Aquaculture, Fish and Fisheries

WILEY

AQUACULTURE, FISH and FISHERIES Open Access

ORIGINAL ARTICLE OPEN ACCESS

Length-Based Assessment of the Seven Most Commonly Caught Coral Reef Fish Species to Support Improve Management of Small-Scale Fisheries in Southwest Madagascar

Miarisoa Lalaina Rakotonaivo[1,2] | Lala N. J. Ranaivomanana[2] | Charlotte Gough[3] | Jérémie R. Ndriamanja[1] | Danny Kornelio Ravelojaona[1] | Ravakiniaina Frida Razafinaivo[4] | Daniel Raberinary[5]

[1]WWF Madagascar Country Office, Antananarivo, Madagascar | [2]Institut Halieutique et des Sciences Marines (IH.SM), University of Toliara, Toliara, Madagascar | [3]Centre for Ecology and Conservation, Faculty of the Environment, Science and Economy, University of Exeter, Cornwall, UK | [4]Madagascar National Parks, Antananarivo, Madagascar | [5]Institut d'Enseignement Supérieur d'Anosy, Fort-Dauphin, Madagascar

Correspondence: Miarisoa Lalaina Rakotonaivo (lrakotonaivo@wwf.mg)

Received: 6 August 2025 | **Revised:** 9 January 2026 | **Accepted:** 16 January 2026

Keywords: data limited fisheries | LBB evaluation | length frequency | locally managed marine areas | overfishing

ABSTRACT

The status of most fish stocks in Madagascar remains poorly documented. Given their importance for food security and livelihoods, it is necessary to define management measures with reliable data. This study applied a length-based Bayesian biomass (LBB) estimation method for analysing the fisheries' representative length-frequency data of seven most commonly caught coral reef fish species in the southwest of Madagascar. Using Froese's indicators, the use of $\frac{B}{B_0}$ as a stock status indicator, allows a consistent comparison among species in multi-gear, multi-species fisheries and provides a practical basis for management advice in data-limited contexts. The stock status was determined based on median estimates for the period 2018–2023, which provide an assessment of the overall status. Estimates for 2023 were used to describe the most recent status of the stocks. The outputs of this study provide a guide for fisheries managers, coastal communities and authorities to formulate effective management strategies for the sustainability of the marine fisheries in Madagascar. A key recommendation from the study is the need for fisheries managers to improve fisheries data and to periodically monitor biological indicators to assess the status of small-scale fisheries stocks.

1 | Introduction

Small-scale fisheries (SSF) contribute at least 40% of the global catch of both marine and inland fisheries, and are particularly important in Africa, contributing 67% of the total catch and 75% of the total contribution to nutrition (Basurto et al. 2025). In Madagascar, the fisheries sector contributes 3.2% to the national GDP, with small-scale marine fisheries accounting for 50% of the total value of production (MPEB 2022). Unfortunately, co-management is likely implemented for only 20% SSF catches globally (FAO, Duke University and Worldfish 2023). This statistic highlights the limited implementation of effective management frameworks in SSF, which remain largely under-regulated and poorly governed despite their critical role in food security (Chuenpagdee et al. 2005).

Small-scale, multi-gear, multi-species, reef fisheries are highly complex. This highlights the need to consider models that promote the integration of management methods to take account of natural fluctuations, human-induced changes and socio-economic factors, to better manage these fisheries (Caddy 1999; Salas et al. 2023). Studies show that small-scale coral reef fisheries

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2026 The Author(s). *Aquaculture, Fish and Fisheries* published by John Wiley & Sons Ltd.

cause a reduction in fish biomass and size, but the extent, magnitude and variability of overexploitation are generally not well documented (Cinner et al. 2009; Jacquet and Pauly 2008; Leenhardt et al. 2016). Insufficient data due to a lack of institutional and financial resources makes it difficult to manage these fisheries and monitor the state of stocks (Dowling et al. 2019).

Assessing data-limited and data-poor fisheries is an emerging topic in marine fisheries and is supported by an increasing focus on the socio-economic and ecological importance of SSF (Shephard et al. 2020). The development and quality of national policies and management plans depend on a strong understanding of the status and trends of the fishery, which in turn is supported by good data. Ultimately, good data supports better decision-making (De Graaf et al. 2011). In addition, fisheries data and information are also important for designing performance indicators, so that fishers and managers can evaluate the impacts of their management strategies (Shepherd 1984).

In Madagascar, fisheries are data-poor, which limits the scope for effective management, especially for SSF, where data is poor. Managers often lack the capacity to assess stock status of key fish species, and to effectively use information when available to make decisions (Costello et al. 2012). For this reason, NGOs frequently complement the work of government fisheries managers and work in collaboration with coastal communities to monitor and collect data on SSF. Non-scientists, such as fishers, currently play an important role in monitoring marine resources, and their participation in these activities is gaining wider acceptance (Obura et al. 2002). In Madagascar, participatory monitoring approach has been found to be particularly appropriate for obtaining information on SSF (Brenier et al. 2012). However, participatory monitoring differs from other forms of local knowledge. While fishers often share what they have learned from their own experience, participatory monitoring involves collecting detailed data with the aim of capturing spatial and temporal changes and using this information to make management decisions (House et al. 2023).

Several data-limited stock assessment methods and models have been developed and widely applied to many fisheries at all levels (Derhy et al. 2024). Most of these methods vary depending on data availability and can be divided into three models; (1) catch-based methods, (2) length-based methods, and (3) abundance-based methods (Fitzgerald et al. 2018). Among the length-based assessment methods, there are the length-based indicators (LBI; Froese 2004), the length-based spawning potential ratio (LBSPR; Hordyk et al. 2014), and the length-based Bayesian biomass (LBB) Froese et al. 2018). Froese et al. (2018) provide such a method, which derives estimates of relative stock size from length frequency (LF) data of exploited stocks. The LBB is a new Bayesian method for the analysis of fisheries-dependent LF data, which are widely available from landing site sampling and fisheries observer programs. LBB is designed to require minimum data input to approximate depletion or current exploited biomass relative to unexploited biomass ($\frac{B}{B_0}$) as one of its key outputs (Froese et al. 2019).

In this study, we applied the LBB estimation method to assess the seven most commonly caught coral reef fish species for the first time in the southwest of Madagascar. To enable minimal data requirements, the LBB method relies on the ratios of natural mortality to somatic growth ($\frac{M}{K}$) and fishing mortality to somatic growth ($\frac{F}{K}$), rather than absolute rates of growth and mortality (Raza et al. 2022).

2 | Materials and Methods

2.1 | Study Area

Data was collected in the southern region of Toliara, Madagascar, stretching from Ambohibola to Maromena and borders the Nosy Ve Androka Marine Protected Area (MPA), managed by Madagascar National Parks. The study area includes a well-developed fringing reef, enclosing a narrow lagoon, and a barrier coral reef which extends north of Sarodrano (Figure 1) (Cooke et al. 2022). NGOs, such as WWF, support fifteen co-managed areas through community-led conservation approach to maintain the ecological integrity of the MPA. These fifteen co-managed sites in the south of Anakao, from Maromena to Ambohibola, are involved in the collection of fisheries data to support the monitoring of the fishery. In Madagascar, co-management is implemented through a formal management transfer of natural resources from national government to local communities. These communities are intended to retain all decision-making power, while receiving technical, institutional, or advisory support from other stakeholders, such as NGOs, private sector, and other actors (Zafimahatradraibe et al. 2025). Marine resources within these co-managed areas are managed through coastal community associations, with regulations established and enforced via traditional social conventions (*dina*) (Barnes and Rawlinson 2009). The *Dina* is a mechanism for reconciling decentralised governance and traditional governance of natural resources in Madagascar, including marine and coastal areas. This mechanism integrates government laws and the legitimate rights of local communities to resolve the problem of law enforcement (Rakotoson and Tanner 2006).

2.2 | Data Sources and Sampling Procedure

Data was collected three times per week by members of the 15 communities in the study site between 2018 and 2023. To monitor and collect data on SSF, data collectors work in pairs, with the number of pairs varying according to the size of the village. In a village with a larger number of fishers, the number of data collectors can be up to eight, equivalent to four pairs.

One of the main challenges experienced in the pursuit of improving knowledge of marine and coastal biodiversity is accurate taxonomic identification (Sarkar et al. 2012). In this study, species identification was established using a community-based participatory approach, that actively involves local communities to provide their traditional knowledge and consisting of presenting illustrated fish catalogues to fishers to obtain correspondence between scientifically identified species and their local names.

A total of 78 data collectors collect data on SSF along the southern coast of Toliara. The majority (80%) of data collectors are women, while they are not fishers themselves, they are sometimes

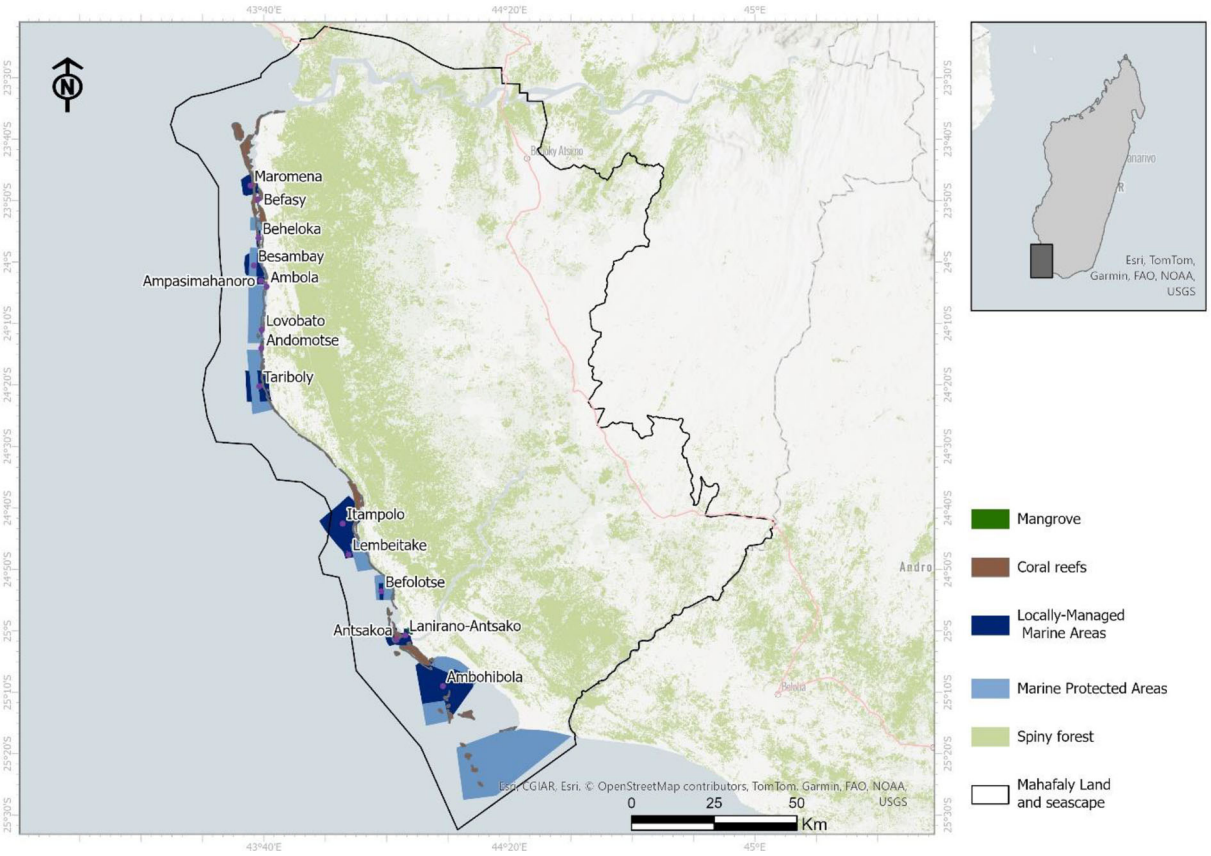


FIGURE 1 | Location of the Mahafaly seascape with LMMAs (locally managed marine areas) boundaries.

fishmongers. Data collectors operate at the landing site and sample 10%–20% of the boats as they return from their fishing trip. Multiple boats might land at the same time, highlighting the importance of increasing the number of data collectors depending on the size of the village and the number of active fishers. For each boat surveyed, the identity of the fisher (name, migrant or non-migrant, gender), the number of fishers fishing on the boat, the gear used, the fishing area and the weight and length of every fish caught were recorded. Length–frequency data were collected for 5–10 specimens randomly selected from each boat to ensure that the full length distribution of the population was captured. Lengths were recorded using a measuring board to the nearest 1 cm fork length (FL) for length-based analysis. Four dominant fishing gears were considered in the study, including two types of nets and two types of handlines. These gears types have different characteristics, and net fishing often has a wider LF than handline fishing. Consequently, a trawl-like selectivity function was applied in the LBB analysis to represent the effective combined selectivity of the gears (Table 1). These gears are used in different ways depending on the fishing season, the target species, and the fishing location (Gough et al. 2020). Fishing duration is estimated at around 6 h for all these fishing gears, other than gillnets, which have an average soaking time of approximately 2 h.

2.3 | Data Validation and Quality Control

Data validation is essential to ensure the reliability and consistency of the data. Data collectors receive capacity-building sessions twice a year on standardized data collection protocols, including species identification, measurement and weighing techniques, sampling methods and verification procedures. A two-tier quality control process is implemented, whereby the data collected are checked by WWF field staff to identify any discrepancies. Supervisors review the completeness and accuracy of the records, and any inconsistencies are promptly corrected following clarification with the data collectors.

2.4 | Description of the LBB Method

The LBB estimation for this study was carried out using the statistical software R and the R-code (LBB_v4.R) and shiny app (LBB_aux_data.Rdata) downloaded online at: https://github.com/ktouloum/CLA_stock_assessment/tree/main/LBB (15 April 2024).

LBB is an approach to access data-limited and data-poor fisheries. It makes use of LF data as the primary input and applies a Bayesian Monte Carlo Markov Chain (MCMC) method to estimate indicators of stock status (Froese et al. 2018). A major assumption of the LBB method is that the size progression in the species is as per von Bertalanffy's growth function (Rahangdale et al. 2022).

$$L_t = L_{inf}\left[1 - e^{-K(t-t_0)}\right]$$

TABLE 1 | Details of fishing gear used in the study area.

Gear type	Local name	Net length (m)	Net height (m)	Mesh size (mm)	Working depth (m)	Number of set	Working period
Gill net 1	Harato valala	100	2.5	20	25–50	10–20	November–May
Gill net 2	Harato tanjaky	100	2.5	25	10–15	5	June–October

Gear Type	Local name	line length (m)	line material	Hook size (mm)	Working depth (m)	Number of line	Working period
Handline 1	Kara lamatra	200	Nylon	25×10	40	2 – 3	June–October
Handline 2	Tsopoke	100	Nylon	18×7 16×6	100	4	November–May

Here L_t is the expected or mean length at age t, L_{inf} denotes the asymptotic length, K is the growth coefficient (per year) and t_0 is the age at zero length.

When the fishes are fully selected by the fishing gear, the curvature of the right side of catch samples is a function of total mortality (Z = M + F) in relation to K:

$$N_L = N_{L_{\text{start}}} \left(\frac{L_{\text{inf}} - L}{L_{\text{inf}} - L_{\text{start}}} \right)^{\frac{z}{k}}$$

L_{start} represents the minimum length class included and corresponds to the smallest size reliably observed in the catch. N_L and $N_{L_{\text{start}}}$ are the total population numbers at length L and L_{start} respectively. N_L is the number of survivors to length L and $N_{L_{\text{start}}}$ is the number at length L_{start} with full selection. The ratio of total mortality rate Z to somatic growth rate denotes the $\frac{z}{k}$.

In addition to the selectivity function, the lengths affected by partial selection are, for each species, a function of the fishing gear given by the function:

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

S_L is the fraction of individuals that are retained by the gear at length L, and α describes the steepness of the ogive (Froese et al. 2018)

To approximate the stock status from the estimated parameters L_{inf}, $\frac{M}{K}$, $\frac{F}{K}$ and L_c, the following equations related to parameters L_{opt} and $L_{\text{c_opt}}$ are used (Froese et al. 2016). First, the length L_{opt} representing the maximum biomass of the unexploited cohort is obtained from:

$$L_{\text{opt}} = L_{\text{inf}} \left(\frac{3}{3 + \frac{M}{K}} \right)$$

Based on a given fishing pressure $\frac{F}{M}$, the mean length at first capture, which maximizes catch and biomass $L_{\text{c_opt}}$, can be obtained from the following equation:

$$L_{\text{c_opt}} = \frac{L_{\text{inf}} \left(2 + 3\frac{F}{M} \right)}{\left(1 + \frac{F}{M} \right) \left(3 + \frac{M}{K} \right)}$$

The obtained estimates of $L_{\text{c_opt}}$ are used later to calculate a proxy for the relative biomass that can produce MSY for a given fishery (Froese et al. 2018).

For this study, the $\frac{M}{K}$ ratio of 1.5 proposed as a life history invariant by Jensen (1996), Hordyk et al. (2014) and Froese et al. (2019) implies that species that reach their maximum age at about 95% of L_{inf} have an adult $\frac{M}{K}$ ratio of 1.5. We let the model estimate L_c. The L_{inf} priors were generated in Fishbase, although where this was not available on Fishbase, we let the model evaluate it (Table 2).

Index catch per unit of effort $\frac{CPUE'}{R}$ obtained by dividing the relative yield-per-recruit $\frac{Y'}{R}$ by $\frac{F}{M}$ (Beverton and Holt 1966), can be evaluated as a function of $\frac{L_c}{L_{inf}}$, $\frac{F}{K}$, $\frac{M}{K}$ and relative fishing mortality $\frac{F}{M}$ as developed by Froese et al. (2018).

$$\frac{CPUE'}{R} = \frac{\frac{Y'}{R}}{\frac{F}{M}} = \left(\frac{1}{M} \right) \left(1 - \frac{L_c}{L_\infty} \right)^{\frac{M}{K}}$$

$$\left(1 - \frac{3\left(1 - \frac{L_c}{L_\infty}\right)}{1 + \left(\frac{1}{\left(\frac{M}{K} + \frac{F}{K}\right)}\right)} + \frac{3\left(1 - \frac{L_c}{L_\infty}\right)^2}{1 + \left(\frac{2}{\left(\frac{M}{K} + \frac{F}{K}\right)}\right)} + \frac{3\left(1 - \frac{L_c}{L_\infty}\right)^3}{1 + \left(\frac{3}{\left(\frac{M}{K} + \frac{F}{K}\right)}\right)} \right)$$

The following equation calculated the relative biomass per recruit in the exploited phase of the population, excluding the fishing activity according to Froese et al. (2018).

$$\frac{B_0' > L_C}{R} = \left(1 - \frac{L_c}{L_\infty} \right)^{\frac{M}{K}}$$

$$\left(1 - \frac{3\left(1 - \frac{Lc}{L_\infty}\right)}{1 + \left(\frac{1}{\left(\frac{M}{K} + \frac{F}{K}\right)}\right)} + \frac{3\left(1 - \frac{L_c}{L_\infty}\right)^2}{1 + \left(\frac{2}{\left(\frac{M}{K} + \frac{F}{K}\right)}\right)} + \frac{3\left(1 - \frac{L_c}{L_\infty}\right)^3}{1 + \left(\frac{3}{\left(\frac{M}{K} + \frac{F}{K}\right)}\right)} \right)$$

TABLE 2 | Basic and prior information of seven most caught coral reef fish species.

Scientific Name	Common name	Min FL (mm)	Max FL (mm)	Class interval	Linf prior (cm)	Z/K prior	M/K prior	F/K prior	L_c Prior	Alpha prior
Siganus sutor	Amboramasake	70	450	10	45	1.5	1.5	0.3	19	8.2
Lethrinus lentjan	Angeleke	100	540	10	56	1.8	1.5	0.3	20	12
Caranx tille	Lanora	80	730	10	80	1.9	1.5	0.36	25	11
Zebrasoma scopas	Angy	40	420	10	44	1.5	1.5	0.3	10	31
Gerres longirostris	Ambariake	60	420	10	44	3.8	1.5	2.3	15	14
Naso unicornis	Fiantsifa	80	680	19	70	1.6	1.5	0.12	27	11
Scarus ghobban	Bodoloha	50	680	10	71	2.4	1.5	0.86	15	19

Note: F, fishing mortality; FL, Fork length; K, somatic growth rate; L_{inf}, asymptotic length; M, natural mortality; Z, total mortality.

$B'_0 > L_C$ denotes the exploitable fraction $>L_C$ of the unfished biomass B_0. The relative biomass $\frac{B}{B_0}$ describe as:

$$\frac{B}{B_0} = \frac{\frac{CPUE'}{R}}{\frac{B'_0>L_C}{R}}$$

Depending on the function above, parameter $\frac{F}{M} > 1$ indicates that the assessed stocks are being overfished, and parameter $\frac{B}{B_0} < 1$ indicates that the current biomass is lower than that unfished biomass. According to Froese et al. (2018), $\frac{B}{B_0}$ values below approximately 0.25 indicate severely depleted stocks, values between 0.25 and 0.5 suggest moderate depletion and values above 0.5 are generally associated with lightly exploited or relatively healthy stocks.

3 | Results

A total of 150 species were identified in the sample. However, seven species contributed more than 1% of the relative abundance and a cumulative frequency distribution of 62% of the total abundance (Figure 2), justifying their selection for further analysis (Table 3). *Siganus sutor* was the most commonly caught species and accounted for 28.3% of catches, followed by Redspot Emperor (*Lethrinus lentjan*), Tille trevally (*Caranx tille*), Twotone tang (*Zebrazoma scopas*), Strongspine silver-biddy (*Gerres longirostris*), Bluespine unicornfish (*Naso unicornis*) and Blue-barred parrotfish (*Scarus ghobban*).

In this study, length data from 46,814 individual fish of the seven most commonly caught coral reef fish species were analysed with LBB method. The parameters $\frac{L_{mean}}{L_{opt}}$, $\frac{L_c}{L_{c_opt}}$, $\frac{L_{95th}}{L_{inf}}$, $\frac{B}{B_0}$, $\frac{F}{M}$, $\frac{F}{K}$ and $\frac{Z}{K}$ were obtained in Table 4. The output of the LBB analysis shows a reasonable fit for the aggregated LF data (AG_LFD) of these 7 species (Figure 3).

3.1 | Length-Based Bayesian Assessments of Overfishing

Of the seven species analysed, two were considered overfished with median $\frac{B}{B_0}$ values below 0.25, two species moderately exploited, with $\frac{B}{B_0}$ values between 0.25 and 0.5, and three species relatively with high biomass levels ($\frac{B}{B_0} > 0.5$) (Table 4).

3.1.1 | S. sutor

The results for Shoemaker spinefoot, locally known as "Amboramasake", indicate that the stock is in good condition overall for the period 2018–2023. The median relative biomass is estimated at $\frac{B}{B_0} = 0.55$ (0.27–0.87), and fishing mortality remains below natural mortality ($\frac{F}{M} = 0.64$). The size structure is close to optimal, suggesting relatively balanced exploitation.

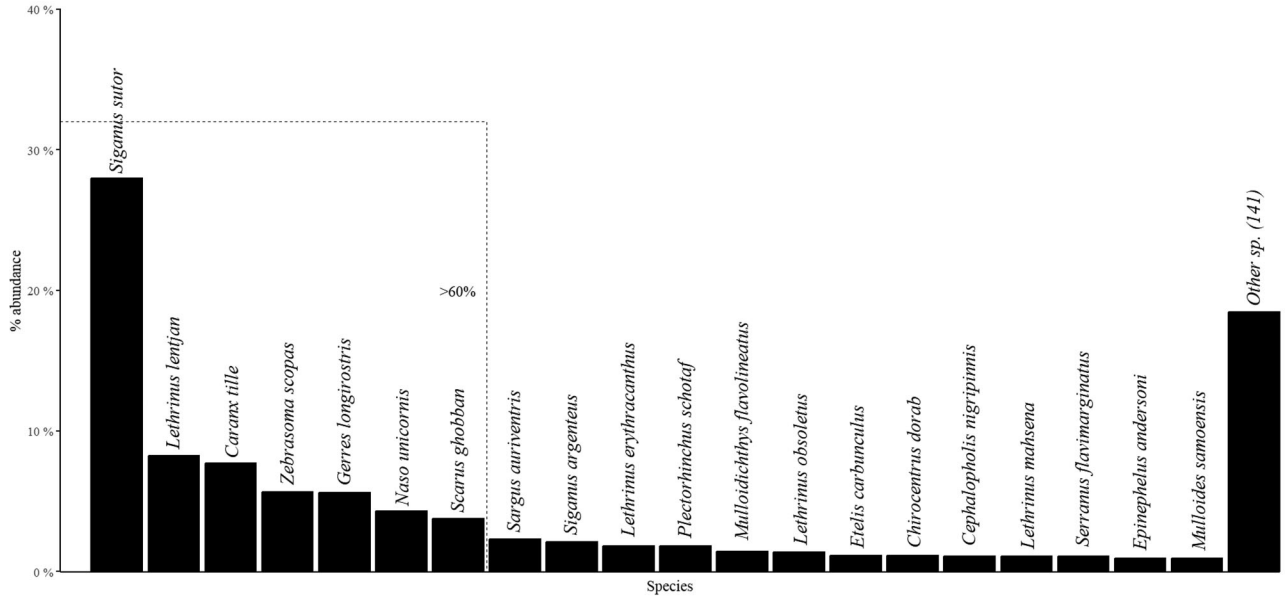


FIGURE 2 | Relative abundance of top 20 species with the 7 most caught species more than 60% of the total abundance.

TABLE 3 | Summary information for each species surveyed during the study.

Species	Total weight (kg)	Number fish landed	Number fish sampled	Boat days
Siganus sutor	49,496	79,653	22,835	94,638
Lethrinus lentjan	14,614	15,863	4738	18,893
Caranx ignobilis	13,699	10,798	4017	11,101
Zebrasoma scopas	10,047	25,805	3850	18,556
Gerres longirostris	9924	29,764	2829	5586
Naso unicornis	7617	4483	3243	3929
Scarus ghobban	6643	8143	5302	5193
Total	112,040	174,509	46,814	157,896

The situation in 2023 appears even more positive, with $\frac{B}{B_0} = 0.87$ and very low fishing pressure ($\frac{F}{M} = 0.09$). The sizes caught are close to the optimal size ($\frac{L_{\text{mean}}}{L_{\text{opt}}} = 0.97$), and large individuals are well represented ($\frac{L_{95\text{th}}}{L_{\text{inf}}} = 0.98$). The estimates $\frac{L_c}{L_{\text{c_opt}}} = 0.91$, which is approximately equal to 1, indicate that the average size of the fish caught is close to the optimum length for maximum production per recruit ($\frac{Y'}{R} = 0.011$). These results confirm that exploitation is sustainable for the stock.

3.1.2 | L. lentjan

For *L. lentjan*, the general references point indicate a moderately exploited stock, with a median relative biomass $\frac{B}{B_0} = 0.45$ (0.27–0.61). Fishing mortality is lower than natural mortality ($\frac{F}{M} = 0.73$), suggesting significant but biologically sustainable fishing pressure over the entire period. The median length at first capture remains slightly below the optimal size, which may contribute to a partial reduction in reproductive potential.

However, estimates for 2023 reveal a marked improvement in the stock status, with high relative biomass ($\frac{B}{B_0} = 0.90$) (Figure 4) and very low fishing pressure ($\frac{F}{M} = 0.08$). The average size of catches exceeds the optimal size ($\frac{L_{\text{mean}}}{L_{\text{opt}}} = 1.1$), and the proportion of mature specimens is high (≈ 81%). These results suggest a recent positive situation, probably linked to a decline in fishing effort, improved selectivity or positive recruitment.

3.1.3 | C. tille

This study suggests that the stock of *C. tille* is moderately exploited but vulnerable. Over the period 2018–2023, the median relative biomass is estimated at $\frac{B}{B_0} = 0.44$ (0.28–0.62), and fishing mortality remains below natural mortality ($\frac{F}{M} = 0.60$). The size structure suggests a catch slightly below the optimum.

TABLE 4 | Summary of LBB outputs for the 7 most caught coral reef fish species landed along the south of Toliara.

Scientific name	$\frac{L_{mean}}{L_{opt}}$	$\frac{L_c}{L_{c_opt}}$	$\frac{L_{95th}}{L_{inf}}$	$\frac{B}{B_0}$	$\frac{F}{M}$	$\frac{F}{K}$	$\frac{Z}{K}$
Siganus sutor	0.97	0.91	0.98	0.55	0.6	0.9	2.4
Median				0.87	0.094	0.13	1.6
2023							
Lethrinus lentjan	1.1	1.1	0.93	0.45	0.7	1	2.5
Median				0.9	0.083	0.12	1.6
2023							
Caranx tille	0.84	0.79	0.85	0.44	0.6	0.9	2.43
Median				0.39	0.74	1.1	2.6
2023							
Zebrasoma scopas	0.9	0.88	0.93	0.89	0.07	0.10	1.51
Median				0.82	0.13	0.19	1.6
2023							
Gerres longirostris	0.81	0.74	0.91	0.19	1.52	2.2	3.7
Median				0.19	1.7	2.5	4
2023							
Naso unicornis	1	1.1	0.88	0.55	0.47	0.69	2.18
Median				0.53	0.57	0.86	2.4
2023							
Scarus ghobban	0.52	0.35	0.8	0.14	1.46	2.17	3.67
Median				0.12	1.7	2.5	4
2023							

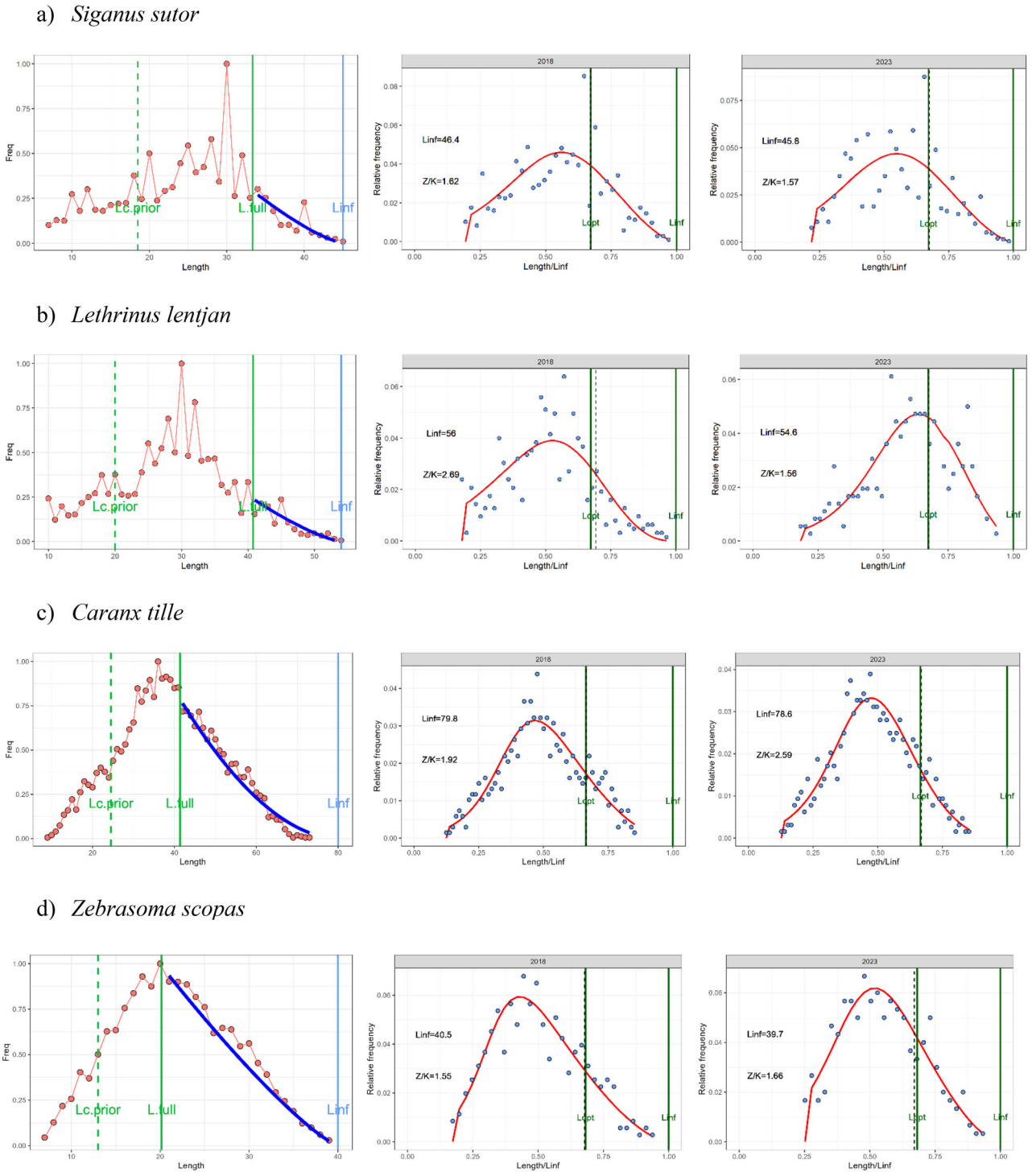
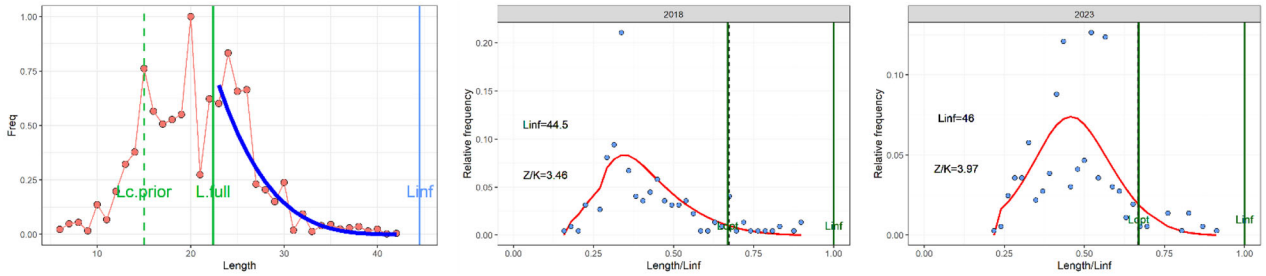
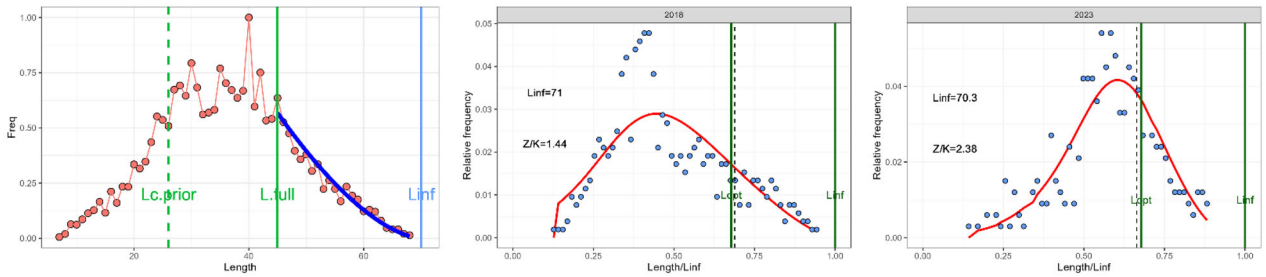


FIGURE 3 | Length-based Bayesian biomass analyses of seven most commonly caught coral reef fish species. The left curves show the fits of the model to the length data; the middle and right curves are the predictions of the LBB analysis (2018 and 2023), L_c is the length of 50% individuals captured by the gear, L_{inf} is the asymptotic length, and L_{opt} is the length where the maximum biomass of the unexploited stock is obtained.

e) *Gerres longirostris*



f) *Naso unicornis*



g) *Scarus ghobban*

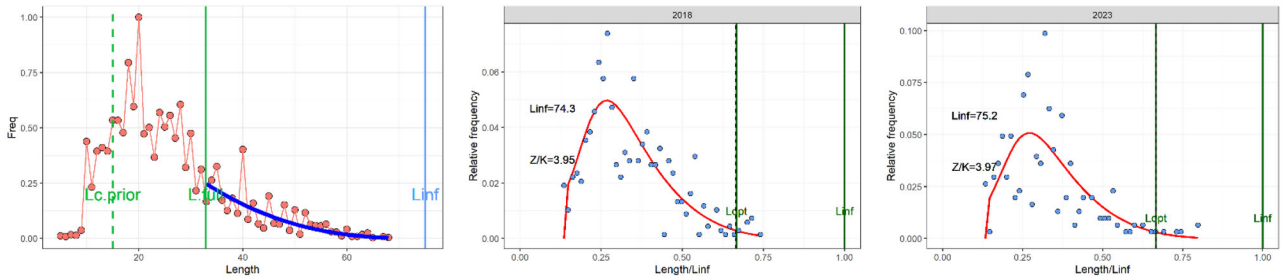


FIGURE 3 | (Continued)

The relative biomass is slightly lower ($\frac{B}{B_0} = 0.39$) in 2023, indicates that the current biomass represents approximately 39% of the unexploited biomass, and fishing pressure increases ($\frac{F}{M} = 0.74$), although it remains below the critical limit. Furthermore, the size at first capture ($L_{C_{50}} = 32.9$ cm) remains below the optimal capture size ($L_{c_opt} = 42$ cm), with a ratio $\frac{L_c}{L_{c_opt}} = 0.79$. This shows that fish are harvested before they reach optimum size, which compromises long-term yield and the sustainability of the stock. However, the presence of large individuals ($\frac{L_{95th}}{L_{inf}} = 0.85$) indicates that the stock retains its capacity for renewal but remains sensitive to any increase in fishing effort.

3.1.4 | Z. scopas

Z. scopas shows biological indicators consistent with a moderately exploited stock. Median estimates for 2018–2023 show high relative biomass ($\frac{B}{B_0} = 0.89$), well above the biological reference point. Fishing mortality is very low, indicating that stock dynamics are mainly regulated by natural mortality ($\frac{F}{M} = 0.07$).

The observed size structure is close to the biological optimum, with an expected average size under sustainable exploitation (L_{mean} if F = M = 22 cm) consistent with the sizes actually caught. The yield per recruit is relatively low, reflecting limited exploitation rather than overfishing.

In 2023, the results confirm this positive situation, with $\frac{B}{B_0} = 0.82$ (0.22–1.8) and $\frac{F}{M} = 0.13$. The sizes observed are close to the optimal size ($\frac{L_{mean}}{L_{opt}} = 0.88$) and large individuals are well represented ($\frac{L_{95th}}{L_{inf}} = 0.93$), suggesting a balanced demographic structure and sustainable exploitation.

3.1.5 | G. longirostris

G. longirostris shows clear signs of persistent overexploitation. The median results for 2018–2023 indicate low relative biomass [$\frac{B}{B_0} = 0.19$ (0.14–0.23)], below the critical limit, and high fishing mortality ($\frac{F}{M} = 1.52$). Most catches occur before the optimal size,

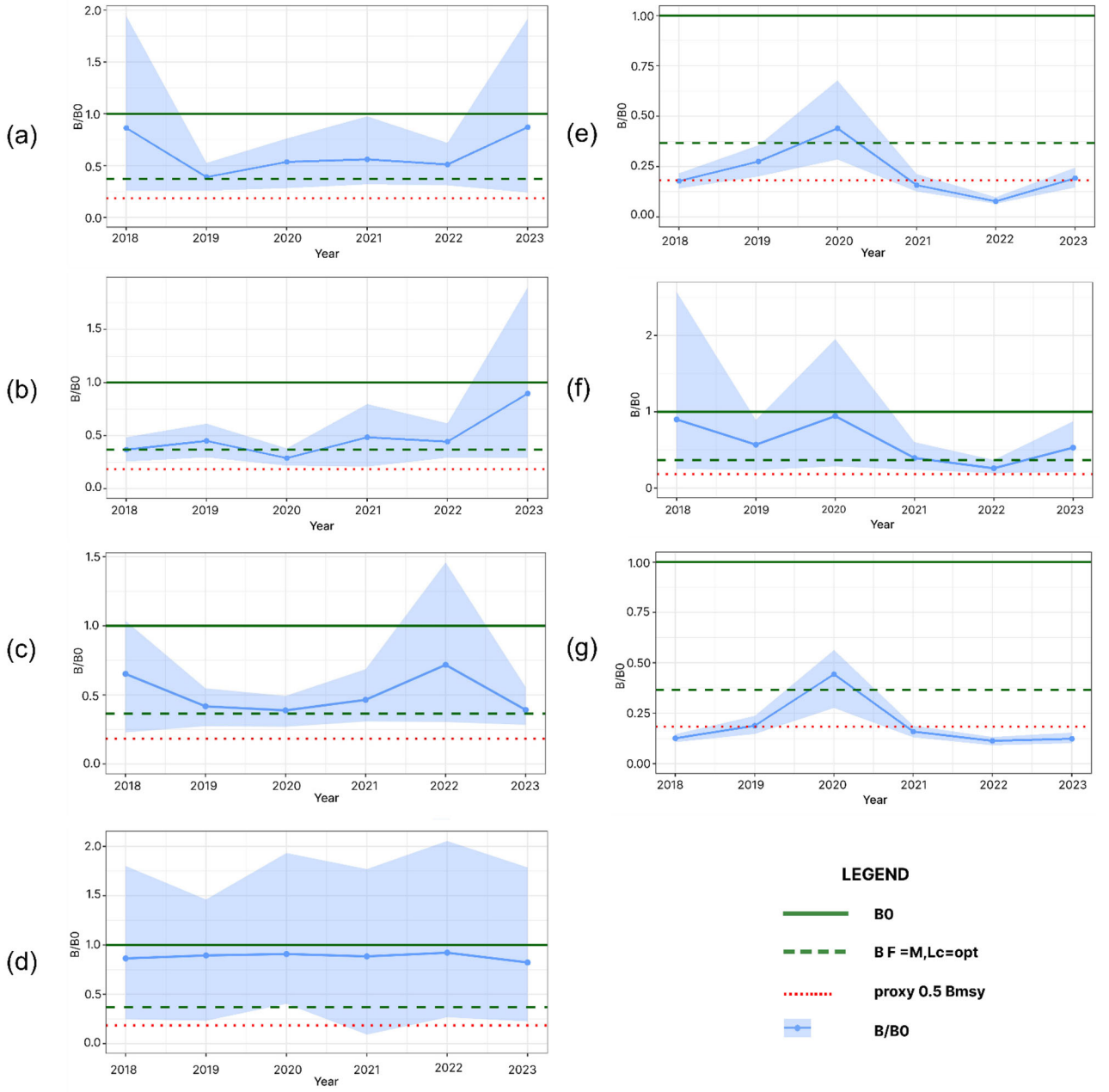


FIGURE 4 | Relative Biomass of seven most caught coral reef fish species. (a) *Siganus sutor*, (b) *Lethrinus lentjan*, (c) *Caranx tille*, (d) *Zebrasoma scopas*, (e) *Gerres longirostris*, (f) *Naso unicornis*, (g) *Scarus ghobban*.

leading to a significant reduction in reproductive potential and sustainable yield.

Estimates for 2023 confirm this concerning situation, with $\frac{B}{B_0}$ = 0.19 (0.15–0.25) and increased fishing pressure ($\frac{F}{M}$ = 1.7). Although the proportion of mature individuals reaches around 54%, the biomass remains insufficient to ensure sustainable renewal of the stock in the long term.

3.1.6 | N. unicornis

N. unicornis shows indicators consistent with a stock in good biological condition. Median results show a relative biomass $\frac{B}{B_0}$ = 0.55 (0.24–0.88) and moderate fishing pressure ($\frac{F}{M}$ = 0.47). The size at first capture is close to, or even greater than, the optimal size, suggesting some selectivity benefit from the fishery.

The 2023 estimates confirm this situation, with $\frac{B}{B_0}$ = 0.53 (0.21–0.87), $\frac{L_{\text{mean}}}{L_{\text{opt}}} \approx 1$, and fishing mortality remaining below natural mortality. The balanced size structure and the presence of large individuals suggest exploitation which is compatible with medium-term sustainability.

3.1.7 | S. ghobban

LBB analysis indicates that *S. ghobban*, locally known as 'Bodoloha' was severely overexploited throughout the period 2018–2023. The general reference points show a median relative

biomass [$\frac{B}{B_0}$ = 0.14 (0.12–0.17)] well below the critical level of 0.25, reflecting a significant reduction in biomass compared to the unexploited biomass. Fishing mortality significantly exceeds natural mortality ($\frac{F}{M}$ = 1.46), confirming excessive and persistent fishing pressure.

The size structure is severely degraded, with an estimated optimal catch size of L_{c_opt} = 44 cm, while the observed catch size is very much smaller [$L_{C_{50}}$ = 15.5 (15.1–15.8) cm]. The exploitation of mainly juveniles is severely limiting the reproductive potential of the stock. The standardised yield per recruit ($\frac{Y'}{R}$ = 0.018) is significantly lower than the estimated potential yield under biologically sustainable conditions.

In 2023, the situation remains critical, with an estimated relative biomass of $\frac{B}{B_0}$ = 0.12 (0.10–0.15) and increased fishing pressure ($\frac{F}{M}$ = 1.7). The average catch size (L_{mean} = 26.2 cm) is only 52% of the optimal size. The ratio $\frac{L_{mean}}{L_{opt}}$ and $\frac{L_c}{L_{c_opt}}$ are less than 1, indicating a truncated length structure and fishing pressure on juveniles which is greater than optimal. These results confirm the persistence of severe overexploitation with no signs of recent recovery.

4 | Discussion

4.1 | Limitations of the Study and Perspectives

This is the first time that coral reef fish stocks from the Southwest of Madagascar have been assessed using the length-based method. Length-based models are sensitive to values of the input life history parameters such as asymptotic length and the ratio of natural mortality to growth (Hordyk et al. 2014). Despite this sensitivity, LBB is particularly well suited to data-limited and data-poor fisheries as it does not require time series of catch or fishing effort, which are often erratic or missing (Sultana et al. 2022). Instead, the method relies on LF data combined with externally derived life history priors, which can be obtained from FishBase. Nevertheless, the effects of the misspecification of priors, as L_{inf} and $\frac{M}{K}$ can generate failures in current stock status classification and in management measures (Medeiros-Leal et al. 2023). For an ecosystem where catch data is difficult to collect, the LBB method provides a method of assessing the relative biomass of exploited stocks (Zhang et al. 2021).

For this study, all the LF data was obtained from a small-scale, multi-species fishery over a six year timeframe and represented all possible length classes of the species analysed, thus meeting all LBB requirements. Representative LF samples from the main gear used in the fishery or from the main landing site may suffice to get a preliminary impression of stock size relative to levels that can produce MSY (Froese et al. 2018). The consistency observed between medians and 2023 estimates reinforces the robustness of the analysis presented. The future integration of independent data, such as abundance index, information on fishing effort and similar length-based models, would make it possible to refine assessments and strengthen management recommendations.

In fact, several length-based approaches have been developed and widely used to serve these data-limited fisheries where only length data are available, such as length-based indicators. A similar method to LBB is the SPR (spawning potential ratio) approach, which uses the section of the length-frequency curve above the length Lm50 where 50% of the individuals are mature, it calculates the corresponding egg production by converting lengths into fecundity using a length–fecundity relationship, and then compares egg production with the one that would be present without fishing (Froese et al. 2018). This information is useful for assessing the state of fisheries and defining management and conservation measures. In addition, SPR is applicable for data-limited and data-poor fisheries, and which requires only biological information and length data that could be proposed as thresholds for overfishing or FMSY proxy (Brooks et al. 2010). However, in a fishery where reliable maturity data are not available, the LBSPR should not be applied to avoid overinterpretation of uncertain estimates.

The LBI (length based indicators) is another model that defines biological reference points and allows to assess qualitative characteristics of the population and fisheries and MSY (Kozobrod et al. 2021). Medeiros-Leal et al. (2023) considers that LBI is more consistent than LBSPR and LBB, and more sensitive to changes in fish population structure, caused by fishing impacts and to adaptive management, but its application its application requires a reliable representation of large individuals and mega-spawners. Therefore, LBI could help fisheries managers to assess changes in the fish community (Kell et al. 2022).

4.2 | Biomass Status of the Seven Assessed Species

The wide variability in biomass conditions among the seven species of reef fish highlights interspecific differences in stock status and the complexity of managing a small-scale multi-species fishery. Two species (*S. ghobban* and *G. longirostris*) showed consistently low biomass levels, with median $\frac{B}{B_0}$ values below 0.25, indicating a depleted stock (Froese et al. 2018). In contrast, three species (*S. sutor*, *N. unicornis* and *Z. scopas*) maintained relatively high biomass levels, with median $\frac{B}{B_0}$ values generally above 0.5, suggesting exploitation levels compatible with biomass maintenance. The other two species (*C. tille* and *L. lentjan*) showed moderate biomass exploitation, with median $\frac{B}{B_0}$ values between 0.25 and 0.5 (Figure 4).

Estimates for 2023 were generally consistent with the general reference points (multi-year medians), indicating that observed biomass trends reflect persistent stock conditions rather than short-term inter-annual variability. For species with relatively low biomass levels, $\frac{B}{B_0}$ values in 2023 remained low and showed no signs of recovery, reflecting continued fishing pressure. Furthermore, species with relatively high median biomass generally maintained similar or slightly improved $\frac{B}{B_0}$ levels in 2023, corresponding to lower fishing mortality and more positive size structures.

In the case of *L. lentjan*, its biomass estimate for 2023 was significantly higher than the multi-year median, suggesting a potential recent increase in biomass associated with a reduction

in fishing mortality. However, the uncertainty surrounding this estimate indicates that this apparent improvement should be interpreted with caution.

Low biomass levels were associated with reduced potential productivity, as evidenced by lower relative values for yield per recruit compared to optimal exploitation scenarios (Beverton and Holt 1957). These results indicate that while some stocks remain relatively resilient, a significant proportion of the species assessed have biomass levels well below their unfished reference points, highlighting the heterogeneous impacts of fishing pressure within the reef fish assemblage.

4.3 | Management Implications

The results of the LBB analysis highlight significant interspecific heterogeneity in the status of reef stocks exploited between 2018 and 2023. The differences observed between species reflect both life history traits and specific modes of exploitation. Five of the seven species show a risk of growth overfishing that occurs when fish are harvested before they reach their optimum size, thus reducing fishery yields (Nadon et al. 2015). Since the length at first capture (L_c) depends on the gear used, it is therefore important to manage the selectivity of fishing gear based on fish size to improve fisheries management in the Southwest of Madagascar (Babcock et al. 2018; Humphries et al. 2019; Ranaivomanana et al. 2023). The LBB outputs gives a comparison of current length at first capture L_c relative to L_{c_opt} that would maximize catch and biomass for the given fishing pressure, management can propose changes in lengths at first capture and in fishing effort until relative biomass predicted by LF data exceeds the approximate MSY level (Froese et al. 2016, 2018).

The findings of this study highlight the need to adopt species-specific management measures rather than a uniform approach in the context of small-scale reef fisheries. For *S. ghobban* and *G. longirostris*, gear selectivity should be shifted upwards such that the peak in frequency is well above L_{mat} to ensure successful reproduction. A target for $L_{C_{50}}$, at which 50% of fish are susceptible to being caught by the fishing gear, would be about half of maximum length, so that the peak in frequency would be close to about 2/3 of L_{inf}. This is likely to end the overfishing, improve the stock size visible in the graphs and secure sustainable catches near the theoretical maximum. An awareness campaign highlighting the message that it's important to allow fish to spawn prior to their capture is likely to support the adoption of such a management measure. This is supported by a social marketing campaign previously held in the Southwest region of Madagascar to improve fishers' knowledge and attitudes toward the *dina* and its enforcement, thereby reducing the practice of destructive fishing (Andriamalala et al. 2013). For moderately exploited but vulnerable species (*C. tille*, *L. lentjan*), a precautionary measure is recommended. Maintaining fishing effort at its current level, accompanied by regular monitoring of size structure and biomass, would prevent a transition to a state of overexploitation.

The establishment of community 'No Take Zones' (NTZs) is currently one of the approaches being used to increase fish abundance. In the southern region of Madagascar, NTZs are implemented as a fisheries management measure due to their potential to facilitate the recovery of depleted stocks, prevent recruitment overfishing and promote spillover of biomass into adjacent fished areas (Humber et al. 2006). In others region, studies have shown that the biomass and abundance of reef fish targeted by fishers are greater in NTZs than in the usual fishing grounds (Westera et al. 2003; Babcock et al. 2009; Wilson et al. 2012). However, this study shows that there is uncertainty in the biomass estimate, which may result in inequitable distribution of effort or in management measures that are not the same in different localities, as in the case of *Zebrasomas scopas*, $\frac{B}{B_0}$ (2023) = 0.92 (0.33–1.9) (Figure 4) Macneil et al. (2015) found that the status of reef fish assemblages on fished reefs against a B_0 baseline varied considerably by locality and whether there were management restrictions on fishing activities. In addition, there are a range of factors that need to be considered for population recovery to occur within NTZs, such as initial population size, intrinsic population growth rate, recruitment success, flow rates across reserve boundaries and the degree of reduction in fishing mortality within the reserve (Jennings 2001; Abesamis and Russ 2005).

4.4 | Implications for Coastal Communities and Their Role in Fisheries Management

In a developing country such as Madagascar, where coastal community dependence on fishing for food and livelihoods is high, the participation of fishers in marine resource management is a preferable approach (Gilchrist et al. 2020). Community-based marine resource management, in which coastal communities manage their own resources on which their survival depends, constitutes a shared management system that highlights the role of each stakeholder (Beyerl et al. 2016). Locally managed marine areas (LMMAs), one form of this management scheme, offers an emerging participatory management approach that can be used to balance the different interests involved in decision-making regarding conserving nature and sustaining local livelihoods (Newell et al. 2019). The involvement of communities in the management of marine resources is therefore crucial, as local authorities seldom have the capacity and resources to effectively monitor the fisheries particularly in remote areas. Highlighting the need to jointly identify and define management measures with fishers, including those based on local knowledge (Salas et al. 2023). Local communities also contribute to fisheries management by participating in data collection, analysis and interpretation, improving data availability in fisheries where data is limited, and enabling a better understanding of stock dynamics and more effective participation in management decisions (House et al. 2023).

Author Contributions

Miarisoa Lalaina Rakotonaivo: Conceptualization, writing – original draft preparation, methodology, data curation, formal analysis, writing – review and editing, visualization. Lala N.J. Ranaivomanana: Conceptualization, supervision, methodology, formal analysis, writing – review and editing. Charlotte Gough: Conceptualization, methodology, formal analysis, writing – review and editing. Jérémie R. Ndriamanja: Methodology, formal analysis, writing – review and editing. Danny Kor-

nelio Ravelojaona: Methodology, administration, formal analysis, writing – review and editing. Ravakiniaina Frida Razafinaivo: Methodology, administration, formal analysis, writing – review and editing. Daniel Raberinary: Conceptualization, methodology, formal analysis, writing – review and editing, visualization

Acknowledgements

The authors would like to acknowledge the work of the 78 data collectors involved in monitoring and data collection on small-scale fisheries in the Mahafaly seascape, as well as Rindra Ranaivomanana and Roddy Randriatsara for their support with data structuring. The authors also gratefully acknowledge Samantha Petersen (WWF SWIO) and Shauna Mahajan (WWF US) for their comments and constructive feedback on the manuscript drafts.

Funding

This work was supported by KfW through Madagascar National Parks, under the Sustainable Coastal Fisheries project and implemented by WWF Madagascar.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data that support the findings of this study are available from the corresponding author upon reasonable request.

References

Abesamis, R. A., and G. R. Russ. 2005. "Density-Dependent Spillover From a Marine Reserve: Long-Term Evidence." *Ecological Applications* 15, no. 5: 1798–1812. https://doi.org/10.1890/05-0174.

Andriamalala, G., S. Peabody, C. J. Gardner, and K. Westerman. 2013. "Using Social Marketing to Foster Sustainable Behaviour in Traditional Fishing Communities of Southwest Madagascar." *Conservation Evidence* 10: 37–41.

Babcock, R. et al. 2009. *Ecosystem Impacts of Human Usage and the Effectiveness of Zoning for Biodiversity Conservation Trophic Effects Surveys*. Final Report to WAMSI. CSIRO 2009.

Babcock, E. A., A. Tewfik, and V. Burns-Perez. 2018. "Fish Community and Single-Species Indicators Provide Evidence of Unsustainable Practices in a Multi-Gear Reef Fishery." *Fisheries Research* 208: 70–85. https://doi.org/10.1016/j.fishres.2018.07.003.

Barnes, D. K. A., and K. A. Rawlinson. 2009. "Traditional Coastal Invertebrate Fisheries in South-Western Madagascar." *Journal of the Marine Biological Association of the United Kingdom* 89, no. 8: 1589–1596. https://doi.org/10.1017/s0025315409000113.

Basurto, X., N. L. Gutierrez, N. Franz, et al. 2025. "Illuminating the Multidimensional Contributions of Small-Scale Fisheries." *Nature* 637: 875–884. https://doi.org/10.1038/s41586-024-08448-z.

Beverton, R. J. H., and S. J. Holt. 1957. *On the Dynamics of Exploited Fish Populations*. H.M. Stationery Office.

Beverton, R. J. H., and S. J. Holt. 1966. *Manual of Methods for Fish Stock Assessment, Part 2: Tables of Yield Functions*. FAO. https://catalog.hathitrust.org/Record/008338124.

Beyerl, K., O. Putz, and A. Breckwoldt. 2016. "The Role of Perceptions for Community-Based Marine Resource Management." *Frontiers in Marine Science* 3: 238. https://doi.org/10.3389/fmars.2016.00238.

Brenier, A., J. Ferraris, and J. Mahafina. 2012. "Participatory Assessment of the Toliara Bay Reef Fishery, Southwest Madagascar." *Madagascar Conservation & Development* 6, no. 2: 60–67. https://doi.org/10.4314/mcd.v6i2.4.

Brooks, E. N., J. E. Powers, and E. Cortés. 2010. "Analytical Reference Points for Age-Structured Models: Application to Data-Poor Fisheries." *ICES Journal of Marine Science* 67, no. 1: 165–175. https://doi.org/10.1093/icesjms/fsp225.

Caddy, J. F. 1999. "Fisheries Management in the Twenty-First Century: Will New Paradigms Apply?" *Reviews in Fish Biology and Fisheries* 9: 1–43.

Chuenpagdee, R., P. Degnbol, M. Bavinck, et al. 2005. "Challenges and Concerns in Capture Fisheries and Aquaculture." In *Fish for Life: Interactive Governance for Fisheries*, edited J. Kooiman, S. Jentoft, R. Pullin, and M. Bavinck, 25–37. Amsterdam University Press.

Cinner, J. E., T. Daw, and T. R. McClanahan. 2009. "Socioeconomic Factors that Affect Artisanal Fishers' Readiness to Exit a Declining Fishery." *Conservation Biology* 23: 124–130. https://doi.org/10.1111/j.1523-1739.2008.01041.x.

Cooke, A., S. Wells, J. Oates, et al. 2022. "Marine and Coastal Ecosystems Marine and Coastal Biodiversity and Conservation." In *The New Natural History of Madagascar*, edited by S. M. Goodman, 311–358. Princeton University Press.

Costello, C., D. Ovando, R. Hilborn, S. D. Gaines, O. Deschenes, and S. E. Lester. 2012. "Status and Solutions for the World's Unassessed Fisheries." *Science* 338: 517–520. https://doi.org/10.1126/science.1223389.

De Graaf, G. J., R. J. R. Grainger, L. Westlund, et al. 2011. "The Status of Routine Fishery Data Collection in Southeast Asia, Central America, the South Pacific, and West Africa, With Special Reference to Small-Scale Fisheries." *ICES Journal of Marine Science* 68: 1743–1750. https://doi.org/10.1093/icesjms/fsr054.

Derhy, G., K. Elkalay, M. M. Rincón, and K. Khalil. 2024. "Stochastic Surplus Production and Length-Based Assessment Models to Compare Maximum Sustainable Yield Advice for the Moroccan Atlantic Chub Mackerel." *Frontiers in Marine Science* 11: 1386541. https://doi.org/10.3389/fmars.2024.1386541.

Dowling, N. A., A. D. M. Smith, D. C. Smith, et al. 2019. "Generic Solutions for Data-Limited Fishery Assessments Are Not so Simple." *Fish and Fisheries* 20, no. 1: 174–188. https://doi.org/10.1111/faf.12329.

FAO, Duke University, and Worldfish. 2023. *Illuminating Hidden Harvests: The Contributions of Small-Scale Fisheries to Sustainable Development—Executive Summary*. Food and Agriculture Organization of the United Nations, Duke University, and Worldfish. https://doi.org/10.4060/cc6062en.

Fitzgerald, C., K. Delanty, and S. Shephard. 2018. "Inland Fish Stock Assessment: Applying Data-Poor Methods From Marine Systems." *Fisheries Management and Ecology* 25, no. 4: 240–252. https://doi.org/10.1111/fme.12284.

Froese, R. 2004. "Keep It Simple: Three Indicators to Deal With Overfishing." *Fish Fish* 5, no. 1: 86–91. https://doi.org/10.1111/j.1467-2979.2004.00144.x.

Froese, R., H. Winker, D. Gascuel, U. R. Sumaila, and D. Pauly. 2016. "Minimizing the Impact of Fishing." *Fish and Fisheries* 17, no. 3: 785–802. https://doi.org/10.1111/faf.12146.

Froese, R., H. Winker, G. Coro, et al. 2018. "A New Approach for Estimating Stock Status From Length Frequency Data." *ICES Journal of Marine Science* 75, no. 6: 2004–2015. https://doi.org/10.1093/icesjms/fsy078.

Froese, R., H. Winker, G. Coro, et al. 2019. "On the Pile-up Effect and Priors for L_{inf} and M/K: Response to a Comment by Hordyk on "a New Approach for Estimating Stock Status From Length Frequency Data"." *ICES Journal of Marine Science* 76, no. 2: 461–465. https://doi.org/10.1093/icesjms/fsy199.

Gilchrist, H., S. Rocliffe, L. G. Anderson, and C. L. A. Gough. 2020. "Reef Fish Biomass Recovery Within Community-Managed no Take Zones." *Ocean & Coastal Management* 192: 105210. https://doi.org/10.1016/j.ocecoaman.2020.105210.

Gough, C. L. A., K. M. Dewar, B. J. Godley, E. Zafindranosy, and A. C. Broderick. 2020. "Evidence of Overfishing in Small-Scale Fisheries in Madagascar." *Frontiers in Marine Science* 7: 317. https://doi.org/10.3389/fmars.2020.00317.

Hordyk, A., K. Ono, S. Valencia, N. Loneragan, and J. Prince. 2014. "A Novel Length-Based Empirical Estimation Method of Spawning Potential Ratio (SPR), and Tests of Its Performance, for Small-Scale, Data-Poor Fisheries." *ICES Journal of Marine Science* 72, no. 1: 217–231. https://doi.org/10.1093/icesjms/fsu004.

House, J., D. Kleiber, D. J. Steenbergen, and N. Stacey. 2023. "Participatory Monitoring in Community-Based Fisheries Management Through a Gender Lens." *Ambio* 52, no. 2: 300–318. https://doi.org/10.1007/s13280-022-01783-3.

Humber, F., A. Harris, D. Raberinary, and M. Nadon. 2006. "Seasonal Closures of No-Take Zones to Promote A Sustainable Fishery for Octopus Cyanea (Gray) in South West Madagascar.".

Humphries, A. T., K. D. Gorospe, P. G. Carvalho, I. Yulianto, T. Kartawijaya, and S. J. Campbell. 2019. "Catch Composition and Selectivity of Fishing Gears in a Multi-Species Indonesian Coral Reef Fishery." *Frontiers in Marine Science* 6: 378. https://doi.org/10.3389/fmars.2019.00378.

Jacquet, J., and D. Pauly. 2008. "Funding Priorities: Big Barriers to Small-Scale Fisheries." *Conservation Biology* 22, no. 4: 832–835. https://doi.org/10.1111/j.1523-1739.2008.00978.x.

Jennings, S. 2001. "Patterns and Prediction of Population Recovery in Marine Reserves." *Reviews in Fish Biology and Fisheries* 10, no. 2: 209–231.

Jensen, A. L. 1996. "Beverton and Holt Life History Invariants Result From Optimal Trade-Off of Reproduction and Survival." *Canadian Journal of Fisheries and Aquatic Sciences* 53, no. 4: 820–822. https://doi.org/10.1139/f95-233.

Kell, L. T., C. Minto, and H. D. Gerritsen. 2022. "Evaluation of the Skill of Length-Based Indicators to Identify Stock Status and Trends." *ICES Journal of Marine Science* 79, no. 4: 1202–1216. https://doi.org/10.1093/icesjms/fsac043.

Kozobrod, I., M. Piatinskii, and E. Vlasenko. 2021. "Azov Sea Vimba Indicator Assessment of the State of Fish Population in Terms of Lack of Biological Data by LBI Model." *Fisheries* 2021, no. 3: 68–75. https://doi.org/10.37663/0131-6184-2021-3-68-75.

Leenhardt, P., M. Lauer, R. Madi Moussa, et al. 2016. "Complexities and Uncertainties in Transitioning Small-Scale Coral Reef Fisheries." *Frontiers in Marine Science* 3: 70. https://doi.org/10.3389/fmars.2016.00070.

Macneil, M. A., N. A. J. Graham, J. E. Cinner, et al. 2015. "Recovery Potential of the World's Coral Reef Fishes." *Nature* 520, no. 7547: 341–344. https://doi.org/10.1038/nature14358.

Medeiros-Leal, W., R. Santos, U. I. Peixoto, et al. 2023. "Performance of Length-Based Assessment in Predicting Small-Scale Multispecies Fishery Sustainability." *Reviews in Fish Biology and Fisheries* 33: 819–852. https://doi.org/10.1007/s11160-023-09764-9.

MPEB. 2022. "Chiffres clés du secteur pêche et de l'aquaculture."

Nadon, M. O., J. S. Ault, I. D. Williams, S. G. Smith, and G. T. Dinardo. 2015. "Length-Based Assessment of Coral Reef Fish Populations in the Main and Northwestern Hawaiian Islands." *PLoS ONE* 10, no. 8: e0133960. https://doi.org/10.1371/journal.pone.0133960.

Newell, S., N. Nagabhatla, N. C. Doubleday, and A. Bloecker. 2019. "'The Potential for Locally Managed Marine Area (LMMAs) as a Participatory Strategy for Coastal and Marine Ecosystems-the Global Commons'." *OIDA International Journal of Sustainable Development* 12, no. 04: 47–62.

Obura, D. O., S. Wells, J. Church, and C. Horrill. 2002. "Monitoring of Fish and Fish Catches by Local Fishermen in Kenya and Tanzania." *Marine and Freshwater Research* 53: 215–222. https://doi.org/10.1071/MF01151.

Rahangdale, S., P. U. Zacharia, R. Kumar, and V. Vase. 2022. "Evaluating the Stock Status of 10 Croaker Species Landed Along the North-Eastern Arabian Sea Using the Length-Based Bayesian Biomass Approach." *Frontiers in Marine Science* 9: 952795. https://doi.org/10.3389/fmars.2022.952795.

Rakotoson, L. R., and K. Tanner. 2006. "Community-Based Governance of Coastal Zone and Marine Resources in Madagascar." *Ocean & Coastal Management* 49: 855–872. https://doi.org/10.1016/j.ocecoaman.2006.08.003.

Ranaivomanana, H. S., S. Jaquemet, D. Ponton, et al. 2023. "Intense Pressure on Small and Juvenile Coral Reef Fishes Threatens Fishery Production in Madagascar." *Fisheries Management and Ecology* 00: 1–13. https://doi.org/10.1111/fme.12637.

Raza, H., Q. Liu, M. S. Alam, and Y. Han. 2022. "Length Based Stock Assessment of Five Fish Species From the Marine Water of Pakistan." *Sustainability* 14: 1587. https://doi.org/10.3390/su14031587.

Salas, S., M. A. Cabrera, E. Coronado, et al. 2023. "Typology of Small-Scale Fisheries of the Yucatan Peninsula, Mexico: Recognizing Complexity of Mixed Fisheries in Assessment and Management." *Ciencia Pesquera* 31: 89–114.

Sarkar, U. K., J. K. Jena, S. P. Singh, A. K. Singh, and S. C. Rebello. 2012. "Documenting Coastal Fish Biodiversity of India: Status, Issues and Challenges." Paper presented at the International Day for Biological Diversity, Marine Biodiversity, Lucknow, India, May 22.

Shephard, S., J. Valbo-Jorgensen, J. Abadía, et al. 2020. Size-based Assessment of Data-*Limited* Inland Fish Stocks – Review and Applications. FAO Fisheries and Aquaculture Circular No. 1214. FAO. https://doi.org/10.4060/cb1594en.

Shepherd, J. G. 1984. "Status Quo Catch Estimation and Its Use in Fishery Management." International Council for the Exploration of the Sea CM, G25.

Sultana, R., Q. Liu, P. Schneider, et al. 2022. "Stock Assessment of Six Sciaenidae Species in the Bay of Bengal, Bangladesh Water Using a Length-Based Bayesian Biomass (LBB) Method." *Fishes* 7: 214. https://doi.org/10.3390/fishes7050214.

Westera, M., P. Lavery, and G. Hyndes. 2003. "Differences in Recreationally Targeted Fishes Between Protected and Fished Areas of a Coral Reef Marine Park." *Journal of Experimental Marine Biology and Ecology* 294, no. 2: 145–168. https://doi.org/10.1016/S0022-0981(03)00268-5.

Wilson, S. K., R. C. Babcock, R. Fisher, T. H. Holmes, J. A. Y. Moore, and D. P. Thomson. 2012. "Relative and Combined Effects of Habitat and Fishing On Reef Fish Communities Across a Limited Fishing Gradient at Ningaloo." *Marine Environmental Research* 81: 1–11. https://doi.org/10.1016/j.marenvres.2012.08.002.

Zafimahatradraibe, J. A., L. N. J. Ranaivomanana, C. Rakotomahazo, B. Randriamanantsoa, A. C. Hartmann, and G. G. B. Todinanahary. 2025. "Authority, Capacity, and Power to Govern: Three Marine Protected Areas Co-Managed by Resource Users and Non-Governmental Organizations." *Marine Policy* 177: 106647. https://doi.org/10.1016/j.marpol.2025.106647.

Zhang, K., J. Zhang, D. Shi, and Z. Chen. 2021. "Assessment of Coral Reef Fish Stocks from the Nansha Islands, South China Sea, Using Length-Based Bayesian Biomass Estimation." *Frontiers in Marine Science* 7: 610707. https://doi.org/10.3389/fmars.2020.610707.