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Length-based stock assessment for Malabar blood snapper in Makassar Strait-Indonesia: Status and recommendation for sustainability

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A R T I C L E I N F O

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A B S T R A C T

Snapper is one of the important groups of fish in demersal-reef fisheries in Indonesia. Malabar blood snapper *Lutjanus malabaricus* is the main and dominant species in snapper fisheries, making it the major target of fishing activities in Indonesia, including in Makassar Strait. Current management is still limited based on aggregate stocks (i.e., TAC for demersal-reef fish, snapper is included in this group), to reduce uncertainty, focused management is needed on specific fish stocks. The length-based approach for stock assessment was conducted under a data-limited situation. This study revealed the character of *L.malabaricus* in the Makassar Strait based on life history parameters as the categories of slow growth, late maturity and long-lived species. The condition of *L. malabaricus* has indicated a decrease in stocks based on several length models (LBSPR, LBB and LBI). A simulation of determining reference points for setting length size as a management intervention has been carried out with the scenarios: BaU (L_c=33.5 cm), Limit (L_c=L_{m50}=47.2 cm), and Target (L_c=$L_{c\text{-}opt}$ =57 cm), but F is constant (F=0.5, as the current F). The BaU scenario performed it is difficult for *L.malabaricus* to achieve sustainability. In the limit scenario, MSY could be achieved by maintaining F=0.5 and SPR at 30% with L_c=L_{m50}. In the target scenario, there is no sustainability risk with F==$F_{SPR40\%}$=0.5 and L_c=$L_{c\text{-}opt}$. It can be said that the limit reference point is determined at SPR 30% with L_c=L_{m50}, while the target reference point is at SPR 40% with L_c=$L_{c\text{-}opt}$.

1. Introduction

Snapper is one of the important groups of fish in demersal-reef fisheries in Indonesia. This fish group is a valuable marine biota, high value, high demand globally for export commodities (Dimarchopoulou et al., 2021; Ernawati and Budiarti, 2020; Halim et al., 2020) and has an important role in supporting the livelihoods and food security of many local, small-scale fisheries and industrial fisheries in Indonesia (Amorim et al., 2019; Fry and Milton, 2009; Halim et al., 2020). One of the main and important species of tropical snapper in Indonesia is Malabar blood snapper *Lutjanus malabaricus* (MBS). MBS is distributed from shallow waters (<10 m) associated with coral reefs to a depth of more than 100 m (Allen, 1985; Ernawati et al., 2021; Ernawati and Budiarti, 2020; Newman, 2002). Due to the high quality and the highest selling price among other snapper species, MBS is the major catch target for almost all Indonesian marine waters, including in the Makassar Strait. MBS is recorded as the dominant species among 100 species landed in Indonesian snapper-grouper fisheries (Wibisono et al., 2019). The character of this species as a deep-sea fish whose growth is slow, long-lived and late in maturity, makes it vulnerable to overfishing (Amorim et al., 2019; Fry et al., 2006; Newman et al., 2016). The risk of overfishing is getting bigger with the market preferring "plate-size" fish (Wibisono et al., 2021). That size includes the category of juvenile fish for MBS that have not yet reached maturity.

The Makassar Strait contributes around 80% of the snapper fishery of the entire area in FMA 713. Snapper fishing activities in Makassar Strait are a wide range of vessel sizes but are mostly carried out by small boats (≤10 GT). It is extensively exploited using a variety of fishing gears

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dominated by bottom-longlines and drop-lines or hand-line (Ernawati and Budiarti, 2020; Wibisono et al., 2021). Management of snapper fishery in Indonesia based on the total allowable catch (TAC) approach is carried out per aggregate (for example, snapper is included in the TAC aggregate for demersal-reef fish) in each Fisheries Management Area (FMA), due to data-limited fisheries. Through the Ministry of Marine Affair and Fisheries (MMAF) Regulation 19/2022, demersal and reef fish including snappers in the Makassar Strait as a part of FMA 713, have been determined to be over-exploitation. This condition drives the need to improve fisheries management which is more appropriate to overcome the problem of overfishing.

The most fish stocks in the world are data-limited and deficient in the comprehensive information necessary to assess biomass and fishing mortality relative to reference points (Costello et al., 2012). This condition applies in tropical and artisanal fisheries which experiences a lack of data for historical catch, fishing effort and population abundance, makes assessment challenging, often with a lack of manageable impacts (Fenner, 2012; Stobutzki et al., 2006), including snapper fisheries in the Makassar Strait, Indonesia (Dimarchopoulou et al., 2021). Given the limited data available for conducting stock assessments to improve suitable fisheries management, length-based models are the best choice for a reliable and cost-effective decision making-tool (Hilborn and Ovando, 2014; Wibisono et al., 2021). Data-limited assessment models are increasingly being used for management needs, reporting the regional fisheries status of several stocks as well as assessing the status of individual stocks with limited data as input for management decision making (Chong et al., 2020; Dowling et al., 2015). In data-limited, using length data is an alternative for estimating life history parameters (e.g., growth, longevity, length at maturity and natural mortality) (Ault et al., 2019). This method is effective and widely used in tropical waters where otolith rings to determine annual growth are unclear (Hordyk et al., 2015). The life history parameters are important as input for many length-based models which are sustainability models in stock assessment.

The need to carry out effective management of certain specific stocks, in this case MBS, will assist in developing a management model for sustainable fish exploitation. A management focus on specific fish stocks compared to the aggregate could reduce uncertainty in management measures. Therefore, this research carries out some length-based models to obtain biological reference points that will be useful in determining the condition of MBS resources and steps for their management. This research aims to assess and understand the stock status and determining biological reference points based on life history parameters, to ensure the sustainability of MBS fisheries in the Makassar Strait, as well as provide recommendations regarding fisheries management options. Finally, this is useful for supporting area-based fisheries management of MBS fishery in Makassar Strait specifically and FMA 713 in general.

2. Material and methods

2.1. Data collection

The fish length data have been widely used for stock assessments of both demersal and pelagic fish (Baldé et al., 2019; Barua et al., 2023; Çiloğlu, 2023; Dutta, 2023; Hirota et al., 2022; Santos et al., 2021; Sarr et al., 2023; Tirtadanu et al., 2023; Turan, 2021). The recording of fish length (total length TL) data was carried out daily every month from each ship or boat which landed the catch at the base of the landing locations. Data collection on the total fish length was carried out from January 2018 to December 2021 (n = 77436). Details the distribution of fish sample numbers by months and years are presented in Table 1. Data was collected from various fishing gears (handline, bottom-longline, traps, gillnet and mix gears) and conducted at fish landing sites in Balikpapan, Bontang, Sangatta, Barru Takalar and Makassar (Fig. 1). The grid map (1° x 1°) is used to confirm the fishermen regarding fishing ground (FG) when catching fish. The dominant fish length data was obtained from bottom-longline and handline which are the main fishing gears for MBS fisheries in the Makassar Strait. These two fishing gears contribute approximately 69.68% and 23.79%, respectively to the total length data from all types of fishing gear. Traps, gillnet and mix gears represented 2.55%, 1.80% and 2.22%, respectively.

Table 1
Sample sizes distribution of Malabar Blood Snapper *L.malabaricus* samples over months and years.

	Sample Sizes Distribution			
	2018	2019	2020	2021
Jan	1054	1208	1139	1105
Feb	1829	1541	1016	1764
Mar	2037	1609	1766	3500
Apr	2511	1244	1347	2494
May	1759	1321	1125	1001
Jun	1228	1287	1211	1026
Jul	1334	1623	1078	979
Aug	1221	1355	1456	1092
Sep	1262	1336	1519	1030
Oct	2896	2080	2511	1063
Nov	2439	2735	3626	1068
Dec	1512	2622	1572	905
Total	**21082**	**19961**	**19366**	**17027**

Collecting samples for maturity analysis was carried out from November 2020 to October 2021. A total of 972 fish samples of *L. malabaricus* were obtained, consisting of 551 females and 421 males. Female samples were used for analysis and were sufficient in number to carry out maturity analysis. In several previous studies, it was reported that a total samples of groundfish including snapper, was determined to be less than 500 individuals for maturity analysis (Bhakta et al., 2024; Fernandes et al., 2022; Kunishima et al., 2021; Santos et al., 2021; TenBrink and Helser, 2021; Uehara et al., 2018; Wang et al., 2020) and the analysis results were relatively fitted. Macroscopic analysis was carried out on female ovaries to determine the level of maturity. The observation procedure, which is given following Brown-Peterson et al. (2011) and Santos et al. (2021).

2.2. Data analysis

2.2.1. Lengths distribution

Differences in mean length for each year were examined using one-way analysis of variance (ANOVA). Length data were log transformed to fulfill the ANOVA assumption which data were normally distributed. This analysis was carried out with a significance level of 95% (α<0.05).

2.2.2. Length at maturity

The length at maturity consists of 50% (L_{m50}) and 95% (L_{m95}) of mature fish or according to reproductive conditions. The length at 50% (L_{m50}) maturity for female fish, or a mean length at maturity, is defined as the length of 50% the all individuals in population has reached a maturity level. The L_{m50} was estimated using logistic formula (King, 2007):

$$P = \frac{1}{(1 + \exp \quad [-b(L - L_{m50})])} \quad (1)$$

where P is proportion of mature individuals by length L and b is as a slope of the curve. L_{m95} was obtained by determining from the plot curve intersection between the proportions of mature (*y* axis) at the 95% level and the length (*x* axis).

This logistic model was fitted by maximizing likelihood of binomial distribution. The analysis was conducted in Microsoft Excel using "SOLVER" tool.

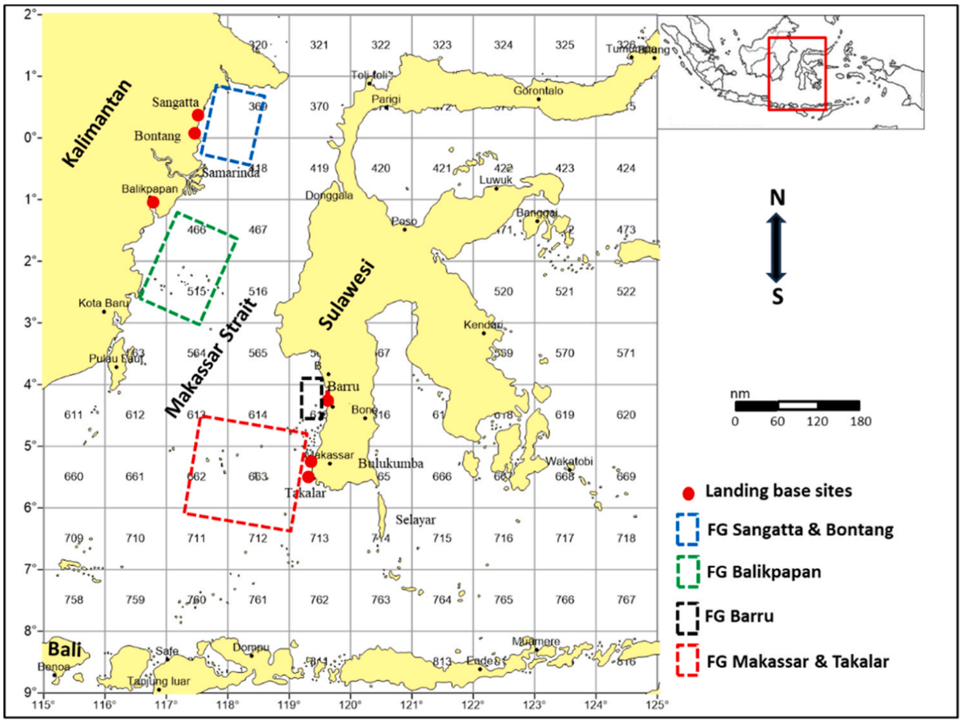

Fig. 1. Map of Makassar Strait with grid (1° x 1°) showing its size and position in the Indonesia archipelagic waters (red square line), the landing sites (solid dot red circle), and the fishing ground (FG) of each landing site (square dashed line).

2.2.3. Growth and mortality

2.2.3.1. Growth. Growth parameters were analyzed using the von Bertalanffy growth function (VBGF) model (Ault et al., 2014; Fry and Milton, 2009):

$$L(t) = L_\infty\left(1 - e^{-K(t-t_0)}\right) \quad (2)$$

where $L(t)$ is the total length at age t, L_∞ is asymptotic total length of MBS, K is growth coefficient (year $^{-1}$) and t_0 is the theoretical age of fish at zero length. The analysis was carried out using quarterly length frequency data from the period between 2018 and 2021. The growth parameters were estimated by the open-source software 'R' with the R'TropFishR' package which implemented length-frequency analysis with a genetic algorithm (ELEFAN GA), including the VBGF method with a growth curve model optimization approach (Mildenberger et al., 2017). The t_0 was calculated following the empirical equation by Pauly (Pauly, 1983):

$$\text{Log}(-t_0) = (-0.3922) - 0.2752 \log (L_\infty) - 1.038 \log (K) \quad (3)$$

2.2.3.2. Mortality. Natural mortality M is difficult to accurately estimate and is calculated based on available life history/environmental parameters (Kenchington, 2014). Therefore, M was calculated using the following empirical formula (Hoenig, 1983; Pauly, 1980; Then et al., 2015) and life history formula (Zhang and Megrey, 2006):

$$M = 5.109/t_{max} \quad (4)$$

(Then et al., 2015)

$$M = \frac{\beta K}{e^{K(Ci\times t_{\max}-t_0)} - 1} \quad (5)$$

(Zhang & Megrey, 2006)

$$M = exp\,(1.46 - 1.01 \times ln(t_{max})) \quad (6)$$

(Hoenig, 1983)

$$log\ M = -0.0066 - 0.279\ log\ L_\infty + 0.654\ logK + 0.463 \log T \quad (7)$$

(Pauly, 1980)

where, M is the natural mortality, $Ci = 0.440$ as the demersal fishery, t_{max} maximum age, T as the annual average of water temperature, and coefficient growth from the length-weight relationship β assumed as 3.0.

Total mortality Z was calculated using a length-converted catch curve (LCCC) formula (Sparre & Venema, 1998):

$$Ln\frac{C(L1, L2)}{\Delta t(L1, L2)} = C - Zt\frac{L1 + L2}{2} \quad (8)$$

where, Z is total mortality, C as the frequency of total length class, $L1$ as fish length at age t, $L2$ as fish length at age $t + \Delta t$, and Δt as average times for fish to grow from $L1$ to $L2$.

The fishing mortality F was estimated with a simple equation (Ault et al., 2019; Sparre and Venema, 1998):

$$F = Z - M \quad (9)$$

2.2.4. Reference points

The reference points as the stock status of fish resources are a basic need for fisheries management input. We approached the exploitation rate E, Spawning Potential Ratio (SPR), length-based Bayesian biomass estimation method (LBB) and length-based indicator (LBI) as reference points.

2.2.4.1. Exploitation rate. The exploitation rate E is the ratio of the number of deaths of individual fish by fishing to the total number of deaths from various causes. The E was calculated using F is divided by Z (Pauly, 1983):

$$E = \frac{F}{Z} \quad (10)$$

The stock is in equilibrium when the E value is around 0.5. This follows from the assumption that catch potential will be optimal if there is equality between natural mortality and fishing-related mortality (Gulland, 1971). Based on this understanding, the provisions are:

- $E < 0.5$, stock is underexploited;
- $E > 0.5$, stock is overexploited; and
- $E = 0.5$, stock is in balance

2.2.4.2. Spawning potential ratio (SPR). SPR can be understood as the condition of a fish resource that has been exploited causing a reduction in the number of fish including egg-laying brood-stock, due to the fishing mortality, resulting in a reduction in total egg production. SPR is an index of the relative reproductive rate of an exploited stock, and is generally used as a reference for fisheries (Hordyk et al., 2015). The SPR principle is the ratio of reproductive potential in conditions of no fishing (virgin stock) assumed to have 100% SPR ($SPR_{100\%}$) to the reduction in reproductive potential caused by fishing mortality which can reduce $SPR_{100\%}$ to $SPR_{x\%}$ (Prince et al., 2014). The assumptions for SPR estimation are knife-edge models for selectivity and length at maturity (Hordyk et al., 2014). SPR required input from life history parameters and length data, according to the formula from Hordyk et al., (Hordyk et al., 2014):

$$SPR = \frac{\sum (1-y)^{(M/K[(F/M)+1])} \widetilde{L}_y^b}{\sum \left(1-\widetilde{L}_y\right)^{M/K} \widetilde{L}_y^b} \text{ for } y_m \le y \le 1 \quad (11)$$

where y is standardized age of individuals, $\widetilde{L}_y$ is fish length, y_m is standard age appropriating with length at maturity, and b is exponent close to 3 ($b \approx 3$).

Considering the uncertainties in the life history parameters was an important factor affecting SPR analysis. Therefore, it was carried out with deterministic (without uncertainty factors) and stochastic (with uncertainty factors) approaches. The sensitivity analysis for stochastic was performed using various possible combinations of life history parameter values, i.e., L_∞, K, M, M/K, L_{m50} and L_{m95} as sources of uncertainty. We used a Monte Carlo by running a thousand iterations to characterize the uncertainty.

The limit reference point (LRP) and target reference point (TRP) of SPR are 20% and 40% (generally considered), respectively (Bunnell and Miller, 2005; Hordyk et al., 2015). SPR decision provisions are SPR<LRP (over-exploited), LRP<SPR<TRP (optimal) and SPR>TRP (under-exploited) (Amorim et al., 2019).

2.2.4.3. Length-based Bayesian biomass (LBB). The length-based Bayesian biomass estimation method (LBB) is an approach determining stock status in data-limited situations and uses length frequency (LF) data (Froese et al., 2018). All related parameters and annual LF are analyzed simultaneously with a Bayesian Monte Carlo Markov Chain (MCMC) approach (Dimarchopoulou et al., 2021; Froese et al., 2018). MCMC is a method in statistics used to generate random samples from complex probability distributions. In the context of Bayesian analysis, this method is useful for obtaining the posterior distribution of the parameters of a statistical model. Bayesian analysis with MCMC makes it possible to combine prior information (before observing the data) and likelihood information to produce a posterior distribution of parameters. This posterior distribution reflects the degree of uncertainty appropriate to the observed data. Uncertainty is always a major issue in the context of data limited in fisheries, so LBB with Bayesian MCMC is a good choice to accommodate this deficiency. This is reflected in LBB which applies a Bayesian stock assessment model approach to fit observed the proportions of lengths (Froese et al., 2018).

In LBB, the asymptotic length L_∞ is not a necessary input, because it can be estimated with a Bayesian model. The default prior for L_∞ is determined by least squares regression of fully selected LF data collected over several years. Alternatively, if a good L_∞ estimated from independent research is available, that value can be presented by the user (Froese et al., 2019). We used four years LF data and life history parameters (L_∞, relative natural mortality M/K, and length at maturity 50% level L_{m50}) which were resulted from this study to get results more accurate.

The LBB outputs were analyzed using script which can be found online at http://oceanrep.geomar.de/43182/ and run in R program. The steps in carrying out a complete estimation refer to Froese et al. (Froese et al., 2018). The LBB assumes that the growth of length data follows the von Bertalanffy formula, as is presented in Eq. (2). In the case of fish fully selected by fishing gear, the curvature of the catch on the length curve is the total mortality Z relative to K expressed in the Z/K function, so the curve is expressed by the equation (Quinn & Deriso, 1999):

$$N_L = N_{L_{start}} \left(\frac{L_\infty - L}{L_\infty - L_{start}}\right)^{\frac{Z}{K}} \quad (12)$$

where N_L is number of individual fish that survive to length L, N_{Lstart} is the number of fish at the length L_{start}, and L_{start} is full selectivity of fishing gear.

The fishing gear selectivity which assumed similar to a trawl can be estimated as the formula:

$$S_L = \frac{1}{(1 + e^{-\alpha(L - L_c)}} \quad (13)$$

where S_L is the fraction of fish that are retained by the fishing gear at length L, L_c is defined the length of 50% fish caught by the gear, and α is description a steepness of the ogive (Sparre and Venema, 1998).

Fitting the parameters of the selection ogive L_∞, L_c, α, M/K and F/K are estimated by two functions (Froese et al., 2018):

$$N_{L_i} = N_{L_{i-1}} \left(\frac{L_\infty - L_i}{L_\infty - L_{i-1}}\right)^{\frac{M}{K} + \frac{F}{K} S_{L_i}} \quad (14)$$

$$C_{L_i} = N_{L_i} * S_{L_i} \quad (15)$$

where N_{Li} is number of individual fish on length class L_i, N_{Li-1} is the number of fish on the length class before L_i, and C_{Li} is the number of individuals vulnerable to the fishing gear and proportionally reflected in the catch.

The framework to analyze the stock status from L_∞, L_c, M/K and F/K was estimated by two equations. First, the optimum length L_{opt} is the maximum of the unexploited cohort biomass that can be obtained from:

$$L_{opt} = L_\infty \left(\frac{3}{3 + \frac{M}{K}}\right) \quad (16)$$

Second, the length at first capture $L_{c\text{-}opt}$ that maximizes catch and biomass at a certain fishing pressure and provides L_{opt} as the mean catch length can be obtained (Froese et al., 2016):

$$L_{c\_opt} = \frac{L_\infty \left(2 + 3\frac{F}{M}\right)}{\left(1 + \frac{F}{M}\right)\left(3 + \frac{M}{K}\right)} \quad (17)$$

Finally, a relative biomass depletion index for the exploited population B/B_0 is then analyzed using the following equation (Beverton and Holt, 1966):

$$\frac{B}{B_0} = \frac{\frac{CPUE'}{R}}{\frac{B'_0 > L_c}{R}} \quad (18)$$

CPUE'/R is the catch per unit effort index, resulting from the index of yield per recruit which is presented as a function of L_c/L_∞, F/K, M/K, and relative fishing mortality F/M. While, $B'_0 > L_c/R$ shows the relative biomass in the exploited population phase if there is no fishing.

The LBB model will provide reference points such as B/B_0, B/B_{MSY} and $L_c/L_{c\text{-}opt}$. The grouping of stock status with parameters B/B_0 refers to Dimarchopoulou et al. (2021) in line with SPR to the risk of overexploitation:

- High risk: $B/B_0 < 0.313$
- Medium risk: $0.313 \le B/B_0 < 0.50$
- Small risk: $B/B_0 > 0.50$

And stock status based on B/B_{MSY} refers to Amorim et al. (2019):

- Over-exploited: $B/B_{MSY} < 0.8$
- Fully-exploited: $0.8 \le B/B_{MSY} \le 1.2$
- non-fully exploited/under-exploited: $B/B_{MSY} > 1.2$.

Further, $L_c/L_{c\text{-}opt} < 1$ is as an indicates that the stock condition is experiencing growth overfishing (Liang et al., 2020; Zhang et al., 2021).

2.2.4.4. Length-based indicator (LBI). The LBI method requires length composition data, life-history parameters and is based on the ratio of several parameters, including: length at first capture (L_c); length at maturity (L_{mat}); 25th percentile of length distribution ($L_{25\%}$); average length of the largest 5% of individuals caught ($L_{max5\%}$); and the proportion of individuals above the optimal harvest size (L_{opt})+10%. The LBI outputs were calculated using the codes LBIndicators.R is available on https://github.com/icestools-dev/ICES_MSY (ICES, 2018) and run in R. Stock status criteria of LBI based on Froese (Froese, 2004) which were three simple and easy to understand reference points, including P_{mat}, P_{opt} and P_{mega}, derived from an understanding of the biology and exploitation of demersal teleost fish stocks. The LBI points are: (i) P_{mat}—the proportion of fish caught that is larger than the length at maturity (L_{mat}); (ii) P_{opt}—proportion of fish larger than the length of optimal possible yield (L_{opt}); (iii) P_{mega}—no fish greater than L_{mega} (L_{opt} + 10%) should be caught and P_{mega} should be at least 30% in the population. Each LBI consists of a statistical ratio of measured length and a corresponding exploitation or life-history threshold.

Conditions for using size-based sustainability indicators (Froese, 2004):

1. The percentage of mature fish caught, ideally 100% as the reference target with the formula:

$$P_{mat} = \%\text{ of sample fish} > L_m \quad (19)$$

2. Percentage of fish caught at 10% around the optimum length for harvest with a target of reference 100%, based on the equation:

$$P_{opt} = \%\text{ fish sample} > L_{opt} - 10\%\text{ and }\%\text{ fish sample} < L_{opt} + 100\% \quad (20)$$

where the optimum length is usually a little greater than the length at first maturity and can be gained from empirical equation (Froese and Binohlan, 2000):

$$log\ (L_{opt}) = 1.053 \times log\ (L_m) - 0.0565 \quad (21)$$

3. Percentage of mega-spawners in the catch, with a target of 0%. If the catch reflects the age structure of the stock, 30–40% of mega-spawners in a catch likely represents a healthy population, with 20% being the lower limit. Mega-spawners less than 20% will be a matter of reducing the stock resilience. The formula used was:

$$P_{mega} = \%\text{ fish sample} > L_{opt} + 10\% \quad (22)$$

2.2.4.5. Kobe plot. Stock condition indicators were determined using the Kobe Plot approach to provide a thorough interpretation of the fishing mortality rate F to achieve sustainable results while maintaining sustainable spawning stock biomass. As a reference limit for determining the threshold for overfishing limit (*OFL*) is used $F/F_{LRP} = 1$ and $B/B_{LRP} = 1$ (Ault et al., 2022). If $F/F_{LRP} > 1$ then the stock faces the risk of overfishing from the fishing mortality rate, while $B/B_{LRP} < 1$ is defined as the reproductive stock capacity (i.e., SPR) experiencing a risk of decreasing the sustainability of the SPR. In the Kobe Plot mechanism, the F and SPR parameters were applied in accordance with current conditions (Business as Usual). The SPR 20% was used as inputs for the Kobe plot with considerations as commonly applied limit. This was observed to see whether the performance of MBS resources in the Makassar Strait is sufficient with 20% as a LRP related to the level of fishing mortality.

2.2.4.6. Sustainability analysis (Simulation). Sustainability analysis was performed by including the population metrics against the current level of fishing mortality, as a way to determine reference points in management (Ault et al., 2019, 2022). Assumptions used in the simulation process were: 1) fishing mortality F is constant, 2) constant recruitment with no variations, 3) length selection follows an asymptotic pattern, and 4) life history parameter values do not change in each scenario. The model simulation was run using as input the life history parameter values which produced in this study (growth, natural mortality, length at maturity, and fishing mortality) and b of length-weight relationship was assumed equal to 3. The two-population metrics used in the simulation were yield in weight ($Y_{\text{-}wg}$) from yield-per-recruit (YPR) and SPR which assumed to be equivalent to relative spawning biomass due to the recruitment assumption. The $Y_{\text{-}wg}$ analysis at time t was estimated following Ault et al. (2022). Model of numerical cohort was utilized to calculate $Y_{\text{-}wg}$ and SPR for all possible combinations of L_c, but F was constant at its current value (no management intervention). This facilitated determining size limitations in finding appropriate reference points and useful for the sustainability of MBS. There are several possible management options that can be implemented to reduce sustainability risks and maximize the production of MBS fish resources through three scenarios: (1) Business as Usual (BaU) is maintaining current S_{L50} or L_c; (2) Limit: increasing L_c level is equal to the mean length at maturity (L_m or L_{m50}); and (3) Target: increase the L_c level to $L_{c\text{-}opt}$ (LBB results). The three scenarios with different L_c values evaluated changes in population SPR and yield per recruit when reaching the maximum position (Y_{max}).

3. Results

3.1. Length distribution

The lengths of MBS from the commercial catches in Makassar strait ranged from 10.0 to 93.0 cmTL, in the period of 2018 – 2021. For combined length data of all years, the mean length was 47.68 ± 12.24 (mean ±SD) cmTL and mode in the length class was identified at 40 cmTL. Meanwhile, the means length for each year were various (Table 2) and significantly different ($\rho < 0.05$) based on ANOVA analysis. From

Table 2
The mean length of *L. malabaricus* from 2018 – 2021 in the Makassar Strait.

Years	Min (cm)	Max (cm)	Mode (cm)	Mean±SD (cm)
2018	10.50	93.00	39.00	45.61±12.72
2019	10.00	92.00	40.00	46.77±12.00
2020	18.00	90.00	43.00	49.14±12.25
2021	16.00	87.00	43.00	50.17±11.07
p-value (*with* $\alpha_{0.05}$)	*0.0000*			

2018–2021, it can be seen the length-sizes of fish in 2020 and 2021 tends to be greater than in 2018 and 2019 (Fig. 2).

3.2. Length at maturity

Collecting female specimens of MBS resulted in a length range between 21 and 72 cmTL and was divided into 18 length classes for estimating ogive maturity. Estimation of the proportion of maturity was conducted by proportioning the length group of mature individuals with the entire samples (combined mature and immature) in each length classes. The logistic function was used to adjust the mature proportion of individuals according to their length, and fitting the model was by maximizing likelihood of binomial distribution.

Maturity analysis of female MBS resulted in L_{m50} of 47.2 cmTL. Estimates of L_{m95} in which 95% of females have entered the matured stage, was 57.3 cmTL (Fig. 3). Based on the length at maturity L_{m50}, it is estimated that the number of fish caught is less than L_{m50} defined as immature fish. In this study, most of the fish caught each year is dominated by the immature (Fig. 2). The contribution of immature fish catches in the entire year period was 55.4% and this result is relatively the same as previous studies in all FMA 713, which obtained an immature catch of 57% and the worst was the catch of *L.malabaricus* in the Java Sea with a composition of 74% immature (Dimarchopoulou et al., 2021).

3.3. Growth and mortality

The MBS growth model was analyzed by combining length data both sexes. Quarterly total length frequency data were tracking by the mode-shifting pattern of the quarterly size distribution. The growth parameters were estimating by the von Bertalanffy equation and the ELEFAN-GA was used for fitting the model. Growth parameters analysis of MBS obtained the following parameter estimation values, length asymptotic L_∞ 83 cmTL and growth coefficient K 0.35 $^{\text{year}-1}$. The L_∞ and K of *MBS* from prior studies varied among locations (Table 3). The theoretical age when fish at zero length was t_0 −0.359, and the maximum age A_{max} was about 9 years in this area study.

Estimates of M from the equation of Then et al. (2015) and Hoenig (1983) for fish were higher than those resulting from Zhang and Megrey (2006). Calculations of M from Pauly's equation was much higher than to the other three analyses. The results of M based on four models are presented in Table 4. The M from the equation of Zhang and Megrey (2006) is used as an input for other models, considering the value is more realistic to the characteristic of *L. malabaricus* in Makassar Strait.

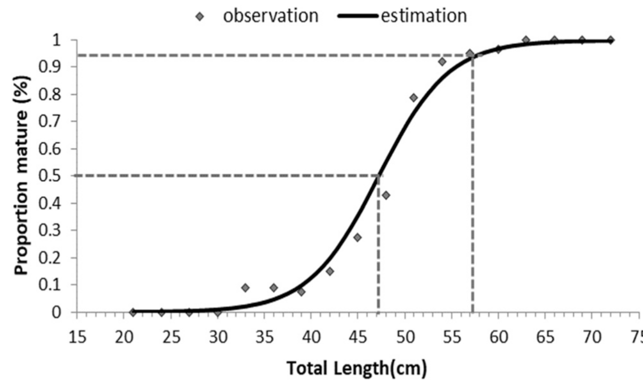

Fig. 3. The length of 50% and 95% (L_{m50}, L_{m95}) of mature female MBS or *L. malabaricus* in Makassar Strait. The gray dashed lines indicate the maturity levels of 50% and 95%, while the vertical dotted gray lines show maturity points.

Table 3
Growth parameters of Malabar blood snapper *L. malabricus* in different areas.

Locations	$K^{\text{year}-1}$	L_∞ (cm)	Methods	References
off the Pilbara coast	0.2	62.3	otolith	(Newman, 2002)
Arafura Sea	0.3	55.3	otolith	(Fry and Milton, 2009)
Eastern Java Sea	0.22	97.65	length-frequency	(Wahyuningsih et al., 2013)
Sinjai Coast	0.29	77.3	length-frequency	(Tirtadanu et al., 2018)
South China Sea	0.21	86.1	length-frequency	(Nurulludin et al., 2019)
Timor Sea	0.51	99.4	length-frequency	(Herwaty et al., 2023)
Makassar Strait	0.35	83	length-frequency	present study

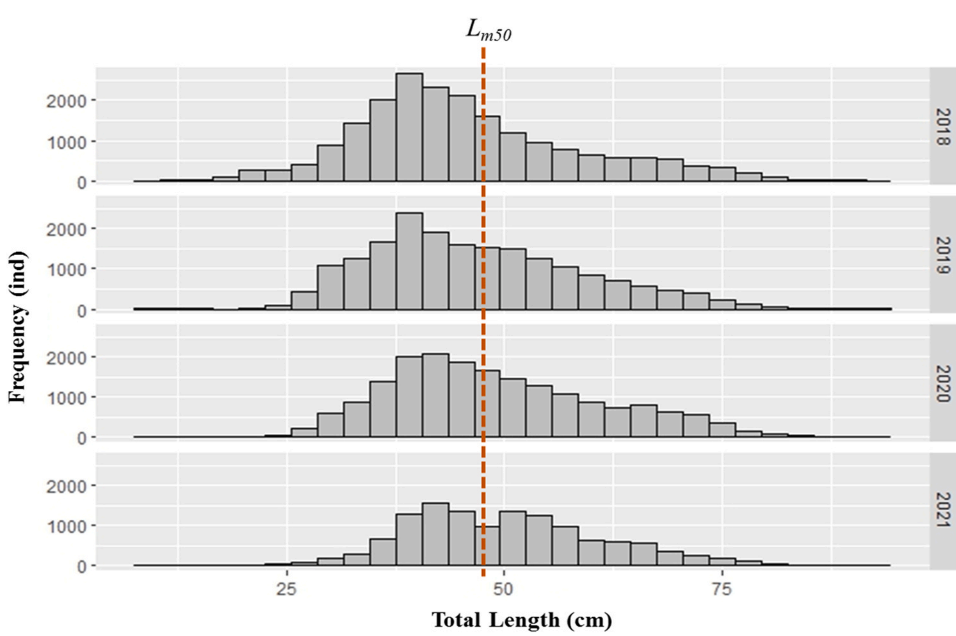

Fig. 2. Length distribution of *L.malabaricus* caught in the Makassar Strait every year from 2018 – 2021 and 50% length at maturity L_{m50} (vertical red dotted line).

Table 4
Estimates of natural mortality M for MBS based on the life history approach (Zhang & Megrey, 2006) and empirical approach (Pauly, 1980; Hoenig, 1983 for fish; Then et al., 2015).

Models	M (year^{-1})
Pauly (1980)	0.680
Hoenig (1983) for fish	0.468
Zhang and Megrey (2006)	0.297
Then et al. (2015)	0.567

In previous studies, snapper species in tropical waters provided M values smaller than 0.4 with an approach using length-based and otolith methods (Ault et al., 2008; Barua et al., 2023; Ernawati and Budiarti, 2020; Fry and Milton, 2009; Huynh et al., 2017; O'Malley et al., 2021; Newman, 2002; Newman et al., 2000). Therefore, this is a consideration for applying the M value from the Zhang and Megrey equation.

The estimation of total mortality Z using a length-converted catch curve (LCCC) resulted in a value of 0.8 ± 0.02 (Z ±SE) year $^{-1}$ which is figured in Fig. 4. Furthermore, with the simple equation Z minus M, the fishing mortality F could be defined and resulted in 0.50 year $^{-1}$.

3.4. Reference points

3.4.1. Exploitation rate (E)

The reference points representing of stock status were determined by exploitation rate E, SPR, LBB and LBI. The exploitation rate E of MBS which was calculated from fishing mortality F divided by total mortality Z, the value is 0.63, indicating higher than optimal $E = 0.5$. It shows that the level of exploitation has exceeded its optimal utilization.

3.4.2. Spawning potential ratio (SPR)

The result of E is also confirmed by the results of deterministic SPR (Fig. 5B) and stochastic SPR (Fig. 5C). The deterministic SPR per year are 0.11 (2018), 0.14 (2019), 0.19 (2020) and 0.15 (2021), respectively. The stochastic SPR has lower, upper and median limits with a boxplot display. Stochastic SPR results each year by looking at the median value obtained 0.14 (2018), 0.18 (2019), 0.24 (2020) and 0.19 (2021), respectively. It can be said that the results of the two SPRs are relatively the same and show a status smaller than the generally LRP (0.2) or over-exploited, excepted stochastic SPR in 2020. The selectivity of the LBSPR output obtained S_{L50} or $L_{c\text{-}50}$ and S_{L95} or $L_{c\text{-}95}$ ranged between 31.8 and 39.2 cmTL and 38.9–50.7 cmTL, respectively (Fig. 5A). It shows that mean length at capture significantly smaller than length at maturity.

3.4.3. Length-based Bayesian biomass (LBB)

The determination of MBS stock status also used the LBB model approach. The parameters used as input for LBB are L_∞, M/K and L_{m50} from the results of this study and are presented in Table 3, Table 4 and Fig. 3. The parameters value used include: L_∞ (83 cmTL), ratio M/K (0.85) and L_{m50} (47.2 cmTL), as well as length- frequency data from 2018 to 2021. The LBB analyses for four years period with original length-frequency data from Makassar strait resulted that the majority length size of the catch was smaller than the optimal length at the maximum biomass of the unexploited stock (L_{opt}) 67 cm and the optimum size of length which could maximize the yield ($L_{c\text{-}opt}$) 57 cm. Running the LBB model using a prior for L_∞ or L_{inf}, M/K and L_{m50} gave result stock being in a poor state or high risk to overexploitation ($B/B_o <$ 0.313 and $B/B_{MSY} <$0.8) (Table 5; Fig. 6).

3.4.4. Length-based indicator (LBI)

The results of the LBI analysis obtained P_{mat} of 40.9% (smaller than 90% as a reasonable target), P_{opt} of 17.2% (very small, compared to the target of 100%) and P_{mega} of 11.2%, which is far below the 20% limit. The LBI indicators revealed the MBS stock in the Makassar strait is unhealthy and depleted.

3.4.5. Kobe plot

Stock status based on the Kobe Plot framework that connects the F/F_{LRP} ratio with B/B_{LRP} shows that the MBS stock status has experienced a risk of being overfished and overfishing phase ($B/B_{LRP} < 1$ and $F/F_{LRP} > 1$) from 2018, 2019 and 2021, considering all stock from the year period is in quadrant III (red) (Fig. 7). Meanwhile, stock status in 2020 showed a different pattern from other years. In that year, stock condition was in the intermediate phase with resource situation $B/B_{LRP} < 1$ and $F/F_{LRP} < 1$ (quadrant IV). This situation shows a slightly better of fishing mortality compared to other years.

3.4.6. Sustainability analysis (Simulation)

Taking into account the LBSPR and LBB results which generally show that the mean catch length (L_c) is much smaller than the length at maturity (L_{m50}), fishing should start with larger individual sizes. Therefore, we created a simulation based on catch length sizes but assuming that fishing mortality F is constant. It is difficult to intervene to reduce F in the small-scale fisheries. In the simulation between YPR and SPR for the management scenario by maintaining F at a constant level (F=0.5), three scenarios were carried out with the mean length at capture at the level of 50% (L_c). The three scenarios consisting of BaU (L_c=33.5 cm), Limit (L_c= L_m=47.2 cm), and Target (L_c=$L_{c\text{-}opt}$=57 cm), the L_c = 33.5 cm was chosen in the BaU scenario because it is the mean of LBB results over the last three years, as well as L_c from $L_{c\text{-}opt}$ in the target scenario. It is shown that in the first scenario, resources appear to be overfishing and overfished more quickly compared to the second and

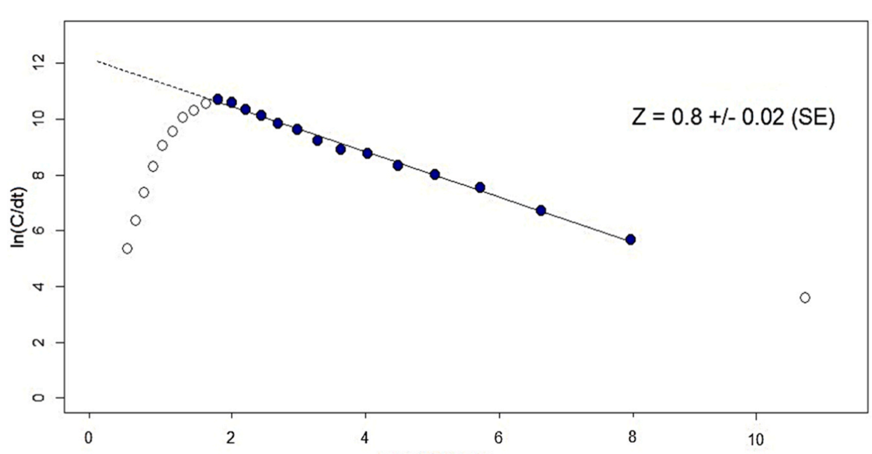

Fig. 4. The total mortality Z estimation of *L.malabaricus* by length-converted catch curve in the Makassar Strait.

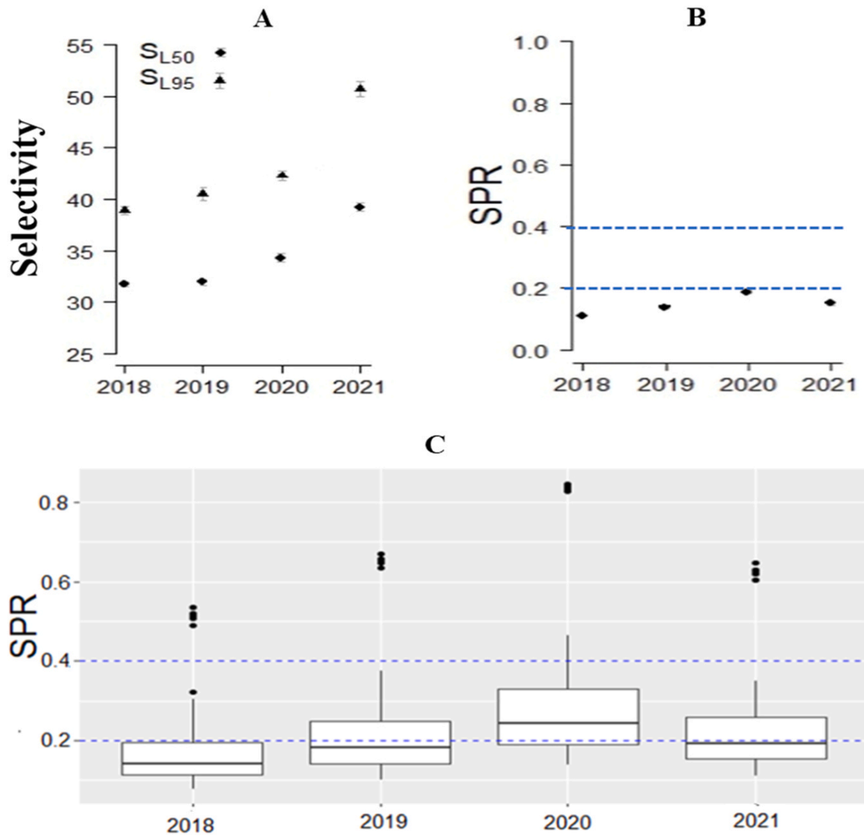

Fig. 5. The LBSPR analaysis of *L.malabaricus*, selectivity output (A) and spawning potential ratio (SPR) with dot black as deterministic SPR (B) and boxplot as stochastic SPR (C), using commonly used LRP (0.2) and TRP (0.4) respectively (dashed blue line).

Table 5
The stock status resulted from LBB outputs for Malabar blood snapper (MBS) in Makassar Strait (mean of last three years, 2019–2021).

Input		Output		Status
L_∞ (cm) prior	83	S_{L50} (cm)	33.5 (33.1 – 33.9)*	
M/K prior	0.85	S_{L95} (cm)	45.4	
L_{m50} (cm)	47.2	B/B_o	0.28 (0.16–0.42)*	high risk
		B/B_{MSY}	0.68 (0.41–1.0)*	over-exploited
		$L_c/L_{c\text{-}opt}$	0.59	growth overfishing

[*] number in brackets showed 95% plausible intervals for the parameters

third scenarios. It can be seen that increasing L_c also has an impact on increasing SPR (Figs. 8A, 8B, 8C). The smallest Y_{max} value was acquired in the first scenario and F is located in right of Y_{max} (showing overfishing situation). In the second scenario, SPR at same level of F is at 30% and F is at the peak of Y_{max}, as well as Y_{max} is a higher than first scenario (indicating the optimum level). The last scenario, Y_{max} achieved the highest value among the other scenarios and F is well to the left of Y_{max} (no sustainability concerns). Furthermore, in the third scenario $SPR_{40\%}$ is achieved at the same position as F. In this simulation, it can also be seen that the $SPR_{20\%}$ of the three scenarios is always at a level that exceeds Y_{max} or at the right point (overfished situation).

4. Discussion

The mean length of *L.malabaricus* caught in Makassar Strait was relatively the same as from the Sinjai waters, part of Bone Bay, namely 48.2 cmTL (Tirtadanu et al., 2018) and the catches from the two waters were larger than those from Timor Sea, with an average of 42.0 cmFL (Herwaty et al., 2023). Furthermore, the mean size capture showed equal to the mean at maturity size at level 50%. However, the length mode indicated relatively young or immature fish in the 40 cmTL length group. This condition was also strengthened by the results of the selectivity output from LBSPR and LBB, which obtained a catch size smaller than the fish maturity length. The same situation was also found in the Java Sea and Sinjai waters (Tirtadanu et al., 2018; Wahyuningsih et al., 2013) which was length at maturity higher than the selectivity length. It points out that most of the fish caught have not spawned yet. The mean size of 50% gonad maturity (L_{m50}) could be an effective indicator of the effects of fishing pressure, and this could be tested and evaluated further after several years as more data become available (Lappalainen et al., 2016). A fishery is at high risk of being overfished when more than 50% of the fish caught are immature (Froese et al., 2016), and may lead to growth overfishing (Wibisono et al., 2021). These species have difficulty achieving sustainability due to high fishing pressure and low resilience to overfished (Fry et al., 2006). In this study, MBS faces a high risk of over-exploitation. Therefore, it suggested that the management approach minimum size, considering the size at maturity as an option for the regulation.

The growth K of *L.malabaricus* in this study is categorized as relatively slow (K <1) (Sparre and Venema, 1998). The results of growth analysis (L_∞, K) of the same species from other areas (Table 3) have been reported, and it pointed out that this species of tropical fish has characteristics as a slow growth and long-lived species. The growth rate of K varied both with models based on otolith data and length frequency. In the estimation using the otolith, there was a difference in K values between Arafura waters (Indonesia) and the Pilbara offshore (Australia), which indicated that snapper from Arafura waters grows faster than from the Pilbara offshore. This condition is very likely to occur because of the tendency of fish in tropical waters to grow faster due to the influence of temperature on their metabolic processes (Heibo et al., 2005). The temperature in tropical waters is relatively stable, with almost no extreme changes. On the other hand, in sub-tropical and temperate

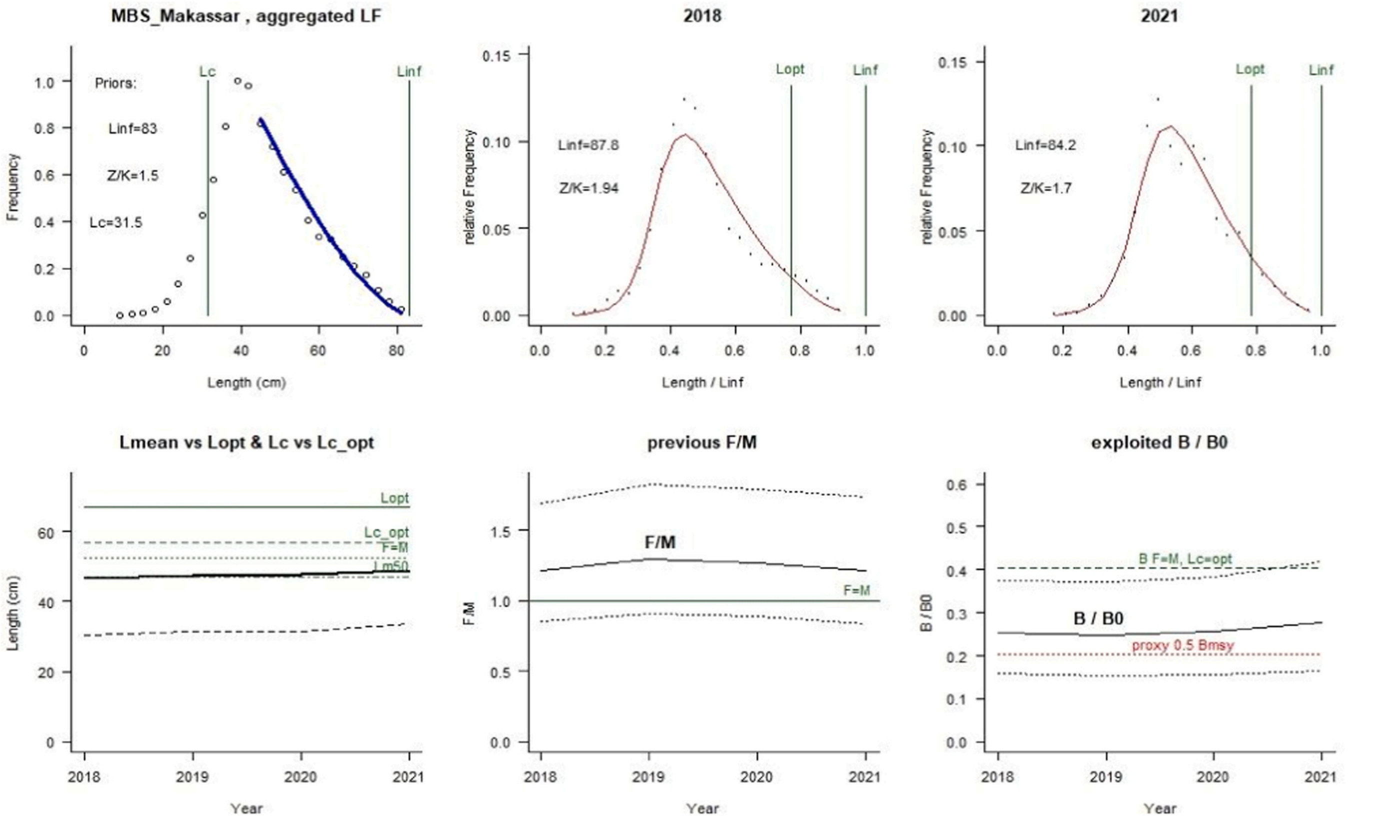

Fig. 6. Length-based Bayesian Biomass estimation of Malabar blood snapper (MBS) in the Makassar Strait for 2018–2021. The upper left shows the length-frequency (LF) data accumulation; the middle and right are the LF data for the first and last years of the data period used for analysis. The lower left graph shows L_{mean} comparing to L_{opt} and L_c comparing to $L_{c\text{-}opt}$. The lower middle graph presents F/M (relative fishing pressure) with approximate 95% confidence limits (dashed line). The lower right represents the annual relative biomass $B/B0$ with 95% confidence limits (dashed line), with a proxy for Biomass at the maximum sustainable yield B_{MSY} (green dashed line) and a proxy for 0.5 B_{MSY} (red dashed line).

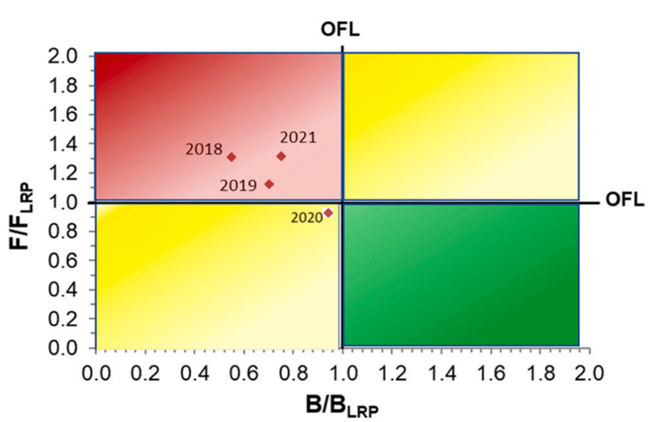

Fig. 7. Kobe plot with overfishing limit (OFL) as a function of the ratio F with F limit reference point (F/F_{LRP}) to reproductive stock capacity (B/B_{LRP}) which is identical to the ratio of SPR and SPR_{LRP}. The Kobe Plot is divided into four quadrants, consisting of: quadrant I (green) is an area of no risk, quadrants II and IV (yellow), respectively show overfishing and overfished which are intermediate situations, and quadrant III (red) is the response to the phase overfished and overfishing (very risky).

waters, temperature changes can occur significantly, especially in winter, thereby limiting metabolic processes and growth. Meanwhile, the variation results of growth parameters with the length model approach in different areas, possibly occurred owing to the uncertainties of applying length-based and sampling estimation models, which did not describe or represent populations in the waters. For example, MBS is caught by various fishing gears with different fishing grounds, so, ideally samples taken for growth analysis need to be obtained from these various fishing gears.

It is known that the natural mortality M is difficult to estimate. There are four groups of methods used to calculate M: a) based on life history theory; b) empirical relationship; c) tagging data; and d) catch-at-age data (Maunder et al., 2023). In this study, the calculation of M used a two-method approach, life history and empirical. Based on the four M calculation formulas, the result of Zhang and Megrey (2006) was chosen as the most realistic M value (0.297) according to the life history characteristics of the snapper in general compared to the results of other formulas. The M equation from Pauly (Pauly, 1980), Hoenig (Hoenig, 1983) and Then et al., (Then et.al., 2015) were not recommended to long-lived species (included *L.malabaricus*). Based on tests of uncertainty and error calculations on the M with M scale the results were skew and tended to give poor estimates, especially for species with low M values. These equations are based on untransformed data thus giving too much weight to data points where M estimates were high (Maunder et.al., 2023).

The length-based method could result in inputs for determining some reference points representing stock status. Considerations in determining stock status using various approaches (more than one model) can certainly provide certainty about the "true" stock condition of fish resource. The MBS with such as a slow growth, late mature, and long-lived character is relatively vulnerable, especially to fishing pressure. Therefore, in determining the stock status, it is necessary to take a careful approach because it is one of the main inputs in management. Moreover, M is an important parameter that can affect stock productivity estimation and the determination of reference points (Maunder et al., 2023). MBS exploitation rate (E=0.63) in Makassar Strait has

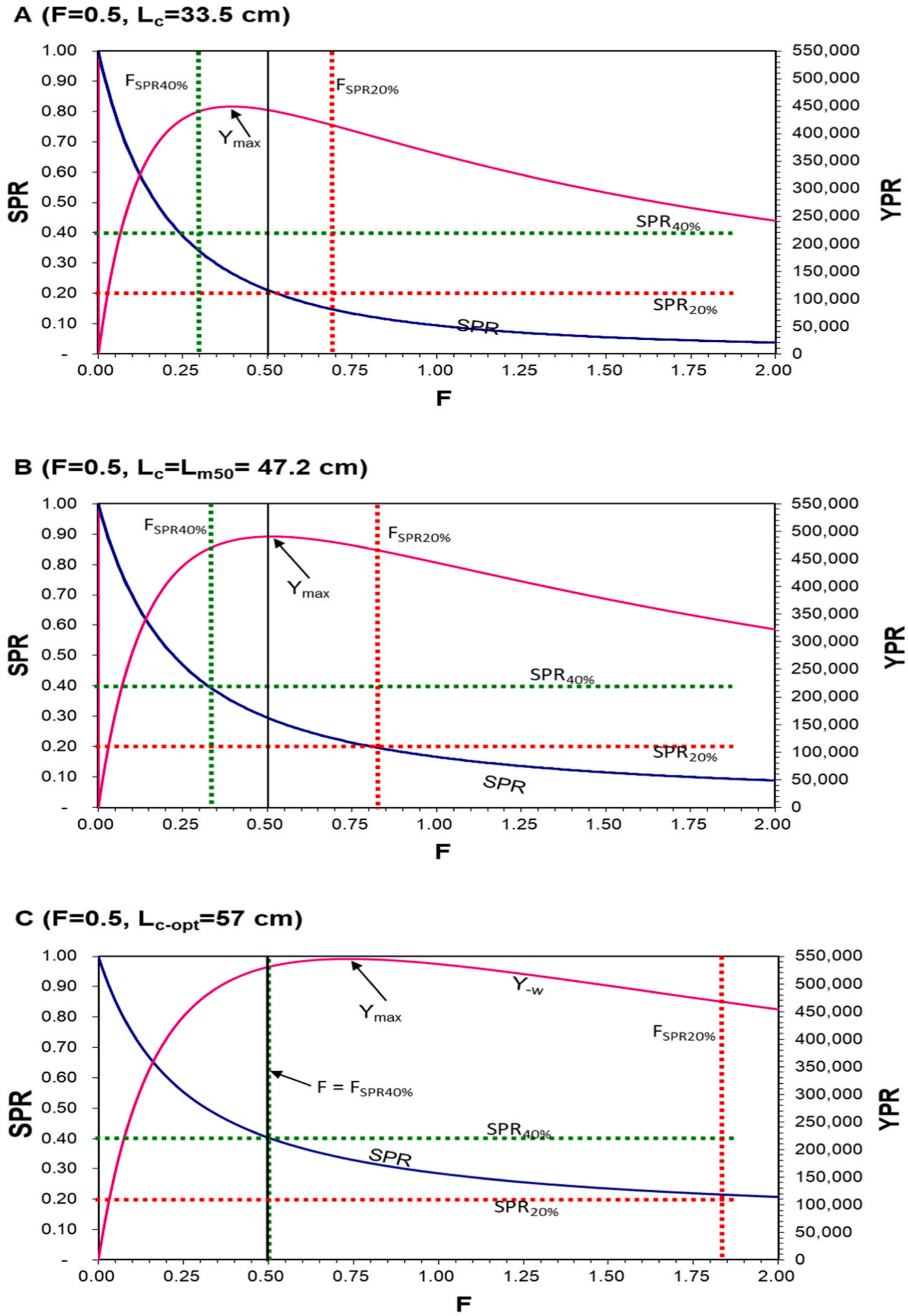

Fig. 8. Illustration of the relationship between yield in weight (Y_{-wg}, purple line) and SPR (blue line) tied to the fishing mortality rate F at a certain Lc according to the scenarios (A, L_c =Business as Usual; B, L_c= L_{m50}; C, L_c=$L_{c\text{-}opt}$). The vertical black line is $F = 0.5$, the green dotted line is the F when the SPR is 40% (horizontal green dotted line). The vertical red dotted line shows F when SPR is at the 20% level (horizontal red dotted line).

exceeded optimal level E (0.5), indicating that overfished has occurred.

SPR also corroborated the results from E. The deterministic and stochastic produce a smaller SPR than the generally limit reference point (0.2). Similar conditions with the same species were also obtained in the Java Sea with an SPR <0.2 (Hapsari et al., 2023). This condition indicates recruitment overfishing in the MBS fishery. If the spawning stocks biomass were depleted to a condition where they could not restock the population with their reproductive capacity, it could lead to overfishing recruitment (Pauly, 1983). SPR is closely related to recruitment because the number of recruits depends on the number of eggs produced by spawning brood-stock. If the SPR decreases, the number of eggs will become less thereby reducing recruitment. Hence, in managing fisheries with SPR for decision making, it is necessary to ensure that the number of spawning stocks does not decline significantly in the fished population. Controlling fishing mortality is the key to maintaining SPR at certain reference points. Fisheries managers may consider tightening regulations to reduce fishing mortality if indicated by low SPR or below LRP. However, it is difficult to regulate F in small-scale fisheries because it is related to the main livelihood of small-scale fishermen. This group of fishermen is dominant in Indonesian fisheries. Additionally, the low SPR is strongly influenced by the selectivity factor which the size of the fish captured is smaller than the size at maturity. Because of that, increasing the average size of the caught to exceed the maturity size allows a high SPR (Hordyk et al., 2014). In the conditions of recruitment overfishing, biomass and catches will rise significantly through increasing catch size based on length at first maturity (Ben-Hasan et al., 2021), and still control the fishing mortality *F*.

SPR result in 2020 was relatively higher compared to other years. This is related to the Covid-19 condition where the government issued a strict lockdown policy so that fishermen cannot carry out fishing activities as under normal conditions. This situation has a positive influence on the condition of fish resources because fishing activities are significantly reduced, thereby reducing *F* and having an effect on the recovery of fish stocks. Hence, during Covid-19, it had a positive impact on CPUE in small-scale fisheries (Macusi et al., 2022). However, this situation did not continue in 2021 because the SPR decreased again even though the restriction policy was still in effect. In the second year of Covid-19, people are already experiencing boredom and frustration. In consequence of demands to meet their family's living needs, fishermen continue to carry out fishing activities as in normal situations. They did not care about the government's restriction policies.

The length-based Bayesian biomass method is a simple model for estimating the relative biomass of exploited size ranges based on length frequency data (Ault et al., 2022). The LBB is a more broadly applicable model that can be adapted to the stock studied when the user used priors for known parameters, such as the asymptotic length of L_∞ and relative natural mortality *M/K* (Dimarchopoulou et al., 2021). In the Asian fisheries, this model has been widely applied (Dimarchopoulou et al., 2021; Kembaren and Suman, 2023; Liang et al., 2020; Tirtadanu et al., 2023; Xu et al., 2023; Yue et al., 2021; Zhang et al., 2021) to determine stock status. Running LBB explores a variety of stock status results, including B/B_0, B/B_{MSY}, and $L_c/L_{c\text{-}opt}$. The result of the B/B_0 (0.28) from LBB to MBS shows a depleted stock condition or high risk of over-exploitation ($B/B_0<0.31$). A similar situation with the same species using the LBB method was also obtained from previous studies in the Java and Arafura Seas (Dimarchopoulou et al., 2021). Furthermore, the biomass status based on B/B_{MSY} (0.68) is in the over-exploited ($B/B_{MSY} < 0.8$) category. The output $L_c/L_{c\text{-}opt}$ of LBB obtained was smaller than one ($L_c/L_{c\text{-}opt}<1$), indicating that MBS in the Makassar Strait experienced growth overfishing. In addition, L_c or S_{L50} was significantly less than $L_{c\text{-}opt}$ indicating that the species was overfished. Therefore, fishing should be conducted by catching larger fish (Medeiros-Leal et al., 2023). The strict fisheries policies are needed to rebuild stocks by limiting minimum sizes at certain times in recovery efforts. Determining the minimum size as a limit based on biological data by shifting size selectivity (Pellowe and Leslie, 2020) can be used as an option to control the mean length at first capture, thereby is potentially to increase the length of the catch-size.

In line with the SPR and LBB results, LBI also indicated the same situation that the MBS stock status in Makassar Strait had experienced a decline and depletion. LBI shows that large individuals and mega-spawners experienced a sharp decline compared to reference points in the population. This situation shows growth-overfishing and recruitment-overfishing conditions. In this situation, fishing should be regulated by implementing a mechanism to increase the size of the catch.

Overall, the length-based assessment methods (LCCC, LBSPR, LBB and LBI) used in this study are quite robust methods, converging on producing the same stock status, in conditions of limited data. These methods are very helpful for application in the context of small-scale fisheries. The findings of the stock status concluded that MBS or *L. malabaricus* in the Makassar Strait had experienced stock depletion, both growth overfishing and recruitment overfishing.

Based on the Kobe Plot scheme with "Business as Usual (BaU)" conditions, the MBS fisheries in the Makassar Strait from the 2018–2021 period have experienced conditions of excessive fishing pressure (Fig. 8). Although the condition for determining the status of spawning biomass used the current SPR ratio and an SPR limit of 20%, the status of spawning biomass is at an alarming level (below *OFL*). It is clear that in BaU conditions, sustainability is difficult to achieve therefore, a management intervention is needed to improve the situation.

In this study we propose an approached in management interventions to achieve sustainability. Given the limited data situation, regulation regarding size at length might be achievable. This is determined through three scenarios by maintaining the *F* level at 0.5, including: (1) **BaU** (L_c=33.5 cm), (2) **Limit** ($L_c= L_{m50}$=47.2 cm), and (3) **Target** ($L_c=L_{c\text{-}opt}$=57 cm) (Fig. 8). In the scenarios, *F* is maintained at the current level considering the situation in small-scale fisheries is difficult to control *F*. This difficulty is related to the regulation of fishing activities carried out by small-scale fishermen, as their main livelihoods of coastal communities. The number of small-scale fisheries is not small but dominates in Indonesian fisheries. Based on the **BaU** scenario (Fig. 8A), it appears that maintaining the mean length at first capture (L_c=33.5 cm) and F=0.5 is at risk for the sustainability of the MBS resource. At condition $F = 0.5$, MBS has led to overfishing (Y_{max} is to the left of *F*). In the **Limit** scenario (Fig. 8B), determined as a limit reference point shows that by increasing L_c to a level equal to L_{m50}, the MBS fishery could reach Y_{max} at the F=0.5 and at the SPR point of 30%. Furthermore, in the second scenario, by increasing the size of L_c, at least equal to L_{m50} and constant *F*, MBS can be at the maximum sustainable yield (MSY) level or as determinant to be limiting. In the third scenario or set as the **Target** (Fig. 8C), by increasing L_c equal to $L_{c\text{-}opt}$ (57 cm), *F* is at the same level as $SPR_{40\%}$ and Y_{max} is to the right of *F*, there are no visible signs of overfishing and overfished. In the third scenario, it can be stated that MBS has not experienced a sustainability risk. So, it is still possible to have an SPR of 40% with L_c =57 cm as the target reference points, and L_c=47.2 cm with SPR at the 30% level can be proposed as a limit reference point for MBS in the Makassar Strait. Through these scenarios, it can be seen that length regulation as a form of management intervention is quite promising to be applied to MBS as an example of a specific species stock in data-limited conditions. Of all the existing scenarios, it is necessary to highlight where the 20% SPR in the MBS case in the Makassar Strait could not be used as a reference limit. The simulation revealed that the 20% SPR is always at the overfishing level. Therefore, it needs to be careful in determining the reference point with SPR, it should be simulated first with other reference parameters.

Finally, knowing the condition of the stock status of *MBS,* which has led to a decline in population or over-exploitation, rational and applicable management is urgently needed. Three strategies for managing the *MBS* fishery in Makassar Strait are proposed as efforts increasing minimum size at first capture L_c or S_{L50} to recover and rebuild the stock:

i) Size limit: Establishing a minimum legal size considering the length at maturity (L_{m50}) would be a suitable management option for reducing the catch of immature fish.
ii) Spatial closure: Area closure to conserve the nursery grounds of snapper. Many juveniles are found in the area of coral reefs and seagrasses (Fry and Milton, 2009), therefore, prohibiting fishing in these areas could lead to greater recruitment to the fishery. Spatial protection of juveniles, such as snapper, should be part of managing deep-slope demersal fishery (Wibisono et al., 2021). Marine Protected Areas (MPA) in areas identified as fish-rearing locations can be developed in fisheries management to protect juvenile stocks.
iii) Habitat rehabilitation: based on previous studies (Fihrin et al., 2022; Renggong et al., 2022; Tahir et al., 2019; Yasir Haya and Fujii, 2020) the coral reefs and seagrass beds in the Makassar Strait had decreased and been damaged, so efforts are needed to restore these habitats which are the main habitat of snapper juveniles. The destruction of nursery habitats could make fish stocks vulnerable to overfishing (Amorim et al., 2019).

By considering these recommendations, MBS stock could recover and increase to maintain the sustainability of resources and the livelihoods of fishermen and other stakeholders.

5. Conclusions

This study revealed that the character of MBS or *L. malabaricus* in the Makassar Strait based on life history parameters included in the categories of slow growth, late maturity and long-lived species. The condition of MBS resources in the Makassar Strait has indicated a decrease in stocks characterized by S_{L50} and S_{L95} which are lower than L_{m50} and L_{m95}; 55.4% of fish caught smaller than the mean length at maturity (L_{m50}); E that exceeds the optimal E, SPR lower than LRP, LBB resulted lower than LRP (B/B_0<0.31; B/B_{MSY} < 0.8; $L_c/L_{c\text{-}opt}$<1), as well as LBI provided lower than reference points. With a simulation of determining reference points for setting length sizes, but F constant at 0.5, MSY is obtained with the SPR position at the level of 30% and L_c= L_{m50} and $F_{SPR40\%}$ could be achieved at the same level as F with L_c=$L_{c\text{-}opt}$, and there is no indication of risk to sustainability. In other words, LRP can be determined at SPR 30% (L_c= L_{m50}), and TRP at SPR 40% (L_c=$L_{c\text{-}opt}$). Three MBS fisheries management strategies related to size regulation are recommended: i) size limit, ii) spatial closure and iii) habitat restoration.

CRediT authorship contribution statement

Glaudy Hendrarsa Perdanahardja: Writing – review & editing, Funding acquisition. **Fayakun Satria:** Writing – review & editing, Supervision. **Nurlisa Alias Butet:** Writing – review & editing, Supervision. **Mohammad Mukhlis Kamal:** Writing – review & editing, Supervision. **Mennofatria Boer:** Writing – review & editing, Supervision. **Tri Ernawati:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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