BIODIVERSITAS
Volume 27, Number 4, April 2026
Pages: 12

ISSN: 1412-033X
E-ISSN: 2085-4722
https://doi.org/10.13057/biodiv/d270417

Analysis of the stock status of red snapper (*Lutjanus malabaricus*) in Saleh Bay, West Nusa Tenggara Province, Indonesia

LORA SANTIKA[1,2,♥], SITTI HILYANA[1,2,3], SORAYA GIGENTIKA[1,2,3], SYAEFUL BACHRI[4], MISBAHUL UMAM[4]

[1]Program of Natural Resources and Environmental Management, Postgraduate Program, Universitas Mataram. Jl. Pendidikan No. 37, Mataram 83125, West Nusa Tenggara, Indonesia. Tel./fax.: +62-370-633007, ♥email: lorasantika97@gmail.com
[2]Scientific Forum on Sustainable Fisheries Management (FIP2B), West Nusa Tenggara Province. Jl. Semanggi No. 8, Mataram 83124, West Nusa Tenggara, Indonesia
[3]Program of Marine Science, Universitas Mataram. Jl. Pendidikan No. 37, Mataram 83125, West Nusa Tenggara, Indonesia
[4]Department of Maritime Affairs and Fisheries, West Nusa Tenggara Province. Jl. Semanggi No. 8, Mataram 83124, West Nusa Tenggara, Indonesia

Manuscript received: 5 November 2025. Revision accepted: 12 April 2026.

Abstract. *Santika L, Hilyana S, Gigentika S, Bachri S, Umam M. 2026. Analysis of the stock status of red snapper (*Lutjanus malabaricus*) in Saleh Bay, West Nusa Tenggara Province, Indonesia. Biodiversitas 27 (4): d270417. https://doi.org/10.13057/biodiv/d270417.* The red snapper (*Lutjanus malabaricus*) is a demersal fish species of high economic value in Indonesia, including in Saleh Bay, Sumbawa, West Nusa Tenggara. Increasing fishing pressure has raised concerns regarding its stock status and sustainability. This study aims to assess the stock condition of *L. malabaricus* in Saleh Bay as a basis for sustainable fisheries management. The analysis was conducted using the Length-Based Spawning Potential Ratio (LBSPR) model applied to 11,945 individuals caught by small-scale fishers between 2017 and 2024. Data were obtained from the Marine and Fisheries Agency of West Nusa Tenggara Province and the Scientific Forum for Sustainable Fisheries Management (FIP2B), with access granted through a formal Data Sharing Agreement authorized by both institutions. The LBSPR model was run assuming a natural mortality to growth ratio (M/K) of 1.47 and logistic selectivity. Results showed an average fish length of 53.88 cm. Growth parameters were estimated with an asymptotic length ($L\infty$) of 85.56 cm, a growth coefficient (K) of 0.22 year^{-1}, natural mortality (M) of 0.323 year^{-1}, and a theoretical age at zero length (t_0) of -0.5711 years. Length at first maturity (Lm) was 45.37 cm, while length at first capture was slightly higher at 47.26 cm. Spawning Potential Ratio (SPR) values fluctuated between 0.21 and 0.38 throughout the study period and declined steadily to 0.21 in 2024. In this study, stock status was interpreted using a precautionary reference point of SPR: 0.30. These results indicate that the red snapper stock in Saleh Bay has transitioned from lightly exploited to fully exploited conditions and is currently at risk of reduced reproductive potential. The findings highlight the need to strengthen management implementation, particularly through enforcement of minimum size regulations and improved control of fishing pressure, to support precautionary and adaptive management of red snapper fisheries in Saleh Bay.

Keywords: LBSPR, length-frequency, *Lutjanus malabaricus*, Saleh Bay

INTRODUCTION

Red snapper (*Lutjanus malabaricus* Bloch & Schneider 1801) is a demersal fish with a wide distribution in tropical and subtropical waters, including Indonesian marine ecosystems (Dafiq et al. 2019). This species is recognized as a premium commodity in international markets and is traded in fresh and processed forms. Indonesia has been reported as the largest global producer of red snapper, contributing 45% of total global trade volume (Ayuningtyas 2024). This highlights the strategic importance of *L. malabaricus* for the national capture fisheries sector. Beyond its economic value, red snapper fisheries support fishers' livelihoods and coastal economic development, especially in regions where demersal fisheries are a major income source (Oktaviyani 2018).

Waters surrounding Sumbawa Island in West Nusa Tenggara Province (NTB) are among Indonesia's most important red snapper production areas. Based on data from the Marine and Fisheries Service of NTB Province (2016), approximately 88.59% of the total snapper production in the province originates from the waters of Sumbawa (Hilyana et al. 2023). Within this region, Saleh Bay is a fishing ground characterized by coral reefs, seagrass beds, and deeper offshore habitats. This environmental complexity supports biodiversity and provides essential spawning, nursery, and feeding habitats for demersal species, including red snapper. Therefore, Saleh Bay is also a critical socio-ecological system for coastal communities.

Despite its ecological and economic importance, increasing market demand and limited management control have intensified fishing pressure on red snapper resources in Saleh Bay. High catch volumes of snapper and grouper reported from Sumbawa waters indicate substantial fishing intensity and raise concerns about overexploitation (Hilyana et al. 2023). Species such as *L. malabaricus*, with relatively slow growth, long lifespans, and late sexual maturity, are especially vulnerable to excessive fishing pressure. Uncontrolled exploitation can cause stock depletion, reduced reproductive capacity, and population declines (Santika and Sarjan 2025). These impacts threaten resource sustainability and the economic resilience of coastal communities that depend on demersal fisheries.

Effective fisheries management requires robust scientific information on stock status to guide harvest regulations, exploitation limits, and conservation strategies (Hilborn and Ovando 2014). However, stock assessment in small-scale fisheries such as those in Saleh Bay is often constrained by limited data, particularly the absence of reliable fishing effort and catch-per-unit-effort (CPUE) records. Under these conditions, length-based assessment approaches offer a practical alternative. The Length-Based Spawning Potential Ratio (LBSPR) model has been widely applied to evaluate stock status using catch length-frequency data without requiring detailed fishing effort information (Wibisono et al. 2021). By integrating biological parameters and size structure, LBSPR estimates exploitation rates and reproductive potential, making it suitable for small-scale fisheries. Although LBSPR has been increasingly used in Indonesia, its application remains largely limited to single-year analyses or broader regional studies, giving limited insight into temporal trends in stock condition at specific fishing grounds.

This study addresses this gap by providing the first multi-year (2017-2024) LBSPR-based assessment of red snapper stock status in Saleh Bay. By analyzing temporal changes in length structure and spawning potential ratio, this study offers a time-series perspective on exploitation dynamics under data-limited conditions. In addition, the results are explicitly interpreted within the context of existing provincial fisheries management regulations in West Nusa Tenggara, thereby linking stock assessment outcomes with current policy frameworks. The objective of this study is to assess the stock status of *L. malabaricus* in Saleh Bay using the LBSPR approach as a scientific basis for evaluating exploitation levels and supporting adaptive, evidence-based fisheries management aimed at ensuring long-term sustainability and socio-economic benefits for coastal communities.

Based on increasing fishing pressure and the life-history characteristics of *L. malabaricus*, this study hypothesizes that the spawning potential ratio (SPR) of the red snapper stock in Saleh Bay has declined over time and frequently falls at or below the precautionary reference point (SPR: 0.30). Specifically, this study addresses the following research questions: i) How does the length structure of *L. malabaricus* catches vary temporally from 2017 to 2024? ii) What are the corresponding annual estimates of fishing pressure (F/M) and spawning potential ratio derived from the LBSPR model? and iii) To what extent do the observed SPR trends indicate increasing exploitation risk under data-limited conditions?

MATERIALS AND METHODS

Study area

This study was conducted in Saleh Bay, Sumbawa, West Nusa Tenggara Province, Indonesia (Figure 1). Fish length data were collected from seven major fish landing sites surrounding the bay. In Sumbawa Regency, sampling locations included Labuhan Kuris, Labuhan Sangoro, Gili Tapan, Teluk Santong, and Labuhan Jambu, while in Dompu Regency, samples were obtained from Soro and Soro Barat. These landing sites represent the main centers of demersal fish landings in the study area.

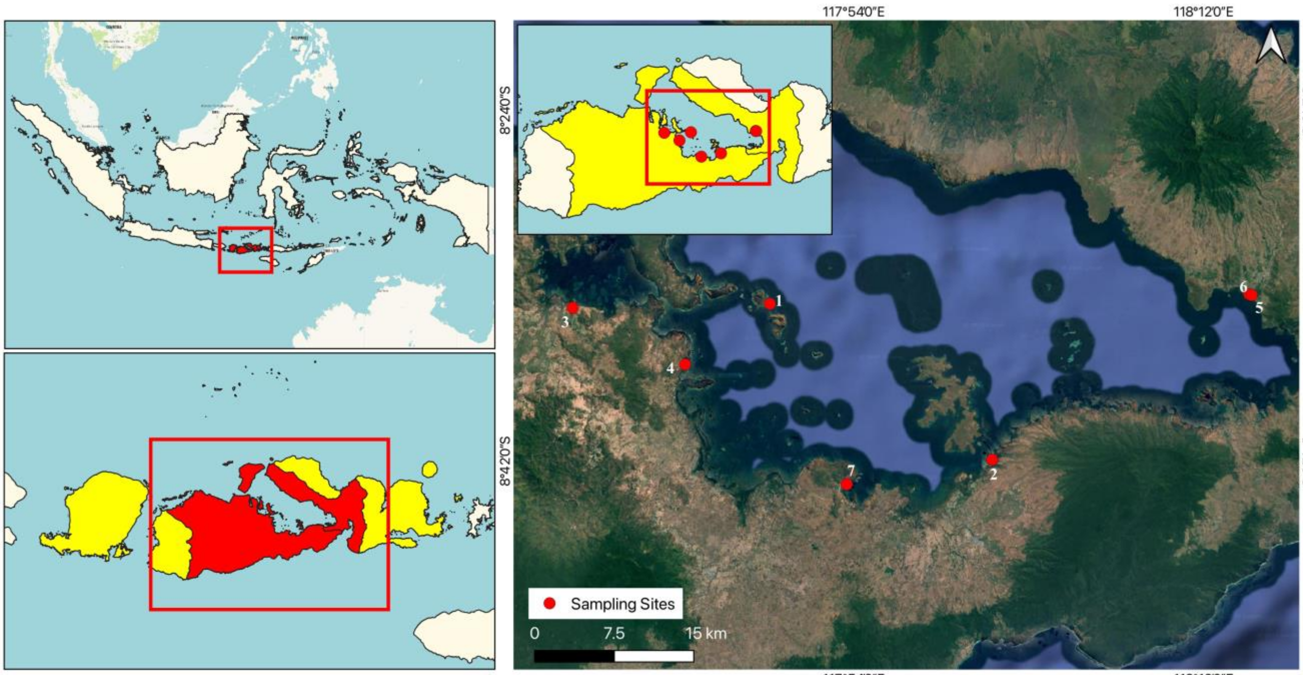

Figure 1. Study area in Saleh Bay, Sumbawa, West Nusa Tenggara Province, Indonesia

The dataset used in this study comprised secondary length-frequency data of *L. malabaricus* routinely collected by the Scientific Forum for Sustainable Fisheries Management (*Forum Ilmiah Pengelolaan Perikanan Berkelanjutan*, FIP2B) of West Nusa Tenggara Province in collaboration with the Provincial Marine and Fisheries Service (DKP). Data access was granted through a formally authorized Data Sharing Agreement between FIP2B and DKP, ensuring legal use and traceability of the dataset. Sampling was conducted regularly for approximately 7-15 days per month at each selected landing site from 2017 to 2024, providing adequate temporal coverage to capture monthly variation in catch composition and fish size structure.

Field measurements were carried out by trained FIP2B enumerators stationed at landing sites. Enumerators received technical training in species identification, standardized measurement procedures, and data recording protocols to ensure consistency across sites and years. Fish size was measured as total length (TL), defined as the distance from the tip of the snout to the end of the caudal fin. Individuals were photographed on a standard measuring board with 1-cm scale resolution, and total length was subsequently extracted through calibrated digital image analysis, producing decimal-length values. Quality assurance and quality control (QA/QC) procedures, including data validation and standardization, were applied prior to analysis to ensure reliability.

Red snapper in Saleh Bay was harvested by small-scale fishers using multiple gear types, including handlines, bottom longlines, droplines, spearguns, set gillnets, and boat lift-nets. All gear types were included to represent the overall size structure of the exploited stock. Gear use was quantified based on the proportion of sampling records associated with each gear type relative to the total annual samples. These percentages reflect sample composition rather than fishing effort or total landings, as sampling was not designed to be proportional to fleet size or effort; therefore, gear-use proportions should be interpreted cautiously when inferring relative fishing intensity.

Over the eight-year period, a total of 11,945 individual red snapper was measured, with annual sample sizes ranging from 561 individuals (2018) to 2,798 individuals (2023). Observed total lengths ranged from 20.15 to 94.22 cm. For analysis, length data were grouped into 2-cm size classes, each represented by its mid-length value. This bin width was selected to balance size resolution and sampling variability while ensuring stable length-frequency inputs for the Length-Based Spawning Potential Ratio (LBSPR) analysis. Annual length-frequency distributions derived from these grouped data served as the primary input for subsequent stock assessment.

Growth parameters

Growth parameters ($L\infty$, K, and t_0) were estimated using the ELEFAN algorithm implemented in the TropFishR package (Mildenberger et al. 2017), which is widely applied in data-limited fisheries because it allows robust estimation of growth parameters from length-frequency data without requiring age-based information. This approach identifies modal progressions within the length-frequency distributions and iteratively fits these modes to the von Bertalanffy Growth Function (VBGF). The growth curve followed the standard formulation of Sparre and Venema (1998):

$$Lt = L\infty (1 - e^{(-K(t - t0))})$$

Where, Lt is the length at age t, $L\infty$ is the theoretical asymptotic length, K is the growth coefficient, and t_0 is the theoretical age at zero length. Parameter estimation was performed through iterative optimization, and the final set of growth parameters ($L\infty$, K, and t_0) was selected based on the best model fit, indicated by the highest goodness-of-fit index between the observed length modes and the modeled growth trajectory.

Natural mortality

Natural mortality (M) was estimated using the empirical equation proposed by Then et al. (2015):

$$M = 4.118 \times K^{0.73} \times L\infty^{(-0.33)}$$

Total instantaneous mortality (Z) was estimated using the length-converted catch curve method following Pauly (1980a), as implemented in the TropFishR package. The regression was fitted to the descending limb of the catch curve using fully selected length classes only. This approach assumes steady-state conditions, constant recruitment and mortality, and representative length-frequency data. Model diagnostics, including the linear fit of the catch curve, were examined to ensure the reliability of the mortality estimates. Fishing mortality (F) was subsequently obtained as:

$$F = Z - M$$

Exploitation rate (E) was then estimated as:

$$E = F/Z$$

The level of exploitation was interpreted based on Gulland's (1971) criterion, which assumes that optimal exploitation occurs when fishing mortality equals natural mortality (F=M), corresponding to an exploitation rate of approximately $E \approx 0.5$. Values of E greater than 0.5 indicate increasing fishing pressure and potential overexploitation, whereas values below this threshold suggest lower exploitation levels.

Maturity and selectivity

Maturity parameters were derived from empirical relationships linking growth parameters with length at maturity. In this study, the length at first maturity (Lm) was defined as the length at 50% sexual maturity and is therefore equivalent to L_{50}. The value of L_{50} was estimated using the empirical relationship proposed by Froese and Binohlan (2000):

$$\text{Log } L_{50} = 0.89979 \times \text{Log } L\infty - 0.0782$$

The length at 95% maturity (L_{95}) was subsequently calculated following Prince et al. (2015):

$$L_{95} = 1.1 \times L_{50}$$

The parameters L_{50} (Lm) and L_{95} were used to construct the logistic maturity ogive, where L_{50} represents the inflection point at which 50% of individuals are mature, and L_{95}

defines the upper asymptote at which nearly all individuals are reproductively mature. This maturity ogive was then used to parameterize the length-based selectivity functions in the LBSPR analysis, allowing the integration of reproductive dynamics and size-dependent vulnerability to fishing. As local maturity data were not available for the study area, these empirical estimates were adopted as a pragmatic approximation of the maturity schedule, consistent with common applications of the LBSPR framework. This maturity ogive was then used to parameterize the length-based selectivity functions in the LBSPR analysis, allowing the integration of reproductive dynamics and size-dependent vulnerability to fishing.

LBSPR settings

The LBSPR assessment followed the framework of Hordyk et al. (2015), using key inputs including the ratio of natural mortality to growth coefficient (M/K: 1.47), the theoretical asymptotic length ($L\infty$), and maturity parameters (L_{50} and L_{95}). Length-frequency data were grouped into 2-cm size classes, consistent with the bin width applied in the growth analysis and with the 1-cm measurement precision used by field enumerators. Selectivity was assumed to follow a logistic function, characterized by a gradual increase in vulnerability to fishing with increasing fish length. Model uncertainty was evaluated through a bootstrap procedure, in which length-frequency data were repeatedly resampled to generate stable estimates of the spawning potential ratio (SPR) and to reduce sensitivity to sampling variability typical of small-scale fisheries.

Stock status was evaluated using a limit reference point of SPR: 0.30, which is commonly applied in LBSPR-based assessments to indicate reduced reproductive capacity (Hordyk et al. 2015). SPR values below this threshold were interpreted as indicating high exploitation pressure. For contextual comparison, additional qualitative interpretation of exploitation levels followed the SPR-based classification proposed by Prince et al. (2015).

Diagnostic analyses indicated that moderate variation in key parameters influenced SPR estimates to differing degrees. Changes in the M/K ratio of ±20% resulted in proportional shifts in estimated SPR values, reflecting the sensitivity of reproductive potential to assumed mortality growth relationships. The maturity ogive was parameterized using L_{50} and L_{95} values to represent a gradual transition to full maturity, following standard LBSPR assumptions. Sensitivity tests showed that varying the L_{95} multiplier produced moderate changes in absolute SPR values, but did not alter the overall stock status classification across plausible maturity parameter ranges.

Length data from all fishing gears were pooled to represent the overall size structure of the exploited stock. Although the LBSPR approach assumes a logistic selectivity curve, the pooled length-frequency distribution exhibited a smooth and unimodal pattern, indicating an approximately logistic and temporally stable selectivity. This pattern was largely driven by the dominance of the bottom longline in the catch composition. Therefore, the pooled data were considered appropriate for estimating stock-level SPR.

Diagnostics and sensitivity

Model robustness was examined through a sensitivity analysis that varied the M/K ratio by ±20% to evaluate the influence of life-history parameter uncertainty on SPR outputs. Additional diagnostic checks assessed the effect of alternative selectivity shapes by adjusting L_{50} and L_{95} within their plausible biological ranges. These diagnostics allowed identification of scenarios in which SPR estimates were most sensitive to changes in biological inputs, thereby improving confidence in the final stock status classification.

Statistical environment

All analyses were conducted using the R statistical environment (version 4.4.1). Growth and mortality parameters were estimated using the TropFishR package, while the Length-Based Spawning Potential Ratio (LBSPR) analysis followed the framework described by Hordyk et al. (2015) and was implemented using The Barefoot Ecologist's LBSPR Toolbox (http://barefootecologist.com.au/lbspr). Additional computations and diagnostic analyses were performed in R using standard packages commonly applied in fisheries stock assessment.

RESULTS AND DISCUSSION

This study aims to assess the stock condition of the red snapper *L. malabaricus* in Saleh Bay, Sumbawa, West Nusa Tenggara, using the Length-Based Spawning Potential Ratio (LBSPR) model as the primary approach for stock status evaluation. The LBSPR model is applied to estimate exploitation levels and the reproductive capacity of the population based on the length distribution of the captured fish, thereby enabling a more representative assessment in data-limited fisheries, particularly when catch-per-unit-effort (CPUE) or biomass information is unavailable. By utilizing key biological parameters such as asymptotic length ($L\infty$), growth coefficient (k), natural mortality (M), length at first maturity (Lm), and length at first capture (Lc), this analysis produces quantitative indicators in the form of the F/M ratio and SPR values to describe the remaining spawning biomass in the wild. In this context, evaluating size patterns of captured fish becomes essential, as length-based characteristics can provide direct insights into population structure and ongoing reproductive potential.

Life history parameters

The biological parameters of *L. malabaricus* in Saleh Bay indicate an asymptotic length of 85.56 cm with a moderate growth coefficient (K: 0.22 $year^{-1}$), suggesting a relatively long lifespan and increased vulnerability to sustained fishing pressure. The estimated natural mortality (M: 0.323 $year^{-1}$) represents population losses due to natural causes and provides an important reference for evaluating fishing intensity. The length at first capture (Lc: 47.26 cm), which slightly exceeds the length at first maturity (Lm: 45.37 cm), indicates that most individuals are likely able to spawn at least once before being captured, offering a minimum level of biological protection to the spawning stock. However, the relatively small difference between Lc and Lm implies that increases in fishing pressure or shifts toward smaller size selectivity could quickly reduce reproductive contributions, highlighting the need to maintain appropriate size-based management measures. It should be noted that the growth and mortality parameters used in this study were derived from length-based methods and are therefore subject to inherent uncertainty associated with sampling structure and model assumptions. Consequently, the inference that Lc slightly exceeding Lm provides a minimum level of biological protection should be interpreted cautiously and viewed as indicative rather than definitive. Indications of stock deterioration can be inferred from temporal changes in fish length distribution. Determining the length at first maturity is important because it serves as a basis for designing appropriate gear size regulations to support sustainable fisheries utilization.

Size frequency distribution

Based on the length-frequency distribution of *L. malabaricus* from 2017 to 2024 (Figure 2), annual size ranges varied moderately but consistently spanned broad length classes. Observed total lengths ranged overall from 20.15 cm (2024) to 94.22 cm (2022), with most years showing minimum sizes above 24 cm and maximum sizes above 70 cm. Across all sampling years, individuals were predominantly concentrated within the 50-55 cm size class, resulting in an overall mean length of 53.88 cm. The size distribution consistently indicates that most captured individuals were above the size at first sexual maturity (Lm), reflecting a catch composition largely dominated by mature fish and the continued presence of larger size classes throughout the monitoring period.

The findings show that red snapper caught in the waters of Saleh Bay exhibit a length at first maturity (Lm) that is smaller than the length at first capture (Lm: 45.37 cm < Lc: 47.26 cm) (Table 1). This indicates that most captured individuals have surpassed the maturity threshold and have spawned at least once prior to capture. Such a condition suggests a favorable potential for stock sustainability, as a proportion of the population is able to contribute to reproductive output before experiencing fishing pressure. According to Grimes (1987) and Prihatiningsih et al. (2020), snapper species typically reach gonadal maturity at 40-50% of their maximum length, and variation in size at maturation is influenced by depth and habitat type, particularly in relation to food availability. The length at first capture (Lc) of red snapper in Saleh Bay, recorded at 47.26 cm, is higher than the value reported by Wahyuningsih et al. (2013) in Brondong Waters, Lamongan, East Java, at 38.51 cm, and by Prihatiningsih et al. (2012) in Kotabaru Waters, South Kalimantan, at 40.5 cm FL. Nikolskii (1969) stated that growth is a fundamental factor in population dynamics; therefore, information on growth parameters is essential as it can be used to assess resource conditions in a given water body, including stock size, exploitation level, and management prospects.

Furthermore, the interpretation of the stock condition of *L. malabaricus* should also be linked to the growth characteristics of the species. *L. malabaricus* exhibits a growth coefficient (K) of 0.22 per year and an asymptotic length (L∞) of 85.56 cm. According to Froese (2005), growth coefficients within the range of 0.16-0.30 $year^{-1}$ indicate a moderate growth rate. Rapi et al. (2023) noted that the value of k reflects the rate at which fish approach their asymptotic length, with higher growth coefficients indicating a faster attainment of maximum size. The growth coefficient (K) is also related to fish longevity, where higher K values correspond to shorter life spans. Fish with high growth coefficients generally have relatively short life spans (Pauly 1980b). Newman et al. (2000) reported that the red snapper *L. malabaricus* has a relatively long-life span, reaching up to 20 years, and exhibits slow growth once it reaches adulthood.

Species with moderate growth rates and long lifespans, such as *L. malabaricus*, are generally more sensitive to sustained fishing pressure because recovery of spawning biomass requires longer time periods. Consequently, variations in fishing intensity are expected to be reflected in indicators such as mean length, the F/M ratio, and SPR. These indicators were evaluated annually to assess temporal dynamics in stock condition, and their summary values for *L. malabaricus* in Saleh Bay during 2017-2024 are presented in Table 2, with stock status classified based on the SPR limit reference point of 0.30.

While temporal indicators provide insight into annual dynamics of stock condition, spatial variability in growth parameters may also influence stock structure and vulnerability to fishing pressure. Differences in fishing grounds can reflect variation in environmental conditions, habitat characteristics, and exploitation patterns, which may affect the growth performance of *L. malabaricus.* Therefore, growth parameters were estimated separately for different fishing grounds to evaluate potential spatial differences in growth characteristics (Table 3).

Table 1. Biological parameters of *Lutjanus malabaricus* in Saleh Bay, Sumbawa, West Nusa Tenggara Province, Indonesia

Parameter	**Unit**	**Value**
Asymptotic length (L∞)	cm	85.56
Growth coefficient (K)	$year^{-1}$	0.22
The theoretical age at a length of 0 cm (t_0)	year	-0.5711
Natural mortality (M)	$year^{-1}$	0.323
Length at first maturity (Lm)	cm	45.37
Length at first capture (Lc)	cm	47.26

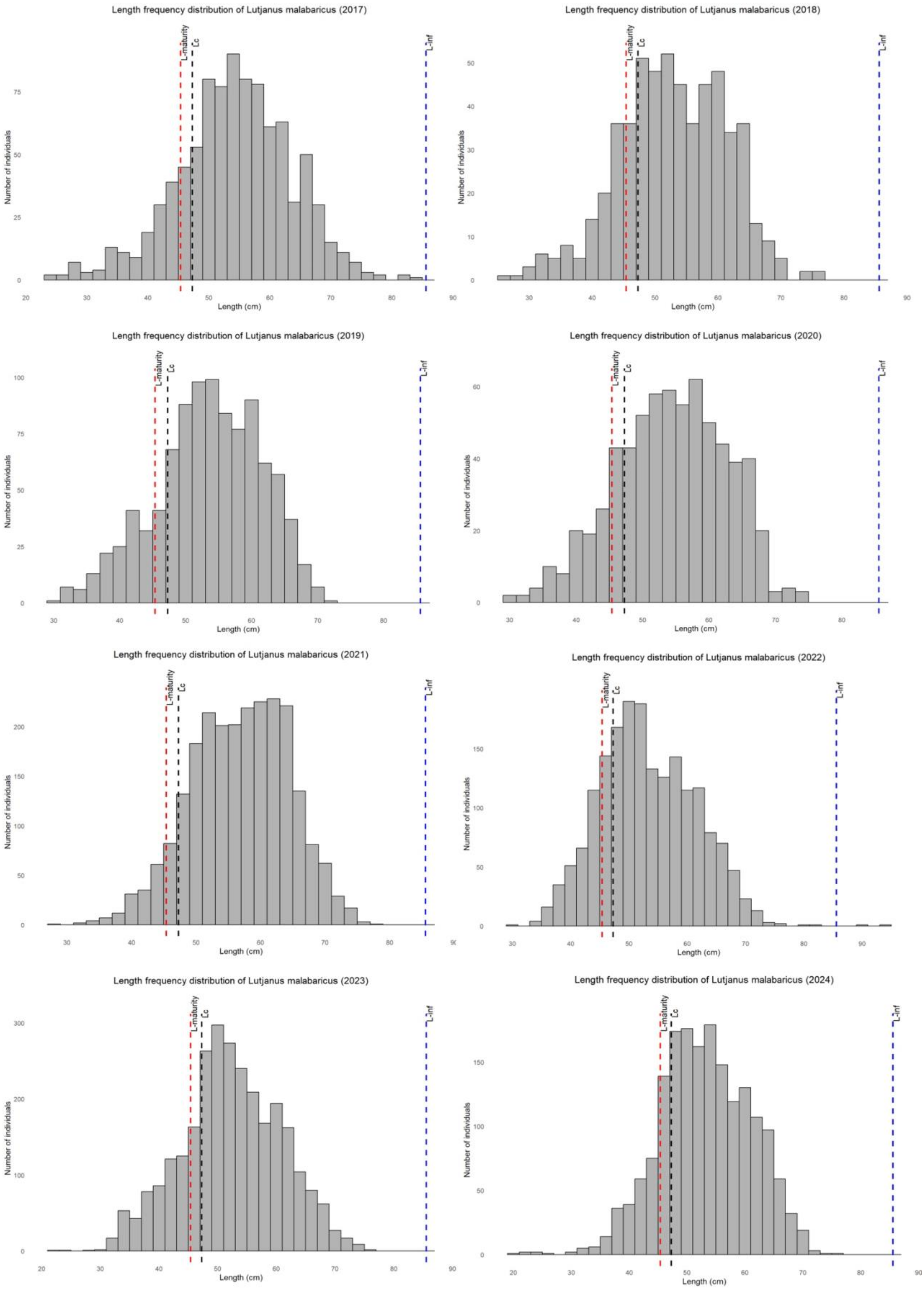

Figure 2. Length frequency distribution of *Lutjanus malabaricus* 2017-2024

Table 2. Recapitulation of F/M, SPR, and morphometric parameters of *Lutjanus malabaricus* (2017-2024)

Year	Sample (n)	Length average (TL) (cm)	F/M	SPR (±CI)	Status
2017	918	54.28	0.87	0.38 (0.31-0.45)	Above limit
2018	561	52.86	1.76	0.24 (0.20-0.28)	Below limit
2019	973	53.52	1.26	0.25 (0.13-0.33)	Below limit
2020	666	54.21	1.21	0.26 (0.17-0.36)	Below limit
2021	2,388	56.85	1.03	0.31 (0.26-0.35)	Above limit
2022	1,853	53.29	1.34	0.26 (0.24-0.29)	Below limit
2023	2,798	52.31	1.63	0.23 (0.20-0.26)	Below limit
2024	1,788	53.11	2.37	0.21 (0.19-0.23)	Below limit

Table 3. Estimation of the parameters for the growth of red snappers in different fishing grounds

L_∞ (cm)	Length type	K (year^{-1})	t_0 (year)	Location	References
70.70	SL	0.168	0.418	Australia	Edwards and Shaher (1991)
68.90	TL	0.358		Kuwait	Mathews and Samuel (1991)
64.40	TL	0.338	0.397	North Java (Indonesia)	Herianti (1993)
57.86	FL	0.238	0.588	South Kalimantan (Indonesia)	Prihatiningsih (2012)
97.65	FL	0.220	-0.024	Brondong, Lamongan (North Java)	Wahyuningsih et al. (2013)
72.95	TL	0.410	-0.28	Pinrang Waters, South Sulawesi (Indonesia)	Rapi et al. (2022)
96.00	TL	0.720	-0.789	Mayangan, Probolinggo (Indonesia)	Ayuningtyas (2024)
85.56	TL	0.220	-0.5711	Saleh Bay, West Nusa Tenggara (Indonesia)	This study (2025)

Overall, the stock status of *L. malabaricus* in Saleh Bay indicates a condition that is close to, and in several years below, precautionary sustainability thresholds. Although most captured individuals exceeded the length at first maturity (Lc>Lm), suggesting some level of reproductive opportunity, temporal trends in spawning potential ratio (SPR) reveal a gradual decline from relatively healthy levels in 2017 toward values near or below the 0.30 reference point in recent years. This decline was accompanied by increasing fishing pressure, as reflected by rising F/M ratios, indicating heightened exploitation risk under data-limited conditions. Taken together, these results suggest that the red snapper stock in Saleh Bay is currently fully exploited and vulnerable to further depletion without strengthened and consistently implemented management measures.

Several studies on the growth parameters of red snapper (*L. malabaricus*) have been conducted in various locations different from the present research, including Australia, Kuwait, northern Java, South Kalimantan, and the waters of Pinrang (Table 3). Growth parameters reported in Table 3 were derived using different length metrics (TL, FL, and SL) as defined in the original studies. Therefore, comparisons among locations are intended to be qualitative, and direct numerical equivalence should be interpreted with caution.

These studies show that the growth parameter values of red snapper vary among locations. This variation is influenced by multiple factors, such as fish size, duration of the study, type of fishing gear used, fishing season, and the fishing grounds during sample collection (Aziz et al. 1992; Nurulludin and Prihatiningsih 2014). In addition, according to Sparre and Venema (1998), differences in the value of *K* may also result from environmental conditions. These findings highlight that in fish growth analysis, both methodological factors and ecological conditions must be carefully considered to produce results that accurately reflect population dynamics.

Differences in Lm (length at first maturity) are thought to be related to environmental factors, including nutrient conditions, seawater temperature, light intensity, feeding habits, fish physiological condition, and fishing location (Lagler et al. 1962; Wootton 1985; Udupe 1986). Latitudinal differences of more than 5° are also estimated to influence the age and size at first maturity (Effendie 1997). This suggests that spatial variation and differing environmental conditions may lead to diverse growth and reproductive strategies within red snapper populations. This is important to consider because misconceptions about environmental influences can lead to errors in estimating reproductive potential, which ultimately affects the effectiveness of stock management.

Apart from environmental factors, fishing pressure also influences Lm. In Saleh Bay, red snapper fishing is one of the more intensively conducted fisheries activities. High fishing pressure may drive fish to mature earlier as a population-level strategy in response to overexploitation (Restiangsih dan Amri 2019). This phenomenon reinforces the idea that fisheries activities not only affect stock abundance but can also induce adaptive changes in the biological characteristics of a species. Understanding biological variation influenced by both environmental conditions and fishing pressure is crucial for developing sustainable management strategies for red snapper in West Nusa Tenggara (NTB).

Growth parameters are also closely linked to the reproductive potential of fish, forming the basis for calculating the Spawning Potential Ratio (SPR). The status of fish resource utilization can also be inferred from the ratio of spawning stock biomass. The spawning potential ratio (SPR) reflects the reproductive capacity of a fish stock (Agustina et al. 2018). SPR is used to indicate the ability of a stock to maintain its spawning potential under exploited conditions. According to Brooks et al. (2010), SPR is an index representing the relative reproductive level of a fish stock subjected to fishing pressure. The SPR value provides insight into how much of the population remains capable of reproducing compared to its unexploited natural condition.

Based on the Spawning Potential Ratio (SPR) graph for *L. malabaricus* in Saleh Bay, it is evident that the SPR trend during the 2017-2024 period experienced considerable fluctuations. From 2017 to 2018, the SPR value declined sharply from approximately 0.38 to 0.24. This condition indicates an increase in fishing pressure or a major disturbance to the spawning stock. This is reflected in the graph (Figure 3), where the F/M value or fishing pressure rose steeply from 0.87 in 2017 to 1.76 in 2018. A low SPR value reflects a reduction in the number of young fish, triggering a decline in the spawning biomass and limiting the number of eggs produced (Suyasa et al. 2023). Thus, it is suspected that between 2017 and 2018, *L. malabaricus* in Saleh Bay experienced increasing exploitation from previously being under-exploited to becoming fully exploited, although not yet categorized as overexploited. Low SPR values (<30%) can reduce the ability of the spawning biomass to produce a sufficient number of adults in the population structure (Ault et al. 2008). According to Prince et al. (2015), fisheries status can be classified into three categories based on Spawning Potential Ratio (SPR) values, namely under-exploited (SPR>40%), moderately exploited (20%<SPR<40%), and over-exploited (SPR<20%). A high SPR value characterizes a healthy fish population, as a sufficient number of mature adults is available to support reproductive processes.

Following this decline, SPR values gradually increased from 2018 to 2021, reaching a peak of 0.31 in 2021. These increases coincided with relatively lower F/M values during the same period, suggesting a possible reduction in fishing pressure compared to subsequent years. The observed improvement in SPR may be associated with reduced fishing activity during the COVID-19 pandemic, which affected market demand and fishing operations for *L. malabaricus*. However, this interpretation is inferred from temporal trends, as direct data on fishing effort or market dynamics were not available in this study.

A similar pattern has been reported elsewhere, where COVID-19-related restrictions were associated with reduced fishing mortality and modest increases in biomass for several commercial fish stocks (Scarcella et al. 2022). In addition, the increase in SPR observed in 2021, which exceeded the 30% reference point, may also reflect the potential influence of fisheries management measures implemented during the same period. In 2018, the NTB Governor Regulation No. 32/2018 on the Sustainable Grouper and Snapper Fisheries Management Action Plan was enacted, including minimum size limits for snapper species such as *L. malabaricus*.

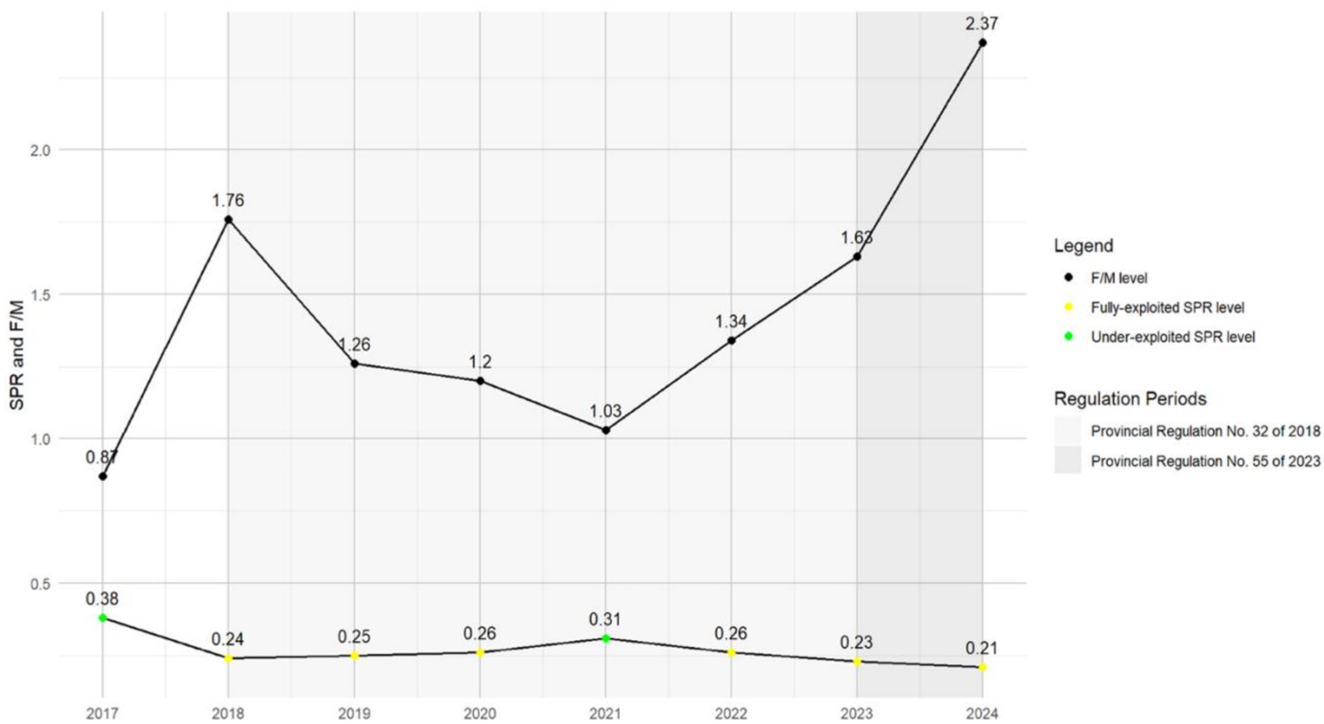

Figure 3. The graph of SPR and fishing pressure of *Lutjanus malabaricus* in Saleh Bay, Sumbawa, West Nusa Tenggara Province, Indonesia (2017-2024)

The SPR pattern observed in 2021 is therefore consistent with a combination of factors, including temporarily reduced fishing activity during the COVID-19 pandemic and the possible cumulative effects of size-based management measures that protect reproductively valuable individuals and help maintain spawning biomass (Lavin et al. 2021). Nevertheless, due to the absence of independent data on fishing effort, CPUE, or fisher compliance, the relative contribution of management measures versus external factors cannot be quantitatively distinguished and should be interpreted as a hypothesis rather than a causal conclusion.

The management reference point of SPR: 0.30 is known to be highly sensitive to relatively small changes in fishing mortality and population size structure. Consequently, even modest increases in fishing effort or reductions in the size of captured fish can result in rapid declines of SPR below sustainable levels. This sensitivity implies that when SPR values approach the 30% threshold, stock conditions become increasingly vulnerable to overexploitation. In this context, SPR serves as a robust indicator of stock status and provides a useful framework for evaluating whether observed stock trends are consistent with management objectives, rather than as definitive evidence of management effectiveness.

Following the peak SPR value in 2021, SPR declined again to 0.26 in 2022 and continued to decrease until 2024, reaching 0.21. This downward trend coincided with a marked increase in fishing pressure, as reflected by rising F/M values (Figure 3), which increased from 1.03 in 2021 to 2.37 in 2024. While this pattern may suggest a weakening in the effectiveness of management implementation, it should be interpreted with caution, as no direct indicators of enforcement intensity or compliance levels are available. The effectiveness of fisheries management depends not only on the existence of regulatory frameworks but also on consistent enforcement and adherence by fishers.

Using the SPR reference point of 0.30 as a precautionary management threshold, only in 2017 and 2021 did SPR values remain above this level, whereas in other years, SPR values were close to or below the critical threshold. This pattern indicates a persistent risk of overexploitation and suggests that the *L. malabaricus* stock in Saleh Bay remains vulnerable to excessive fishing pressure. In relation to regional regulations, the temporal increase in SPR following the implementation of Governor Regulation No. 32/2018 is consistent with a potential positive response of the stock to management measures, although this response became apparent only after several years.

However, the subsequent decline in SPR after 2021, despite the regulation remaining in force until 2023, may reflect declining compliance, implementation challenges, or increasing external pressures such as market demand and fishing intensity. In response to these conditions, the NTB Provincial Government enacted Governor Regulation No. 55/2023 on Sustainable Snapper and Grouper Fisheries Management. The effects of this more recent regulation are not yet evident in the 2023-2024 SPR estimates, which is not unexpected given that fisheries management interventions typically require time before measurable biological responses become apparent.

Overall, while the observed SPR trends are consistent with periods of management intervention, the lack of independent data on compliance and fishing effort represents an important limitation of this study. These findings highlight the need for strengthened enforcement, improved monitoring of fishing practices, and complementary analyses of fishing gear composition to understand sources of fishing pressure better. As noted by several authors, the success of capture fisheries management depends not only on regulatory design but also on effective implementation and compliance (Charles 2001).

It should be noted that this stock assessment refers to the Saleh Bay management unit and does not necessarily represent a fully closed biological stock. *L. malabaricus* is a demersal species with the potential for movement across adjacent fishing grounds surrounding Saleh Bay. Such spatial connectivity may allow immigration and emigration processes to occur, which can influence observed length composition and exploitation indicators. Consequently, the assessment results should be interpreted as reflecting stock status within the Saleh Bay management context rather than an isolated biological population. Depending on the direction of movement, immigration of larger individuals may lead to overestimation of SPR, whereas emigration of mature fish could result in underestimation of stock status.

Distribution of fishing gear utilization

Based on the composition of length-recorded sampling records, fishing-gear utilization during 2017-2024 exhibited a fluctuating pattern, with bottom longline consistently remaining the dominant fishing gear throughout the study period (Figure 4). Gear utilization percentages were calculated as the proportion of sampling records associated with each gear relative to the total number of records in a given year. A total of 4,831 sampling records were analyzed, with annual sample sizes ranging from 156 records in 2018 to 1,102 records in 2023.

During the early years (2017-2020), overall gear representation in the sampled records was relatively low, and bottom longline accounted for a modest share of observations, while handline and troll line contributed only minor proportions. Entering the 2020-2021 period, a notable increase in bottom-longline records was observed, reaching approximately 16% of the annual records, whereas other gear types remained at very low levels (<1%). The highest contribution of bottom longline occurred during 2022-2023, accounting for approximately 15.3-17% of total annual records. In 2024, a shift in gear-use patterns was observed, characterized by a decline in bottom-longline representation to about 11.3%, accompanied by increased contributions from other gears, particularly boat liftnet, which reached approximately 3.1%.

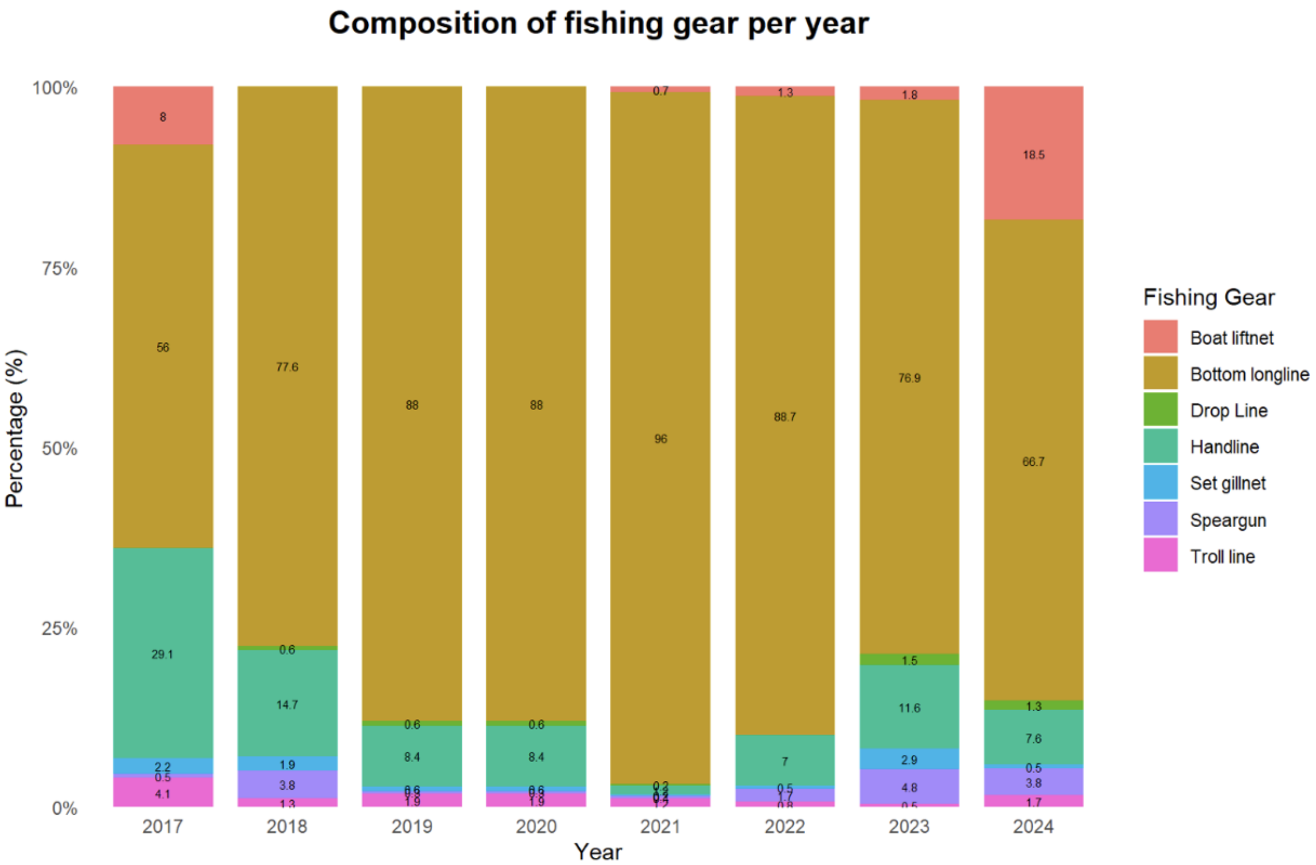

Figure 4. Graph of fishing gear utilization for *Lutjanus malabaricus* in Saleh Bay, Sumbawa, West Nusa Tenggara Province, Indonesia (2017-2024)

Overall, bottom longline accounted for the largest proportion of sampled records across the study period, followed by handline, boat lift-net, speargun, set gillnet, troll line, and dropline, indicating that bottom longline consistently represented the most frequently recorded fishing gear in Saleh Bay.

The dominance of bottom longline in the sampled records may be related to its operational characteristics and accessibility to small-scale fishers. This gear is relatively simple to operate and consists of long mainlines equipped with numerous hooks deployed over demersal habitats suitable for *L. malabaricus* (Lima et al. 2025). The proportion of bottom longline records increased sharply and peaked around 2021 before declining in 2024, although it remained more prevalent than other gear types (Figure 4).

In contrast, other fishing gears (including handline, dropline, set gillnet boat lift-net, troll line, and speargun) contributed smaller proportions to the sampled gear composition. Although some degree of fishing-gear diversification has been observed since 2017, this diversification has not altered the overall pattern in which bottom longline remained the dominant gear in the sample records. It is important to emphasize that the reported percentages represent the proportion of sampled records rather than standardized fishing effort, catch volume, or CPUE. Consequently, differences in gear representation should be interpreted descriptively and not as direct indicators of relative fishing efficiency or productivity.

Contrasting patterns have been reported in other regions. For example, Dafiq et al. (2019) found that gillnets were more effective than bottom longlines in catching red snapper in Indramayu Waters, West Java, underscoring that gear performance is context-specific and influenced by environmental conditions and local fishing practices.

Within the context of this study, temporal variation in gear representation appears to coincide with changes in SPR dynamics. Periods characterized by higher representation of bottom longline in the sampled records were associated with lower SPR values, whereas periods with relatively lower bottom-longline dominance corresponded with higher SPR estimates. However, this relationship should be interpreted strictly as an association based on temporal patterns. Due to the absence of independent data on fishing effort, CPUE, or compliance levels, this study does not establish a causal relationship between specific gear types and changes in stock status.

Bottom longline was consistently identified as the dominant fishing gear targeting red snapper in Saleh Bay, concentrating a substantial portion of recorded fishing activity within a single gear category. While existing Governor Regulations in West Nusa Tenggara provide management measures, including minimum size limits and gear arrangements, the observed SPR trends highlight the importance of strengthening implementation and monitoring overall fishing pressure. Priority actions include reinforcing compliance with minimum size regulations to maintain the Lc>Lm condition and improving oversight of aggregate fishing effort, rather than attributing stock fluctuations to any single gear type.

In conclusion, this study presents a multi-year assessment of the stock status of red snapper (*Lutjanus malabaricus*) in Saleh Bay, West Nusa Tenggara, using a Length-Based Spawning Potential Ratio (LBSPR) approach under data-limited conditions. Analysis of 11,945 individuals collected during 2017-2024 indicates growth parameters of $L\infty$: 85.56 cm and K: 0.22 $year^{-1}$, with length at first capture (Lc: 47.26 cm) exceeding length at first maturity (Lm: 45.37 cm), suggesting that most individuals had the opportunity to spawn at least once before capture. However, the SPR declined markedly from 0.38 in 2017 to below 0.21 in 2024, indicating a shift in stock status from under-exploited toward fully exploited conditions. Bottom longline was consistently identified as the dominant fishing gear, concentrating fishing pressure on a single gear type. Although provincial regulations have established minimum size limits and fishing gear controls, the declining SPR trend suggests the need to strengthen implementation, particularly through enforcement of minimum size regulations (to maintain Lc>Lm) and improved control of bottom longline fishing effort. This assessment remains subject to limitations, including reliance on secondary length-frequency data, assumptions of logistic selectivity and steady-state conditions, and the absence of independent data on fishing effort, CPUE, and enforcement intensity. Therefore, integrating LBSPR with improved monitoring of fishing effort, gear-specific selectivity, compliance indicators, as well as socio-economic data and spatial analyses, is essential to support adaptive and precautionary management of red snapper fisheries in Saleh Bay.

ACKNOWLEDGEMENTS

The author gratefully acknowledges financial support from the Directorate General of Higher Education (DIKTI) through the 2025 Master's Thesis Research Scheme (PTM). The author also thanks the Marine and Fisheries Office (DKP) of West Nusa Tenggara Province, Indonesia, and the Sustainable Fisheries Science Forum (FIP2B) of West Nusa Tenggara Province for providing data, technical support, and access throughout the research process. Appreciation is also extended to all field teams and individuals involved in data collection and analysis.

REFERENCES

Agustina S, Natsir M, Boer M, Purwanto, Yulianto I. 2018. Parameter populasi kerapu sunu (*Plectropomus* sp.) dan opsi pengelolaannya di Perairan Karimunjawa. Mar Fish 9 (2): 119-131. https://doi.org/10.29244/jmf.9.2.119-131.

Ault JS, Smith SG, Luo J, Monaco ME, Appeldoorn RS. 2008. Length-based assessment of sustainability benchmarks for coral reef fishes in Puerto Rico. Environ Conserv 35 (3): 221-231. https://doi.org/10.1017/S0376892908005043.

Ayuningtyas OA. 2024. Strategi Pengelolaan Perikanan Kakap Merah (*Lutjanus malabaricus*) di Pelabuhan Probolinggo dengan Basis Penangkapan WPPNRI 718. [Thesis]. Institut Pertanian Bogor, Bogor, Indonesia. [Indonesian]

Aziz KA, Muchsin I, Boer M. 1992. Kajian Dinamika Populasi Ikan-Ikan Niaga Utama di Perairan Pantai Barat Bengkulu. [Unpublished Research Report]. Fakultas Perikanan IPB, Bogor. [Indonesian]

Brooks EN, Powers JE, Cortés E. 2010. Analytical reference points for age-structured models: Application to data-poor fisheries. ICES J Mar Sci 67 (1): 165-175. https://doi.org/10.1093/icesjms/fsp225.

Charles AT. 2001. Sustainable Fishery Systems. Blackwell Science Ltd., Oxford, United Kingdom.

Dafiq AH, Anna Z, Rizal A, Suryana AAH. 2019. Analisis bioekonomi sumber daya ikan kakap merah (*Lutjanus malabaricus*) di perairan Kabupaten Indramayu, Jawa Barat. Jurnal Perikanan Kelautan 10 (1): 8-19. [Indonesian]

Edwards RRC, Shaher S. 1991. The biometrics of marine fishes from the Gulf of Aden. Fishbyte 9 (2): 27-29.

Effendie MI. 1997. Biologi Perikanan. Yayasan Pustaka Nusatama, Yogyakarta. [Indonesian]

Froese R, Binohlan C. 2000. Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length-frequency data. J Fish Biol 56 (4): 758-773. https://doi.org/10.1111/j.1095-8649.2000.tb00870.x.

Froese R. 2005. Life-history Strategies of Recent Fishes: A Meta-Analysis. [Dissertation]. Christian-Albrecht University of Kiel, Kiel, Germany.

Grimes CB. 1987. Reproductive biology of the Lutjanidae: A review. In: Polovina JJ, Ralston S (eds). Tropical Snappers and Groupers: Biology and Fisheries Management. Westview Press, Boulder and London.

Gulland JA. 1971. The Fish Resources of the Ocean. Fishing News (Books) Ltd., Surrey, England.

Herianti I, Djamal R. 1993. Dinamika Populasi Kakap Merah (*Lutjanus malabaricus*) di perairan utara Laut Jawa. Jurnal Penelitian Perikanan Laut 78: 18-25. [Indonesian]

Hilborn R, Ovando D. 2014. Reflections on the success of traditional fisheries management. ICES J Mar Sci 71: 1040-1046. https://doi.org/10.1093/icesjms/fsu034.

Hilyana S, Gigentika S, Kartawijaya T, Hernawati, Damayanti AA, Waspodo S, Amir S. 2023. Grouper and snapper fisheries dynamics in Sumbawa Waters, Indonesia, as a database for sustainable fisheries management. AACL Bioflux 16 (3): 1220-1230.

Hordyk A, Ono K, Valencia S, Loneragan N, Prince J. 2015. A novel length-based empirical estimation method of spawning potential ratio (SPR) and tests of its performance for small-scale, data-poor fisheries. ICES J Mar Sci 72: 217-231. https://doi.org/10.1093/icesjms/fsu004.

Lagler KE, Bardach JE, Miller RR. 1962. Ichthylogy. John Wiley and Sons, New York.

Lavin MF, Boaden A, Newman SJ, Wakefield CB, Meekan MG, Skepper CL, Currey-Randall LM, Taylor BM, Williams AJ, Halford A. 2021. Minimum size limits and the reproductive value of numerous young, mature female fish. Proc R Soc B 288: 20202714. https://doi.org/10.1098/rspb.2020.2714.

Lima YL, Sine KG, Kangkan AL. 2025. Komposisi jenis ikan hasil tangkapan rawai dasar yang dioperasikan nelayan di Desa Oenggae, Kecamatan Pantai Baru, Kabupaten Rote Ndao. Jurnal Ilmiah Bahari Papadak 6 (1): 93-104. [Indonesian]

Mathews CP, Samuel. 1991. Growth, mortality, and length-weight parameters for some Kuwaiti fish and shrimp. Fishbyte 9 (2): 30-33.

Mildenberger TK, Taylor MH, Wolff M. 2017. TropFishR: An R package for fisheries analysis with length-frequency data. Methods Ecol Evol 8: 1520-1527. https://doi.org/10.1111/2041-210X.12791.

Newman SJ, Cappo M, Williams D. 2000. Age, growth, mortality rates, and yield estimates of tropical red snappers (*Lutjanus* spp.) from the central Great Barrier Reef. Fish Res 48: 1-14. https://doi.org/10.1016/S0165-7836(00)00115-6.

Nikolskii GV. 1969. Theory of Fish Population Dynamics as the Biological Background for Rational Exploitation and Management of Fishery Resources. Oliver and Boyd, Edinburgh.

Nurulludin N, Prihatiningsih W. 2014. Parameter populasi dan tingkat eksploitasi ikan kuniran (*Upeneus sulphureus*) di Laut Jawa. Bawal 6 (3): 163-168. https://doi.org/10.15578/bawal.6.2.2014.103-110. [Indonesian]

Oktaviyani OS. 2018. Mengenal marga *Lutjanus*, salah satu komoditas unggulan dalam perikanan tangkap. Oseana 43: 29-39. https://doi.org/10.14203/oseana.2018.Vol.43No.3.61. [Indonesian]
Pauly D. 1980a. A Selection of Simple Methods for the Assessment of Tropical Fish Stocks. FAO Fish, Rome.
Pauly D. 1980b. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J Cons 39: 175-192. https://doi.org/10.1093/icesjms/39.2.175.
Prihatiningsih, Kamal MK, Kurnia R, Suman A. 2020. The spawning season, growth, and mortality of humpback red snapper (*Lutjanus gibbus* (Forsskål, 1775)) in the southern Banten waters, Indonesia. Bioflux 13 (2): 1079-1089.
Prihatiningsih, Wahyuningsih. 2012. Pertumbuhan, umur dan mortalitas ikan kakap merah (*Lutjanus malabaricus*) dari perairan Kotabaru (Pulau Laut), Kalimantan Selatan. Proceeding National Seminar Capture Fisheries. Manado, 30-31 October 2012. [Indonesian]
Prince J, Victor S, Kloulchad V, Hordyk A. 2015. Length-based SPR assessment of eleven Indo-Pacific coral reef fish populations in Palau. Fish Res 171: 42-58. https://doi.org/10.1016/j.fishres.2015.06.008.
Rapi NL, Djumanto, Murwantoko. 2023. Dinamika populasi ikan kakap merah (*Lutjanus malabaricus*) di Perairan Pinrang. Jurnal Penelitian Perikanan Indonesia 28 (4): 177-185. https://doi.org/10.15578/jppi.28.4.2022.177-185.
Restianingsih YH, Amri K. 2018. Biological aspects and food habits of skipjack tuna (*Katsuwonus pelamis*) in Flores Sea and adjacent waters. Bawal 10 (3): 187-196. https://doi.org/10.15578/bawal.10.3.2018.187-196.
Santika L, Sarjan M. 2025. Dimensi filsafat dalam pengelolaan sumber daya alam: Kajian peran manusia dalam menjaga keseimbangan lingkungan. Lambda Jurnal Pendidikan MIPA dan Aplikasinya 5 (1): 54-60. https://doi.org/10.58218/lambda.v5i1.1205. [Indonesian]
Scarcella G, Angelini A, Armelloni EN, Costantini I, De Felice A, Guicciardi S, Leonori I, Masnadi F, Scanu M, Coro G. 2022. The potential effects of the COVID-19 lockdown and the following restrictions on the status of eight target stocks in the Adriatic Sea. Front Mar Sci 9: 920974. https://doi.org/10.3389/fmars.2022.920974.
Sparre P, Venema SC. 1998. Introduction to Tropical Fish Stock Assessment. FAO, Rome.
Suyasa IN, Sari AFR, Agustina S, Prasetia R, Suharti R, Ruchimat T, Wiryawan B, Yulianto I. 2023. Length-based stock assessment of the Pacific yellowtail emperor in southern Sulawesi, Indonesia. Fish Aquat Sci 26: 216-223. https://doi.org/10.47853/FAS.2023.e18.
Then AY, Hoenig JM, Hall NG, Hewitt DA. 2015. Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. ICES J Mar Sci 72 (1): 82-92. https://doi.org/10.1093/icesjms/fsu136.
Udupe KS. 1986. Statistical method of estimating the size at first maturity in fishes. Fishbyte 4: 8-10.
Wahyuningsih, Prihatiningsih, Ernawati T. 2013. Parameter populasi ikan kakap merah (*Lutjanus malabaricus*) di perairan Laut Jawa bagian timur. Bawal 5 (3): 175-179. https://doi.org/10.15578/bawal.5.3.2013.175-179. [Indonesian]
Wibisono A, Destryana RA, Ghufrony A. 2021. Pelatihan Partial Least Squares (PLS) bagi mahasiswa. Jurnal Abdiraja 4: 24-30. https://doi.org/10.24929/adr.v4i2.1542. [Indonesian]
Wootton RJ. Energetics of reproduction. In: Tytler P, Calow P (eds). Fish Energetics: New Perspectives. Springer, Dordrecht.