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RESEARCH ARTICLE

# Detection of potential fishing zones of Bigeye tuna (*Thunnus obesus*) at profundity of 155 m in the eastern Indian Ocean

**Achmad Fachruddin Syah*[1], Jonson Lumban Gaol[2], Mukti Zainuddin[3], Nadela R. Apriliya[1], Dessy Berlianty[4] and Dendy Mahabror[4]**

[1]University of Trunojoyo Madura , Bangkalan, Madura, Indonesia. [2]IPB University, Babakan, Dramaga, Bogor, Jawa Barat, Indonesia.[3]University of Hasanuddin, Makassar, Indonesia. [4]Institute for Marine Research and Observation, Negara, Jembrana, Bali, Indonesia.

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**Correspondent email:**
fachrudin@trunojoyo.ac.id

**Abstract** Remotely sensed data and habitat model approach were employed to evaluate the present of oceanographic aspect in the Bigeye tuna's potential fishing zone (PFZ) at a profundity of 155 m. Vessel monitoring system was employed to acquire the angling vessels for Bigeye tuna from January through December, 2015-2016. Daily data of sub-surface temperature (Sub_ST), sub-surface chlorophyll-a (Sub_SC), and sub-surface salinity (Sub_SS) were downloaded from INDESO Project website. Vessel monitoring system and environmental data were employed for maximum entropy (maxent) model development. The model predictive achievement was then estimated applying the area under the curve (AUC) value. Maxent model results (AUC>0.745) exhibited its probable to understand the Bigeye tuna's spatial dispersion on the specific sub-surface. In addition, the results also showed Sub_ST (43,1%) was the most affective aspect in the Bigeye tuna dispersion, pursued by Sub_SC (35,2%) and Sub_SS (21,6%).



## 1.Introduction

Tuna (*Thunnus.sp*) is one of the most essential fishery sources objected by fishermen from different countries including Indonesia (Nootmorn 2004). Tuna has a great financial worth in the world trade. Production of tuna in the world has increased from about 400.000 tons in 1950 to more than 4.000.000 tons in 2002 because the use of purse-seine with fish-aggregating devices (FADs) (Baylift et al., 2004). One of the commercially important tuna species is Bigeye tuna (*Thunnus obesus*). Bigeye tuna production was about 20.000 tons per year in the early 80s and achieved about 140.000 tons in the 90s. However, in 2000 – 2013 the catch of Bigeye tuna experienced a decline with the lowest catch value occurring in 2010 which only reached 87,926 tons (IOTC 2014). Oceanographic conditions are believed to be one of the causes of the fluctuations in tuna catches (Howell & Kobayashi 2006; Lehodey et al., 2010; Briand et al., 2011).

Bigeye tuna (*Thunnus obesus*) prefers to live near, and generally below the thermocline and appear to the surface regularly (Pepperell, 2010). Hanamoto (1987) and Mohriet al., (1996) found out that isotherm 10° – 15°C, below the thermocline depth, is the optimal water state at hook depths for Bigeye tuna. Mohri & Nishida (1999) and Howell et al. (2010) stated that the main fishing depth range in the Indian Ocean for Bigeye tuna is 161–280 m and that it could reach 0 –100 m at night. What's more, Hartoko (2010) and Sukresno,et al. (2015) expressed that fish was commonly found at the profundity around 150 m. Hartoko (2009) demonstrated that sub-surface temperature can be utilized as a pointer of the presence of water development either vertically and on a level plane which conveys supplements. These conditions demonstrated that oceanographic factors in sub-surface can impact the circulation of fish.

In the Indian Ocean, most study concentrated on how circulation of Bigeye tuna was affected by a surface oceanographic factor (Song et al., 2009; Song & Zhou 2010). However, integrated high-resolution vessel monitoring system (VMS), together with habitat modeling and sub-surface oceanoraphic factor, such as a at depth of 155 m, has not been utilized to foresee the Bigeye tuna's PFZ in the eastern Indian Ocean (EIO). Automatic monitoring of angling vessels position is relatively new development. In Indonesia, VMS is a angling vessel monitoring program established by the Ministry of Maritime Affairs and Fisheries since 2003. Information about VMS for fishermen is still lacking. The use of VMS is a form of Indonesia's commitment to meet international, regional and national provisions in terms of conservation and sustainable fisheries management. VMS has been implemented by installing transmitters on fishing vessels measuring over 30 GT such as angling vessels for Bigeye tuna in the EIO. Vessel monitoring system data can give data on the quantity of vessels, including the profile of the vessel, the position, speed and course of the vessel during angling. Therefore, in this study, we used VMS data to understand the angling vessels position of Bigeye tuna. The location of the angling vessels then was assumed to represent the Bigeye tuna fishing location in the EIO. Hence, in this examination, we utilized VMS information to comprehend the angling vessels position of Bigeye fish. The area of the angling vessels at that point was accepted to speak to the Bigeye tuna angling area in the EIO.

Identification PFZ are imperative to contribute fishery action because of the high change in gets of Bigeye tuna. Along these lines, in this examination, we utilized multi sensor satellite data collections and VMS data with a maximum entropy model to build an exact expectation and explore the Bigeye tuna's PFZ in the EIO. The points of this investigation were to make sense of the impacts of oceanographic conditions on the foundation of PFZ and to clarify the Bigeye tuna's PFZ in the EIO particularly at profundity of 155 m.

## 2.The Methods

This investigation was directed in the EIO (104° – 120°E and 6° – 16°S) (Figure 1). This locale has been known as a Bigeye tuna angling region. The prevailing wave and current system that gives impact to this region could bee seen in the following figure (Molcard et al., 2001; Syamsudin et al., 2004; Gordon 2005; Zhou et al., 2008; Sprintall et al., 2009; Gordon et al., 2010; Sprintall et al., 2010). The complicated dynamic current and wave system in this area creates an interest and significant regions to understand the effect of oceanographic parameters againts Bigeye tuna's PFZ.

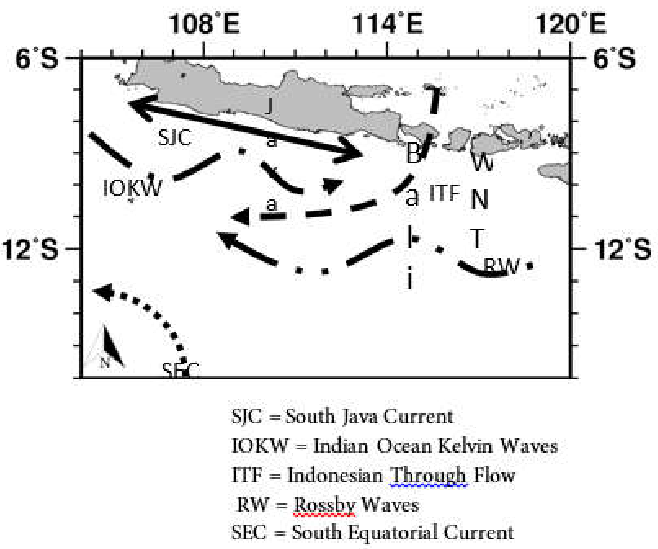


Figure 1. The current and wave system in the eastern Indian Ocean. Redrawn after Syamsudin et al., (2013).

### Location of angling vessel from VMS data

Ministry of Maritime Affairs and Fisheries Indonesia (http://integrasi.djpt.kkp.go.id) received and distributed the VMS data. VMS data doesn't give data about the profundity of angling exercises. In any case, the VMS information give data about the speed of angling vessels and kind of angling gear. Thusly, the information was picked for examination dependent on the speed of angling vessels and sort of angling gear. The speed of vessels less 3 bunches were viewed as directing angling exercises while vessels speeds multiple bunches were expected not to lead angling exercises. What's more, longline is a typical angling gear used to get Bigeye tuna in EIO (Syamsuddin et al., 2013; Barata et al., 2011). In this study, therefore, we chose vessels fitted with longline tuna angling gear and vessel speeds below 3 bunches as the region of Bigeye tuna angling vessels in the EIO. It was then believed that the location of the angling vessels reflected the Bigeye tuna angling area in the EIO.

### Satellite-derived environment variable

Sub_SC, Sub_ST, and Sub_SS data at profundity of 155 meter from 2015 through 2016 were utilized as ecological factors in the maxent models. The Sub_SC, Sub_ST and Sub_SS data were obtained from Infrastructure Development of Space Oceanography site (www.indeso.web.id.). All oceanographic data have a spatial resolution of 9 km. To get the information at profundity of 155 m, we have to click profundity of 155 m. To establish the habitat suitability model, the daily data were reprocessed with ArcGis 10.2.2 and afterward incorporated in a seasonally and annually data base. We changed over to Esri ASCII grid format (Esri, Redlands, CA) or to comma-separated values (CSV) format with the grid feature of Generic Mapping Tools, vers. GMT 4.5.7 (http://gmt.soest.hawaii.edu/). This arrangement was required by the software Maxent.

### Development of a maxent model

The correct testing procedure can improve model outcomes impressively and diminish the chance of making a mistaken, one-sided or uncertain forecast. For that objective, Hirzel and Guisan (2002) offered a few factors that could create model expectation execution. These are the expansion of test size, the utilization of normal examining, and the utilization of ecological data to stratify inspecting. Vulnerability will be declined asymptotically with the expanding test size. Likewise, Valavanis et al. (2008) expressed that species dissemination demonstrating is just in the same class as the data utilized. Accordingly, in this examination to develop the base territory appropriateness model, we utilized annual data. Further, Radosavljevic & Anderson (2014) announced that species-explicit tuning of model parameters can improve the exhibition of Maxent models. The Maxent, type 3.3.3k sofware program was utilized to create a model with a maximum entropy approach. Development of a model, the setting used in the software maxent follow Syah et al. (2019).

### Model's evaluation and validation

To assess the model fit, we utilized area under the curve (AUC) (Phillips et al., 2006). Heuristic assessments of variable significance dependent on the expansion in the model addition were utilized to analyze the overall commitment of individual natural factors inside the maxent model. To infer the appropriate ecological reaches for PFZ, response curves were produced for each factor inspected. The models were utilized to make habitat suitability indices (HSIs) that acclimatized comparable ecological layers for relating period for northwest monsoon (October – March) and southeast monsoon (April – September). Spatial HSI maps for Northwest Monsoon (October – March) and Southeast Monsoon (April – September) were produced and overlaid with VMS data.

Table 1. Number of vessel-watching vessels for the period 2015 to 2016

| Year | 2015 | 2016 |
|---|---|---|
| January | 12 | 8 |
| February | 13 | 18 |
| March | 24 | 33 |
| April | 27 | 31 |
| Mei | 31 | 51 |
| Junne | 21 | 54 |
| Jule | 19 | 26 |
| August | 11 | 41 |
| September | 29 | 46 |
| October | 26 | 59 |
| November | 26 | 28 |
| December | 27 | 46 |

## 3.Results and Discussions

### Spatio temporal distribution of fishing locations

One of practical and economical tool for monitoring success, surveillance and control of fishing activities is a vessel monitoring system (VMS). Vessel monitoring system gives precise and auspicious data about the area and movement of controlled angling vessels. Vessel monitoring system had been used by many researchers to locate the spatial distribution of angling vessels for marine fishes (Gerritsen & Lordan 2011; Saitoh et al., 2011). In this study, fishing location from VMS and oceanographic parameters were utilized to anticipate PFZ Bigeye tuna (*Thunnus obesus*) in the EIO by using maximum entropy models.

We gathered 707 VMS data from January through December 2015 – 2016 (Table 1). Examinations of VMS data enabled us to decide angling vessel of Bigeye tuna crosswise over reality. We accepted that Bigeye tuna were trapped in a similar area where angling vessels were resolved. In this way, from angling vessels position, we had the option to appraise the spatial and transient dispersion of Bigeye tuna PFZ.

The dispersion variety of angling vessels for Bigeye tuna during northwest monsoon (October – March) and southeast monsoon (April – September) 2015 – 2016 is exhibited in Figure 2. The figures indicated that for Bigeye tuna fishing areas, the waters south of Bali – Nusa Tenggara archipelago are more suitable than the waters south of Java Island. However, in the southern waters of Java Island there were still vessels that conduct Bigeye tuna angling activities.

| Variable | % contribution |
|---|---|
| Sub_ST | 43,1 |
| Sub_SC | 35,2 |
| Sub_SS | 21,6 |

Table 2. Heuristic estimates of the environmental variables's relative contribution to models. Sub_ST=sub-surface temperature; Sub_SC=sub-surface chlorophyll-*a*; Sub_SS=sub-surface salinity

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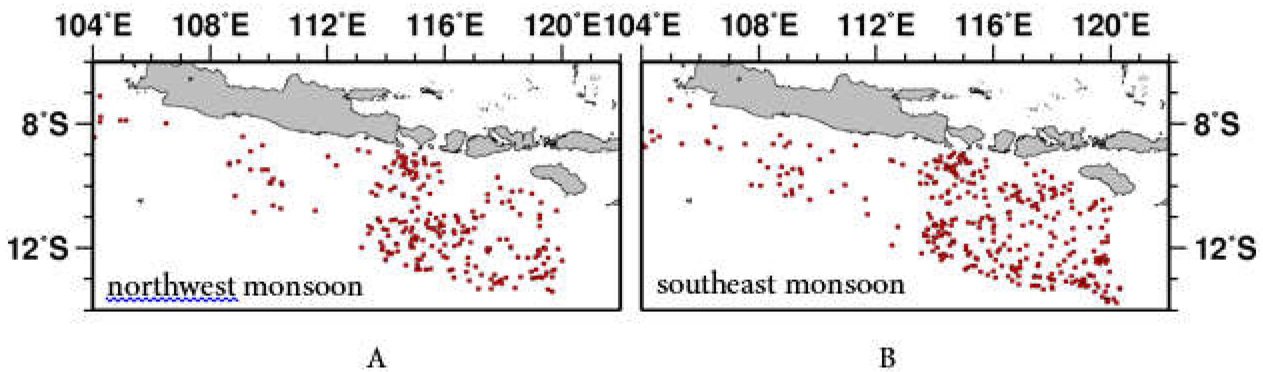


Figure 2. Spatial conveyance of Bigeye tuna (red dot) fishing locations in the eastern Indian Ocean pooled during two different monsoons.

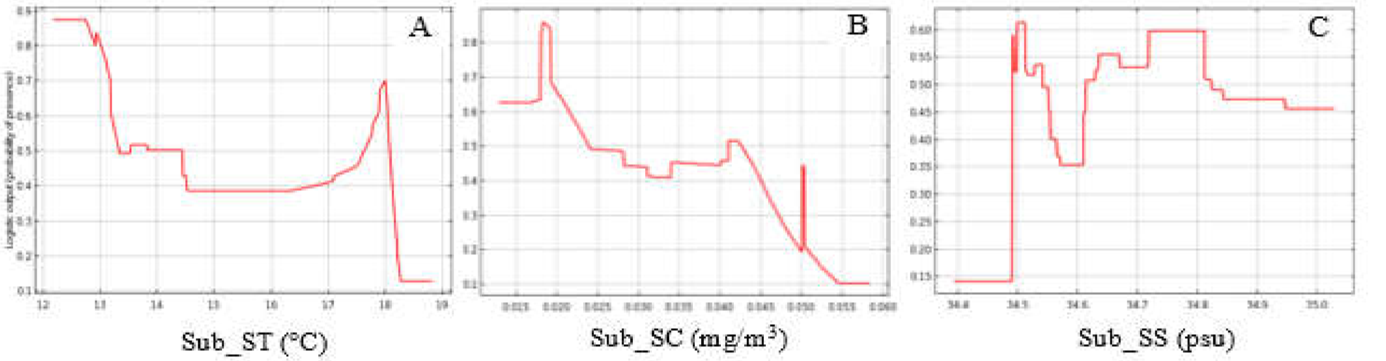


Figure 3. Model response curves for (A) sub-surface temperature (Sub_ST) (B) sub-surface chlorophyll-*a* (Sub_SC), and (C) sub -surface salinity (Sub_SS) in the eastern Indian Ocean.

## Model performance

We utilized a maximum entropy model to research the impacts of ecological factors againts the arrangement PFZ of Bigeye tuna in the EIO. The high AUC value (0,745) shows that the model had great concurrence with the test information. Moreover, the outcomes indicated that the impacts of oceanographic conditions emphatically impact the dissemination of Bigeye fish. The overall commitment of every parameter is appeared in Table 2.

The adjustments in ecological obvious from the varieties in salinity, temperature, currents, and wind fields are accepted to impact the profitability and fish circulation (Southward et al., 1988; Alheit & Hagen, 1997). In this examination, Sub_ST (among the arrangement of oceanographic factors inspected) demonstrated the most elevated commitment to the model, show the affectability of Bigeye tuna to Sub_ST changes. Holland et al., (1992) and Brill et al., (2005) brought up that Bigeye tuna is exceptionally delicate to changes in ocean surface temperature.

Figure 3 demonstrated the model-inferred favored reaches for each ecological variable. The plots demonstrated the exhibition and commitment of the different ecological data to fit the model. Our outcomes show that Bigeye tuna nearness for the most part showed up in Sub_ST of 13° – 18° C (Fig. 3A). Sukresno et al. (2015) upheld this outcome, detailing that Bigeye tuna saw the profundity of approximately 150 m as more support with an ideal temperature between 16° – 21°C ranges.

Sub-surface chlorophyll-*a* (Sub_SC) was a second significant oceanographic indicator of Bigeye tuna dissemination in the EIO (Fig. 3B). The Indian Ocean is one of regions that intensely impacted by El Nino occasions. The extreme El Niño occasions in the Indian Ocean, effectively affect on primary production and can cause bizarre high estimations of ocean surface chlorophyll-a concentration (chl-*a*) (Murtugudde et al., 1999). In this manner, a territory with high estimations of chl-*a*, for example, upwelling territories with intermingling zones for plankton collection, is potential for pulling in bigger predators, for example, tunas (Lehodey et al., 1997). These chl-*a* can result in increased catches during the El Niño event (Polovina et al., 2001; Lehodey et al., 2003; Polovina et al., 2004; Miller 2007). In this investigation, Bigeye tuna presence generally saw in Sub_SC concentration of 0,015 – 0,020 mg/m$^3$.

Among the 3 ecological factors analyzed in the model, Sub_SS showed the most reduced commitment to the model forecast in the EIO. Salinity is another key abiotic factor that effects fish physiology, influencing the capacity of fishes to flourish in various territories. Faizah (2010) found out that various oceanographic factors, including salinity, affect the distribution of Bigeye tuna. Bigeye tuna is quick swimmers fish and exceptionally transitory species. Salinity has a strong influence on marine species physiology (osmotic pressure), including tunas. Our analysis showed that the majority of Bigeye tuna angling sets are 34.5 – 34.8 psu in Sub_SS. The finding was confirmed by Novianto & Susilo (2016) who stated that Bigeye tuna generally disseminated at a salinity value of 34 psu. In addition, high salinity were believed defer the relocation of Bigeye tuna.

Other than the three parameters above, other researchers revealed that other oceanographic parameter, for example, sea-surface-height (SSH), additionally influence the dispersion of Bigeye tuna in EIO. In feeble of sea-surface-height peculiarity condition, the thermocline will be pushed upward, closer the surface and as an outcomes Bigeye tuna will be increasingly accessible to longline gear since the angling layer of in any event 50 m profundity (Syamsuddin et al., 2013; Gaol et al., 2015). This condition is one of the causative factors in the southeast monsoon season which increases the tuna hook level. Moreover, SSH in the Indian Ocean and Bengal Bay corresponds with thermocline depth (Bray et al., 1996; Yu 2003). Gaol et al. (2015) additionally demonstrated that the most elevated Bigeye tuna hook rate (≥ 1.5) was identified in the fronts among cyclonic and anti-cyclonic eddies. Higher efficiency can be found in frontal locale between eddies. The area could be a feeding ground as well as a tuna barrier (Sund et al., 1981). What's more, Hsu (2010) additionally demonstrated that the Bigeye tuna hook rate in area close mesoscale eddies was higher than in non-eddy

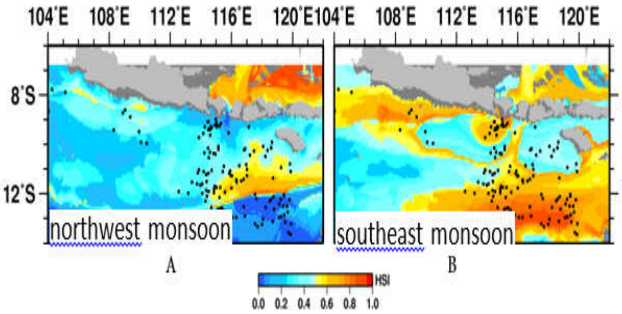


Figure 4. The spatial conveyance of angling areas (black spots) for Bigeye tuna from VMS, overlays the habitat suitability map during two different monsoons. The suitability is shown as Habitat Suitability Index (HSI) value ranging from 0 to 1, representing of "poor" to "good" habitat.

areas. Eddies create attractive pelagic habitats, for higher trophic level aquatic organisms (Godø et al., 2012). Eddy-supported upwelling exports nutrients from profound water to the euphotic zone (McGillicuddy & Robinson, 1997), and almost certainly, this procedure adds to eddy development in the EIO area (Gaol et al., 2015).

### Predicition potential fishing zones

The predicted HSI maps during northwest monsoon (October – March) and southeast monsoon (April – September) are shown in Figure 4. During northwest monsoon, the anticipated possibility of existence of Bigeye tuna in EIO has a low value of HSI (< 0.5) particularly along the south of the Java Island – Nusa Tenggara (Figure 4A). The high value of HSI (> 0.6) showed up seaward territories around 12 °S. During this period the quantity of angling vessels for the most part show up seaward zones of Bali – Nusa Tenggara. Conversely, the anticipated possibility of existence of Bigeye tuna during the southeastern monsoon has a high HSI value (> 0.6), particularly in territories of 113° – 120°E and 9° – 13° S (Figure 4B). This zone corresponded with the angling vessel position for Bigeye tuna. The regular inconstancy sub-ST in the EIO were believed impact the differentiating conditions (Qu, et al., 2005). Also, during southeast monsoon the quantity of angling vessel of Bigeye tuna somewhat increments looked at during northwest monsoon. A large area of high PFZ during the southeast monsoon indicates that the ecological factor for tuna during this time was greater than for the northwest monsoon. Sukresno et al. (2015) pointed out that during the southeastern monsoon PFZ was closer to the Java shoreline, while in the northwestern monsoon the PFZ was moved south to the near 13°S. This situation was increasingly positive for tuna due to the upwelling activity (Susanto & Marra 2005), which produced the Sub_ST along the Java shoreline was increasingly favorable for the tuna, especially in the southeastern monsoon.

At last, VMS data were seen as accommodating for reviewing the appropriation of angling vessels – an outcome that supports the prior investigations (Gerritsen & Lordan 2011; Saitoh et al., 2011) –, for example, angling vessels for Bigeye tuna. The VMS results can be accumulated inside a couple of days, while reported data may set aside an all-inclusive time of effort to gather. Be that as it may, lack signal VMS could be constrained the utilization of VMS data; thusly, logbook data are still essential to affirm the legitimacy of fish existence in the future.

## Conclusions

As a rule, the model had great performace with high AUC value (0,745). South of Bali – Nusa Tenggara Island is best regions for angling exercises Bigeye tuna. Among the arrangement of oceanographic factors inspected, sub-surface temperature (43,1%) demonstrated the most elevated commitment to the model, trailed by sub-surface chlorophyll -a (35,1%) and sub-surface salinity (21,6%). VMS is valuable to examine the circulation of angling vessels. Coordinating the VMS with logbook or Visible Infrared Imaging Radiometer Suite (VIIRS) boat detection (VDB) data, opening up a scope of potential future applications to analyse fisheries data more a calculable than was conceivable beforehand.

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