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Small-Scale Tuna Seasonality and Fishing Grounds in the Flores Sea

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ABSTRACT

The Flores Sea is a tuna fishing area with limited data on the fishery, including vessels, fishing gear, fishing grounds, seasonality, fuel consumption, catch volume, and the size of tuna caught. This study examined and analyzed the fishing grounds of small-scale hand-line tuna fishermen and the size of tuna caught in the Flores Sea following the research methodology described by Ebata. The results showed that the fishing vessels were suitable for catching tuna with hand-line fishing gear and operated throughout the year. The fishing grounds were in tuna habitat and migration routes in the Flores Sea and were influenced by the fishing season. The composition and production volume of the sampled catch (n = 1,210) was dominated by yellowfin tuna (*Thunnus albacares*) in the length/weight range 34-46.2 cm/1.5-3.9 kg (84.5%, 1,023 fish), followed by larger yellowfin tuna (local name *opo*') in the length/weight range 61-211 cm/10.5-80 kg (183 fish 15.1%), with big eye tuna (*Thunnus obesus*) contributing just four fish (0.33%) in the length/weight range 110-189 cm/38.5-58 kg. The catch composition indicates that the yellowfin tuna fishery is likely to be unsustainable, marked by range collapse with a southwards shift towards fishing grounds further from the base in the Flores Sea.

Keywords: *Fishing season; Flores sea; length-frequency distribution; small-scale handline; Thunnus albacares.*

INTRODUCTION

Small-scale fisheries play a central role in Indonesia's socioeconomic development, as they serve as a key driver of food security, rural employment, and foreign exchange earnings (Duggan & Kochen 2016; Tran *et al.* 2017). Beyond its economic aspects, small-

Marine Fisheries: Journal of Marine Fisheries Technology and Management
Vol. 17 (2): 85-99, July 2026.

scale fisheries (SSF) often target pelagic species that are ecologically vital and underpin marine biodiversity and food web processes (Ward *et al*. 2016; Marcos *et al*. 2021; Zeller *et al*. 2023). Characterized by high socio-ecological diversity and location-specific operational dynamics, SSF dominates the coastal landscapes of developing island nations, making effective governance crucial for balancing marine conservation with community livelihoods (Arthur *et al*. 2021; Sari *et al*. 2021).

However, the open-access paradigm that has long prevailed in tropical fisheries has encouraged uncontrolled exploitation of resources, leading to widespread stock depletion and ecosystem degradation (Serajuddin *et al*. 2018; Hilborn *et al*. 2020). In many developing regions, increasing fishing pressure combined with unregulated, unreported, and unsustainable fishing practices threatens the long-term productivity of small-scale fisheries (Arias & Pressey 2016; Halim *et al*. 2020; Pham *et al*. 2023). Because the spatial and ecological conditions of fishing grounds directly reflect the health of managed stocks (Huang & He 2019; Stafford 2019), the transition from unmonitored open-access exploitation to a data-driven management framework tailored to SSF has become an urgent global imperative (Exton *et al*. 2019; Natasha *et al*. 2021; Zeller *et al*. 2023).

The Flores Sea, as a critically important fishing ground for coastal communities in South Sulawesi, has been the subject of extensive oceanographic and fisheries research, including studies on sea surface dynamics, climate impacts, and tuna migration patterns (Zainuddin *et al*. 2015; Putriani *et al*. 2019; Handoko *et al*. 2021). However, small-scale handline tuna fisheries in remote coastal areas such as Bulukumba Regency remain a critical “blind spot” in management. Although handline fishing is widely considered sustainable, the lack of explicit spatial data on fishing areas and monitoring of catch sizes obscures the potential risks of overfishing as populations grow and spatial conflicts arise. Conventional data collection frameworks are often inapplicable to geographically isolated small-scale fisheries, and these data gaps stem from limited access and monitoring infrastructure.

To address this gap, this study offers an innovative methodological approach by integrating direct field measurements with indirect spatial tracking to evaluate the operational dynamics, catch size structure, and spatial extent of small-scale handline tuna fishing in the Flores Sea. Specifically, this study examines seasonal variations across four fishing seasons—taking into account gear specifications, spatial distribution, fuel consumption, species composition, and fish length frequency distributions. By addressing data gaps in small-scale fisheries in remote areas, the empirical insights generated by this study provide a replicable framework for formulating strategies for spatial management and sustainable harvest control in data-limited archipelagic waters.

METHODS

Study Area

This research was conducted in the Flores Sea area of South Sulawesi (Figure 1) from July 2020 to June 2021. Small-scale tuna fishermen operating in the Flores Sea are based in the Takalar, Jeneponto and Bulukumba Regencies. According to data from the South Sulawesi Provincial Marine and Fisheries Service (KKP 2021), Bulukumba is the regency with the most fishing vessels (33 units).

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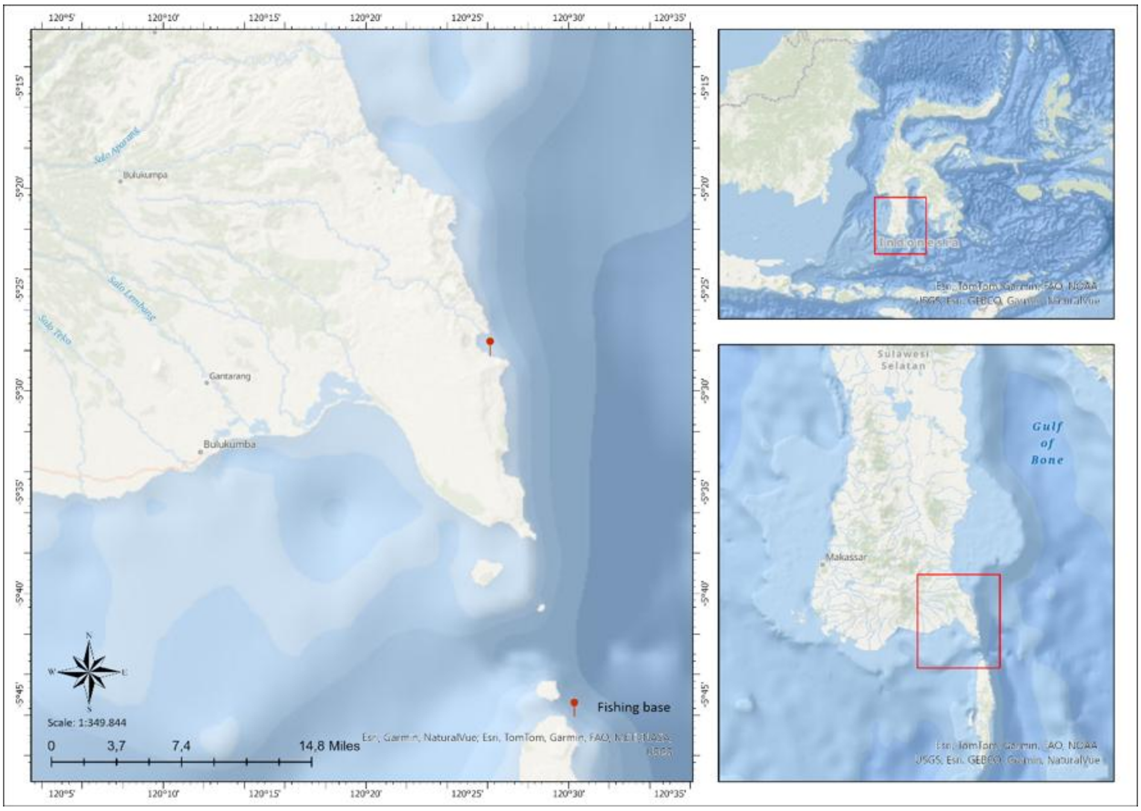

Figure 1 A map of the study area showing the locations of small-scale tuna fishing bases in Bulukumba Regency, South Sulawesi, Indonesia. The inset map shows the location of the area within South Sulawesi and the Flores Sea (bottom right) as well as its national location within Indonesia (top right).

Data Collection

Variables used to assess the seasonality and fishing grounds of small-scale tuna fisheries in the Flores Sea were production (catch) volume, number of fishing days, duration of fishing operations, extent and geographic coordinates of fishing grounds used during each fishing season. The variables used to assess the size of the tuna caught were fish length, weight, and species. Data were collected following Ebata *et al*. (2012) using three main approaches: (1) on-board surveys and interviews with fishermen; (2) logbook of fishing operations recorded by fishermen; and (3) analysis of weather data. This survey used purposive sampling, with the assumption that the fishing units in Bulukumba Regency that operated in the Flores Sea with tuna hand line fishing gear were homogeneous. The sample was one fishing unit (three fishing vessels) with a vessel size ≤ 10 GT. The one year study period (July 2020 – June 2021) was divided into four seasons: east season, east to west transitional period, west monsoon, and west to east transitional period.

The on-board surveys included conducting interviews with fishermen, watching, recording and taking photographs to record activities during fishing operations. The position of the fishing vessels during fishing operations and the position of each fish aggregating device (FAD) used were recorded using a GPS unit. Data collected from the on-board surveys and interviews with fishermen included the following:

1. Fishing vessel data (size, shape, construction materials, engine power and make, auxiliary equipment).
2. Vessel movements and fishing patterns/operational procedures. The vessel track and position of each FAD visited by the three fishing vessels in the sampled fishing unit was recorded on a GPS type 46s unit.
3. Handling of the catch from when the fish was hooked until it was unloaded at the fishing port.
4. The species and size of the fish caught.

The fishing operations logbook yielded data on production volume, the number of operational fishing days, and the length of time spent fishing. The tuna caught and landed at the fish landing site were

Marine Fisheries: Journal of Marine Fisheries Technology and Management
Vol. 17 (2): 85-99, July 2026.

measured for every fishing trip over the year from July 2020 – June 2021. The tuna caught were weighed and the fork length (FL) was measured from the tip of the snout to the center of the fork of the tail. The local tuna size system was used, where *opo'* are yellowfin tuna weighing 10 kg and above, and *kalaholong* are yellowfin tuna weighing from 2 kg upwards but less than 10 kg. All *opo'* caught were measured, as well as 10% of the *kalaholong*.

Data analysis

From the data collected, the production volume, the number of fishing days and the duration of fishing operations were calculated for each trip during the one year study period. The data obtained were analyzed to determine the coordinates and characteristics of each fishing ground, the peak fishing season(s), how the fishermen adapted to seasonal changes (in terms of fishing gear, fishing grounds, fuel consumption, catch size composition and volume), using the same analyses as other studies (Ebata *et al*. 2012; Ahrens & Henson 2019; Baskoro & Yusfiandayani 2019; Baskoro & Suherman 2017; Zainuddin *et al*. 2015; Safruddin *et al.* 2015). Catch composition analysis followed Sugiono (2025). Logbook data were analyzed descriptively to give production figures (fish length and weight) for each month during the year. Spatial data on fishing ground location and extent were analyzed by season using GIS software.

Temporal aspects of production volume, production value and catch composition

To describe the temporal aspects of production volume, production value and catch composition, the following parameters were calculated, following Ebata *et al*. (2012):

1. Mean fishing operations duration per day (hours) = total time spent fishing over the year/number of fishing days during the year
2. Mean daily catch volume (kg) = total catch volume over the year/number of fishing days during the year
3. Mean gross income per day (IDR) = total sales value of the catch sold over the year/number of fishing days during the year
4. Mean daily fuel consumption (L) = total volume of fuel used over the year/number of fishing days during the year
5. Catch per unit of fuel (kg/L) = total catch volume over the year/total fuel consumed over the year
6. Gross income per unit of fuel (IDR/L) = total sales value of the catch sold over the year/total fuel consumed over the year
7. Catch per unit of time (kg/hour) = total catch volume over the year/total time spent in fishing operations over the year
8. Gross income per unit of time (IDR/hour) = total sales value of the catch sold over the year/total time spent in fishing operations over the year

The catch composition was expressed as the percentage of each species identified in the total catch following Sugiono (2025).

Fishing ground spatial data

The position and extent of fishing grounds during each season were estimated using geographic information system (GIS) software, based primarily on the GPS data recorded while fishing during the one-year study period (July 2020 – June 2021). These data were supplemented by secondary data in the published literature as well as from research reports and data from relevant institutions. Vector data in the form of polygons were derived from the coordinates of the outermost points of the fishing grounds during the year and over each season. Once the polygons were drawn, the area inside each polygon was calculated in Microsoft Excel.

Weather conditions, wave height, current speed and direction

Data on weather conditions, wave height, current speed and direction were estimated based on data provided by the Paotere Maritime Meteorological Station in Makassar, the Indonesian Meteorological, Climatological and Geophysical Agency as well as the predictions/perceptions of the fishermen during each fishing trip over the study year. Additional secondary data were obtained from the published literature as well as from research reports and data from relevant institutions.

RESULTS

Fishing vessels, fishing operations, catch handling and fishing ground extent

Most fishing vessels at the study site were less than 10 GT although a few were

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larger than 10 GT. Length over all (LOA) ranged from 12-15 m, with a beam of 2.30-3.00 m, and midships hull depth 0.8-1 m (Table 1). The boats are generally quite long and narrow, with a fairly deep draught for their size and constructed mainly from *Vitex cofassus* timber, a hardwood locally called kayu bitti. The vessels belong to the fishermen, and their design allows for fast maneuvers to catch tuna and easily ride or cut through the waves. The traditional boatbuilding villages in Bontobahari District, Bulukumba Regency, are Tana Beru in Tana Lemo suburb, Panrang Luhu' in Bira Village, and Mandala Ria in Ara Village. These three villages are quite close to Ekatiro Village; the first two are around 14 km away while Ara Village is just 7 km away. Boats can also be built in Para'-Para Village in Ekatiro Suburb by craftsmen from Ara and Tana Beru. Each vessel was fitted with 2-3 engines of different makes and horsepower (HP) ratings.

The fishermen typically catch tuna around fish aggregating devices spread out in the Flores Sea which is considered a migration route for large pelagic fishes. Many FADs are also placed in the Gulf of Bone which opens into the Flores Sea and in the waters around Bira at the southeast tip of South Sulawesi, in order to attract and catch both tuna and small pelagic fishes. However, the FADs most often used for tuna hand-line fishing are concentrated in areas further offshore, typically 6–13 hours away from the fishing base. The fishing grounds used varied between seasons (Figure 2).

Each trip typically lasted around two weeks and used 1-3 FADs as fishing grounds. Fishing operations took place during the day and at night, depending on the presence of fish, typically around fish aggregating devices (FADs). The fishers used lights when fishing at night. The fishermen used different gear sizes depending on the size-class of the yellowfin tuna targeted, with three size classes: *opo'* (10 kg or more, export quality); *kalaholong* (2 to <10 kg, in-country trade); and *pani'-pani'* (under 2 kg). The fishermen used live bait (small pelagic fish) for *opo'* and artificial bait (made from fine shiny silken threads) for *kalaholong* and *pani'-pani'*. During the west monsoon, the fishers mostly fished around FADs 1 to 5, and during the east monsoon around FADs 6 to 8. During the transition seasons, the fishermen used FADs 1 to 8. The extent of the fishing grounds around the eight FADs were: FAD 1 = 9.07 Ha, FAD 2 = 25.86 Ha, FAD 3 = 16.03 Ha, FAD 4 = 10.30 Ha, FAD 5 = 7.18 Ha, FAD 6 = 20.58 Ha, FAD 7 = 5.99 Ha and FAD 8 = 5.49 Ha.

Over the one-year study period, weather and sea conditions varied according to data from the Paotere Maritime Meteorology Station of the Indonesian Meteorological, Climatology and Geophysics Agency (BMKG) in Makassar (Table 2) and the fishing vessel crews (Table 3). Overall, the current speed range was 24-100 cm/s according to the BMKG, and 0.1-0.55 knots according to the fishers; wave height range was 0.23-1.88 m (BMKG) and 0.01-0.90 m (fishers); and sea water temperature ranges were 28-31^{0}C at the sea surface and 26-30^{0}C at 50m depth (BMKG). Prevailing current direction varied between and within seasons, flowing mostly from the south or southeast during the east monsoon and east to west transition period, mostly from the west or north during the west monsoon, and highly variable during the west to east transition period. The prevailing weather conditions were mostly sunny with clouds during the east monsoon; mostly sunny or cloudy with light rain during the east to west transition period; frequent light rain or cloudy with rain during the west monsoon; and mostly sunny with clouds during the west to east transition period.

Table 1 Principal structural dimensions (length, beam, and depth) of sampled small-scale handline tuna fishing vessels in Bulukumba Regency, South Sulawesi, Indonesia.

Vessel name	Length (m)	Beam (m)	Depth (cm)
1. Ian Jaya	13	2.9	90
2. Mattirobulu 01	12	2.3	80
3. Mattirobulu 02	15	3.0	100

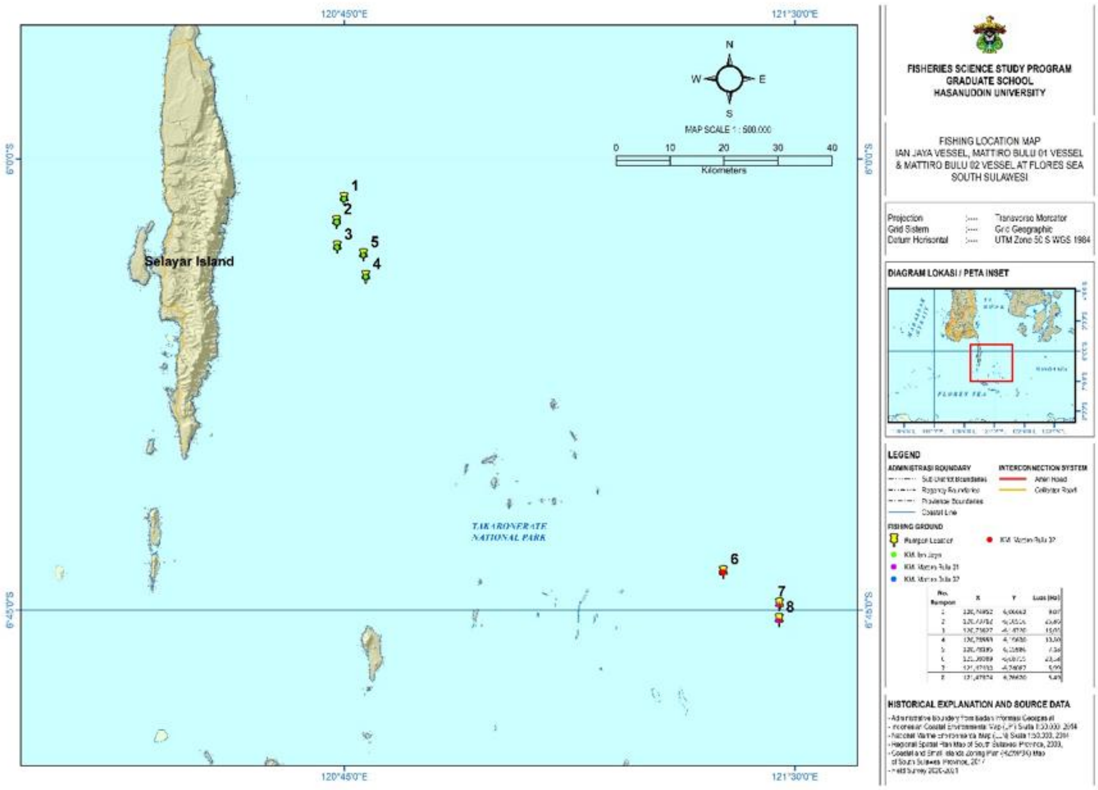

Figure 2 Map showing the positions of the fishing vessels and extent of the FAD-centered fishing grounds in the Flores Sea used by the tuna hand-line fishers of Ekatiro Village, Bontotiro District, Bulukumba Regency, South Sulawesi Province, Indonesia over the one year study period (July 2020 to June 2021).

Table 2 Weather conditions, wave height, current speed and direction, and average temperature of the Flores Sea fishing ground during the research period according to the Meteorological, Climatology and Geophysics Agency Paotere Maritime Meteorology Station in Makassar Indonesia.

	Month	Sea Temperature (^{0}C)		Current*		Wave height (m)	Typical weather conditions
		Surface	50 m	Direction (from-to)	Speed (cm/s)		
1	July	-	-	W-NE, S-W	24 – 50	1.03 – 1.88	Bright, cloudy
2	August	-	-	SE-NW	29 – 62	0.75 – 1.40	Bright, cloudy
3	September	-	-	SE-NW	40 – 73	0.73 – 1.38	Bright, cloudy
4	October	-	-	SW-NW, W-N	29 – 59	0.52 – 1.04	Bright, cloudy, light rain
5	November	-	-	NW-NE, N-E	37 – 68	0.49 – 0.84	Cloudy sunny, light rain
6	December	-	-	N-E, NE-SE	56 – 100	0.71 – 1.43	Light rain, cloudy
7	January	28 – 31	26 – 30	NE-SE, N-E	49 – 89	0.86 – 1.52	Rainy
8	April	28 – 31	26 – 30	NE-SE, NW-NE, E-S	39 – 73	0.23 – 0.69	Cloudy, sunny

N = North; S = South; E = East; W = West.
* Sea surface and 50 m temperature data were not available for July to December because raw data were not available from the modelling using the Inawav and Inacau Model.

Table 3 Monthly weather conditions and oceanographic parameters (wave height, current speed, and prevailing current direction) in small-scale tuna fishing grounds of the Flores Sea, South Sulawesi (Indonesia), based on field observations by vessel crews (July 2020–June 2021).

Month		Weather	Wave height (m)	Current speed (knot)	Current direction *
1	July	cloudy, sunny	1.500	0.7000	NE
2	August	cloudy, sunny	0.2000 – 0.900	0.2333 – 0.6000	S, NE
3	September	sunny	0.0033 – 0.5000	0.2333 – 0.3333	S, E
4	October	sunny, overcast	0.0700 – 0.6500	0.1000 – 0.5000	S, E, NE
5	November	sunny, cloudy, overcast	0.1000 – 0.1350	0.5500	E
6	December	cloudy, sunny	0.0100 – 0.1000	0.1000 – 0.2000	E
7	January	rain	0.8000 – 1.1500	0.5000	E
8	April	cloudy	1.0000 – 1.5000	0.1000 – 0.8000	NE

*Current towards direction shown; N = North; S = South; E = East; W = West.

Seasonal effects on fishing operations and fuel consumption

a. *Fishing duration, production and income*

The data on fishing operations duration, production and income over the one-year study period are shown in Table 4. Collectively, the total time spent on fishing operations over the year by the three vessels was 2,770 hours, with a total catch volume just over 10 tonnes, a total gross income just over IDR 244 million, and fuel consumption of 5,820 L. The mean catch per liter of fuel was 9.6 kg/L and mean gross income per liter of fuel was 231,600 IDR/L. Mean catch per unit of fishing time was 19.7 kg/hour and mean gross income per unit of fishing time was approximately 475,000 IDR/hour.

Table 4 Annual operational performance, catch volume, gross income, fuel consumption, and unit-based efficiency metrics of sampled small-scale handline tuna vessels in Ekatiro Village, Bulukumba Regency, South Sulawesi (Indonesia) (July 2020–June 2021).

Vessel No.	Fishing time (hours)	Catch (kg)	Gross Income (IDR)	Fuel Used (L)	Catch per unit of fuel (kg/L)	Income per unit of fuel (IDR/L)	Catch per unit of time (kg/h)	Income per unit of time (IDR/h)
1	910	2,400	61,350,000	1,700	6.9226	176,446	13.0	331,017
2	680	3,613	89,775,000	1,200	12.0433	299,250	21.8	541,078
3	1,180	3,992	92,959,000	2,920	9.8483	237,103	24.3	552,710
Total	2,770	10,005	244,084,000	5,820	28.8142	712,799	59.1	1,424,805
Mean	923.3	3,335	81,361,333	1,940	9.6047	231,600	19.7	474,935

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b. Catch composition, length and weight distribution

The catch volume and composition varied between months (Table 5). During four months (February, March, May and June 2021), the log books were not filled in because the catch was very small. In addition to the local names by size class, other local names included *balangkulisi* for tuna in general (Konjo language), and *la didi* for yellowfin tuna *T. albacares* (Konjo, Bira dialect). The smaller *kalaholong* yellowfin tuna comprised the majority (≈85%) of the 1,210 fish caught, while less than 200 large export-sized *opo'* yellowfin tuna (≈15%) were caught during the year. Only four bigeye tuna (*Thunnus obesus*), locally called *sabau* were caught, comprising less than 1% of the annual catch.

Table 5 Monthly catch composition, local size-class categorization, volume (abundance and percentage), and biometric size ranges (length and weight) of handline-caught tunas (Thunnus albacares and Thunnus obesus) in Ekatiro Village, Bulukumba Regency, South Sulawesi (Indonesia) (July 2020–June 2021).

No.	Month	Scientific name (*Thunnus* sp.)	Local name	Catch volume		Size range	
				n	%	length (cm)	weight (kg)
1	July	*T. albacares*	*opo'*	20	1.653	100-184	20-64
		T. albacares	*Kalaholong*	124	10.248	38-43	2.0-3.2
2	August	*T. albacares*	*opo'*	40	3.306	65.1-198	14-75
		T. obesus	*Sabau*	1	0.083	110	38.5
		T. albacares	*Kalaholong*	289	23.884	34-40.6	1.5-3.0
3	September	*T. albacares*	*opo'*	40	3.306	62-167	13-48
		T. albacares	*Kalaholong*	60	4.959	39.2-42.5	2.0-2.8
4	October	*T. albacares*	*opo'*	21	1.736	64.5-184	13-63
		T. albacares	*Kalaholong*	250	20.661	39-45	2.0-3.5
5	November	*T. albacares*	*opo'*	31	2.562	61-173	10.5-50
6	December	*T. albacares*	*Kalaholong*	300	24.793	40-46.5	2.1-3.9
7	January	*T. albacares*	*opo'*	22	1.818	170-211	45-80
8	April	*T. albacares*	*opo'*	9	0.744	95-185	21-57
		T. obesus	*Sabau*	3	0.248	175-189	51-58
Total catch volume/species composition		*T. albacares*	*opo'*	183	15.124	61-211	10.5-80
		T. albacares	*Kalaholong*	1,023	84.546	34-46.2	1.5-3.9
		T. obesus	*Sabau*	4	0.331	110-189	38.5-58
Total				1,210	100	34-211	1.5-80

DISCUSSION

As previously reported in other studies (Ebata *et al*. 2012; Ahrens & Henson 2019; Baskoro & Yusfiandayani 2019; Baskoro & Suherman 2017; Zainuddin *et al*. 2015; WWF-Indonesia 2026), the fishing vessel types, fishing gears, fishing methods and fishing ground characteristics enable fishermen to operate during all seasons throughout the year. According to Bramantya *at al*. (2021), yellow fin tuna larval rearing in water quality parameters in water with a mean temperature of 29.30^{0}c, pH 8.2, and dissolved oxygen 6.0 ppm and using *Nannochloropsis oculate* and *Brachionus rotundiformes* as feed gave a hatching rate of 75.34 but a survival rate of 0%. According to Heltria *et al*. (2024), in the West Sumatran yellowfin tuna fishing grounds the sea surface temperature ranged from 26.4-34.5^{0}C and the chlorophyll concentration ranged from 0.03-5.45 mg/m^3. The use of FADs as an auxiliary fishing gear is based on the universal attraction of schooling pelagic fish to such structures, thereby creating a fishing ground where the fish are comparatively easy to catch (Baskoro & Yusfiandayani 2019; Baskoro & Suherman 2017, WWF-Indonesia 2026).

Before storing the catch in the hold, gills and entrails were removed from the large, *Opo'* size-class yellowfin tuna, but not from the smaller *Kalaholong* class. Research by Lan *et al*. (2021) found that the PH value, metmyoglobin (metMb) content, total volatile base nitrogen (TVB-N) content, histamine content and total volatile count (TVC) in big eye tuna stored at low temperature increased when the temperature fluctuated, indicating a decrease in tuna quality so that it is important to control the temperature and keep it stable. Erdaide *et al*. (2016) found that the phenomenon known as burnt tuna (BT), also known as *yake-niku*, could occur, resulting in low quality, pale with a grainy and exudative texture. This problem is caused by the activation of enzymes after death, and the presence of a 43 kDA band of creatine kinase under proteomic analysis can be a good indicator of BT risk in big eye and yellow fin tuna. Isoelectric solubilization/precipitation (ISP) is a process that enables the selective pH-induced aqueous solubilization of proteins through simultaneous separation of lipids and removal of materials not intended for human consumption such as bones, scales, skin, etc. The recovered protein retains its functional properties and nutritional value. Yellowfin tuna egg isolates can be a promising source of valuable nutrients for human food and animal feed (Lee *et al*. 2016). Four egg protein isolates (RPI) from yellowfin tuna eggs prepared under different dissolution and precipitation conditions yielded lipid content levels (5.6–7.4%) lower than that of freeze-dried concentrate (10.6%) with Leucine and lysine as the most abundant amino acids (8.8–9.4 and 8.5–8.9 g/100 g protein respectively) and S, Na, P, K as the most abundant minerals.

During the east monsoon, the waves to the east of the Selayar Islands tend to be bigger with higher wind-speeds. These conditions are called *je'ne'kebo* and *tambaruh* by Selayar and Bira people. Therefore, the fishermen generally go to fishing grounds that are further south, to the southeast or southwest of the Selayar Islands. During the west monsoon the situation is reversed, so fishermen tend to operate in seas to the east of the Selayar Islands. Fishermen can operate in all these area (east, south and west) during the transition seasons because the weather is generally relatively calm, and the waves are not too big or hazardous to fishing operations. In addition, during these transition periods the tuna can easily see the fishing gear lines in the calmer, clearer waters. Habitat suitability mapping for yellowfin tuna in West Sumatran waters revealed that most fishing vessel coordinates were in areas with habitat suitability index (HIS) scores of 0.6-0.9, and potential areas for tuna fishing were found in the Mentawai Islam (Heltria *et al*. 2024). During the northern hemisphere winter (December, January and February), high pressure cells tend to form on the Asian continent, while the southern hemisphere summer concurrently results in the formation of low pressure cells on the Australian continent (Ahrens & Henson 2019). This difference in air pressure between the two continents means that from December to February the predominant winds blow from the high pressure areas in Asia to the low pressure areas in Australia, so that this season is generally called the west monsoon or northwest monsoon season. During June, July and August, the phenomenon is reversed, with low pressure cells over Asia and high pressure cells over Australia, driving the east or southeast monsoon. Ormaza-Gonzales *et al*. (2016) found that tuna biomass is higher in the cold phase of the Pacific Decadal Oscillation (PDO) (2000-2030) than in the warm phase (1980-1999). These findings mean that commercial fishing operations and fisheries management need to be based on an analysis of oceanographic conditions.

Marine Fisheries: Journal of Marine Fisheries Technology and Management
Vol. 17 (1): 85-99, July 2026.

Research on various fishing gears including set nets, fish traps, crab gill nets, fish gill nets, squid trolling lines, and hook and line conducted in Rayon, Thailand using the same variables as this study found that fishermen operate various fishing gears or combinations of fishing gears at different times (months) throughout the year (Ebata *et al*. 2012). In contrast, the fishermen in Ekatiro Village, Bontotiro District, Bulukumba Regency only operated one type of fishing gear throughout the year, irrespective of the season, tuna hand-line gear.

The production volume, the duration of fishing operations and fuel consumption were calculated for each of the four seasons: the east monsoon (June, July and August), the transition from east to west monsoon or transition II (September, October, November), the west monsoon (December, January, February), and the transition from west to east monsoon or transition I (March, April, May). In terms of the number of fish caught, production was dominated throughout most of the study period by the smaller *kalaholong* size category of yellowfin tuna, although in most months some larger tuna (*opo'*) were caught, with bigeye tuna caught in small numbers during two months. Yellowfin tuna of both sizes (*kalaholong* and *opo'*) were caught during each of the four seasons while big-eye tuna were only caught during the east monsoon and the transition I (west to east) period. It seems that fishermen only count the types of tuna caught that are purchased by traders/middlemen and are therefore target species. According to Nainggolan *et al*. (2017), pole and line catch comprised skipjack tuna (*Katsuwonus pelamis*) 147,263 kg (72.7%), yellowfin tuna (*Thunnus albacares*), 49,659 kg (24.5%) and bullet tuna (*Auxis rochei*), 5,665 kg (2.8%). Anchovies (*Stolephorus* sp.) were used as live bait a catch to bait ratio from 5.8 to 10.7 to 1.0. In the handline fisheries in Ekatiro, Bontotiro District, Bulukumba Regency, it seems that fishers only counted the tuna catch that was sold to traders, comprising species specifically targeted by the handline fishing business units. There was a problem with exporting from Manado, in North Sulawesi, because the fishers could not meet the minimum unit volume for export to Japan (3 million tons per trip) due to quality issues. Some tuna caught did not meet the Japanese quality standards dua to poor onboard handling (fishing methods and post-harvest processing), with the supply limited to fish landed in the Bitung Main Fishing Port; furthermore, the transportation facilities for transporting the tuna from the port to the exporter were inadequate for maintaining export quality (Posundu *et al*. 2024).

The *kalaholong* yellowfin tuna were below the size at first maturity (Lm) for this species. According to FishBase, the global database of fishes (Froese & Pauly 2022), Lm = 103 cm, with a range of size at maturity of 78-158 cm. Yellowfin tuna over 20 kg in weight could be classed as adult, while other sources report that this species reaches maturity at around 100 cm in length (Novitasari *et al*. 2019). Based on these Lm data, most of the *opo'* yellowfin tuna were mature. Bramantya *at al*. (2021) found that captive female tuna broodstock were ready to spawn at a weight of 20 kg after rearing for one year in captivity (initial weight 5 kg and length ≈ 25 cm). Immature or "baby tuna" (under 20 kg) which would not have spawned prior to capture were mostly caught in August, September and October (east monsoon and transition period II – from east to west monsoons). The presence of fish in a given sea area is related to the environmental characteristics of the waters that influence the growth, survival and reproduction of a given fish species; therefore, when fish can be found at any time in a given area, this indicates that these waters are a habitat of the fish species, even though they may migrate, as long as they then return to the waters in question (WWF-Indonesia 2026). The seasonality of the *opo'* and *kalaholong* size classes over the one-year study period indicates that the Flores Sea provides yellowfin tuna habitat, including migration routes for this species.

The bigeye tuna (*Thunnus obesus*) measured during this study were over 102±4.5 cm FL, close to or above reported values of mean length at first maturity (L_{50}) for female bigeye tuna (Zudaire *et al*. 2016), including the FishBase value of Lm = 112.5 cm, with a range of 100-125 cm at maturity (Froese & Pauly 2022). Based on the fishing seasons when bigeye tuna were caught, it can be assumed that the Flores Sea is on a migration route for this species rather than being a permanent habitat. Based on the size of the fish caught, the spawning seasons and the latitude where they are typically found (Agus *et al*. 2021; WWF-Indonesia 2026), there are indications that the migration by yellowfin tuna and bigeye tuna during the east monsoon and the east to west transition season are most likely related to finding suitable areas for growth and feeding, as well as seeking preferred environmental parameters, while during the west monsoon and east to west transition these tuna may be looking for spawning areas, food and suitable environmental conditions. This differs from patterns reported for the Pacific bluefin tuna (*Thunnus orientalis)*, a commercially important species in Korea and the countries of the North Pacific. Monthly *T. orientalis* catches around Jeju Island from 2004-2013 were negatively correlated with temperature at 50 m depth and positively correlated with the Pacific Decadal Oscillation Index (PDOI) (Shin *et al*. 2018). The highest catch volume and catch per unit effort (CPUE) were reported at a at a depth of 50 m and seawater temperatures of 15 – 16 ˚C at the meeting between offshore and coastal water bodies. The time-series dataset showed that the length of the fish caught ranged from 19 to 193 cm FL and was negatively correlated with seawater temperature at 50 m depth and positively with PDOI. In Sri Lanka, the total production volume of tuna and tuna-like species in 2016 was 85,295 tons, dominated by skipjack tuna (35,512 tons), with yellowfin tuna comprising around 22% (26,240 tons), and bigeye tuna comprising around 5% (Hewapathirana & Gunawardane 2017). In 2012, the International Union for the Conservation on Nature (IUCN) Red List of threatened species placed most tuna in at risk categories, although in the most recent version (IUCN 2023), only the southern bluefin tuna (*Thunnus maccoyii*) is still listed as endangered (EN), the bigeye tuna (*Thunnus obesus*) as vulnerable (VU), and the Pacific Bluefin Tuna (*Thunnus orientalis*) as near threatened (NT), while the Atlantic bluefin tuna (*Thunnus thynnus*), yellowfin tuna (*Thunnus albacares*) and albacore tuna (*Thunnus alalunga*) are no longer considered threatened, being listed as least concern (LC).

This downgrading in threat levels can be seen as a vindication of the way in which the management of tuna, as a group of highly migratory species, is regulated by global, regional or subregional organizations under the Regional Fisheries Management Organizations (RFMOs). There are currently five tuna RFMOs: Commission for the Conservation of Southern Bluefin Tuna (CCSBT); Inter-American Tropical Tuna Commission (IATTC); International Commission for the Conservation of Atlantic Tunas (ICCAT); Indian Ocean Tuna Commission (IOTC); and the Western and Central Pacific Fisheries Commission (WCPFC). Nonetheless, despite these positive initiatives and trends at the global level, at the local level, several studies report signs that Indonesian tuna stocks in particular may still be at risk of overfishing or unsustainable fishing patterns such as excessive catch of juvenile tuna. For example, a study in Indonesian Fisheries Management Area (FMA) 715 reported the average length at capture was 44.4cm (above Lm) for skipjack tuna, but only 46.1 cm (well below Lm) for yellowfin tuna (Nainggolan *et al*. 2017). Based on the size composition of yellowfin tuna caught during the study, there are indications that the handline tuna fishing in the Flores Sea may be unsustainable.

In addition, the interview data indicated that the distance to the fishing grounds in the Flores Sea is increasing, with fishers needing to go further south from the fishing base, a phenomenon known as range collapse (Nadiarti *et al*. 2021). However, as handline fishing is the main livelihood activity for a considerable number of local families, it is necessary to find a solution to maintain the tuna stocks on which this fishery depends. For comparison, Korea is a country that is increasingly aware of the need to take precautionary measures to develop sustainable fisheries, including protecting marine ecosystems and the environment, in particular to anticipate increasingly strong demands from the international community (Lee *et al*. 2022). Although the Korean tuna longline fleet, which includes a deep longline fishery (100-300 m depth), is not subject to mandatory turtle by-catch mitigation measures and does not operate within the scope of the RFMO convention, the fishermen voluntarily apply measures such as using circle hooks and using whole fish as bait. In addition, the national regulations and management programs for turtle bycatch prevention adopted by the Republic of Korea can be considered comparable in effectiveness to those of the United States.

CONCLUSION

This study demonstrates that small-scale hand-line tuna vessels (≤ 10 GT) in Bulukumba Regency operate year-round in the Flores Sea, with FAD-centered fishing grounds shifting seasonally and expanding southwards (*range collapse*). Operational performance averaged a catch rate of 19.7 kg/hour (474,935 IDR/hour) and fuel efficiency of 9.6 kg/L (231,600 IDR/L). However, the fishery faces severe biological risk: the catch (n = 1,210) is heavily dominated (84.5%) by small, immature yellowfin tuna (*Thunnus albacares*, *kalaholong*; 34–46.2 cm FL) caught well below the length at first maturity

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(Lm » 103 cm), whereas mature yellowfin (*opo'*, 15.1%) and bigeye tuna (*Thunnus obesus*, *sabau*, 0.33%) comprise minor fractions. These spatial, operational, and biometric indicators collectively confirm that current hand-line practices in the Flores Sea are ecologically unsustainable, threatening local stock recruitment.

SUGGESTION

The high proportion of immature fish caught and the growing distance travelled by fishers to find productive fishing grounds indicate a need for management interventions to maintain tuna stocks and ensure the sustainability of this fishery which sustains the coastal communities in the study area. These could include training for fishermen on the behavior, physiology, life cycle and other aspects of tuna resources to support sustainable, efficient and effective fishing operations.

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