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To cite this article: Mukti Zainuddin *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **763** 012045

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Dynamics of Thermal Fronts Distribution in the Flores Sea, Indonesia: An implication for locating potential skipjack tuna fishing ground

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Abstract. Flores Sea is one of the most productive fishing grounds within the Indonesian Fisheries Management Area 713 which has the unique physical structures such as topographic feature, the seasonal wind driven upwelling, and also the dynamics of frontal patterns. The purposes of this study were to map the dynamic spatial of the thermal fronts in the east and the second transition seasons, and to describe their implications to the skipjack fishery. We applied the satellite data of sea surface temperature (SST) for the period of June-October 2018 with spatial and temporal resolutions of 0.04 degree latitude and longitude and monthly, respectively. For fishery data, we used sampling data of skipjack tuna fishing ground distributions during this period. The thermal fronts were estimated using a Single Image Edge Detection (SIED) algorithm and the available fishing ground data were superimposed on the SST frontal maps. The results showed that the spatial distribution patterns of thermal fronts along Flores Sea tended to be different every month. However, the thermal fronts were consistently detected throughout the study period. Skipjack tuna fishing grounds started to develop in the eastern area of Selayar Island in June (before upwelling event) and reached a peak in October (after upwelling). During these months, the skipjack fishing grounds well formed around the thermal fronts with the distance of 0-40 km. It implies that the formation of the thermal fronts especially after upwelling gives a significant contribution on the development of skipjack fishery in the Flores Sea.

Keywords: *thermal front, SIED, skipjack, Flores Sea, second transition season*

1. Introduction

Skipjack is a highly migratory tuna that supports important commercial fisheries in Indonesia particularly within Indonesia Fisheries Management Area (FMA) 713 [1,2]. Most of the distribution and abundance of tuna are markedly affected by the oceanographic features such as fronts [3,4]. In Makassar Strait, skipjack tuna associate well with the optimum surface temperature and chlorophyll concentration [1,5], and thermal front [6]. Our preliminary study showed that large size of the fish mainly occupies the Flores Sea.

Flores Sea is known to plays an important role in providing skipjack tuna stock in the FMA 713. This area provides the special oceanographic structures such as variability of the bathymetric feature



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and variability of chlorophyll-a concentration, the main path of the Indonesia Throughflow (ITF) [7,8], important upwelling/ downwelling area associated with the southeast monsoon winds [9] and dynamics of the oceanic fronts [6]. The southern area of FMA 713 is also depicted by the distribution areas of both cyclonic and anti-cyclonic eddy [10] which are important for feeding opportunity. The dynamics of the biophysical oceanographic structures in this area yields in a highly productive habitat, which provides a good fishing ground for various commercially important species, such as skipjack tuna (*Katsuwonus pelamis*), flying fish *Hirundichthys oxycephalus* and mackerel (*Rastrelliger kanagurta*) [2,11–13].

The previous study, we have investigated the thermal front pattern in Makassar Strait [6]. However, little is known about the dynamics of thermal fronts in the FMA 713 especially in the Flores Sea. Thermal fronts are important area for aggregating spots for many commercial pelagic species [14]. Therefore, the objectives of this paper were to map the dynamic spatial of the thermal fronts in the east and the second transition seasons, and to describe their implications to the skipjack fishery in the Flores Sea.

2. Data and Methods

SST images derived from satellite remote sensing from June to October 2018 were used to detect and identify the thermal front patterns using Single Image Edge Detection (SIED) algorithm developed by [15]. To get the frontal formation within study area, we used MODIS/Aqua surface temperature with standard mapped image data level 3 with spatial and temporal resolution of about 0.04° both altitude and longitude and monthly data, respectively. The input data used for detection of the frontal zone process were sea surface temperature images from June to October. The temperature images were available in the NetCDF (NC) data format provided by NASA (<http://oceancolor.gsfc.nasa.gov>). The SST global image data were processed using the SeaDAS software package 7.5.3 to crop the study area (Flores Sea). We converted the raster data into txt format in the software and then created again raster data format using the kriging interpolation method in ArcGIS 10.2. The raster data were then changed into integer format using map algebra in the spatial analyst tools. The resulting integer data were then processed using MGET (the Marine Geospatial Ecology Tools) plugin in the ArcGIS toolbox. All the steps to find and detect automatically the thermal frontal patterns used the methods available in the website (<https://code.env.duke.edu/>) with a horizontal gradient (surface front) based on specified SST levels. The frontal lines have 4 km spatial resolution.

In this study, we used high resolution sampling data of skipjack tuna distributions using pole and line fishing gear in June and October 2018, representing the east and the second transition season, respectively. We superimposed these data on the SST frontal maps to verify the suitable positions of the available fishing data relative to the dynamics of the thermal fronts. Apart from these data, we also used historical skipjack catch data for the period of 2006-2011 to observe the trend of catch. We obtained the data from Incorporated Company of Indonesian Government, PT. Perikanan Samudra at Kendari, Southeast Sulawesi.

3. Results and discussion

Distribution of thermal fronts in the study area during June-October varied monthly (Figures 1, 3 and 5). This will have a significant effect on the skipjack distribution pattern and abundance. The distribution patterns of this species have been proven to associate with thermal fronts [16] particularly in Makassar Strait [17]. In June, thermal front in the Flores Sea was well enhanced, whereas in July, there was a decrease in intensity. The interesting point that in this month there was an early indication of upwelling by observing the thermal front. We found that the upwelling was clearly observed during August-September based on the information of the frontal pattern in the northwestern side of study area. This result is strengthened from the previous study [9]. Upwelling has a great implication for providing a good feeding opportunity for skipjack tuna.

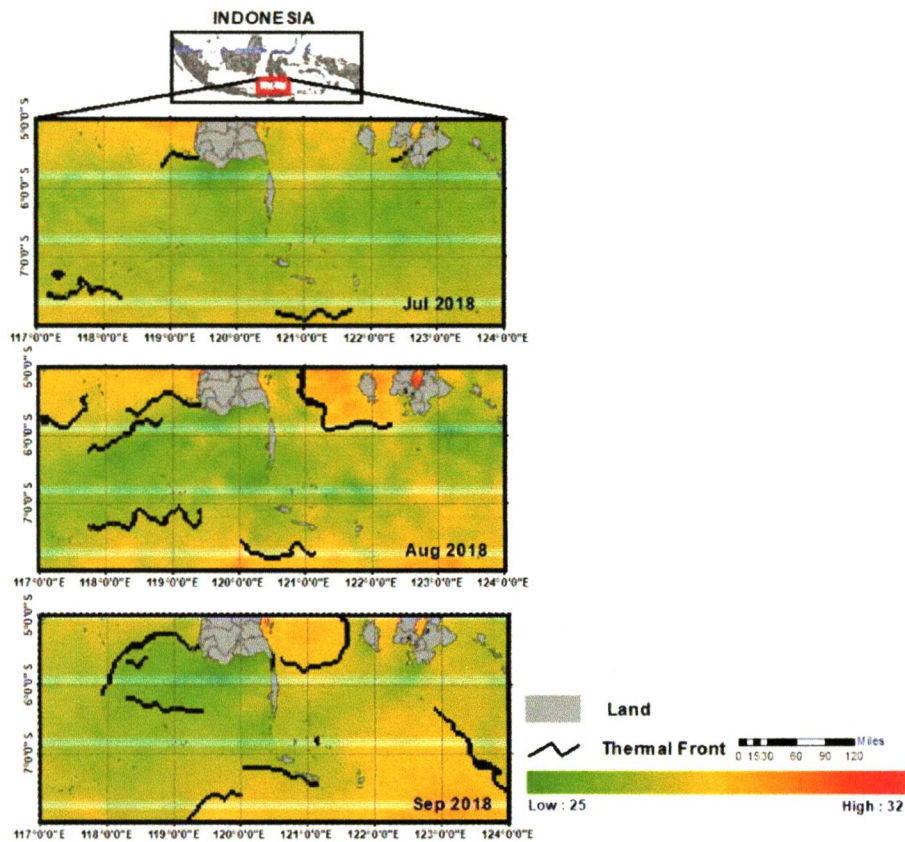


Figure 1. Distribution of SST and thermal front from July to September 2018 with 4 km spatial resolution derived from satellite data MODIS/Aqua.

Historical catch data performed that the highest skipjack catch was found in October (Figure 2). The increasing catches start from June and reach a peak in October. It means that skipjack catches after upwelling were higher than before upwelling event. Using monthly data resolution, these facts indicate that the greatest catches occur about one or two months after upwelling event. The time period is needed to stimulate the areas with high density of skipjack tuna forage. This result is in accordance with the results found previous study which found that maturation process of this event to provide a high probability of finding forage organisms for tuna is about four weeks [18]. This information is very important for skipjack fishing strategy in the Flores Sea.

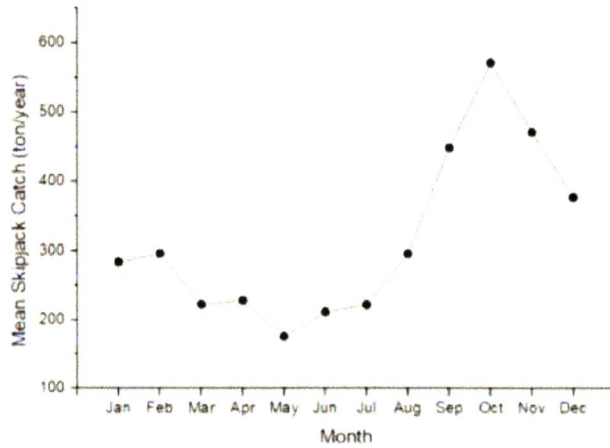


Figure 2. Temporal variability of skipjack tuna catch using the historical catch data from 2006 to 2011.

In the Flores Sea, the distribution of thermal front well developed in June especially in eastern area (Figure 3). Most of the pole and line fishing efforts occupy the area around the frontal zone near Selayar Island (right side). The SST conditions at the main fishing ground positions was approximately ranged from 29 to 31°C, indicating that skipjack tuna schools prefer warm SST. The fish occurs within the favorable area which may have a link with increased forage fish. These results are mainly supported by the previous investigations [5,6]. It is important to note that the fish schools aggregate near the coastal area in good association with front. It implies that commercial fisheries in this month could improve the fishing success by observing the frontal pattern [14].

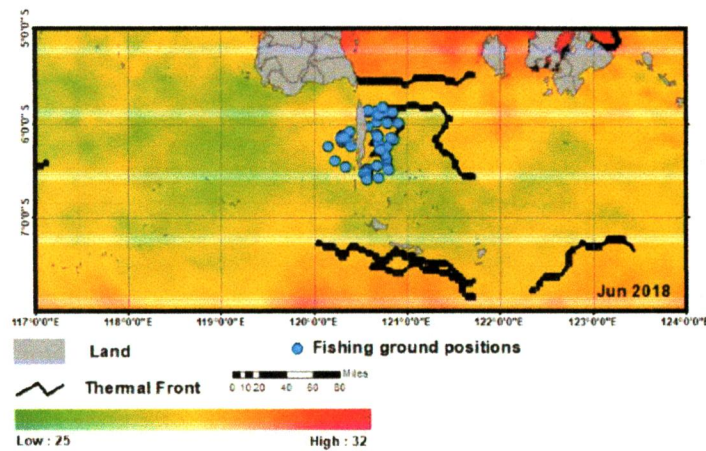


Figure 3. Distribution of pole and line fishing effort shown as blue dots overlain on SST image with thermal fronts (black line) in June 2018.

Most of skipjack fishing set distributed around thermal front with the distance of about 0-50 Km (Figure 4). The highest concentration of the fishing effort was in the distance of 0-5 Km. These results may support greatly for pelagic fisheries in determining fishing position relative to the front. The number of fishing set distribution tended to increase as the distance gets closer to the front line. Large pelagic species are mostly caught in substantial number when the fish are in close proximity to the fronts [4,6,19].

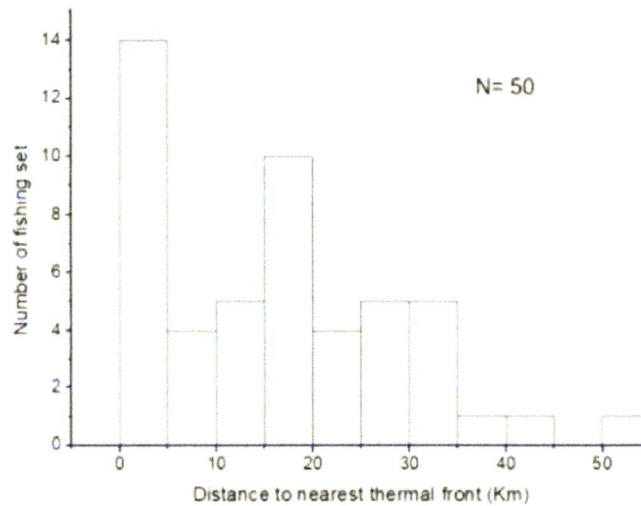


Figure 4. The relationship between number of pole and line fishing effort and the distance to nearest thermal front in June 2018.

In October, frontal areas well formed relatively closer to coast, notably near Bulukumba District in the southern side and Selayar Island in the northern area (Figure 5). There is a striking difference of surface temperature conditions between left and right sides of Selayar Island, then creating the thermal front. The right side was relatively warm SST of about 29-30°C, while in the left side was relatively colder than the other side (< 29°C). Skipjack tuna fishing efforts concentrated mostly in the warm SST areas which are relatively closer to the thermal front [6]. In this month, the period after upwelling showed that the fishing set and skipjack CPUEs (catch per unit efforts) were much higher than those in June (period before upwelling). Our results support and strengthen the investigation by [20] that large pelagic fish CPUE were significantly higher on the warm side of surface thermal fronts associated with events of intensification/relaxation of coastal upwelling.

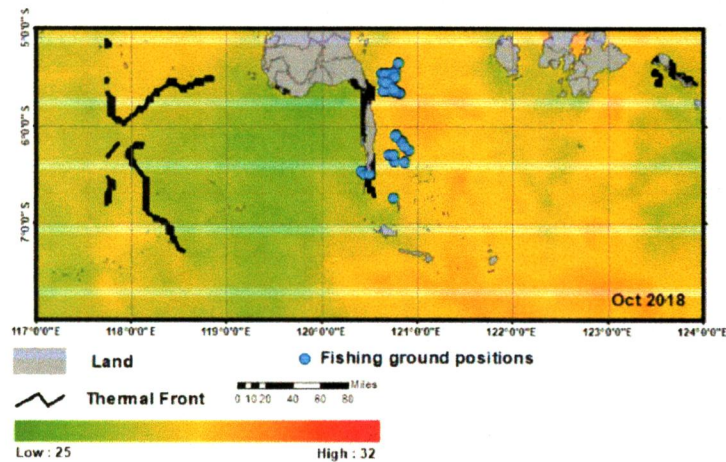


Figure 5. Distribution of pole and line fishing effort shown as blue dots overlain on SST image with thermal fronts (black line) in October 2018.

The fishing sets tended to accumulate at the distance with the nearest thermal fronts of approximately 0-40 Km (Fig 6). The highest fishing frequencies occur at the distance of about 20-40 Km from the fronts. It may be caused by the closer front positions from the coast so that skipjack fishing sets locate the distance to maintain preferred area of the oceanographic factors notably warm SST and favorable salinity.

The substantial points from this study, we found that the skipjack fishing grounds well formed around the thermal fronts with the distance of 0-40 km. The greatest fishing sets and CPUEs were obtained after upwelling period. It is interesting to note that all these facts give an important implication where the formation of the thermal fronts especially after upwelling provides a significant contribution on development of skipjack fishery in the Flores Sea.

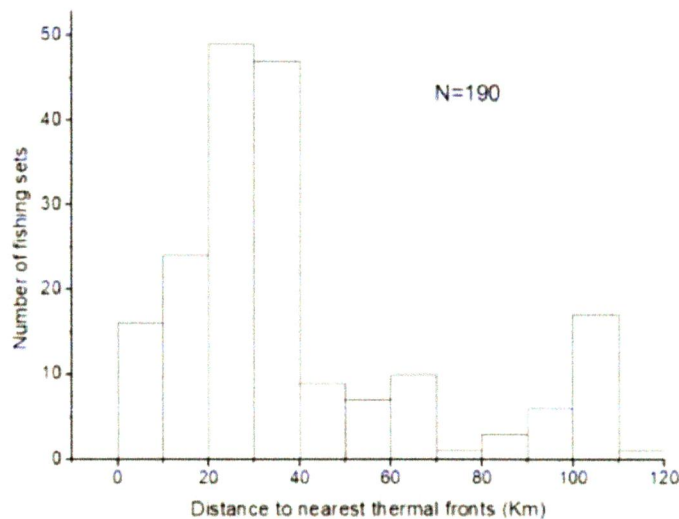


Figure 6. The relationship between number of pole and line fishing effort and the distance to nearest thermal front in October 2018.

Acknowledgments

We thank the use of AQUA-MODIS SST datasets, downloaded from the ocean color portal NASA (<http://oceancolor.gsfc.nasa.gov>). This research was fully supported to MZ by PMDSU 2020 Ministry of Research, Technology and Higher Education of the Republic of Indonesia, and UNHAS Internal Research Grants (PDU 2020).

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