSC concentrations structures in the different monthly (Figs. 3 and 4) and showed warm temperatures in the northern area, and nearshore areas were followed with chlorophyll-a concentrations which decreased gradually with depth changes. Figures 3 and 4 showed that LPF fishing grounds were mostly in coastal and off shore areas with warmer SST, and lower SSC.

The varied LPF abundance and distribution were recorded monthly during the experimental fishing from April to September 2018, and were higher in April and September than in other months. To get a better understanding of these phenomena, the present study overlaid the LPF distribution and biomass with the oceanographic conditions for each month of the 2018 southeast monsoon (Figs. 3 and 4).

The SST was highest in April and the waters gradually cooled from May to September (Fig. 3). Based on the data in Figure 3, the highest SST values (warmest areas) were found in the western part of IFMA 713 and the warmer water masses disappeared in September. The highest SSC concentrations were found in the coastal area this pattern was consistent from April to September. The peak SSC concentration occurred in July (Figure 3).

Figure 3 shows that the oceanographic condition (SST and SSC) in the IFMA 713 was influenced by the ITF. The various water masses were not completely mixed, making it easy to identify the warmer temperatures from equatorial regions and cooler water masses from southern areas. Thus, the changes in oceanographic conditions may have influenced the LPF distribution pattern in the water column. To verify this phenomenon, the current study also provided the horizontal profiles of oceanographic condition in the study area. Sea surface temperatures indicated significant differences among sites within the study area. The SST in April 2018 was warmer than those measured in other months. On the other hand, SST in September 2018 was cooler. The fishing operations mostly occurred in April and September 2018 in both study areas.

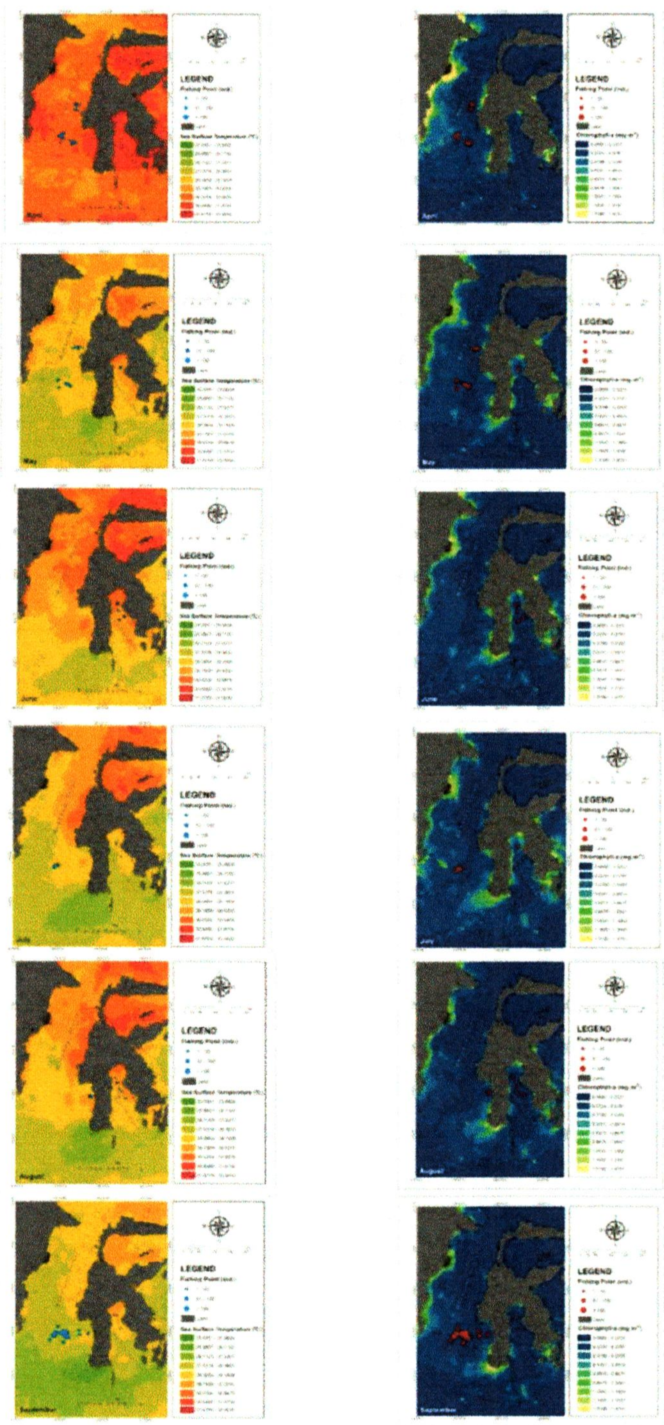

Figure 3. Sea Surface Temperature and Sea Surface Chlorophyll-a Profiles from April to September 2018. The Data were derived from Satellite Remote Sensing

The LPF fishing grounds were mostly found in the high SST and lower SSC areas. The LPF were widely across depth profiles from near coastal to offshore areas (Figure 4).

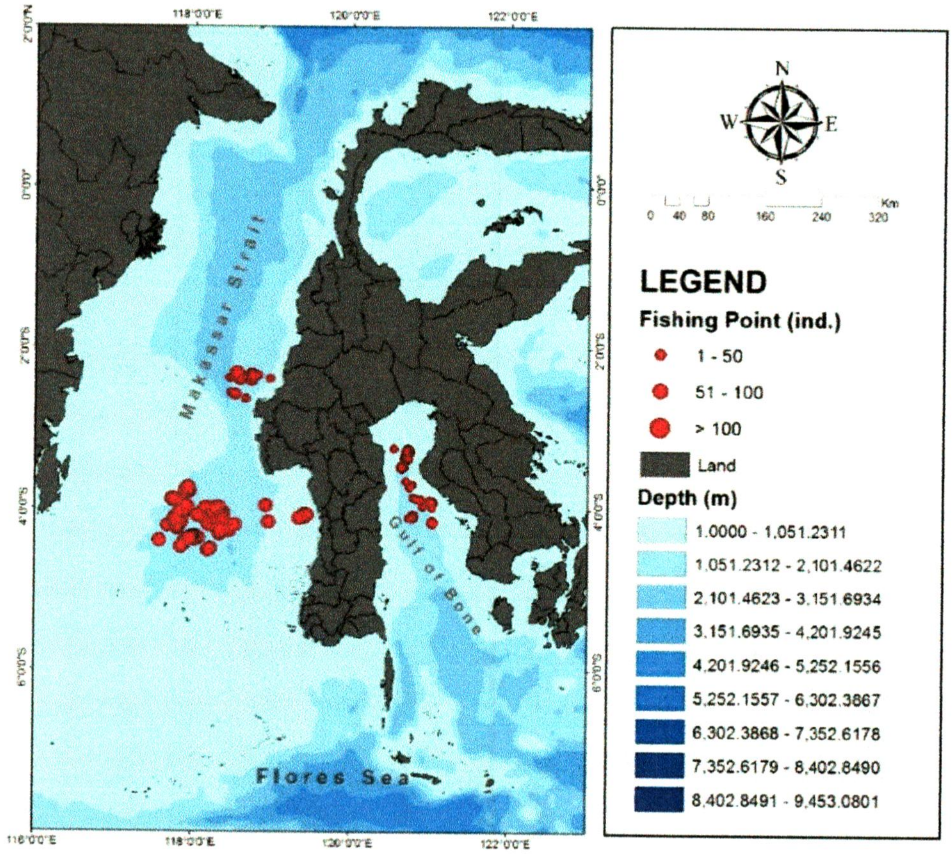

Figure 4. Bathymetric profile overlay with fishing ground positions in April to September 2018. The Oceanographic data derived from Satellite remote sensing

The short term relationship between oceanographic conditions and LPF catches based on the spatial pattern of fishing grounds in IFMA 713, remotely sensed satellite images of SST, SSC concentration, and fishing depth together with catch data were used. The preferred ranges provide a good indicator for initially detecting potential LPF fishing grounds. The high LPF distribution and abundance corresponded well with SST of 30.0–31.0 oC and SSC of 0.20–0.30 mg m-3 (Figure 5). This study suggested that SST and SSC may important mechanisms in explaining the temporal and spatial dynamics of LPF distribution and abundance in IFMA 713. They are mostly found in nearshore and offshore areas (maximum depths around 2,000 m) as shown in Figure 5. The models revealed that the selected oceanographic parameters play an important role in explaining the LPF fishing grounds. In spite that there are still many gaps to fill on the possible changes to the LPF distribution and abundance by global warming for example, considerations on possible future scenarios related to climate change and tunas fisheries.

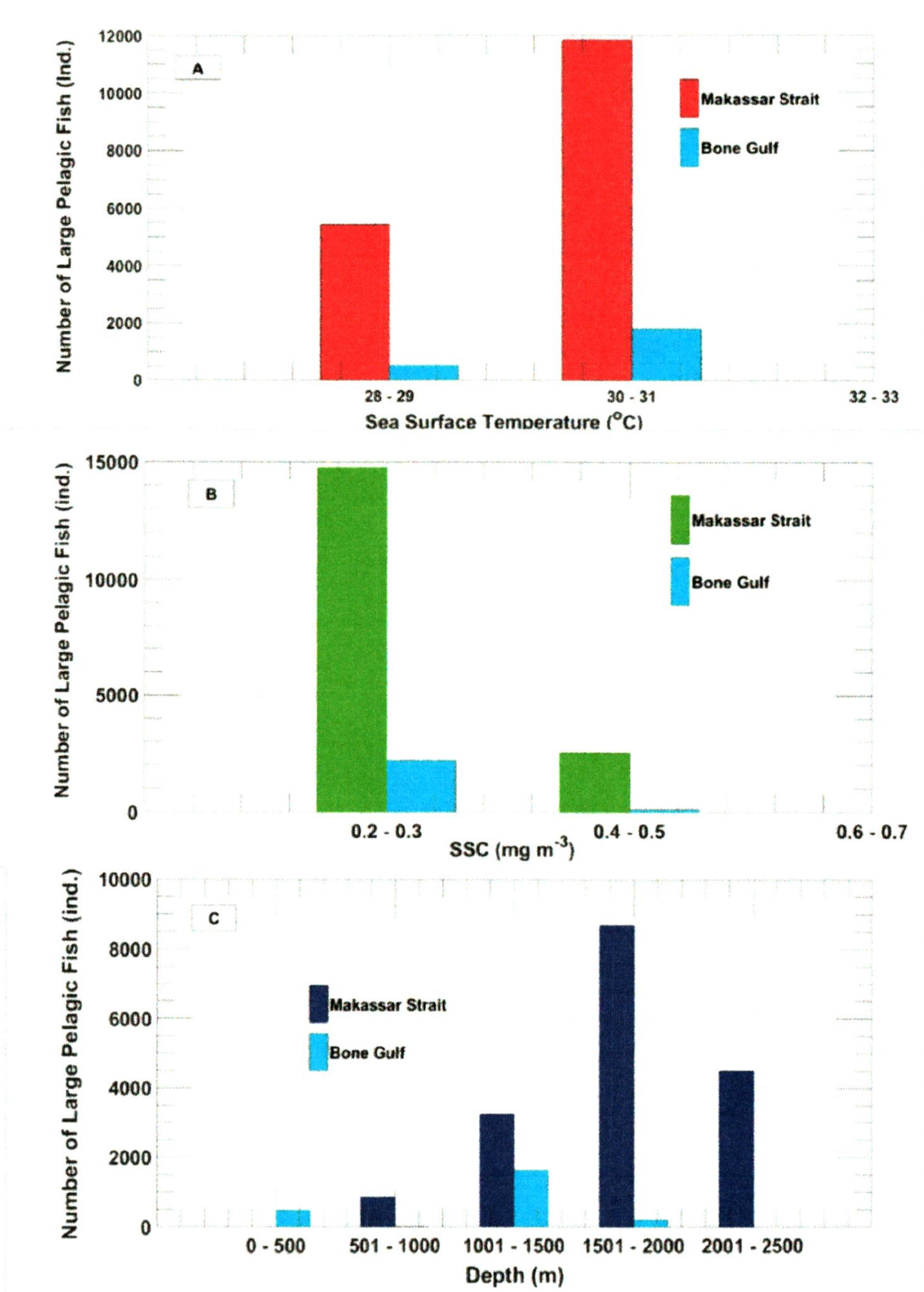

Figure 5. Preferences of oceanographic conditions: (a) SST; (b) SSC; (c) depth for Large Pelagic Fish. All datasets from April to September 2018 were used; the numbers of fish caught during experimental fishing are shown

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3.2. Effects of oceanographic factors on fish distribution

In the current study, the oceanographic condition on each fishing ground of large pelagic fish school was used for display and further analysis. Table 1 presents the models constructed from predictor factors such as SST, SSC, and fishing depth on the fish distribution in present scenario using GAMs. The results for each of the 7 GAM models constructed are also presented in Table 1.

Table 1. Summary GAM statistics: oceanographic factor effects on LPF distribution (n=241) with significance level and percentage cumulative deviance explained (CDE)

No.	Model	Variable	P-*value*	CDE (%)
1.	SST	SST	0.12	1.21%
2.	SSC	SSC	0.0187 *	2.96%
3.	Depth	Depth	<2e-16 ***	14%
4.	SST + SSC	SST	0.0498 *	4.33%
		SSC	0.0125 *	
5.	SST + Depth	SST	0.225	14.6%
		Depth	<2e-16 ***	
6.	SSC +Depth	SSC	8.04e-09 ***	20.4%
		Depth	< 2e-16 ***	
7.	SST + SSC + Depth	SST	0.112	20.6%
		SSC	9.2e-09 ***	
		Depth	< 2e-16 ***	

Significant codes: 0.001 '***' 0.01 '**' 0.05 '*'

The Tables 1 showed each of the models constructed from one predictor, two predictors and the last, three predictors. Over all, for each model the predictor factor (s) had a significant factor on the school density in $p<0.05$ reference levels except SST as a single predictor, and in a combination with SST in two model predictor and three model predictors in GAMs. Tables 1 suggested that the effects of oceanographic factor might be taken into account for variability in LPF distribution in the IFMA 713.

The resulted GAMs in IFMA 713 (the Gulf of Bone and Makassar Strait) were constructed as listed in Tables 1. The resulted GAMs were single parameter models had the lowest cumulative deviance explained (CDE), especially for SST (1.21%). The fishing depth (14%) showed the highest deviance explained among the single parameter models followed by SSC (2.96%). Combination of SSC and depth explained relatively higher variability in large pelagic fish distribution, according to deviance explained (20.4%) and as the best model predictor. The three parameter models also had high deviance explained (20.6%). All the results obtained from the addition of predictor factors at different levels showed increase or decrease in CDE.

Variations in oceanographic conditions play a key role in natural fluctuations of LPF stocks; for example, SST and SSC can have a considerable impact on larval fish stages and fish distribution. SST is a good indicator for fishing grounds and has been used for decades by fishermen and researchers. Moreover, changes in oceanographic factors (physical and biological) may have profound effects on the migration patterns and growth of fish. SST plays important roles in fish physiology, and temperature variations are often linked to the biological richness of oceanic waters [14].

Distribution of LPF was predominantly confined to offshore regions, sometimes in large schools (Figure 3). In this section, the study presented the detail of relationship between LPF and their physical environment at different time and spatial scales in an attempt to understand the various processes. [15] reported that the contrasting responses of the fish populations to the SST rise can be explained by different temperature preference in terms of growth rate in larval and early juvenile stages; for example, cooler temperatures are preferred by sardines and warm temperatures are preferred by saury and anchovy.

Knowing the oceanographic conditions is crucial for estimating the potential zones of LPF fishing ground in the IFMA 713, because they influence the distribution of LPF in their natural habitat. The LPF distribution was investigated during the daytime and was linked to the dynamics of oceanographic condition. As shown in Tables 1 and Figs.4a-d, the influence of oceanographic factors on LPF distribution and biomass in the water column were noted. The influences of oceanographic condition on LPF catch was evaluated based on the *p*-value and the CDE value. [16] noted that pelagic fish can also modify their aggregation level under certain conditions, although this is not always fully understood, but commonly attributed to environmental changes. Thus, the oceanographic factors related to LPF distribution become a matter of great importance to understand their habitat preference.

The present study revealed that the oceanographic conditions in which LPF schools tend to concentrate include SST between 30 to 31°C and SSC of 0.2 – 0.3 mg/m^{-3} (Figure 5). Even though the study area is influenced by the ITF and monsoon [3], LPF could be found in the optimum habitat. Sea surface temperature of IFMA 713 waters changed considerably depending on the monsoon, while SST concentration does not change so much and remained higher in the coastal areas than offshore areas from April to September 2018. The results also showed that LPF distribution and abundance were found mainly in offshore waters about 1,500 m in depth (Figure 4 and Figure 5).

Generalized additive model as a nonlinear model had the highest explained deviance, for understanding effect of oceanographic factors on LPF distribution and abundance in water column as showed in Table 1. A previous study reported GAM models to be very useful for investigating the effects of oceanographic factors on the fish abundance and distribution in the water column for many pelagic fish [14]. This study suggested that LPF schools prefer and tend to concentrate in areas with specific ranges of oceanographic factors such as SST, SSC and depth. These suitable conditions may represent the optimal habitat of the LPF especially in the study area during the southeast monsoon season. Looking to the future, research is needed on and monitoring of the effects of global warming on LPF, especially tuna species, in IFMA-713 and the surrounding sea areas.

4. Conclusion

This paper discusses the oceanographic conditions in the fishing ground of large pelagic fish in the Indonesian Fisheries Management Area 713. Large pelagic fish (LPF) distribution and abundance tended to be highest in specific oceanographic conditions, specifically SST of 30.0 - 31.0°C and SSC of 0.20 - 0.30 mg.m^{-3}. LPF were mostly found in nearshore and offshore areas (maximum depth of about 2,000 m). The models showed that the selected oceanographic parameters play an important role in explaining the LPF fishing grounds. This information could be used for spatial prediction of potential fishing zones for LPF in relation to LPF distribution and abundance during the southeast monsoon in IFMA-713.

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