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Research Article

Assessment of the Fish Stock Status Using LBSPR with Its Implications on Fisheries Management: A Case Study of *Nemipterus virgatus*, *Priacanthus macracanthus*, and *Saurida undosquamis* in the Northern South China Sea

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This study utilized the length-based spawning potential ratio (LBSPR), a data-limited model, to assess the stock status of three fin fish species in the northern South China Sea. The analysis used the "LBSPR" package in *R* software, incorporating catch-length data of the study species and life history ratios. The results revealed a depletion of the stock's reproductive biomass for *S. undosquamis* and imminent risks of stock collapse for *P. macracanthus*, with SPRs of 10% and 19%, respectively. In contrast, *N. virgatus* exhibited a relatively high SPR of 32%, surpassing the limit reference point (LRP) (20%). This study identified high fishing pressure (F/M) and the prevalence of destructive fishing practices as contributing factors to stock depletion. Effective management strategies, such as implementing stricter mesh size regulations, reducing catch limits, and reducing fishing efforts, are essential for addressing these issues. Adopting sustainable practices with an SPR target of 40% could lead to economic benefits for *N. virgatus*. Immediate interventions are crucial for *P. macracanthus* and *S. undosquamis* to prevent further declines. Continuous monitoring of the SPR, adaptive management, and active stakeholder engagement are vital for ensuring compliance with conservation measures and achieving long-term sustainability in the region.

1. Introduction

Anthropogenic impacts stress marine fisheries, with species extinction being a potential outcome [1]. Fisheries are vital to global economies and food security, particularly in China, where they support livelihoods [2]. Countries have launched various initiatives to counteract the reduction in fish stocks, including stock enhancement programs [3–5]. China has implemented such programs for over 100 species and has restored habitats through artificial reefs and mangrove plantations. However, concerns have arisen regarding the genetic and ecological impacts of such interventions [6]. Therefore, it is essential to bolster alternative management approaches and emphasize thorough stock assessments to ensure the sustainability of fish stocks.

Stock assessment serves as a method for monitoring fluctuations and underpins the formulation of fishery management strategies [7]. This procedure encompasses sampling surveys, recording catch statistics, and model estimates of population status, which are crucial for informed decision-making [8]. Precise assessment and crafting of efficient management strategies encourage the adoption of quantitative analytical methods [9]. Despite this, a significant portion of marine stocks fall under the category of "data-limited" [10]. Fortunately, the emergence of data-limited models has facilitated stock assessments, even in scenarios with limited data availability [11–13].

The length-based spawning potential ratio (LBSPR) model evaluates fisheries with limited data by utilizing

species' length and life history ratios (LHRs). Its focus lies on determining the impact of fishing pressure on stocks [14]. This impact is quantified through the spawning potential ratio (SPR), an estimate of the reproductive output of a fished population relative to its output if unfished [15].

This study focused on the populations of the following three finfish species in the northern South China Sea: the golden threadfin bream (*Nemipterus virgatus*), spotted bigeye (*Priacanthus macracanthus*), and brushtooth lizardfish (*Saurida undosquamis*). These species are vital for marine biodiversity in Southeast Asia, the East-Indo-west-Pacific region, and Northern Australia and support commercial fishing and coastal communities. However, the expansion of coastal cities threatens their sustainability, necessitating urgent conservation measures [16]. In addition, challenges in assessing small-scale fisheries exacerbate these threats, especially in regions like China, where marine stocks face overexploitation and global issues such as technological limitations and data privacy concerns further complicate accurate assessments.

Given these challenges, this study adopts the length-based spawning potential ratio (LBSPR) methodology to evaluate the population status and fishing pressure of the finfish mentioned above. By employing this approach, we aim to provide valuable insights into their current state while contributing to informed management practices and sustainable utilization of marine resources in the area. Moreover, this study serves as an exemplar, demonstrating how similar assessments can be conducted for other stocks facing data scarcity, thereby enhancing our ability to address the challenges confronting fisheries management worldwide.

2. Materials and Methods

2.1. Study Area and Data Collection. Fish samples were collected from the northeastern coastal waters of Hainan Island, located in the northern South China Sea, within a sampling area of 19.25-20.25 N and 111.75–114.25 E (Figure 1). A bottom trawling boat survey was conducted in two fishing seasons, April and September 2019, using a 40 mm cod-end net mesh. Captured fish were transported to the laboratory for sex identification and length recording. The standard lengths of female individuals were measured using digital callipers to the nearest 0.01 mm, resulting in a total of 428, 579, and 458 individuals for *N. virgatus*, *S. undosquamis*, and *P. macracanthus*, respectively. Maturity levels were examined macroscopically based on gonad development, and only specimens with gonad levels III–VI were considered mature.

3. Data Analysis

3.1. Assumptions and Analysis Inputs. The LBSPR method relies primarily on catch samples of female individuals. This method is sensitive to the underestimation of the asymptotic size (L_∞) [11, 13]. Moreover, the accuracy of the model estimations can be influenced by the data-collection techniques employed [17]. In cases where data are insufficient, biological data from robust studies of similar geographical locations and related taxa can be used [18]. In this model, SPR is determined by the interaction between fishing mortality relative to natural mortality (F/M) and the two life history ratios (LHRs). The first LHR considers the natural mortality (M) and Von Bertalanffy growth coefficient (K), (M/K). In contrast, the second LHR accounts for the ratio of the size of maturity when 50% of a population matures into adults (L_{50}) and the asymptotic length (L_∞), (L_{50}/L_∞). To employ the LBSPR model, additional inputs beyond species length data are necessary, including the parameters listed in Table 1. Using these inputs, the model calculates the SPR, fishing pressure (F/M), and net selectivity (SL) by applying the maximum likelihood method.

3.2. The Assessment Proxies. International fisheries management employs spawning potential ratios (SPRs) of 20% and 30–40% to measure the status of fish stocks. When the SPR falls below 20%, it indicates overfishing and a weak reproductive capacity, designating 20% SPR as a limit reference point (LRP). A 30–40% SPR is considered the SPR target [19]. Generally, an SPR above 20% suggests that the fish population can self-replenish effectively, indicating an ample population of spawners to sustain the continuity of the species over generations while reducing the risk of recruitment failure and stock collapse [20]. Management authorities can set different reference points based on the status of the species. In this study, we utilized the LRP of 20% and SPR target of 40%. On the other hand, an F/M value ≤ 1.0 implies that the fishing pressure on the fish stock is sustainable. However, interpreting the F/M value along with the observed SPR and estimates of the net selectivity is crucial. Occasionally, an F/M >1.0 may not necessarily signify a declining stock but rather serve as an alert to unsustainable fishing practices [13].

3.3. Parameters Estimations. The LBSPR model traces its theoretical development from the Von Bertalanffy Growth Function (VBGF) [21], expressed as $L_t = L_\infty(1 - \exp(-K(t - t_0)))$, where L_t is the length at age t, L_∞ is the length that a fish would reach corresponding to zero increments (also referred to as the asymptotic length), K is the growth coefficient (the rate at which L_∞ approaches), and t_0 is the theoretical age at zero length. Based on the requirements of the LBSPR model [22], Fisheries Statistics Computer Software FiSAT II (FAO-ICLARM stock assessment tool) [23] was used to estimate the L_∞ and K values of the species based on their length frequencies. The natural mortality coefficient (M) was derived using the empirical equations presented in Table 2. These equations utilized inputs such as the species' maximum recorded age (A_{max}), K, L_∞, and average sea surface temperature (T), which was 27°C for the study area. Notably, the maximum ages recorded for *N. virgatus*, *P. macracanthus*, and *S. undosquamis* are 5, 9, and 11 years, respectively [29–31]. To calculate L_{50} and L_{95}, which are the body lengths at which 50% and 95% of the species are matured, respectively, a logistic regression analysis was performed for the observed maturity levels. This analysis modelled the probability of maturity as a function of body length. The estimated parameters are listed in Table 1.

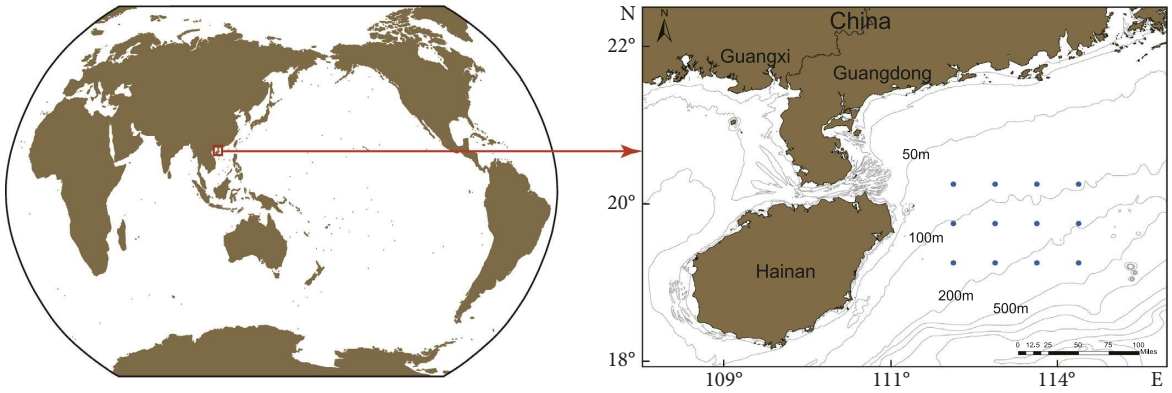

Figure 1: Map of coastal waters of Hainan Island; the blue points indicate the bottom trawl operation region.

Table 1: Details of primary data for the LBSPR model analysis (95% confidence intervals in brackets).

Parameters	*N. virgatus*	*P. macracanthus*	*S. undosquamis*
L_{∞}	233.1 (230.14–236.06)	270.90 (268.28–273.52)	234.15 (231.93–236.37)
K	0.31	0.17	0.36
L_{50}	106.0 (103.04–108.96)	168.0 (165.38–170.62)	155.0 (152.78–157.22)
L_{95}	210.0 (207.04–212.96)	227.79 (225.17–230.41)	221.0 (218.78–223.22)
M	0.68	0.44	0.45
M/K	2.19	2.59	1.25
CV L_{∞}	0.1	0.1	0.1

L_{50}: the size of maturity at which 50% of a size class is mature (mm); L_{95}: the size of maturity at which 95% of a size class is mature (mm); L_{∞}: asymptotic length (mm); CV L_{∞}: coefficient of variation of the asymptotic length; K: growth coefficient (year^{-1}); M: natural mortality (year^{-1}).

Table 2: Estimation of the natural mortality "M" of the study species (year^{-1}).

No.	Equation	Priors	Estimated M			Reference
			NV	PM	SU	
1	$\text{Log}\ (M) = -0.0066 - 0.279\ \text{log}\ (L_{\infty}) + 0.6543\ \text{log}\ (K) + 0.4634\ \text{log}\ (T)$	L_{∞}, K, and T	0.46	0.30	0.51	[24]
2	$M = 1.5K$	K	0.47	0.26	0.54	[25]
3	$M = 4.118 \times K^{0.73} \times L_{\infty}^{-0.33}$	L_{∞} and K	0.29	0.18	0.32	[26]
4	$M = 4.899 \times A_{\max}^{-0.916}$	$A_{\max}$	1.12	0.95	0.54	[26]
5	$M = e^{1.46 - 1.01 \times \ln A_{\max}}$	$A_{\max}$	0.85	0.47	0.38	[27]
6	$M = e^{1.44 - 0.98 \times \ln A_{\max}}$	$A_{\max}$	0.87	0.49	0.40	[28]
	Average M		0.68	0.44	0.45	

NV: *N. virgatus*; PM: *P. macracanthus*; SU: *S. undosquamis*.

3.4. LBSPR Analyses. LBSPR analyses were conducted, which involved simulation modelling using *R* code available at https://cran.r-project.org/web/packages/LBSPR (access date: 24 December 2023), based on standard length data for female individuals and other inputs in Table 1. All model estimates were calculated with 95% confidence intervals.

4. Results and Sensitivity Analysis

4.1. Results

4.1.1. N. virgatus. Figure 2(a) shows the length composition of *N. virgatus*, from which 32% SPR was calculated. This estimate indicates that the stock is healthier, exceeding the limit reference point (20%). The model estimated the relative fishing pressure (F/M) to be 0.78, which is less than 1.0, indicating a sustainable F/M ratio. However, estimates of net selectivity vividly reveal signs of poor fishing practices, suggesting the existence of destructive fishing methods. Figures 2(b) and 2(c) illustrate fishing practices that target young individuals.

4.1.2. P. macracanthus. Figure 3(a) shows the size composition of the species from which a 19% SPR was calculated. The calculated SPR reveals the declining reproductive biomass of the stock. The estimated F/M for the species exceeded 1.0, indicating intense fishing pressure on the stock (Figure 3(d)). From the estimates of net selectivity (SL50 and SL95), the fishing gear employed seemed to target juvenile species (Figures 3(b) and 3(c)).

4.1.3. S. undosquamis. A 10% SPR value was calculated from the size composition of *S. undosquamis* (Figure 4(a)). This SPR is significantly below the LRP (20%) (Figure 4(d), SPR

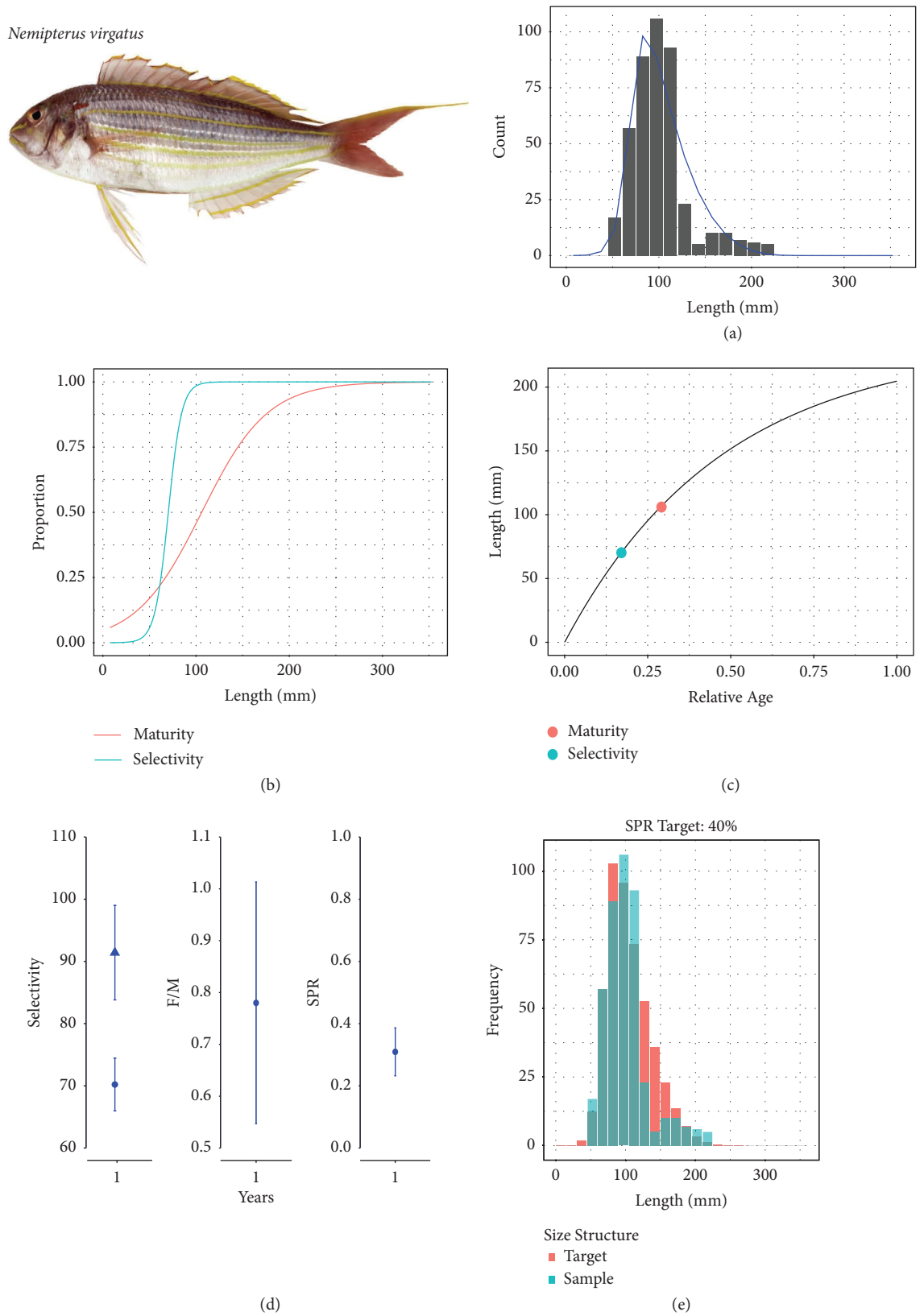

FIGURE 2: LBSPR estimates of *Nemipterus virgatus* from the Northern South China Sea; standard length catches from the bottom trawl. (a) Size composition of the sample fitted by the LBSPR curve. (b) Plot of selectivity curve relative to the curve of size at maturity. (c) Plot of growth curve showing size selectivity and size of maturity. (d) LBSPR estimates with their confidence intervals (95%), selectivity panel (left side), *F*/*M* panel (middle), and SPR panel (right side) (values indicated by the points are as in Table 3). (e) The sample length-frequency data plotted against the expected size composition at the SPR target (40%).

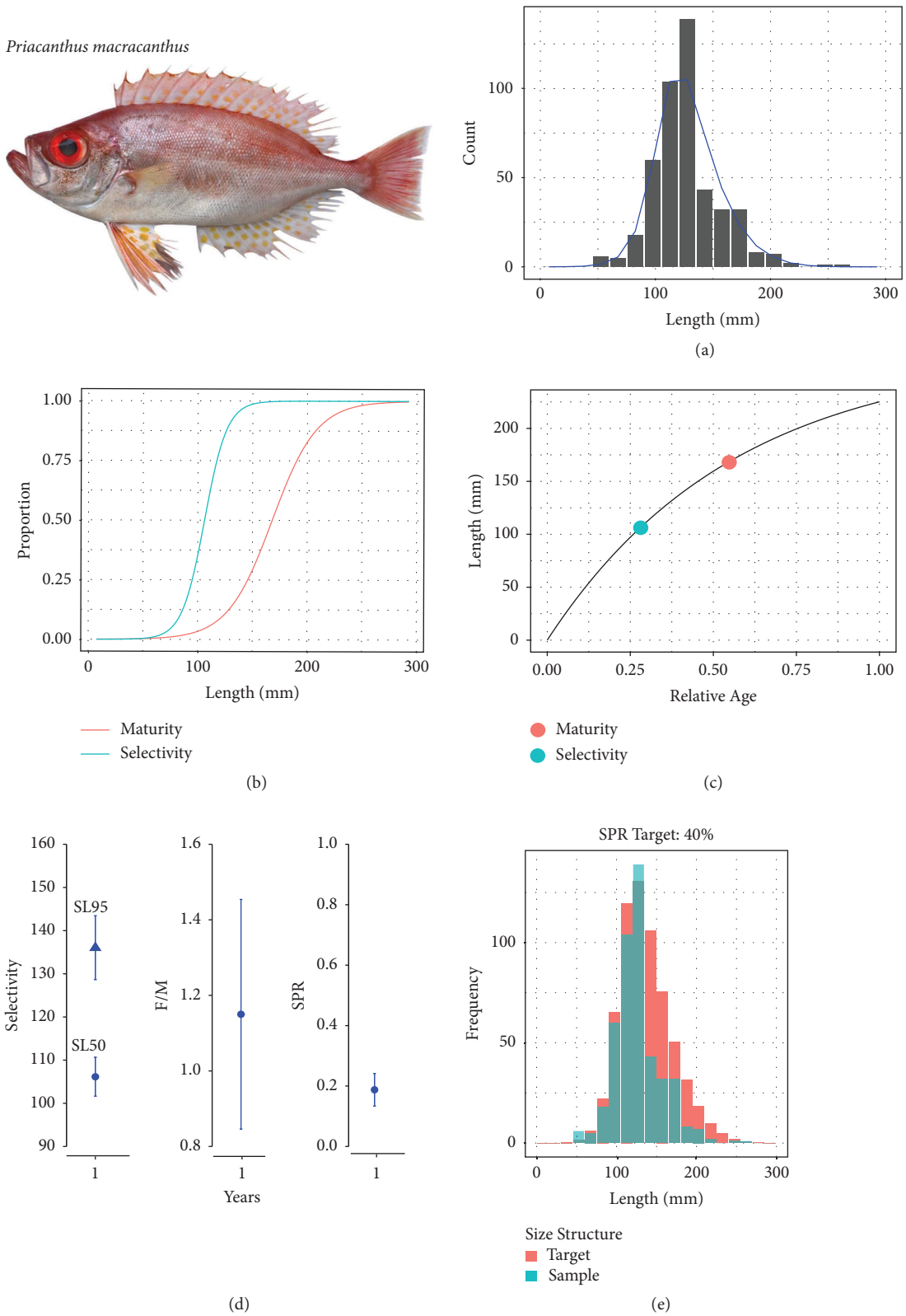

FIGURE 3: LBSPR estimates of *P. macracanthus* from the Northern South China Sea; standard length catches from the bottom trawl. (a) Size composition of the sample fitted by the LBSPR curve. (b) Plot of selectivity curve relative to the curve of size at maturity. (c) Plot of growth curve showing size selectivity and size of maturity. (d) LBSPR estimates with their confidence intervals (95%), selectivity panel (left side), *F*/*M* panel (middle), and SPR panel (right side) (values indicated by the points are as in Table 3). (e) The sample length-frequency data plotted against the expected size composition at the SPR target (40%).

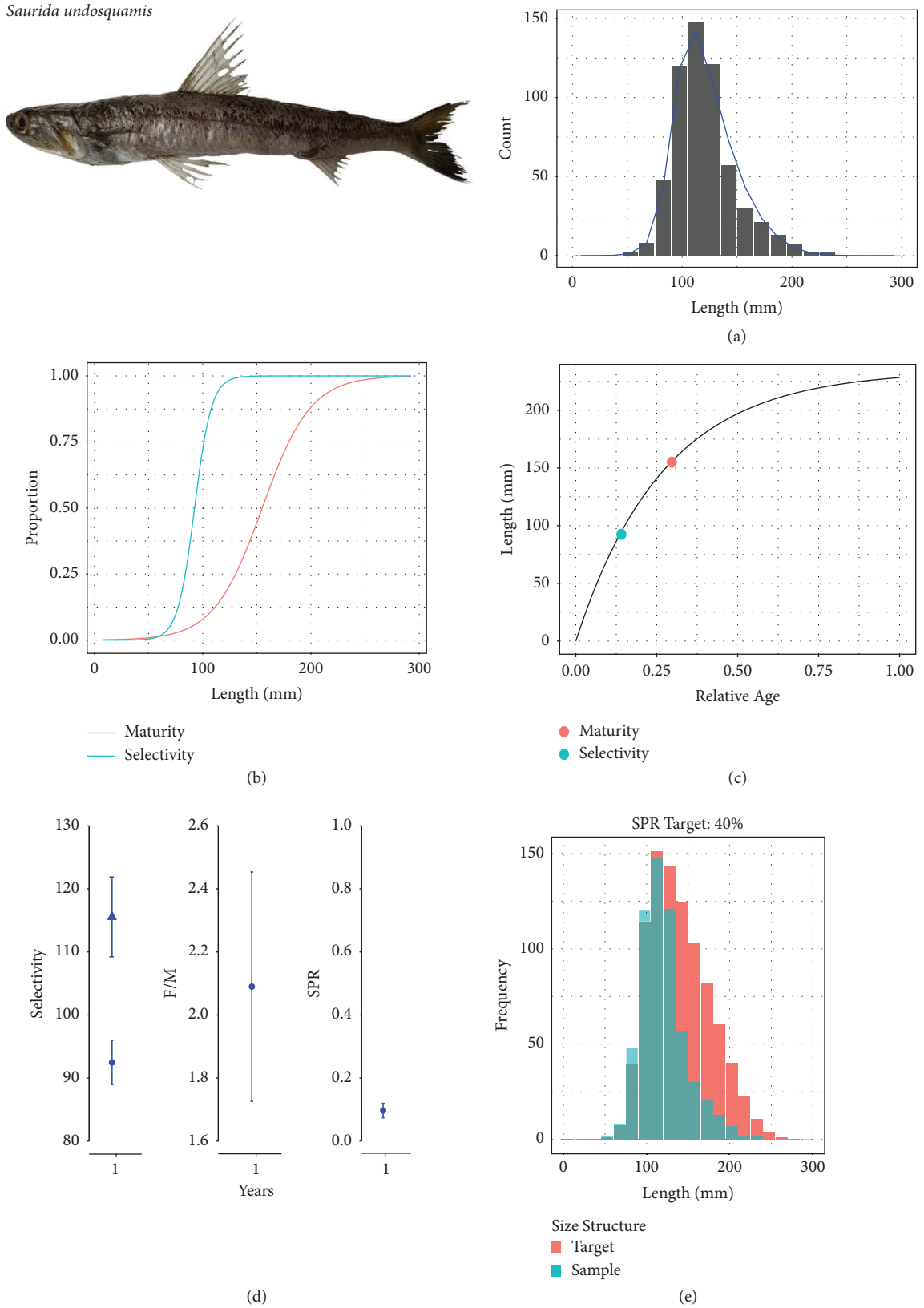

FIGURE 4: LBSPR estimates of *S. undosquamis* from the Northern South China Sea; standard length catches from the bottom trawl. (a) Size composition of the sample fitted by the LBSPR curve. (b) Plot of selectivity curve relative to the curve of size at maturity. (c) Plot of growth curve showing size selectivity and size of maturity. (d) LBSPR estimates with their confidence intervals (95%), selectivity panel (left side), *F*/*M* panel (middle), and SPR panel (right side) (values indicated by the points are as in Table 3). (e) The sample length-frequency composition and the expected size composition at the SPR target (40%).

panel), indicating that the stock is overfished or collapsing. The F/M estimates indicated that the stock was under high fishing pressure, which seemed to negatively affect the reproductive potential of the species (Table 3). The net selectivity estimates (SL50 and SL95) indicate unsustainable fishing practices. Fishing nets with small mesh sizes and destructive gear (such as fish traps and arrows) are likely the most commonly used fishing methods (Figures 4(b), 4(c), and 4(d), selectivity panel). Consequently, fishermen catch most fish species before reaching sexual maturity, as shown in Figures 4(b) and 4(c).

4.2. Sensitivity Analysis. A sensitivity analysis was conducted to evaluate the impact of parameter uncertainties on the length-based spawning potential ratio (LBSPR) model for the study species (Table 4). The key parameters L_∞, K, L_{50}, and M were varied within a range of ±10% to simulate realistic uncertainties. For *Nemipterus virgatus*, the parameters were varied as follows: L_∞ (209.79–256.41 mm), K (0.279–0.341 year^{-1}), L_{50} (95.4–116.6 mm), and M (0.612–0.748 year^{-1}); for *Priacanthus macracanthus*, L_∞ (243.81–297.99 mm), K (0.153–0.187 year^{-1}), L_{50} (151.2–184.8 mm), and M (0.396–0.484 year^{-1}); and for *Saurida undosquamis*, L_∞ (210.735–257.565 mm), K (0.324–0.396 year^{-1}), L_{50} (139.5–170.5 mm), and M (0.405–0.495 year^{-1}). Scenarios were created by varying each parameter while keeping others constant.

Sensitivity analysis of the LBSPR model outputs, focusing on the spawning potential ratio (SPR), revealed high sensitivity to changes in L_∞ across all species. For *N. virgatus*, the SPR was very sensitive to variations in the growth rate (K) and natural mortality rate (M), while *P. macracanthus* showed high sensitivity to increased K and length at maturity (L_{50}). Both *S. undosquamis* and *N. virgatus* exhibited moderate sensitivity to these parameters. In addition, a decrease of L_{50} significantly affected *P. macracanthus*, with *S. undosquamis* showing moderate sensitivity. These findings emphasize that accurate estimation of L_∞ is crucial to ensuring reliable LBSPR results [11, 13]. Many studies have used LBSPR with sensitivity analyses to determine whether the sensitivity of input parameters varies by species or whether LBSPR itself is sensitive to these parameters [13, 22, 32]. Future research should focus on enhancing the precision of these input parameters to improve the robustness of LBSPR model outputs. For parameters identified as more sensitive, precise estimates are crucial to ensure the accuracy of LBSPR evaluations. In addition, it is important to allocate survey budgets effectively and invest more resources in estimating the susceptible parameters.

5. Discussion

In this study, *Saurida undosquamis* and *Priacanthus macracanthus* exhibited the lowest spawning potential ratio (SPR) estimates of 10% and 19%, respectively (Table 3). According to Goodyear [33], the stock of *S. undosquamis* is collapsing. Such low SPR adequately reflects biomass depletion [17]. These two stocks indicate a heightened risk of recruitment failure and stock collapse, which threaten population stability. At these SPRs, the fishery cannot continue to provide resources without depleting the stock, adversely affecting both the ecosystem and human stakeholders. The SPR for *Nemipterus virgatus* (32%) exceeded the limit reference point (LRP) of 20%. However, it remains below the maximum sustainable yield (MSY) level, estimated to be within the SPR range of 35–40% [34]. Despite being above the LRP, the SPR of 32% suggests that while the population has some ability to self-replenish, it is not optimal and could be improved to reach sustainable levels closer to the MSY. The study area appears to have been subjected to high fishing pressure, as evidenced by the F/M values of *S. undosquamis* and *P. macracanthus* (Table 3). Panels (b) and (c) of Figures 2, 3, and 4 illustrate significant fishing pressure in the study area. Given that the net selectivity (SL50) of the species falls below the 50% maturity threshold, this indicates that the current fishing practices capture fish before they can reproduce. Even a seemingly stable stock of *N. virgatus* is at risk due to these practices.

Despite the poor fishing practices shown in Figures 2(b) and 2(c), the analysis of *N. virgatus* suggests the potential for increased economic benefits with further enhancements. The current relative fishing mortality (F/M) ratio of 0.78 indicates that the existing fishing pressure is still sustainable. However, to reach the target size structure of the population portrayed in Figure 2(e), management should aim for stable or reduced fishing efforts and ensure compliance with appropriate mesh sizes to prevent overfishing. In contrast, *P. macracanthus* (Figure 3) presents a more concerning scenario. An SPR of 19% (below 20%, LRP) indicates a population at risk of inadequate replenishment. The F/M ratio and net selectivity highlight unsustainable fishing pressure on the stock. Immediate management interventions, such as enforcing stricter mesh size regulations and reducing the overall catch limits, are necessary to alleviate this pressure. The most critical scenario is observed with a collapsing stock of *S. undosquamis* (Figure 4). The high F/M ratio (2.09) confirms unsustainable fishing practices, which pose a threat of stock collapse. Drastic reductions in fishing efforts, coupled with strict controls on fishing gear, are essential to prevent the collapse of this species [35, 36]. Enforcing larger mesh sizes will reduce juvenile catch, enable more fish to mature, and enhance the spawning stock.

According to this study, a diverse array of fishing gear, including potentially damaging methods, are likely to predominate, as shown in panels (b), (c), and (d) of Figures 2, 3, and 4. The widespread use of these methods can accelerate the depletion of fish stocks before they mature, leading to overexploitation [37]. Furthermore, the capture of juvenile fish can induce evolutionary shifts, resulting in reduced average fish size and altered population age distribution [38–41]. Coastal communities heavily reliant on fishing for sustenance are particularly susceptible to destructive fishing methods [35]. Commonly observed in small-scale fisheries, these practices detrimentally affect aquatic ecosystems and often exceed the MSY [37].

Table 3: LBSPR analysis results for the study species (mean estimates with 95% confidence intervals).

LBSPR parameter	*N. virgatus*	*P. macracanthus*	*S. undosquamis*
SPR	32% (24–39%)	19% (14–24%)	10% (8–12%)
SL0	70.21 (65.89–74.53)	106.15 (101.62–110.68)	92.48 (88.97–95.99)
SL95	91.41 (84.04–98.78)	136.05 (9128.64–143.46)	115.53 (109.16–121.9)
F/M	0.78 (0.53–1.03)	1.15 (0.84–1.46)	2.09 (1.72–2.46)

SPR : spawning potential ratio; SL50: net selectivity when 50% of species are matured (mm); SL95: net selectivity when 95% of species are matured (mm); F/M: relative fishing mortality.

Table 4: LBSPR sensitivity analysis (mean SPR estimates with 95% confidence intervals).

Parameter (±10%)	SPR *N. virgatus* (%)	SPR *P. macracanthus* (%)	SPR *S. undosquamis* (%)
L_∞ lower bound	NA	30 (21–38)	NA
L_∞ upper bound	19 (14–24)	10 (7–014)	6 (4–7)
K lower bound	37 (28–46)	21 (15–28)	11 (9–14)
K upper bound	25 (19–31)	14 (10–18)	8 (6–10)
L_{50} lower bound	31 (24–38)	22 (17–28)	12 (10–15)
L_{50} upper bound	28 (21–35)	11 (6–15)	7 (5–9)
M lower bound	24 (18–30)	13 (9–17)	8 (6–10)
M upper bound	36 (27–45)	21 (15–27)	11 (9–14)

NA: indicates an error because the maturity parameter (L_{95}) becomes higher than the L_∞ lower bound value.

Effective management strategies are crucial for replenishing dwindling fish stocks and reducing fishing pressures in the study area. Prioritizing the achievement of the LRP is essential for preventing stock collapse and reaching the suggested SPR target (40%). Economic optimization can be attained from the fishery by aiming for an SPR target, as shown in panel (e) of Figures 2, 3, and 4. The LBSPR results highlight the SPR levels that demand targeted and adaptive fishery management. SPR improvement requires the first capture size to be larger than the maturity size, thus protecting stocks from being caught around maturity [42, 43]. For *N. virgatus*, the focus should be on maintaining sustainable practices and making incremental improvements to achieve optimal economic outcomes. In contrast, it is essential to prioritize reducing the fishing pressure on *P. macracanthus* and *S. undosquamis* to allow their populations to recover. These approaches require continuous monitoring of the SPR, adjustment of catch limits as needed, and active engagement with stakeholders to ensure compliance with conservation measures [44, 45].

6. Conclusion

Monitoring fish stocks is essential for supporting sustainable fisheries as it provides valuable insights into the sustainability of resources. This study effectively used the LBSPR model to evaluate the stocks of three finfish species in the Northern South China Sea, offering valuable management recommendations. The use of the LBSPR model is particularly advantageous for stocks with limited available data due to its scientific validity and efficiency. Data-limited models play a crucial role in protecting species and ecosystems when data is scarce. In the future, it would be beneficial to explore other length-based assessment methods, such as length-based Bayesian (LBB) and length-based indicators (LBIs). To promote the use of diverse assessment methods, it is important to adapt data-collection approaches to local contexts and invest in technologies that make data reporting and collection more accessible.

Data Availability

All data used to support the findings of this study are available on request from the corresponding author.

Ethical Approval

All experiments were conducted following the guidelines and approval of the Animal Research and Ethics Committee of the Guangdong Ocean University.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Hagai Nsobi Lauden conceptualized the study and prepared the original draft; Xinwen Xu and Shaoliang Lyu performed the experiments and curated the data; Hagai Nsobi Lauden and Kun Lin analyzed the data; Ning Chen reviewed and edited the study; Xuefeng Wang supervised the study, reviewed and edited the study, and performed funding acquisition,. All the authors have approved the version of the manuscript submitted to the journal.

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