Detection potential fishing zones of Longtail tuna (*Thunnus tonggol*) using fisheries and remotely sensed data in the waters around Madura Island

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**Abstract.** In situ data of Longtail tuna fishing location and satellite-based oceanographic data of chlorophyll-\(a\) concentration (chl-\(a\)), sea-surface temperature (SST), and salinity were employed to figure out the impacts of oceanographic condition on the pattern of potential fishing zones for Longtail tuna in waters around Madura Island. The relation of those parameters to the dissemination of Longtail tuna was analyzed with a maximum entropy (Maxent). The predictive model performance was estimated using the area under the curve (AUC). The jackknife test was then employed to examine each parameter’s model contribution. The results from the Maxent model exhibited a high predictive success of the model with AUC value of 0.932. Maxent prediction showed a high probability occurrence of Longtail tuna occurred in the offshore area of the Java Sea. The results also revealed that the Longtail tuna habitat selection was significantly controlled by the salinity ranges from 32.3 – 32.5 ppt, SST ranges from 29.5–30.5°C, and chl-\(a\) ranges from 0.2 – 0.4 mg/m\(^3\). Besides, among the set of oceanographic variables utilized (SST and chl-\(a\)), salinity exhibited the highest value of the jackknife test. Therefore salinity expressed to be the most significant factor in the geographic dissemination of Longtail tuna in the waters Madura Island.

1. **Introduction**

Longtail tuna, *Thunnus tonggol*, is an economically important pelagic species inhabiting tropical and subtropical provinces of the Indo-Pacific region [1]. From northern Australia, Papua New Guinea, and Indonesia and northwest through Malaysia and Thailand, the species has continuous dissemination to the northeast to southern Japan and the northwest to Iran and the Red Sea. Yaki [2] reported that the dissemination of Longtail tuna is unique compared to others in the *Thunnus* genus. Longtail tuna nearly exclusively occupy neritic areas close to landmasses and are rarely found offshore. The species is being exploited by commercial and artisanal fisheries in several countries throughout the Indo-Pacific [2, 3]. Along the Indian Ocean region, the highest contribution to Longtail tuna catch is by Iran (34\%) and Indonesia (31\%) followed by Taiwan, Thailand, Oman, Pakistan, Malaysia, India, and Australia. It is the second smallest of eight species of *Thunnus* and grows to a maximum size of 142 cm total length and 35.9 kg [4].

Longtail tuna are massively utilized by small-scale commercial fisheries in at least 17 countries throughout the Indo-Pacific. They are mostly targeted by purse-seine, gillnet, and trolling and constitute a significant portion of multispecies fisheries for small neritic tuna, including mackerel tuna (*Euthynnus affinis*) and frigate tuna (*Auxis thazard* and *A. rochei*) [2]. Thailand, Indonesia, Malaysia, and Iran contribute most to reported annual landings, which reached 248 000 t in 2007 [5]. As
Longtail tuna add to essential artisanal and subsistence fisheries in many countries, these reported landings are likely to be underestimates. Most studies of Longtail tuna have concentrated on its fishery and size composition in the catch [6, 7, 8, 9] and growth studies [10, 11], biology and population characteristics [3, 12, 13] age and growth [14, 15, 16, 17, 18] or investigation of otolith microstructure from a small sample size (n = 26) [19] or truncated size dissemination (13–49 cm Lf) [10]. However, integrated fisheries data and environmental data from remotely sensed data in habitat modeling, have not been used to detect the potential fishing zone for Longtail tuna (Thunnus tonggol). Therefore, the purpose of this study was to investigate how Longtail tuna dissemination is affected by the oceanographic condition and to describe the potential fishing zones of Longtail tuna is in the water around Madura Island based on remotely sensed data and fisheries data.

2. Material and methods
2.1. Study Area
This study was conducted in the waters around Madura Islands, spanning between 112°66’ – 114°66’ BT and 6°5’ – 7°4’ LS (figure 1). The south side of the Madura Islands is Madura Strait meanwhile the north side is the Java Sea.

![Figure 1. Map of the study area](image)

2.2. Data
In this study, we employed fishery and satellite remotely sensed data. Longtail tuna data and remotely sensed data environmental data during northeast monsoon (October 2018 – March 2019) were evaluated. The period northeast monsoon was chosen for analysis because it corresponds with the available in situ data from local fishermen.

2.3. Fisheries Data sets
Fishing location of Longtail tuna were obtained from local fisherman. Data collection on fishing positions was carried out on the north (Java Sea) and south (Madura Strait) sides of Madura Island. However, not all regions have Longtail tuna catches. Longtail tuna catch only obtained from the water of the north side of Madura Island (Java Sea).

2.4. Environmental Data
We used satellite-derived data—chlorophyll-a concentration (chl-a), sea surface temperature (SST), and salinity — as environmental factors in the maximum entropy models. Monthly chl-a and SST values were collected from satellite images were downloaded from NASA Goddard Space Flight Center (http://oceancolor.gsfc.nasa.gov/). These data were processed with the SeaDAS package, vers. 7.4. Monthly salinity was produced and distributed by the marine Copernicus website (http://marine.copernicus.eu/). The grid function of the software package Generic Mapping Tools, vers.
GMT 4.5.7 was used to resample to 1-km resolution and converted to Esri ASCII grid format or comma-separated values (CSV) format, as required by the software program Maxent.

2.5. Maximum entropy model
We used the Maxent software (version 3.3.3k). A cross-validation procedure was used to calculate the performance of the models. The data were randomly split into 2 categories, training data (75%) and test data (25%). The test points were then used to calculate the area under the curve (AUC) metric of the receiver operating characteristic (ROC) [20]. The jackknife test was then used to examine the parameter's model contribution. The test executed by the subsequent omission of the environmental parameter, producing a model with remaining environmental factors and achieving a model applying each environment factor in solitude [21]. The response curve achieved for each environmental factor was used to examine the favorable environmental ranges. Derived environmental ranges reflect the favorable environmental conditions of the potential Longtail tuna fishing zones.

3. Results and discussion
3.1. Spatiotemporal dissemination of fishing locations and environmental data
In this study, we collected 130 fishing position data during the northeast monsoon. Figure 2 showed the dissemination of fishing position of Longtail tuna around the water of Madura Island. As stated in the previous chapter, data collection was carried out on the north and south sides of Madura. However, the results showed that the fishing activities for Longtail tuna occurred in the water of the north part of Madura Island.

Figure 2. Fishing vessel position of Longtail tuna (black dot) during northeast monsoon (October 2018 – March 2019).

Figure 3 showed the environmental (SST, chl-a, and salinity) conditions during the northeast monsoon (October 2018 – March 2019). In general, SST and chl-a in Madura Strait were higher rather than in the Java Sea. In contrast, salinity in the Java Sea was higher compared to Madura Strait. During the period, the study area has value SST between 29.23– 33.11 °C, chl-a between 0.18 – 13.95 mg/m³ and salinity between 31.12 – 33.06 ppt.
Figure 3. Images of mean values during the northeast monsoon (October 2018 – March 2019) obtained from remotely sensed data for (A) sea surface temperature (SST) (°C), (B) chlorophyll-α concentration (chl-α) (mg/m³) and (C) salinity (ppt)

3.2. Model performance and potential fish habitat
Fishing position and oceanographic data were used to detect the potential fishing zone for Longtail tuna using a maximum entropy model. The results showed a high predictive success of the model, indicating by AUC > 0.5 (AUC = 0.932). The contribution of the environmental parameters to model prediction is shown in figure 4. Results showed that among the three variables examined, salinity was mostly accounted for the corresponding increase in model gain. SST reported the least contribution in the model developed for Longtail tuna. Model-derived preferred ranges for each environmental variable are shown in figure 5. The derived environmental ranges in Longtail tuna potential zone were between 29.5–30.5 °C, 0.2 – 0.4 mg/m³ and 32.3 – 32.5 ppt for SST, chl-α, and salinity, respectively.

Figure 4. Jackknife test results of variable importance derived from the model.
Figure 5. Response curves for each environmental variable (A) sea surface temperature (SST), (B) chlorophyll-a concentration (chl-a), and (C) salinity

3.3. Prediction potential fishing zone

Figure 6 showed the predicted map of the potential fishing zone for Longtail tuna during the northeast monsoon. During this period, the predicted probability of Longtail tuna occurrence mostly occurred in the Java Sea with high probability (HSI ≥ 0.6) in the offshore area (113°40’ – 114°15’ E and 6°5’ – 6°6’ S). In general, the dissemination of Longtail tuna form on the HSI revealed acceptable spatial correlation with actual fishing position from local fisherman.

Figure 6. The spatial dissemination of fishing location (black dots) for Longtail tuna (Thunnus tonggol) during northeast monsoon (October 2018 – March 2019), overlain on maps suitability prediction. The suitability is illustrated as a Habitat Suitability Index (HSI) score ranging from 0 to 1, symbolizing “poor” to “good” habitat quality, respectively.
The Longtail tuna inhabits continental shelf and ocean waters in warm temperatures and tropical regions of the Indo-west Pacific. Because of their rapid acceleration, long tail tuna are regarded as sport fish but their very dark flesh gives them a low market acceptance. Griffiths et al. [11] reported that Longtail tuna is an important sport fish due to their size, fighting ability and because they targeted by small vessels in sheltered inshore waters and even from the shore. In this study, we used a fishing position of Longtail tuna and oceanographic factors in a maximum entropy model to detect the potential fishing zone for Longtail tuna during northeast monsoon in the water around Madura Island. In this study, during the northeast monsoon, the fishing activities for Longtail tuna occurred in the water of the north part of Madura Island (Java Sea). It was indicated that the Java Sea is appropriate for fishing areas for Longtail tuna.

The predicted dissemination of Longtail tuna in water around Madura Island during northeast monsoon also showed high probability (HSI ≥ 6) on the north sides of Madura Island (Java Sea). Susilo and Suniada [22] reported that during northwest monsoon (December – May), the high epipelagic micronekton biomass found in the Java Sea, especially found close to shore of the Java Island. The epipelagic micronekton biomass in the Java Sea ranging between 1 – 2.5 g/m², while at the coastal area are higher, approximately 2.5 – 3.5 g/m². Longtail tuna is an epipelagic predator that mainly feeds on small pelagic fishes families Engraulidae and Scombridae, crustacean (Alima, Decapoda, and Penaeidae) and miscellaneous cephalopods, cephalopods and a range of crustacea [18]. In addition, [23] reported that feeding ecology of Longtail tuna included 101 prey taxa, with most common taxa (in terms of biomass) being: small pelagic fishes (Engraulidae, Clupeidae, Scombridae, Belonidae, and Hemiramphidae), demersal fishes (Carangidae, Leiognathidae and Sillaginidae), cephalopods (Teuthoidea and Sepia spp.) and crustaceans (Portunidae, Penaeidae, and Squillidae).

The performance of the maximum entropy model was high showed by an AUC value of 0.932. The value reflected that the model had excellent agreement with the test data. Productivity and fish dissemination are determined by environment changes from the variation in sea surface temperature, currents, salinity, chlorophyll-a concentration, and wind fields [24,25,26]. In this study, salinity showed the highest contribution to the model gain. Longtail tuna is an epipelagic fish and highly migratory species. Salinity is very influential in physiology (osmotic pressure) of marine species including tunas. Faizah [27] pointed out that the dissemination of tuna is affected by various oceanographic factors including salinity. Our study showed that most Longtail tuna fishing appeared were located in a salinity value of 32.3 – 32.5 ppt. Collette and Nauen [28] reported that Longtail tuna tend to avoid areas near the mouths of large estuaries with low salinity or high turbidity. Chl-a was the second-most important oceanographic factor for Longtail tuna dissemination. Our results pointed out that Longtail tuna presence mostly occurred in low chl-a concentration, 0.2 – 0.4 mg/m³. This result was backed up by [29] who pointed out that chl-a was a significant parameter in the dissemination of tuna with relatively low chl-a values. Among the 3 environmental variables examined, SST exhibited the lowest contribution to the model prediction. Our results reflect that Longtail tuna mostly appear in the SST value of 29.5–30.5°C. Itoh et al. [30] reported that Longtail tuna can be found in a range of water temperatures between 16°C - 30°C, which optimal water range value of 24 – 25.6 °C [31,32].

4. Conclusion
High potential fishing zone for Longtail tuna (Thunnus tonggol) appeared north of Madura Island (Java Sea). Salinity showed the highest contribution to the habitat suitability model, followed by chl-a concentration and sea-surface temperature.

5. References
[1] Froese R, and Pauly D E 2010 Fish Base. World Wide Web electronic publication. www.fishbase.org, version (02/2010)
[2] Yesaki M 1994 A review of the biology and fisheries of the longtail tuna (Thunnus tonggol) in the Indo-Pacific region. FAO Fisheries Technical Paper 336 370 – 387
[3] Griffiths S P, Pepperell J, Tonks M, Sawynok W, Olyott L, Tickell S, Zischke M, Lynne J, Burgess J, Jones E, Joyner D, Makepeace C, and Moyle K 2009 Biology, fisheries and status of longtail tuna (Thunnus tonggol), with special reference to recreational fisheries in Australian waters. FRDC Final Report 2008/058, 101 pp

[4] IGFA 2008 World record game fishes. International Game Fish Association, FL, USA

[5] FAO 2009 FISHSTAT Plus: Universal software for fishery statistical time series, version 2.3. FAO Fisheries Department, Fishery Information, Data, and Statistics Unit

[6] Muthiah C 1985 Bull Cent Mar Fish Res Inst, Cochin. 36 51–70

[7] Silas E G, Pillai P P, and Siraimeetan P 1985 CMFRI Bull. 36 184 –187

[8] Siraimeetan P 1985 Bull Cent Mar Fish Res Inst. 36 86 –103

[9] Pillai N G K, Ganga U, and Dhokia H K 2005 Proc Tuna Meet-2003 58 – 63

[10] Itoh T, Yuki Y, and Tsuji S 1999 Bull of the Nat Res Ins of Far Seas Fish. 36 47–53

[11] Griffiths S P, Gary C F, Fiona J M, and Dong C L 2010. ICES J Mar Sci. 67 125 – 134

[12] Abdussamad E M, Koya K P S, Ghosh S, Rohit P, Joshi K K, Manojkumar B, Prakasan D, Kompapraj S, Elayath M N K, Dhokia H K, Sebastian M, and Bineesh K K 2012 Indian J Fish. 59 (2) 7 –16

[13] Hedayatifard M 2007 The International Conference on Science and Technology of Aquaculture, Fisheries and Oceanography in the Arabian Seas, State of Kuwait p. 1-11

[14] Silas E G, Pillai P P, Srinath M, Jayaprakash A A, Balan M V, Yohannah C T M, Siraimeetan P, et al. 1986 Bull of the Cent for Mar Fish Res Inst, Cochin 36 20–27

[15] Supongpan S, and Saikliang P 1987 Report of the Marine Fisheries Division Department of Fisheries, Bangkok, 3 78

[16] Prabhakar A, and Dudley R G 1989 Age, growth and mortality rates of longtail tuna Thunnus tonggol (Bleeker) in Omani waters based on length data. Indo-Pacific Tuna Development and Management Programme, IPTP/89/GEN, 16: 90–96

[17] Yesaki M 1989 Estimates of age and growth ofkawakawa (Euthynnus affinis), longtail tuna (Thunnus tonggol) and frigate tuna (Auxis thazard) from the Gulf of Thailand based on length data. Indo-Pacific Tuna Development and Management Programme, IPTP/89/GEN 17 94–108

[18] Khorshidian K, and Carrara G 1993 An analysis of the length- frequencies of Thunnus tonggol in Hormuzgan waters, Islamic Republic of Iran. Expert Consultation on Indian Ocean Tunas TWS/93/2/4. 12 pp

[19] Wilson M A 1981 The biology, ecology and exploitation of longtail tuna, Thunnus tonggol (Bleeker) in Oceania. BSc Masters thesis, Macquarie University, New South Wales 195 pp

[20] Phillips S J, Anderson R P, and Schapire R E 2006 Ecol Model. 190 231–259

[21] Alabia I D, Saitoh S, Mugo R, Igarashi H, Ishikawa Y, Usui N, Kamachi M, Awaji T, and Seito M 2015 Fish Oceanogr. 24 190–203

[22] Susilo E, and Suniada K I 2015 Proc Int Symp on Mar and Fish Res. 233 – 239

[23] Griffiths S P, Fry G C, Manson F J, and Pillans R D 2007 Mar and Fresh Res. 58 376 – 397

[24] Southward A J, Boalch G T and Maddock L 1988 J Mar Biol Assoc U K. 68 423–445

[25] Alheit J, and Hagen E 1997 Fish Oceanogr. 6 130–139

[26] Syah A F, Gaol J L, Zainuddin N, Aprilia N R, Berlianty D, and Mahabror D 2019 Proc Int Conf on Life Sci and Tech. 1 – 9

[27] Faizah R 2010 Biologi reproduksi ikan tuna mata besar (Thunnus obesus) di Perairan Samudra Hindia, Tesis. Institut Pertanian Bogor

[28] Collette B B, and Nauen C E 1983 FAO species catalogue. Scombrids of the world. An annotated and illustrated catalogue of tunas, mackerels, bonitos and related species known to date. FAO Fisheries Synopsis Vol. 2. 125, 137

[29] Syamsuuddin M L, Saitoh S I, Hirawate T, Bachri S, and Harto A B 2013 Fish Bull. 111(2) 175-188

[30] Itoh T, Tsuji S, Chow S 1996 Catch information of longtail tuna, Thunnus tonggol, in Japan
[31] Mohri M, Fukada K, Yamada H, Inoue H 2005 Relationship between longtail tuna catches and water temperature on the Sea of Japan off the coast of Yamaguchi Prefecture. Memoirs of the Faculty of Agriculture of Kinki University 38 68-75

[32] Mohri M, Fukada K, Takikawa T, Miura M 2008 Mathematical and Physical Fisheries Science 6 58-67

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