

Original Paper

## SPATIAL DISTRIBUTION OF *Thunnus.sp*, VERTICAL AND HORIZONTAL SUB-SURFACE MULTILAYER TEMPERATURE PROFILES OF IN-SITU AGRO FLOAT DATA IN INDIAN OCEAN.

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### ABSTRACT

*The study was the first ever attempt in fisheries oceanography sciences to explore the empiric correlation between the spatial distribution of tuna (*Thunnus.sp*) and sub-surface in-situ temperature data. By means of optimization and use of an in-situ data of both vertical and horizontal which will be processed into a multilayer subsurface seawater temperature of ARGO Float in Indian ocean. So far only sea surface temperature (with temperature around 29 °C) data were used to look for the correlation for tuna spatial distribution, while the *Thunnus.sp* swimming layer as widely known is in about 80 – 250m depth with seawater temperature between 15 – 23 °C. The noble character of ARGO Float data is as in-situ data recorded directly by the sensors, transmitted to the satellite, transmitted to the ground station and ready to be used by researcher all over the world. In the study, about 216 seawater temperature coordinates of ARGO Float and actual tuna catch data in the same day were used to represent the dry season (April – November 2007) analysis, and about 90 data were used for the rainy season (December – March 2007). The actual tuna catch and its coordinates data were collected with permission from PT. Perikanan Samudra Besar, (PT.PSB) Benoa – Bali Indonesia. Then both seawater temperature and tuna data were processed using a Krigging method or spatial interpolation method. Based on a monthly actual tuna production by fishing fleet of PT.PSB operated in Indian Ocean indicates that there were two cycles of low catch in March and July and high catch in May and December 2007. In general, seawater temperature in depth of 80m, 100m, 150m and 200m of the dry season was 2 °C warmer than those of the rainy season. Range of seawater temperature will decrease due to the water depth, range of seawater temperature at depth of 150m was between 14 – 22 °C and at depth of 200m between 12 – 20 °C. Based on the regression and correlation between tuna catch and seawater temperature revealed that seawater temperature at depth 150m has the highest coefficient of correlation than to the seawater temperature at depth 100m and 200m.*

**Key words** : spatial distribution; subsurface seawater temperature; *Thunnus.Sp*; Indian ocean

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### INTRODUCTION

Joint research of Marine and Fisheries Research Agency - Ministry of Marine and Fisheries or (BRKP) and Indonesian Institute of Science (LIPI), potential marine fish resources of Indonesia was estimated 6.410 million ton/year. Consist of Indonesian territorial water with about 4.625 million ton/year and EEZ (*highseas*) water about 1.785 million ton/year. Since Indonesian government policy in managing of the fish resources based on *precautionary approach*, then the 'allowable fish catch' was limited to 80% out of the total

resources or about 5.1 million ton/year (Barani *vide* Budiono, A, 2004). The exploitation in the south Java EEZ seawater was regarded as under-exploited (Wiadnya *et. al.*, 2001). In a whole the exploitation level in Indian ocean is about 59.42% of the national resources. That is why for the coming years the development of fisheries resources use would be based upon spatial approach, with consideration to its resources potential and oceanographic characters (DKP, 2001).

A suitable fishing ground was regarded where there was a reasonable amount of targeted fish, or regarded as the schooling point of the targeted fish. In which its oceanographic conditions and from the economic point of view is suitable for fishing operation. In a fishing industry, availability of suitable fishing gears, adequate fisherman skills and know how, long experience of understanding an ideal area as a fishing ground is a vital aspect in supporting the fish production. To consider an area in the sea as a good fishing ground, some oceanographic parameters should take into account, that are physical, chemical and biological characteristic such as seawater temperature, thermocline depth, salinity, primary productivity, plankton abundance, seasonal current pattern, as well as the targeted fish characters.

The development and progress in science and technology, there was an increasing tendency for scientist and government institutions to use Geographic Information System as a tool for 'decisive making' in managing fisheries resources with 'precautionary approach' is getting more important. In order to gain an optimum use of fish resources in responsible manner. There were two main approach in order to know the oceanographic characters of the sea, that is direct and indirect approach. Direct approach is a conventional method by means of in-situ measurement, while an indirect approach is using remote sensing technology. A comprehensive information and database of the fishing ground is important in a fishing operation and for fishing fleet, in order to set out the exact location in a such wide of high seas, which fishing ground should be well planned and in turn will minimize the fishing cost (Hartoko, et al., 2000; Hartoko and Helmi, 2004).

Colaboration of Marine and Fisheries Research Agency - Ministry of Marine and Fisheries, Marine Fisheries Research Center or BRKP with the Australian government, specifically CSIRO had agreed to deploy a number of "Robotic/Autonomous Profilling Floats" or known as Argo Float in Indian ocean. Argo float is an instrument moving in the seawater column along with the underwater current and recording the seawater temperature up to 2000 m depth in many locations (vertical and horizontal movement). By this method, monitoring of seawater temperature, salinity, depth and current velocity and pattern can be

done continuously and those collected data would be transmitted to the base station then distributed for users. Argo Float can be dropped from an airplane or ships into the ocean and slowly it will submerge in the seawater up to 2000 meter depth or known as "parking depth" in 6 hours with 10 cm/s velocity. Then Argo Float will moving horizontally in the seawater for 9 days along with the existing current directions. Argo float will move upwards towards the surface water gradually with its oil pressure regulation in the cylinder. The oil would be pumped from internal reservoir and by moving the external bladder or pneumatik sac mechanism. Measurement of vertical temperature and salinity would be done in a set of depth interval then stored in its data logger simultaneously ([www.argo.ucsd.edu](http://www.argo.ucsd.edu)).

Any change in seawater temperature can cause the generation of seawater circulation and stratification, which in turn will directly or indirectly affect to the spatial distribution of the fish or marine organism. Fish will tend to look for a certain seawater temperature so that they can live favourably. Their metabolism activity and spatial distribution is believed to be affected by the seawater changes, and very sensitive even to only 0.3°C seawater changes. Seawater temperature fluctuation and its movement were found as an important factors in promoting fish aggregation and thus a fishing ground (Laevastu dan Hayes, 1981). An overview and analysis in this study is focusing to the use of both seawater temperature profile and depth data of Argo Float which will be correlated to the spatial distribution of the actual *Thunnus.sp* catch based on the *Dynamic Mapping* concept (Hartoko, 2000) during dry and rainy monsoon in Indian ocean, especially in south Java.

Aims of the research were : (1) to built database and analysis of seawater temperature, both vertical and horizontal profile, using *ARGO Float* during the west and east season in Indian ocean, (2) to built database and spatial distribution of *Thunnus.sp* based on the actual catch data from PT. Perikanan Samudra Besar, (PT. PSB) Benoa, Bali during the west and east season in Indian ocean, (3) to explore and conduct regression and correlation analysis between the seawater temperature and actual *Thunnus.sp* spatial distribution.

## MATERIAL AND METHODS

The fundamental scientific concept to be applied in the study is *Dynamic Mapping*, that is building spatial database variabel data *spatial-temporal*, according to seasonal pattern (dry and rainy season) and exploring any specific ecosystem variabels as well as spectral specific (Hartoko, 2000; Hartoko and Helmi, 2004). Material used in the study were : (1) Actual *Thunnus.sp* catch specifiend to the east and west season from PT. PSB Benoa, Bali in Indian ocean, in 2007; (2) Sea surface and 80 m, 100 m, 150 m and 200 m temperature of *Argo Float* data in Indian ocean *coverege area* between  $8^{\circ} - 18^{\circ} S$  and  $100^{\circ} - 118^{\circ} E$  [http://www.usgodae.org/cgi-bin/argo\\_select.pl](http://www.usgodae.org/cgi-bin/argo_select.pl). (A) **Argo Float Data**, was processed using Hartoko procedure (Hartoko,2010a, *in press*). Software used in the study were : ER.Mapper 6.4 to built horizontal sub-surface seawater temperature layer with Kriging method (spatial interpolation method). WinRar and *Ocean Data View* (ODV) 4.1.3 Software to extract seawater temperature data of *Argo Float*. (a). Data downloaded from Argo Data Center (GODAE *Webserver*) : [http://www.usgodae.org/cgibin/argo\\_select.pl](http://www.usgodae.org/cgibin/argo_select.pl) ; (b). Data Extraction, using WinRar software; Extracted data then opened, read and displayed using ODV (*Ocean Data View*) software and then saved in a ".txt" file format; and finally opened using Microsoft Excel *software* in a table format. Followed by *Kriging* steps in ER Mapper *software* in order to convert from points (coordinates) into a spatial layer data. (B). **Actual *Thunnus.sp* catch data**. The actual *Thunnus.sp* catch data was compilled from *Log-book* of each Tuna fishing vessels from PT. PSB Benoa, Bali and splitted into two season, that is the dry season (April - November) and rainy season (December - March) in a table format in a Microsoft Excel, then saved into a .txt format file for the input process in the Kriging of Er- Mapper *software*. Fishing gear used was *Deepsea Tuna Long Liner*. In standard form, each Long Line unit consist of 15 main long line and 14 hook-eye, 1 float and 1 float-rope. Curve coeficient of the tuna long-line was set at 0.70 and thus the distance of one float to the next was :  $0.70 \times 15 \times 50 \text{ m} = 525 \text{ m}$ , and the hook reach to the depth between 85 m up to 277 m. (C).

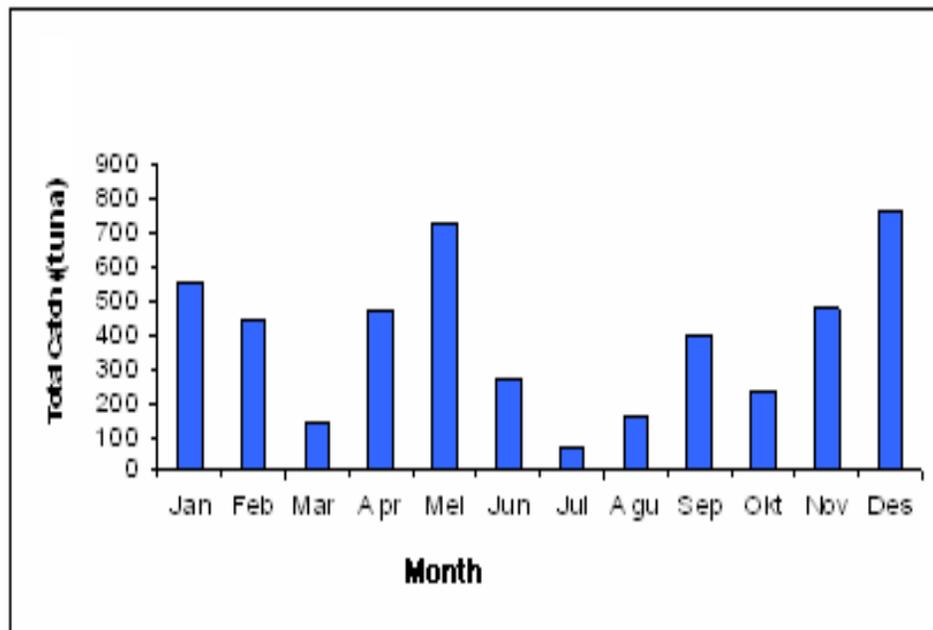
**Statistic Analysis (Regression and Corelation)**. The corelation method was employed in order to analize the close relationship of two variabels. The analysis will not take into account any dependent and independent variables. All studied variables were regarded as independent variable and the procedure based on the probability distribution go along with other variable (bivariate distribution for two variables). The dry and rainy season of tuna (*Thunnus.sp*) data was firstly tested with Normality Test for its normal distribution, followed by data transformation for a non normal distributed data, then a regression and correlation test, followed by F-Test and T-Test.

## RESULT AND DISCUSSION

Several tuna belongs to family of Scombridae are *Thunnus alalunga* (Albacore), *Thunnus albacores* (Yellowfin tuna), *Thunnus macoyii* (Southern Bluefin tuna), *Thunnus obesus* (Big eye tuna) and *Thunnus tongkol* (Longtail tuna). Unlike with other fish species that has a white flesh meat color, the group of *Thunnus.sp* has a reddish flesh meat color, this is since tuna flesh meat has more myoglobine content. Tuna as widely known as a fast swimming fish and a highly migratory species. Hela dan Laevastu. (1970); Marpaung. (2001) explained that big-eye tuna can be found in both tropical and sub-tropical waters such as in Atlantic, Indian and Pacific ocean. These species enjoy very much in seawater temperature range of  $13^{\circ} - 23^{\circ} C$ , and optimum seawater temperature between  $17^{\circ} - 22^{\circ} C$ . Their vertical distribution may vary due to a seasonal changes and depth of *thermocline layer*. They belongs to a *poikilothermic* or a thermo-conformer group of fish. High hook-rate (HR) of big-eye tuna in Indonesia was found in Banda and Arafura sea, north Sulawesi, north Papua, Mollucas and Tomini bay with 0.66; 0.58; 0.56; 0.41 respectively. Highest of HR was found in south Java Indian ocean (0.95), followed by south Bali-Nusatenggara (0.83) and west Sumatera (0.63). Wyrтки (1961) and Uktolseja *et. al* (1998) suggest that south Java and Nusa Tenggara (Sumbawa - Timor) known as the upwelling zone.

With occurrence of up-welling will increase the depth of the thermocline layer up to about 50m depth approaching to the surface water. Furthermore, he suggests that the HR of big-eye tuna (*Thunnus obesus*) is bigger than those of *Thunnus albacares*.

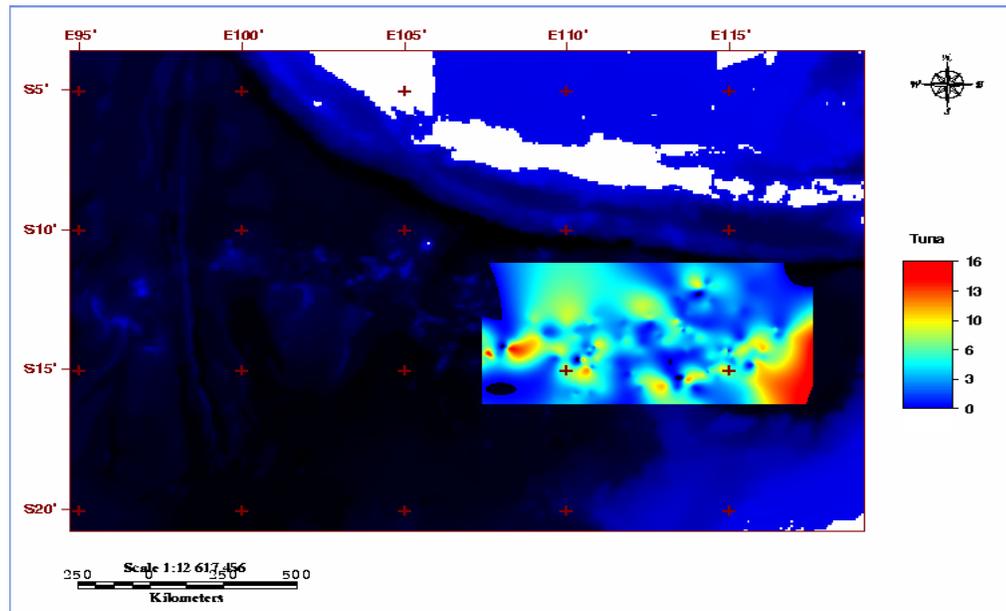
A plot of monthly tuna production yielded by tuna fishing fleet of PT. PSB Bena Bali operated in the Indian ocean in year 2007 as shown as in **Fig. 1.** below, where there were two low tuna production period that was in March and July and high tuna production in May and December.



**Fig. 1** Monthly tuna production of PT. PSB Bena Bali 2007.

Dry and rainy seasonal of *Thunnus.sp.* spatial distribution in Indian Ocean Fishing operation and *Thunnus.sp.* production in Indian ocean by PT.PSB Bena Bali was continually carried out throughout the year. Considering to the specific differences oceanographically of the Indian ocean then the analysis of data was grouped into two main seasonal event in the area. That is dry season : April – November and rainy season : December – March. This was with assumption based on other *Thunnus* spatial distribution data in west Sumatra was also behaves differently during the west and east season (Hartoko, unpublished data). Spatial distribution of actual *Thunnus.sp.* catch in the south of Java, Bali, Timor Indian ocean with fishing base at PT. PSB Bena Bali during the

dry season is shown in **Fig. 2.** The figure indicates that in general the fish catch range from 2 – 16 tuna/catch and high actual *Thunnus.sp.* catch was found in around 15° S and 117° E with range of 10 – 16 tuna/catch. Spatial horizontal sub-surface in-situ of both tuna catch and ARGO Float data in Indian ocean were processed from 216 coordinates and focused into four main seawater temperature layer depth, that are 80 m, 100 m, 150 m and 200 m depth. Sub-surface in-situ seawater temperature at those depth was assumed as the more associated with tuna horizontal spatial distribution, although each horizontal sub-surface seawater temperature has its own detail differences in each depth as shown in **Fig. 3.**



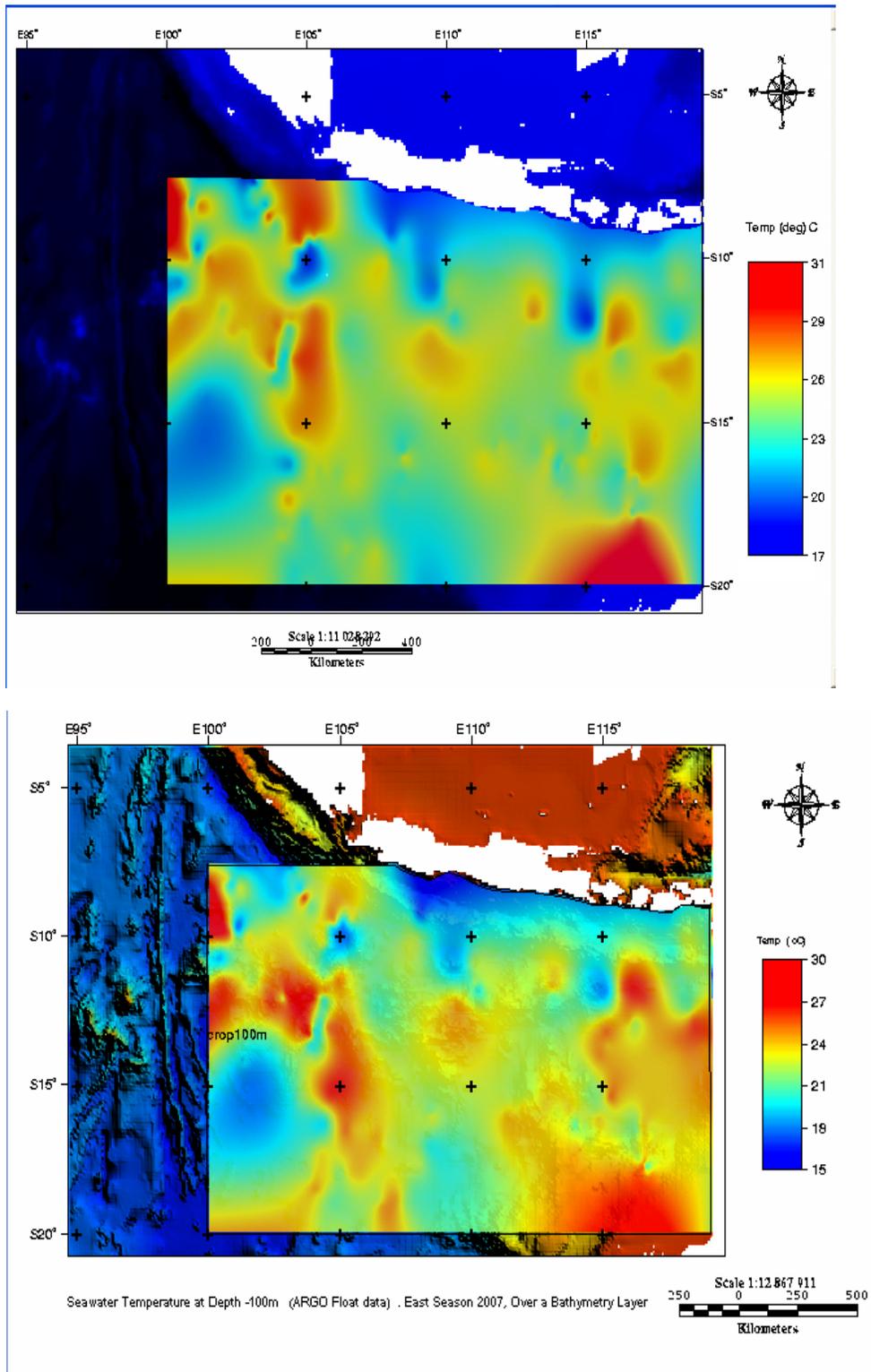
**Fig. 2.** Spatial distribution of *Thunnus.sp.* (actual catch) during dry season : April - November 2007 in Indian ocean.

The focus on those four seawater temperature layer depth was based on information from Soepriyono (Fishing operation manager PT. PSB Cabang Bena Bali - personal communication 2010), that based on their long experience, most of the fishing vessel skipper indicates that dominant *Thunnus.sp* had been caught is big-eye tuna (*Thunnus obesus*). Then considering that the swimming layer of this species, the *depth layer* of hook-eye were set to the depth layer of 80 m, 100 m (Fig. 3), 150 m and 200 m (Fig. 4). Another advice based on their long experience suggest that most of this species were caught in depth between 100 – 280 m. Spatial distribution of horizontal seawater temperature at depth 100 m, 150 m and 200 m during dry season : April – November in Indian ocean is range from 18 – 25 °C and in general found a little bit warmer than horizontal seawater temperature at depth of 80 m which is somewhat cooler that is in a range of 15 – 22 °C.

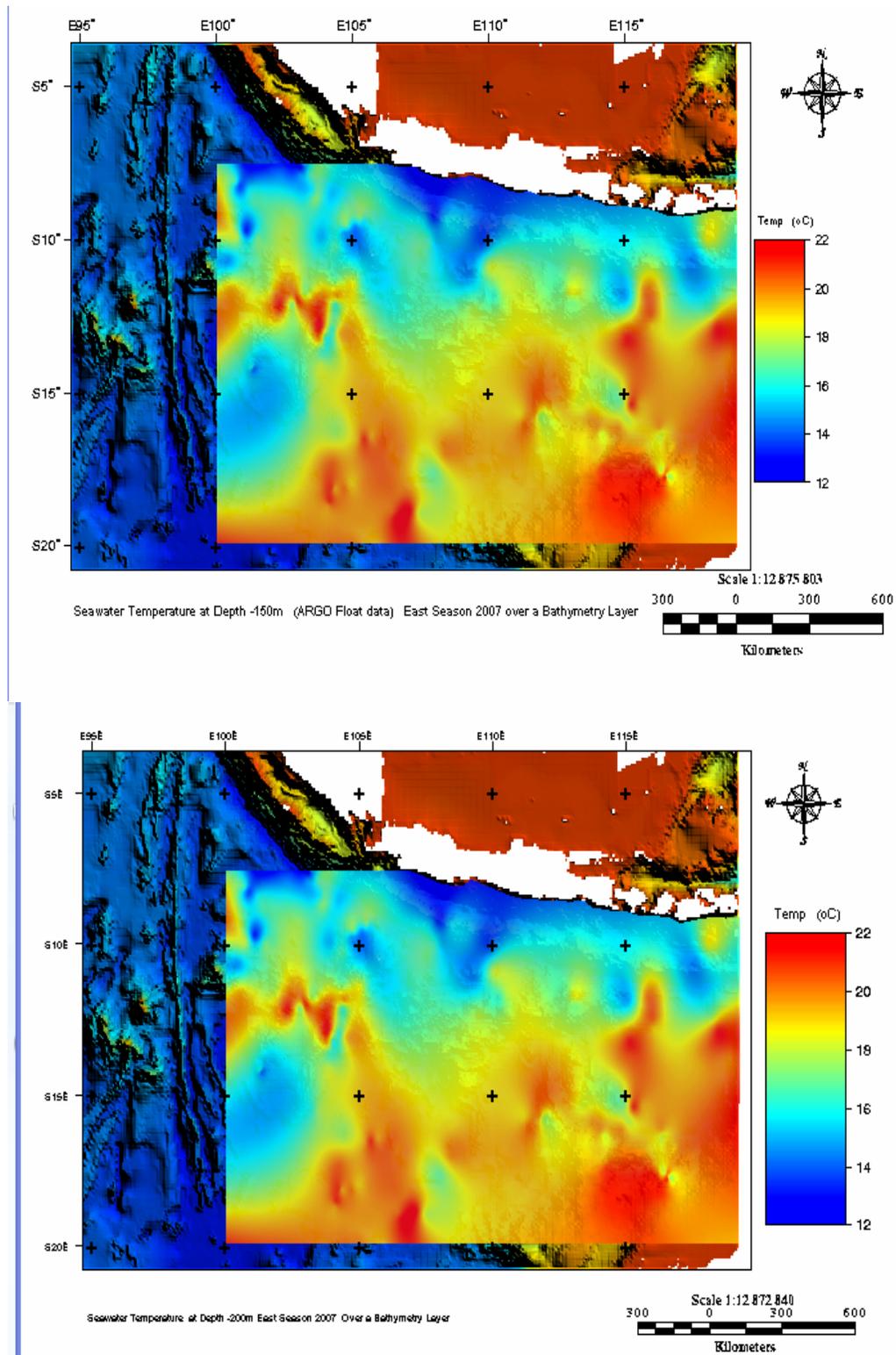
Spatial actual *Thunnus.sp* catch during the rainy season : December – March 2007 in Indian ocean based on fishing operation log-book of Tuna *Long Line* owned by PT. PSB Bena Bali was shown in Fig. 5. High tuna catch was found around 15,5° S and 115,5° E coordinates or about the north of Australia with

range of 8 – 16 tuna/catch, and medium zone catch with range 4 – 8 tuna/catch was found around 14° S and 114° E coordinate.

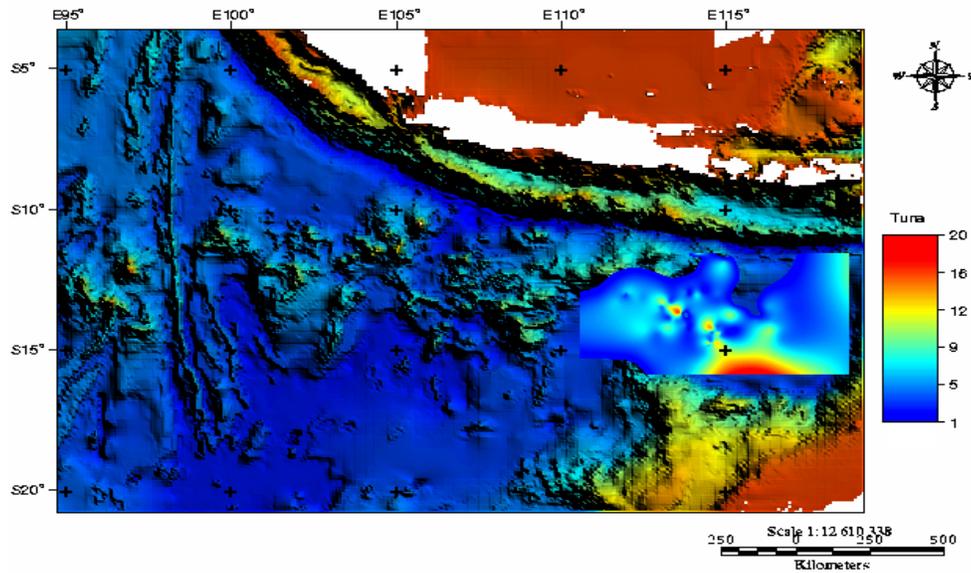
Sub-surface seawater temperature during the rainy season (December – March) in Indian ocean of ARGO Float data was shown in Fig. 6. The range of horizontal seawater temperature at depth of 80 m and 100 m during this season was about similar similar seawater distribution pattern, but 0.5 °C warmer in depth of 80 m around 102,5°E/ 12° S coordinate. Horizontal seawater temperature distribution in depth of 150 m and 200 m as shown in Fig. 7. indicates a similar pattern with those temperature in depth of 100 m. But the seawater range in depth of 150 m : 14 – 22 °C and in depth of 200 m : 12 – 22 °C. In general the seawater temperature during rainy season was found 1°C cooler than those in dry season. Monthly tuna production as shown in Fig.1. indicates that highest production in December and May with the value of 765 and 730 tuna/month and smallest production on July with the value of respectively was 63 tuna/month. Almost all tuna catch was dominated with *Big Eye Tuna*, based on log-book of PT. PSB Bena Bali.



**Fig. 3.** Horizontal sub-surface in-situ seawater temperature at 80 m (above) and 100 m depth (below) in Indian ocean, dry season : April – November 2007. (Processed ARGO Float data)



**Fig. 4.** Horizontal sub-surface in-situ seawater temperature at 150 m and 200 m depth in Indian ocean, dry season : April – November 2007. (Processed ARGO Float data)



**Fig. 5.** Spatial actual *Thunnus.sp* catch distribution during rainy season : December - March 2007 in Indian ocean.

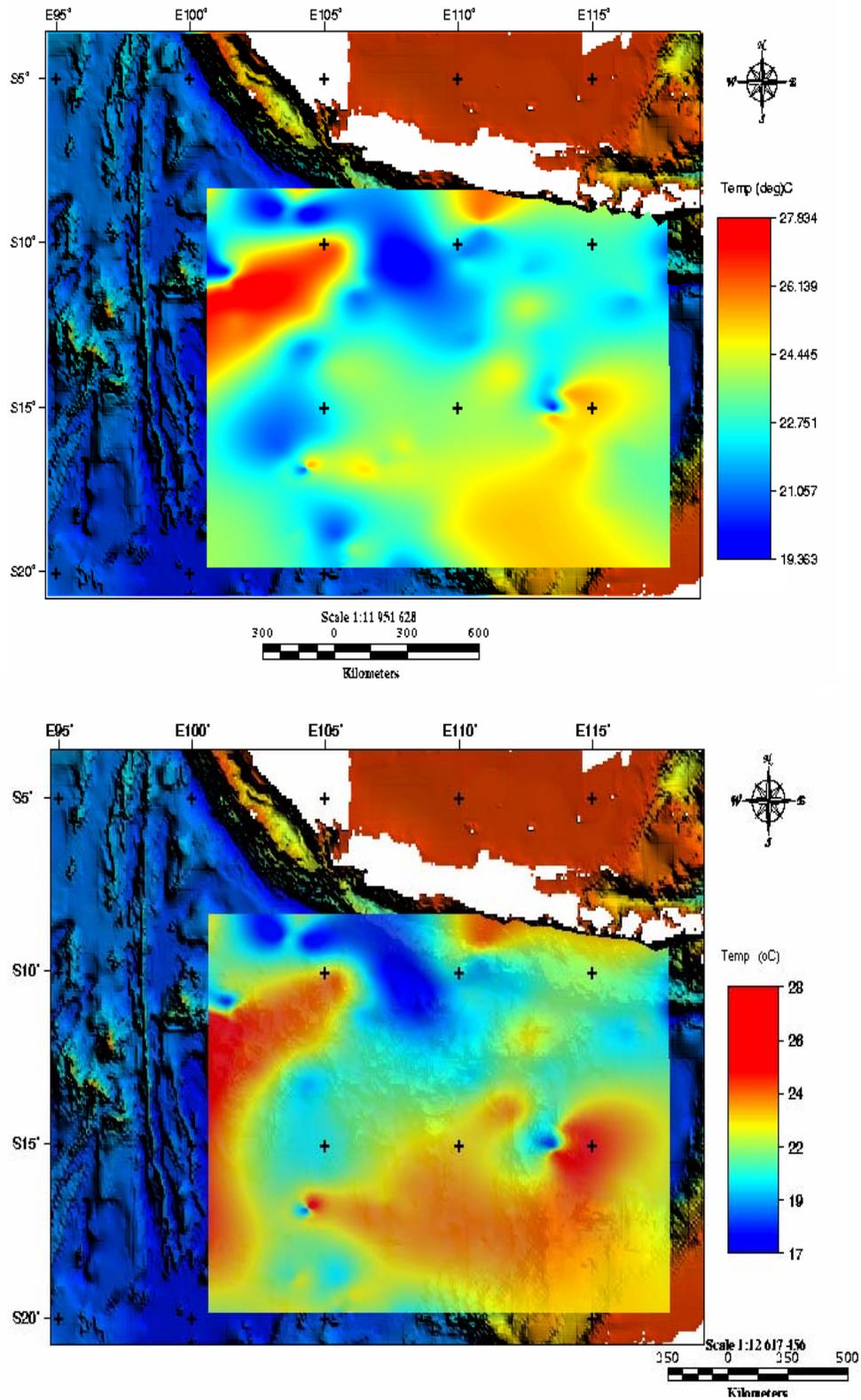
One of oceanographic factors that cause the monthly tuna fluctuation as explained by Marpaung (2001) is that big-eye tuna as one of highly migratory species so that their occurrence in one area and time is highly variable. Their migratory activity was assumed as affected by seasonal and spatial seawater distribution pattern. Tuna was found favour or preferred in a seawater temperature range of 13 – 23 °C or its optimum range of 17 - 22 °C. Another tuna occurrence may vary where adult tuna live in deeper water than those of younger or baby tuna who tends to approach the surface water, and this was regarded due to the *thermoregulation process* (Hartoko, unpublished).

Robinson (1991) in Budiono, (2004), stated that combination of seawater temperature and increase of nutrients during the vertical mixing will increase plankton productivity.

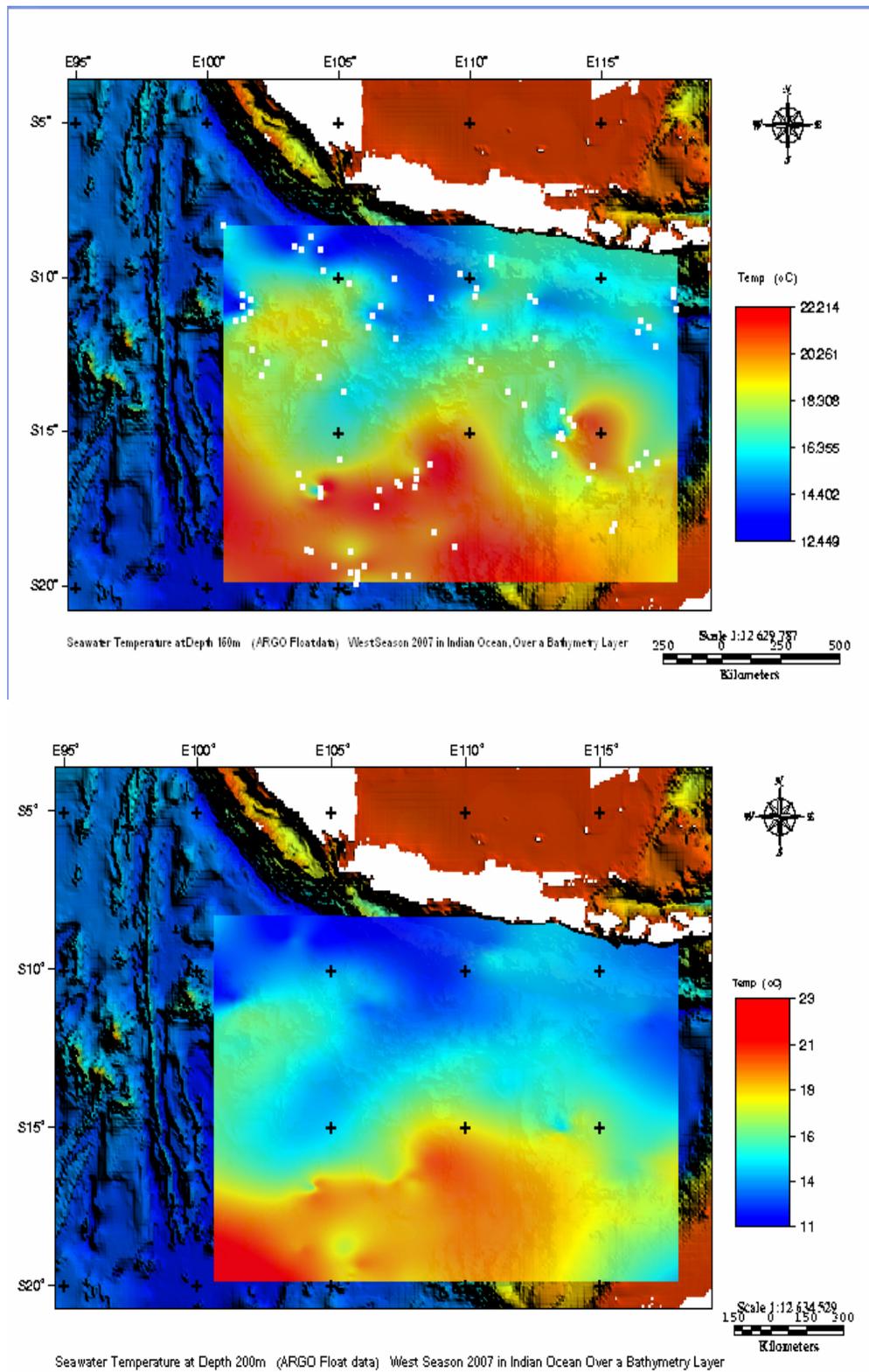
This phenomena will be followed by the increasing of tuna schooling in the area. Horizontal seawater front in another point of view will act as barrier for tuna migration because of high speed water movement and big waves. But another scientist argue that with the occurrence of seawater front will have high primary productivity and thus a good pelagic fish *Feeding Ground* would be a good *fishing ground*. Migratory pattern of big tuna was considered as identical with seawater pattern since tuna as a 'Poikilothermic or Ektothermic' fish, where their body temperature was affected by its surrounding temperature, although can

not be used to predict their abundance (Nakamura, 1969 in Marpaung, 2001). Vertical distribution of tuna was associated with *swimming layer*, where big-eye tuna categorized as epipelagic, mesopelagic and oceanic swimmer from the surface water up to 250 m depth, not the same with yellow fin tuna. Seawater temperature and depth of thermocline layer were the most important factor in regulating their occurrence, both for vertical and horizontal distribution. Big-eye tuna was found in seawater temperature range of 13 - 23°C and optimum in a range of 17 - 22°C (Collete and Nauen, 1983) around the thermocline layer.

High tuna production during April – November 2007 was found in around 15° S and 117° E regarded as effect of dry season conditions. While during December – March high tuna catch move to the west around 15.5° S and 115.5° E and some in around 14° S and 114° E. The westward movement of tuna catch was assumed due to the effect of *South Equatorial Current* Nontji (2002) in south of Java Indian ocean, which move westward along the year, and with a relatively small seawater temperature variation especially in tropical seas such as Indonesian seas. Horizontal seawater may not vary significantly in some Indonesian seas, especially those surface *isothermal zone* on the surface water was generally parallel with the earth latitude, where area in the same altitude will have a similar sun light radiation.



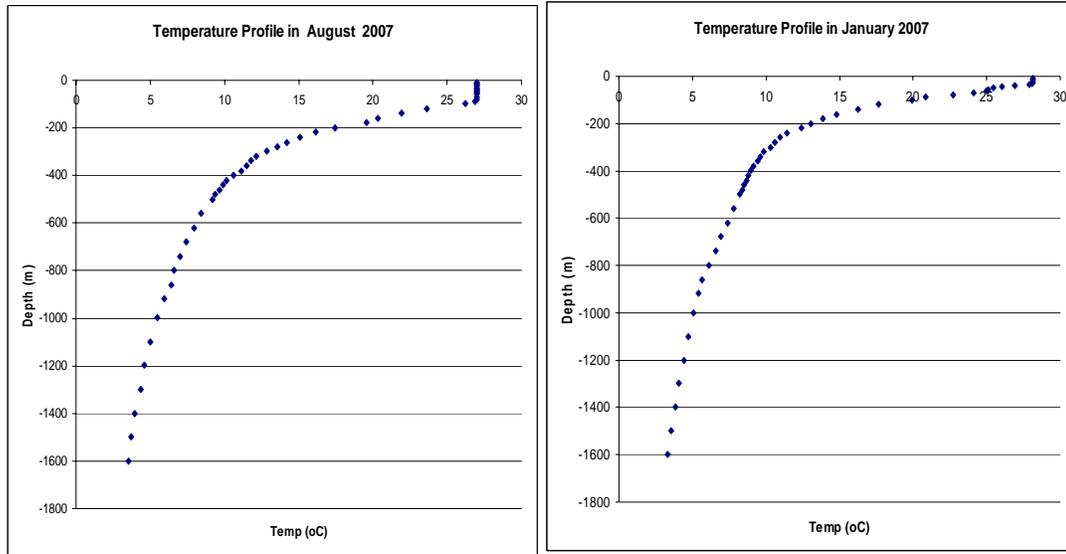
**Fig. 6.** Horizontal sub-surface in-situ seawater temperature at 80 m (above) and 100 m depth (below) in Indian ocean, rainy season : December – March 2007. (Processed ARGO Float data)



**Fig. 7.** Horizontal sub-surface in-situ seawater temperature at 150 m and 200 m depth in Indian ocean, dry season : December - March 2007. (Processed ARGO Float data)

Hartoko, *et al.*, (2000); Hartoko. (2007); Hartoko. (2009) and result of this study (Fig. 8.) revealed that vertical seawater distribution in Indonesia was basically can be classified into three main seawater layer, that are the warm *homogenous layer* near to the surface layer up to 80 m to 100 m with seawater temperature about 28 °C; the thermocline

(*discontinuity layer*) in the middle column of water where seawater temperature decrease extremely from 20 °C to 10 °C in the depth range of 200 m – 300 m; and the cool *deep layer* below 300m depth, usually with seawater temperature below 10 °C and seawater temperature decrease gently less than 5 °C in depth below 1000 m or deeper.



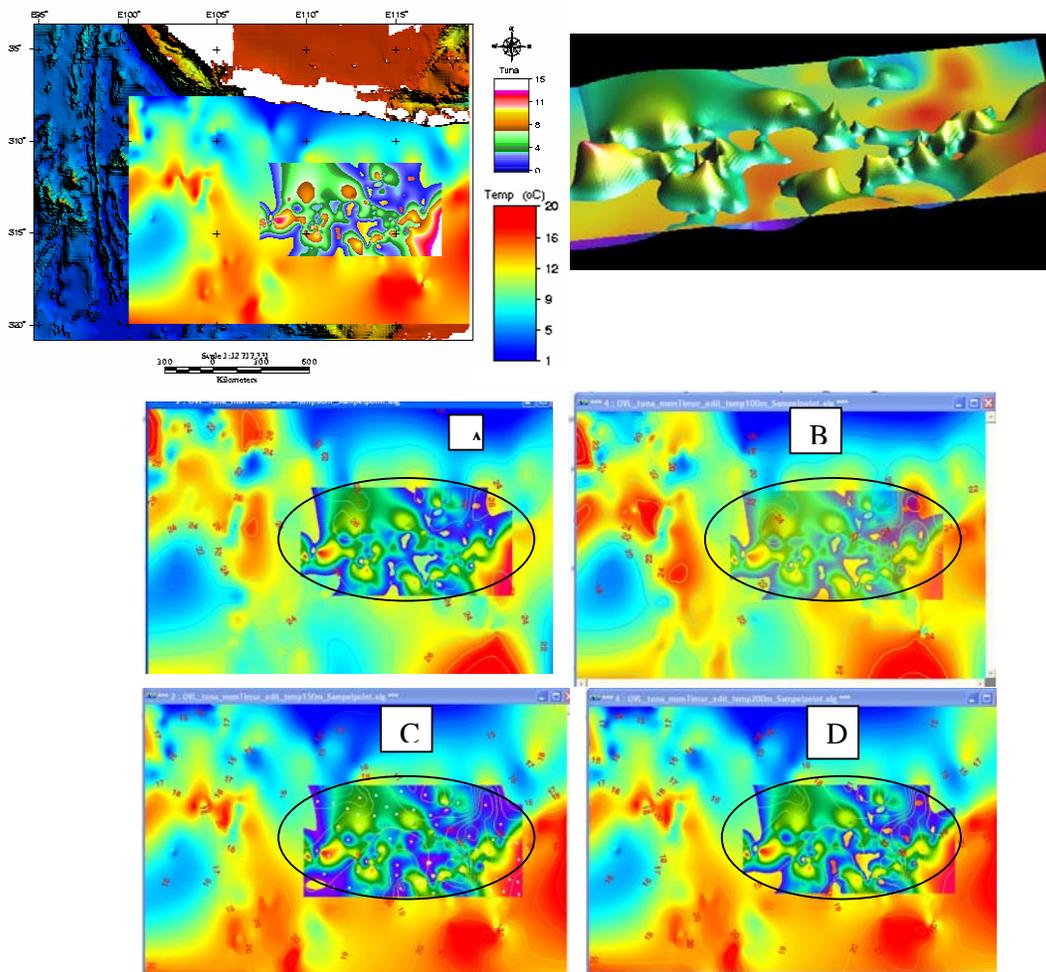
**Fig 8.** Vertical seawater temperature in dry season (August 2007 – left) and rainy season (January 2007 – right) of processed ARGO Float data in Indian ocean

Important finding from this study is that there was the increase of thermocline layer depth happened during the rainy season as shown in Fig. 8. Wyrtsky (1961) and Wyrtsky (2005) explained that short term thermocline depth vertical variation was affected by the sea surface water movement, tide and water current,

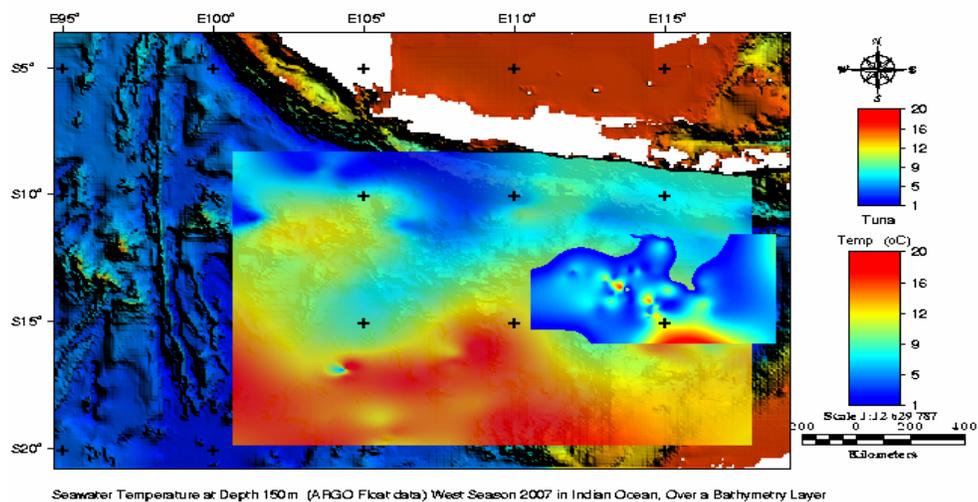
in a depth from 120 m up to 140 m in area approaching the south equatorial current. As well as sub-surface seawater temperature changes as the effect of Indian Ocean Dipole (IOD) modes and the role of Rossby waves (Suryachandra, *et.al.*, 2001).

**Table 1.** Regression, polynomial equation and correlation coefficient (r) of tuna catch and seawater temperature at depth of 80 m, 100 m, 150 m and 200 m during dry season 2007 in Indian ocean

Regression :	Polynomial/ Curvatrrix equation	r
Tuna x temp in 80 m depth	$Y = 2.0424 X^2 - 96.975 X + 1151.2$	0.4399
Tuna x temp in 100 m depth	$Y = 0.0091 X^2 - 1.8297 X + 42.478$	0.8563
Tuna x temp-150 m depth	$Y = 0.1092 X^2 - 1.5556 X + 2.5582$	<b>0.9694*</b>
Tuna x temp-200 m depth	$Y = 1.9597 X^2 - 67.766 X + 585.05$	0.723



**Fig. 9** Overlay of dry season actual tuna catch on the 150 m seawater temperature at depth (above) and actual tuna catch over seawater temperature at depth of 80 m (A), 100 m(B), 150 m(C) and 200 m(D) respectively (below).



**Fig. 10** Overlay of actual tuna catch on seawater temperature at 150 m depth during the rainy season 2007 in Indian ocean

## CONCLUSSION

Seawater temperature variable has a significant effect to the spatial distribution of the actual tuna catch both during dry and rainy season (after a regression, T-test and F-test). A better polynomial correlation on spatial distribution of actual tuna catch with seawater temperature at 150 m depth (with highest value of  $r$ ) was revealed, than those seawater temperature at the depth of 80 m, 100 m or 200 m. Meaning that tuna which is especially dominated by *Thunnus obesus* in Indian ocean was found to be more favour in the depth of around 150 m with seawater temperature range of 15 – 17 °C.

## ACKNOWLEDGEMENT

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