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Oceanographic factors related to Eastern Little Tuna (*Euthynnus affinis*) catches in the west Java Sea

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Abstract. The satellite data included sea surface height anomaly (SSHA) from AVISO, sea surface temperature (SST) and chlorophyll-*a* (Chl-*a*) from Aqua MODIS and Eastern Little Tuna (*Euthynnus affinis*) catches were used as a combined dataset to understand the ocean variations and further addresses their relations with the Eastern Little Tuna catches in the Java Sea. The fish catches and remotely sensed data were analyzed for the 5 years datasets from 2010-2014. The relationships of oceanographic factors and catch distribution were explored with a generalized additive model (GAM). Catch rates varied temporally relatively significant over year-round. The Eastern Little Tuna catch rates have the peak season in March and October (900 ton to 1000 ton). The ELT catch peaks during the transition season from southeast to northwest monsoon (September to November) and decreases during southeast monsoon (June to August). The GAM results showed that the 3-oceanographic parameter combination models explained the highest deviance (41.4%) with Chl-*a* explained the highest deviance (23.3%). High probabilities of Eastern Little Tuna catches corresponded to marine productivity of Chl-*a* concentration ranging from 0.3-0.5 mg/m^3, for SSHA ranging from 0-8 cm and SST ranging from 28-29°C. We recommend to have further investigations through the use of long-term historical time series to predict fishing ground locations and an emerging need to improve our climate understanding and forecast skill to conserve small pelagic catches.

1. Introduction

The Eastern Little Tuna (*Euthynnus affinis*) represents a dominant catch in the Java Sea. The Eastern Little Tuna is an epipelagic, neritic species inhabiting water temperatures ranging from 18 °C to 29 °C and tend to form multispecies schools by size. The Eastern Little Tuna is largely confined to continental shelves and islands of the western Pacific and the Indian Ocean [1]. Although also inhabiting ocean waters, this species prefer to stay close to the coast and juvenils are even found in the bays and harbours. It is a highly migratory species and frequently forms large schools which are often mixed with other scombrid species. Although sexually mature fish may be encountered throughout the year, there are seasonal spawning peaks varying according to regions: i.e. March to May in Philippine waters; from the middle of the North West monsoon period to the beginning of the South East monsoon (January to July) off East Africa; and probably from August to October off Indonesia [2].

The behaviour and survival of Eastern Little Tuna have been related to a range of environmental and ecological factors, necessitating the need to combine several oceanographic factors to investigate the effects of oceanographic factors on the Eastern Little Tuna catch in the west Java Sea. As proxies of potential tuna fishing grounds, sea surface height (SSH) measurement which could indicate oceanic features, as well as measurements of sea-surface temperature (SST), have been used to investigate productive frontal zones [3]. Thermal or color gradients in satellite images that arise from the circulation of water masses often indicate areas of high productivity [4]. Chlorophyll-*a* (Chl-*a*) data can also be used as a valuable proxy for water mass boundaries that can influence pelagic fish distribution in a region.

On the other hand, there seems to be only a few studies of the oceanographic variability impacts on Eastern Little Tuna distributions in the Java Sea. The satellite data included SSHA, SST and Chl-*a* and Eastern Little Tuna catches were used as a combined dataset to understand the ocean variations and further addresses their relations with the Eastern Little Tuna catches in the Java Sea. Therefore, understanding the effect oceanographic conditions and Eastern Little Tuna catches is an essential step towards the sustainable management of Eastern Little Tuna resources in the Java Sea.

2. Study area

The study area was in the western of Java Sea in the Indonesian Seas region focusing on geographical coordinates of 3 °S to 7 °S and 108 °E to 110 °E, as shown in Figure 1. The oceanographic condition in the study area is affected by the monsoon wind reversal drives the surface layer of the Java Sea southeastward, bringing relatively cool, fresh South China Sea water into the region [5].

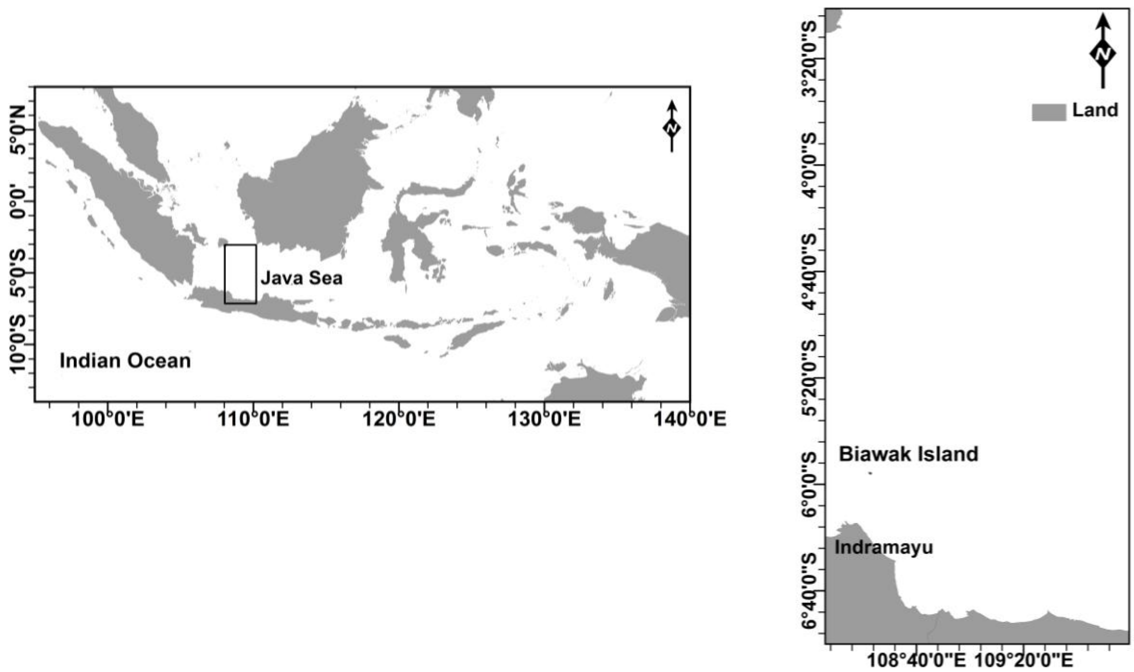


Figure 1. Map of Indonesian Seas with the inset box representing the study area in the west Java Sea

3. Data and methods

3.1 Data

This study utilized a time series of Eastern Little Tuna catch data that were collected from fishing logbooks provided by the Fishing Port of Indramayu, West Java and the Ministry of Marine Affairs and Fisheries Indonesia. The remotely sensed data consist of sea-surface temperature (SST), sea surface height anomaly (SSHA) and Chlorophyll-*a* (Chl-*a*). The SST and Chl-*a* were derived from satellite imagery of Aqua Modis and downloaded from http://oceancolor.gsfc.nasa.gov. The SST and Chl-*a* data had spatial and temporal resolutions of 4 km and monthly, respectively. The SSHA data derived from the TOPEX and Poseidon ERS-1/2 altimeters which are produced and distributed by Archived Validation and Interpretation of Satellite Oceanographic Data (AVISO). For data analysis, all SSHA, SST, and Chl-*a* were composed into monthly data and resampled into 9 km spatial resolution. In this study, the fish catch and satellite remotely sensed data were analyzed for the 5 years datasets from January 2010-December 2014.

3.2 Methods

3.2.1 Wavelet Spectrum Analysis

In this study, the wavelet analysis was applied on the monthly Eastern Little Tuna catch data, SSHA, SST and Chl-*a* data. This study applied the cross wavelet spectrum (XWT) and wavelet coherence (WTC). The XWT finds region in time frequency space where the time series show high common power and the WTC analysis can provide further information about time-scale-dependent phase shifts and correlations between two different time signals. In the other words, wavelet coherence analysis provides a quantitative way to describe the correlations between two time signals as a function of both time scale and phase shift.

The spectra are significant at the 95% confidence level assuming a background red noise. High energy variances are represented in red and low values are in blue as shown in the colorbars that represent different wavelet amplitude. The black line (solid contour) shows the 95% confidence level and a thin black line shows the cone of influence (COI) and are the region of the wavelet spectrum in which edge effects become important [6].

3.2.2 Generalized Additive Model (GAM)

This study examined the relationship between Eastern Little Tuna and oceanographic variables using generalized additive model (GAM). The GAM has been utilized in the previous fishery studies related to the oceanographic factors [7,8]. The advantages in using GAM are its simplicity beside the predictor variables having non-linear effects upon the response variable. The GAM was applied to Eastern Little Tuna catches in order to explore the spatial trends in distribution influenced by the SSHA, SST, and Chl-*a*.

All explanatory model terms were treated as continuous variables with the spline smoothers initially fitted to each term in the model [9]. A step-wise GAM was performed to determine the best fitting model prior to applying the final GAM to the entire data set. Akaike's information criterion (AIC) were used to determine the optimal set of explanatory variables. The model with the smallest AIC can be selected as the optimal model. GAMs were constructed in the R program (version 2.14.0) software using the *gam*.function of the *mgcv* package [10]. The GAMs were fitted in the formula:

$$g(u_i) = \alpha_0 + s_1(x_{1i}) + s2(x_{2i}) + s3(x_{3i}) + \ldots . s_n(x_{ni}), \quad (1)$$

where,

g = the link function,

u_i = the expected value of the dependent variable (HR of bigeye tuna),

α_0 = the model constant,

s_n = a smoothing function for each of the model covariates x_n.

4. Result and Discussion

4.1 Oceanographic factors associated with Eastern Little Tuna cathes

This study has shown the effect of monsoon inducing oceanographic condition in the west Java Sea. Seasonal change features were dominant for all the selected oceanographic parameters of SSHA, SST and Chl-*a*, and also Eastern Little Tuna catches, respectively. The time series plots on Figure 2 showed that the Eastern Little Tuna catch rates have the peak season in March during transition period from northwest monsoon to southeast monsoon and October during transition period from southeast monsoon to west monsoon (900 ton to 1000 ton).

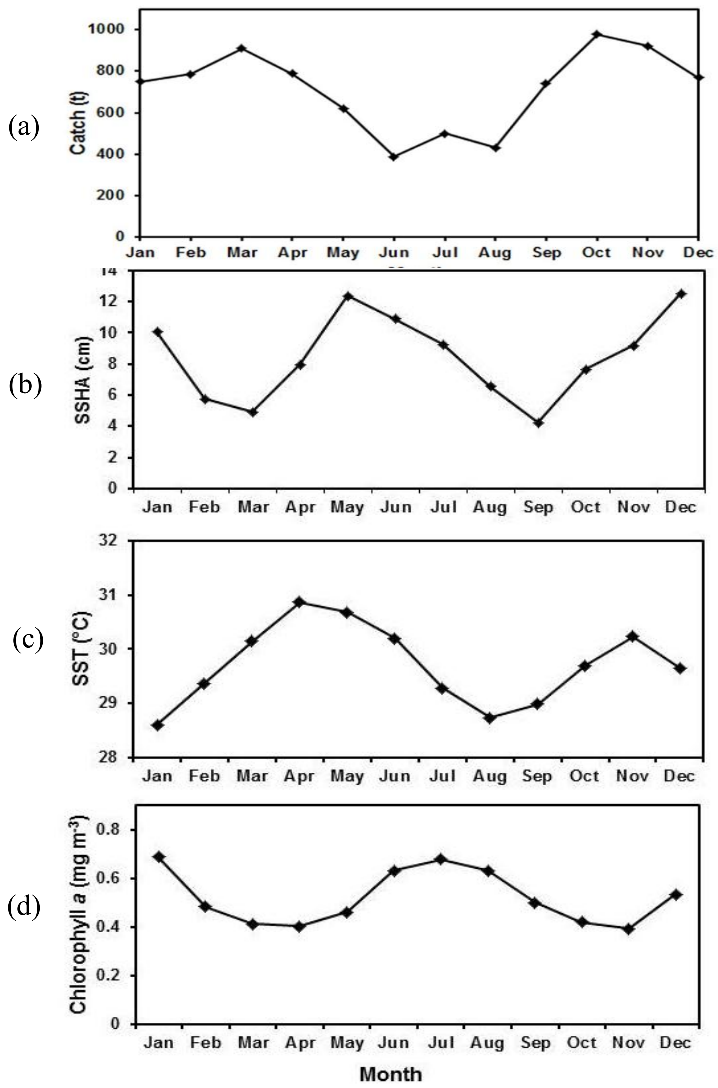


Figure 2. Mean monthly of (a) catch rate of Eastern Little Tuna, (b) SSHA, (c) SST, (d) Chl-*a* concentration during 2010-2014. The x-axis represents the month, and y-axis shows the variable value.

The peak catches corresponded with the value of SSHA ranging from 4-8 cm, SST ranging from 29 °C to 30 °C following the decreasing Chl-*a* concentrations in September to November (0.4 to 0.5) mg · m^{-3}. These results are consistent with previous studies who found that Eastern Little Tuna peaks during transition period from northwest monsoon to southeast monsoon with the preference habitat of warmer SST from 29.03-31.58°C and lower nutrient [11]. Other research revealed that Eastern Little Tuna is a typical warm water species that does not a preference for low temperature, thus ocean temperature plays an important role in the distribution of *Euthynnus affinis* [12].

4.2 Fishing ground modeling of GAM

The results of the GAM are presented as 1-parameter, 2-parameter, and 3-parameter models. The GAM analysis showed all explanatory variables used in the models to be statistically highly significant (P<0.0001) for SSHA, SST, Chl-*a* (Table 1). The addition of predictor variables at different levels gave an increased result in the deviance explained. GAM models explained 23.3%, 14.2%, and 0.0024% of the deviance explained in the single parameter models for Chl-*a*, SSHA, and SST, respectively. The three-parameter combination models explained the highest deviance (41.4%).

Table 1. Results from general additive models (GAMs) derived from catch rates of Eastern Little Tuna in 2010–2014 as a function of the oceanographic parameters (N=61 samples). The best model was selected on the basis of the significance of predictor terms, and increase in cumulative deviance explained (CDE).

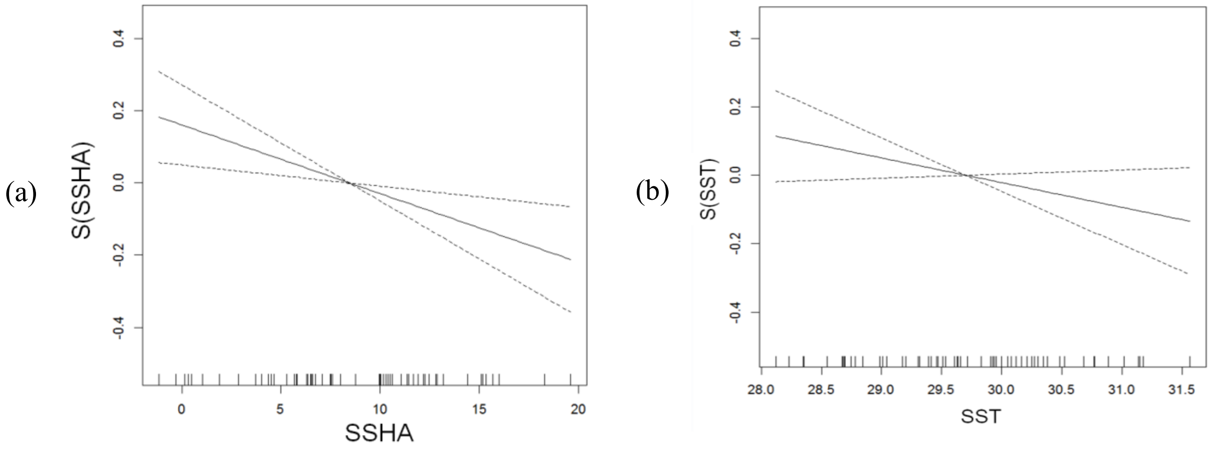
Model	**Parameter**	**Deviance explained (%)**
catch ~ s(chla)	Chl-*a*	23.3***
catch ~ s(ssha)	SSHA	14.2**
catch ~ s(sst)	SST	0.0024
catch ~ s(chla) + s(ssha) + s(sst)	Chl-*a*, SSHA, SST	41.4***

***indicates statistical significance at the 0.0001 level

Figure 3 showed the individual effects of predictor variables associated with each variable of SSHA, SST, and Chl-*a* on Eastern Little Tuna catch. The model results showed the most favorable oceanographic condition for Eastern Little Tuna as observed for SSHA ranging from 0 to 8 cm, for SST between 28ºC and 29.5ºC, for Chl-*a* from 0.3 to 0.5 mg m^{-3}. The declined catches of bigeye tuna were observed for higher SSHA 8 -20 cm; SST values from 29.6 to 31.5ºC; higher Chl-*a* values above 0.5 mg m^{-3}.

Our finding is in agreement with other research indicating that *Euthynnus affinis* prefer to live in warmer surface water with the average value of SST 29.46 ºC and lower Chl-*a* concentration of 0.3 mg m^{-3} [13].

The GAM results confirmed that Chl-*a* seemed to be one of the dominant factors to explain the variability in the study area. Thermal or Chl-*a* fronts often indicate areas of high biological productivity, and hence a high probability finding fish. Primary production provides an attractive habitat for small pelagic fish species [4,14]. The SSHA and SST were the second and third significant predictor of Eastern Little Tuna. Predominantly positive SSHA and warm SST have a greater effect on catches implying preference for habitat optimum of Eastern Little Tuna.



(c)

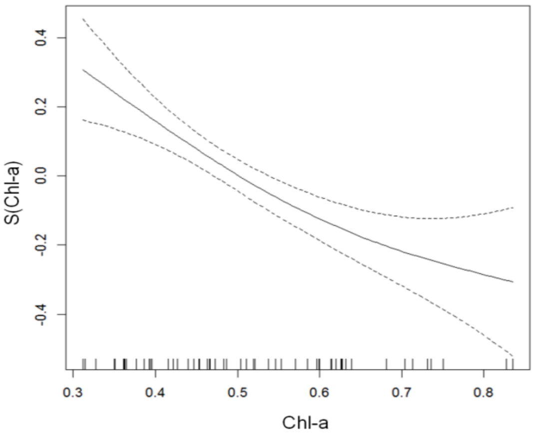


Figure 3. Effect of the 3 oceanographic variables (a) sea-surface-height anomaly (SSHA), (b) sea-surface temperature (SST), and (c) chlorophyll-*a* (Chl-*a*) concentrations—on Eastern Little Tuna catches derived from generalized additive model (GAM) during 2010-2014 (N=61 samples). The x-axis shows the values of the explanatory variables, and the y-axis shows the contribution of the smoother to the fitted values. The tick marks on the horizontal axis represent the values of the observed data points; the thick line indicates the fitted function. Dashed lines represent 95% confidence intervals

4.3 Cross wavelet spectrum analysis (XWT) and Wavelet Coherence (WTC)

In order to clarify the physical characteristics of the seasonal change, we performed the wavelet spectrum analysis. The Cross Wavelet Transform (XWT) finds regions in time frequency space where the time series show high common power. The XWT showed correlations of Eastern Little Tuna catch with SSHA, SST, and Chl-*a* from 2010 until 2014. The XWT signal revealed the interannual signal with the period of 16 months for all parameters (Figure 4). The XWTs between Catch and Chl-*a* indicated correlations within interannual signal of period 16 months during middle of the year of 2011-2014. The XWT between Catch and SST, Catch and SSHA were also showed that there was a strong correlation within seasonal signal of period 4-8 months and interannual signal of 16 months during the year of 2012-2014.

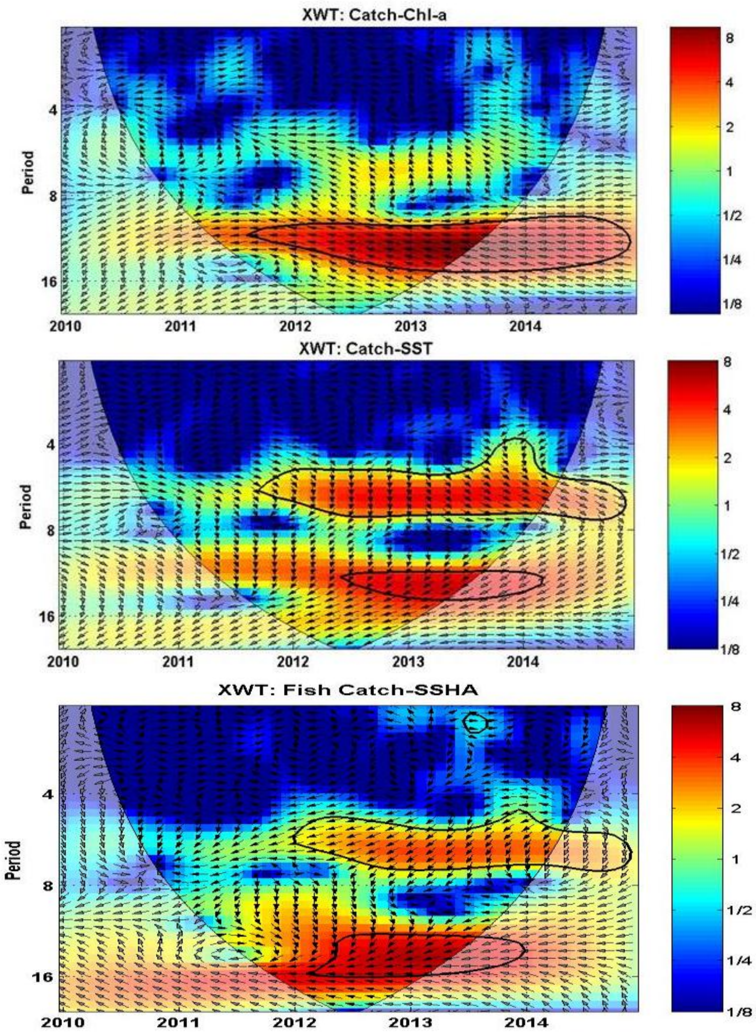


Figure 4. The cross wavelet spectrum (XWT) for Eastern Little Tuna catch in relation to SSHA, SST and Chl-*a* during 2010-2014. The y-axis is represented a period (monthly) and x-axis showed the time (year). Colorbars represented different wavelet amplitude, the black line (solid contour) showed the 95% confidence level and a thin black line showed the cone of influence

The wavelet coherence (WTC) is especially useful in highlighting the time and frequency intervals where two phenomena have a strong interaction. The coherence is defined as the cross-spectrum normalized to an individual power spectrum. It is a number between 0 and 1, and gives a measurement of the cross-correlation between two time-series and a frequency function. If the coherence between two series is high, the arrows in the coherence spectra show the phase between the phenomena: arrows at 0° (horizontal right) indicate that both phenomena are in phase and arrows at 180° (horizontal left) indicating that they are in anti phase. The WTCs between the parameters are shown in Figure 5.

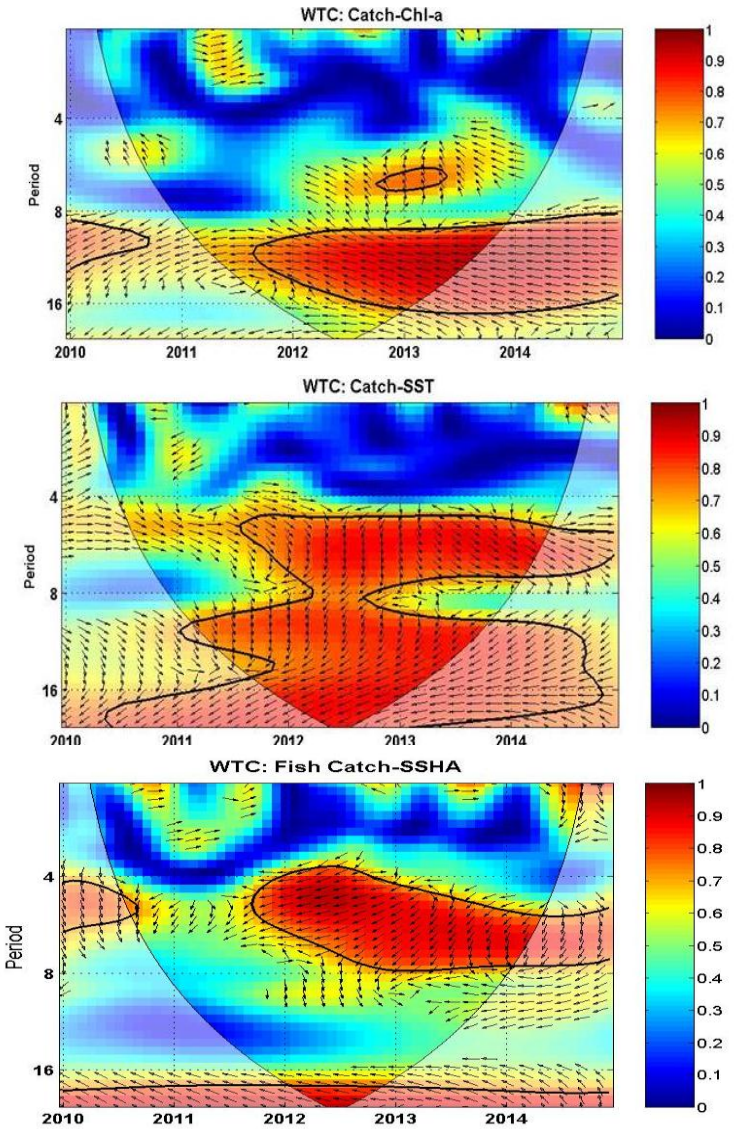


Figure 5. The wavelet coherence (WTC) for Eastern Little Tuna in relation to SSHA, SST and Chl-*a* during 2010-2014. The y-axis is represented a period (monthly) and x-axis showed the time (year). Colorbars represented different wavelet amplitude, the black line (solid contour) showed the 95% confidence level and a thin black line showed the cone of influence

The WTC between Eastern Little Tuna catches and all oceanographic parameters had a coherence of 0.8 (80%) within interannual signal of period 16 months during middle of 2011-2014. The coherence of 0.8 between catches and chl, ssha at the 4 and 16 months frequency in the interval 2012-2014 with tendency, anti phase for catches, SST, Chl-*a*, and SSHA.

The results of XWT indicated that the strong correlation of among catches, Chl-*a*, SST and SSHA within interannual and seasonal pattern were consistent with the strong coherence of 80% from the WTC analysis. This means that all oceanographic parameters have strong correlation with the Eastern Little Tuna catches. Furthermore, the results of GAM and wavelet analysis could be used to identify the correlation among the catches and all oceanographic parameters. The wavelet results emphasize how oceanographic factors influence the Eastern Little Tuna catches and identify the peak catches based on the season changing. This is very important precursor to know when is the best fishing season and the information will be useful for the fisherman and policy maker to reduce risk and to have sustainable fishing management.

5. Conclusion

The present study could identify the favourable oceanographic condition as a habitat preferences for Eastern Little Tuna based on the changing of oceanographic factors. High probabilities of Eastern Little Tuna catch were observed for Chl-*a* concentration ranging from 0.3-0.5 mg.m^{-3}, for SSHA of 0-8 cm and SST values of 28-29°C. Statistical analysis showed very clear relationship between Eastern Little Tuna catches and all oceanographic parameters to seasonal change with most predominant signal in the interannual time scale. The GAM results for the period of 2010-2014 indicated that 3-oceanographic parameter combination models explained the highest deviance (41.4%) in which the Chl-*a* is a more important contributing factor than the other environmental variables (SSHA and SST) in this region. The wavelet coherence confirmed that there were a strong correlation between catches and all parameters (0.8). This information will be useful for the fishermen and policy maker to have sustainable fishing management. We recommend to have further investigations through the use of long-term historical time series to predict fishing ground locations and an emerging need to improve our climate understanding and forecast skill to conserve small pelagic catches.

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References

[1] Pepperell, J 2010 *Fishes of the open ocean*. The University of Chicago Press, Chicago. 75-80 pp

[2] FAO 2017 Species Fact Sheet Euthynnus affinis. Food and Agriculture Organization of the United Nations. FAO Fisheries and Aquaculture Department.

[3] Zainuddin M, Saitoh S, and Saitoh K 2004 Detection of potential fishing ground for albacore tuna using synoptic measurements of ocean color and thermal remote sensing in the northwestern North Pacific. *Geophysical Research Letter*.

[4] Saitoh S, Chassot E, Dwivedi R, Fonteneau A, Kiyofuji H, Kumari B, Kuno M, Matsumura S, Platt T, Raman M, Sathyendranath S, Solanki H, and Takahashi F 2009 Remote sensing applications to fish harvesting. *In* Remote sensing in fisheries and aquaculture. *Reports of the International Ocean-Colour Coordinating Group (IOCCG)*, No. 8 (M.-H. Forget, V. Stuart, and T. Platt, eds.), IOCCG, Dartmouth, Canada. 57–76pp.

[5] Qu, T., Y. Du, J. Strachan, G. Meyers, and J. Slingo 2005 Sea Surface Temperature and Its Variability in the Indonesian Region. *Oceanography*. **18**: 50–123.

[6] Torrence, C., and Compo, G.P 1998 A practical guide to wavelet analysis. *Bulletin of the American Meteorological Society*, **79**: 61-78.

[7] Howell and Kobayashi 2006 El Nino effects in the Palmyra Atoll region: oceanographic changes and bigeye tuna (*Thunnus obesus*) catch rate variability. *Fisheries Oceanography*. **15**: 477-489.

[8] Sabates, A., Martin, P., and Raya, V 2012 Changes in life-history traits in relation to climate change:bluefish (*Pomatomus saltatrix*) in the northwestern Mediterranean. *ICES Journal of Marine Science*, **69**(6): 1000-1009.

[9] Zuur A F, Ieno E N, Walker N J, Saveliev A A, and Smith G M 2009 *Mixed effects models and extensions in ecology with R*. Springer, New York. 574 p.

[10] Wood S N 2006 *Generalized additive models, an introduction with R*. Chapman and Hall, London. 392 p.
[11] Amri K dan Satria F 2013 Impact of climate anomaly on catch composition of neritic tuna in Sunda Strait. Ind. Fish. Res. J, **19**(2):61-72
[12] Chiou W D, Lee, L K 2004 Migration of kawakawa Euthynnus affinis in the waters near Taiwan. Fisheries Science, **76**:746-737
[13] Hidayat T, Febrianti E, Restianingsih, Y H 2016 Pattern and Spawning Season of Kawakawa (*Euthynnus affinis*, Cantor 1850). Bawal, **8**(2):101-108
[14] Syamsuddin M, Saitoh S, Hirawake T, Syamsudin F, and Zainuddin M 2016 Interannual variation of bigeye tuna (Thunnus obesus) hotspots in the eastern Indian Ocan off Java *International Journal Of Remote Sensing*