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Oceanographic characteristics at fish aggregating device sites for tuna pole-and-line fishery in eastern Indonesia

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ABSTRACT

The research was conducted to investigate the oceanographic characteristics at three traditional anchored Fish Aggregating Device (FADs) sites for tuna pole-and-line fishery in eastern Indonesia. The FADs locations, and sea surface temperature (SST) and chlorophyll-a (chl-a), salinity (sal), wave height (wav), wind (win) current (cur) were examined using a geographic information system (GIS). Relationships between Catch-per-Trip (CPT) with oceanographic characteristics (SST, chl-a, sal, wav, win and cur), were analysed using correlation and generalised additive models (GAMs) analyses. Correlation analyses was used in order to determine how strongly pairs of variables were related to one another, and generalised additive models (GAMs) were used in order to model relationships between Catch-per-Trip (response variable) and the oceanographic variables SST, chl-a, sal, wav, win and cur (predictor variables). Correlation analyses showed that significantly negative correlations were found in entire locations between SST and chl-a while in contrarily, the lowest correlation was found between CPT and chl-a. Furthermore, the GAM plots indicated that a positive association was observed between catch-per-trip and SST with approximately > 26.5 °C, chl-a was < 0,4 mg/m^3, salinity was observed between > 33 to < 34.5 (psu) for entire sites while wav was found at > 0.23 for Sorong and > 0,87 (m) in Larantuka and < 0.64 in Pulau Bacan. Win variable had positive effects at > 4.1 m/s in entire research sites while cur had a positive effect on CPT occurred at < 56 (m/s) for entire locations. The GAM models showed that SST explains up to 20 % whereas chl-a explains as the lowest variable (up to 0.78 % of the deviances) in skipjack CPT relationships, and the addition of predictor variables resulted in an increase in the deviance explained. This research provides evidence that skipjack tuna CPT has relationship with oceanographic variables in eastern Indonesia.

1. Introduction

Skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) are mostly caught by pole-and-line in eastern Indonesia at the traditional man-made artificial anchored fish aggregating devices (FADs), called *rumpon*. The used of FADs to attract skipjack schooling in eastern Indonesia dates back to 1985 (Dempster, 2004; Girard et al., 2004; Yusfiandayani, 2013). In eastern Indonesia, tuna pole-and-line fishers deploy anchored FADs in order to create an artificial shelter for skipjack and also sometimes yellowfin tuna, as well as to create a more effective method of targeting tuna (Kim, 2015; Rodriguez-Tress et al., 2017; Khan et al., 2018). A research by Taquet (2013) found that approximately 40 % of tuna catches worldwide were from the use of FADs, and concluded that skipjack fishing grounds are highly

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dependent on their deployment (Madjid et al., 2012; Robert et al., 2014; Wang et al., 2014). Thereupon, a research by Scott and Lopez (2014) reported that more than 90 % of the world's tropical tuna catches with are dominated by skipjack tuna which is come from fisheries that deploy FADs. In relation to fishing operations, the position of FADs is important for fishers in order to minimizing the search time for find tuna schooling and as well as the operation costs (Davies et al., 2014).

Furthermore, the oceanographic conditions, including sea surface temperature (SST) and chlorophyll-a (chl-a) (Andrade and Garcia, 1999; Zainuddin et al., 2013; Harsono et al., 2014) are the main parameters affect their abundances, since researchers have found that the local oceanographic environment greatly affects tuna natural migration patterns and the corresponding fishing effort (catch-per-trip) (McElroy and Uktolseja, 1992; Proctor et al., 1995). There is a greater need to observe how oceanographic characteristics variations affect tuna pole-and-line catches in eastern Indonesia, and more specifically, relationships between tuna pole-and-line Catch-per-Trip (CPT) and oceanographic characteristics (e.g. SST and chl-a) are likely to be an important driver of tuna abundance (Yuniarta et al., 2017). Eastern of Indonesia is one of the locations of migration and feeding ground of marine biota due to the high concentration of nutrient. These locations as a path of Indonesian trough-flow (ITP) currents (Harsono et al., 2014) and upwelling area (Purba and Khan, 2019).

This research aims to identify the oceanographic variable characteristics at the FADS sites and to examined relationships between tuna pole-and-line CPT and oceanographic variables at three FADs sites as the pole-and-line fishing grounds in eastern Indonesia.

2. Methods

2.1. Research sites

This research was conducted at three landing sites in eastern Indonesia, namely Sorong, Pulau Bacan and Larantuka were chosen as representative locations for fishery operations known to use FADs sites (Fig. 1). Information about the FADs coordinates as considering as the fishing grounds by the fishers were obtained from a questionnaire at Sorong and Larantuka and by observation of typical pole-and-line fishing operations of the fishers during a fishing trip in Pulau Bacan.

The two locations (Sorong and Pulau Bacan) are representing migration of tuna from Pacific Ocean where the currents come from the North and South Pacific to inner Indonesia waters, namely, the Indonesia Troughflow (ITF) currents (Harsono et al., 2014). This area also dominated by monsoonal situation periodically. Furthermore, Larantuka is located near the east side of Indian Ocean and also known as the most events of upwelling regions (Purba and Khan, 2019).

2.2. Data sources

2.2.1. Landings, trips and catch-per-trip

Fisheries data, including landings and trips undertaken during the study period were collected from landing site managers, government fisheries officers and tuna processing companies from each location. Landings and trips data in Sorong for the period 2012–2015 were obtained from a field survey conducted by a private company with monthly basis data. There was no fish processing company in operation in Pulau Bacan (Khan et al., 2019). Moreover, landings and trips data for 2007–2015 were collected from the Government of Maluku Utara Province port landing records. Landings and trips data for Larantuka were collected from two sources: those for 2010–2014 were derived from the private company; and those for the year 2015 were obtained from the landings port official's office, then the Catch-per-Trip (CPT) data comes from landings divided by trip data. Trip data refers to number of fishing trip by pole-and-line fishing vessel. One trip data means that a journey taken by a pole-and-line from fishing base to fishing ground and returns. Fishing operation at the FADs consist

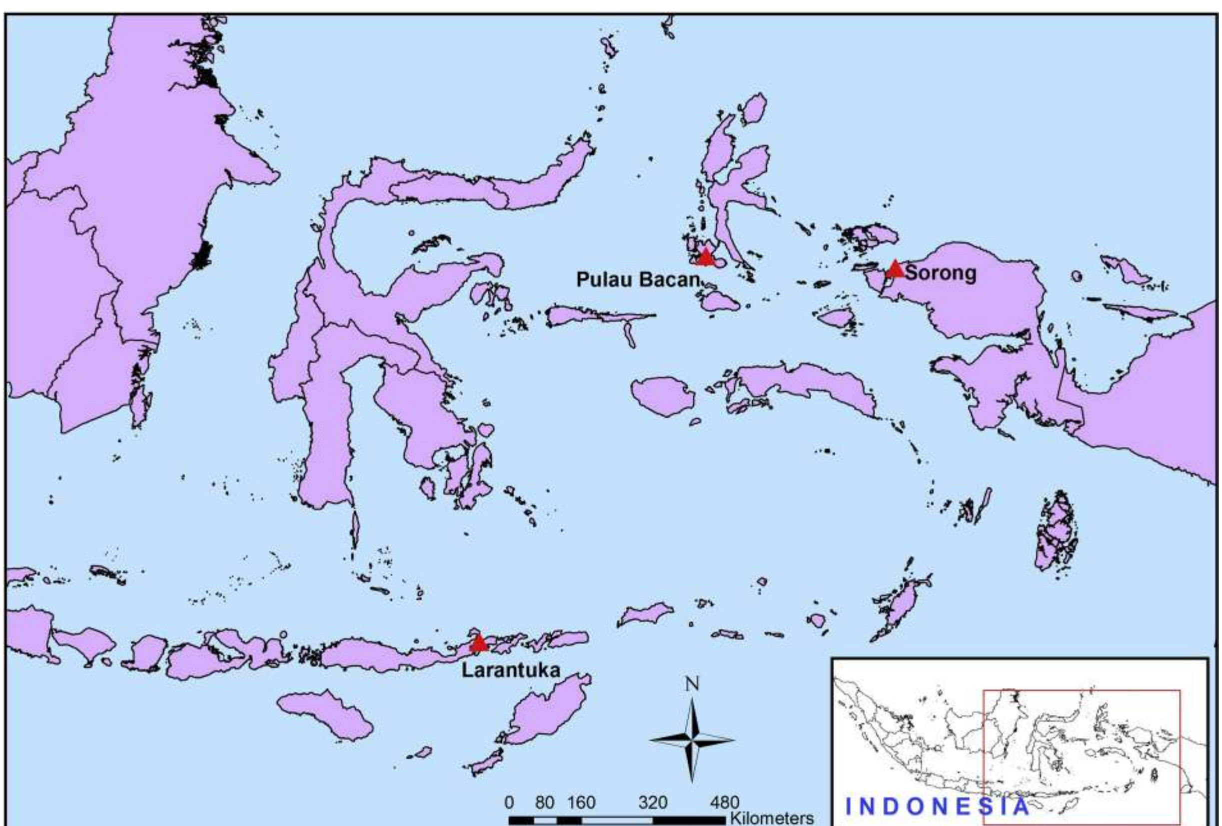

Fig. 1. Locations of research site (Sorong, Pulau Bacan, and Larantuka) in eastern Indonesia.

Table 1
FADs coordinates and oceanographic data resolutions.

Locations	FADs sites	Data resolution					
		SST	Chl-a	Sal	Wav	Win	Cur
Sorong	3^0 28' 12.8" S – 132^0 17' 46.9" E	0.1^0	$0.05\ ^0$	0.25^0	0.1^0	0.25^0	0.1^0
Larantuka	9^0 3' 9.5" S – 122^0 55' 3.47" E	0.1^0	$0.05\ ^0$	0.25^0	0.1^0	0.25^0	0.1^0
Bacan	0^0 59' 18.9" S – 127^0 22' 11.9" E	0.1^0	$0.05\ ^0$	0.25^0	0.1^0	0.25^0	0.1^0

between 45 – 60 min early in the morning but the time travelled between fishing base to fishing ground (FADs deployment's location) can be between 6–48 h. Fishing activity jointly carried out by 5–10 fishing boats and each boat consist of 10–15 crews.

2.2.2. Oceanographic data

The oceanographic data derived from satellites, especially the sea surface temperature (SST), chlorophyll-a (chl-a), salinity (sal), sea surface height (wav), wind (win) and velocity current (cur). Those data were taken on a monthly basis for relevant time periods, surface water, and corresponding to the FAD's sites. For the SST, the data were taken from the Advanced Very High Resolution Radiometer (AVHRR) Pathfinder Version 4+ Global Area Coverage (GAC) with a geographic resolution of 8 km and for chl-a, the data were taken from Aqua moderate resolution imaging spectroradiometer (Modis) with a spatial resolution of 4 km. Both SST and and chl-a data are distributed by NOAA satellite (http://pifsc-oceanwatch.irc.noaa.gov). Salinity (sal) data were taken from ECCO2 cube92 daily average Sea Surface Salinity (http://apdrc.soest.hawaii.edu) (Table 1). These oceanography data sources have proven to describe the ocean conditions (Bulgin et al., 2016; Park et al., 2015).

The oceanography spatial data set were corresponding to the three specific FADs sites and with specific temporal data period of interest. Considering several factors for oceanographic data availability, null data have been removed from the dataset. Oceanographic data were resampled into sampling interval (monthly) temporal resolution and then subset to the Catch-per-Trip (CPT) data (Zainuddin et al., 2017). It was assumed that the spatial data resolution of the oceanographic characteristics and fisheries data are not considerably varies within the spatial resolution for fishing location in the research sites (Rajapaksha et al., 2013).

2.3. Data analysis

2.3.1. Global information system (GIS)

The oceanography variables (SST and chl-a) data were mapped for each FADs sites and surrounding waters using ArcGIS 10.2.1, and a graphic visualisation of these oceanic variables was undertaken in order to understand the distribution of the specific oceanographic conditions.

2.3.2. Relationships between CPT and oceanographic factors

Correlation analysis was used in order to determine how strongly pairs of variables were related to one another, and generalized additive models (GAMs) were used in order to model the relationships (Zainuddin et al., 2017) between Catch-per-Trip (CPT) as response variable and the oceanographic variables SST, chl-a, salinity, wave, wind and currents as the predictor variables at the FADs sites (Wang et al., 2014). The CPT was log-transformed which followed a normal distribution and modelled using the Gaussian distribution family (Coletto et al., 2019). Explanatory model terms were treated as continuous variables, and splines were fitted to each term in the model (Zuur et al., 2009b). The Akaike Information Criterion (AIC) and deviance were used to understand and qualify the optimum model (Zuur et al., 2007, 2009a).

Table 2
Landings, trip, and CPT for each landing sites.

Year/Location	Landings (Kg)	Trip	Catch-per-trip (Kg/trip)
Sorong			
2012	822,887	56	14,694.4
2013	1,543,917	89	17,347.4
2014	1,587,489	69	23,007.1
2015	1,714,169	69	24,843
Larantuka			
2010	5,010,765	3,746	1,337.9
2011	3,831,731	3,599	1,064.7
2012	3,593,743	2,868	1,253.1
2013	2,471,204	1,287	1,920.1
2014	2,259,945	1,443	1,566.2
2015	1,890,731	1,435	1,317.6
Pulau Bacan			
2007	755,188	1,230	614
2008	514,935	1,243	414
2009	534,982	1,256	426
2010	1,311,741	1,184	1,108
2011	1,917,264	1,734	1,106
2012	2,371,204	2,217	1,070
2013	3,218,914	1,503	2,142
2014	2,728,331	1,916	1,946
2015	3,158,457	990	3,190

The GAMs was tested based on the following formula:

$$\log(CPT) = \alpha 0 + s(SST) + s(Chl - a) + s(Sal) + s(Wav) + s(Win) + s(Cur) + \varepsilon$$

Where:

$\alpha 0$ = model constant
s = smoothing function of the variables
ε = error terms

The correlation and GAMs analyses were constructed in an R software environment (version 3.0.2; R Development Core Team) with the function of the mgcv package for the GAM (Everitt and Hothorn, 2010; Martínez-Rincón et al., 2012) and the nlme package used for the linear model then the performance analytics package for correlation analyses.

3. Result

3.1. Landings conditions

All landings data (Table 2) shows a fluctuated trend among research locations. Annual tuna landings in Sorong increase more than doubled within four years (2012–2015). As in Pulau Bacan, the annual landings data increase more than 100 % in eight years, from 2007 to 2015. Landings data were low in 2007–2010 and then steadily in 2011–2015. Contrarily, tuna landings data in Larantuka has revealed that the annual landings declined more than tripled within five years (2010–2015).

Furthermore, the FAD in Sorong is located around 166 nautical miles (nm) in a south-eastern straight-line direction from their fishing base, and is adjacent to the Kabupaten Fakfak District of Papua Barat Province (Fig. 2A) and part of Aru Seas. This location has also been confirmed by a statement from one of the key informant fishers (KI-02) during the research survey, who stated, "*our FAD location is in Fakfak in the Seram Sea. It is approximately* 28 h*'cruise time and more than 120 nm in a straight line from the fishing base in Sorong to the FAD location*" (KI-02, 08 August 2015). The mean chl-a around the FAD during 2012–2015 ranged from 0.06 mg/m^3 to 1.58 mg/m^3 (Fig. 2B), whilst the mean SST ranged from 23.8–30.9 °C (Fig. 2C). Furthermore, in Pulau Bacan the FAD is located 22.5 nm in a straight-line and in a south-western direction from the fishing base (Fig. 2D) in the Maluku Sea, Kabupaten Halmahera Selatan District (Maluku Utara Province). One of the fishers

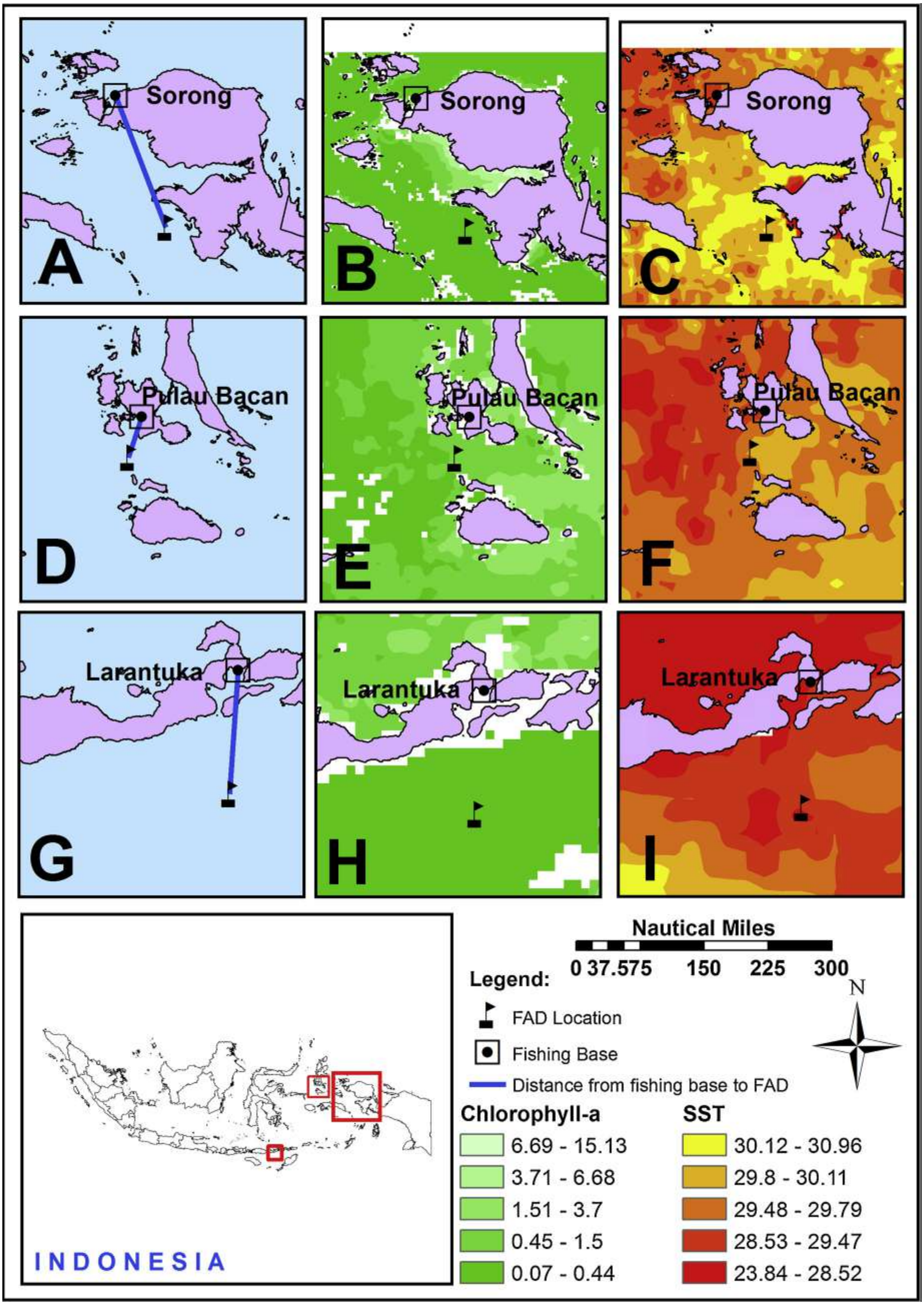

Fig. 2. FAD locations, fishing bases and oceanographic characteristics at the three locations. The blue line indicates the straight-line distance on a given bearing from the fishing base to the FAD location in Sorong (A), Pulau Bacan (D), and Larantuka (G). (B) Mean chlorophyll-a from 2012 to 2015 at the FAD and surrounding waters in Sorong. (C) Mean SST from 2012 to 2015 at the FAD and surrounding waters in Sorong. (E) Mean chlorophyll-a from 2007 to 2015 at the FAD and surrounding waters in Pulau Bacan. (F) Mean SST from 2007 to 2015 at the FAD and surrounding waters in Pulau Bacan. (H) Mean chlorophyll-a over the period 2010–2015 at the FAD and surrounding waters in Larantuka. (I) Mean SST from 2010 to 2015 at the FAD and surrounding waters in Larantuka. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

Table 3
Correlation matrix.

Location	Parameters							
		CPT	SST	Chl-a	Sal	Wav	Win	Cur
Sorong	CPT		−0.19	−0.06	−0.1	0.41	−0.23	−0.44
			0.69	0.9	0.84	0.36	0.62	0.33
	SST	−0.19		−0.88	0.86	0.29	−0.79	−0.51
		0.68		0.0095	0.01	0.53	0.03	0.25
	Chl-a	−0.06	−0.88		−0.61	−0.12	0.6	0.61
		0.9	0.0096		0.15	0.8	0.15	0.15
	Sal	−0.1	0.86	−0.61		0.61	−0.87	−0.37
		0.84	0.01	0.15		0.14	0.01	0.41
	Wav	0.41	0.29	−0.12	0.61		−0.77	−0.12
		0.36	0.53	0.8	0.15		0.04	0.79
	Win	−0.23	−0.79	0.6	−0.87	−0.77		0.48
		0.62	0.03	0.15	0.01	0.04		0.27
	Cur	−0.44	−0.51	0.61	−0.37	−0.12	0.48	
		0.33	0.25	0.15	0.41	0.8	0.27	
Pulau Bacan	CPT		−0.25	0.16	0.15	−0.1	−0.05	−0.27
			0.59	0.73	0.75	0.84	0.93	0.56
	SST	−0.25		−0.94	0.34	−0.24	−0.04	0.16
		0.56		0.002	0.46	0.61	0.93	0.73
	Chl-a	0.16	−0.94		−0.59	0.11	−0.17	−0.09
		0.73	0.002		0.16	0.82	0.72	0.84
	Sal	0.15	0.34	−0.59		−0.04	0.07	−0.06
		0.75	0.46	0.16		0.94	0.88	0.9
	Wav	−0.1	−0.24	0.11	−0.04		0.38	0.07
		0.84	0.61	0.82	0.94		0.39	0.88
	Win	−0.05	−0.04	−0.17	0.07	0.38		−0.38
		0.93	0.93	0.72	0.88	0.39		0.4
	Cur	−0.27	0.16	−0.09	−0.06	0.07	−0.38	
		0.56	0.73	0.84	0.9	0.88	0.4	
Larantuka	CPT		0.08	−0.13	−0.02	0.12	−0.3	−0.32
			0.86	0.77	0.96	0.79	0.51	0.48
	SST	0.08		−0.98	0.84	0.34	−0.44	−0.54
		0.86		0.0001	0.02	0.45	0.32	0.21
	Chl-a	−0.13	−0.98		−0.86	−0.29	0.35	0.59
		0.77	0.0001		0.01	0.53	0.44	0.16
	Sal	−0.02	0.84	−0.86		0.06	−0.41	−0.62
		0.96	0.02	0.01		0.91	0.35	0.14
	Wav	0.12	0.34	−0.29	0.06		−0.53	0.03
		0.79	0.45	0.53	0.91		0.22	0.94
	Win	−0.3	−0.44	0.35	−0.41	−0.53		−0.04
		0.51	0.32	0.44	0.35	0.22		0.94
	Cur	−0.54	0.59	−0.62	−0.62	0.03	−0.04	
		0.45	0.21	0.16	0.14	0.95	0.94	

Note from parameters:
First row: correlation values.
Second row: significances.

participated on the field survey (KI-40) stated that "*our fishing ground is where the FAD was deployed and is approximately four hours' cruise and around 55 nm in a straight line from the fishing base in Pulau Bacan*" (KI-40, 16 August 2015). The mean chl-a concentration around the FAD ranged from 0.04 mg/m^3 to 3.04 mg/m^3 between 2007 and 2015 (Fig. 2E), the SST ranged from 28.1 °C to 30.9 °C (Fig. 2F). Whilst, in another site, in Larantuka, the FAD is located in the Sawu Sea, which is approximately 44 nm in a straight-line and in a southern direction from the fishing base (Fig. 2G). A key informant fisher (KI-33) has confirmed this location by stating that, *"the fishing ground is where the FAD was deployed and located in the Sawu Sea and approximately eight hours' cruise and 20 nm from the fishing base in Larantuka"* (KI-33, 25 August 2015). The mean chl-a at the FAD (and in the surrounding waters) during 2010–2015 ranged from 0.05 mg/m^3 to 2.7 mg/m^3 (Fig. 2H), and then the mean SST varied from 28.1 °C to 30.9 °C (Fig. 2I).

3.2. Relationship between CPT and oceanographic factors

Result from correlation analysis showed that mostly the predictor variables (SST, chl-a, sal, wav, win and cur) were not significantly correlated with CPT (Table 3). However, the highest significantly negative correlations were found between SST and chl-a in Sorong ($r = -0.88$; $p \leq 0.05$), in Pulau Bacan ($r = -0.94$; $p \leq 0.005$) and Larantuka ($r = -0.98$; $p \leq 0.001$). Contrarily, the lowest negative correlation was found between CPT and chl-a in Sorong ($r = -0.06$; $p \leq 1$) and Larantuka ($r = -0.13$; $p \leq 1$) as well as positive correlation in Pulau Bacan ($r = 0.16$; $p \leq 1$) (Table 3).

The results from GAM plots indicated that oceanographic variables (SST, chl-a, sal, wav, win and cur) have effects on CPT (Fig. 3). A positive association was observed between CPT and SST in the ranges from 26.5–29.5 °C in Sorong, < 28.75 °C and > 29,75 °C in Pulau Bacan, and > 29.3 °C for Larantuka. There were also positive effects on CPT where chl-a was approximately < 0.4 mg/m^3 for entire location (Sorong, Pulau Bacan, and Larantuka). Salinity variable had positive effect on CPT at > 33.9 and < 34.4 (psu) in Sorong, between < 33.5 and > 34.1 (psu) in Pulau Bacan and between < 33.5 and > 33.7 (psu) in Larantuka. This research found that wav had a positive effect on CPT approximately > 0.23 (m) for Sorong and Pulau Bacan but also between < 0.64 and > 0.87 (m) in Larantuka. Positive effect on wind occurred at > 4.1 m/s in Sorong and Larantuka but slightly different for Pulau Bacan, the positive effect was found at > 3.2 m/s. GAM plot results are shown in Fig. 3 for cur had a positive effect on CPT occurred

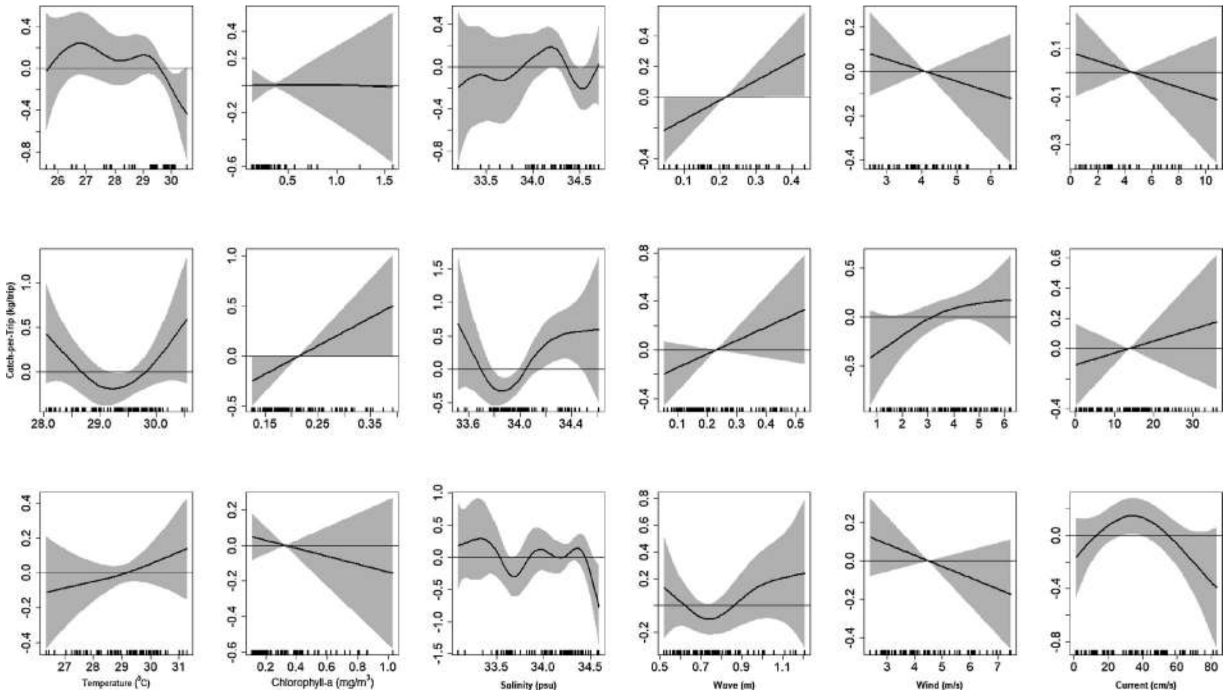

Fig. 3. GAM plots the effect of oceanographic characteristics for SST, chl-a, sal, wav, win and cur (columns) on monthly tuna pole-and-line CPT for Sorong (top row), Pulau Bacan (middle row) and Larantuka (last row). The x-axis represents the values of predictor variables and the y-axis shows the results of smoothing the fitted values. The tick marks on the *x*-axis represents the values of the observed data points; the solid line indicates the fitted function. The grey area shows 95 % confidence bands. The horizontal line at zero represents no effect and positive effect on Catch-per-Trip with predictor variables above the zero-point line.

at < 5 (cm/s) in Sorong, > 14 (m/s) for Pulau Bacan and between > 18 and < 56 (m/s) in Larantuka.

SST explained the highest deviances in skipjack CPT at 20.4 % in Sorong, furthermore sal explained 15.8 % for Pulau Bacan and 17. % in Larantuka, on the contrary, the chl-a explained the lowest deviances in skipjack' CPT at 0.31 % in Sorong and 0.78 % for Larantuka followed with cur variable at 0.63 % in Pulau Bacan (Table 4). The addition of predictor variables resulted in an increase in the deviance explained. The final model derived from the GAM demonstrated that CPT and the oceanographic variables (SST, chl-a, sal, wav, win and cur) explained at 43.6 %, 51.8 % and 40.5 % for Sorong, Pulau Bacan and Larantuka respectively (Table 4).

From the GAM analysis' result in this research (Table 4), SST is the most significant explanatory variable in explaining skipjack CPT rather than chl-a in Sorong then salinity in Pulau Bacan and Larantuka. The final model with additional of other oceanographic factors as predictor variables, it was then used to understand the natural relationship between Catch-per-Trip and the covariates.

4. Discussion

4.1. FAD locations and oceanographic conditions

CPT data clearly play a highly significant role in fisheries management, and most landings data published by some countries may result in underestimates (Anticamara et al., 2011) and can lead to a misinterpretation of the landings data during analysis. Nevertheless, in this research, the findings only provide an illustrative snap-shot of the tuna landings and oceanographic characteristics at FADs sites in eastern Indonesia. The CPT data revealed no significant difference overall in the tuna pole-and-line fisheries in Sorong, Pulau Bacan and Larantuka. These results can vary in every location particularly when the data reported by companies may be biased and misreported. As Pet-Soede et al. (1999); Khan et al. (2018) and Khan et al. (2019) observed, the accuracy and validity of Indonesian production data is still debatable. Not only in Indonesia, another researchers also found that the lack of sound fisheries data were one of the problems that faced by the US government related to creating sustainability in fisheries development (Benson et al., 2016).

The deployment of FADs for tuna pole-and-line fishery in this research is located more than 20 nm from their fishing bases. During the field survey, it was observed that the pole-and-line fishery targeted only skipjack and yellowfin tuna and heavily depends on the deployment of FADs. These findings are consistent with evidence from other research. For example, skipjack tuna have a strong tendency to associate with anchored floating objects (Matsumoto et al., 1984) and yellowfin tuna were found to orientate themselves towards FAD within a radius of approximately 10 km (Girard et al., 2004). furthermore, yellowfin tuna had longer FAD residence times than skipjack (Rodriguez-Tress et al., 2017) and it can be assumed that skipjack have greater mobility than yellowfin (Matsumoto et al., 2016).

Aside from the presence of FADs, oceanographic factors, such as SST and chl-a were also found relate to tuna abundance in the region. In this study, SST varied from 23.8 °C to 30.9 °C at the FADs, and in the surrounding waters. This finding is unsurprising considering that the oceanographic factor most widely considered likely to affect tuna schooling behaviour is SST (Lehodey et al., 1997; Santos, 2000; Matsumoto et al., 2016). Chl-a variation between 0.04 and 1.58 mg/m^3 was found across FAD sites. This is consistent with other researches within the region by Zainuddin et al. (2013) and Syamsuddin et al. (2013) which found that levels of chl-a abundance affected the distribution of skipjack and yellowfin tuna. These oceanographic characteristics are important for the spatial distribution of the tuna schooling in the tropical waters such as Indonesia (Zainuddin et al., 2013). SST might not represent temperature distribution below surface waters, but additional oceanographic variables may reduce to bias on understanding the relationship with CPT. Realizing that only the satellite infrared SSTs can represent the SST of the 10 < mu > m thick skin layer of the ocean, future efforts should be aimed at separating the satellite skin SSTs from the 1 − 5 m deep bulk SSTs measured by the

Table 4
Results of GAM on tuna pole-and-line log-CPT: adjusted R^2, p value, deviance explained and the Akaike's Information Criterion (AIC).

Model	Explanatory variable	R^2 adjusted	*p*-value	Deviance explained	AIC
Sorong					
1. SST	SST	0.128	0.157	20.4 %	46.1
2. Chl-a	Chl-a	−0.024	0.964	0.31 %	47.7
3. Salinity	Salinity	0.086	0.4	18.9 %	49.1
4. Wave	Wave	0.071	0.047	9.3 %	46.3
5. Wind	Wind	−0.007	0.41	1.64 %	49.8
6. Current	Current	−0.006	0.39	1.75 %	49.8
7. SST +	SST	0.28	0.05	43.6 %	39.7
Chl-a +	Chl-a		0.08		
Sal + Wav	Salinity		0.39		
+ Wind +	Wave		0.21		
Cur	Wind		0.56		
	Current		0.19		
Pulau Bacan					
1. SST	SST	0.06	0.09	7.7 %	266.5
2. chl-a	chl-a	0.03	0.05	3.8 %	271
3. Salinity	Salinity	0.13	0.008	15.8 %	262.5
4. Wave	Wave	0.02	0.14	2.19 %	270.3
5. Wind	Wind	0.03	0.17	3.99 %	271.8
6. Current	Current	−0.004	0.43	0.63 %	274.3
7. SST +	SST	0.41	0.02	51.8 %	229.8
Chl-a +	Chl-a		0.003		
Sal + Wav	Salinity		1.1×10^6		
+ Wind +	Wave		0.12		
Cur	Wind		0.76		
	Current		0.46		
Larantuka					
1. SST	SST	−0.00023	0.45	1.63 %	127.9
2. chl-a	chl-a	−0.00639	0.46	0.78 %	124
3. Salinity	Salinity	0.1	0.18	17.7 %	120.9
4. Wave	Wave	0.031	0.35	6.55 %	121
5. Wind	Wind	0.007	0.23	2.07 %	123.1
6. Current	Current	0.071	0.11	9.86 %	119.4
7. SST +	SST	0.25	0.96	40.5 %	111.7
Chl-a +	Chl-a		0.38		
Sal + Wav	Salinity		0.05		
+ Wind +	Wave		0.56		
Cur	Wind		0.17		
	Current		0.03		

buoys and ships (North et al., 2014)

Other factors affected the success of FAD deployment at fishing grounds, including fishers' experiences. Fishers selection of productive fishing grounds reflected fishers knowledge of the migration paths of the tuna (Roza Yusfiandayani, *personal communication*, 20 July 2017), and ocean sea bed contours related to the installation of the FADs (Pradipta, 2014). Furthermore, socio-economic factors are considered in the deployment of FADs. For example, the distances between FADs deployment and fishing bases for the Philippines FAD fishery are based on the fishers personal financial resources (Macusi et al., 2017b), the cost and efficiency of fishing operations (Cayre, 1991) including fuel cost considerations (Macusi et al., 2017a) and the need to maintain catch freshness (Macusi et al., 2015).

The ranges SST anomaly at the research locations fluctuated between 2.5 and 4.9 °C while the chl-a range varied between 0.27 and 1.45 mg/m^3. These observation accord with other work in these tropical waters, where although there is significant seasonal variation, there is low inter-annual variation in both SST (Matear et al., 2015) and sea-surface chl-a concentration (Messié and Radenac, 2006). For example, Karman et al. (2016) found that inter-annual variation of SST in Pulau Bacan from 2008 to 2012 was low, ranging between 1.8 and 2.6 °C, whilst the chl-a difference was 0.2 mg/m^3. Setiawati et al. (2015) reported that in the southern Java and Bali waters, where small differences in SST (1.2–1.3 °C) and chl-a data (0.05-0.06 mg/m^3) occurred from January 2006 to December 2010.

4.2. Relationship between CPT and oceanographic factors

The oceanographic characteristics in this research (SST, chl-a, sal, wav, win and cur) were the natural explanatory variable in explaining skipjack CPT relationships. This is consistent with other researches within Indonesia and the regions (Kuo-Wei et al., 2017; Kanaji et al., 2012; Zainuddin et al., 2013). For instance, there was a relationship between skipjack tuna CPUE and SST in Brazilian waters (Andrade and Garcia, 1999; Andrade, 2003). But on the other hand, skipjack CPUE variations were probably influenced by seasonal variability of other environmental conditions than just SST and chl-a alone, such as depth, fronts and abundance of prey (Andrade and Garcia, 1999). In line with this study, a correlation was shown between tuna CPUE with SST and chl-a within the regions (Syamsuddin et al., 2013; Zainuddin et al., 2013; Usman et al., 2017). Relationships variation between CPUE with SST and chl-a from this research might be influenced by other factors that are not included in the analysis, such as depth (Syamsuddin et al., 2013; Harsono et al., 2014).

However, the nature relationship between skipjack CPUE and SST was confirmed by Andrade and Garcia (1999) who found that other biotic and abiotic factors are more important in the relationships between skipjack tuna CPUE and SST (Andrade, 2003), as this species is better adapted to coping with temperature variations in equatorial waters (Zainuddin et al., 2013). There may be a correlation between tuna biological life history with oceanographic variables, which would support the idea that skipjack tuna have little tolerance of low SST (Boyce et al., 2008) at some stage. Moreover, this may have varied according to the progressive biological stages of the tuna from larva, juvenile and adult stages, where adult tuna had more tolerance of the temperature ranges (Boyce et al., 2008). The distribution and prevalence of their natural prey (e.g. anchovies, sardines) may have also influence any relationship between CPUE with SST and chl-a, which are associated with thermal fronts (Klemas, 2013). The model results from the GAM analyses in this research showed that additional oceanographic variables are the best explained variations in CPT.

5. Conclusions

This research illustrated the relationships of oceanographic variables (SST,chl-a, sal, wav, win and cur) on CPT at representative FAD sites in Sorong, Pulau Bacan and Larantuka, eastern Indonesia. Tuna pole-and-line fishing grounds in eastern Indonesia are heavily dependent on the deployment of FADs. The models from the CPT, with SST, chl-a, sal, wav, win and cur may have explained up to 51.8 % of their relationships. However, future studies must be relied to investigate the relationships between CPUE and other biotic and abiotic factors that are not included in this research, such as depth and live-baits availability to give a more integrated and comprehensive analyses.

Declaration of Competing Interest

None.

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