The effect of chlorophyll-a on the catches of skipjack tuna *(Katsuwonus pelamis)* in Banda Sea, Maluku, Indonesia

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Abstract. The Banda Sea is located in the waters of Central Maluku Regency, Maluku Province. The topography of the seabed is very complex with a basin in the west and a trough in the east. The shape of the topography is also decisive in controlling the exchange of water masses. The purpose of this study was to analyze the relationship of chlorophyll-a and the effect of its distribution on the catch of skipjack tuna (*Katsuwonus pelamis*). The study used the data analysis method, namely the multiple linear regression (computerized data processing using the SPSS 25 program). Primary data was obtained by following fishing operations and secondary data was collected from chlorophyll-a images downloaded from the NASA database in the form of an average per trip. The results of the study showed that the coefficient of determination (R_2) is 0.196 or 19.6%. This shows that the chlorophyll-a factor used can only explain the actual model by 19.6%, so that the remaining 80.4% are explained by other factors such as salinity and currents. The results of the t-test obtained a t_count chlorophyll-a value of 3.320, sig value of 0.029 and t_table value of 2.77. Based on the value of t_count>t_table and the value of sig 0.029<0.05, there was a significant effect between chlorophyll-a and *K. pelamis*; the ANOVA table showed the value of R^2=0.779 or 77.9% the effect of chlorophyll on *K. pelamis*, so the remaining 22.1% was influenced by other factors. Based on the results obtained, chlorophyll-a had a significant effect on *K. pelamis*.

Key Words: purse seine, remote sensing, sea surface temperature (SST), catch season.

Introduction. The Banda Sea owes its abundance to a high nutrient load. The distribution of these nutrients can be seen by the upwelling phenomenon in the Banda Sea (Putra et al 2017). The topography of the seabed is very complex, with a basin in the west and a trough in the east (Suyarso 1999; Tapilatu 2016). This complex topographical shape also determines the mass exchange of water. The circulation of different water massesvaries between seasons and is influenced by the monsoon system's wind pattern. The circulation of water mass in Indonesian waters differs between the west monsoon and the east monsoon. In the west monsoon, water masses generally flow to the east of Indonesian waters. The eastern monsoons develop perfectly, supplying water masses originating from the upwelling areas in the Arafura and Banda Seas (Hasanudin 1998). The upwelling process that occurs in the Banda Sea results in a decrease of temperatures, an increase of salinity and the removal of nutrients, so that their availability will affect the abundance of plankton in the waters (Baars et al 1990; Armus et al 2019).

The potential area for catching skipjack tuna (*Katsuwonus pelamis*) has a close relationship with the environmental parameters, especially the chlorophyll-a, whose optimum ranges from 0.12 to 0.22 mg m^3 (Zainuddin 2011; Hidayat et al 2019; Wangi et al 2019). Almost all fish populations that live in marine waters, including *K. pelamis*, require optimal sea surface temperature (SST) range and chlorophyll-a values for their survival (Jufri et al 2014). Remote sensing technology helps observing the oceanographic parameters of the surrounding waters in the Banda Sea, so that it can determine the effect of chlorophyll-a on the catch of *K. pelamis* in the Banda Sea.

K. pelamis likes areas where there is a convergence of currents that mostly occur in areas with many islands. The vertical distribution of *K. pelamis* starts from the surface to a depth of 260 m during the day, while at night it will go to the surface (diurnal migration) (Ekayana et al 2017). *K. pelamis* specimens from the small size category tend to be caught at a more homogeneous (warm) SST, while large *K. pelamis* are caught in a wider range of SST (cold and warm) (Simbolon & Limbong 2012). *K. pelamis* congregate at low chlorophyll-a concentrations and water depths of ≥500 m, because *K. pelamis* is a carnivorous fish with the main prey of small pelagic fish such as *Stelophorus* sp. and *Sardinella* sp., which are abundant in the continental shelf and sloping waters (Bubun et al 2015).

Remote sensing technology is an alternative method that is very beneficial if it is used in a country with a very large area such as Indonesia (Syah 2010). Remote sensing is a technique for collecting information about objects and their environment from a distance without physical touch (Lo 1986). The use of remote sensing methods to detect oceanographic parameters including sea surface temperature (SST), salinity, chlorophyll-a index, currents and other oceanographic conditions is a very appropriate alternative (Tangke 2016; Mashita & Lumban-Gaol 2019). Remote sensing technology has several advantages including cheap and easily accessible data prices, wide area coverage, high temporal resolution and digitalized data supply, making it a potential source for the geographic information system (GIS) data (Louhenapessy & Waas 2009). One of the sensing satellites equipped with sensors that can detect the chlorophyll-a content is the Aqua MODIS satellite (Utari 2013). The variables measured by the Aqua satellite include the aerosols, land-covering plants, phytoplankton and dissolved organic matter in the oceans, as well as the air, land and water temperature (Putra et al 2012). The Aqua MODIS satellite has a polar sun-synchronous orbit. The satellite crosses the equator at noon, approaching at 13:30 local time (Karif 2011).

Changes in fishing actually occur when the seasons' change. Seasonal changes directly affect the oceanographic aspects of the waters, especially sea surface temperature and chlorophyll-a, which greatly influence the presence of fish in an area, determining the fishing grounds in that area. Both of these parameters can trigger natural events or phenomena such as upwelling and fronts (Waileruny & Wiyono 2014). The fishing season in Southeast Sulawesi waters can be found in January to April and from July to September, and it can affect the salinity of the habitat of the caught fish species. In the eastern monsoon (June to September), high salinity water masses originating from the Flores Sea and Pacific Ocean flow through the Makassar Strait to the Java Sea. In the western season (December to March) surface currents move from the South China Sea into the Java Sea from west to east (Bubun & Mahmud 2016). The present research aimed to analyze how much influence chlorophyll-a had on the number of *K. pelamis*, knowing the distribution of chlorophyll-a concentrations in the Banda Sea, Maluku. In this way, fishermen can be more effective in determining the area and time of catch.

Material and Method. The tools and materials needed in the implementation of this research include: stationery, cameras, rulers, GPS, MODIS data and the softwares SeaDas, SPSS Statistics 25 and Surfer 13.0.

Method of collecting data. The data collection method uses primary data, carried out *in situ* by direct observation of the fishing operation including operating time, the number of catches and the position of the fishing area, and by using secondary data including the image of the distribution of chlorophyll-a, from the level 3 of the Aqua MODIS, downloaded from the NASA database (http://www.oceancolor.gsfc.nasa.gov). Data were processed using the Seadas to get the chlorophyll value and the Surfer 13 to get the distribution of chlorophyll-a in the form of images.

The chlorophyll-a image data chosen to be processed is a standard 8-day image with a 4 km resolution map of level 3, at night, from November 2017 to March 2018.

Chlorophyll-a data was calculated using chlorophyll-a image data that has been adjusted with both atmospheric and geometrical corrections. Seadas produced the chlorophyll-a distribution data which was reprocessed using a computer device, then using the Surfer 13, which will produced the distribution data of chlorophyll-a in the JPEG image format. The catch used includes the catch weight of *K. pelamis* analyzed by calculating the weight per fishing trip, so that fluctuations in the catch based on time (temporal) and fishing location (spatial) can be observed.

Multiple correlation analysis. The multiple correlations showed the direction and strength of the relationship between the studied variables. To be able to provide an interpretation of the correlation coefficients found, reference values are listed in Table 1 (Sugiono 2007).

Table 1

Assessment of the correlation coefficient (Sugiono 2007)

Coefficient interval	*Relationship level*
0.00–0.199	Very low
0.20–0.399	Low
0.40–0.599	Moderate
0.60–0.799	Strong
0.80–1.00	Very strong

The double correlation formula for two variables is the following (Sugiono 2007):

$$R_{y.x_1x_2} = \sqrt{\frac{r^2_{yx1} + r^2_{yx2} - 2r_{yx1}r_{yx2}\,r_{x1x2}}{1 - r^2_{x1\,x2}}}$$

Where:
$R_{y.x_1x_2}$ - correlation of the variables X_1 and X_2 with the variable Y;
ryx_1 - correlation between X_1 and Y;
ryx_2 - correlation between X_2 and Y;
rx_1x_2 - correlation between X_1 and X_2.

Multiple linear regression analysis. When the correlation coefficient is sufficiently high, a multiple linear regression was used to examine the variables relationship, as follows (Sugiono 2005):

$$Y = a + b_1X_1 + b_2X_2$$

Where:
X_1 - variable sea surface temperature;
X_2 - chlorophyll-a variable;
Y - the maximum quantity of certain fish species caught;
a, b_1, b_2 - constants.

Multiple linear statistical test. According to Hasan (2004), multiple linear regression statistical tests are used to test the significance of the relationship of more than two variables through the regression coefficient. The multiple linear regression statistical tests can be divided into two categories, namely:
1. Concurrent test
The test is carried out in multiple linear regressions using the F test, a statistical test for the regression coefficient that together affects Y, namely:

$$F_o = \frac{R^2(n-k-1)}{k(1-R^2)}$$

Where:
n - number of fish caught;

k - number of independent variables;
R^2 - determination coefficient.
2. Individual test
Individual test, namely the regression statistic with only one regression coefficient affecting Y, using the t_{test}:

$$t_o = \frac{b_1 - B_i}{S_{b1}}$$

Where:
b_1 - regression slope coefficient;
B_i - hypothesized slope;
S_{bi} - standard deviation of slope.

Geographical information analysis. The Surfer 13 software was used to map the distribution of *chlorophyll-a* from November 2017 to March 2018, based on time (temporal) and fishing location (spatial), with the aim of producing information about the relationship of these variables.

Results and Discussion

This research was conducted from November 2017 to May 2018 by following a fishing operation using a purse seiner in the Banda Sea, Maluku Indonesia.

Figure 1. Purse seiner (original photo).

Fish catch results. The fishing operation was carried out in seven trips, with a total catch of 56,689 kg and an average of 12,558.17 kg per 34 operations. The number of catches on the 2nd trip (6 operations) was the largest, with a total catch of 11,954 kg (an average of 1,992.33 kg per operation) or 21.1% of the total catch. Meanwhile, the 3rd trip (2 operations) recorded the smallest total catch, namely 5,522 kg or 9.7% of the total catch, but with the highest average per operation, of 2,761 kg (Table 2).

Table 2

The number of fish catch per trip

Trip	*Number of operations*	*Amount (kg)*	*Average (kg)*	*Percentage (%)*
1st	4	8,226	2,056.5	14.5
2nd	6	11,954	1,992.33	21.1
3rd	2	5,522	2,761	9.7
4th	4	7,006	1,751.5	12.4
5th	6	9,607	1,601.16	17
6th	6	7,982	1,330.33	14.1
7th	6	6,392	1,065.33	11.2
Total	34	56,689	12,558.17	100

Catch composition. The catch data consists of seven trips with 34 operations. The main catches are *K. pelamis*, *Thunnus albacares*, *Euthynnus affinis* and *Decapterus russelli*. Based on the results obtained, the highest *T. albacares* catches were on the 7th trip and the lowest was on the 5th trip. *K. pelamis* catches reached the highest value on the 2nd trip and the lowest on the 6th trip. The highest *T. albacares* catches were on the 2nd trip and the lowest was on the 7th trip, and the highest *D. russelli* was on the 6th trip and the lowest was on the 3rd trip. The composition of the catch can be seen in Table 3 below.

Table 3

The composition of the catch based on the type of fish

Trip	*Total catch (Kg)*				*Total*
	T. albacares	*K. pelamis*	*E. affinis*	*D. russelli*	
1st	825	3,018	2,590	1,793	8,226
2nd	230	5,676	4,430	1,618	11,954
3rd	90	4,270	497	665	5,522
4th	569	2,948	1,817	1,672	7,006
5th	0	4,467	4,290	850	9,607
6th	13	2,536	670	4,763	7,982
7th	915	4,323	0	1,154	6,392

Based on the data mentioned above, the highest catch was on the second trip, and the lowest catch was on the 3rd trip. The highest catch of *T. albacares* was on the 7th trip, as much as 915 kg, while the lowest was on the 5th trip, with no catch. The highest catch of *K. pelamis* was on the 2nd trip, as much as 5,676 kg, while the lowest was on the 6th trip, with 2,536 kg. The highest *E. affinis* catch was on the 2nd trip, as much as 4,430 kg, and the lowest on the 7th trip, with no catch. The highest *D. russelli* catch was on the 6th trip, as much as 4,763 kg, and the lowest was on the 3rd trip, with 665 kg. Based on all catches, *K. pelamis* was the most dominant fish caught compared to other fish (Figure 2).

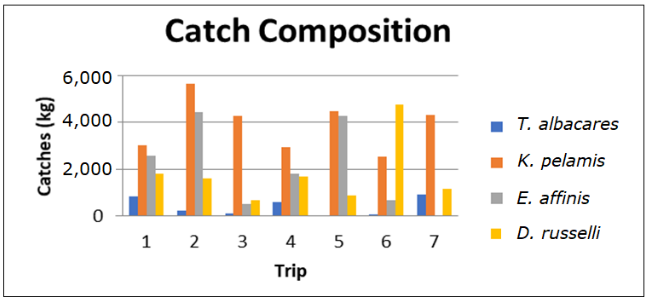

Figure 2. Composition diagram of the catch.

Average K. pelamis per operation. The catch of *K. pelamis* is higher than that of other types. The total catch of *K. pelamis* from the 1st trip to the 7th trip was 27,238 kg. The average highest catch per operation of *K. pelamis* was recorded on the 3rd trip, with 1,495 kg, while the lowest catch per operation was recorded on the 6th trip, with 422.67 kg. The catch of the 1st trip was 3,018 kg, the 2nd trip was 5,676 kg, the 3rd trip was 4,270 kg, the 4th trip was 2,948 kg, the 5th trip was 4,467 kg, the 6th trip was 2,536 kg, the 7th trip was 4,323 kg (Figure 3).

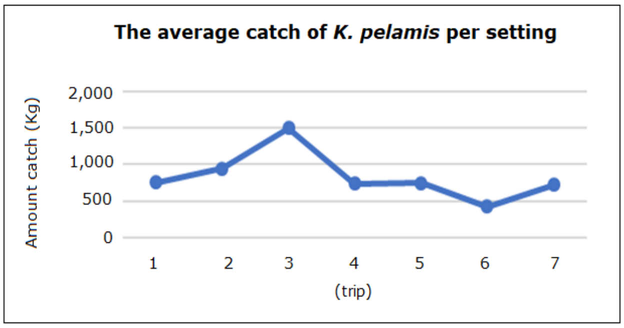

Figure 3. Diagram of the average catch of *Katsuwonus pelamis.*

Chlorophyll-a. Because fertile waters contain high chlorophyll-a concentrations, the chlorophyll-a is eligible as an indicator of fertility in waters. The chlorophyll-a concentration is also influenced by other factors such as currents. Chlorophyll-a image data were downloaded from the NASA database (http://www.oceancolor.gsfc.nasa.gov). The research data was processed using Seadas to produce chlorophyll-a data. Furthermore, the data was processed using Surfer 13 into JPEG format images that display the distribution of chlorophyll-a with different colors. The distribution of chlorophyll-a was taken based on the time and position of the capture operation. Figure 4 shows the chlorophyll-a distribution over the 7 fishing trips.

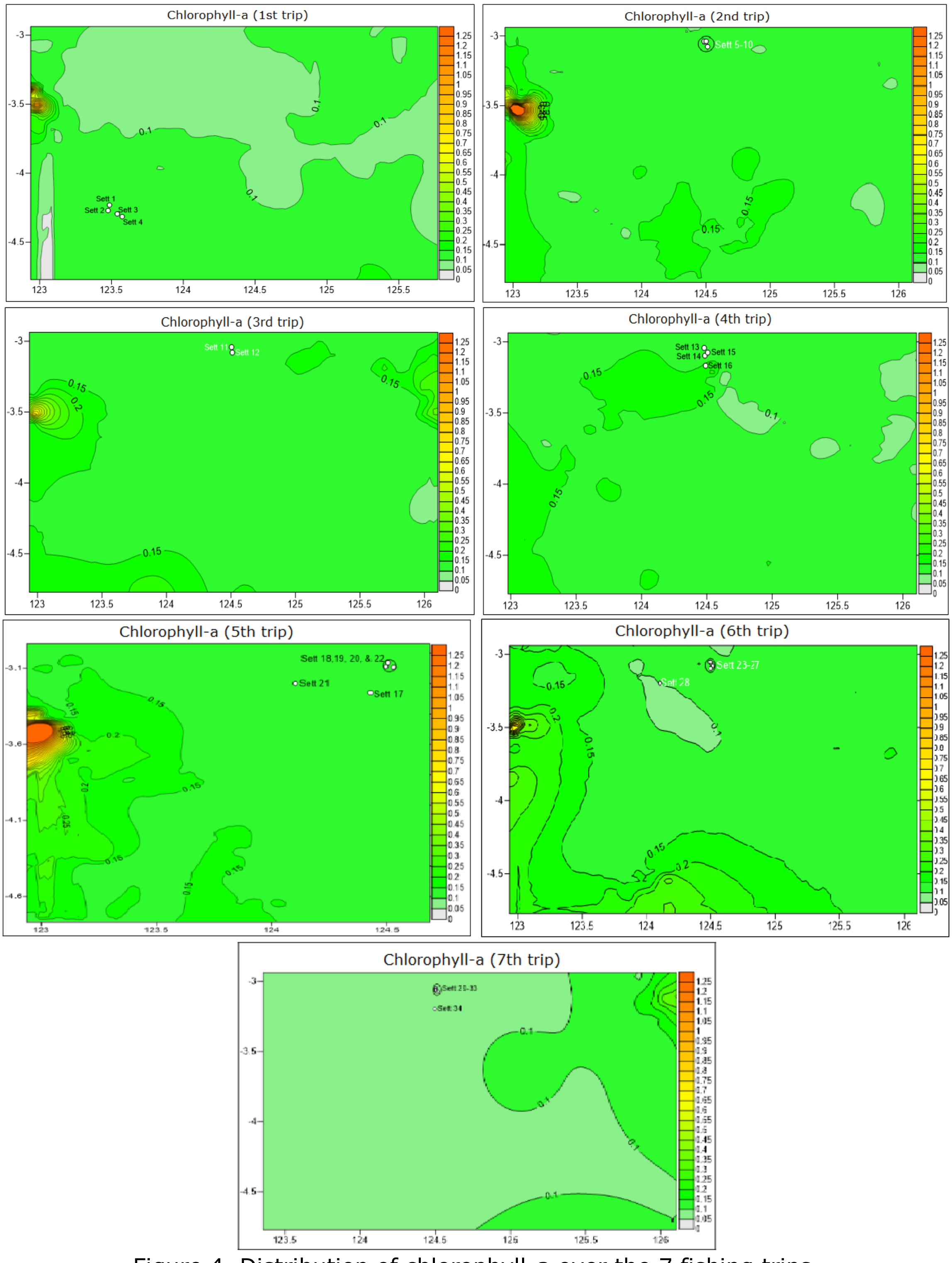

Figure 4. Distribution of chlorophyll-a over the 7 fishing trips.

The chlorophyll-a concentration values can be seen in Table 4 below.

Table 4

Chlorophyll-a concentration values

Trips	*Chlorophyll-a concentration value (mg m³)*						*Average*
	1st operation	*2nd operation*	*3rd operation*	*4th operation*	*5th operation*	*6th operation*	
Trip 1	0.1308[a]	0.1292	0.1273	0.1268[b]	-	-	0.1285
Trip 2	0.1176	0.1176	0.1173[b]	0.1266	0.1176	0.1266[a]	0.1205
Trip 3	0.1399[a]	0.1342[b]	-	-	-	-	0.1370
Trip 4	0.1046[b]	0.1080	0.1077	0.1632[a]	-	-	0.1209
Trip 5	0.1314	0.1312	0.1312	0.1314[a]	0.1313	0.1258[b]	0.1303
Trip 6	0.1208	0.1288[a]	0.1287	0.1227	0.1281	0.1001[b]	0.1215
Trip 7	0.0895	0.0903	0.0913[a]	0.0880	0.0875[b]	0.0894	0.0893

[a] the distribution of the highest chlorophyll-a concentrations; [b] the distribution of the lowest chlorophyll-a concentrations.

The chlorophyll-a concentration value on the 7th trip decreased significantly, compared to the other trips. The higher the chlorophyll-a concentration value in the waters, the more fertile the waters.

Average chlorophyll-a. The average chlorophyll-a can be seen in Figure 5, where the concentration of the 7th trip decreased, compared to the other trips. The average chlorophyll-a concentration was the highest on trip 3 and the lowest on trip 7. The difference between the highest and lowest concentrations is 0.0477 mg m^{-3}.

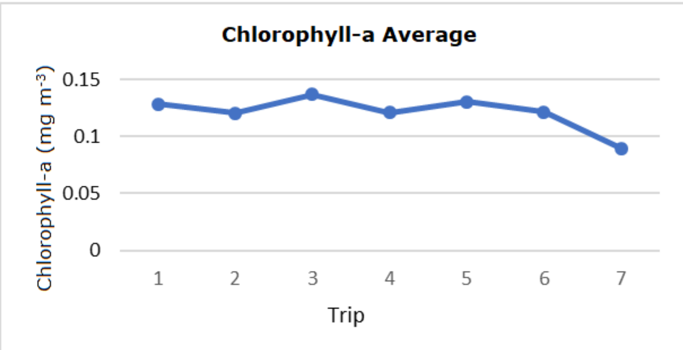

Figure 5. Diagram of average chlorophyll-a for 7 trips.

The relationship between average chlorophyll-a against K. pelamis. The relationship of chlorophyll-a to the catch of *K. pelamis* was calculated using a multiple correlation test. The multiple correlation estimator for the level of chlorophyll-a relationship to *K. pelamis* catch was determined by using SPSS 25.

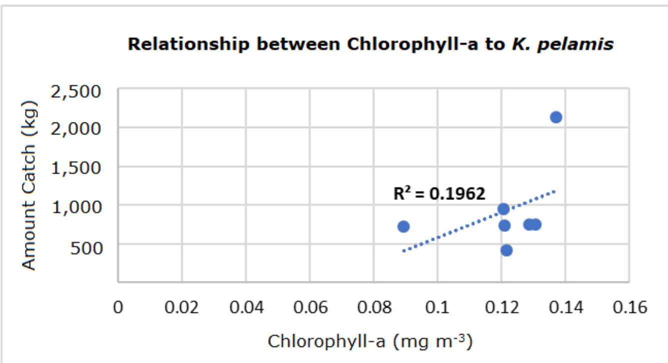

Figure 6. Graph of chlorophyll-a relationship to *Katsuwonus pelamis.*

Based on Figure 6 above, the coefficient of determination (R^2) is 0.196 or 19.6%. This shows that the chlorophyll-a factor used can only explain the actual model by 19.6%, so that the remaining 80.4% are explained by other factors such as salinity and currents.

The value of the correlation coefficient using SPSS 25 can be seen in table 4. The correlation coefficient value was obtained at 0.443, which means that the positive relationship between chlorophyll-a and the catch of *K. pelamis* is moderate, because the correlation coefficient value is in the correlation interval 0.40-0.599. This relationship is positive: if the value of one variable is increased, it will increase the value of the other variables and vice versa (Sugiono 2007), while if the chlorophyll-a decreases, it will decrease the catch of *K. pelamis*.

Hypothesis testing via the t test is used to determine whether the hypothesis is accepted or rejected, based on the coefficients table (Table 7). Based on this table, the t_{count} value of chlorophyll-a is 3,320, $t_{count}>t_{table}$ (3,320>2.77, respectively) and the sig value of 0.029 (<0.05), therefore the null hypothesis is rejected, due to the significant effect of chlorophyll-a on the catch of *K. pelamis*, in accordance with a previous research conducted by Demena et al (2017), which states that chlorophyll-a and the number of catches *K. pelamis* have a unidirectional relationship and the chlorophyll-a concentration affects the presence of *K. pelamis*.

The effect of chlorophyll-a on the catch of K. pelamis. Chlorophyll-a is an indicator that greatly influences the presence of fish in the waters, especially *K. pelamis*, a migratory species. The effect of chlorophyll-a on the catch of *K. pelamis* is calculated using the multiple linear regression, with the SPSS 25, and manual calculations were performed using a computer device.

Based on the results obtained in Table 5, the coefficient of determination (R^2)=0.779 or 77.9%. This shows an influence of 77.9% of the chlorophyll-a on the catch of *K. pelamis*, so that the remaining 22.1% are influenced by other factors such as currents and salinity. The correlation coefficient (R) in the model summary table above is 0.882. Based on table 5, the relationship level, given by the correlation coefficient (R), is included in the interval at 0.80-1.00, which means that the level of chlorophyll-a relationship to the catch of *K. pelamis* is very strong.

Table 5

Model summary

Model	*R*	*R square*	*Adjusted R square*	*Std. error of the estimate*
1	0.882[a]	0.779	0.668	320.54745

[a]Predictors: (Constant), Chlorophyll-a.

The hypothesis test used is the F test, carried out to test the effect of SST and chlorophyll-a on *K. pelamis* catches which will determine whether the results of the hypothesis are accepted or rejected. Hypothesis testing used SPSS 25 and manually obtained the value of F_o=7.030 and value=6.94 (Table 6). The results obtained in the ANOVA table have a sign value of 0.049<0.05. If H_o is rejected and H_1 is accepted, it means that there is a significant effect between SST and chlorophyll-a on *K. pelamis* catches, this is in accordance with the research conducted by Demena et al (2017) which stated that SST and chlorophyll-a are two indicators that greatly affect the presence of fish in the waters, especially *K. pelamis.*

Table 6

ANOVA regression table

Model	*Sum of squares*	*df*	*Mean square*	*F*	*Sig.*
Regression	1,444,657.089	2	722,328.544	7.030	0.049[b]
Residual	411,002.672	4	102,750.668		
Total	1,855,659.760	6			

[b] Predictors: Constant, Chlorophyll-a, Sea Surface Temperature (SST).

Relationship of average SST to K. pelamis. SST can be used as an indicator to determine the presence of a fish species in waters. Each fish species has a certain temperature tolerance value so that it affects the presence and distribution of fish in the waters. To see the relationship between SST and the presence of *K. pelamis*, the catch data (in-situ) and SST data on the position and time of catching (ex-situ) were taken with SPSS 25 using a computer device. The relationship of SST to the catch of *K. pelamis* was calculated using the multiple correlation test, as an estimator (Figure 7).

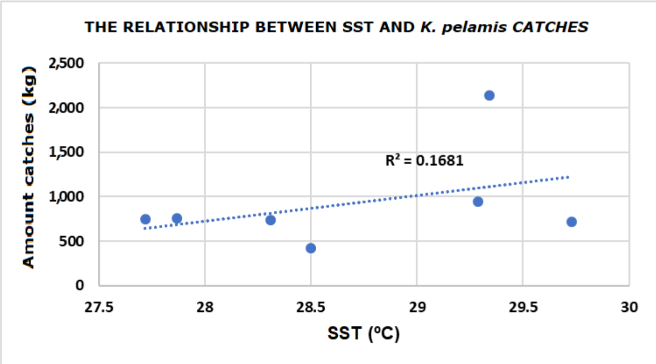

Figure 7. Graph of the relationship between SST and *Katsuwonus pelamis.*

Based on the graph above, the coefficient of determination (R_2) is 0.168 or 16.8%. This shows that the SST factor used can only explain the actual model by 16.8% so that the rest is explained by other factors of 83.2%.

The assessment of the value of the correlation coefficient using SPSS 25 can be seen in Table 7. The correlation coefficient value obtained is 0.410, which means that the positive relationship between SST and the catch of *K. pelamis* is moderate, because the correlation value is in the correlation interval of 0.40-0.599.

Table 7

Correlations

Correlations				
Model		*K. pelamis*	*SST*	*Chlorophyl-a*
Pearson correlation	*K. pelamis*	1.000	0.410	0.443
	SST	0.410	1.000	-0.532
	Chlorophyl-a	0.443	-0.532	1.000
Sig. (1-tailed)	*K. pelamis*	0	0.180	0.160
	SST	0.180	0	0.109
	Chlorophyl-a	0.160	0.109	0
N	*K. pelamis*	7	7	7
	SST	7	7	7
	Chlorophyl-a	7	7	7

Based on Table 8, the results obtained the $t_{count}>t_{table}$ and sig value 0.032<0.05, it was found that H_o was rejected and H_1 accepted, there was a significant effect between SST and the catch of *K. pelamis*. A previous research conducted by Fajrianti (2016) stated that SST had a significant effect on the catch.

Based on the output of SPSS 25 (the coefficients matrix), the multiple linear regression equation could be expressed as follows:

$$Y = -21,557.333 + 642.160\ X_1 + 33,535.607\ X_2$$

The multiple linear regression equation above can be interpreted as follows:

- if the variables X_1 (SST) and X_2 (chlorophyll-a) have a value of 0, then the variable Y is -21,557.33 kg (intercept).
- if the variable X_1 (SST) increases by 1ºC and the other variables are constant, then the variable Y will increase by 642,160 kg.

- if the X_2 variable (chlorophyll-a) increases by 1 mg m^{-3} and the other variables are constant, then the Y variable will increase by 33,535.607 kg.

Table 8

Coefficients

Coefficients[a]						
Model		*Unstandardized coefficients*		*Standardized coefficients*	*T*	*Sig.*
		B	*Std. error*	*Beta*		
1	(Constant)	-21,557.333	6,416.374		-3.360	0.028
	SST	642.160	198.028	0.902	3.243	0.032
	Chlorophyl-a	33,535.607	10,100.263	0.923	3.320	0.029

Distribution of chlorophyll-a with K. pelamis catch. The graph of the relationship between chlorophyll-a and the catch of *K. pelamis* shows that the concentration of chlorophyll-a and the catch of *K. pelamis* have a unidirectional relationship (Figure 8).

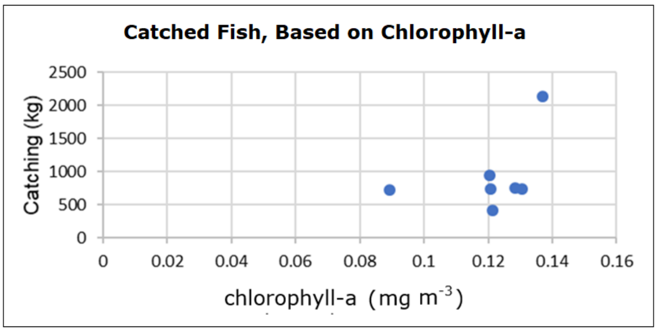

Figure 8. Catch based on chlorophyll-a.

In the figure above, the highest catch occurs at a concentration of 0.137 mg m^{-3}. The results showed that the *K. pelamis* maximum fishing potential occurs at an optimal chlorophyll-a concentration of 0.13 mg m^{-3}. This is in accordance with previous research conducted by Jufri et al (2014) which states that the potential fishing area for *K. pelamis* is closely related to the environmental parameters, especially to a chlorophyll-a in the optimal range of 0.12-0.22 mg m^{-3}.

Conclusions. From the results of the research, it can be concluded that the main catches were *T. albacares*, *K. pelamis*, *E. affinis* and *D. russelli*, *K. pelamis* being the most caught type of fish. The relationship between the sea surface temperature and *K. pelamis* catches was obtained in the form of a coefficient of determination (R_2) of 0.168 or 16.8%. This shows that the SST factor used can only explain the actual model by 16.8% so that the rest is explained by other factors of 83.2%. There was a positive relationship between chlorophyll-a and *K. pelamis* catches, meaning that if the chlorophyll-a is higher, it will increase the catch, and vice versa if chlorophyll-a is lower, it will decrease the catch of *K. pelamis*. The results of the study concluded that the potential area for *K. pelamis* catching based on the optimum sea surface temperature was around 29°C and the optimum concentration for chlorophyll-a was around 0.13 mg m^{-3}.

Conflict of interest. The authors declare no conflict of interest.

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