Effects of environmental factors on anchovies *Stolephorus* sp distribution in Bone Gulf, Indonesia

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Abstract. This paper explores the relationship between environmental factors and anchovies *Stolephorus* sp distribution obtained from experimental fishing in the gulf of bone, Indonesia. Selected environmental factors employed included sea surface temperature (SST) and sea surface chlorophyll-a (SSC). Generalized additive models (GAMs) revealed that the selected environmental factors play an important role in the explanation of the anchovy distribution in the study area. Most of the anchovy schools that were catched by fishing (large liftnet) were located in the coastal area. The high anchovy concentrations corresponded well with SST of 29.5–30.5^{o}C, and SSC of 0.5–1.0 mg/m^{-3}. We noted that anchovy migrating in the Gulf of Bone could have followed the both SST and SSC optimum during southeast season which they occupied in the warmer and high productivities waters. These preferred conditions may represent the optimal habitat of the anchovy in Bone Gulf during the southeast monsoon period.

Key Words: experimental fishing, optimal habitat, SST, SSC, GAM.

Introduction. Small pelagic fish plays an important role in marine ecosystems, not only as an herbivore for plankton but also as a target fish for local commercial fisheries. Small pelagic fish are most important targets by marine fisheries in the world's oceans. One species of small pelagic fish that is a very important capture of fishermen is anchovies (*Stolephorus* sp, Lacepede, 1803). Anchovy is a coastal pelagic species inhabiting all tropical and subtropical waters.

The variations in environmental conditions could change the natural fluctuations of the anchovy stock especially in the coastal area where plankton is abundant. Therefore, information is rapidly needed on the effects of environmental conditions in related with anchovy distribution in the field for anchovy fishery management purposes. Generalized Additive models (GAMs) as a method can be one of the most useful for determining the fish distribution in relation with environmental condition such Sea Surfece Temperature (SST) and Sea Surface Chlorophyll-a (SSC) (Zainuddin et al 2013; Safruddin et al 2014).

In this paper, we aimed to reveal the presence of the anchovy's distribution using large lift net fishing gear in the night time, and to discuss the environmental factors affecting the anchovy distribution.

Material and Method. The study area was located in Bone Gulf, South Sulawesi, Indonesia (Figure 1). The field surveys used large lift net (local commercial fisheries) to known the weight of anchovies species (in kg) directly. Environmental observations (satellite imagery data) were conducted monthly during the southeast monsoon (April – September) 2017 (Figure 2 and Figure 3).

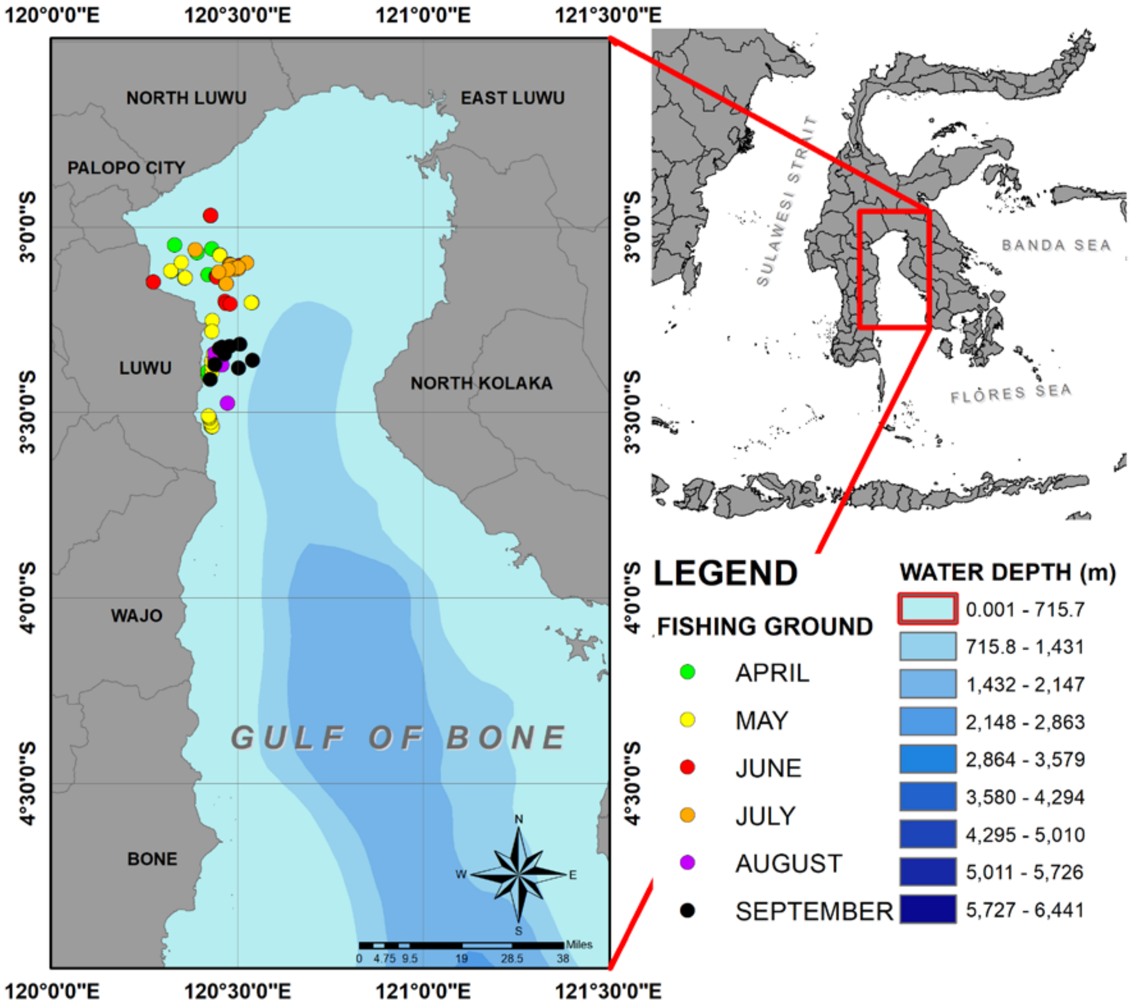

Figure 1. The study area, Bone Gulf, Sulawesi Island, Indonesia.

Matching anchovies catches data to environmental data. We conducted a concurrent four months investigation of the environmental factors that were used for the analysis of monthly changes in SST and SSC conditions in the study area. Furthermore, we derived the information on their effects on anchovy's distribution.

The spatial interpolation was used to compose datasets such as geostatistical analysis and validation and prediction tools (ESRI, Arc.GIS 10.2, USA). Ordinary kriging method was employed to predict the levels of all environmental factors at the position of anchovies fishing ground (Fisher 2007).

The environmental selections were predicted by the R program version 3.4.2 (R Development Core Team 2017). The statistical model was constructed in the presence of anchovies based on the lift net catches. The responding variable was anchovies in presence (fish number in kg) scenarios and the candidate predictor factors were the environmental factors such as SST and SSC. Generalized additive models (GAMs) with Gaussian distribution were applied to determine the effect of environmental factors on the anchovy's schools distribution (Wood 2006; Murase et al 2009; Safruddin 2013). The GAMs were constructed using the "gam" function of the mgcv package. A model of the form is shown in the following equation:

$$g(\mu_i) = a_0 + s_1\ (\text{temperature}) + s_2\ (\text{chlorophyll-a}) + \varepsilon$$

Where g - spline smooth function, μi - the expected value of the response variable (anchovies catches), a_0 - the model constant coefficient, s_n - a smoothing function of the predictor variables and ε - a random error term.

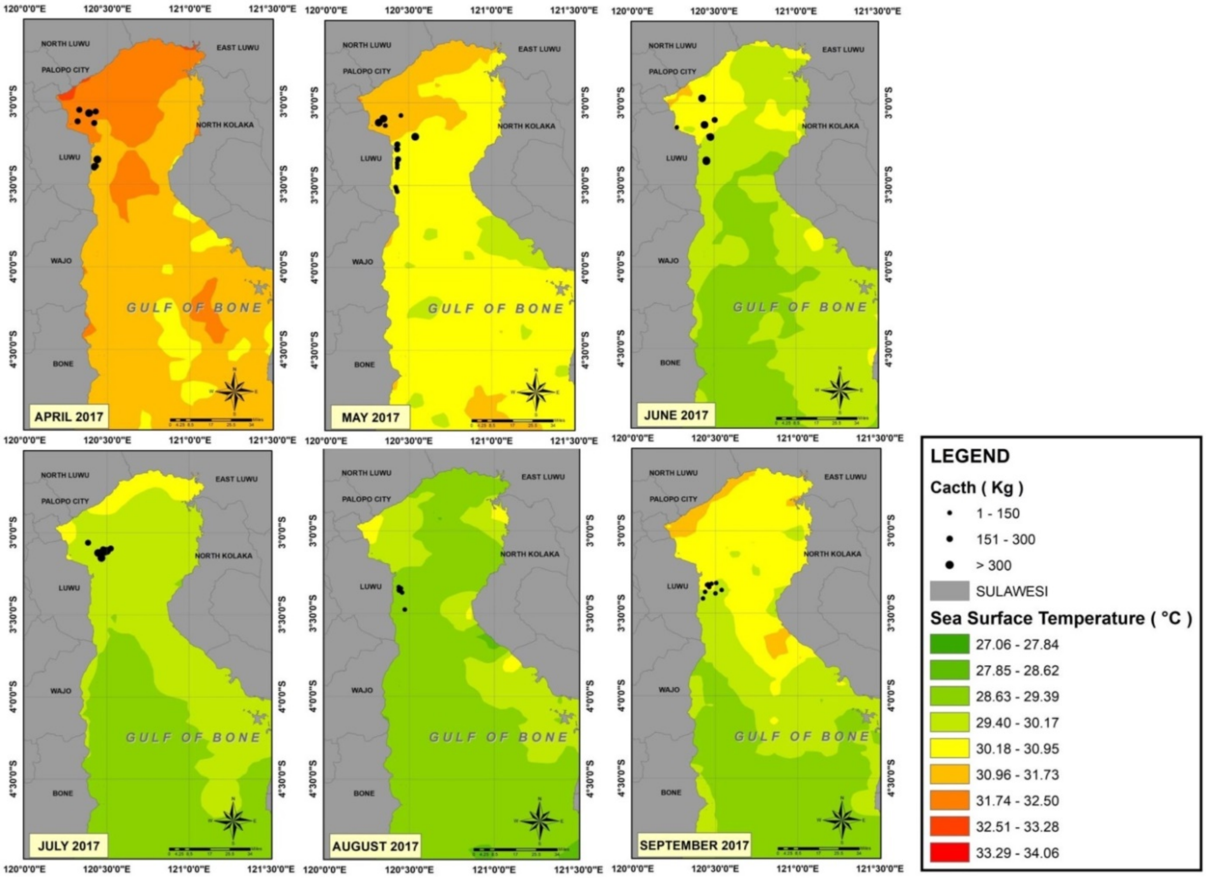

Figure 2. Horizontal profiles of sea surface temperature overlain with anchovies fishing ground form April to September 2017. The SST provided by AQUA-MODIS, NOAA. Anchovy weight is also shown.

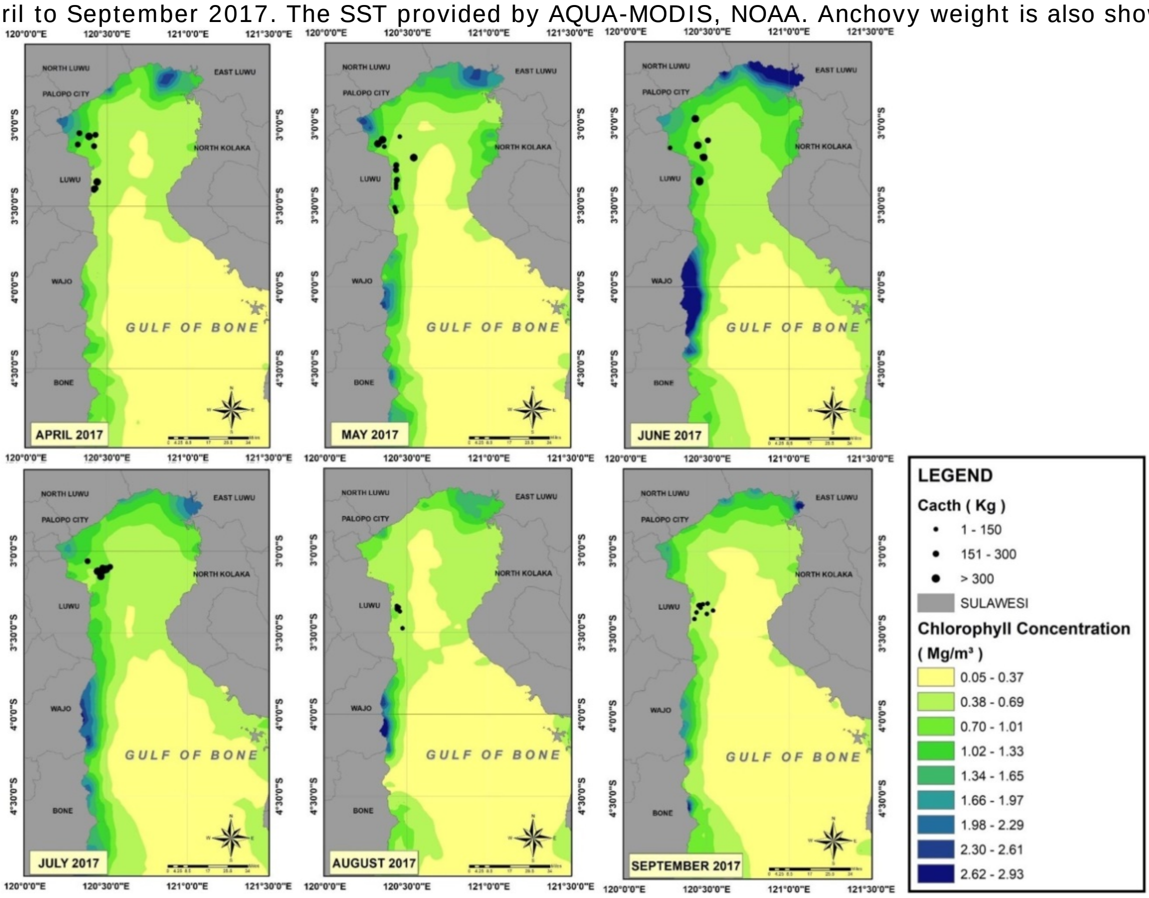

Figure 3. Horizontal profiles of sea surface chlorophyll-a overlain with anchovies fishing ground form April to September 2017. The SSC provided by AQUA-MODIS, NOAA. Anchovy weight is also shown.

Results

Distribution of anchovies. We found that anchovies were distributed mainly in near the coastal area in the depth range of 11 to 7,000 m (Figure 1). The horizontal profiles of SST and SSC structures of each month in 2017 (Figures 2 and 3) were warmer at near the coastal area than at the off shore. Anchovy's schools occupied the area in near the coastal where they selected warmer SST and higher SSC (Figures 2 and 3).

The environmental conditions on anchovies fishing ground for four monthly datasets were used. Thus the preference ranged to suggest possible relationship among all variables observed. Figure 4 showed that anchovies were distributed in the ranges of SST from 29.5−30.0°C. In relation to SSC, on the other hand, the schools congregated in the narrow ranges of 0.5−1.0 mg$^{-3.}$

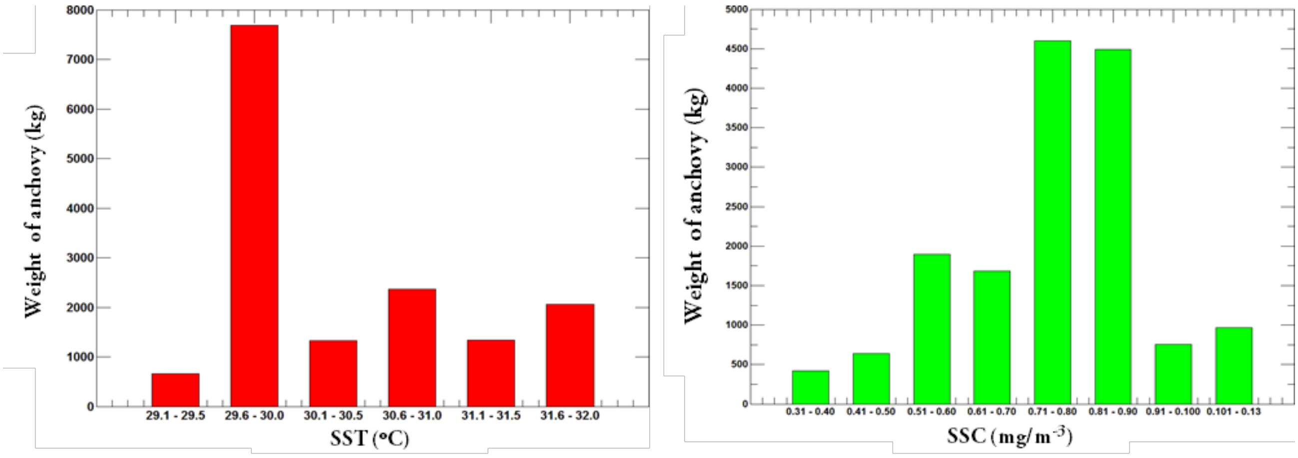

Figure 4. Preferences of oceanographic conditions for anchovies. Anchovies weight for each oceanographic parameter was as noted.

Environmental effects on anchovies distribution. Knowing the environmental conditions is crucial for estimating the distribution of anchovy in the Gulf of Bone, because they influence the distribution of anchovy in their natural habitat. Model prediction that was constructed had the combination from one to two environmental factor predictors. As the result, all combinations were selected as significant models for explaining the anchovy's distribution (Table 1).

Table 1

Summary statistic of the GAMs: oceanographic variables effects on the anchovies distribution (n= 193). The significant factor, Akaike information criterion (AIC) value and percent cumulative deviance explained (CDE) are also shown.

No.	*Model*	*Variable*	*p-value*	*AIC*	*CDE (%)*
1.	Temperature	Temperature	0.00315**	2285.773	12.9%
2.	Chlorophyll-a	Chlorophyll-a	0.000466***	2280.987	13.4%
3.	Temperature + Chlorophyll-a	Temperature	0.0581	2277.280	18.34%
		Chlorophyll-a	0.0191*		

Signifiance codes: 0.001 '***' 0.01 '**' 0.05 '*'

Chlorophyll-a concentration had the lowest Akaike Information Criterion (AIC) value and the highest cumulative deviance explained (CDE; 13.4%) among the single predictor variables. The final model combination of SST, and SSC had the lowest AIC value (2277.280) and highest CDE (18.34%) as listed in Table 1. Temperature had the positive effect on anchovies distribution in the ranges of 29.5−30.5°C (Figure 5a) and in relation to SSC, the plot on SSC (Figure 5b) showed a positive effect on school distribution and was observed in the ranges of 0.5−1.0 mg^{-3}.

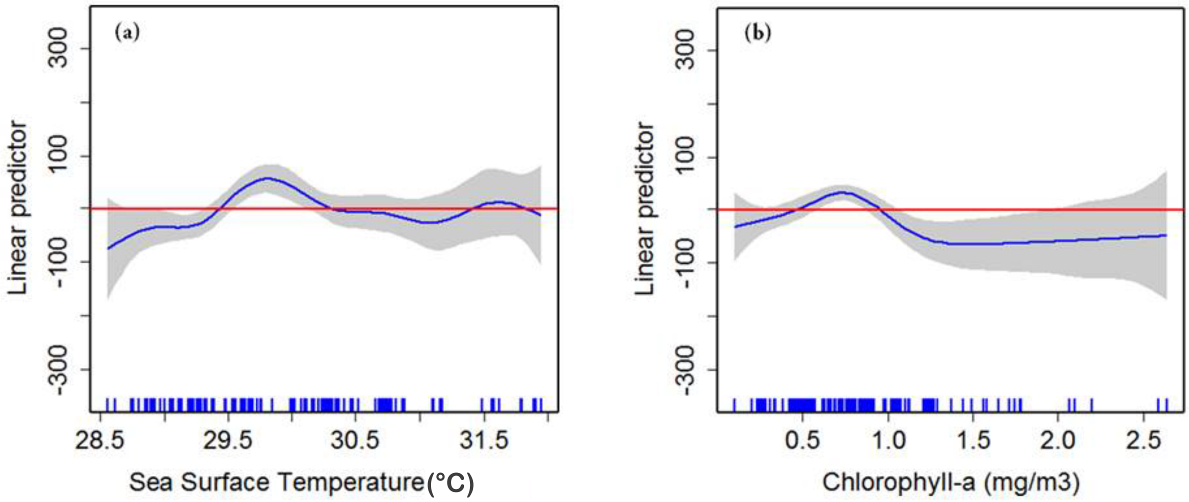

Figure 5. GAM derived effect of the best model predictor; (a) temperature and (b) chlorophyll-a. Grey area indicates the 95% confidence intervals. The relative density of data points is shown by the rug plot on the x-axis. Values of a predictor factor showing a positive effect on anchovies distribution were read as all values for which the fitted GAM function was above the zero-axis (red line), except in fewer data point.

Discussion. The dynamics of environmental condition in the Gulf of Bone can influence the existence of anchovies. Environmental factors such as temperature (Lehodey et al 1997) and chlorophyll-a (Polovina et al 2001) play an important role in determining marine fish habitat in this area particularly from April to September 2017. We investigated the eastern season distribution of anchovies in the northern coast of Gult of Bone during the night time for lift net which was linked to the dynamism of environmental conditions (Hendiarti et al 2005). The environmental conditions in this area are highly influenced spatial and temporal (Gordon 2005). In addition, changes of their environmental conditions may have profound effects on their abundance, migration patterns, distribution, and also growth (Murase et al 2009). Therefore, it is very important to understand how the environmental factor affects the anchovy's distribution in the Gulf of Bone.

GAM as an exploratory tool was used to identify the shapes of the relationships between oceanographic factors and anchovies distribution as it was most likely that the expected relationships are non-linear. Furthermore, the shape of the relationships between the anchovies biomass and each predictor (temperature, and chlorophyll-a) were identified. As shown in Table 1 and Figures 5a−b, the effects of environmental factors on anchovies distribution in the horizontal profiles were provided. Geographic Information System techniques were used in the analysis of the distribution of small pelagic fish (Castillo et al 1996). We found that the influences of the environmental condition on anchovies distribution could be evaluated based on statistical criterions. Thus the environmental factors related to anchovies distribution have become a matter of great importance to understand their habitat preferences. Watanabe (2009) 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 such as cool temperatures are preferred by sardine and warm temperatures are preferred by saury and anchovy.

Variations in environmental conditions play a key role in natural fluctuations of anchovy stocks, SST and SSC that have the greatest impact on small pelagic fish distribution. Thus SST is a good indicator for fishing areas and has been used for decades by fishermen and researchers. Moreover, changes on environmental factor (physical and biological) may have profound effects on migration patterns and growth of fish (Murase et al 2009). Marrari et al (2013) noted that Chlorophyll-a dynamics explained most of the variability observed in Argentine anchovy recruitment, most likely via fluctuations in the availability of adequate food for the larvae.

The current study provided the best available information and advice from the effects of environmental factors on anchovies distribution for sustainable utilization of the fishery and management of the anchovies fishery. Future work needs to incorporate other factors that could have had an effect on the anchovies abundance and distribution that was not considered in this study area. Among the factors to be considered is the abundance of zooplankton associated with anchovies positions because have been linked to zooplankton densities (Safruddin 2006).

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