Comparing skipjack tuna catch and oceanographic conditions at FAD locations in the Gulf of Bone and Makassar Strait

R Hidayat1, M Zainuddin2, A Mallawa3, M A Mustapha3, A R S Putri1

1Postgraduate Student, Faculty of Marine Science and Fisheries, Hasanuddin University, Makassar, South Sulawesi, Indonesia
2Faculty of Marine Science and Fisheries, Hasanuddin University, South Sulawesi, Indonesia
3Faculty of Science and Technology, Universiti Kebangsaan Malaysia

Email; rh191993@gmail.com

Abstract. This study aimed to compare the differences between characteristics of skipjack tuna (Katsuwonus pelamis) fishing grounds in the Gulf of Bone and in the Makassar Strait. We used catch size and volume data from FAD areas in the Gulf of Bone and Makassar Strait, and satellite image data including sea surface temperature (SST) and chlorophyll-a (CHL-a). We used ECDF (Empirical Cumulative Distribution Function) analysis to determine the relationship between the oceanographic variables and skipjack CPUEs that occurred in the Gulf of Bone and the Makassar Strait. The resulting data for the two fishing areas were then compared using the Spatial Analyst in ArcGIS 10.2. The analysis showed that the average SST and CHL in the Gulf of Bone (30°C and 0.3 mg m⁻³) were higher than those in the Makassar Strait (29.5°C and 0.24 mg m⁻³). The size of skipjack tuna caught in the two fishing areas was different. The mean total length of Skipjack tuna caught in the Makassar Strait was 23 cm, while in the Gulf of Bone it was 41 cm. There was little overlap in the size distributions. These data suggest that skipjack tuna caught around FADs in the Gulf of Bone tend to be larger than those in the Makassar Strait which may be stimulated by relatively higher productivity and thus feeding opportunity.

1. Introduction
Fish are an important resource in the Pacific Region, providing food (protein), livelihoods, and economic growth [1,2]. One target fish caught in large volumes is the skipjack tuna (Katsuwonus pelamis). As a distinctive tropical tuna species with a high economic value, the skipjack tuna is one of the globally important tuna species [3]. The skipjack tuna is a large pelagic fish that has wide distribution in the waters of the Pacific and Indian Oceans, and can migrate over long distances [4,5]. The migratory movement of marine fishes is strongly influenced by environmental factors such as sea surface temperature and chlorophyll-a, and even the current velocity can also have an impact [6–8].

Recently, fishing methods have developed rapidly, not only in shallow waters but also in deep waters [9]. Fish aggregating devices (FADs) are one technology used for collecting fish in the water. Although FADs are not a new technology in the field of fisheries, FADs are quite effective in concentrating fish at certain points in a water body or sea area [10]. The basis for using FADs is due to the tendency of many fishes to be attracted to floating objects; the resulting concentration of potential prey then attracts larger predatory species [11]. Not only skipjack tuna, but also other tunas and predators such as sharks tend to be found in the area around a FAD [12]. The size range of fish...
aggregating around FADs is therefore of considerable interest. In addition, oceanographic anomalies in the areas around FADs can also be of interest in a fisheries context.

The Gulf of Bone and the southern Makassar Strait are both situated at low latitudes south of the equator, with a fairly stable climate and relatively low seasonal variation in many environmental factors [13,14]. However, there are differences, in particular due to the influence of the Indonesian Throughflow, especially in the Makassar [15]. This natural phenomenon results in fertile waters which can be integrated with the occurrence of chlorophyll-a fronts in various regions of the Makassar Strait and Gulf of Bone [16]. Furthermore, concentrations of some small pelagic fishes that are preyed on by skipjack tuna can also be found in sea areas with high levels of chlorophyll-a [17].

In Indonesia's territorial waters, the Makassar Strait and Gulf of Bone are regions which produce a lot of skipjack tuna [18]. Many FADs have been installed in these areas. Therefore, this study aimed to compare the size of skipjack tuna caught as well as the oceanographic factors at FAD locations in the Makassar Strait and the Gulf of Bone.

2. Material and methods

2.1. Study area
Skipjack tuna catch data were collected from 2017 to 2018. The catch data were obtained from purse seine and pole and line fishing vessels that use FADs and operate in the two study areas, i.e. the Gulf of Bone and the southern Makassar Strait.

![Fish aggregating device (FAD) locations in the southern Makassar Strait and the Gulf of Bone.](image)
2.2. Satellite data
This study used two types of satellite data, sea surface temperature (SST) and chlorophyll-a. (chl-a). The data were obtained from the high-resolution Spectra-Resolution Imaging Spectroradiometer (MODIS) Aqua sensor, with a spatial resolution of 4 km. In this study, we used a monthly temporal resolution.

2.3. ECDF (Empirical Cumulative Distribution Function) analysis.
Empirical Cumulative Distribution Function analysis was applied to evaluate the relationship between oceanographic parameters and the CPUE of skipjack tuna fishing vessels operating around FADs. The analysis was based on [19,20] as follows:

\[ f(t) = \frac{1}{n} \sum_{i=1}^{n} l(x_i) \]

with the indication function

\[ l(x_i) = \begin{cases} 1, & \text{if } x_i \leq t \\ 0, & \text{otherwise} \end{cases} \]

\[ g(t) = \frac{1}{n} \sum_{i=1}^{n} \frac{y_i}{y} l(x_i) \]

\[ D(t) = \max |f(t) - g(t)| \]

where:
- \( f(t) \) is an empirical cumulative frequency distribution function
- \( g(t) \) is catch-weighted cumulative distribution function
- \( l(x_i) \) is an indication function
- \( D(t) \) is the absolute value of the difference between the two curves \( f(t) \) and \( g(t) \) at any point \( t \), and assessed by the standard Kolmogorov–Smirnov test
- \( n \) is the number of fishing trips
- \( x_i \) is the measurement for satellite-derived oceanographic variables in a fishing trip
- \( y_i \) is the CPUE obtained in a fishing trip
- \( y \) is the estimated mean of CPUE for all fishing trips

The coordinate labelled ‘max’ represents the specific value of the variables at which the difference between the two curves (\(|f(t) - g(t)|\)) was maximum.

2.4. Comparing catches and oceanographic factors at FADs in Makassar Strait and Gulf of Bone
The comparison method was based on the ECDF analysis and on simple graphs generated from the extraction of catch points and oceanographic factors from the data. The extraction process was carried out using the ArcGIS Spatial Analyst in ArcGIS 10.2 software. The satellite and fisheries data were overlaid and the Spatial Analyst captured the values of oceanographic factors at the fishing (FAD) locations (coordinates). Graphics were created in R-Studio 1.2.1335 software using the ggplot2 plug-in.

3. Results and Discussion
The development of FADs worldwide has been very rapid both in terms of design and size [12]. Data stated that half of the global tuna caught were fish obtained in FADs [21]. Besides FADs, environmental factors can also have a significant effect [8]. Table 1 shows the results of the ECDF analysis indicating that the optimum chlorophyll-a in FADs in the Makassar Strait was between 0.24 to 0.28 mg m\(^{-3}\), while for the Gulf of Bone it was 0.24 to 0.40 mg m\(^{-3}\). Sea surface temperatures in the
Makassar were, on average, lower than in the Gulf of Bone. The conditions around the FADs tended to have a high enough chlorophyll-a concentration value and suitable sea surface temperature distribution for skipjack tuna.

Table 1. Comparison of skipjack tuna catch volume and environmental data in the Makassar Strait and the Gulf of Bone.

| Location            | n   | Catch (fish) | $\bar{X}$ CHL (mg m$^{-3}$) | $\bar{X}$ SST (°C) | CHL ECDF (mg m$^{-3}$) | SST ECDF (°C) |
|---------------------|-----|--------------|-----------------------------|-------------------|------------------------|---------------|
| Makassar Strait     | 104 | 37,906       | 0.24                        | 29.5              | 0.24 - 0.28            | 29.2 - 30.3   |
| Gulf of Bone        | 153 | 2,763        | 0.30                        | 30.0              | 0.24 - 0.40            | 29.7 - 31.2   |

3.1. Skipjack distribution by size at Makassar Strait and Gulf of Bone

This study used catch data from 2017 to 2018. Figure 2 shows that the size distributions of skipjack tuna caught in the Gulf of Bone and in the Makassar Strait were very different in terms of size (total length, TL). The largest size classes were only caught in the Gulf of Bone, where the mean size of fish caught was 41 cm (TL) with a range from 18 cm to 58 cm. The mean size of fish caught in the Makassar Strait was 23 cm with a size range from 17 cm to 36 cm.

Figure 2. Size class distribution of skipjack tuna caught around FADs in the Makassar Strait and Gulf of Bone during 2017 and 2018.

3.2. Comparison of chlorophyll-a distribution Makassar Strait and Gulf of Bone

Figure 3 shows maps of chlorophyll-a concentration in May 2018 for the Makassar Strait and June 2018 for the Gulf of Bone, with FAD fishing positions overlaid. Distribution of chlorophyll-a in the Makassar Strait and Gulf of Bone, when viewed as a whole, was similar (Figure 3). However, the FAD fishing areas in the Makassar Strait and Gulf of Bone had different spatial characteristics. Visible catch points with FADs in the Makassar Strait were quite widely spread out, with chlorophyll-a concentrations ranging from 0.16 to 0.46 mg m$^{-3}$ (Figure 4). In the Gulf of Bone, the FADs were closer to each other, with a range of chlorophyll-a concentrations from 0.18 to 0.62 mg m$^{-3}$ (Fig. 4).
Figure 3. Chlorophyll-a distribution in the Makassar Strait (May 2018) and Gulf of Bone (June 2018) overlaid with FAD fishing positions.

There was a strong correlation between the fishing operations and the optimal chlorophyll-a ranges based on the ECDF analysis (Table 1). The highest numbers of fish caught (catch volumes) occurred in the range of 0.24 - 0.28 mg m$^{-3}$ in the Makassar Strait and 0.24 - 0.40 mg m$^{-3}$ at Gulf of Bone in both 2017 and 2018 (Fig 4). Chlorophyll-a was one of the key indicators for the distribution of fish in these waters. This event was related to the potential for large amounts of food for large pelagic fishes like skipjack tuna in areas that have good chlorophyll-a concentrations. In a previous study, it was found that the optimum chlorophyll-a concentration range was from 0.15 to 0.35 [8].

Figure 4. Chlorophyll-a distribution at FAD fishing locations in the Gulf of Bone and Makassar Strait.
3.3. Comparison of Sea Surface Temperature distribution Makassar Strait and Gulf of Bone

The distribution of sea surface temperature in the Makassar Strait and Gulf of Bone was not significantly different (Figure 5). In the Makassar Strait, the SST range was 28.60 - 30.78 °C, while in the Gulf of Bone it was 28.75 - 31.12 °C (Figure 6). Sea surface temperature was an indicator of skipjack tuna presence together with chlorophyll-a, and was likely influenced by fish behaviour regarding temperature. Skipjack tuna are usually found in waters that have a fairly warm temperature range. Figure 6 shows that there were many occurrences of skipjack tuna in the optimum temperature ranges obtained through ECDF analysis (Table 1).

![Figure 5](image1.png)

**Figure 5.** Sea surface temperature distribution in the Makassar Strait (May 2018) and Gulf of Bone (June 2018) overlaid with FAD fishing positions.

![Figure 6](image2.png)

**Figure 6.** Sea surface temperature distribution at FADs in the Gulf of Bone and Makassar Strait.
Sea surface temperature and chlorophyll-a can have a very large impact in determining potential fishing zones [6,16]. This can be attributed to food availability and the resilience of fish to environmental temperatures. Many other factors also influence the distribution of fish in marine waters. Associated with the distribution of FADs, water depth can be a very influential factor [22].

4. Conclusion
Comparison of fisheries catch data and oceanographic factors in the Makassar strait and Gulf of Bone shows that, in terms of fish size, the skipjack tuna (*Katsuwonus pelamis*) caught around fish aggregating devices (FADs) in the Gulf of Bone were larger in size than those caught around FADs in the southern Makassar Strait. Analysis of oceanographic factors found that the average chlorophyll-a (chl-a) and sea surface temperatures (SST) values were higher in the skipjack tuna FAD fishing areas in the Gulf of Bone than in the southern Makassar Strait.

Acknowledgements
We recognise the use of AQUA-MODIS Sea surface temperature and chlorophyll-a datasets downloaded from the ocean color portal (http://oceancolor.gsfc.nasa.gov). This study was funded under the scholarship program of the Ministry of Research, Technology and Higher Education of the Republic of Indonesia (PMDSU research Grant No. 1739/UN4.21/PL.01.10/2019). We also wish to thank the Skipjack Spot Hunter team.

References
[1] Bell J D, Kronen M, Vunisea A, Nash W J, Keeble G, Demmke A, Pontifex S and Andrefouet S 2009 Planning the use of fish for food security in the Pacific *Mar. Policy* 33 64–76
[2] Gillett R and Cartwright I 2010 *The Future of Pacific Fisheries* (Noumea; Honiara: Secretariat of the Pacific Community and Forum Fisheries Agency)
[3] FAO 2009 *The State of World Fisheries and Aquaculture* 2008 (Rome: FAO)
[4] Mugo R, Saitoh S, Nihira A and Kuroyama T 2010 Habitat characteristics of skipjack tuna (*Katsuwonus pelamis*) in the western North Pacific: a remote sensing perspective *Fish. Ocean.* 19 382–96
[5] Arai T, Kotake A, Kayama S, Ogura M and Watanabe Y 2005 Movements and life history patterns of the skipjack tuna *Katsuwonus pelamis* in the western Pacific, as revealed by otolith Sr:Ca ratios *J. Mar. Biol. Assoc. UK* 85 1211–1216
[6] Hidayat R, Zainuddin M, Putri A R S and Safruddin 2019 Skipjack tuna (*Katsuwonus pelamis*) catches in relation to chlorophyll-a front in Gulf of Bone during the southeast monsoon *AACL Bioflux* 12
[7] Hidayat R and Zainuddin M 2019 Detection of cyclonic and anti-cyclonic eddy in relation to potential Skipjack Tuna fishing ground in Makassar Strait *IOP Conf. Ser. Earth Env.* 241
[8] Zainuddin M, Farhum S A, Safruddin, Selamat M B, Sudirman, Nurdin N, Syamsuddin M, Ridwan M and Saitoh S 2017 Detection of pelagic habitat hotspots for skipjack tuna in the Gulf of Bone-Flores Sea, southwestern Coral Triangle tuna, Indonesia *PlosOne* 12 e0185601
[9] Campbell B, Hanich Q and Delisle A 2016 Not just a passing FAD: Insights from the use of artisanal fish aggregating devices for food security in Kiribati *Ocean Coast. Manag.* 119 38–44
[10] Dagorn L, Kim N, Holland, David G and Itano 2007 Behavior of yellowfin (Thunnus albacares) and bigeye (T. obesus) tuna in a network of fish aggregating devices (FADs) *Mar. Biol.* 151 595–606
[11] Dempster T and Taquet M 2004 Fish aggregation device (FAD) research: gaps in current knowledge and future directions for ecological studies *Rev Fish Biol Fish* 14 21–42
[12] Dagorn L, Holland K N, Restrepo V and Moreno G 2013 Is it good or bad to fish with FADs? What are the real impacts of the use of drifting FADs on pelagic marine ecosystems? *Fish Fish.* 14 391–415
[13] Putri A R S and Zainuddin M 2019 Application of remotely sensed satellite data to identify Skipjack Tuna distributions and abundance in the coastal waters of Gulf of Bone IOP Conf. Ser. Earth Environ. Sci. 241

[14] Putri A R S and Zainuddin M 2019 Impact of Climate Changes on Skipjack tuna (Katsuwonus pelamis) catch during May-July in the Makassar Strait IOP Conf. Ser. Earth Environ. Sci. 253

[15] Gordon A L 2005 Oceanography of the Indonesian Seas and their throughflow Oceanogr. 18 14–27

[16] Hidayat R, Zainuddin M, Safruddin S, Mallawa A and Farhum S A 2019 Skipjack Tuna (Katsuwonus pelamis) catch in relation to the Thermal and Chlorophyll-a Fronts during May – July in the Makassar Strait OP Conf. Ser. Earth Environ. Sci. 253

[17] Safruddin, Rachmat H and Zainuddin M 2018 Effects of environmental factors on anchovies Stolephorus sp distribution in Gulf of Bone, Indonesia AACL Bioflux 11 387–93

[18] Lehodey P, Bertignac M, Stoens A, Memery L and Grima N 1998 Predicting skipjack tuna forage distributions in the equatorial Pacific using a coupled dynamical bio-geochemical model Fish. Oceanogr. 7 317–25

[19] Andrade H A and Garcia C A E 1999 Skipjack tuna fishery in relation to sea surface temperature off the southern Brazilian coast Fish. Oceanogr. 8 245-54.

[20] Zainuddin M, Saitoh K and Saitoh S 2008 Albacore tuna fishing ground in relation to oceanographic conditions of northwestern North Pacific using remotely sensed satellite data Fish Oceanogr. 17 61–73

[21] Miyake M P, Guillotreau P, Sun C-H and Ishimura G 2010 Recent Developments in Tuna Industry: Stocks, Fisheries, Management, Processing, Trade and Markets (Rome: FAO Fisheries and Aquaculture Technical Paper)

[22] Cayre P 1991 Behaviour of yellowfin tuna (Thunnus albacares) and skipjack tuna (Katsuwonus pelamis) around fish aggregating devices (FADs) in the Comoros Islands as determined by ultrasonic tagging Aquat. Living Resour. 4 1–12