Mapping distribution patterns of skipjack tuna during January-May in the Makassar Strait

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Abstract. Skipjack tuna is an important fishery species, targeted by purse seine and handline fisheries in Makassar Strait. Fish distribution patterns are markedly influenced by several underlying oceanographic factors. This study aimed to assess the relationship between skipjack CPUE and some oceanographic variables, and map out the distribution pattern of this fish in the study area during January-May 2018. To meet these objectives, we combined satellite data of sea surface temperature (SST) and chlorophyll-a concentration (chl-a) with catch data. We used generalized additive models (GAMs) to explore skipjack abundance in relation to the oceanographic conditions and we employed the gravity centre of fishing ground movements to map the fish distribution pattern. Results indicate that SST and chl-a significantly influenced skipjack tuna CPUE. The fish schools were mostly located in the eastern Makassar Strait. In January skipjack schools were initially in Majene offshore waters and moved to Mamuju waters in February. The skipjack schools returned to the border area between Polman and Majene waters in March and then made a continuous migratory journey to the south-western areas of Barru and Pare-pare offshore waters in April. In May, the skipjack tuna returned to concentrate in southern areas of Majene waters. We proposed that the fish schools followed a clock-wise distribution movement pattern where the habitat displacements may have a link with the dynamic ranges of preferred oceanographic conditions (habitat hotspots). It is likely that these areas provide good feeding opportunities for skipjack tuna.

1. Introduction

The skipjack tuna, *Katsuwonus pelamis*, is a commercially important and highly migratory fish occurring in all tropical and subtropical waters of the world. Skipjack is one of the largest predators of the oceans, reaching 108 cm in fork length and 34.5 kg in weight [1]. Distribution and migrations of skipjack tuna have been explored in the western Pacific Ocean [2]. [3] reported that there are a number of semi-independent stocks of skipjack tuna in the Pacific Ocean. Several studies found that many skipjack tuna tend to remain around their tropical spawning area, and do not demonstrate long-distance migratory movements, migrating toward the northern and southern temperate regions [4]. Information concerning skipjack tuna distribution patterns would provide basic knowledge for fish movement studies, conservation, and fisheries management, supporting effective and sustainable use of skipjack tuna resources.

In the western Pacific and tropical Pacific Ocean, dynamic movements and abundance of the skipjack tuna are reported as being strongly associated with a number of oceanographic factors, in particular sea surface temperature (SST) and chl-a concentration [5–8]. A salinity front with SST of 28.5°C and hotspots with chl-a 0.2 mg m^{-3} provided a good proxy for skipjack tuna movement and abundance in the western equatorial Pacific [6–9].

Makassar Strait is an important skipjack fishing ground in the western coral triangle area, and is located in the western part of Indonesian Fisheries Management Area 713. However, little is known about the distribution pattern of skipjack tuna in that area. Using synoptic measurements of remotely sensed satellite data on SST and chl-a concentration, this study aimed to investigate the relationship between skipjack tuna CPUE and a number of oceanographic variables, and map the distribution pattern of this fish in the southern Makassar Strait during January-May 2018.

2. Data and Methods

2.1. Fishery data

The purse seine fishery extending from the Bone Gulf to Flores Sea (116°E-121°E and 1°S-6°S) captures mainly skipjack tuna throughout the year. Scientific fishing surveys were conducted in the Makassar Strait during January-May 2018 to collect fishery and oceanographic data. The fishery data comprised daily geo-referenced fishing positions (latitude and longitude), catch (number of skipjack tuna) and effort (fishing set) data, from which catch per unit effort (CPUE) was determined in number of fish per setting. These data were further analysed to compile a monthly resolution dataset. These fishing observation data were plotted on satellite images.

2.2. Satellite Data

The bio-physical environmental data used to describe the oceanographic condition around the purse seine fishing locations were surface chl-a concentration and sea surface temperature (SST). Aqua/MODIS (Moderate Resolution Imaging Spectroradiometer) level 3 standard mapped images (SMI) data were used to estimate surface chl-a concentration and SST at all fishing ground positions across the study area. NASA distributes the level 3 binary data in NetCDF (Network Common Data Form) format. These data were obtained from NASA GSFC's Distributed Active Archive Center (DAAC) (http://oceancolor.gsfc.nasa.gov/). For this study, we used Global Area Coverage (GAC), monthly mean MODIS data with a spatial resolution of about 4 x 4 km in latitude and longitude for the period of January to May 2018.

2.3. Analysis of Skipjack Distribution Pattern

To analyse the distribution patterns of skipjack tuna in the study area, firstly we plotted the skipjack fishery data on the SST and chl-a images from January to May 2018. The satellite data were then extracted for each pixel corresponding to the purse seine fishing locations. Secondly, we assessed the relationship between the oceanographic variables derived from satellite and the skipjack CPUE at all fishing positions using a Generalized Additive Model (GAM) [6]. Thirdly, we used predicted CPUE and the fishing positions to analyse the skipjack distribution pattern using the centre gravity of the fish distribution approach [9]. The monthly gravity centres of fishing grounds were mapped using the ArcGIS 10.x software package. This study used the following formulas to calculate predicted CPUE and the gravity centre of CPUE, respectively [9,10]:

$$CPUE = \alpha + s(SST) + s(chl\text{-}a) + \varepsilon$$

$$GC_{ij} = \frac{\Sigma L_{ij}(CPUE)_{ij}}{\Sigma CPUE_{ij}}$$

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where α = constant
$s(.)$ = spline smooth function of SST and chl-a
ε = random error term
GCij = monthly gravity centre of fishing grounds at longitude and latitude position (Lij)
CPUEij = catch per unit effort (fish/fishing set) at the ij position.

3. Results and Discussion

Figures 1 and 2 show the spatial distribution of skipjack tuna fishing grounds and CPUE overlain on chl-a and SST images, respectively, during January-May 2018.

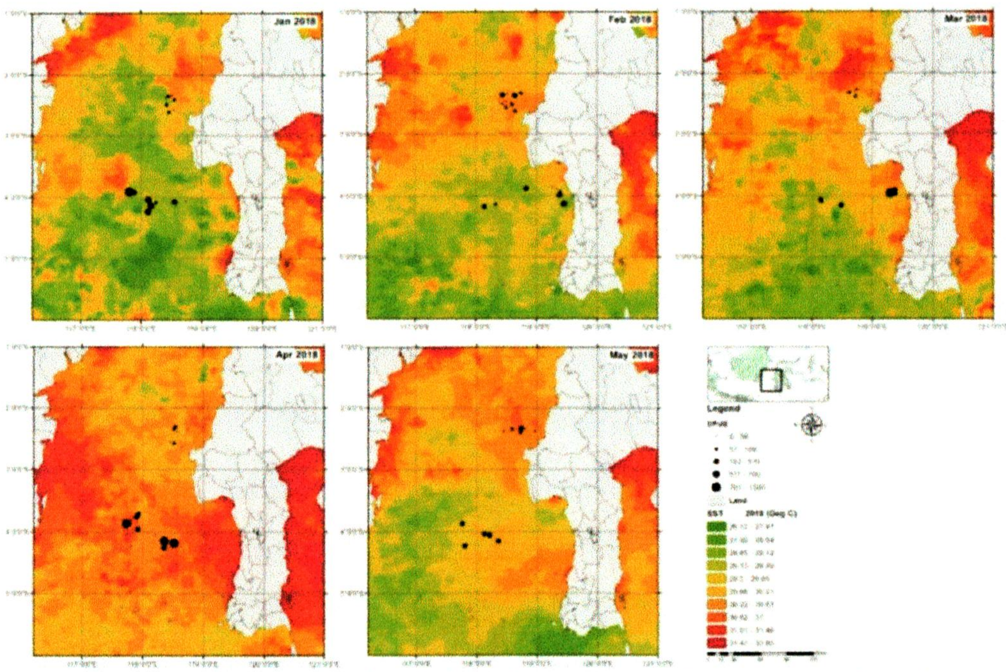

Figure 1. The spatial distribution of skipjack CPUE (fish/set) from the purse seine fishery shown as black dots (dot size indicates CPUE) overlain on Aqua/MODIS SST images for January-May 2018.

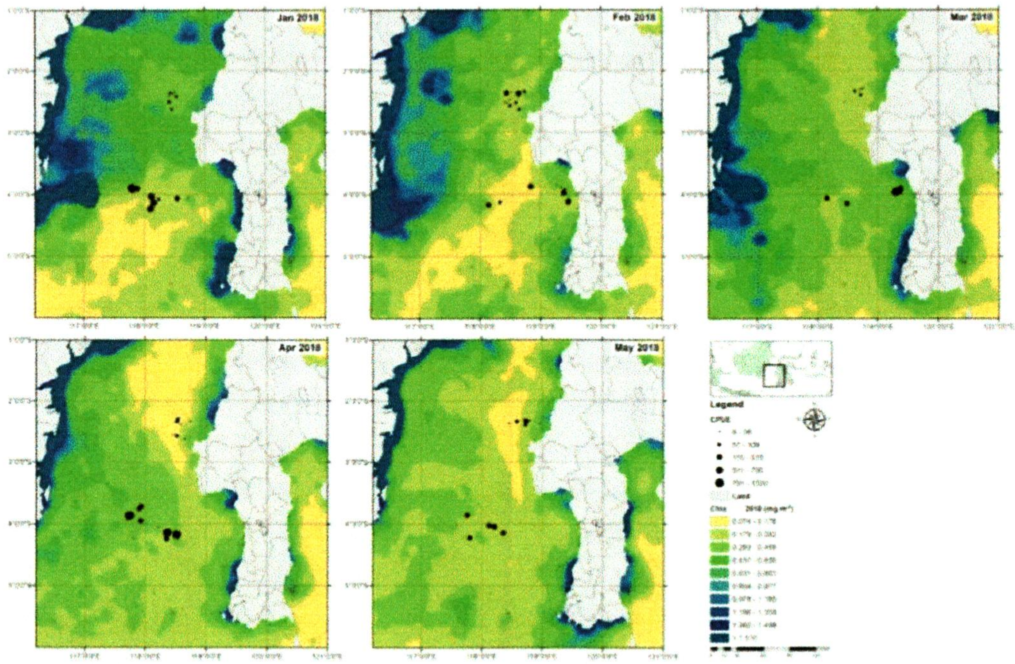

Figure 2. The spatial distribution of skipjack CPUE (fish/set) from the purse seine fishery shown as black dots (dot size indicates CPUE) overlain on Aqua/MODIS chl-a images for January-May 2018.

In January, relatively high skipjack tuna concentrations were found in the southern part of Makassar Strait. Specifically, the fish mostly assembled in areas of 117.5-118.5 °E and 3.5-4.5°S which are known as one of the best fishing grounds in the eastern part of Indonesia [11,12]. Along an area stretching from west to east from January-March, skipjack fishing grounds were well developed and strongly associated with chl-a of 0.18-0.28 mg m^{-3} and SST of 29-30°C, particularly in January. Both oceanographic variables had a significant effect in explaining skipjack abundance in Makassar Strait, as previously reported [13].

In January, the highest CPUE values tended to be concentrated near the fishing ground position of 118°E and 4°S, in waters offshore from Parepare, Pinrang and Barru Districts. The SST and chl-a image maps in February shows that the distribution of skipjack fishing grounds was well developed in both Mamuju and Barru-Parepare coastal waters, where the greatest CPUEs corresponded with 29.86-30.21°C SST and 29.13-29.85°C SST, respectively, with skipjack tuna distribution mainly occurring in areas with relatively high chl-a concentrations (0.18-0.46 mg m^{-3}). The spatial distribution in February was more extensive compared with the previous month, and the skipjack tuna concentrations tended to move towards the northern part of the fishing area.

During February-March, skipjack fishing grounds which formed in the coastal waters of Barru, Parepare and Pinrang districts corresponded with the 29 and 30°C SST isotherms, and 0.2-0.3 mg m^{-3} chl-a isopleths (Figures 1 and 2). It was found that mean skipjack CPUE was lower during February-March than in January. Preferred oceanographic conditions in terms of both SST and chl-a developed offshore in January and moved towards coastal areas along the 4°S line of latitude during February-March. In March, skipjack concentrations moved back southwards, to the coastal waters of Barru-Parepare.

Both variables (SST and chl-a) had significant effects and contributed towards explaining skipjack CPUE (Table 1). The dynamics of the preferred habitat niche appeared to be consistent with the fishing ground distributions. In the Gulf of Bone and the Flores Sea, the isotherm 30°C SST and 0.2 mg m^{-3}chlaisopleth have also been found to be a good proxy for skipjack tuna hotspots [6,8,14].

Table 1. Statistical description of the GAM for skipjack CPUE in relation to oceanographic variables.

Statistics	Oceanographic variable		Total
	SST	chl-a	
Probability value	0.00521**	0.0266*	
Deviance explained	13.3%	3.04%	28.2%
Akaike information criterion (AIC)	2349.302	2357.535	2334.369

The distribution patterns of CPUE in April and May were very similar, but skipjack tuna abundance differed. Skipjack tuna CPUE was generally higher in April than in May (Figures 1 and 2). April had the highest CPUE values of any month during the study period. The satellite images show that in April the skipjack fishery occupied the southern part of the study area, where SST (30.0-31.5°C) and chl-a (0.3-0.60 mg m^{-3}) were relatively higher than in May. The data shown in Figure 3 confirm that the highest catches occurred in areas of SST from 30 to 30.5°C and chl-a 0.15-0.20 and 0.25-0.30 mg m^{-3} with lower Akaike information criterion (AIC) value for total variables. These results are similar to those from previous studies in the Gulf of Bone and Flores Sea [6].

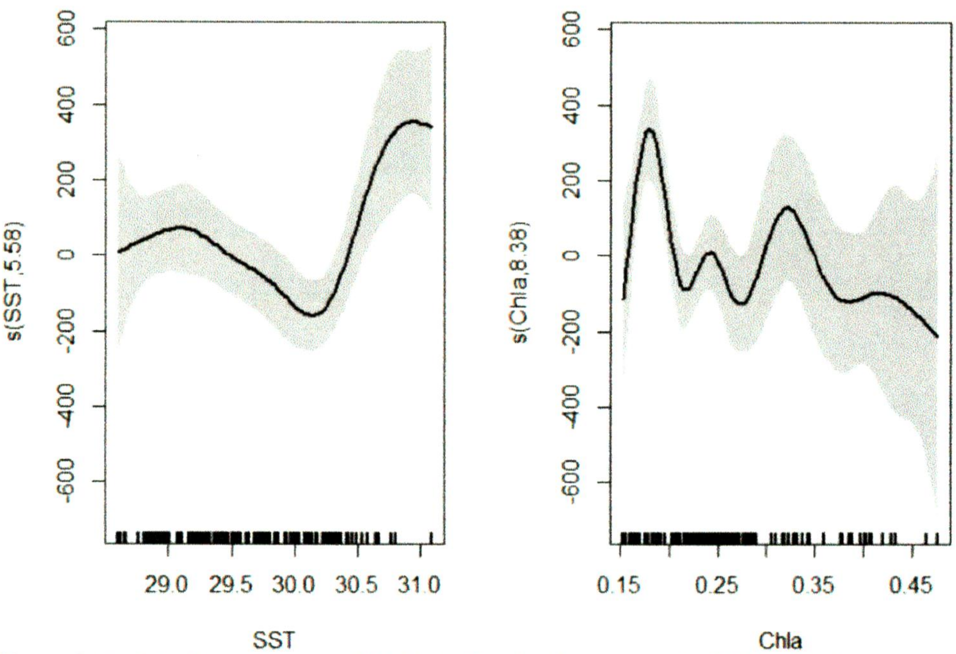

Figure 3. Partial effect estimates of GAM for the significant variables SST and chl-a concentration. Shaded regions are 95% confidence bands for smoothed splines (black lines) showing the respective association of each variable with skipjack tuna abundance. The density of raw data is displayed in the rug plot at the bottom of each diagram.

The highest catch rates of skipjack tuna in the Gulf of Bone were significantly related to the thermal and chl-a fronts [8]. In the northern area of the Makassar Strait (Mamuju waters), the highest fish concentrations (based on CPUE) were mainly obtained in waters of 29.5-31.0 °C SST and 0.07-0.28 mg m^{-3}chla density. During April-May, skipjack CPUE were consistently highest in the same areas (117.5-118.5 °E and 3.5-4.5°S for southern Makassar Strait, 2-3°S and 118.5-119.0°E for the northern area, in Mamuju waters). It also seems that during the study period the skipjack tuna concentrations moved westwards in April and appeared to move northwards in May.

It was interesting to note that the overall pattern of skipjack tuna movement in the study area during January-May describes a clock-wise shift in distribution (Figure 4). The skipjack tuna seem to have moved from offshore to the northern part of the study area in January and then during February-March the movement continued towards the coastal areas off Barru-Parepare-Pinrang districts in the southeastern Makassar Strait. Finally, during April-May the fish concentrations moved west to towards offshore areas and then began to move north towards the waters off Mamuju District. This finding suggests that the distribution pattern of the fish schools is probably associated with the dynamic movement of the preferred oceanographic conditions in terms of both SST and chl-a, which could provide good feeding opportunities for the skipjack tuna schools within study area.

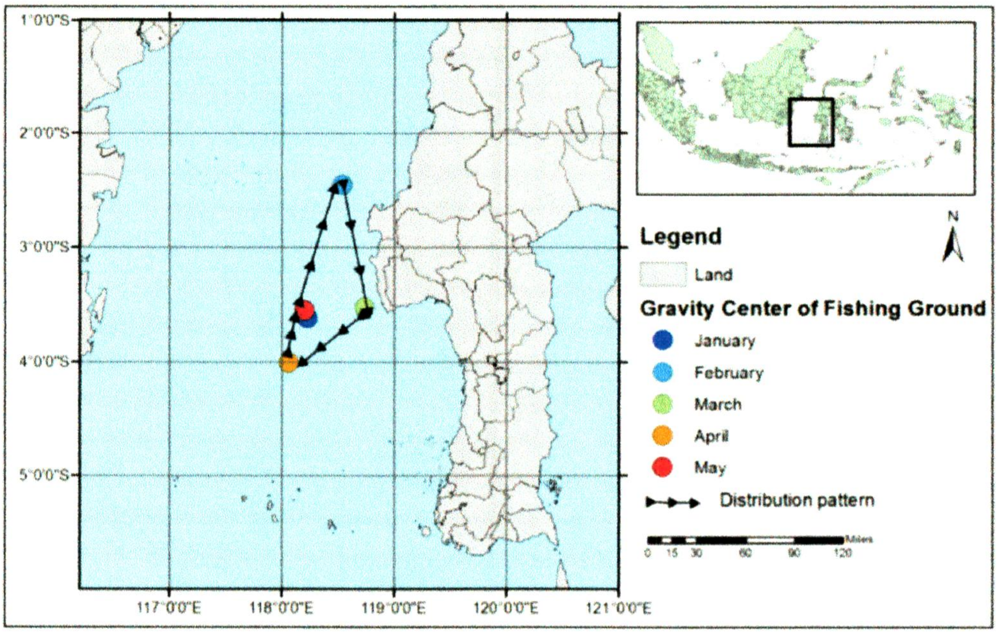

Figure 4. Distribution pattern of skipjack tuna schools shown as monthly gravity centres of fishinggrounds estimated from the GAM over the period from January to May 2018

4. Conclusion

We found that SST and chl-a, significantly influenced the variation of skipjack tuna CPUE. The distribution patterns of skipjack tuna associated well with the shifts in the variables, reflecting the oceanographic preferences of this species. We observed that the fish school distribution pattern indicated a small-scale clock-wise migration pattern. We propose that these habitat displacements may be linked to the dynamic movement of preferred ranges of oceanographic parameters (habitat hotspots).

Acknowledgments

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