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RESEARCH ARTICLE

Length-based Assessment of Population Dynamics and Exploitation Status of Bali sardinella *Sardinella lemuru* (Bleeker, 1853) in the Waters of Fisheries Management Area 7

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ABSTRACT

Sardinella lemuru, better known as Bali sardinella, is an important commodity in Fisheries Management Area (FMA) 7 because of its high economic value. However, *overfishing threatens S. lemuru stocks*. Studies of population parameters are necessary to understand their status and dynamics and to provide a foundation for developing management schemes to conserve and protect the resource. For this study in FMA 7 waters, 104,389 specimens of *S. lemuru* from the drift gillnet and ring net fisheries were randomly measured at different landing centers using the National Stock Assessment Program (NSAP) standard methodology from January 2019 to December 2022. Results revealed that *S. lemuru* is a year-round species in FMA 7, being exploited by the dominant fisheries, namely drift gillnet and ring net. The population dynamics were estimated through FiSAT II routines. The size distribution ranged from 10.25 cm to 21.25 cm. This species is fast-growing (K=0.9, K=0.77), with two recruitment pulses throughout the year. Fishing mortality (F=3.94, F=4.56) exceeded the natural mortality (M=1.79, M=1.65), revealing high fishing pressure. The length at first capture (Lc_{50}) was 14.57 cm for *S. lemuru* caught by the drift gillnet fishery and 12.69 cm caught by the ring net fishery, which were quite higher and lower than the recalculated length at first maturity (L_m), implying that a substantial portion of the catch consists of individuals harvested at spawning ages and before they could reproduce, signifying recruitment and growth overfishing. To achieve optimum yield (E_{cur}=E50), fishing effort should be reduced through appropriate fishing regulation schemes to support the sustainability and conservation of fisheries in FMA 7.

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1. INTRODUCTION

In the Philippines, *Sardinella lemuru* is one of the most abundant small pelagic finfish, contributing to the fishery production (Labrador, 2021). Of the nine sardine species recorded in the Philippines, six are *Sardinella lemuru*, *Sardinella gibbosa*, *Sardinella albella*, *Amblygaster sirm*, *Escualosa thoracata*, and *Sardinella fimbriata* found in the Philippines (Herre, 1953; Oceana n.d.; BFAR 2022). *S. lemuru* is one species in the sardine assemblage in Philippine waters (Bleeker, 1853), also known as Bali sardinella (Willette and Santos, 2013), and forms shoals in coastal waters over the continental margin at depths of less than 200 meters (Willette et al. 2011).

As a food source, sardines are important and have economic value because of their high nutrient content (Morello and Arneri, 2016; Mahrus et al. 2023). *S. lemuru* is a small marine fishery commodity that provides health benefits and nutritional value. It contains high levels of omega-3 fatty acids (eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)), which are essential fatty acids (Bender, 1972; Suprakto, 2022; Haryati, 2024). This small

pelagic fish also contains nutrients such as protein, iron, calcium, and Vitamins A, E, and K (Mahrus et. al. 2023). The available polyunsaturated fatty acids (PUFA) of the species prevent several diseases according to Rubio-Rodríguez et al. (2010). Additionally, the fish oil content of *S. lemuru*, EPA and DHA, will reduce the risk of obesity (Ali et al. 2022). Moreover, total production of *S. lemuru* in 2023 was 275,843.88 metric tons, equivalent to 11,411,273.70 pesos. In the Bicol region alone, the total volume was 34,076.83 metric tons, valued at 864,929.37 pesos (Philippine Statistics Authority 2025). The contribution of sardine catches to the total fish catch in the Philippines is large, accounting for approximately 15% of the average fish catch in the total marine capture fisheries, according to the National Sardine Management Plan published in 2020 (BFAR 2020). Sardines, according to Willette et al. (2011) and Ramos et al. (2023), provide an affordable protein source for millions of Filipinos, supporting both the economy and food security, especially during disasters (Willette et al. 2011; Ramos et al. 2023). Additionally, a published report by DA-AFID (2025) indicates that *S. lemuru* is included in the Codex Standard for exporting to international markets. In Fisheries Management Area 7, sardine stocks are abundant; however, research indicates a decline due to overfishing, particularly in Bicol and Samar (Oceana 2021).

Nevertheless, despite their economic and ecological value, *S. lemuru* is threatened by fishing pressure, climate change, and widespread overfishing (Luceño et al. 2014; Willette et al. 2011). As Liu et al. (2025) note, ocean temperature affected the distribution of pelagic species, year-class production, and sardine yield. Factors that lead to earlier spawning and maturity of sardines at a smaller size were due to overfishing resulting from inadequate and a lack of conservation efforts and anthropogenic pressures, according to Oceana (n.d.). Additionally, the documented fluctuating abundance of small pelagic species like sardines and anchovies, with patterns of peak abundance, subsequent recovery, and collapse, was documented (Kawasaki 1992; Radovich 1982; McFarlane and Beamish 2001; Lecomte et al. 2004). Meanwhile, *S. lemuru* (Bali sardinella) production decreased from the first quarter of 2023 to the first quarter of 2024, from 55,667.84 MT to 39,037.36 MT (PSA 2024).

The Fisheries Management Area 7 spans roughly 1,669,900 hectares and includes 9 provinces and 90 cities/municipalities in regions 4A (Calabarzon), 5, and 8, with BFAR Region 5 serving as the designated lead (DA BFAR). The FMA covers a large area, including the marine region, stretching from Ragay Gulf in the north to Ticao and Burias Passes/San Bernardino Strait and southward to the Samar Sea. According to Campos et al. (2023), this area is one of the country's most significant sardine fishing grounds for catching Bali sardines. To catch sardines, common fishing gear includes nets (drift gillnets), traps, hook and line, and other tools and equipment (Okwuosa et al. 2018; NOAA Fisheries 2026; FAO 2025). According to Bjordal (n.d.), fishing gear must be specifically designed for the target species. Furthermore, in fisheries, the fundamental management unit is the stock; thus, recognizing it is crucial for effective fisheries assessment and resource management (Kritzer and Liu 2014).

Given the current status of sardines in the Philippines, particularly *S. lemuru*, this study aimed to address information gaps about the species, especially in FMA 7, where it was conducted. Thus, using the length-frequency data, the present study attempted to evaluate the growth rates, mortality coefficients, probability of capture, recruitment, and exploitation rate of this species in FMA 7. These parameters needed updating so the stock status could be properly addressed by designing suitable management measures for conservation and sustainability.

2. MATERIALS AND METHODS

2.1 Study area

The study was conducted in 54 NSAP-established landing centers in regions 4A, 5, and 8 within Fisheries Management Area (FMA) 7 (Figure 1). FMA 7 encompasses a vast marine region, extending from the Ragay Gulf in the north to the Ticao and Burias Passes/San Bernardino Strait, and southward to the Samar Sea. It has an area of approximately 1,669,900 hectares, spanning across nine provinces, namely Albay, Biliran, Camarines Sur, Leyte, Masbate, Northern Samar, Sorsogon, and Quezon, covering 90 cities/municipalities, 987 coastal barangays, and the rest are interior.

2.2 Sampling

This study used a sampling method described by Lopez (2017). In this method, a small part of something, or a small number of items from a group, is selected for examination or analysis to estimate the quality of the whole. The data used in the present study come from random sampling conducted every two days at NSAP-established landing sites in FMA

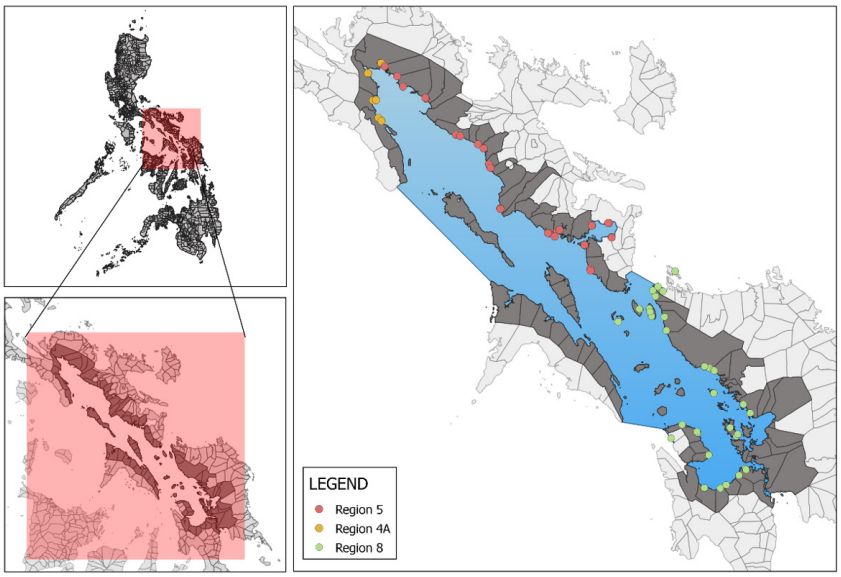

Figure 1. Map of FMA 7 highlighting the NSAP-established landing centers.

7, regardless of Saturdays, Sundays, and Holidays, during January 2019 to December 2022. Bali sardinella (*Sardinella lemuru* Bleeker, 1853) were taken from drift gillnet and ring net fisheries, following the NSAP standard methodology (Lopez 2017; Santos et al. 2017). Each *S. lemuru*'s total length (TL, cm) was measured to establish the sample size-frequency distribution.

2.3 Statistical analysis

2.3.1 Population parameters

The accumulated length measurements from 2019 to 2022 were grouped into 0.5 cm class intervals and processed in Microsoft Excel. The length frequency data were uploaded into the FiSAT (FAO-ICLARM Stock Assessment Tool) II software (Gayanilo et al. 2005) to estimate growth parameters such as asymptotic length (L_∞) and growth coefficient (K).

The Phi-prime, or the growth performance index ($\emptyset$) was calculated to allow comparison of growth parameters with published values. The estimates of L_∞ and K were used to compute the $\emptyset$- in terms of the length of the species (Pauly and Munro 1984): $\emptyset = LogK + 2LogL\infty$

Mortality coefficients such as total mortality (Z), instantaneous natural mortality (M), and fishing mortality (F), as well as the exploitation rate (E), were estimated using the FiSAT II program (Gayanilo and Pauly, 1997). The instantaneous rate of total mortality (Z) was estimated using the length-converted catch curve method (Pauly 1984) and split into natural mortality (death due to age, disease, predation, etc.) and fishing mortality (inflicted by humans). After estimating Z and M (at 28 °C), instantaneous fishing mortality (F) was calculated as F=Z–M.

The exploitation rate (E) was expressed as E=F/Z (Pauly 1980). We adopted the threshold level E=0.5 suggested by Gulland (1971). Thus, if E exceeds 0.5, the stock is overfished.

The probability of capture was computed from the length-converted catch curve by selecting the linear regression fitted to estimate the values of L_{25}, L_{50}, and L_{75}. The relative yield per recruit (Y'/R) and relative biomass per recruit (B'R) were estimated by the selection ogive module of the FiSAT II.

3. RESULTS

3.1 Population parameters

3.1.1 Size distribution of *S. lemuru* in FMA 7 from drift gillnet and ring net fishery

In this study, a total of 104,389 *S. lemuru* caught by drift gillnet and ring net were sampled, and the total length (TL) ranged from 10.25 to 21.25 cm and 10.25 cm to 19.75 cm, respectively (Figure 2). For the drift gillnet fishery, the mean was 16.79 cm, while for the ring net fishery, it was 14.81 cm. Both length curves demonstrate a left-skewed distribution, indicating that more large specimens were recorded. The mean TL ± SD of *S. lemuru* caught by the drift gillnet and ring net fisheries in FMA 7 in 2019 was 16.79 cm ± 1.19 and 14.81 cm ± 1.37, respectively. Likewise, the length at first maturity of *S. lemuru* caught by drift gillnet and ring net fisheries was 14.09 cm and 13.22 cm, respectively. The length at first capture of *S. lemuru* caught by drift gillnet and ring net fisheries was 14.57 cm and 12.69 cm, respectively.

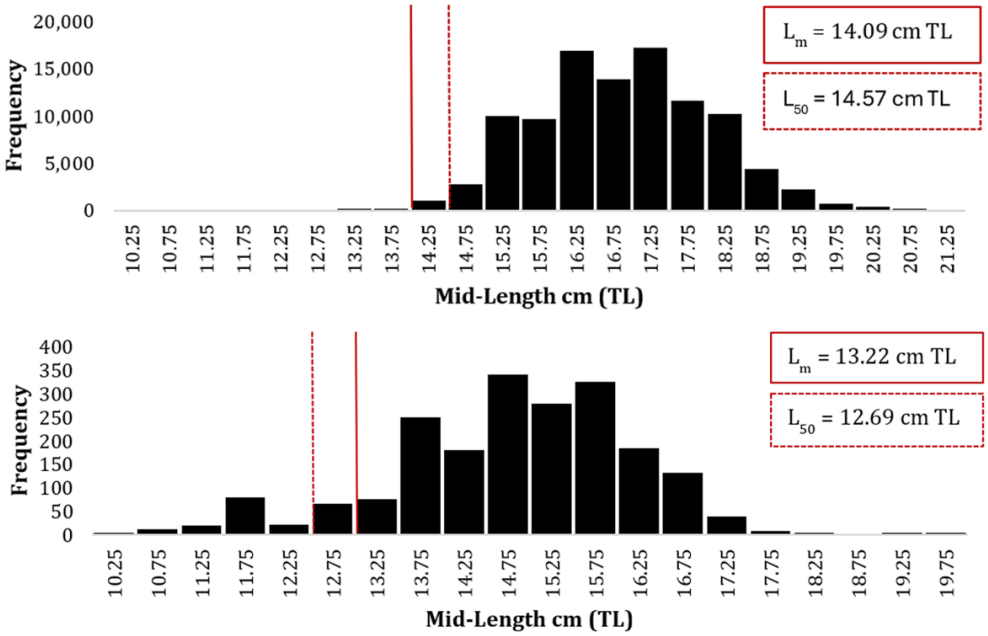

Figure 2. Length frequency distribution of *S. lemuru* caught by drift gillnet (above) and ring net (below) fishery in FMA7.

3.2 Growth parameters

Table 1 reports the best estimates of growth parameters, such as asymptotic length (L_∞), growth coefficient (K), and growth performance index (start equation empty set), from FISAT for *S. lemuru*. Table 2 shows growth parameters for *S. lemuru* from other authors, while Figure 3 shows the growth curves generated using the ELEFAN I method.

Table 1. Estimated population parameters of *S. lemuru* in FMA 7.

Parameters (/year)	Estimates	
	Drift gillnet	Ring net
Asymptotic Length (L∞)	23.27 cm	21.66
Growth coefficient (K)	0.90 year^{-1}	0.77 year^{-1}
Growth performance index (Ø)	2.68	2.55

3.2.1 Mortality and exploitation

Table 3 shows the estimated mortality and exploitation parameters for *S. lemuru*. Using the 0.5 criterion suggested by Gulland (1971), it could be said that *S. lemuru* in FMA 7 has already exceeded the sustainable limit.

3.2.2 Probability of capture

The probabilities of capture and length at first capture were estimated using the length-converted catch curve, yielding L_{25}=14.23 cm, L_{50}=14.57 cm, and L_{75}=14.91 cm for drift gillnet and L_{25}=12.40 cm, L_{50}=12.69 cm, and L_{75}=12.91 cm for ring net, as shown in Figure 4.

Table 2. Growth parameters of *S. lemuru* from different fishing grounds across the Philippines.

Authors/Source	Lmax (cm)	L∞ (cm)	K (year)	Ø	Fishing Ground
De Guzman et al. 2018	19.96	20.25	0.64	2.15	Eastern Sulu Sea and Basilan Strait
Mamalangkap et al. 2018		22.37	1.30		ARMM, Sulu Sea
		20.62	0.85		
		24.04	0.97		
Ramos et al. 2018	20.40	20.36	0.88	2.56	Tayabas Bay
	18.47	19.08	0.67	2.38	
	19.75	21.15	0.48	2.33	
fishbase.org		15.8	1.10	2.44	Visayas
		19.4	1.00	2.58	South Sulu Sea
		21.5	1.05	2.69	Visayan Sea
		27.0	0.90	2.82	
		23.0	1.10	2.76	Palawan

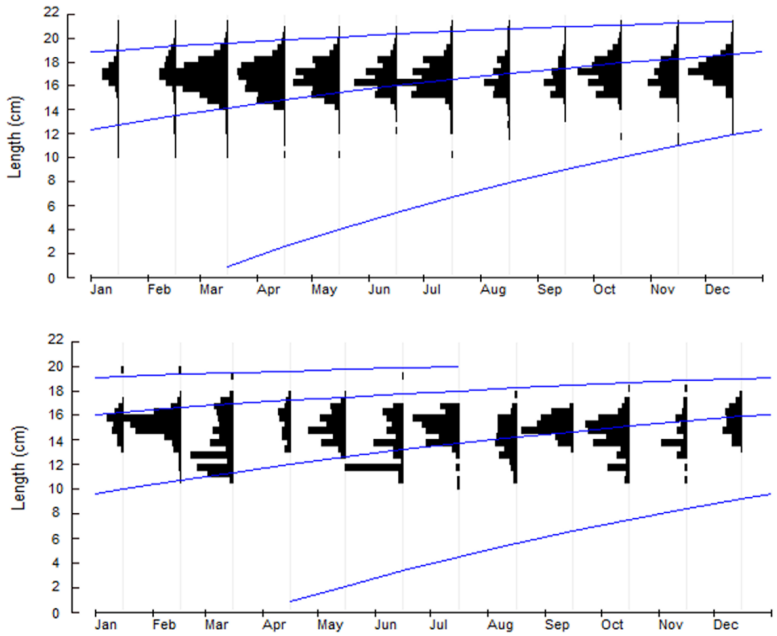

Figure 3. Growth curve of *S. lemuru* using ELEFAN I method caught by drift gillnet (above) L_{∞}=23.27 cm K=0.9 year^{-1} and ring net (below) L_{∞}=21.66 cm K=0.77 year^{-1}.

Table 3. Mortality and Exploitation parameters of *S. lemuru* in FMA 7.

Parameters (/yr)	Estimates	
	Drift gillnet	Ring net
Z	5.73	6.21
M	1.79	1.65
F	3.94	4.56
E	0.69	0.73
E_{10}	0.31	0.25
E_{50}	0.25	0.24
E_{max}	0.39	0.37

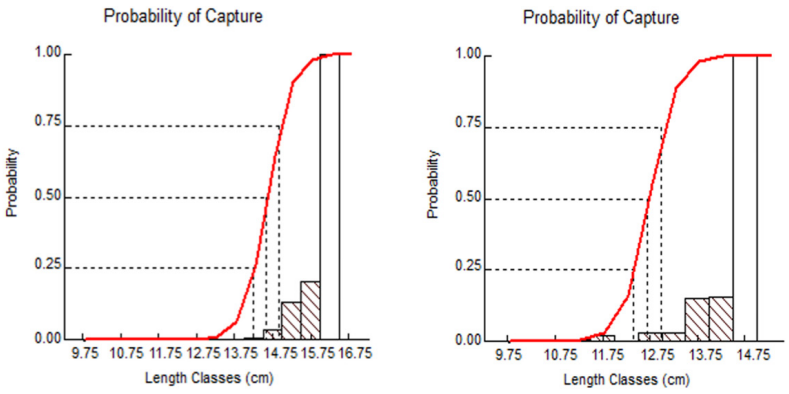

Figure 4. Capture probabilities of *S. lemuru* caught by drift gillnet (left) (L_{25}=14.23 cm, L_{50}=14.57 cm, L_{75}=14.91 cm and ring net (right) fishery L_{25}=12.40 cm, L_{50}=12.69 cm, L_{75}=12.99 cm).

3.2.3 Recruitment

Figure 5 illustrates the recruitment pattern of *S. lemuru* caught by drift gillnet and ring net fisheries in FMA 7 from January to December 2019. The species recruits throughout the year in two pulses. For *S. lemuru* caught by the drift gillnet fishery, the first pulse was recorded in July (17.15%), the second in September (21.66%), while the lowest was in March. For *S. lemuru* caught by the ring net fishery, the first pulse was recorded in June (20.70%), the second in September (23.25%), and the lowest in January.

3.2.4 Yield per recruit

The knife-edge method was used to calculate the relative yield-per-recruit (Y/R) and biomass-per-recruit (B/R), which are demonstrated in Figure 6. The exploitation rate (E_{max}) that gives the maximum yield-per-recruit was 0.39 for the drift gillnet and 0.37 for the ring net. The exploitation rate at which a marginal increase of 10% occurred (E_{10}) was observed to be 0.31 and 0.25, respectively. The exploitation rate (E_{50}), which represents 50% of the virgin (unexploited stock) relative biomass-per-recruit, was estimated at 0.25 and 0.24.

4. DISCUSSION

Sardinella lemuru is the dominant sardine species in Fisheries Management Area (FMA) 7 and is targeted by both commercial and municipal fisheries. In this study, the total length (TL) ranged from 10.25 to 21.25 cm and from 10.25 to 19.75 (Figure 2). The highest

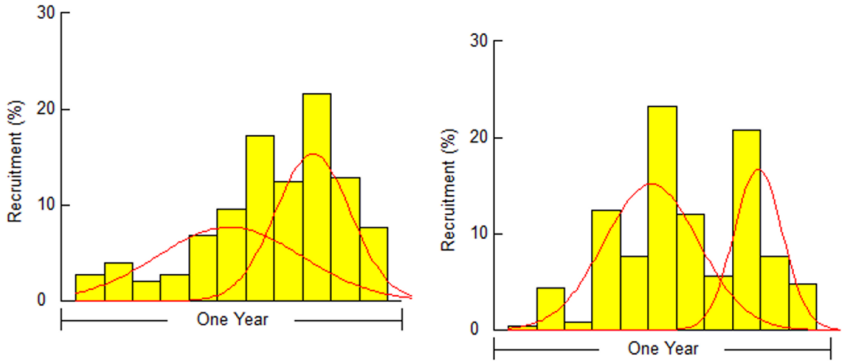

Figure 5. Temporal recruitment patterns of *S. lemuru* caught by (left) drift gillnet (right) ring net in FMA 7 from January to December.

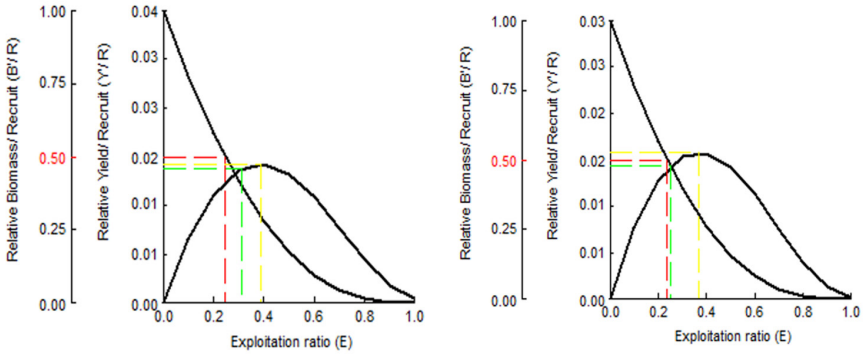

Figure 6. Relative yield-per-recruit and relative biomass-per-recruit curves of *S. lemuru* caught by drift gillnet (left): E_{10}=0.31 (Green), E_{50}=0.25 (Red), and E_{max}=0.39 (Yellow), and ring net (right): E_{10}=0.25 (Green), E_{50}=0.24 (Red), and E_{max}=0.37 (Yellow).

frequency of catches from the drift gillnet fishery was 15.25 to 18.75 cm (87.79%), while the highest frequency from the ring net fishery was 13.75 to 16.75 cm (77.08%). Likewise, the asymptotic length for *S. lemuru* from the drift gillnet and ring net fishery, L_∞= 23.27 cm and L=21.66 cm, and the proportion of stocks based on length L_{50}=14.57 cm, L_{50}=12.69 cm) imply the dominance of mature individuals in the catch (98.32%, 93.38%).

The estimated asymptotic length L_∞=23.27 cm and K=0.9 year^{-1} from the drift gillnet fishery and L_∞=21.66 cm and K=0.77 year^{-1} from the ring net fishery, respectively, showed rapid growth increment, indicating that this species is fast-growing and attains maximum length in less than three years. As such, *S. lemuru* in FMA 7 has a similar growth rate in the Visayan Sea (K=0.900 year^{-1}), as reported in fishbase. org, and in ARMM, Sulu Sea (K=1.3 year^{-1}, 0.85 year^{-1}, 0.97 year-^{1}), as reported by Mamalangkap et al. (2018). However, some studies report a slightly lower growth rate than in the present study (Table 1). Likewise, larger specimens reaching L_∞=27.0 cm have been reported in the Visayan Sea (Froese and Pauly 2026). The observed differences between values of L_∞ (Table 2) could be due to different length ranges of the sampled specimens, which could be attributed to the fishing gears, type of length applied in measurement, and other factors influencing the growth parameters such as different ecological conditions, seasons, habitats, and other interspecific differences as observed in other fish species (Salarpouri et al. 2019).

Ahouansou Montcho (2011) stated that mortality and growth parameters are antagonistic factors in population dynamics. Ingles and Pauly (1984) specified that the optimum fishing mortality in an exploited stock should be approximately equal to natural mortality. This study obtained estimates of instantaneous mortalities (Z=5.73 year^{-1}, Z=6.21 year^{-1}; F=3.94 year^{-1}, F=4.56 year^{-1}; and M=1.79 year^{-1}, M=1.65 year^{-1}) from the drift gillnet and ring net fishery, respectively. In comparison, fishing mortality is more than twice natural mortality, indicating that *S. lemuru* stocks in FMA 7 are no longer healthy and reiterating the intense fishing pressure on the species (Guanco et al. 2009). The low mortality rate estimated from this study could be due to the fast-growing

nature of the species. Moreover, the obtained total mortality (Z) was higher than the reported estimates of other authors, such as Ramos et al. (2018), Z=2.43, Z=2.37, and Z=2.42; De Guzman et al. (2018), Z=3.67; and Mamalangkap et al. (2018), Z=3.64 and Z=3.74 for *S. lemuru*. These differences may be attributed to the number of fishing fleets targeting the fishery for the local market and domestic trade.

The length at first capture (Lc_{50}) of the species should always be more than the length at first maturity (L_m); in that way, the stocks are given at least one chance to mature and spawn in their life span to contribute to the regeneration of the natural stock (Shah et al. 2019). The recalculated length at first maturity (L_m) in FishBase (Froese and Pauly 2026), based on the estimated L∞ and K at 28.0°C for *S. lemuru* caught by the drift gillnet and ring net fishery, is 14.09 cm and 13.22 cm. In this condition, the size of captured *S. lemuru* in FMA 7 of the drift gillnet fishery was relatively larger than the Lm, suggesting they were in spawning condition. Froese (2004) describes this scenario as recruitment overfishing, in which adult populations are heavily fished and could, in one way or another, lead to a dramatic decline in spawning biomass. As such, a change in the stable equilibrium to a low level may lead to fisheries collapsing. In contrast, *S. lemuru* caught by the ring net fishery in FMA 7 were smaller than L_m or immature. The lower length at first capture obtained from this study was attributed to the small mesh size of the fishing gear. Fishing pressure on the juvenile population may also increase in the future, and the remaining stocks will probably be forced to mature and spawn early to meet the market demand. Additionally, in this study, individuals ranging from 14.25 cm to 21.75 cm and 13.25 cm to 19.75 cm, which are beyond the recalculated length at first maturity and indicate proficient size yield, comprised 87.78% of the drift gillnet fishery and 85.02% of the ring net fishery, respectively.

Olaño et al. (2009) reported that peak sardine productivity and spawning in the country occur in the latter half of the year and often coincide with the Southwest monsoon. In this study, spawning-capable individuals were recorded year-round, and the species shows a year-round recruitment pattern with two noticeable pulses. In the drift gillnet fishery, distinct pulses were observed from July to September (17.15% and 21.66%), while in the ring net fishery, the highest pulse was in June (23.25%) and the second in September (20.70%). Additionally, Tajonera (2016) reported that *S. lemuru* shows a movement pattern during spawning, specifically starting during the Northeast monsoon down in the areas of Ticao Pass, which peaks in November and December, and afterward moves southwards to the San Bernardino Strait up to the beginning of summer months from March to May; then it will move upward again. Campos et al. (2017) cited that, in the upwelling area of Northern Zamboanga, as well as waters further south, the spawning of *S. lemuru* takes place from October to January, but in the Visayan Sea, through the intensive monitoring from 1998 to 2002, the major spawning coincides from March to June. The continuous recruitment pattern shown by the species could be a sign that the environment in FMA 7 is advantageous for their reproductive cycle. Moreover, the variation and migration patterns of this species before spawning and reproduction could be further explained by reproductive biology studies, particularly in FMA 7.

Gulland (1971) suggested that E of 0.5 is always safe for a fish stock, where F_{opt}=M. The current exploitation rates (E=0.69, E=0.73) are higher than the optimum level (E_{opt}=0.5), confirming that *S. lemuru* stocks in FMA 7 are under heavy fishing pressure. The exploitation rates (E) in the present study are higher than the allowable maximum exploitation rate (E_{max}=0.386, E_{max}=0.367). Thus, we cannot recommend a specific E level at present, but we can say, to a certain degree of accuracy, that reducing fishing effort would be ideal for the stock in FMA 7.

5. CONCLUSION

The present study indicates that the stocks of *S. lemuru* in FMA 7 are in a state of overexploitation. Mature individuals dominated the population size structure; however, a significant portion of the catch consisted of fish smaller than the recalculated length at first maturity, highlighting concerns about capturing immature individuals and indicating growth overfishing. Further, the obtained estimates of fishing mortality (F) correspondingly indicate that heavy fishing pressure is exerted by the fishing fleets targeting the species. Thus, to achieve sustainable catches, it is recommended to implement management measures such as increasing mesh sizes, enforcing size limits to protect juveniles, setting harvest limits, and reducing fishing effort. As it is a migratory species, continued monitoring of stock status and reproductive biology is essential to support adaptive management strategies aimed at maintaining the resilience and long-term productivity of *S. lemuru* populations in FMA 7.

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AUTHORS CONTRIBUTIONS

Benavidez JM: Conceptualization, Supervision. **Ballaran EN:** Methodology, Software. **Mago LJL**: Data curation, Visualization, Investigation, Writing-Original draft preparation. **Asilum MEC**: Writing-Original draft preparation. **Borja V:** Writing-Reviewing and Editing. **Argarin THE:** Supervision. **Amigo MF:** Supervision.

CONFLICTS OF INTERESTS

To the best of our knowledge, no conflict of interest exists.

ETHICS STATEMENT

No animal or human studies were carried out by the authors.

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