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# Dynamics of Tuna Fisheries Associated With Fish Aggregating Devices (FADs) Landed in Sorong City, Southwest Papua Province

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## ABSTRACT

The unregulated deployment of fish aggregating devices (FADs) has intensified exploitation, disrupting the marine food chain and reducing fish stocks. Tuna production at Sorong Coastal Fishing Port and Klademak Fishing Port, Sorong has declined annually due to uncontrolled FAD placement. This study maps tuna FAD distribution, catch production trends, fishing seasons, and weight distribution of landed tuna in Sorong City. Data sources include tuna catch records (2019–2024), FADs positions from fishermen's GPS waypoints, and weight data from KKP enumerators (January–December 2024). Analyses include catch per unit effort (CPUE), the Fishing Season Index (using the moving average method), and descriptive spatial assessments. The research findings reveal that FADs are predominantly concentrated in the waters of Northern Waigeo, Northern Papua extending to the Pacific Ocean, and the Seram Sea. The distance between FADs ranges from 1.35 to 17.4 NM, with 86.75% positioned within 10 NM. Notably, all FADs remain unregistered. Tuna CPUE declined by 18.63% (2019–2024). The peak fishing season occurs in January, March-May, and October, with moderate activity in February, June, November, and December, and a lean season from July to September. Large tuna (>16 kg) are primarily caught April–December, while smaller tuna (<16 kg) dominate January–March.

## INTRODUCTION

Tuna is a commercially valuable species that significantly contributes to economic development and government revenue, serving as a key commodity in international trade **(Moore *et al.*, 2020; Hoshino *et al.*, 2024)**. Global tuna production reaches approximately 7 million tons per year, accounting for 20% of the total market value of marine fisheries **(Akia *et al.*, 2023)**. Indonesia, as the world's largest tuna producer, contributed approximately 19.1% of global tuna production, with an export value of US$565 million in 2022, which increased to US$927.13 million in 2023 **(KKP, 2024)**. In 2023, Indonesia's tuna export volume reached 203,202.50 tons, distributed across 82 countries. The largest export destinations included Japan, Thailand, the United States, Saudi Arabia, the Philippines, Italy, Vietnam, Spain, and Australia **(BPS, 2024)**. Tuna resources are distributed across various Indonesian Fisheries Management Areas (WPPs) and are landed at 62 designated fishing ports **(Mardiah *et al.*, 2023)**. Southwest Papua Province serves as a key habitat and distribution area for tuna within WPPs 715 and 717.

Sorong City is one of the key tuna-producing centers in Southwest Papua Province, strategically positioned as a base for the tuna fisheries industry **(Loupatty *et al.*, 2024)**. It is surrounded by the Seram Sea to the south (WPP 715) and the Pacific Ocean to the east (WPP 717), both of which are highly productive tuna fishing grounds. These waters are part of the Regional Fisheries Management Organization (RFMO) and fall under the jurisdiction of the Western and Central Pacific Fisheries Commission **(WCPFC, 2024)**. Tuna catches in the WCPFC region were reported to be within sustainable limits in 2022, accounting for 54% of global tuna landings, with a total value of US$5.95 billion **(Haas *et al.*, 2024)**. The strategic location of Sorong City, coupled with the moderate status of tuna stocks in the WCPFC region, presents a significant opportunity for the local government to optimize tuna fisheries development. Leveraging this potential can contribute to increased income and improved livelihoods for tuna fishers, who constitute the majority of Sorong's fishing community.

An assessment of tuna stocks in Fisheries Management Area (WPP) 717, particularly in the waters of Sorong City, reveals discrepancies compared to the moderate stock status reported by WCPFC. Tuna production between 2019 and 2024 exhibited significant fluctuations, with a declining trend. In 2019, production was recorded at 637.75 tons; however, despite a 7.14% increase in fishing effort in 2024, total production declined to 518.96 tons, reflecting an 18.63% reduction **(PSDKP Sorong, 2024)**. A substantial decline in fish production is often indicative of prolonged overexploitation, serving as a key indicator of diminishing resource abundance in the region **(Suherman *et al.*, 2025)**. Tuna fishing activities in Sorong City predominantly employ handline, pole-and-line, and mini purse seine gear, targeting the yellowfin tuna (*Thunnus albacares*) and the bigeye tuna (*Thunnus obesus*) **(Labobar *et al.*, 2021)**. Landings primarily take place at two major fishing ports: the Sorong Coastal Fisheries Port (PPP Sorong) and the Klademak Sorong Fisheries Port **(Yuliandri *et al.*, 2023)**.

Tuna fishing in the waters of Sorong City employs fish aggregating devices (FADs) strategically placed in fishing grounds. FADs are considered highly effective for aggregating fish and optimizing fuel efficiency **(Wain *et al.*, 2021)**. However, the enforcement of regulations governing FAD deployment continues to face significant challenges across various regions **(Nurani *et al.*, 2018; Hoshino *et al.*, 2024)**. Fishermen in Sorong set the FADs without undergoing a formal licensing process, and there is currently no available data on their distribution. This unregulated practice may lead to an excessive increase in FAD numbers and improper placement, violating existing regulations. Uncontrolled FAD deployment, coupled with declining catch production, poses a threat to the sustainability of tuna fisheries. To ensure sustainable management, FAD placement must be regulated by established policies **(Nurani *et al.*, 2018; Soghirun *et al.*, 2024)** and aligned with the carrying capacity of the marine ecosystem **(Nurdin *et al.*, 2012)**. Proper regulation is essential to maintaining the balance of the marine food web and ensuring the long-term availability of fish stocks **(Leroy *et al.*, 2013; Orúe *et al.*, 2020)**.

Tuna fishing in Sorong City, which relies on FADs, necessitates a comprehensive assessment to understand its dynamics. These dynamics provide critical insights into FAD distribution, productivity trends, fishing seasons, and the biological condition of harvested tuna. The distribution and abundance of tuna are influenced by catch fluctuations and seasonal variation **(Hobday *et al.*, 2011; Orúe *et al.*, 2020; Posundu *et al.*, 2024)** as well as oceanographic conditions **(Wiryawan *et al.*, 2020; Nurani *et al.*, 2022; Pratama *et al.*, 2022)**. Seasonal fishing information enhances catch optimization and efficiency, whereas fish distribution data inform management strategies to minimize the capture of juvenile or undersized tuna **(Sepri, 2012; Anggara *et al.*, 2023; Posundu *et al.*, 2024)**.

Given the heavy reliance of small-scale fishers on FADs, an in-depth evaluation of fishery dynamics is essential to mitigate potential threats to resource sustainability. This study aimed to map and analyze FAD distribution, assess production trends and fishing seasons, and examine the size distribution of landed tuna in Sorong City. The research approach involves mapping the distribution of FAD placement, calculating catch per unit effort (CPUE), estimating fishing seasons, and calculating the weight composition of tuna caught. This biological information on tuna is crucial and serves as the scientific basis for policymakers in managing and implementing a sustainable tuna fisheries regulatory framework.

Sustainability is a keyword that aligns with Indonesia's vision for blue economic development in 2045, namely the sustainable management of coastal and marine resources to create socio-economic prosperity, ensure a healthy marine environment, and strengthen resilience for present and future generations **(Leonardo *et al.*, 2023)**. This research also supports the achievement of the Sustainable Development Goals (SDGs), particularly SDG 14 (Conserving Marine Resources for Sustainable Development); SDG 1 (Eradicating Poverty); SDG 2 (Eliminating Hunger and Improving Food Security); SDG 8 (Decent Work and Economic Growth); SDG 12 (Responsible Consumption and Production); and SDG 13 (Climate Action).

Several studies have confirmed that the presence of fish aggregating devices (FADs) can expand the range of fishing and increase catch yields **(Gigentika *et al.*, 2017; Nurhayati *et al.*, 2018)**. However, uncontrolled placement of FADs, including overly close spacing between devices and zoning violations, poses serious risks to the sustainability of tuna resources as it can trigger stock depletion and increased catch of juvenile fish **(Yusfiandayani *et al.*, 2015; Leroy *et al.*, 2013; Orúe *et al.*, 2020)**. Although several studies have been conducted in various fisheries management areas, research that comprehensively assesses the interaction between FAD distribution, multi-gear productivity trends, seasonal fishing patterns, and catch size structure in Sorong City, West Papua, remains very limited. Therefore, this study is expected to fill this gap and to provide a scientific basis for more sustainable tuna fishery management based on fish aggregating devices.

## MATERIALS AND METHODS

Data collection was carried out through a systematic survey over three months (October–December 2024) in Sorong City, Southwest Papua Province. The study area is illustrated in Fig. (1). This research specifically examined tuna fishing vessels that land their catches at the Sorong Coastal Fisheries Port and Klademak Sorong Fisheries Port.

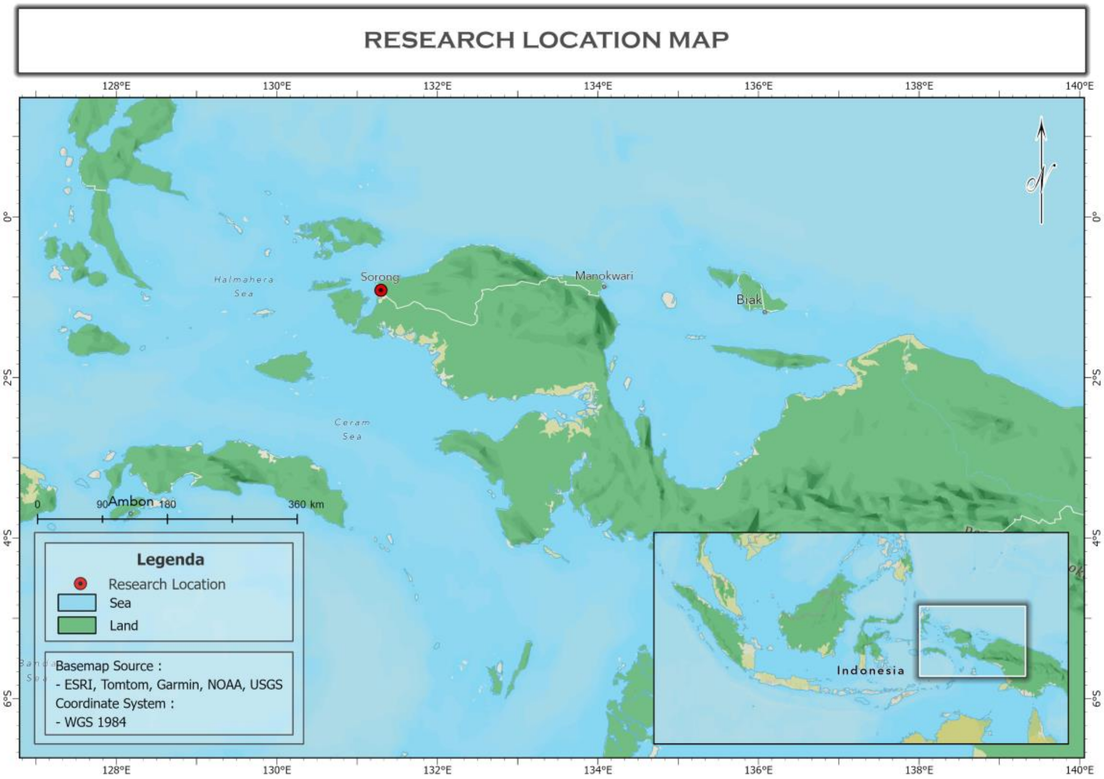


**Fig. 1.** The study location is in Sorong, Southwest Papua

Data on production and fishing effort were obtained from the statistical records of PPP Sorong, PP Klademak, and PSDKP Sorong, covering six years (2019–2024). Structured interviews were conducted with fishermen, vessel operators, and fisheries management authorities to evaluate tuna fisheries management practices. Fishing location data were collected using GPS devices and other digital applications used by tuna fishers. Tuna weight distribution data were sourced from enumerator records of the Marine and Fisheries Office, spanning January to December 2024.

The distribution of fish aggregating devices (FADs) was analyzed descriptively using Marine Geographic Information Systems (GIS) with ArcGIS to map FAD distribution, measure distances between FADs, and assess compliance with regional fisheries management zoning regulations. Catch-per-unit effort (CPUE) calculations, tables, and graphical representations were used to descriptively assess production data. The moving average approach was used to calculate the Fishing Season Index (FSI). Class interval distribution analysis was used to provide a descriptive overview of tuna size distribution. Fishing Season Index (FSI) analysis was adapted from **Dajan (1983)**, CPUE calculations were based on **Sparre and Venema (1998)** and further developed by **Wiyono *et al.* (2006)**, and FAD mapping followed ArcGIS guidelines **(Esri, 2023)**. Tuna size distribution intervals were determined using the equation of **Freedman and Diaconis (1981)**.

**Analysis of FAD distribution**

The spatial distribution of FADs was mapped using the ArcGIS 10.8 overlay method **(Esri, 2023)** through the following procedures:

1. **Conversion of GPS coordinates** – GPS coordinate data were transformed into CSV format for compatibility with ArcGIS.
2. **Importing FAD position data into ArcGIS 10.8** – In ArcGIS, navigate to *Map* > *Add Data* > *XY Table*. Select the CSV file, specifying Latitude (Y) and Longitude (X). Configure the coordinate system to WGS 1984 to ensure geospatial accuracy, then integrate spatial data layers.
3. **Base mapping** – Import the Indonesian Topographic Map to provide a georeferenced base map.
4. **Regulatory alignment** – Incorporate the Marine Spatial Planning Map for Southwest Papua Province to align with regulatory zoning policies.
5. **Spatial analysis** – Measure distances between FADs to assess spatial clustering and fishing effort distribution. Analyze FAD positioning relative to the zoning boundaries of Southwest Papua Province to ensure compliance with fisheries management regulations.

**CPUE analysis**

The CPUE analysis compares the overall catch volume to total fishing effort to determine the productivity of fishing gear. Tuna fishing methods in Sorong, Southwest Papua Province, include handline, pole-and-line, and micro purse seine. The following formula, adapted from the study of **Sparre and Venema (1998)**, was used to estimate CPUE:

1. The catch and effort data are tabulated, and the CPUE is computed

   $$CPUE = \frac{Catch}{Effort} \quad \text{.......} \quad (1)$$

   Where, CPUE = catch per unit effort (ton/trip); *Catch* = volume of tuna catches (ton); *Effort* = number of the trip of the tuna fishing vessels.

2. Setting catch effort standards

   The standardization of fishing gear for CPUE analysis was conducted because tuna are caught using multiple gear types, including handline, pole and line, and mini purse seine. Standardization is required since the efficiency of each type of fishing gear varies. The gear standardization was carried out using the formula below.

   a) Calculation of Fishing Power Index (FPI)

   $$\text{FPI} = \frac{\text{CPUE}dst}{\text{CPUE}st} \quad \text{.......} \quad (2)$$

   Where, FPI = *Fishing power index*; CPUE*dst* = the CPUE of fishing operations to be standardized (tons per trip); CPUE*st* = CPUE standard fishing gear (tons/trip).

   b) The computation of the standard effort

   $$\text{Fs} = \text{FPI} \times \text{Fdst} \quad \text{.......} \quad (3)$$

   Where: Fs = standardized fishing effort based on catch standardization results (trips), Fdst = fishing effort associated with catch results for standardization (trips).

   c) CPUE analysis

   The standardized fishing effort was used to recalculate the CPUE value, but the catch value stays the same.

   $$\text{CPUEs} = \text{Catch/Effort} \quad \text{.......} \quad (4)$$

Where : CPUEs = catch unit effort standard (tons/trip); Catch = the catch month i (tons);
Effort = standardization of fishing effort in month i (trip)

Increasing the trend of CPUE over time indicates a healthy fish stock and sustainable fishing, suggesting continued economic viability. Conversely, a declining CPUE trend signals overfishing **(Nurhayati *et al*., 2018; Sofiati & Alwi, 2019)**.

***Seasonal fishing pattern***

The pattern of the fishing season was estimated by applying the moving average technique referred to by **Dajan (1983)** and later modified by **Wiyono *et al.* (2006)**, following these steps.

1. Constructing a CPUE time series over six years (2019–2024)

$$n_i = CPUE_i \quad \text{......} (5)$$

Where, i = 1, 2, 3,…, n; $n_i$ = order-i

2. Calculating the moving average of CPUE (RG)

$$RG_i = \frac{1}{2}\left(\sum_{i=1-6}^{i+5} CPUE_i\right) \quad \text{......} (6)$$

Where, i = 7, 8,…, n-5; $RG_i$ =12-month moving average of the i-th sequence; $CPUE_i$ = CPUE at the jth position in the time series $n\ i$

3. Calculating a time series of cumulative CPUE over 24 months for each month (RGP)

$$RGP_i = \frac{1}{2}\left(\sum_{i=1}^{i=1} RG_i\right) \quad \text{......} (7)$$

Where, $RGP_i$ = centered moving average of CPUE at the i-th position; $RG_i$ = 12-month moving average at the i-th position; i = 7,8,….., n-5

4. Calculating the average monthly value (Rb)

$$Rb_i = \frac{CPUE_i}{RGP_i} \quad \text{......} (8)$$

Where, $Rb_i$ = average monthly ratio at the i-th position; $CPUE_i$ = CPUE at the i-th position; RGPi = centered moving average of CPUE at the i-th position; i = 7, 8,.…, n-5.

5. Develop an i× j matrix of average ratio values for each month (July–June), followed by calculating monthly and overall average ratios to determine fishing season patterns
   a) Average ratio for the i-th month

   $$RRB_i = \frac{1}{n}\left(\sum_{j=1}^{n} Rb_{ij}\right) \quad \text{......} (9)$$

   Where, RRBi = the average of Rb ij for the i-th month; $Rb_{ij}$ = monthly average ratio within an i×j matrix, i = 1, 2, 3,….., 12; j = 1, 2, 3,.….,n.

   b) Sum of the monthly average ratios

   $$JRRB = \sum_{i-1}^{12} RRB_i \quad \text{......} (10)$$

Where, RRBi = the average of Rb ij for the i-th month; $RRB_i$ = Average Rbij for the i-th month; i = 1, 2, 3, ….., 12.

c) Calculating the correction factor

$$FK = \frac{1200}{JRBB} \quad (11)$$

Where: FK = the correction factor value; JRBB = Total monthly average ratio.

d) The fishing season index (FSI) can be calculated using the formula:

$$FSI = RRB_i \ x \ FK \quad (12)$$

Where: FSIi = index of the i-month fishing season; $RRB_i$ = Monthly average ratio; FK = the correction factor value; i =1, 2, 3,….., 12.

The Fishing Season Index (FSI) allows for the classification of the fishing season into two groups. A fishing season is indicated by an FSI above 100%, while a non-fishing season is indicated by an FSI below 100% **(Wiyono *et al.*, 2006)**.

***Analysis of tuna weight distribution***

The analysis of tuna weight distribution was described using a class interval histogram, following the equation proposed by **Freedman and Diaconis (1981)**.

1. Determining the number of classes

   $$K=1+3.322\log n \quad (13)$$

   Where, K = number of classes; n = total number of data

2. Determining the data range (R)

   $$R=Xmax-Xmin \quad (14)$$

   Where, R = renting data; X max = the maximum value found in the data; X min = the minimum value found in the data.

3. Calculating the class interval length (I)

   $$I = \frac{R}{K} \quad (15)$$

   Where, I = Class interval length; R = Data range; K = Number of classes.

4. Creating class intervals, starting from the smallest value and adding the class interval length to form the interval groups.

5. Calculating the class midpoint (Xc)

   The midpoint of each class can be calculated using the formula.

   $$Xc = \frac{L+U}{2} \quad (16)$$

   Where, $Xc$ = the class midpoint; $L$ = the class interval's bottom limit; $U$ = the class interval's top limit.

## RESULTS

### 1. Distribution of tuna FADs locations

Handline tuna fishing vessels operate between latitudes 00°16.737′ N and 00°52.783′ S, and longitudes 131°12.477′ E and 132°32.949′ E. Mini purse seine vessels operate between latitudes 00°00.906′ N and 00°45.079′ S, and longitudes 132°02.583′ E and 136°20.896′ E. Pole-and-line vessels operate between latitudes 00°07.000′ N and 02°40.000′ S, and longitudes 129°43.000′ E and 130°48.000′ E. A total of 81 GPS waypoints representing fishing locations were obtained from fishermen, consisting of 38 waypoints for tuna handline, 25 waypoints for mini purse seine, and 18 waypoints for pole-and-line fishing.

According to fishermen interviews, the distribution of handline tuna fishing areas for vessels of 1–4 GT extends from the waters of Tanjung Momfafa (Tanjung Pamali) in North Waigeo, Raja Ampat District, to the waters of Sansapor, Tamrau District. Vessels over 5 GT operate in the waters of Tanjung Saobas and Warai in North Waigeo, Raja Ampat District, in the waters of Sansapor and Tamrau District, and extend to the northern waters of Papua and the Pacific Ocean. Mini purse seine operations are concentrated in the northern waters of Papua, extending into the Pacific Ocean.

Pole-and-line vessels operate primarily in the Seram Sea, with 15 waypoints recorded, and in the waters around Gag Island, Raja Ampat District, with 3 waypoints. The total number of fish aggregating devices (FADs) recorded includes 7 in North Waigeo, 10 in the waters of Sansapor, and 47 in the northern waters of Papua and the Pacific Ocean—comprising 22 used by handline vessels and 25 by mini purse seine vessels (Fig. 2). Not all of the mini purse seine FADs are owned by Sorong fishermen; many belong to the Indotuna Bitung company. However, Sorong tuna fishermen also utilize these devices through collaborative arrangements with Bitung fishermen. The reported number of FADs is based on information provided by local fishermen and may be higher, as some fishing locations have not been disclosed.

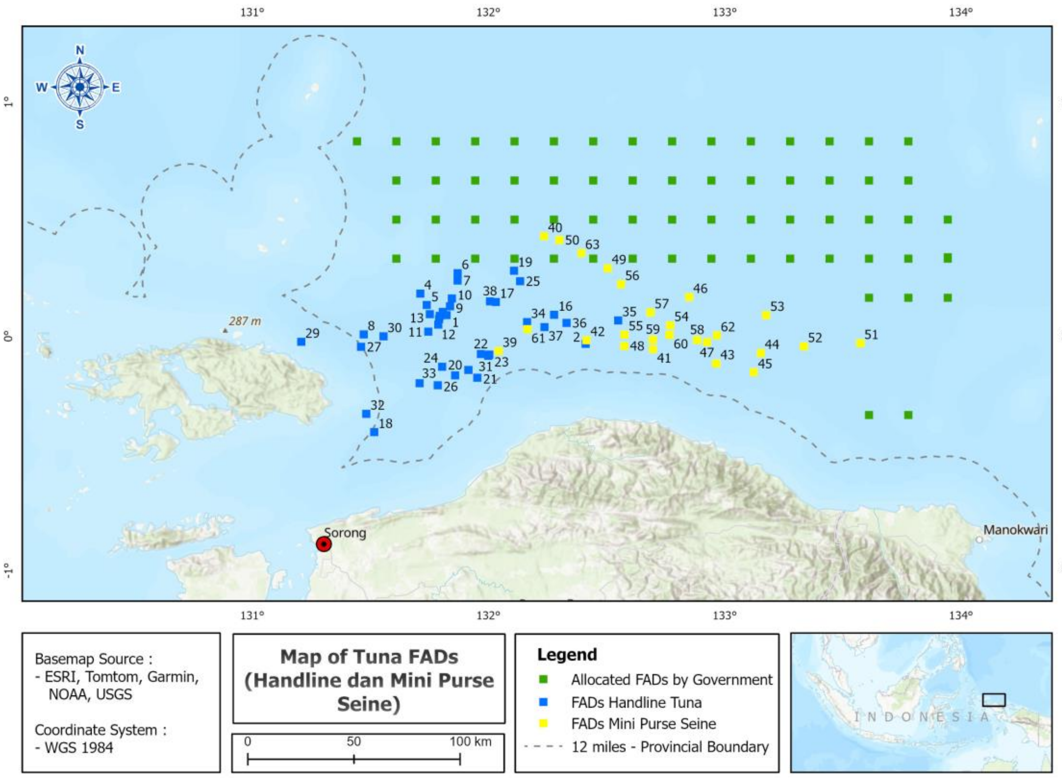


**Fig. 2.** Distribution of handline and mini purse seine FADs

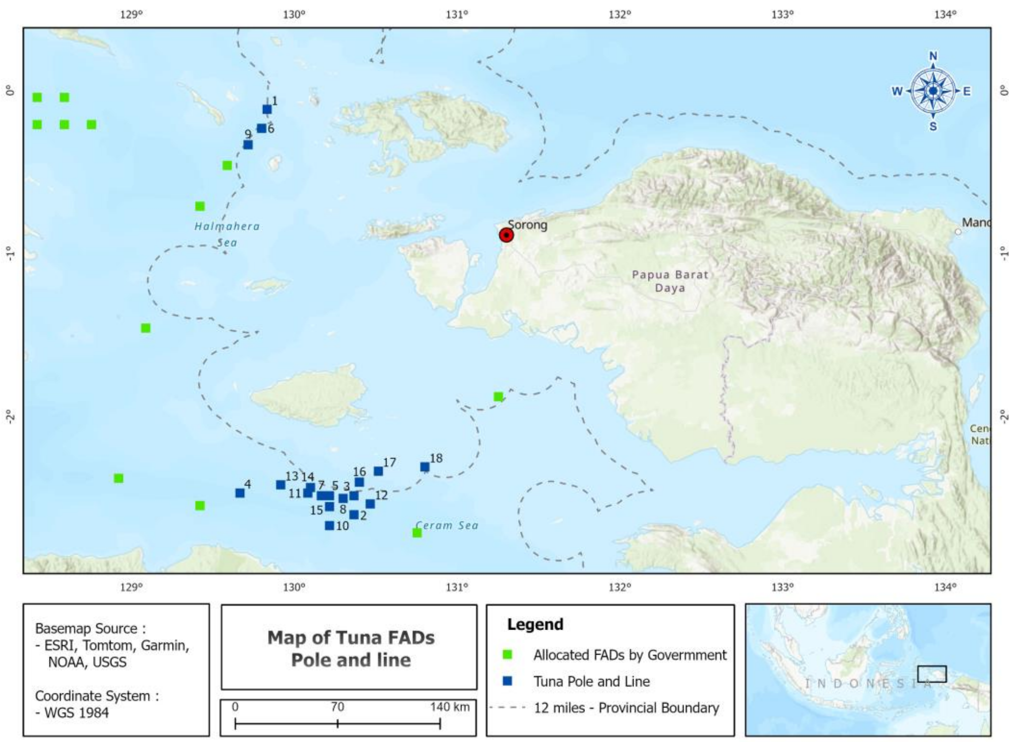


**Fig. 3.** Distribution of pole and line FADs

The distance from the fishing base to the fishing grounds ranges from 32–97 NM for handline operations, 80–151 NM for mini purse seine operations, and 93–164 NM for pole-and-line operations. Two FAD locations are situated less than 12 NM from the fishing base—FAD 32 (8.8 NM) and FAD 29 (4.65 NM)—both located in the Raja Ampat waters. All other FAD positions are beyond 12 NM (12.4–46.9 NM). According to the RZWP3K, these two nearshore FADs are located within the designated small pelagic fish capture fisheries zone.

The distance between FADs used for tuna handline fishing is generally shorter than for mini purse seine fishing. For handline vessels, FAD spacing ranges from 1.35 NM to 10.2 NM, with 68.29% located 1–5 NM apart, 29.26% located 5–10 NM apart, and only 2.43% more than 10 NM apart. The only handline FAD pair spaced at 10.2 NM is between FAD 2 and FAD 35, but this location is adjacent to a mini purse seine FAD only 2.41 NM away.

For mini purse seine vessels, FAD spacing ranges from 3.13 NM to 14.4 NM, with 28.57% located 3–5 NM apart, 42.85% located 5–10 NM apart, and 28.57% more than 10 NM apart. At least five handline FADs (FADs 2, 16, 34, 35, and 36) are located near mini purse seine FADs, with distances ranging from 2.41 NM to 9.4 NM.

Two pole-and-line FADs are located less than 12 NM from shore—FAD 17 (5.3 NM) and FAD 16 (8.9 NM)—both within the pelagic fisheries utilization zone (Fig. 3). The nearest pole-and-line FADs are FAD 14 and FAD 11 (2.17 NM apart), while the farthest are FAD 17 and FAD 18 (17.4 NM apart). Three pole-and-line FADs (16.67%) are spaced more than 10 NM apart; the remainder are within 10 NM.

None of the existing FAD locations fall within officially designated government-permitted positions, and thus their legality is not formally registered. Several FADs are close to government-permitted areas—FADs 6, 7, 19, 25, and 49—at distances of 4.32–6.5 NM. Three mini purse seine FADs (FAD 40, FAD 50, and FAD 63) are located beyond the boundaries of permitted government zones.

## 2. CPUE analysis

Tuna fishing is carried out primarily by handline vessels (4–27 GT) targeting yellowfin tuna (*Thunnus albacares*) and bigeye tuna (*Thunnus obesus*) as the main catch. Pole-and-line vessels (58–97 GT) and small pelagic mini purse seine vessels (29–77 GT) occasionally catch tuna as bycatch.

Handline fishermen use small boats (3 m × 0.8 m × 0.5 m) equipped with 9-horsepower outboard engines, locally known as *pakura*. Catches are landed at the Sorong Coastal Fisheries Port (PPP Sorong) and the Klademak Sorong Fisheries Port, where they are recorded. Tuna meeting company standards are sold to the Fish Processing Unit (UPI), while the remainder are sold in local markets.

Pole-and-line vessels primarily target skipjack tuna, while small pelagic mini purse seine vessels target mackerel, scad, and skipjack tuna. However, because both gears often operate around FADs, tuna associated with these devices are also caught as bycatch.

The tuna catch and fishing effort for each fishing gear type are summarized in Table (1).

**Table 1**. Tuna catch landed in Sorong City during the 2019-2024 period

| Year | Handline | | | Huhate | | | Mini Purse Seine | | |
|---|---|---|---|---|---|---|---|---|---|
| | Catch (ton) | Effort (trip) | CPUE | Catch (ton) | Effort (trip) | CPUE | Catch (ton) | Effort (trip) | CPUE |
| 2019 | 328.95 | 435 | 0.76 | 159.64 | 145 | 1.10 | 149.16 | 82 | 1.82 |
| 2020 | 299.24 | 325 | 0.92 | 199.93 | 120 | 1.67 | 147.45 | 44 | 3.35 |
| 2021 | 237.69 | 308 | 0.77 | 129.04 | 113 | 1.14 | 197.78 | 45 | 4.40 |
| 2022 | 339.56 | 393 | 0.86 | 18.24 | 32 | 0.57 | 175.95 | 59 | 2.98 |
| 2023 | 239.02 | 332 | 0.72 | 35.31 | 34 | 1.04 | 138.20 | 60 | 2.30 |
| 2024 | 308.85 | 628 | 0.49 | 72.13 | 40 | 1.80 | 137.98 | 43 | 3.21 |
| Total | 1,753.30 | 2,421 | 0.72 | 614.29 | 484 | 1.27 | 946.52 | 333 | 2.84 |

[#]Footnote: Sorong fishing port statistics data (processed data).

Tuna fishing using handline gear contributed the largest share of the total tuna catch (52.90%), followed by mini purse seine (28.56%) and pole-and-line (22.75%). This total catch reflects the high number of fishing trips made by handline vessels, which have dominated tuna fishing efforts over the past six years. Handline vessels recorded 2,421 trips (74.77% of the total 3,238 trips), while mini purse seine vessels accounted for the smallest share of effort (10.28%).

Although handline vessels contribute the largest proportion of tuna catches, their productivity is the lowest, ranging from 0.49 tons/trip to 0.92 tons/trip, with an average of 0.72 tons/trip. In contrast, mini purse seine vessels, despite having the smallest fishing effort, achieve the highest productivity, ranging from 1.82 tons/trip to 4.40 tons/trip, with an average of 2.84 tons/trip.

The differences in CPUE values among tuna handline, pole-and-line, and small pelagic mini purse seine gears demonstrate that each fishing method has distinct catch capabilities. Therefore, standardization was carried out using the Fishing Power Index (FPI). The FPI values used for the standardization of tuna fishing gear are presented in Table (2).

**Table 2.** Fishing power index (FPI) of tuna fishing gear

| Fishing | Catch total (ton) | Effort total (trip) | CPUE total | FPI |
|---|---|---|---|---|
| Handline | 1,753.30 | 2,421 | 0.72 | 0.25 |
| Pole and line | 614.29 | 484 | 1.27 | 0.45 |
| Purse seine | 946.52 | 333 | 2.84 | 1.00 |

The Fishing Power Index (FPI) analysis indicates that the standardized fishing gear for tuna capture is the small pelagic mini purse seine, as it records the highest CPUE value at 2.84 tons/trip. Accordingly, the FPI values obtained were 1.00 for the small pelagic mini purse seine, 0.46 for pole-and-line, and 0.25 for handline tuna. These FPI values were then used as standardized effort inputs to calculate the CPUE Standard for tuna fishing. The CPUE Standard values for Sorong tuna fisheries are presented in Table (3).

**Table 3**. Standardized CPUE of tuna fishing in Sorong City

| Year | Total Catch (ton) | Effort Standard (trip) | CPUE Standard |
|---|---|---|---|
| 2019 | 637.75 | 257.58 | 2.48 |
| 2020 | 646.62 | 180.39 | 3.58 |

| | | | |
|---|---|---|---|
| 2021 | 564.50 | 173.93 | 3.25 |
| 2022 | 533.75 | 173.42 | 3.08 |
| 2023 | 412.53 | 159.77 | 2.58 |
| 2024 | 518.96 | 220.87 | 2.35 |

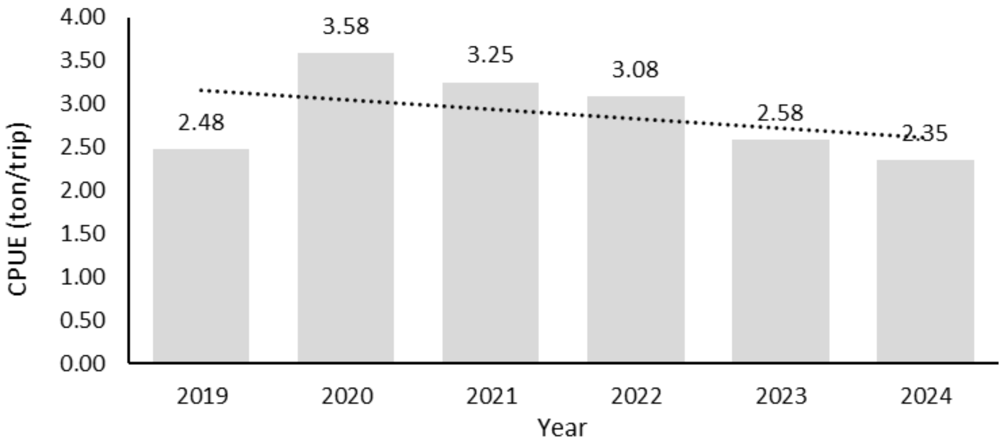


**Fig. 4.** CPUE of Tuna in Sorong for years 2019-2024

The CPUE values for tuna in Sorong City over the last six years (2019–2024) were 2.48 tons/trip, 3.58 tons/trip, 3.25 tons/trip, 3.08 tons/trip, 2.58 tons/trip, and 2.35 tons/trip, respectively (Table 3). The CPUE trend over this period shows a consistent decline (Fig. 2). In 2019, the CPUE was relatively low at 2.48 tons/trip, then increased sharply by 44.35% in 2020 to 3.58 tons/trip. Since 2020, the CPUE value decreased each year—by 9.21%, 5.23%, 16.23%, and 8.91% in successive years.

The highest CPUE was recorded in 2020 at 3.58 tons/trip, while the lowest occurred in 2024 at 2.35 tons/trip. In terms of fishing effort, the highest level was recorded in 2019 at 257.58 standardized trips, and the lowest in 2023 at 159.77 standardized trips (Fig. 4). Notably, CPUE values in 2019 and 2024 were the lowest of the six-year period despite both years recording higher fishing effort than the other four years. This indicates that increased fishing effort in these years corresponded with reduced fishing productivity.

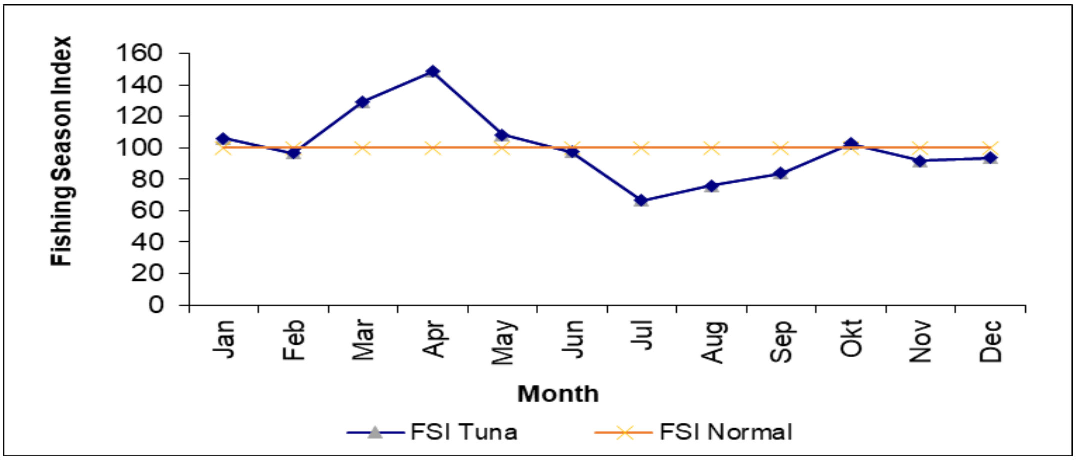


**Fig. 5.** Tuna fishing season index value 2019–2024 in Sorong

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The Tuna Fishing Season Index (FSI) exceeded 100%—indicating peak fishing months—only in January, March, April, May, and October, with respective values of 105, 129, 148, 108, and 102%. These months do not occur consecutively. Fig. (5) shows that the seasonal pattern of tuna fishing is highly fluctuating and unstable. The fishing season generally spans from January to May, with peak activity in March and April (129 and 148%, respectively), which are considered the core peak months. The FSI then declines from June to September, reaching its lowest levels in July (66%) and August (75%), suggesting these months represent the lean season. The index rises again in October (102%) before slightly decreasing in November (91%) and December (93%), which are considered moderate fishing months.

### 3. Tuna weight distribution

The Ministry of Marine Affairs and Fisheries (KKP) employs enumerators to record tuna landings under the measured fisheries program. However, purse seine and pole-and-line vessels do not maintain individual fish weight records; only tuna landed by handline vessels have complete and accurate size data. Tuna caught by purse seine and pole-and-line vessels are generally small (2–7 kg) and are weighed in baskets on board rather than individually.

From January to December 2024, individual tuna weights recorded from handline landings in Sorong City show the size distribution of tuna caught throughout the year. Fig. (6) illustrates the weight distribution of individual fish landed in 2024.

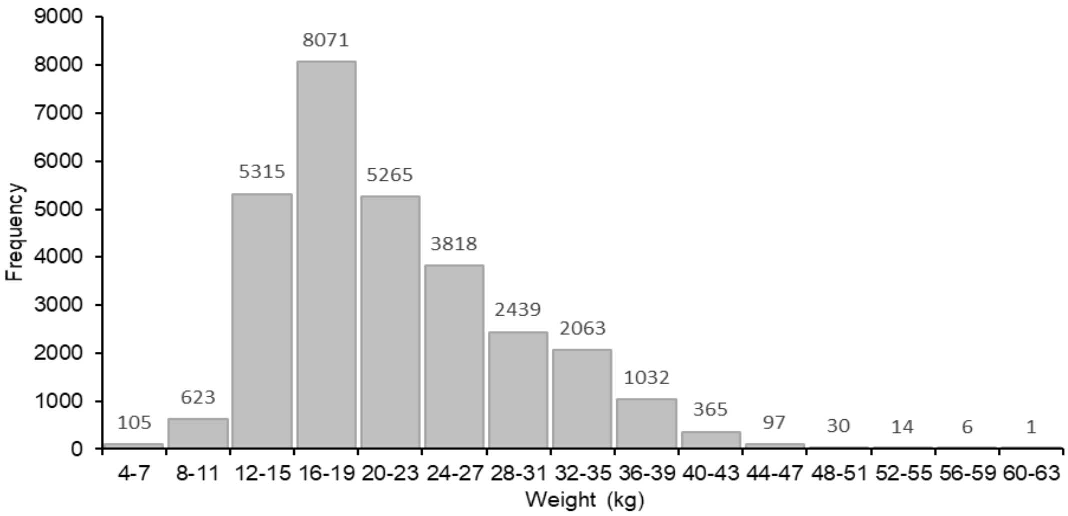


**Fig. 6.** Weight distribution of tuna in the 2024 period
Source: Processed Data from KKP Sorong Enumerator, 2024

A total of 29,244 individual tuna were recorded, with weights ranging from 4kg (11 individuals) to 63kg (1 individual). The mean weight was 21.56kg, with a median of 20kg and a standard deviation of 7.39 kg. The most common weight class was 16–19 kg. As shown in Fig. (6), the majority of the catch—63.78% (n = 18,651)—fell within the 12– 23kg range. The proportion of larger tuna declined with increasing weight: fish in the 24– 39kg range comprised 31.97% (n = 9,352), those in the 40– 51kg range made up 1.68% (n = 492), and the largest size class (51– 63kg) accounted for only 0.07% (n = 21). Immature or "baby" tuna weighing 4– 11kg were rare, representing just 2.4% (n = 728) of the total catch.

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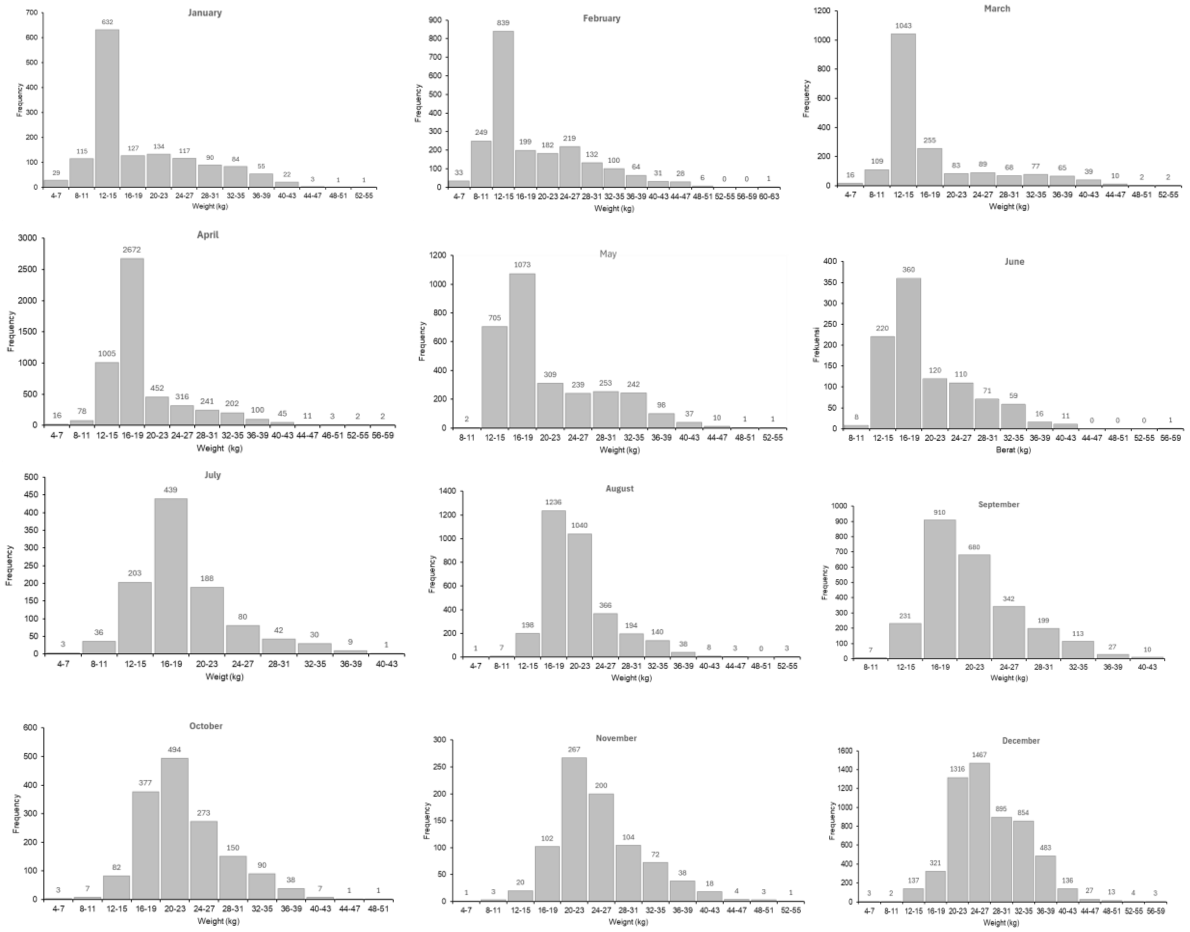


**Fig. 7.** Weight distribution of tuna caught by handline period January - December 2024
Source: Processed Data from KKP Sorong Enumerator, 2024

Fig. (7) illustrates the monthly weight distribution patterns of tuna from January to December 2024. From January to March, the catch was dominated by the 12– 16kg weight class, comprising 44.82% (n = 632), 40.28% (n = 839), and 56.13% (n = 1,043) of the total catch in each respective month. Other size classes represented between 13 and 0.07% during this period.

Between April and June, the dominant weight range shifted upward to 12– 19kg, accounting for 71.46% (n = 3,677) in April, 59.86% (n = 1,778) in May, and 59.42% (n = 580) in June. The modal weight for these months was 16– 19kg.

From July to September, the mode remained at 16– 19kg, but the proportion of larger fish (20– 23kg) increased. In July, 80.31% (n = 828) of the catch fell within the 12– 23kg range. In August and September, the dominant range narrowed to 16– 23kg, comprising 70.38% (n = 2,276) and 63.12% (n = 1,590), respectively.

Larger tuna became more common from October to December. In October, 75.12% (n = 1,144) of the catch was between 16 and 27kg, while in November, 80.79% (n = 673) was between 16 and 21kg. By December, the majority (80.06%, n = 4,532) fell within the 20–

39kg range. The mean weight in October and November was 20– 23kg, while the modal weight in December increased to 24– 27kg.

## DISCUSSION

Sorong tuna handline fishermen began constructing fish aggregating devices (FADs) around 2016, following the issuance of Ministerial Regulation No. 15 of 2015 concerning the moratorium on the operation of foreign vessels in Indonesian waters. Initially, Sorong fishermen utilized FADs left behind by the Philippine company's *ant* fleet. These FADs were later supplemented with housing structures (locally called rafts) to accommodate anglers, as Sorong fishing vessels at the time were small (< 5 GT) and unable to carry tuna anglers using *pakura* boats. Sorong fishermen, who initially targeted only skipjack and juvenile tuna, learned large-tuna handline fishing techniques from Filipino fishermen. Since then, the number of raft-type FADs has increased, along with the development of larger vessels (> 5 GT) operating in Sorong waters and surrounding areas.

Interviews with fishers indicate that handline tuna FADs were first deployed in Makbon waters, before expanding in 2018 to Mega waters, Tamraw Regency, located 20–40 NM from Sorong City. Mini purse seine FADs are positioned in the North Papua waters and the Pacific Ocean, while pole-and-line FADs are located in the Seram Sea. During the COVID-19 pandemic, many handline fishermen suffered losses, prompting several FAD owners to collaborate with mini purse seine operators to encircle their FADs—an unregulated activity. Since 2022, many Sorong tuna fishermen have relocated their FADs to more distant areas, including the North Papua waters and the Pacific Ocean, where mini purse seine FADs are also deployed. The relocation was driven by overcrowding at the original sites, making it increasingly difficult to catch tuna. This high density of handline FADs, combined with unsustainable fishing patterns, is believed to have reduced tuna abundance at those sites. Excessive FAD numbers have also led to increased catches of juvenile tuna, threatening ecosystem sustainability **(Jaya *et al.*, 2018; Nurani *et al.*, 2018; Indahyani *et al.*, 2024)**.

The government has issued permits for 415 FAD allocations in WPPNRI 717 and 75 in WPP 715, but field observations reveal that actual placement often does not comply with the permits. Illegal FADs have proliferated **(Nurani *et al.*, 2018)**, with numbers now estimated in the thousands across Indonesian waters **(Hoshino *et al.*, 2024)**. Fishermen report that handline vessels cannot reach many of the government-permitted sites, although some FAD locations (FADs 6, 7, 19, 25, 49) are relatively close—4.32–6.5 NM away. Several handline FADs are also positioned near Sorong mini purse seine FADs and those belonging to the Indotuna Bitung company. This overlap reduces tuna catch efficiency, as purse seine vessels capture many small pelagic fish and juvenile tuna. Purse seine operations also generate high bycatch levels, which can disrupt pelagic ecosystem balance **(Moreno *et al.*, 2016; Escalle *et al.*, 2019)**.

Three key regulations govern FAD management in Indonesia—Ministerial Regulation No. 26 of 2014, No. 7 of 2022, and No. 36 of 2023 **(KKP, 2014, 2022, 2023)**—which require FADs to be spaced at least 10 NM apart and prohibit placement in shipping lanes, conservation areas, archipelagic sea lanes, or marine mammal and turtle migration routes. FAD placement must comply with designated fishing zones under Regulation No. 7 of 2022.

However, licensing and enforcement remain ineffective, as current FAD locations do not comply with these regulations, and unlicensed FADs continue to appear across multiple regions **(Gigentika *et al.*, 2017; Nurani *et al.*, 2018; Hoshino *et al.*, 2024)**.

Fishers often deploy new FADs close to existing high-yield devices, leading to dense clustering. In Sorong, some handline FADs are only 1.35 NM apart, while mini purse seine FADs can be as close as 3.13 NM. Excessively close spacing can reduce fish abundance and hinder stock recovery due to the capture of large numbers of juvenile tuna **(Leroy *et al.*, 2013; Yusfiandayani *et al.*, 2015; Gigentika *et al.*, 2017)**. Furthermore, all current FAD sites lie outside permitted locations, posing safety risks, as permitted sites are designated based on navigational safety, shipping lanes, regional zoning plans (RZWP3K), conservation area boundaries (> 12 NM offshore), submarine cable routes, and ecological considerations related to tuna behavior.

From 2019–2024, total tuna production in Sorong has generally declined. The only increase occurred in 2020, when production rose 1.39% from 637.75 t to 646.62 t, before falling to 518.96 t in 2024. Initial declines were linked to the COVID-19 pandemic, which caused a sharp drop in market demand and prices. Tuna prices fell from IDR 50,000–60,000/kg to IDR 15,000– 25,000/kg, prompting fishers to reduce activity. Similar impacts occurred elsewhere: in PPP Pondok Dadap Malang, demand fell 30% **(Atmajaya *et al.*, 2021)**; in Cilacap, prices dropped 30– 40%; and nationwide, prices averaged a 50% decline **(Sari *et al.*, 2020)**. International markets also suffered—Portugal's tuna production fell 44%, and in Spain, demand and prices remained unstable **(Gonzalez *et al.*, 2022; Seixas *et al.*, 2024)**.

The pandemic's effects persist. By 2021, six handline operators had ceased business, and by 2022, four PT Radios Apirja pole-and-line vessels had stopped operating. Mini purse seine vessels remained relatively stable, supplying the domestic market. Some handline operators entered into prohibited partnerships with mini purse seine vessels to fish around their FADs. Mini purse seine production remained steady at 138–197 t/year.

Post-pandemic recovery has been slow. In 2024, tuna production rose 25.80% (106.43 t) from the previous year but was still 18.63% (118.79 t) lower than in 2019. This stagnation reflects reduced fleet capacity, as several handlines and pole-and-line vessels remain inactive. Tuna prices have not fully recovered, discouraging investment in fishing capacity. The increasing distance to productive grounds and persistently low prices remains key challenges, consistent with global trends where industry profitability has not rebounded **(Aura *et al.*, 2023; Seixas *et al.*, 2024; Suherman *et al.*, 2025)**.

Among gears, handline tuna shows the lowest productivity, averaging 0.72 t/trip from 2019–2024—similar to Bone Bay's 786.4 kg/trip, which is considered suboptimal **(Pontoh *et al.*, 2024)**. Fishers report that profitability requires at least 0.8 t/trip. In PPS Bitung, handline CPUE reaches 1.56 t/trip in WPP 715 and 1.64 t/trip in WPP 716 **(Posundu *et al.*, 2024)**. Mini purse seine vessels, with larger capacities and active fishing methods, have the highest productivity at 2.84 t/trip. Fishing capacity varies: handline (4–20 GT, 6–8 crew, 7– 10 days passive trips), pole-and-line (50–60 GT, 20–25 crew, 14 days semi-active trips), and mini purse seine (20–30 GT, 14 days active trips). Productivity is influenced not only by geographic and oceanographic conditions **(Arrizabalaga *et al.*, 2011)** but also by FAD depth and fishing methods **(Sepri, 2012; Escalle *et al.*, 2019; Orúe *et al.*, 2020)**.

Standardized CPUE trends for WPP 717 show a 44.78% increase in 2020, followed by a steady decline through 2024. This downward trend may indicate declining tuna stocks due to high exploitation rates, concentrated fishing areas, and uncontrolled FAD deployment **(Yusfiandayani *et al.*, 2015; Muhamad *et al.*, 2016; Pontoh *et al.*, 2019; Sofiati & Alwi, 2019)**. Purse seine bycatch of juvenile tuna around FADs is also thought to reduce stock abundance **(Leroy *et al.*, 2013; Scott & Lopez, 2014)**.

The fishing season in Sorong is irregular, with high FSI values in January, March–May, and October, peaking in April (148.41), and low seasons in July–September (minimum 75.71 in August). This differs from patterns in the Morotai **(Sofiati & Alwi, 2019)**, Maluku Sea **(Dalegi *et al.*, 2020)**, and WPP 716 **(Tuyu *et al.*, 2023; Hehanussa *et al.*, 2024)**, and from Kaur Regency, Bengkulu **(Zamdial *et al.*, 2024)**. Fishermen note that adverse southern wind conditions in July–August restrict operations to vessels > 10 GT.

Tuna from purse seine and pole-and-line vessels generally weigh 2– 7kg, well below the catchable size (≥ 16 kg, based on a yellowfin Lm of 103.3cm). In 2024, 73.95% of handline catches were ≥ 16 kg, with 26.05% (≈ 80.45 t) under the legal size. All purse seine and pole-and-line tuna were juvenile, totaling 210.12 t. Overall, 55.99% (290.57 t) of 2024's tuna catch was undersized. This proportion varies across regions, from 55% legal-sized in Sendang Biru to juvenile-dominated in Prigi, and nearly all legal-sized in Benoa **(Agustina *et al.*, 2020; Safitri *et al.*, 2021; Kartikaningsih *et al.*, 2023)**.

Monthly weight patterns (Fig. 7) show that catchable tuna (> 16 kg) predominated from April–December, with larger fish (> 20 kg) most common in October–December. Smaller fish (< 16 kg) dominated January–March catches. Seasonal shifts may relate to vertical fish movements, as handline fishers operate at 50–100 m depths **(Alianto *et al.*, 2014; Haruna *et al.*, 2022)**. Large tuna may move to these depths from October–December, while smaller fish migrate there in January–March. This pattern aligns with west monsoon transitions influencing vertical distribution and depth-specific catch trends **(Sepri, 2012; Patrick *et al.*, 2024)**. To optimize catches of larger tuna, handline fishers should target depths > 150m during January–March. Government regulations should also consider seasonal catch restrictions to protect juvenile tuna and ensure long-term sustainability.

## CONCLUSION

FAD management regulations have not been effectively implemented, resulting in uncontrolled numbers and placements of tuna FADs, with many positioned too closely together—conditions that can lead to reduced tuna stock abundance. From 2019 to 2024, tuna productivity has shown a continual decline, likely driven by post–COVID-19 impacts, environmentally unsustainable fishing practices, and decreasing fish abundance in FAD-associated fishing grounds. The tuna fishing season occurs in January, March, April, May, and October, with peak activity in March and April. Moderate seasons occur in June, November, and December, while lean seasons are in July, August, and September. The largest tuna (> 20kg) are most frequently caught between October and December, whereas smaller fish (< 16kg) dominate catches from January to March. Tuna between 16– 21kg are most common from April to September.

## RECOMMENDATION

The government should reorganize FAD placement in strict accordance with existing regulations, prohibit cooperation between handline tuna operators and purse seine vessels targeting small pelagic fish around tuna FADs, and establish clear zoning rules to separate tuna FADs from purse seine FADs to support tuna stock recovery. In collaboration with the Directorate General of Surveillance for Marine and Fisheries Resources (PSDKP KKP) and tuna fisheries associations, strategies should be developed to restore tuna prices to pre-pandemic levels. During the January–March fishing season—when a large proportion of the catch is tuna weighing less than 16kg—fishers should be encouraged to operate their gear at depths exceeding 150m to reduce juvenile capture. Additionally, restrictions on fishing effort should be considered as a measure to ensure the sustainability of tuna stocks..

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