

Effect of climate change on the distribution of skipjack tuna *Katsuwonus pelamis* catch in the Bone Gulf, Indonesia, during the southeast monsoon

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Abstract. About 59% of Katsuwonus pelamis production of South Sulawesi Province is from the Bone Gulf. However, the threat of climate change could decline the fish production level. The purpose of this study was to identify the existence of climate change in the Bone Gulf, and to analyze the effect of the climate change on the distribution and abundance of K. pelamis during the southeast monsoon. This study used a survey method to collect two types of datasets, primary and secondary data. The primary data consisted of the fishing position, catch, in situ sea surface temperatures (SST), and chlorophyll-a, and secondary data comprised SST and chlorophyll-a obtained from satellite data of TERRA/MODIS. Ten years satellite data of 2005-2014 were used to analyze spatial and temporal of SST and chlorophyll-a anomalies, to identify the existence of climate change in the Bone Gulf. Generalized Additive Model (GAM) were used to analyze the effect of the climate change on the K. pelamis distribution using R 3.1.2 software package. All SST and chlorophyll as well as fishing data were mapped using ArcGIS 10.1. SST anomaly map in the Bone Gulf indicated that SST tended to be higher than usual over the last 10 years as mucsh as 0.5685–0.773°C especially in the Luwu Timur district waters, whereas chlorophyll-a tended to lower low tendency than usual as much as -0.2187 - -0.0659 mg m⁻³ particularly n the Kolaka district waters. K. pelamis catches tended to be high at the SST anomaly of -0.05-0.2°C and the fish tend to concentrate at the low anomaly of chlorophyll-a (-0.02-0.03 mg m⁻³). This study suggests that the low negative anomaly and the high positive anomaly of the oceanographic conditions caused the change of the distribution pattern and declining of K. pelamis catch in the Bone Gulf for the period of June-August. Key Words: pole and line, SST anomaly, chlorophyll-a anomaly, catch, GAM.

Introduction. The waters of Bone Gulf are bordered by South Sulawesi Province to the west and north, Southeast Sulawesi province to the east, and the south by the Banda Sea. The coastal area of Bone Gulf is divided into 15 districts or cities covering: Kab. Bulukumba, Kab. Selayar, Kab. Sinjai, Kab. Bone, Kab. Wajo, Kab. Luwu, Kab. Luwu Utara, Kab. East Luwu, Palopo City, Kab. North Kolaka, Kab. Kolaka, Kab. Bombana, Kab. Muna, Kota Bau Bau, and Kab. Buton, in South Sulawesi and Southeast Sulawesi province that stretches along 1,128 km² of coastline with an area of about 31,837 km² has a big enough fishery resource potential especially *Katsuwonus pelamis* fishery because 13.616 tons (59%) of *K. pelamis* production of South Sulawesi is from Teluk Bone (Ministry of Marine and Fisheries Affairs 2008).

Pole and line fishing gear in Bone Gulf, Luwu regency, South Sulawesi has been exposed to a large pelagic potential such as skipjack tuna, so the pole and line fishing effort is very developed in this area. There are 13 pole and liners operating in Bone Gulf in 2015. All of them mainly focus on catching *K. pelamis* with daytime fishing.

K. pelamis is one of the most important fishery resources both as an export commodity and as a domestic ingredient. Therefore its role in the addition of foreign

exchange is quite meaningful. In developed countries including Japan, Korea, and the United States, research on *K. pelamis* has been done, both concerning aspects of biology, distribution, and techniques of his capture. In Indonesia, such research has not been done so much that the available information is still lacking.

The distribution of *K. pelamis* is influenced by spatial and temporal oceanographic conditions (Jamal et al 2011). The availability of foods both in quantity and quality affects predation rates and is an important variable for *K. pelamis* populations. The availability of food is related to the food chain (food chains). Plankton plants (phytoplankton) through the process of photosynthesis can produce organic materials (primary producers), so it can be done better preparation to conduct more targeted fishing operations. In Indonesia, the content of chlorophyll-a in Bone Gulf waters ranges from 0.2 to 0.8 mg m⁻³ (Tadjuddah 2005).

The main problem faced by traditional fisherman or capture fishery industry is the existence of dynamic fishing area, always changing or moving following the movement of fish. Naturally, the fish will choose a more suitable habitat. Fishing activities will become more efficient and effective if fishing areas can be predicted before the fishing fleet departs from the base.

Indonesia's coastal and marine resources are currently threatened with degradation due to two main factors, namely destructive fishing, and over-fishing. Threats from climate change such as weather uncertainty, extreme weather conditions, rising sea surface temperature (SST), and changes in wind direction, decreasing the level of productivity of fishermen together will make our coastal and marine conditions worse. Almost all of the fish populations live in sea having the optimum temperature for their life (Laevastu et al 1981). SST was the most important habitat predictor for K. pelamis migration in the western North Pacific (Mugo et al 2010). Recent studies show that the distribution of small pelagic fish is affected by climate change (Nurdin et al 2017). The El Nino event and favorable oceanographic conditions, resulting in a significant increase in Thunnus obesus catch (Syamsuddin et al 2016). Given the importance of coastal and marine resources to the livelihoods of the people, we must immediately adapt to coastal and ocean development. Therefore, the purposes of this study were to identify the existence of climate change in the Bone Gulf, and to analyze the effect of the climate change on the distribution and abundance of K. pelamis during the southeast monsoon (June-August) over the last ten years from 2005 to 2014.

Material and Method

Study area. The research was conducted for five months, June to September 2014 and January 2015 in three places, namely in the Laboratory of Information System of Fishing of FIKP UNHAS, at the Water Quality Laboratory of FIKP UNHAS, and in the waters of Teluk Bone, South Sulawesi by fishing base of this research at TPI Murante, Suli Subdistrict, Luwu Regency. The study area extends from 2° S to 8° S in latitude and from 117.5° E to 123.5° E in longitude, covering the important *K. pelamis* fishing ground in the central Indonesia waters.

Satellite remote sensing data. This research used remote sensing satellite data of sea surface temperatures (SST), and chlorophyll-a. The secondary data (SST and chlorophyll-a) were obtained from satellite data of TERRA/MODIS. Ten years satellite data of 2005-2014 were used to analyze spatial and temporal of SST and chlorophyll-a anomalies, to identify the existence of climate change in the Bone Gulf. Terra/ MODIS (Moderate Resolution Imaging Spectroradiometer) level 3 standard mapped images (SMI) data were used to estimate sea surface chlorophyll-a concentration and SST at all pole and line fishing ground locations. MODIS has a fairly high radiometric resolution of 12 bits (Puruitaningrum 2010). NASA distributes the level 3 binary data with HDF (Hierarchical Data Format) format. We obtained these data from NASA GSFC's Distributed Active Archive Center (DAAC) (http://oceancolor.gsfc.nasa.gov/). For this study, we used Global Area Coverage (GAC), monthly mean MODIS images with a spatial resolution of about 4x4 km for the study period during 2005-2014.

Pole and line fishery data. Pole and line fishing gear used during the research is fishing gear operated in Bone Gulf waters with the fishing base used during the research is fishery base at Fishery Landing Base Murante Suli District Luwu with the geographical location that is 03° 28 '35.5 "S latitude and 120° 22 '47.7 "E longitude. The *K. pelamis* catch data was obtained from June to August 2014.

Analysis of SST and chlorophyll-a anomalies. Ten years satellite data of 2005-2014 were used to analyze spatial and temporal of SST and chlorophyll-a anomalies. To identify the existence of climate change, the anomalies of monthly SST and CPUE were calculated for each year (Andrade & Garcia 1999):

$$\delta_{ij} = \overline{T}_{ij} - \overline{T}_{i}$$

Where:

 δ_{ij} denotes the anomaly of the considered variable (SST or ChI-a) in month i and year j, T_{ij} represents the mean of the variable in month i and year j, and T_i signifies the monthly mean of the variable for 10 years.

From the results of the above analysis described that if the anomaly was equal to zero, then there was no a significant spatial variable change on the site. If the anomaly was greater than 0 (positive anomaly) then the observed parameters is higher than the average for the last 10 years. Whereas, if the anomaly was less than 0 (negative anomaly), then the observed parameters is lower than the average for the last 10 years.

Analysis of General Additive Model (GAM). Included is a discussion of several new approaches applicable to GLMs and GAMs, such as ridge regression, an alternative to stepwise selection of predictors, and methods for the identification of interactions by a combined use of regression trees and several other approaches (Guisan et al 2002). GAM analysis is a non-parametric analysis, meaning that this analysis can be used even if the sample data is not spreading normally. The advantage of GAM analysis is that it has a high degree of accuracy. This analysis is used to study the relationship between response variables (CPUE) and predictor variables (SST, chlorophyll-a, SST and chlorophyll-a anomalies).

Results

Sea surface temperature anomalies and chlorophyll-a 2005 - 2014

Anomalies of sea surface temperature

June. In June, the sea surface temperature anomaly was -0.897 to 0.3484°C (Figure 1), where the lowest SST anomaly in Bone Gulf waters was in the waters of North Kolaka and Kolaka regencies i.e. -0.897 - -0.648°C which means that SST in the area is lower than SST June average over the past 10 years. While the highest SST anomaly is in the waters of Luwu and North Luwu districts was of 0.09928 - 0.3484°C which means that the SST in the area is higher than the average SST of June 10 last year. The *K. pelamis* catches by means of the pole and line fishing gear in Bone Gulf waters in June are at anomalous SST -0.0928 to 0.3484°C. This suggested that the SST in the fishing area is higher than the average SST of June 2011 waters.



Figure 1. Spatial *Katsuwonus pelamis* catch distributions (expressed in dots) overlain on sea surface temperature anomaly map in the Bone Gulf in June 2014.

July. In July, the sea surface temperature anomaly was -0.6596 to 0.773°C (Figure 2), where the lowest SST anomaly in Bone Gulf waters is in the waters of Luwu Regency i.e. -0.6596 to -0.455°C which means SST in the area is more lower than the average SST for July over the past 10 years. While the highest SST anomaly is in the waters of East Luwu regency of 0.5685 to 0.773°C which means that SST in the area is higher than the average SST of July for the last 10 years. The *K. pelamis* catches by using the pole and line fishing gear in Bone Gulf waters in July were at an anomaly of SST -0.4549 to -0.2504°C. which in this waters had a lower SST than the average SST of July for the last 10 years.



Figure 2. Spatial *Katsuwonus pelamis* catch distributions (expressed in dots) overlain on sea surface temperature anomaly map in the Bone Gulf in July 2014.

August. In August, the sea surface temperature anomaly was -0.3061 to 0.6641°C (Figure 3), where the lowest SST anomaly in Bone Gulf waters is in the waters of Luwu Regency that is -0.3061 to -0.0172°C which means SST in the region is lower than the average SST for July over the past 10 years. While the highest SST anomaly is in the

AACL Bioflux, 2018, Volume 11, Issue 2. http://www.bioflux.com.ro/aacl waters of East Luwu and Kolaka regencies of 0.3408 to 0.6641° C which means that the SST in the area is higher than the average SST of July for the last 10 years. The *K. pelamis* catches by using the pole and line fishing gear in Bone Gulf waters in July were at an anomaly of SST -0.0173 to 0.3407° C, which in these waters had a higher SST than the average SST of July 10 during the last year.



Figure 3. Spatial *Katsuwonus pelamis* catch distributions (expressed in dots) overlain on sea surface temperature anomaly map in the Bone Gulf in August 2014.

Anomalies of chlorophyll-a

June. In June, anomalous chlorophyll-a in Bone Gulf waters was -0.2187 - >0.6988 mg m⁻³ (Figure 4), where the lowest chlorophyll-a anomalies in Bone Gulf waters were in the waters of North Kolaka and Kolaka regencies is -0.0658 to -0.087 mg m⁻³ which means that the chlorophyll-a in the area is lower than the average chlorophyll-a June in the last 10 years.



Figure 4. Spatial *Katsuwonus pelamis* catch distributions (expressed in dots) overlain on chlorophyll-a anomaly map in the Bone Gulf in June 2014.

The the highest chlorophyll-a anomaly is in the waters of East Luwu Regency and Luwu Utara Regency that is >0.6988 mg m⁻³ which means that the chlorophyll-a in the area is higher than the chlorophyll-a on the average of June for the last 10 years. The *K. pelamis* catches by using the pole and line fishing gear in Bone Gulf waters in June are at anomaly chlorophyll-a -0,2187 to -0.0659 mg m⁻³, which means that chlorophyll-a in the fishing area is higher than that of the chlorophyll-a average of June for the last 10 years.

July. In July, the chlorophyll-a anomaly was -0.1604 to >0.4839 mg m⁻³ (Figure 5), where the lowest chlorophyll-a anomalies in Bone Gulf waters are in the waters of Luwu Regency, Palopo City and some waters of North Kolaka 0.1604 to 0.0531 mg m⁻³ which means that the chlorophyll-a in the area is lower than the average chlorophyll-a in July for the last 10 years. While the highest chlorophyll-a anomalies were in the waters of East Luwu Regency, Luwu Utara District and Kolaka District at values of 0.3766 to >0.4839 mg m⁻³ which means that chlorophyll-a in the area is higher than chlorophyll-a month average in July over the last 10 years. The *K. pelamis* catch by means of a pole and line fishing apparatus in Bone Gulf waters in July was at an anomaly chlorophyll-a 0.1604 to 0.1617 mg m⁻³, which in this waters had a lower chlorophyll-a in July forthr last 10 years.



Figure 5. Spatial *Katsuwonus pelamis* catch distributions (expressed in dots) overlain on chlorophyll-a anomaly map in the Bone Gulf in July 2014.

August. In August, the chlorophyll-a anomalies were -0.1678 -> 0.4883 mg m⁻³ (Figure 6), where the lowest chlorophyll-a anomalies were in Bone Gulf in the waters of Kolaka Utara and Kolaka regencies of 0.1678-0558 mg m⁻³, which means that the chlorophyll-a in the area is lower than the average chlorophyll-a of August for the last 10 years. While the highest chlorophyll-a anomalies were in the waters of East Luwu Regency, North Luwu Regency and Palopo City that is 0.379 -> 0.4883 mg m⁻³ which means that the chlorophyll-a in the area is higher than the chlorophyll-a avergare of August for the last 10 years. The *K. pelamis* catches by using the pole and line fishing gear in Bone Gulf waters in August were at anomaly chlorophyll-a -0.0584 - -0.0508 mg m⁻³, which in this waters had a lower chlorophyll-a than the chlorophyll-a average of August for the last 10 years.



Figure 6. Spatial *Katsuwonus pelamis* catch distributions (expressed in dots) overlain on chlorophyll-a anomaly map in the Bone Gulf in August 2014.

Based on the above description can be seen that in June the anomaly of sea surface temperature was -0.897 to 0.3484°C, in July -0.6596 to 0.773°C and in August -0.3061 to 0.6641°C. While Chlorophyll-a anomaly in June was -0.2187 to >0.6988 mg m⁻³, in July -0.1604 to >0.4839 mg m⁻³ and in August -0.1678 to >0.4883 mg m⁻³. From these data, it is concluded that in Bone Gulf waters during 2005 to 2014 the effect of climate change in terms of environmental conditions are present in the form of parameters of sea surface temperature and chlorophyll-a. The sea surface temperature anomaly varied from observations during June, July and August over the last 10 years i.e. in 2005 to 2014, where the highest sea surface temperature anomaly occurred in July i.e. reaching the range 0.5685 to 0.773°C while the lowest anomaly occurred in months June that reach the range -0.897 to -0.648°C. Based on observations during June, July and August over the last 10 years i.e. in 2005 to 2014, the anomalous chlorophyll-a also varied greatly with the highest chlorophyll-a anomaly occurred in June at approximately >0.6988 mg m⁻³ and the lowest anomaly occurred in June with a range of -0.2187 to -0.0659 mg m⁻³.

Discussion

K. pelamis catch. *K. pelamis* is the main target for Pole and line fishery in the in the Bone Gulf (Zainuddin 2011). Fishing with this gear on *K. pelamis* waters is done when the fish is actively looking for food in the morning that is at 07:00–11:00 AM. *K. pelamis* usually forms a school when the fish is actively looking for food. When the fish is active foraging, the hordes move quickly while leaping on the water surface. Based on Figure 7 it is known that during the months of June, July and August were significant anomalies occurred, the highest *K. pelamis* catch rate in July was an average of 131 individuals and the lowest in June with an average of 30 individuals.



Figure 7. Diagram of *Katsuwonus pelamis* catch with pole and line landed at fishing base, Luwu, Indonesia.

Effect of SST and chlorophyll-a on the number of K. pelamis catches. Fish life patterns cannot be separated from the existence of various environmental conditions. Fluctuations in environmental conditions have a great influence on the seasonal migration period and the presence of fish somewhere (Gunarso 1985). Oceanographic factors that directly affect the existence of *K. pelamis* in the form of SST and chlorophyll-a.

SST can be used as a way to predict the presence of organisms in aquatic medium especially of fish. This is because the fish is poikilothermic. The high level of sea surface temperature in waters is mainly influenced by radiation. Changes in the intensity of light will result in changes in sea temperature both horizontal, vertical, weekly, monthly and yearly (Edmondri 1999).

Metabolic activity and fish distribution are influenced by water temperature and fish are very sensitive to temperature changes although with only 0.03°C. Temperature is an important factor for determining and assessing a fishing area. Based on temperature variations, high-temperature variations are important factors in determining the migration of a fish species. Temperatures that are too high, not normal or unstable will reduce the speed of fish feeding (Gunarso 1985). According to Tampubolon (1990), *K. pelamis* is sensitive to temperature changes, especially meal times that are tied to certain habits.

In Figure 8 there is a diagram of the relationship between SST and fish capture in Bone Gulf waters. The *K. pelamis* is most caught with pole and line fishing gear at SST 28.5-29°C with the catch of 1763 tail and at SST 29.5-30°C of lowest catch with 4 fish/hauling.



Figure 8. SST diagram with Katsuwonus pelamis catch of pole and line, Luwu, Indonesia.

The catch of fish in waters is also determined by the fertility of the waters. The level of water fertility is usually associated with nutrient concentrations in the aquatic bodies. Phytoplankton containing chlorophyll-a is a marine plant whose existence is highly dependent on nutrient content in waters. This is because phytoplankton can directly utilize nutrients through the process of photosynthesis. Therefore, chlorophyll-a is one of the water-fertility measurements associated with the productivity of the catch. Waters with high chlorophyll-a content must have much phytoplankton favored by fish schools (Wilson et al 2008).

In the chlorophyll-a in relation to the catch (Figure 9) it appears that the *K. pelamis* in the Bone Gulf are mostly caught within chlorophyll-a concentration of 0.21-0.23 mg m⁻³ with 1,140 fish/hauling and there were caught on the chlorophyll-a density range of 0.15-0.17 mg m⁻³ and 0.25-0.27 respectively.



Figure 9. Chlorophyll-a diagram with *Katsuwonus pelamis* catch of pole and line in Murante Village, Suli, Bone District, Indonesia.

In this study, data retrieval was done for 3-5 times a trip in a month. The absence of catches at specific intervals from Figure 8 and Figure 9 is probably due to the lack of data (samples) used in this study. So in the future, if done research like this then it can be done by the following trip more than done in this research.

Effect of SST and chlorophyll-a on the number of K. pelamis catches. In the waters of Bone Gulf during the years 2005-2014 there was an anomaly that varied both negative and positive anomalies. Based on the diagram below (Figure 10), the highest catch was in the SST anomaly range between 0.05 and 0.15°C, while the lowest catch with a total of 0 fish was in the range of SST anomalies between 0.25-0.35°C.





Judging from the anomalous parameters of chlorophyll-a (Figure 11), K. pelamis catches fluctuated from negative anomalies to positive anomalies The highest catch (1,070 fish/hauling) occurred in the range of chlorophyll-a anomalies between -0.1 and -0.05 mg m⁻³, whereas the lowest catch with zero catch was recorded at -0.05 - 0 mg m⁻³ anomalies of chlorophyll-a.



Figure 11. Chlorophyll anomaly diagram with Katsuwonus pelamis catch of pole and line in Luwu, Indonesia.

Effect of oceanographic parameters on distribution and catch. The effect of some oceanographic parameters as measured against pole and line catch. Data is processed through multiple regression analysis with Generalized Additive Model (GAM) method using software R 3.0.2. The measurement of SST (X1) parameters, SST anomaly (X2), chlorophyll-a (X3) and chlorophyll-a anomaly (X4) are then used as independent variables while the K. pelamis catch (Y) is used as dependent variable.

Based on the regression test using software R 3.0.2 with GAM model, the following results are obtained in Table 1.

Table 1

Variable	Df	Sum Sq	Mean Sq	F value	Pr (>F)
s(SST)	1	3052	3052.0	0.6201	0.0001759 ***
S(SSTanom)	1	28296	28296.3	5.7493	0.02693 *
S(chl)	1	417	416.8	0.0847	0.000287 ***
S(chlanom)	1	12657	12656.9	2.5717	0.12529
Residuals	19	93512	4921.7		

Result of GAM model test

Signifiance codes: 0 '***' 0.001 '**' 0.05 '.' 0.1 ' ' 1.

Table 1 shows the significance values of the four SST parameters, the SST anomaly, chlorophyll-a, and a-chlorophyll anomalies are 0.0001759, 0.02693, 0.0012156, and 0.12529. The significance value of the three parameters is <0.05 then it can be concluded that the SST, SST anomaly, and chlorophyll-a parameters significantly influence the K. pelamis catches in the waters of Bone Gulf.

Based on Figure 12 many K. pelamis are caught in the SST range of 28.5-29.5°C. According to Angraeni et al (2014), the ideal temperature for K. pelamis is between 28-32°C. Zainuddin et al (2017) suggest that K. pelamis catches tend to increase starting from SST of near 29°C which seem to be similar to our results.

SST anomaly affects K. pelamis catch in Bone Gulf waters (Figure 12b). Many K. pelamis are caught in the anomalous range SST of -0.05 - 0.2°C, meaning that K. pelamis tends to favor high SST anomalies.

Figure 12c shows that the dominant *K. pelamis* caught is at 0.13-0.23 mg m⁻³ chlorophyll content and tended to be significant at 0.3 mg m⁻³ chlorophyll content. While in Figure 11d can be seen that the *K. pelamis* were mostly caught on chlorophyll anomalies of -0.02 - 0.03 mg m⁻³ and tended to be significant in the range of -0.02 - 0.01 mg m⁻³. *K. pelamis* tends to prefer a low chlorophyll anomaly.



Figure 12. The effect of oceanographic parameters on catch; (a) The effect of SST on catch; (b) The effect of SST anomalies on catches; (c) The influence of chlorophyll-a on the catch; (d) The effect of chlorophyll-a anomalies on catches.

It can also be seen that both negative (low) and negative (high) anomalies lead to shifting of distribution and decrease of *K. pelamis* catches in Bone Gulf waters seen from the increasingly dashed-dotted lines in Figures 12b and 12d (broken line -connection away from the center line).

Conclusions. During the last 10 years (2005-2014) the Bone Gulf waters shows the effect of climate change within the occurrence of SST or chlorophyll-a anomalies. Bone Gulf waters have a higher SST tendency than usual for the last 10 years in the waters of East Luwu Regency, while chlorophyll-a has a tendency to lower than was usual for the last 10 years in Kolaka District waters. *K. pelamis* tend to concentrate in relatively high SST anomalies and relatively low chlorophyll-a anomalies. Negative anomalies (low) as well as positive (high) anomalies are suspected as one of the causes of shifting distribution and reduced *K. pelamis* catches in Bone Gulf waters.

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