Sustainability of tuna fisheries in southern Java waters

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Abstract. Tuna fisheries in FMARI 573, particularly in the southern waters of Java, face sustainability challenges due to fishing pressure, which has resulted in increasingly distant fishing grounds and changes in fishing practices. These dynamics highlight the importance of assessing the sustainability of tuna fisheries in this region. This study aimed to assess the sustainability of tuna fisheries at Cilacap Ocean Fishing Port (OFP) and Sadeng Coastal Fishing Port (CFP) from ecological and socio-economic/community perspectives. The assessment of the sustainability of tuna fisheries covered biomass and biomass trends, fish size, community resilience and self-reliance, human carrying capacity, fairness, sustainable fishing fleet capacity, and long-term food supply. Data were collected through field observations, interviews, questionnaires, and a literature review. The results showed that tuna catch per unit effort (CPUE) fluctuated but declined by 30.8% at Cilacap OFP and 25.9% at Sadeng CFP during 2020-2024. Most tuna landed at Cilacap OFP had reached the length at first maturity (Lm), whereas 100% of the yellowfin tuna sampled at Sadeng CFP were below Lm. Ecological sustainability at Cilacap OFP was classified as high (0.66), whereas that at Sadeng CFP was classified as low (0.27). Conversely, socio-economic/community sustainability at Sadeng CFP was classified as high (0.62), while that at Cilacap OFP was classified as moderate (0.41). These findings indicate that strategies to support sustainable tuna fisheries should be tailored to the characteristics of each location, with an emphasis on strengthening socio-economic resilience at Cilacap OFP and improving ecological sustainability at Sadeng CFP.

Keywords: dynamic fisheries, ecology, resource pressure, socio-economics, sustainability assesment.

Introduction. Tuna is a leading commodity in Fisheries Management Area Republic of Indonesia (FMARI) 573, especially in the Indian Ocean waters south of Java Island (Laily Dona et al., 2018; Buana et al., 2018; Nurani et al., 2018; Anggawangsa et al., 2021; Damayanti et al., 2023; Fitriana & Ciptaningtyas, 2025). FMARI 573 covers the Indian Ocean waters south of Java to Nusa Tenggara, as well as the western parts of the Sawu Sea and Timor Sea. The influence of three seawater masses, seasonal differences between Asia and Australia, and upwelling phenomena are among the factors that make the waters south of Java abundant in fish resources (Azizah et al., 2023; Panggabean et al., 2023). The main tuna species caught include skipjack (*Katsuwonus pelamis*), bigeye (*Thunnus obesus*), yellowfin (*Thunnus albacares*), southern bluefin (*Thunnus maccoyii*), and albacore (*Thunnus alalunga*). Yellowfin tuna is the dominant species in the catch (Ghofar et al., 2021).

Tuna landing sites in FMARI 573 include Palabuhanratu Nusantara Fishing Port (NFP) (West Java), Cilacap Ocean Fishing Port (OFP) (Central Java), Prigi NFP (East Java), Sadeng Coastal Fishing Port (CFP) (Special Region of Yogyakarta – DIY), and Pondok Dadap Sendang Biru CFP (East Java). Tuna fishing activities across several locations exhibit high dynamics driven by climate change and fishing pressure. In recent

years, tuna production and fishing efforts using specific gear have declined, with modifications to fishing vessels and shifts in gear. Research by Karsana & Patanda (2019) and Ariefandi & Isdianto (2023) indicates that tuna production, as the main catch, continues to decline due to high fishing intensity and increasing market demand.

Research by Riandani et al. (2015) and Zuleca et al. (2024) reported a shift in fishing gear among fishers at Sadeng CFP from handline in 2010-2011 to purse seine in 2013-2014 to catch yellowfin tuna and skipjack tuna. Purse seine is considered more efficient because it can catch pelagic and demersal fish in large quantities, thereby increasing catch production (Riandani et al., 2015; Zuleca et al 2024). Meanwhile, tuna fishing activities at Cilacap OFP have also begun to experience pressure due to technological modernization and increased fishing effort, with a utilization rate reaching 69% in 2019 and already exceeding sustainable potential (Zahra et al., 2023).

The sustainability of tuna fisheries will be threatened if the dynamics of FMARI 573, particularly in South Java, are not addressed. Fisheries sustainability is fundamental to the utilization and management of fisheries, ensuring that fishery resources provide benefits to the current generation without neglecting the interests of future generations. Pursuit of economic, community and ecological sustainability through fisheries assessments require new types of data and analysis to guide science-based policy in addition to traditional biological information and modeling (Anderson et al., 2015).

Therefore, this study aims to assess the sustainability of tuna fisheries in the waters of South Java, specifically at Cilacap OFP and Sadeng CFP. The approach for sustainability assessment uses sustainability indicators assessment (Charles, 2023). Sustainability assessment of fisheries, according to Charles (2023), includes ecological, socio-economic, community/society, and institutional sustainability. This manuscript is limited to ecological and socio-economic sustainability. This research is expected to benefit the government in managing tuna fisheries at the Cilacap OFP and the Sadeng CFP.

Material and Method

Data collection. Field data collection was conducted from July to September 2025 at Cilacap OFP (Cilacap, Central Java) and Sadeng CFP (Gunungkidul, Special Region of Yogyakarta) (Figure 1).

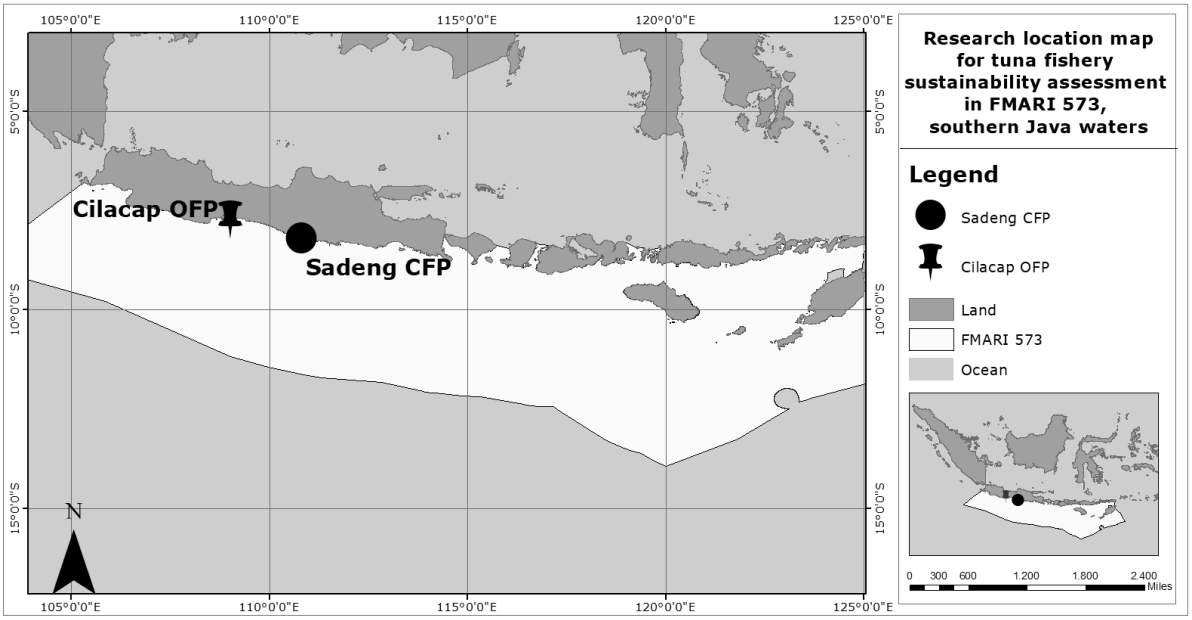


Figure 1. Field data collection sites at Cilacap OFP and Sadeng CFP

Data were collected through field observations, in-depth interviews, questionnaires, and a literature review. The study involved 60 respondents at Cilacap OFP and 50 respondents at Sadeng CFP, comprising tuna fishery stakeholders, including fishers and

fishery entrepreneurs. The questionnaire was developed based on the sustainability assessment framework proposed by Charles (2023). Sustainability indicators for the ecological dimension included biomass and biomass trends and catch size, while those for the socio-economic/community dimension included community resilience and self-reliance, human carrying capacity, fairness, sustainable fishing fleet capacity, and long-term food supply. The data types, sources, and analytical methods for each sustainability indicator are presented in Table 1.

Table 1

Type, source, and data analysis for each sustainability indicator

Indicator	*Data type*	*Data source*	*Data analysis*
Ecological sustainability assessment			
Biomass and biomass trend	Tuna catch and fishing effort data for 2020-2024	Fisheries statistics from Cilacap OFP and Sadeng CFP	CPUE analysis
Size of fish caught	• Fish length measurements from tuna landed at the study sites • Length at first maturity (Lm) based on the literature	• Direct measurements • Literature review	Descriptive analysis
Socioeconomic sustainability assessment/community			
Community resilience	Number and types of alternative livelihoods among fishers	Interviews and questionnaire surveys	Descriptive analysis
Community self-reliance	Fishers' level of dependence on subsidized fuel		
Human capacity	• Respondents' age • Productive-age threshold and age threshold for declining physical capacity		
Fairness	Fishers' perceptions of the level of fairness in the profit-sharing system		
Sustainable fleet capacity	Fishers' perceptions of the appropriateness of fleet size relative to fish stock conditions		
Food supply	• Fishers' perceptions of the availability of fish for community consumption • Community fish consumption rate (kg capita^{-1} year^{-1})	• Interviews and questionnaire completion • Fish consumption statistics	

CPUE analysis. Biomass and biomass trends were represented by the trends in tuna catch per unit effort (CPUE) at Cilacap OFP and Sadeng CFP. This analysis aimed to estimate relative biomass and describe trends in fishing productivity over time (Gulland, 1983; Rodríguez-Marín et al., 2003). Following Sparre & Venema (1998), CPUE was calculated using the following formula:

$$CPUE = \frac{Ci}{Fi}$$

where: CPUE = catch per unit effort (kg trip^{-1});
Ci = total catch (kg);
Fi = total fishing effort (trip).

Sustainability assessment. The sustainability assessment of tuna fisheries in the waters of south Java was based on Charles (2023) and modified to suit the requirements of this study. The assessment used a scale ranging from 0 to 1, with values approaching 1 indicating a higher level of sustainability. The sustainability assessment consisted of four stages: (1) determining indicator scores; (2) determining indicator weights; (3) calculating the sustainability index for each dimension; and (4) classifying the sustainability status.

Determination of indicator scores. Indicator scores were determined based on the number of sustainability categories used:

$$Vi = \frac{k}{m}$$

where: Vi = score of indicator i;
k = order of the sustainability category;
m = number of sustainability categories.

An example of the determination of indicator scores is presented in Table 2.

Table 2

Simulation of indicator value determination for each sustainability category based on Charles (2023)

Level of sustainability	*k*	*Indicator value (Vi)*
Very low	1	1/5 = 0.2
Low	2	2/5 = 0.4
Moderate	3	3/5 = 0.6
High	4	4/5 = 0.8
Very high	5	5/5 = 1.0

Determination of indicator weights. Indicator weights were determined using pairwise comparison based on the Saaty 1-9 scale to evaluate the relative importance of indicators. A score of 1 indicates equal importance between two indicators, whereas a score of 9 indicates that one indicator is extremely more important than the other (Saaty 1985, 1991). Five experts assessed the relative importance of indicators within each dimension. The comparison matrix was normalized to obtain the priority vector, which was then averaged and normalized so that the total weight for each dimension was equal to 1. The results of indicator scoring and weighting are presented in Table 3.

Table 3

Scores and importance weights for each sustainability indicator

Indicators	*Assessment criteria*					*Weight*
	Score 1 (0.20)	*Score 2 (0.40)*	*Score 3 (0.60)*	*Score 4 (0.80)*	*Score 5 (1.00)*	
	Very low	*Low*	*Moderate*	*High*	*Very high*	
Ecological sustainability assessment						
Biomass and biomass trend	Consistently declining trend	Declining but fluctuating trend	Relatively stable or fluctuating trend	Increasing but fluctuating trend	Consistently increasing trend	0.36

Size of fish caught	<25% of fish have reached the length at first maturity	25-<50% of fish have reached the length at first maturity	50-75% of fish have reached the length at first maturity	>75-<100% of fish have reached the length at first maturity	100% of fish have reached the length at first maturity	0.64
Socioeconomic/community sustainability assessment						
Community resilience	No alternative livelihood	1 alternative livelihood	2-3 alternative livelihoods	4-5 alternative livelihoods	> 6 alternative livelihoods	0.16
Community self-reliance	Highly dependent on subsidized fuel	Predominantly dependent on subsidized fuel	Partially self-reliant in fuel provision	Predominantly self-reliant in fuel provision	Fully self-reliant in fuel provision	0.28
Human capacity	≥ 80% Predominantly > 45 years (declining physical capacity)	60-<80% High proportion at risk	40-<60% Moderate proportion at risk	20-<40% Low proportion at risk	< 20% Very low proportion at risk	0.14
Fairness	Very unfair	Unfair	Moderately fair	Fair and equitable	Very fair and equitable	0.20
Sustainable fleet capacity	Overcapacity	At risk of overcapacity	Adequate but not stock-based	Appropriate with room for improvement	Fully appropriate	0.15
Food supply	Very frequently experiencing shortages	Frequently experiencing shortages	Beginning to decline	Stable and sufficient	Very stable and sufficient	0.07

Calculation of the dimensional sustainability index. The sustainability index for each dimension was calculated using the weighted arithmetic average method as described by Charles (2023):

$$SId = \sum_{i=1}^{n} (Vi \; x \; Wi)$$

where: SId = dimensional sustainability index;
Vi = value of the i-th indicator;
Wi = weight of the i-th indicator.

Classification of sustainability status. Sustainability status was classified using the equal interval classification method. The classification of sustainability status is presented in Table 4.

Table 4

Classification of fisheries sustainability index values based on Charles (2023)

Sustainability index (SI)	*Sustainability status*	*Flag*
0.00 ≤ SI ≤ 0.20	Very low	
0.21 < SI ≤ 0.40	Low	
0.41 < SI ≤ 0.60	Moderate	
0.61 < SI ≤ 0.80	High	
0.81 < SI ≤ 1.00	Very high	

Results

Ecological sustainability

Biomass and biomass trend indicators. Biomass and biomass trends were represented by CPUE. Tuna CPUE showed fluctuating patterns at Cilacap OFP and Sadeng CFP. At Cilacap OFP, CPUE decreased from 27.36 tons trip^{-1} in 2020 to 18.94 tons trip^{-1} in 2024, despite an increase in 2022 (Figure 2). At Sadeng CFP, CPUE fluctuated from 1.12 tons trip^{-1} in 2020 to 0.83 tons trip^{-1} in 2024, with the highest value of 1.38 tons trip^{-1} recorded in 2022 (Figure 3). Overall, tuna CPUE declined at both fishing ports during 2020-2024, by approximately 30.8% at Cilacap OFP and 25.9% at Sadeng CFP.

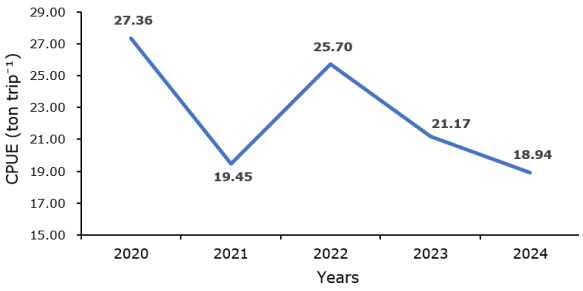


Figure 2. CPUE of tuna landed at Cilacap OFP.

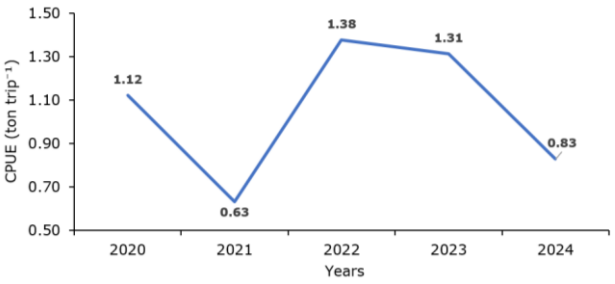


Figure 3. CPUE of tuna landed at Sadeng CFP.

Size of fish caught indicator. The tuna species landed at Cilacap OFP were more diverse than those at Sadeng CFP, comprising yellowfin tuna, bigeye tuna, and albacore tuna, whereas Sadeng CFP was dominated by yellowfin tuna. At Cilacap OFP, length measurements were taken from 20 yellowfin tuna, 25 bigeye tuna, and 20 albacore tuna, with length ranges of 114-162 cm, 135-149 cm, and 65-130 cm, respectively (Figures 4a-c). At Sadeng CFP, 19 yellowfin tuna were measured, with a length range of 30-69 cm (Figure 5).

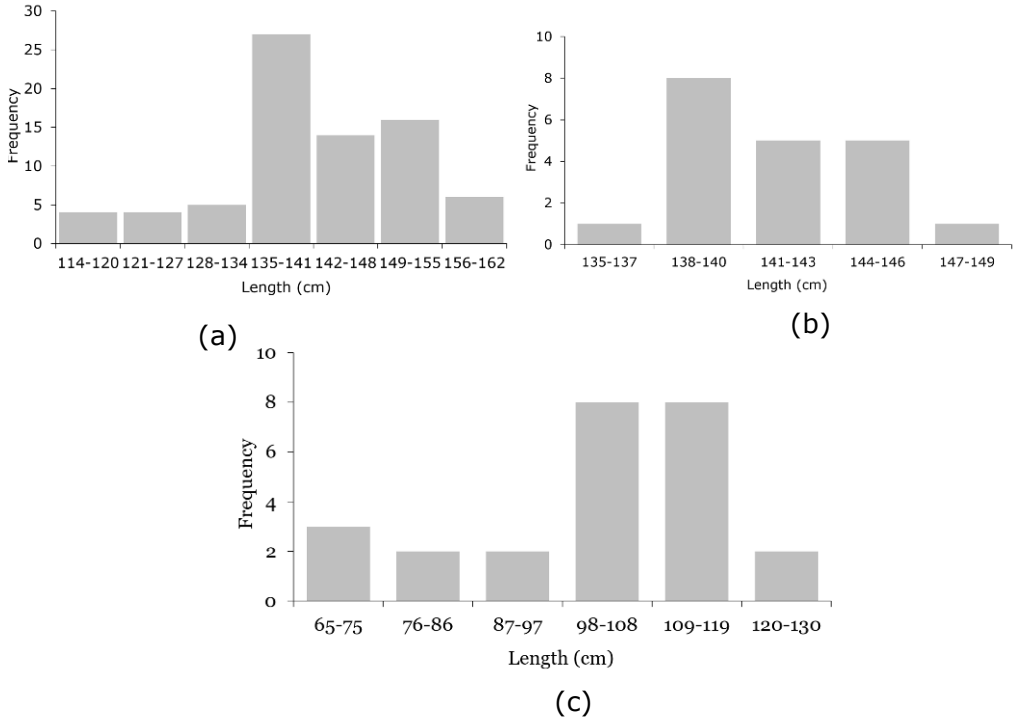


Figure 4. Length distribution of fish caught at Cilacap OFP: (a) yellowfin tuna; (b) bigeye tuna; (c) albacore.

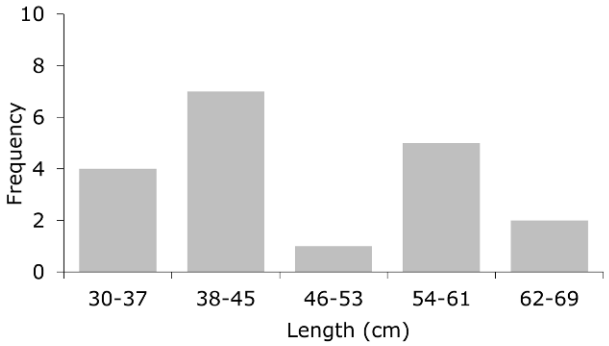


Figure 5. Length distribution of yellowfin tuna caught at Sadeng CFP.

Based on FishBase data, the Lm of yellowfin tuna, bigeye tuna, and albacore tuna is 103.3, 112.5, and 85.2 cm, respectively. At Cilacap OFP, 100% of the landed yellowfin tuna and bigeye tuna had reached Lm, while 80% of albacore tuna had reached Lm. In contrast, 100% of yellowfin tuna at Sadeng CFP were below Lm. Thus, tuna landed at Cilacap OFP were generally larger than those landed at Sadeng CFP.

Socioeconomic/community sustainability

Community resilience. Community resilience assessment showed that fishers at Sadeng CFP had greater livelihood diversification than those at Cilacap OFP (Figure 6). At Cilacap OFP, 33 fishers had no alternative livelihood, whereas at Sadeng CFP, 40 fishers had 1-2 alternative livelihoods. This condition indicates that livelihood diversification at Sadeng CFP was relatively better and may contribute to strengthening fishers' resilience to changes in fishery conditions.

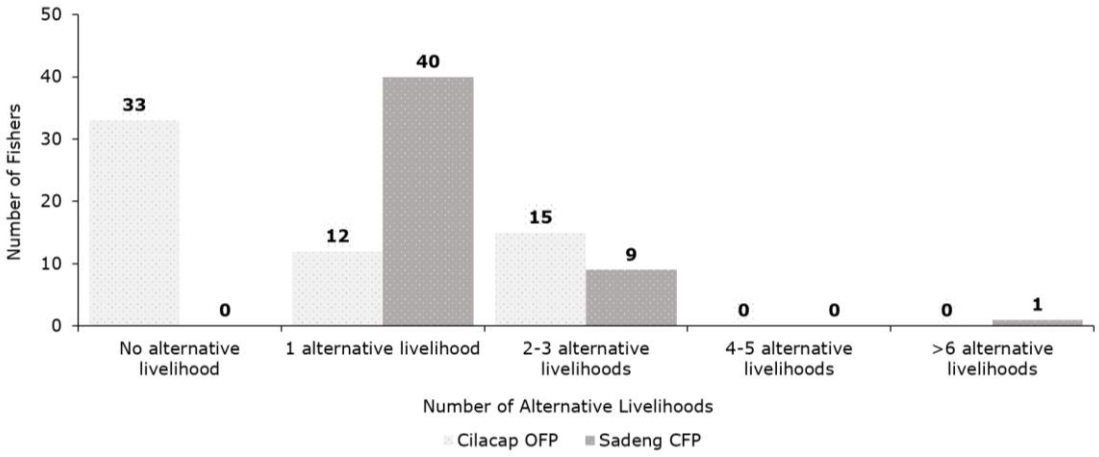


Figure 6. Number of alternative livelihoods among fishers at Cilacap OFP and Sadeng CFP.

Community self-reliance. Most fishers at Cilacap OFP remained dependent on subsidized fuel, with 41 fishers classified as predominantly dependent and 9 as highly dependent. In contrast, most fishers at Sadeng CFP were classified as self-reliant, with 26 fishers predominantly self-reliant and 19 partially self-reliant. These findings indicate that fishers at Sadeng CFP had a higher level of self-reliance in meeting their fuel requirements than those at Cilacap OFP (Figure 7).

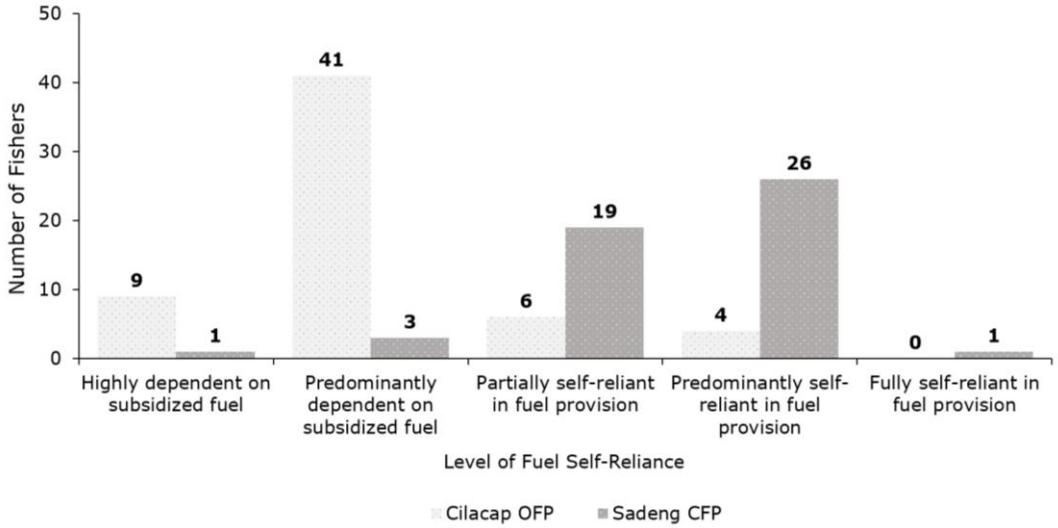


Figure 7. Level of fishers' fuel self-reliance at Cilacap OFP and Sadeng CFP.

Human capacity. The age structure of fishers showed that most were aged ≤ 45 years, accounting for 70% at Cilacap OFP and 64% at Sadeng CFP (Figure 8). Conversely, fishers aged > 45 years accounted for 30% at Cilacap OFP and 36% at Sadeng CFP. The higher proportion of fishers aged > 45 years at Sadeng CFP indicates a relatively greater risk of declining physical capacity compared with Cilacap OFP. Sumampouw & Joseph (2022) explained that the physical capacity of fishers tends to decline with increasing age, particularly in occupations requiring high mobility and heavy workloads.

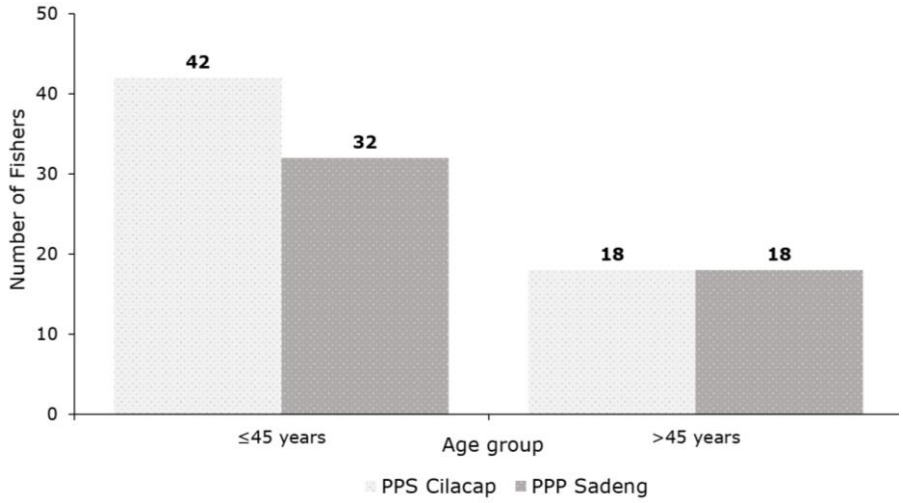


Figure 8. Age structure of fishers at Cilacap OFP dan Sadeng CFP.

Fairness. Fairness was assessed based on fishers' perceptions of the profit-sharing system. At Cilacap OFP, most respondents considered the profit-sharing system moderately fair (30 fishers), followed by fair and equitable (25 fishers) and unfair (5 fishers). At Sadeng CFP, 23 fishers considered the system fair and equitable, 20 considered it moderately fair, and 7 considered it unfair. Overall, the profit-sharing system was perceived as relatively fair at both fishing ports (Figure 9).

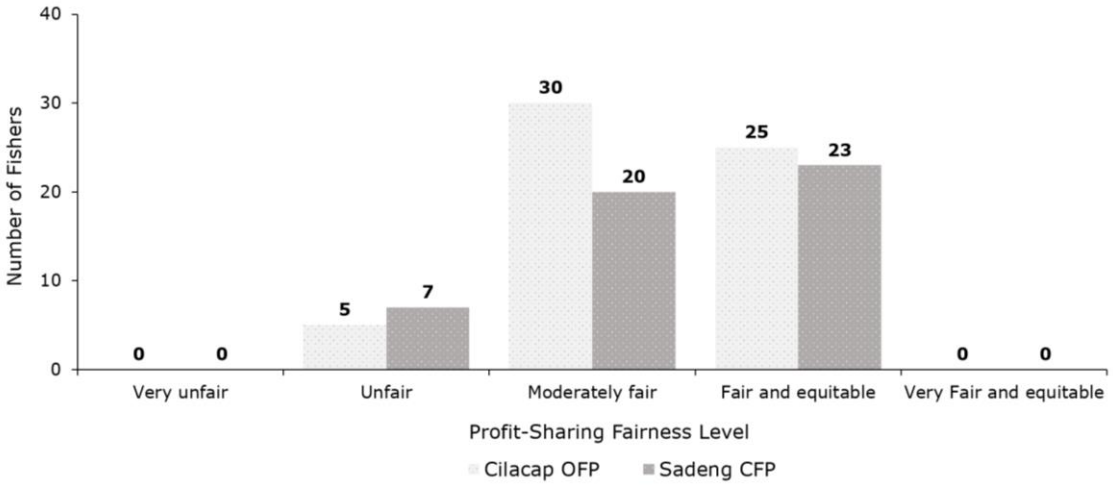


Figure 9. Fairness: (a) Cilacap OFP; (b) Sadeng CFP.

Sustainable fleet capacity. Fishers' perceptions indicated differences in fishing fleet capacity between Cilacap OFP and Sadeng CFP. At Cilacap OFP, most fishers (32) perceived the fleet as overcapacity, followed by 12 who considered the fleet adequate but not stock-based, 7 who considered it appropriate with room for improvement, 5 who considered it at risk of overcapacity, and 4 who considered it fully appropriate. In contrast, at Sadeng CFP, most fishers (31) considered the fleet to be at risk of overcapacity, while 9 considered it appropriate with room for improvement, 4 considered it fully appropriate, and 3 considered it adequate but not stock-based. Overall, perceptions of fishing fleet capacity indicated greater concern at Cilacap OFP than at Sadeng CFP, as the overcapacity category was most prevalent at Cilacap, whereas Sadeng was dominated by the at-risk-of-overcapacity category (Figure 10).

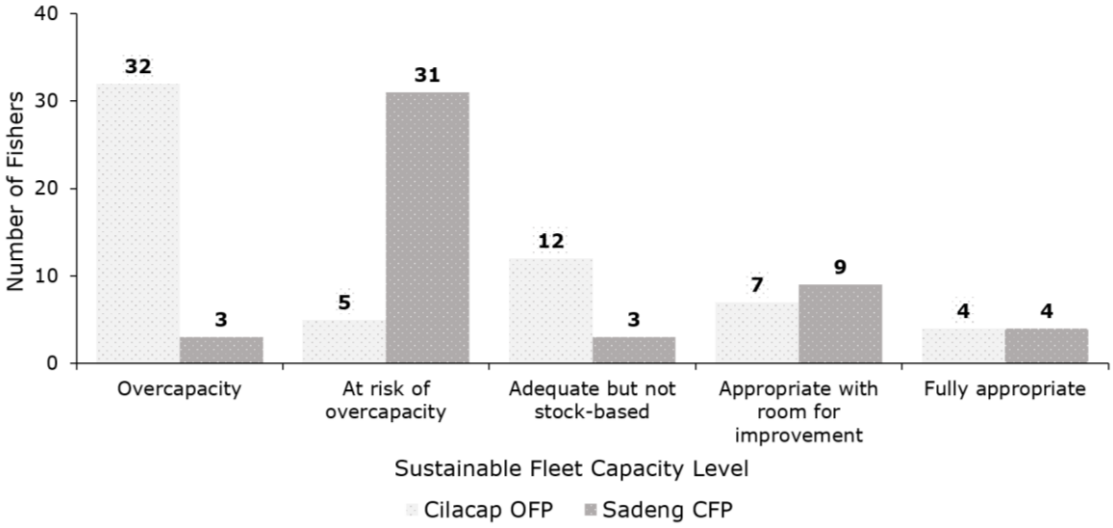


Figure 10. Sustainable fishing fleet capacity at Cilacap OFP and Sadeng CFP.

Long-term food supply. Food supply was relatively stable and sufficient at both locations. At Cilacap OFP, 45 fishers perceived fish supply as stable and sufficient, while 15 considered it very stable and sufficient. At Sadeng CFP, 42 fishers considered fish supply stable and sufficient, 4 considered it very stable and sufficient, 3 perceived a declining supply, and 1 reported frequent shortages. This condition was consistent with per capita fish consumption, which was 32.14 kg capita^{-1} year^{-1} in Cilacap Regency and 31.43 kg capita^{-1} year^{-1} in Gunungkidul Regency (Table 5). However, both values were lower than those recorded for Central Java (40.14 kg capita^{-1} year^{-1}), the Special Region of Yogyakarta (35.83 kg capita^{-1} year^{-1}), and the national average (58.91 kg capita^{-1} year^{-1})

(Table 5). Thus, although food supply was relatively stable at both locations, per capita fish consumption remained lower than that in the corresponding provinces and at the national level (Figure 11).

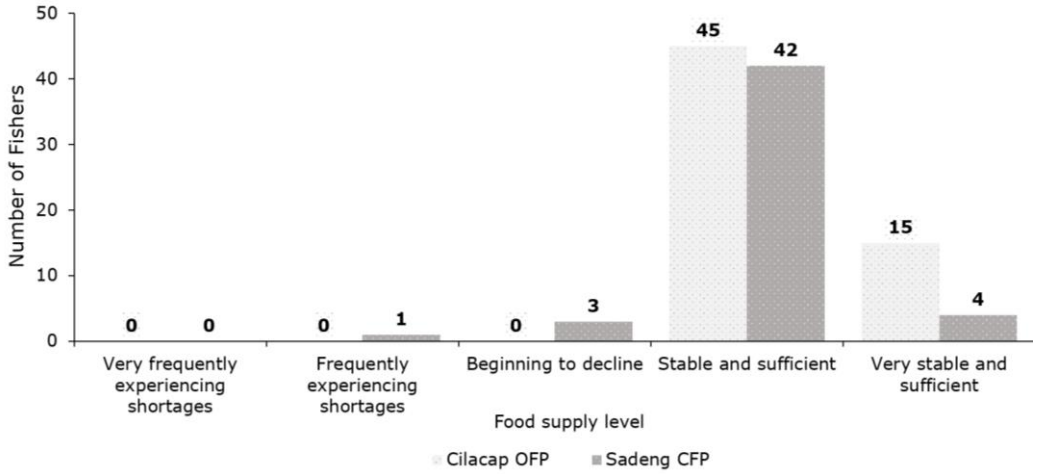


Figure 11. Long-term food supply at Cilacap OFP and Sadeng CFP.

Table 5

Per capita fish consumption in 2024

Region	*Fish consumption rate (kg capita^{-1} year^{-1})*
Cilacap Regency	32.14
Central Java Province	40.14
Gunungkidul Regency	31.43
Special Region of Yogyakarta	35.83
National	58.91

Source: Cilacap Regency Government (2024); Ministry of Marine Affairs and Fisheries (2024); Gunungkidul Regency Government (2025).

Tuna fishery sustainability status. The results of the sustainability assessment showed that the ecological dimension of tuna fisheries at Cilacap OFP had a higher sustainability index (0.66), classified as high (Table 6), compared with Sadeng CFP, which had a sustainability index of 0.27, classified as low (Table 7). The low ecological sustainability score at Sadeng CFP was primarily attributed to the predominance of tuna landed at sizes below the Lm.

Table 6

Assessment of the ecological and socioeconomic/community sustainability of the tuna fishery in the Cilacap OFP

Indicator	*Score*	*Weight*	*Final value*
Sustainability in the ecological dimension			
Biomass and biomass trend	0.4	0.36	0.14
Size of the catch	0.8	0.64	0.51
Index value			0.66
Sustainability in the socioeconomic/community dimension			
Community Resilience	0.2	0.16	0.03
Community Self-Reliance	0.4	0.28	0.11
Human capacity	0.4	0.14	0.06
Sustainable fleet capacity	0.2	0.15	0.03
Fairness	0.6	0.20	0.12
Food supply	0.8	0.07	0.06
Index value			0.41

For the socio-economic/community dimension, Sadeng CFP had a higher sustainability index of 0.62, classified as high (Table 7), whereas Cilacap OFP had an index of 0.41, classified as moderate (Table 6). This condition was associated with limited alternative livelihood opportunities and the high dependence of fishers at Cilacap OFP on fishing activities and subsidized fuel. In contrast, fishers at Sadeng CFP had relatively greater livelihood diversification, with most having 1-2 alternative livelihoods, as well as greater capacity to meet their fuel requirements independently.

Table 7

Assessment of the ecological and socioeconomic/community sustainability of the tuna fishery in the Sadeng CFP

Indicator	*Score*	*Weight*	*Final value*
Sustainability in the ecological dimension			
Biomass and biomass trend	0.4	0.36	0.14
Size of the catch	0.2	0.64	0.13
Index value			0.27
Sustainability in the socioeconomic/community dimension			
Community Resilience	0.4	0.16	0.06
Community Self-Reliance	0.8	0.28	0.22
Human capacity	0.4	0.14	0.06
Sustainable fleet capacity	0.4	0.15	0.06
Fairness	0.8	0.20	0.16
Food supply	0.8	0.07	0.06
Index value			0.62

Discussion. The ecological sustainability of tuna fisheries at Cilacap OFP was higher than that at Sadeng CFP. Cilacap OFP obtained an ecological sustainability index of 0.66 (high), whereas Sadeng CFP scored 0.27 (low). This difference was primarily influenced by the size composition of landed tuna. Most tuna landed at Cilacap had reached or exceeded the Lm, whereas all tuna landed at Sadeng were smaller than Lm. This difference may be attributed to the fishing gear employed. Tuna landed at Cilacap OFP were caught using longlines, whereas those landed at Sadeng CFP were caught using handlines.

The predominance of small-sized tuna at Sadeng is consistent with previous studies by Nurani et al. (2012), Lestari et al. (2015), and Agustina et al. (2019). Nurani et al. (2012) reported that tuna landed at Sadeng were predominantly small-sized and below the recommended catch size. In contrast, other studies at Cilacap indicated relatively better conditions. Azzahra et al. (2026) found that approximately 54.29% of tuna had reached the recommended catch size. Nevertheless, these findings indicate that the capture of undersized tuna still occurs.

CPUE at Cilacap OFP and Sadeng CFP declined by 30.8% and 25.9%, respectively, during 2020-2024. Agustina et al. (2019) also reported fluctuations in yellowfin tuna CPUE at several landing sites along the southern coast of Java, whereas Azzahra et al. (2026) recorded an 11.7% decline in CPUE at Cilacap over the same period. The decline in CPUE indicates changes in fishery productivity, although it cannot be directly interpreted as a decrease in stock abundance, as it may also be influenced by changes in fishing effort, fishing technology, and environmental conditions (Hermawan et al., 2025).

The socioeconomic and community sustainability score at Sadeng CFP was higher (0.62; high) than that at Cilacap OFP (0.41; moderate). This difference was primarily supported by greater livelihood diversification and higher fuel self-sufficiency among fishers at Sadeng. Most fishers at Sadeng had one or two alternative livelihoods and were able to independently cover their fuel requirements, whereas fishers at Cilacap were relatively more dependent on subsidized fuel and had fewer alternative employment opportunities. This finding is consistent with Suharno et al. (2018), who reported that some fishers in Cilacap waters still relied primarily on fishing as their main source of income, while livelihood diversification had not been adopted by all respondents. In the

context of Indonesian tuna fisheries, McClean et al. (2024) also reported high household income dependence on tuna and limited alternative income sources, which may increase fishers' vulnerability to changes in fishery conditions.

Meanwhile, Madina et al. (2024) reported that fisheries business development in Sadeng remains constrained by limited capital, technology, human resources, and supporting infrastructure. This indicates that although Sadeng exhibited a higher socioeconomic sustainability score in the present study, challenges related to business development and access to productive resources remain important. Human capacity and equity also contributed to sustainability at both locations. The proportion of fishers aged > 45 years was higher at Sadeng CFP (36%) than at Cilacap OFP (30%), potentially indicating challenges in workforce regeneration. Furthermore, perceptions of inequity in profit-sharing arrangements among some fishers may affect their welfare and the distribution of economic benefits.

Sadeng exhibited relatively better socioeconomic conditions despite its lower ecological sustainability, whereas Cilacap demonstrated better ecological conditions but faced greater socioeconomic challenges. Therefore, tuna fisheries management should integrate resource conservation, livelihood diversification, enhanced economic self-reliance, and more equitable benefit distribution.

Conclusions. The sustainability of tuna fisheries differed between the two locations. Cilacap OFP had a high ecological sustainability score (0.66), whereas Sadeng CFP had a low score (0.27). In contrast, socioeconomic/community sustainability was higher at Sadeng CFP (0.62) than at Cilacap OFP (0.41). Therefore, management strategies should be tailored to the specific characteristics of each location, with an emphasis on strengthening socioeconomic sustainability at Cilacap OFP and improving ecological sustainability at Sadeng CFP.

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Data Availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

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