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# Empirical Cumulative Distribution Function (ECDF) Analysis of *Thunnus.sp* using ARGO Float Sub-surface Multilayer Temperature Data in Indian Ocean South of Java

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**Abstract**

Spatial distribution of tuna *(Thunnus.sp)* in Indian Ocean south of Java has been investigated. Tuna was scientifically known as thermo-conformer species, thus their distribution were strongly influenced by sub-surface temperature. Tuna species in this study comprise of bigeye tuna *(Thunnus obesus),* albacore tuna *(Thunnus alalunga),* yellowfin tuna *(Thunnus albacares)* and southern bluefin tuna *(Thunnus maccoyii).* The study was conducted in the area between 100°E – 127°E and 7°S – 20°S during 2013 covering of southeast monsoon (April – September) and northwest monsoon (October – March) data. About 1200 coordinate of ARGO Float data and actual catch of tuna from fishing fleet in the same day were processed to obtain the polynomial equation and correlation coefficient. ARGO Float data were processed using kriging method. Correlation coefficient method that used in the study was Empirical Cumulative Distribution Function (ECDF), while spatial distribution equation was developed by polynomial regression equation. Sub-surface temperature in Indian Ocean south of Java fluctuates seasonally. Temporal distribution of dataset indicates that sub-surface temperature was warmer in northwest monsoon than in southeast monsoon. Seasonal fluctuation of sub-surface temperature may vary due to occurrence of upwelling. *T. alalunga, T. Albacares* and *T. Obesus* were found to be more favour in the depth around 150m with optimum temperature between 16°C – 21°C, while *T. maccoyii* were found in the dept around 250m with optimum temperature between 13°C – 16°C. Potential fishing zone for *Thunnus.sp* in southeast monsoon was wider than in northwest monsoon. This condition was according to seasonal variability of sub-surface temperature.



**Keywords:** Tuna *(Thunnus.sp)*. ARGO Float, sub-surface temperature, empirical cumulative distribution function (ECDF), Indian Ocean


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## 1. Introduction

Tuna *(Thunnus.sp)* is the most important fishery resources targeted by fishermen from various countries including Indonesia [1]. This condition is due to its very high economic value in the world market. Tuna is also an important food source in the world. Production of tuna in Indian Ocean has increased [2]. Increase of tuna production began in the early 80s where total catch of yellowfin tuna was about 50,000 tonnes per year and has reached about 350,000 tons per year in the late 90s. Big eye tuna production in the early 80s was about 20,000 tons per year and has reached about 140,000 tons per year in the 90s [3]. Total catch of tuna landed in Benoa fishing port in 2005 was about 14.000 tons and increased to about 18.000 tons in 2009. Highest number of tuna that landed at Benoa fishing port was big eye tuna *(T. obesus)* followed by yellowfin tuna *(T. albacares),* albacore tuna *(T. alalunga)* and southern bluefin tuna *(T. maccoyii)*[4].

Sub-surface temperatures in Indian Ocean can influence the distribution of tuna. The importance of sub-surface temperature is due to the fact that it can be used as an indicator of the existence of water movement either vertically and horizontally which carries nutrients. Changes in nutrient concentrations will affect the fertility of water, so it will affect the distribution of tuna [5]. Furthermore [6] examined the spatial distribution of tuna in the Indian Ocean and its relationship with the sea water temperature profile vertically and horizontally. Tuna was generally found at the depth around 150m. [7], stated that *T. maccoyii* has the ability to maintain body temperature remained warm even in the cooler waters.

Another study on the distribution of tuna was performed by [8], which was used the data of sea surface temperature and chlorophyll-a concentration from Aqua-MODIS satellite. Preparation of the prediction map of the potential fishing zone is done by using a statistical method based on knowledge-based expert systems. The results had showed the accuracy of the prediction map is more than 80%. [9], revealed that that spatial distribution of tuna was influenced by oceanographic parameter. Remote sensing dataset was used to formulate predicted potential fishing zones, especially tuna in the Gulf of Bone-Flores sea. Variables used in the study were sea surface temperature, current speed and chlorophyll-a. Generalized additive models (GAM) was used to determine the correlation between oceanographic variables with actual catches of tuna .[10], examined spatial distribution of tuna using sea surface temperature, sea surface height anomaly and chlorophyll-a concentrations. The data were then correlated with actual tuna catches data. The method used is the EOF and GAM. The results of the study were revealed that some specific oceanographic parameters influence spatial distribution of tuna.

Several tuna of *Scombridae* family found in the Indian Ocean are yellowfin tuna *(T. albacares)*, bigeye tuna *(T. obesus)*, albacore *(T. alalunga)*, and southern bluefin tuna *(T. maccoyii)* [11]. Analysis of tuna spatial distribution based on oceanographic characteristics can be done by various methods. One method that based on spatial data analysis is empirical cumulative distribution function (ECDF). [12], determined the oceanographic conditions that correspond to the presence of yellowfin tuna *(T. albacares)* in the waters around Sri Lanka using ECDF method. The same method was also used by [13], to see the correlation between the presences of skipjack tuna with oceanographic conditions using satellite data.

Determination of tuna spatial distribution in Indian Ocean south of Java is important to develop algorithm for tuna spatial distribution. This information will improve the effectiveness and efficiency of tuna catch operational. Development of dynamic map of potential fishing zone based on algorithm will give usefull information for fishermen and stakeholder.

Aims of the research were : (1) to built database of sub-surface temperature spatial distribution both vertical and horizontal, using ARGO Float data analysis during northwest and southeast monsoon in Indian Ocean south of Java, (2) to built spatial and temporal database of *Thunnus.sp* based on actual catch data from Benoa and Cilacap fising port, (3) to built algorithm for tuna spatial distribution based on actual data catch and sub-surface temperature .

## 2. Material and Methods

Material used in the study were : (1) Actual catch of *Thunnus. sp* comprise of *T. albacares*, *T. obesus*, *T. alalunga*, and *T. maccoyii* from fishing fleet with permission from Benoa and Cilacap Fishing port in 2013. About 1200 coordinates of data had collected during northwest monsoon (October – March) and southeast monsoon (April – September). (2) Sub-surface temperature of ARGO Float data in the depth around 50m, 100m, 150m, 200m and 250m in Indian Ocean south of Java during 2013, coverage area between 100$^{o}$E - 127$^{o}$E and 7$^{o}$S - 20$^{o}$S. ARGO Float data was obtained from ARGO data center (GODAE webserver) http://www.usgodae.org/cgi-bin/argo_select.pl.

ARGO Float data was processed using Hartoko procedure [6]. Data was extracted using WinRAR and was displayed using ODV (Ocean Data View) and then was stored in ASCII format. Microsoft excel software was used to convert data format. Spatial interpolation was conducted using ER Mapper 7.0 to build sub-surface temperature .

Sub-surface temperature data that has been generated from the initial processing, was extracted according to the fishing ground based on actual data catch and then analyzed using empirical cumulative distribution function (ECDF).

ECDF analysis was carried out by applying three main steps [14], [13], with the governing system of equations can be written as follows :

$$f(t) = 1/n \times \sum l(x_i) \quad (1)$$

$$l(x_i) = 1 \; if \; x_i \leq t \quad \text{, 0 otherwise}$$

$$g(t) = 1/n \times (\sum (y_i / \bar{y}) \times l(x_i)) \quad (2)$$

$$D(t) = \max |f(t) - g(t)| \quad (3)$$

where *f (t)* : empirical cumulative frequency distribution function, *t* : depth , *n* is the number of fishing ground, *l (xi)* : function indication, *xi*: value of sub-surface temperature extracted from fishing ground at any point, *g(t)* : catch-weighted cumulative distribution function, *yi*: hook rate at every point of fishing ground. *D (t)*: the absolute value of the difference between the curve *f (t)* and *g (t )* at any point *t*

Polynomial regression was used to develop algorithm of tuna spatian distribution based on sub-surface temperature [15]:

$$y = a_0 + a_1 x + a_2 x^2 \quad (4)$$

where *y* : potential value of fishing zone, *a* : constant, *x* : sub-surface temperature at specific depth or max *D (t)* from previous step.

## 3. Result and Discussion

### 3.1 Sub-surface Temperature

Sub-surface sea water temperature built from ARGO Float data at the depth around 50m, 100m, 150m, 200m and 250m with kriging method. interpolation was divided into northwest monsoon in October to March and southeast monsoon in April to September, as presented in **Fig.1** Sub-surface temperature in Indian Ocean south of Java fluctuates seasonally. Monthly average of sub-surface temperature was found tend to vary from January to december . Temporal distribution of dataset indicates that sub-surface temperature was warmer in northwest monsoon than in southeast monsoon. The range of sub-surface temperature during northwest monsoon in the dept around 50m was about 27$^o$C, while in southeast monsoon was about 26.1$^o$C. Vertical distribution analysis shows the profile of Sub-surface temperature. Warm temperature was recorded in the upper layer, while cooler temperature was recorded in deeper layer. Increase of sub-surface temperature was started in October and reached maximum value in February or March. Lowest temperature was occured in August or September. This result was in accordance with opinion of [16] ,who had stated that sub-surface temperature in Indian Ocean was influenced by monsoon. [6] , also explained that sub-surface temperature in northwest monsoon was warmer than in southeast monsoon.

Seasonal fluctuation of sub-surface temperature may vary due to occurrence of upwelling in Indian Ocean south of Java , based on research of [17], who had reported that during southeast monsoon, upwelling occurs in Indian Ocean south of Java as a result of the strong winds, so that sub-surface temperature becomes colder. [18], was also explained that Indian Ocean south of Java was Characterized by occurence of upwelling and downwelling. upwelling will bring more nutrients to the upper layer, while downwelling will bring chlorophyll-a to the deeper layer.

Ocean phenomenon that has a strong influence on the oceanographic characteristics in the Indian Ocean south of Java is the Indian Ocean Dipole Mode (IOD) [19]. IOD is an oceanographic phenomenon that occurs in the Indian Ocean which is characterized by extreme sea temperature anomalies that has influence on weather and climate in the world. Influence of IOD leads to changes in oceanographic conditions. This conditions will affect spatial distribution of tuna due to a change in favorable condition for tuna which is a potential fishing zone [10].

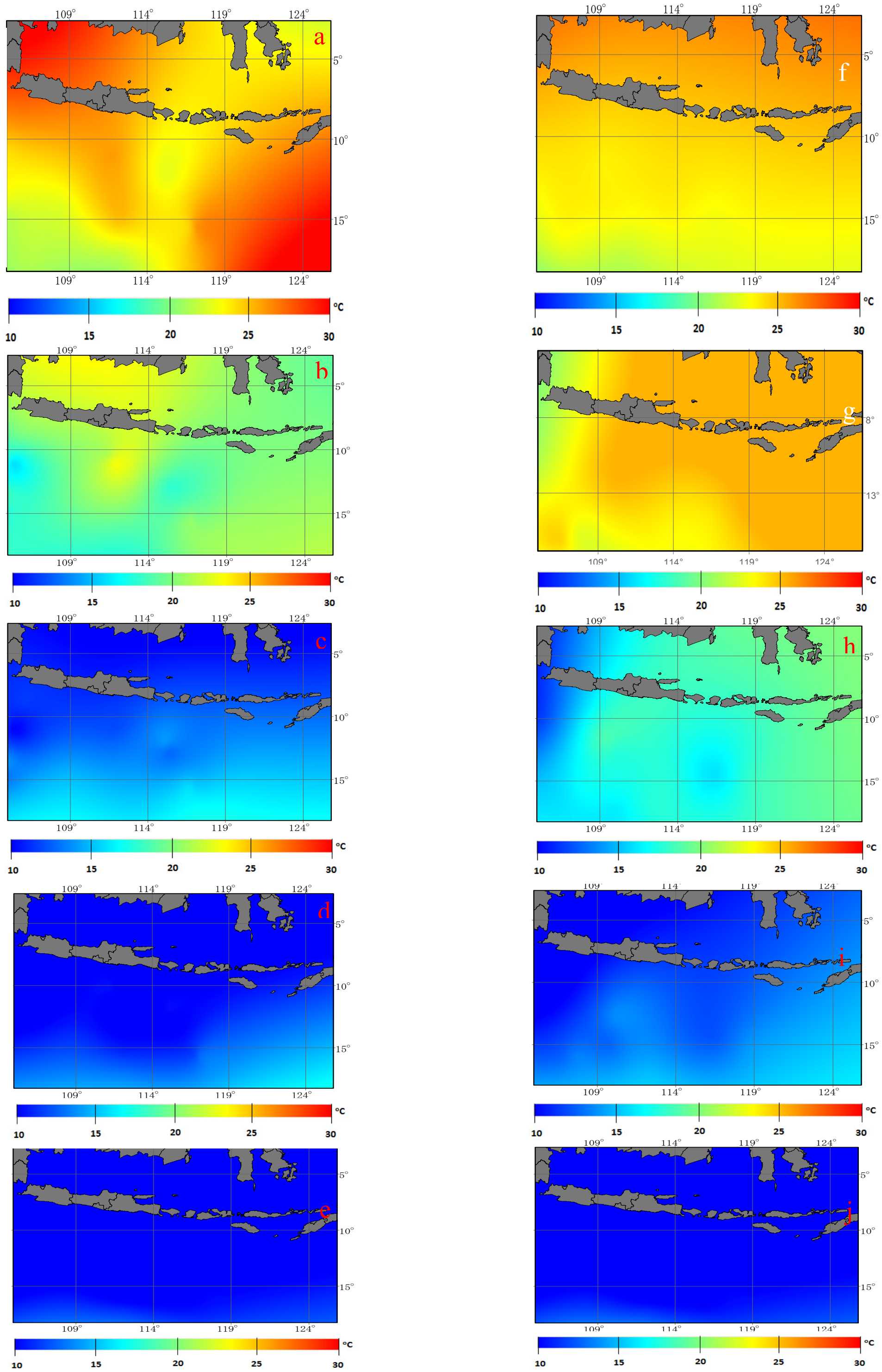

**Fig. 1.** Sub-surface temperatures during northwest monsoon in the depth around 50m (a), 100m (b), 150m (c), 200m (d) and 250m (e) and during southeast monsoon in the depth around 50m (f), 100m (g), 150m (h), 200m (i) and 250m (j) (Processed ARGO Float data using spatial interpolation method)

### 3.2 Spatial Distribution of *Thunnus.sp*

Spatial distribution of tuna was analyzed based on empirical cumulative distribution function (ECDF) as presented in **Fig.2**. When values of *D*(t) had obtained, then further analysis was carried out using polynomial regression method as presented in **Fig.3.**

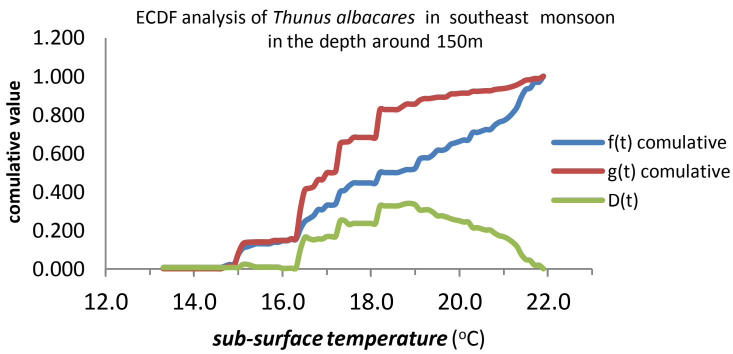


**Fig. 2.** ECDF analysis of *T. albacares* in southeast monsoon in the depth around 150m (Processed actual catch and sub-surface temperature of ARGO Float using ECDF analysis)

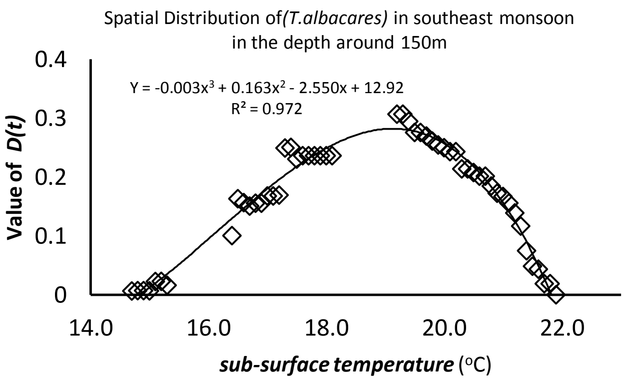


**Fig. 3.** Spatial distribution analysis of *T. albacares* in southeast monsoon in the depth around 150m (Processed *D(t)* value from ECDF analysis using polynomial regression analysis)

Considering to the seasonal differences of the sub-surface temperature, then the analysis of tuna spatial distribution was grouped into two main event, that are southeast monsoon (April – September) and northwest monsoon ( October – March). Algorithm based on polynomial regression equation of tuna were presented in **Table. 1**. and **Table. 2**. Result of vertical distribution analysis shows that *T. albacares*, *T. Obesus* and *T. Alalunga* were found mostly in the dept around 150m with optimum temperature generally between 16°C - 21°C, while *T. Maccoyii* was found in the depth around 250m with optimum temperature between 13°C - 16°C.

*T. Obesus* was found in the dept around 150m with optimum temperature between 17°C - 21°C. This result was similar with [6],who had revealed that several tuna belongs to family of Scrombidae especially *T. Obesus* were found to be more favour in the dept of around 150m. [20] explained that *T. Obesus* was distributed in tropical waters between 10° N to 15° S. The spatial distribution of *T. Obesus* was strongly influenced by temperature. This study was revealed that the change of sub-surface temperature was influenced spatial distribution of *T. Obesus.*

Since water temperature in Indian Ocean south of Java was influenced by Indian Ocean Dipole Mode (IOD),[19] [21] [22] , thus spatial distribution of *T. Obesus* was also influenced by IOD , [23].

**Table. 1**. Spatial distribution algorithm of tuna during southeast monsoon.

| Depth (m) | Algoritm | $R^2$ | Temp range (°C) |
|---|---|---|---|
| | ***T. albacares*** | | |
| 50 | $P = -0.006t^2 + 0.377\,t - 5.104$ | 0.319 | 27 – 29 |
| 100 | $P = -0.029\,t^2 + 1.430\,t - 16.96$ | 0.840 | 23 – 25 |
| **150** | $\mathbf{P = -0.003t^3 + 0.163t^2 - 2.550t + 12.92}$ | **0.972** | **18 – 21** |
| 200 | $P = -0.038t^2 + 1.222t - 9.401$ | 0.845 | 15 – 17 |
| 250 | $P = -0.038t^2 + 1.035t - 6.778$ | 0.960 | 13 – 15 |
| | ***T. obesus*** | | |
| 50 | $P = -0.022t^2 + 1.256t - 17.44$ | 0.718 | 27 – 29 |
| 100 | $P = -0.008t^2 + 0.408t - 4.885$ | 0.640 | 23 – 25 |
| **150** | $\mathbf{P = -0.002t^3 + 0.139t^2 - 2.512t + 14.99}$ | **0.856** | **19 – 21** |
| 200 | $P = -0.0005t^2 - 0.000t + 0.016$ | 0.005 | 15 – 19 |
| 250 | $P = -0.001t^3 + 0.073t^2 - 0.935t + 3.935$ | 0.614 | 13 – 15 |
| | ***T. maccoyii*** | | |
| 50 | $P = -0.036t^2 + 2.054t - 28.6$ | 0.828 | 27 – 29 |
| 100 | $P = -0.013t^2 + 0.642t - 7.707$ | 0.917 | 23 – 25 |
| 150 | $P = -0.06t^2 + 2.386t - 23.63$ | 0.672 | 19 – 21 |
| 200 | $P = -0.002t^2 + 0.078t - 0.615$ | 0.434 | 15 – 17 |
| **250** | $\mathbf{P = -0.008t^2 + 0.237t - 1.635}$ | **0.865** | **13 - 15** |
| | ***T. alalunga*** | | |
| 50 | $P = -0.053t^2 + 2.927t - 40.24$ | 0.712 | 27 – 28 |
| 100 | $P = -0.026t^2 + 1.309t - 15.96$ | 0.706 | 24 – 26 |
| **150** | $\mathbf{P = -0.004t^3 + 0.234t^2 - 4.179t + 24.63}$ | **0.720** | **19 – 21** |
| 200 | $P = -0.012t^2 + 0.385t - 2.791$ | 0.632 | 15 – 16 |
| 250 | $P = -0.022t^2 + 0.649t - 4.469$ | 0.809 | 13 – 15 |

Note : $P$ = Potential fishing zone, scale (0 – 100 %) ; $t$ = sub-surface temperature (°C) of specific depth

Based on spatial distribution analysis as presented in **Table. 1** and **Table. 2**, *T. Alalunga* were found in the depth around 150m with optimum temperature between 17°C – 21°C. This result was almost similar with [24], who was mentioned that spatial distribution of mature *T. Alalunga* was correlated with sub-surface temperature in the depth around 100m. *T. Alalunga* scientifically known as temperate tuna [6]. These species were a highly migratory tuna because of his ability in thermoregulation and metabolism. Their spatial distribution was influenced by sea water temperature. They were found in wide area around 5°N – 25°S [25], while other oceanographic condition such as sea surface temperature, chlorophyll concentration and surface salinity will only influenced immature *T. Alalunga* .

[12] stated that spatial distribution of *T. albacares* was corellated with oceanographic condition such as sea surface temperature, chlorophyll-a concentration and sea surface height. Migratory pathway is important to predict the habitat of this species. Based on spatial distribution analysis in this study , *T. Albacares* were found in the dept around 150m with optimum temperature between16°C – 21°C.

[7] mentioned that *T. maccoyii* have a larger size compare with other tuna species. They have the ability to maintain their body temperature remains warm in cooler water temperature. Result of this study reveal that *T. Maccoyii* were distributed in the depth around 250m with optimum temperature between 13°C – 16°C.

**Table. 2**. Spatial distribution algorithm of tuna during nortwest monsoon.

| Depth (m) | Algoritm | $R^2$ | Temp range (°C) |
|---|---|---|---|
| | ***T. albacares*** | | |
| 50 | $P = -0.008t^3 + 0.666t^2 - 17.86t + 159.1$ | 0.862 | 27 – 29 |
| 100 | $P = -0.003t^2 + 0.175t - 1.917$ | 0.767 | 22 – 24 |
| **150** | $\mathbf{P = 0.006t^3 - 0.354t^2 + 6.449t - 38.83}$ | **0.807** | **16 – 18** |
| 200 | $P = -0.003t^4 + 0.190t^3 - 4.318t^2 +43.22x - 161.3$ | 0.682 | 14 – 16 |
| 250 | $P = -0.008t^2 + 0.206t - 1.279$ | 0.843 | 12 – 14 |
| | ***T. obesus*** | | |
| 50 | $P = -0.025t^2 + 1.451t - 20.51$ | 0.953 | 28 – 29 |
| 100 | $P = -0.002t^2 + 0.091t - 0.94$ | 0.239 | 20 – 22 |
| **150** | $\mathbf{P = -0.000t^4 + 0.023t^3 - 0.579t^2 + 6.209t - 24.87}$ | **0.731** | **17 – 19** |
| 200 | $P = -0.012t^2 + 0.411t - 3.229$ | 0.794 | 15 – 17 |
| 250 | $P = -0.002t^4 + 0.096t^3 - 1.725t^2 +13.57t - 39.77$ | 0.827 | 13 – 15 |
| | ***T. maccoyii*** | | |
| 50 | $P = 0.007t^3 - 0.569t^2 + 15.41t - 138.1$ | 0.89 | 24 – 26 |
| 100 | $P = 0.001t^3 - 0.083t^2 + 1.982t - 15.407$ | 0.44 | 21 – 23 |
| 150 | $P = -0.008t^2 + 0.307t - 2.727$ | 0.86 | 17 – 19 |
| 200 | $P = -0.001t^4 + 0.070t^3 - 1.475t^2 + 13.64t - 46.91$ | 0.92 | 16 – 19 |
| **250** | $\mathbf{P = -0.002t^3 + 0.098t^2 - 1.102t + 3.818}$ | **0.93** | **14 – 16** |
| | ***T. alalunga*** | | |
| 50 | $P = -0.011t^2 + 0.627t - 8.532$ | 0.641 | 26 – 28 |
| 100 | $P = 0.000t^3 - 0.024t^2 + 0.587t - 4.586$ | 0.206 | 22 – 25 |
| **150** | $\mathbf{P = -0.014t^2 + 0.508t - 4.369}$ | **0.828** | **17 - 18** |
| 200 | $P = -0.001t^2 + 0.039t - 0.00$ | 0.049 | 14 – 15 |
| 250 | $P = -0.009t^2 + 0.248t - 1.534$ | 0.70 | 12 – 14 |

Note : $P$ = Potential fishing zone, scale (0 – 100 %) ; $t$ = sub-surface temperature (°C) of specific depth

Spatial distribution patern of tuna in 2013 during southeast monsoon and northwest monsoon were presented in **Fig. 4**. Predicted potential fishing zone with actual catch data shows a similar spatial distribution. Potential fishing zone in southeast monsoon was wider than in northwest monsooon. This condition was according to seasonal variability sub-surface temperature [16] . Wide area of potential fishing zone indicates that monsoon sub-surface temperature during southeast was more favorable for tuna than during northwest monsoon.

In southeast monsoon potential fishing zone was closer to the shoreline of Java, while in northwest monsoon was move southward to the location near 13°S. This condition was due to occurence of upwelling [17], that make sub-surface temperature near shoreline of Java during southeast monsoon was more favorable for tuna.

Each species of tuna has a different spatial distribution patern as shown in **Fig. 4**. This indicates that they have a specific favorable temperature range. The distribution of tuna is strongly influenced by sea water circulation and stratification, particularly sub-surface temperatures. Change in sea water temperature even only 0.3°C will affect metabolic activity and spatial distribution of tuna since tuna was scientifically known as thermo-conformer species. Data used in the study was ARGO Float data. Sub-surface temperature obtained from spatial interpolation was used to analyze the distribution of tuna. The study explained that tuna fishing decreased in March and July but increased in May and December [6]. Coordinate point of actual catch shows relatively similar with predicted potential fishing zone. This study suggest that the use of spatial distribution algorithm for development of predicted potential fishing zone will give usefull information to fisherman and stakeholder.

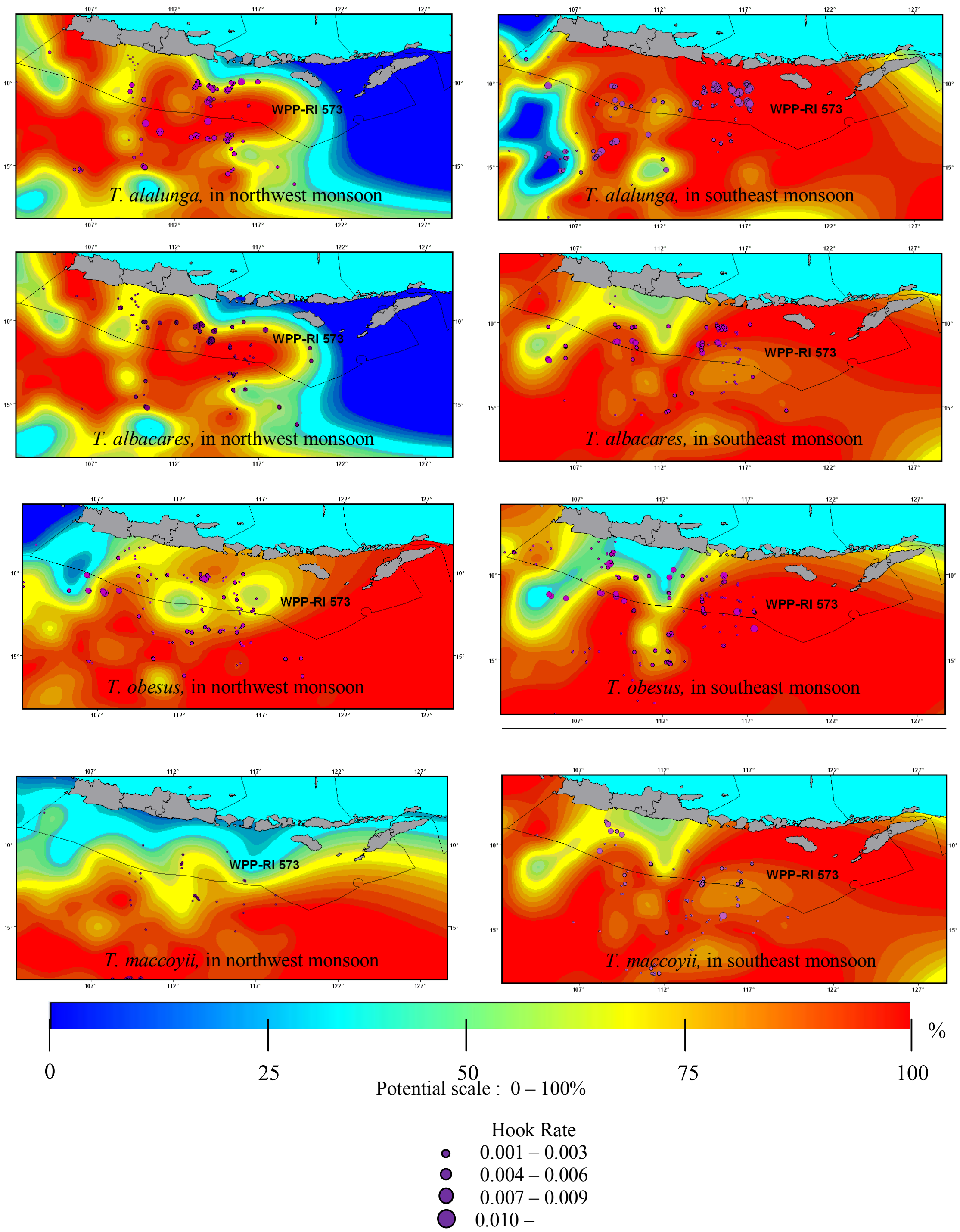


**Fig. 4.** Spatial distribution patern of tuna during 2013 overlied with actual catch (Processed sub-surface temperature using spatial distribution algorithm)

## 4. Conclusion

Sub-surface temperature in Indian Ocean south of Java fluctuates seasonally. Temporal distribution of dataset indicates that sub-surface temperature was warmer in northwest monsoon than in southeast monsoon. Warm temperature was recorded in the upper layer, while cooler temperature was recorded in deeper layer. Increase of sub-surface temperature was started in October and reached maximum value in February or March. Lowest temperature was occured in August or September. Seasonal fluctuation of sub-surface temperature may vary due to occurrence of upwelling.

Spatial distribution of *Thunnus. sp* were correlated with sub-surface temperature. *T. alalunga, T. Albacares* and *T. Obesus* were found to be more favour in the depth around 150m with optimum temperature between 16°C – 21°C, while *T. maccoyii* were found to be more favour in the dept around 250m with optimum temperature between 13°C – 16°C.

Potential fishing zone for *Thunnus. sp* in southeast monsoon was wider than in northwest monsoon. This condition was according to seasonal variability of sub-surface temperature. Wide area of potential fishing zone indicates that monsoon sub-surface temperature during southeast was more favorable for tuna than during northwest monsoon.

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