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Skipjack tuna (*Katsuwonus pelamis*) catches in relation to chlorophyll-*a* front in Bone Gulf during the southeast monsoon

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Abstract. This research aims to detect the presence of chlorophyll-*a* front using Single Image Edge Detection (SIED) method and spatial analyst technique as one indication of the potential area of skipjack (*Katsuwonus pelamis*) fishing and assesses the effect of chlorophyll-*a* front on *K. pelamis* catch. We collected Catch per Unit Effort (CPUE), fishing position, and field oceanographic data. Chlorophyll-*a* data was obtained from relatively high-resolution satellite imagery (4 km). The distance of detected chlorophyll-*a* fronts was then analyzed in relation to the *K. pelamis* catches using the statistical Generalized Additive Model (GAM). The results showed that chlorophyll-*a* front was detected in every month (April to September 2017) of observations where chlorophyll-*a* front was more developed in May in specific areas with chlorophyll-*a* indicator of 0.2 mg m^{-3} along Bone Gulf waters. There is a significant relationship between CPUEs and the front where the *K. pelamis* catch tended to be higher with closer fishing position with the front especially at a distance of 0-10 km.
Key Words: potential area, spatial analyst, SIED, GAM, CPUE.

Introduction. Bone Gulf is located in Fisheries Management Area (FMA 713) known as one of the potential fishing areas in eastern part of Indonesia. The estimation of skipjack (*Katsuwonus pelamis*) catch in the area is 49,709 ton $month^{-1}$ (Malik 2014). The species is a large pelagic fish resource exploited by fishermen in Bone Gulf waters by using pole and line fishing gear from both South Sulawesi and Southeast Sulawesi provinces (Mallawa et al 2010).

The front can be considered as a water boundary marker between two different types of water characteristics (Kirby et al 2000). Chlorophyll-*a* front is an indicator that can be used in determining a fishing area that is also related to the availability of food sources in the waters (Polovina et al 2001). The concentration of chlorophyll-*a* has a significant effect on the increase of *K. pelamis* catches in the eastern waters of Southeast Sulawesi (Syahdan et al 2007).

K. pelamis is a very dynamic and highly migratory species that widely distribute either vertically or horizontally. Dynamic movement of the fish is related to the changes of environmental factors such as surface temperature and chlorophyll-*a* concentration (Andrade 2003; Zainuddin et al 2017). The potential fishing zones are heavily influenced by both physical, chemical, and biological oceanography factors including sea surface temperature (SST), salinity, chlorophyll-*a* concentration and front and upwelling phenomena (Simbolon 2009; Nurdin et al 2017).

Information on characteristics of oceanographic conditions over the large area can be obtained using remote sensing technology (Butler et al 1988). Several studies using the oceanic front as an oceanographic indicator have been investigated based on the relationship between catches and the ocean color and thermal fronts (Laurs et al 1984; Podesta et al 1993; Zainuddin et al 2017). The formation of the potential fishing zone in southeast monsoon is related to environmental factor preferences in associations with 500 m shelf breaks and upwelling in the study site (Bone Gulf) (Zainuddin et al 2013b). The spatial and temporal dynamics of *K. pelamis* corresponded with thermal front and chlorophyll-*a* front around Seram Sea (Mustasim et al 2015). The front and upwelling identification in Flores Sea-Bone Gulf support the abundance of *K. pelamis* in the east season (Putri et al 2018).

It is mostly probably that tuna species distribution and abundance have a strong association with environmental features such as fronts. During the southeast monsoon in Bone Gulf, the chlorophyll front plays a significant role in determining potential fishing ground for *K. pelamis*. Therefore, this study aims to detect and analyze the relationship between the chlorophyll front and the fishing areas based on satellite remote sensing and catch data.

Material and Method

Description of the study sites. The study was conducted in the Bone Gulf, eastern part of Indonesia from April to September 2017. We collected the fishing sampling positions and number of catches by following the pole and line fishing operations. The Bone Gulf is known as an area of high productive chlorophyll-*a* concentration during the southeast monsoon period (Gordon 2005; Zainuddin et al 2017; Safruddin et al 2018).

In-situ and ex-situ data collection. In-situ data were obtained through direct observations by following fishing operations using 5 pole and liner which are available at Fish Landing Site of Murante, Luwu Regency. We collected the data from 156 fishing ground points. The coordinates of the fishing points were determined using Global Positioning System (GPS). The in-situ field data consisted of fishing position, catch per unit effort (CPUE) in unit skipjack per trip, and chlorophyll-*a*.

And the ex-situ data like chlorophyll-*a* image data were obtained from satellite data of high-resolution Moderate-Resolution Imaging Spectroradiometer (MODIS) aqua with spatial resolution of 4 km during April to September 2017. In this study we used monthly temporal resolution.

Single Image Edge Detection (SIED). The input data used for the front detection process is chlorophyll-*a* derived from satellite images. The algorithm used is Single Image Edge Detection (SIED) (Cayula & Cornillon 1992). The chlorophyll-*a* image data with formatted Network Common Data Form (NetCDF), were then applied to MGET plugin in ArcGIS toolbox. The data were then changed from floating point to integer format using algebra map in spatial analyst tools.

Generalized Additive Model (GAM). The monthly data of chlorophyll-*a* is obtained from satellite images with spatial resolution of 4 km which is then carried out further testing with GAM. The statistical model used is Generalized Additive Model (GAM) with R language program (version 3.3.2). GAM is a non-linear model, usually used to understand the interrelationships between observed variables through the identification of positive value ranges. The response variable μi (the amount of *K. pelamis* catch in tail units) and the predictor variable (front distance) can be formulated with the following equation:

$$g(\mu_i) = a + s\,(\text{front distance}) + \varepsilon$$

where: g is a spline smooth function;

μi is the expected value of the response variable (the amount of *K. pelamis* catch in tail units);

a is the model constant coefficient;

s is a smoothing function of the predictor variables and ε is a random error term.

Prior to GAM modelling, a dataset exploration was firstly aimed at identifying the data of sine and collinearity between each explanatory variable. GAM modelling is done using the mgcv package contained in the R language program (version 3.3.2). GAM modelling is done by using Gaussian distribution and identity link function. As the response variable is the catch, while the explanatory variable is the front distance.

Results

***K. pelamis* catch in April to September 2017**. The *K. pelamis* catch in the Bone Gulf waters using pole and line fishing gear looks uneven. The catch does not show an increase in every month. The data used are direct catch data in the field from April to September 2017.

Based on data obtained in the field, Figure 1 shows that the highest catch occurred in April with an average catch of 103.5 fish/effort then decreased in June, and again increased in July. The difference in the low catch is obtained based on field data in line with the results of interviews with fishermen said that the type of live bait is favored by *K. pelamis* tuna that is the type of anchovies (*Stolephorus* sp.) but in June the anchovies is little catch and dominated by sardine type bait fish (*Sardinella fimbriata*), this is what makes the *K. pelamis* hard to catch and then the catch in June is low.

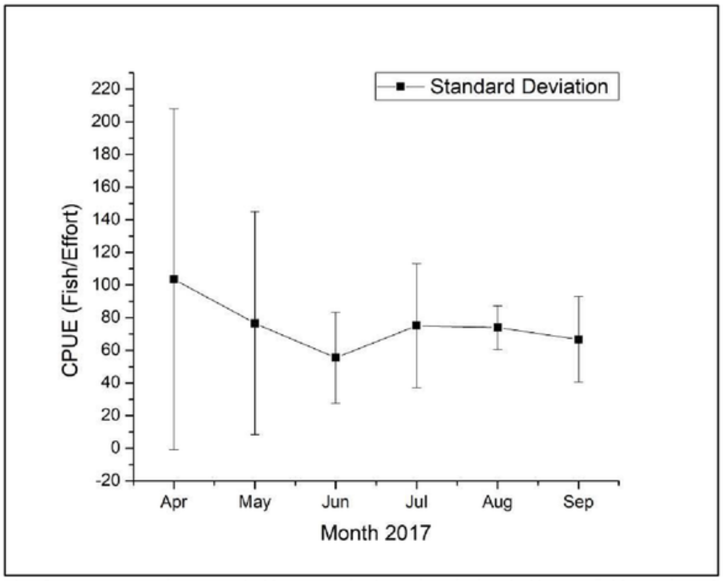


Figure 1. Average value variation and standard deviation of *K. pelamis* catch in April-September 2017 in Bone Gulf waters.

Anomalies of chlorophyll-a in April to September 2017. Spreading and high chlorophyll-*a* concentration is closely related to oceanographic conditions of water. Distribution of chlorophyll-*a* concentration can be known by performing the visual analysis of the map, where the difference of chlorophyll-*a* concentration is shown by color difference.

The distribution of chlorophyll-*a* concentration in the waters of Bone Gulf in April to September 2017 (Figure 2) is in the range of 0.23-0.78 mg m^{-3}. Distribution of chlorophyll-*a* concentration tends to be high in coastal waters with a range of values from 0.42 to 0.99 mg m^{-3} whereas the distribution of low chlorophyll-*a* concentration is in deep sea waters with a range of values 0.02-0.41 mg m^{-3}.

The results showed that the highest catch in April (Figure 1) was obtained when the mean value of chlorophyll-*a* was about 0.28 mg m^{-3} (Figure 3). Then when chlorophyll-*a* peaks with a value of about 0.51 mg m^{-3} the catch tends to decrease i.e. in June, then again increases in July when the mean value of chlorophyll-*a* is about 0.37 mg m^{-3}. It is assumed that certain characteristics where potential areas of *K. pelamis* fishing with chlorophyll--*a* concentration tend to be in the average range of 0.28-0.37 mg m^{-3}. The frequency of caught *K. pelamis* catch and the number of catches related to chlorophyll-*a* concentration in April to September 2017 can be seen in Figure 4a and 4b.

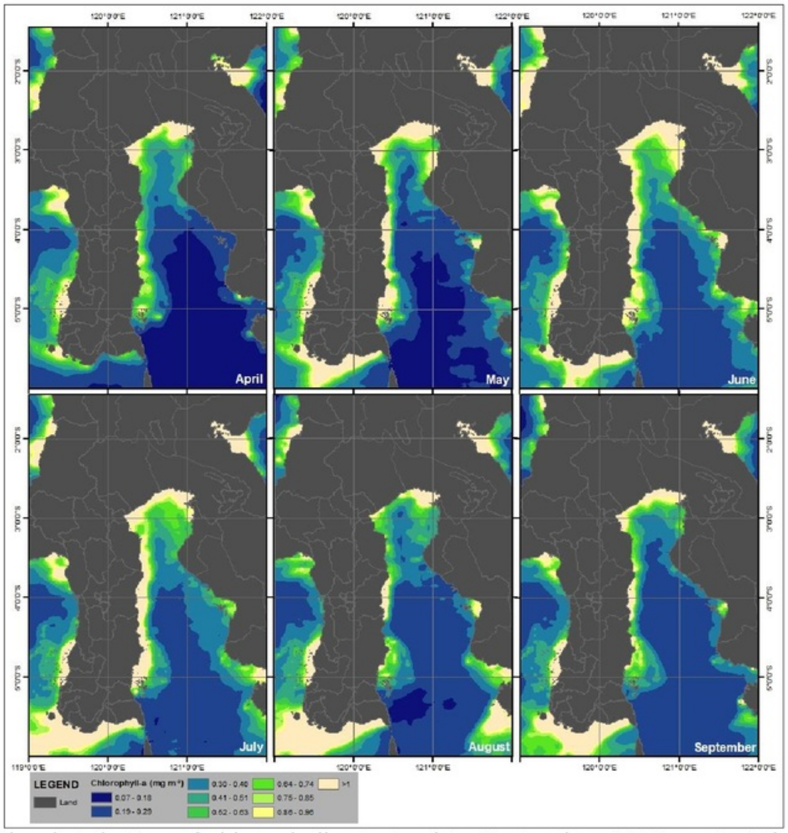


Figure 2. The distribution of chlorophyll-*a* in April to September 2017 against the catch of *K. pelamis* in Bone Gulf waters.

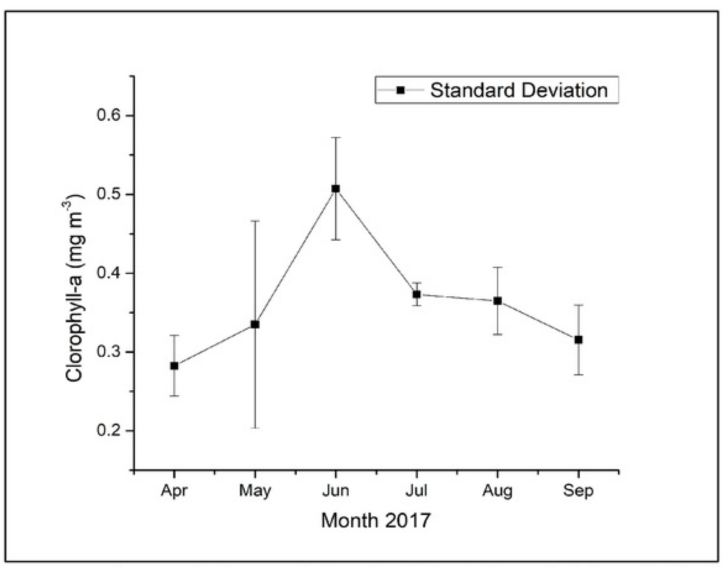
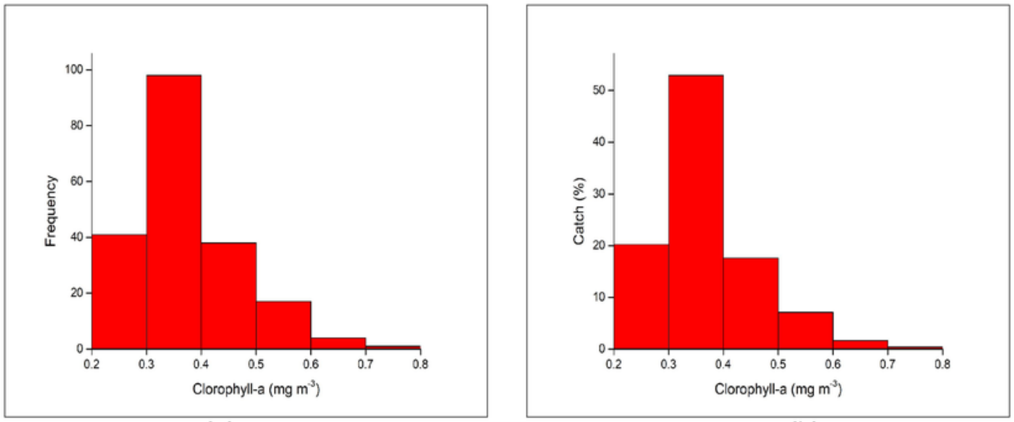


Figure 3. Average value variation and standard deviation of chlorophyll-*a* in *K. pelamis* fishing ground in April to September 2017 in Bone Gulf waters



(a) (b)

Figure 4. (a) Frequency of caught *K. pelamis* fishing in April to September 2017 in Bone Gulf waters associated with chlorophyll-*a*; (b) the *K. pelamis* catches in April to September 2017 in the waters of Bone Gulf in relation to chlorophyll-*a*.

K. pelamis fishing in April to September 2017 is at the distribution of chlorophyll-*a* concentration 0.2-0.8 mg m^{-3} (Figure 4a). For the highest catch frequency was at chlorophyll-*a* concentration 0.3-0.4 mg m^{-3} as much as 98 times the incidence. As for the lowest frequency is at the concentration of chlorophyll-*a* 0.7 to 0.8 mg m^{-3} as much as 1 time the incidence.

As well the relationship between chlorophyll-*a* and the catch is shown in Figure 4b which shows that *K. pelamis* fishing in April to September 2017 in Bone Gulf waters is at a concentration range of 0.2-0.8 mg m^{-3}. The highest catch is in the distribution of chlorophyll-*a* 0.3-0.4 mg m^{-3} which is 52.91% of the total catch while the lowest catch is in the range of 0.7-0.8 mg m^{-3} with the catch 0.43% of total catch.

Chlorophyll-a front

Front detection with SIED method. Processing of chlorophyll-*a* image data for the front detection process using SIED method requires initial processing first to enter the front detection stage. This step is to adjust the data format that can be processed by SIED algorithm. The value of chlorophyll-*a* concentration having floating point format should be converted to integer values by multiplying every pixel of chlorophyll-*a* concentration by 100. SIED method is more objective, can assist interpreter in the determination of potential fishing area. The results of chlorophyll-*a* front detection of satellite image data using SIED method are presented in Figure 5.

The result of front detection by SIED algorithm which automatically detects meeting of two different water masses characteristic shows that chlorophyll-*a* front is detected in every observation month that is April to September 2017 and much detected in the northern part of Bone Gulf around Luwu and North Kolaka. In general, chlorophyll-*a* front was detected more in the eastern and central regions of Bone Gulf waters where *K. pelamis* fishing activity in April-September was conducted close to the occurrence of a chlorophyll-*a* front and there were several catch points in the observation moon directly to the front for example in May, August and October. The results of chlorophyll-*a* front-April-September detection also showed that more dominant chlorophyll-*a* fronts were detected in coastal waters compared to offshore waters.

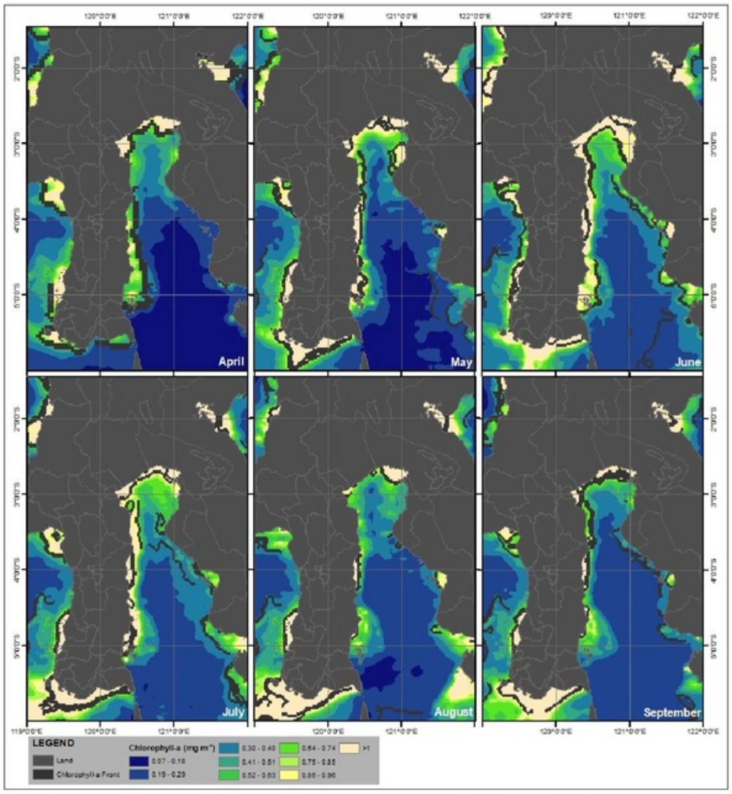


Figure 5. Map of chlorophyll-*a* front detection with SIED method in April to September 2017 in Bone Gulf waters.

The relationship of chlorophyll-*a* front distance to the *K. pelamis* catch based on the front detection map with SIED method can be seen in Figure 6. *K. pelamis* fishing in Bone Gulf waters during the observation month is in the range of 0-50 km distance from the area of the front. The highest catch is in the range of 10-20 km with a catch of 61.25% of the total catch. From the diagram in Figure 6, it can be concluded that the *K. pelamis* catch is relatively higher at the close catching position of the frontal occurrence area.

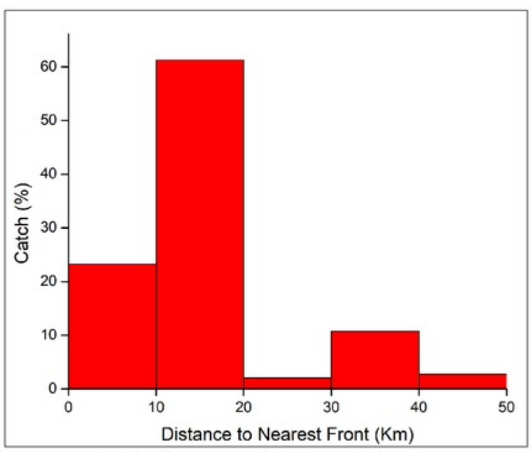


Figure 6. Relationship of chlorophyll-*a* front distance and K. *pelamis* catches based on front detection with SIED method in April to September 2017 in Bone Gulf waters.

Chlorophyll-a front in relation to K. pelamis catch using GAM. After the detection of front, the significant relationship between the distance of chlorophyll-*a*-front and the *K. pelamis* catch was shown using the GAM model. *K. pelamis* catches in April-September 2017 based on maps analyzed by SIED method were relatively higher in the range of 0-10 km distance from the area of the occurrence of the front (Figure 7).

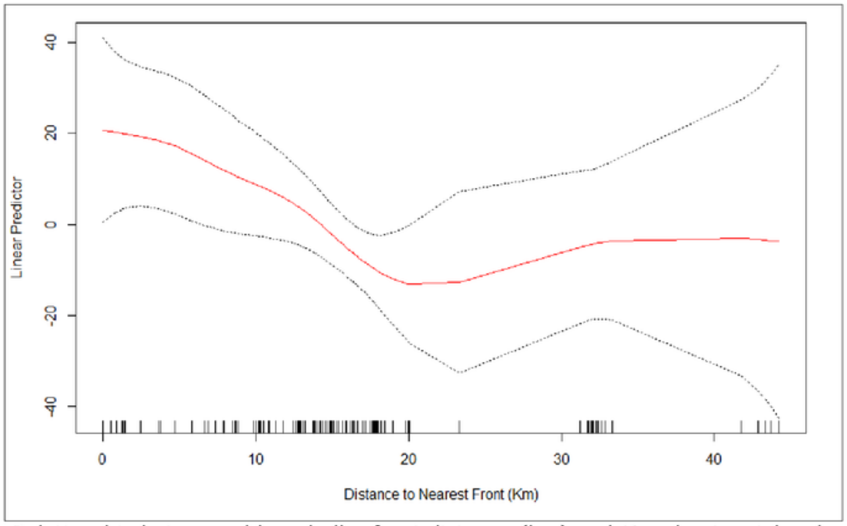


Figure 7. Relationship between chlorophyll-*a* front distance (km) and *K. pelamis* catches based on front detection by SIED Method in Bone Gulf water.

Based on the results of chlorophyll-*a* distance analysis of the *K. pelamis* catch, the *K. pelamis* catches are relatively higher at close proximity of the frontal occurrence area. This happens because the front area is a fertile area and there is abundant food for small fish that stimulate bigger pelagic fish to come (Polovina et al 2001; Zainuddin et al 2017). The significance values of the chlorophyll-*a* front distance is 0.03801 (Table 1). The significance value of the parameter was < 0.05 then it can be concluded that the chlorophyll-*a* front distance parameter significantly influence the *K. pelamis* catches in the Bone Gulf.

Table 1

The result of GAM model test

Variable	*Df*	*Sum Sq*	*Mean Sq*	*F Value*	*Pr (>F)*
S (distance)	1	7370	7370.2	4.3789	0.03801 (< 0.05)
Residuals	156	262567	1683.1		

Discussion

Chlorophyll-a. The content of chlorophyll-*a* in aquatic environment can be used as a measure of the amount of phytoplankton to be used as a fertility or productivity parameter of seawater (Butler et al 1988). The optimum chlorophyll-*a* concentration for *K. pelamis* in Bone Gulf waters is in the range 0.15-0.35 mg m^{-3} (Zainuddin et al 2017). While in the northwest monsoon the optimum chlorophyll-*a* concentration range for *K. pelamis* in Bone Gulf is 0.12-0.22 mg m^{-3} (Jufri et al 2014). Characteristic of the potential area of *K. pelamis* fishing in Bone Gulf is at a chlorophyll-*a* concentration between 0.12 and 0.23 mg m^{-3} (Zainuddin et al 2013a). The *K. pelamis* fishing area formation develop in May which may associate with chlorophyll-*a* values of about 0.2 mg m^{-3} (Zainuddin et al 2017).

Front. One of the parameters that influence the existence of fish in water is the presence or absence of food sources. Albacore tuna (*Thunnus alalunga*) and *K. pelamis* gathered along the beach near the front associated with upwelling around the coast linked to eating activities (Laurs et al 1984). According to Lalli & Parsons (1994) chlorophyll-*a* can be used as an indicator of fertility and aquatic productivity. Chlorophyll-*a* is closely related to the availability of food sources in waters where fertile areas have high nutrients and are indicated by the abundance of phytoplankton characterized by high chlorophyll-*a*. This is in line with the gathering of tuna species (*Thunnus* sp.) in the front for feeding areas (Laurs et al 1984) in addition to tuna utilizing chlorophyll-*a* front zones as migration paths and feeding habitats (Polovina et al 2001). Chlorophyll-*a* front detected in coastal waters as in Figure 6, due to rivers carrying nutrients and nutrient additions from weathering of mangrove debris to the coast, then currents from offshore carry poor water nutrients toward the near beach so that the meeting of the mass of water rich in nutrients and poor nutrients (Mustasim et al 2015).

The existence of oceanographic phenomena such as the phenomenon of the front can affect the physical and biological conditions of water. The chlorophyll-*a*-front transition zone affects tropical transfer associated with food pyramids and creates convergence areas where the area increases the feeding habitat for the top predators along the front (Polovina et al 2001).

The front is one of the criteria in determining potential fishing ground and is meeting two different water masses of characteristics. The presence of front zone in the waters is very important in marine productivity because it tends to bring together cold water and rich in nutrients compared with warmer but poorer nutrients (Mustasim et al 2015). The combination of temperature and the increase in nutrient content arising from this mixing will increase the productivity of plankton. This will be demonstrated by the increasing stock of fish in the area (Figure 4b). The formation of the front is a feeding ground for pelagic fish (Figure 5).

The presence of chlorophyll-*a* front increases the availability of food sources in the area that are also associated with a food chain that will invite large pelagic fish. There are several explanations for tuna and *K. pelamis* associations with fronts that are 1) appropriate food availability, 2) traps for the optimum physiological temperature range, 3) as temperature gradients for thermoregulation, and 4) as limitations of hunting efficiency visually associated with clarity of water and can be seen in Figures 6 and 7 where on a front that has a certain distance from the mainland shows the number of *K. pelamis* catches is abundant (Kirby et al 2000).

Conclusions. The result of chlorophyll-*a* front detection using Single Image Edge Detection (SIED) from April to September 2017 (southeast monsoon) were more developed (more apparent formation) around the area with indicator of chlorophyll-*a* values specific 0.23 mg m^{-3} along the waters of Bone Gulf. The relationship between chlorophyll-*a* front and *K. pelamis* catch concluded that the highest catches are in close proximity with chlorophyll-*a* front especially in the distance of 10-20 km.

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