Wiley
Journal of Applied Ichthyology
Volume 2024, Article ID 8547916, 13 pages
https://doi.org/10.1155/2024/8547916

Research Article

Population Dynamics of the *Sebastes schlegelii* Stock in Zhangzi Island's Waters, China: Implications for Management and Conservation

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Received 13 January 2024; Revised 22 March 2024; Accepted 15 May 2024

Academic Editor: Pronob Das

Sebastes schlegelii is a species of great economic significance in Zhangzi Island's waters in the Northern Yellow Sea. Since the beginning of the 21st century, there has been a significant decline in the fishery resources of *Sebastes schlegelii*, and the reduction in size has become increasingly apparent. Therefore, it is imperative to understand the characteristics of *Sebastes schlegelii* and develop management tactics. Based on biological data from *Sebastes schlegelii* collected in Zhangzi Island's waters, an analysis was conducted on the relationship between body length and weight, growth equations were formulated, and an assessment was made of the resources' status. The study simulated and evaluated the effects of various closed season management strategies on egg production per recruit (EPR) and spawning biomass per recruit (SBR). The results showed the following. (1) The length-weight relationship was $W = 5 \times 10^{-5} L^{2.882}$. (2) Von Bertalanffy's growth equation was $L_t = 450[1 - e^{-0.31(t+0.42)}]$ and $W_t = 2215.8[1 - e^{-0.31(t+0.42)}]^{2.882}$. (3) The resource is in an overfished state with an exploitation rate (E) of 0.737, a steady-state biomass of 1471 t, and a maximum sustainable yield of 466 t. (4) The closed season for *Sebastes schlegelii* in Zhangzi Island's waters is suggested to be from November to February, coinciding with the recovery of the EPR value to 68.33% and the SBR value to 29.53%.

1. Introduction

The United Nations set forth 17 global Sustainable Development Goals (SDGs) in 2015. These goals were created to guide the world towards a sustainable development trajectory by addressing the social, economic, and environmental aspects of development in a comprehensive manner until 2030 [1]. The Sustainable Development Goals (SDGs) 1 (No Poverty), 2 (Zero Hunger), and 14 (Life Below Water) have a strong connection to fisheries, as they offer significant prospects and essential resources for attaining these objectives. In 2019, aquatic food made up around 17% of the total consumption of animal protein. However, in low- and middle-income countries in Asia and Africa, this percentage increased to over 50% [2]. Hence, it is crucial to systematically exploit marine fishery resources in a scientific manner to attain sustainable development of the global blue economy [3]. However, only 64.6% of the global marine fish population is currently utilized in a sustainable manner [2]. Effective management of fish stocks is essential to safeguard the sustenance of fishermen, biodiversity, and food security. Therefore, it is urgent to employ a scientific methodology in the utilization of fishery resources to ensure their sustainable exploitation.

Sebastes schlegelii belongs to the *Sebastes* genus in the *Scorpaenidae* family, which is part of the *Scorpaeniformes* order. It is distributed in the Bohai Sea, the Yellow Sea, the East China Sea, and the offshore waters of Korea and Japan [4]. *S. schlegelii* is a commercially valuable species in Zhangzi Island's waters in the Northern Yellow Sea. In recent years, the number of this species has decreased significantly due to overfishing and pollution of the marine environment. Additionally, the species is encountering challenges related to size miniaturization and younger age [5]. The scientific utilization and conservation of fishery resources of *S. schlegelii* have garnered attention from local fishery management authorities. Conducting research on the management parameters of this species is of utmost importance. Nevertheless, there is a scarcity of published research that focused on the population dynamics of *S. schlegelii* in the waters surrounding Zhangzi Island. Prior studies have primarily concentrated on the biology, behavior, and artificial reproduction of *S. schlegelii*. Yaoglioglu et al. first documented the physical characteristics and genetic composition of *S. schlegelii,* a species of Korean rockfish found on the Russian coast of the Black Sea [6]. There is a limited amount of research on growth characteristics of *S. schlegelii* and the evaluation of population dynamics, with a primary focus on the waters of Shandong Province, China. For example, Chen et al. studied the early developmental characteristics of *S. schlegelii* and found that under ambient conditions, *S. schlegelii* can grow to more than 25 mm in only 45 days of incubation, and its growth is particularly rapid after the juvenile stage [7]. Zhuang et al. studied the otoliths of the *S. schlegelii* in Qingdao's offshore waters [4], and Chen et al. evaluated the resources of *S. schlegelii* in the artificial reef area of Shandong Province offshore waters [8]. There are no published reports on population dynamics of *S. schlegelii* in Zhangzi Island's waters.

Presently, fishery management measures primarily focus on attaining sustainable utilization of fishery resources through tuning the total allowable catch (TAC), determining the catchable size of objective species, and designating closed seasons and areas. Human activities and environmental changes (e.g., climate change) are the main factors affecting the sustainable utilization of fishery resources [9]. Therefore, science-based management is crucial for the sustainable exploitation of the fishery resources of *S. schlegelii*. This study analyzed the growth characteristics and resource dynamics of *S. schlegelii*, using field survey data of *S. schlegelii* collected in Zhangzi Island's waters. The findings are expected to contribute to the sustainable fishery of *S. schlegelii* in the studied area.

2. Materials and Methods

2.1. Data Collection and Fish Sample. Biological data were collected in Zhangzi Island's waters from 2011 to 2019, and the number of catches per year is shown in Table 1. The survey stations are shown in Figure 1, which was drawn using ArcGIS software. The fishing gear included cage traps (with 25 mm mesh size, 13 m length, 4 m width, and 3 m height). At the end of the survey, the samples were promptly placed in an insulated container to maintain low temperatures and preserve their freshness and integrity. The biological characteristics of the specimens, including sex, length, and weight, were collected.

Table 1: The number of catches around Zhangzi Island from 2011 to 2019.

Date	2011	2012	2013	2014	2015	2016	2017	2018	2019
Number	22	25	13	16	12	20	11	12	15

2.2. Data Analysis

2.2.1. Length-Weight Relationship. A power function was used to fit the relationship between length and weight of *S. schlegelii* collected in this study [10], and the equation is as follows:

$$W_t = a \cdot L^b, \tag{1}$$

where W is the body weight (g), L is the body length (mm), a is the condition factor parameter, and b is the power exponent coefficient.

2.2.2. Growth Model. In this study, the von Bertalanffy growth model was used to fit length-frequency data (as in equations (2) and (3)).

$$L_t = L_\infty\left[1 - e^{-k\left(t-t_0\right)}\right]. \tag{2}$$

The electronic length frequency analysis method (ELEFAN I in the FiSAT II computer program) [11] was used to estimate the maximum asymptotic body length L_∞ and the growth coefficient k, while Pauly empirical equation (4) was used to calculate the theoretical age t_0 [12]. The equations are as follows:

$$W_t = W_\infty\left[1 - e^{-k\left(t-t_0\right)}\right]^b, \tag{3}$$

$$lg\left(-t_0\right) = -0.3922 - 0.2752\, lg\, L_\infty - 1.038 lgk, \tag{4}$$

where L_∞ is the maximum asymptotic length, b is the power exponent coefficient, and the maximum asymptotic weight W_∞ is obtained from equation (1).

2.2.3. Growth Inflection Age. The growth inflection age in fish refers to the specific age at which an individual's growth rate transitions from being rapid to becoming slow [13]. The growth inflection age can be obtained using the following equation:

$$d^2L_t/dt^2 = 0 \text{ or } d^2W_t/dt^2 = 0. \tag{5}$$

2.2.4. Mortality and Exploitation Rates. The instantaneous rate of mortality of fish is a crucial parameter to assess the population dynamics. The total instantaneous rate of mortality (Z) is divided into two categories, the instantaneous rate of fishing mortality (F) and the instantaneous rate of natural mortality (M). M represents the relative mortality of the fish population in unit time caused by natural factors such as predation, disease, and aging; F represents the relative mortality of fish stock caused by

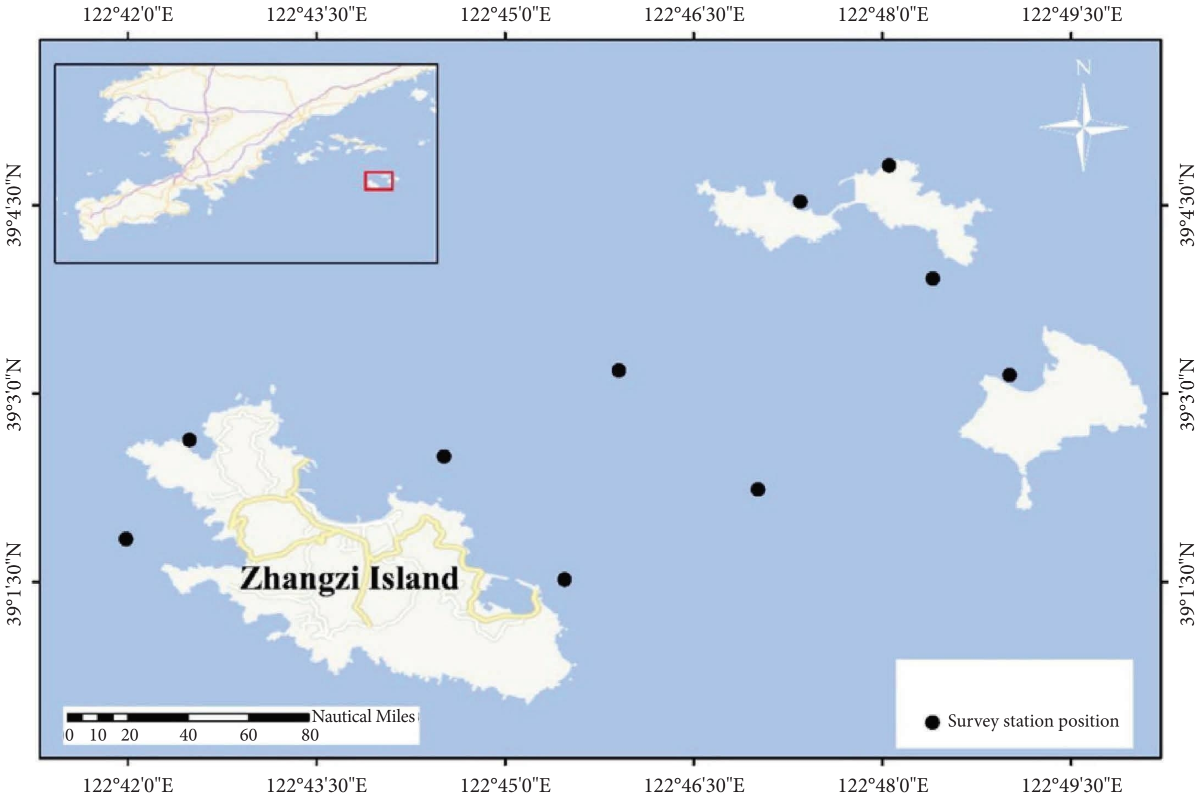


FIGURE 1: Sampling stations around Zhangzi Island (Yellow Sea of China) for the establishment of the growth parameters of *S. schlegelii* from 2011 to 2019.

fishing activities. In this study, the body length-converted catch curve method is used to estimate Z, and Pauly's empirical equation is used to estimate M. Finally, the parameter F is estimated by subtracting M from Z using the equation $F = Z - M$.

(1) The estimation of Z was conducted using the body length-converted catch curve method in the FiSAT II computer program [12, 14].

(2) The estimation of Z was conducted using Pauly's empirical equation [15].

$$lgM = -0.0066 - 0.279\, lg\, L_{\infty} + 0.6543 lgk + 0.4634 lgT, \tag{6}$$

where T is the annual average habitat water temperature; this study takes $T = 20°\mathrm{C}$.

(3) The estimation of F can be derived from Z and M, using the following equation:

$$F = Z - M. \tag{7}$$

(4) The exploitation rate (E) is the ratio of F to Z and can be expressed using the following equation:

$$E = \frac{F}{Z}. \tag{8}$$

2.2.5. *Critical Age.* The critical age refers to the point in the life cycle of a population of fishery resources where the biomass reaches its highest level without any fishing activity. It is also the age at which the rate of growth in body weight is equal to the rate of natural mortality. The critical age can be determined by utilizing the von Bertalanffy weight growth model and M [16]. The equation for calculating the critical age is as follows:

$$T_c = \left[\frac{kt_0 - \ln M + ln(3k + M)}{k}\right]. \tag{9}$$

2.2.6. *Population Abundance Estimation.* The length composition of the population was analyzed using the Length-structured Virtual Population Analyses (LVPA) method, and the amount of resources was estimated [11]. The equations are as follows:

$$N_t = C_t \cdot \frac{(M + F_t)}{F_t}, \qquad C_i = N_{i+\Delta t} \cdot \left(\frac{F_i}{(M + F_i)}\right) \cdot \left(1 - e^{-(M+F_i)\Delta t_i}\right), \tag{10}$$

where $\Delta t_i = (t_{i+1} - t_i), t_i = t_0 - (1/k) \cdot \ln(1 - L_i/L_{\infty})$, C_t is the catch at maximum body length, M is the instantaneous rate of natural mortality, F_t is the instantaneous rate of fishing mortality at maximum body length, N_i and $N_{i+\Delta t}$ are the resources at age i and $i + \Delta t$, C_i is the catch at age i, and F_i is the instantaneous rate of fishing mortality at age i.

2.2.7. Calculation of Fecundity. The number of eggs produced by one female fish in a reproductive season that can be fertilized and can grow into fish is known as individual fecundity [17]. Due to the difficulty in accurately estimating the number of eggs with the ability to fertilize and develop, scholars generally use the number of eggs carried by females directly to express the fecundity of individual fish in order to simplify and standardise research, rather than using the number of eggs that are capable of fertilization and development [18].

S. schlegelii exhibits a relatively delayed sexual maturity, with males typically reaching maturity at the age of three years, while females reach maturity at the age of two years [19]. Gonads of *S. schlegelii* stages III to IV were used to determine fecundity [18], through counting the number of eggs (gravimetric method) in weighed subsamples from the left and right gonads of each specimen. To compute the individual absolute fecundity and individual relative fecundity [20], the following formulas were used:

$$\begin{aligned}&\text{individual absolute fecundity: } Fec = \left(\frac{W}{w}\right) \times e,\\&\text{length relative fecundity: } Fec_L = \frac{Fec}{L},\\&\text{weight relative fecundity: } Fec_W = \frac{Fec}{W},\end{aligned} \tag{11}$$

where Fec is the individual absolute fecundity (eggs), W is the gonad weight (g), w is the subsample weight, and e is the number of eggs in each subsample.

2.2.8. BPR, YPR, EPR, and SBR Models. Biological Reference Points (BRPs) are frequently used to assess the status of fishery resource. They can be determined by calculating various factors such as the biomass per recruit (BPR), the yield per recruit (YPR), the spawning biomass per recruit (SBR), and the egg production per recruit (EPR) [21]. Based on the YPR and BPR models, the exploitation rates at optimum yield, maximum sustainable yield, and maximum yield can be obtained as $E_{0.1}, E_{0.5}$, and $E_{\max}$, respectively. When the exploitation rate $E_{\mathrm{cur}} > E_{0.1}$, the fishery resources are in an overfished state. EPR and SBR usually use the F that restores the values of EPR and SBR to the 25% and 40% as BRPs, i.e., $F_{25\%\mathrm{EPR}}, F_{25\%\mathrm{SBR}}, F_{40\%\mathrm{EPR}}, F_{40\%\mathrm{SBR}}$ [22, 23].

BPR and YPR were often used to analyze the current state of the utilization of fishery stock. In this study, the length-frequency distribution of *S. schlegelii* can be used to calculate L_c (i.e., the catchable size), E, L_c/L_∞, and M/k. Then based on L_c/L_∞ and M/k, relative YPR, relative BPR, and $E_{0.1}, E_{0.5}$, and $E_{\max}$ can be obtained. The above parameters in this paragraph were calculated using FiSAT II software.

SBR and EPR are models for assessing population dynamics based on a fish stock conservation perspective. The number of spawners and eggs required to sustain the fishery stock can be obtained by calculating SBR and EPR at different F [24, 25]. The stock status was assessed using the Beverton–Holt model [26], and the EPR and SBR values were calculated under various F using equations (12) and (13), respectively. In this study, F was utilized as a variable to calculate the EPR and SBR values for various F in order to assess the merits and demerits of the management strategies.

EPR value calculation equation:

$$\mathrm{EPR} = \frac{EP}{R} = \sum_{t=0}^{t_{\max}} \exp\left(-\left(\left(F \cdot S_t \cdot A_t\right) + M\right)t\right)P_t \cdot g_t \cdot e_t. \tag{12}$$

SBR value calculation equation:

$$SBR = \frac{SB}{R} = \sum_{t=0}^{t_{\max}} \exp\left(-\left(\left(F \cdot S_t \cdot A_t\right) + M\right)t\right) \cdot a\left(L_t\right)^b \cdot G_t, \tag{13}$$

where EP is the total egg production; SB is the total spawning stock biomass; g_t is the proportion of female fish in age t; e_t is the egg production of t-age fish; R is the recruitment (here it takes the value of 1); P_t is the proportion of sexual maturity of t-age fish; F and M are the instantaneous rate of fishing mortality and the instantaneous rate of natural mortality; a and b are body length and weight relationship constants; L_t is the average body length of t-month age; $t_{\max}$ is the maximum age in the samples; the parameter A_t corresponds to whether the month at age t is the fishing season or not; if yes, it is 1, otherwise 0. The starting month $t = 0$ is set to November, when juveniles begin to emerge; the sexual maturity parameter G_t and the gear selectivity parameter St are both "knife-edge", with G_t being 0 when $t < t_m$ and 1 otherwise, and t_m being the age at which 50% of the fish are sexually mature; when $t < t_c$, S_t is 0 and 1 otherwise, and t_c is the age at which the first catch is made.

The protection of mega-spawners and juveniles is one of the main objectives for formulating fishery management scheme [27]. This study used the EPR model and SBR model to simulate and analyze the variations in EPR and SBR values of *S. schlegelii* under different management strategies. Additionally, it put forth scientific suggestions for implementing closed seasons to safeguard spawning fishes. The parameter values are displayed in Table 2.

1. *Strategy 1.* The closed season is a five-month period from May to September (current resource utilization pattern).
2. *Strategy 2.* The closed season is a seven-month period from November to May. This is the breeding season for *S. schlegelii.*
3. *Strategy 3.* The closed season is a four-month period from November to February.

Table 2: SBR and EPR model parameters.

Parameters	Numerical value
a	5×10^{-5}
b	2.882
L_∞	450 mm
k	$0.31\ \mathrm{a}^{-1}$
t_0	-0.42 a
F_{cur}	$1.7765\ \mathrm{a}^{-1}$
M	$0.6335\ \mathrm{a}^{-1}$
$t_{\max}$	6 a
50% sexually mature body length	225 mm
Catchable size (L_c)	137 mm

(4) *Strategy 4.* The closed season is a three-month period from March to May.

3. Results

3.1. Length-Weight Composition. After sex identification of 146 samples, 48 fish could be identified by sex, where 23 were females and 25 were males. There was no significant difference ($P > 0.05$) in the length composition of female and male *S. schlegelii* in Zhangzi Island's waters. The length distribution was 82 to 280 mm and average length was 176.33 mm. The dominant length group was 182–222 mm, which accounted for 37.6% of the total number of samples (Figure 2(a)). The weight ranged from 11.9 to 450.1 g and average weight was 174.18 g. The dominant weight group was 172–252 g, which accounted for 36.3% of the total number of samples (Figure 2(b)).

3.2. Length and Weight Relationship. Based on the analysis of covariance (ANCOVA) conducted on the 48 samples with identified gender, there is no statistically significant difference in the relationship between weight and length between males and females ($P > 0.05$). The length and weight data were modeled using a power function to generate the curve shown in Figure 3. The length-weight relationship is as follows:

$$W = 5\times10^{-5}L^{2.882}\left(R^2 = 0.9643\right). \tag{14}$$

3.3. Growth Model. The length-frequency distribution of was determined based on the collected length data, using a 10 mm length group interval. The maximum asymptote length L_∞ and the growth coefficient k were calculated by the ELEFAN I method (FiSAT II). According to equations (1) and (2), the maximum asymptote weight W_∞ and the theoretical age t_0 are calculated, respectively. The resulting parameters for the length and weight growth equations are obtained as follows: $L_\infty = 450$ mm, $W_\infty = 2215.8$ g, $k = 0.31\ \mathrm{a}^{-1}$, and $t_0 = -0.42$ a. The growth curve of the *Sebastes schlegelii* is shown in Figure 4.

$$\begin{aligned} L_t &= 450\left[1 - e^{-0.31(t+0.42)}\right],\\ W_t &= 2215.8\left[1 - e^{-0.31(t+0.42)}\right]^{2.882}. \end{aligned} \tag{15}$$

3.4. Growth Inflection Age of S. schlegelii in Zhangzi Island's Waters. The growth inflection age can be determined by $d^2L_t/dt^2 = 0$ or $d^2W_t/dt^2 = 0$.

The length and weight growth equations were derived separately, and the results were as follows:

$$\begin{aligned} \frac{dL_t}{dt} &= 139.5e^{-0.31(t+0.42)},\\ \frac{dW_t}{dt} &= 1979.64e^{-0.31(t+0.42)}\left[1 - e^{-0.23(t+0.42)}\right]^{1.882}. \end{aligned} \tag{16}$$

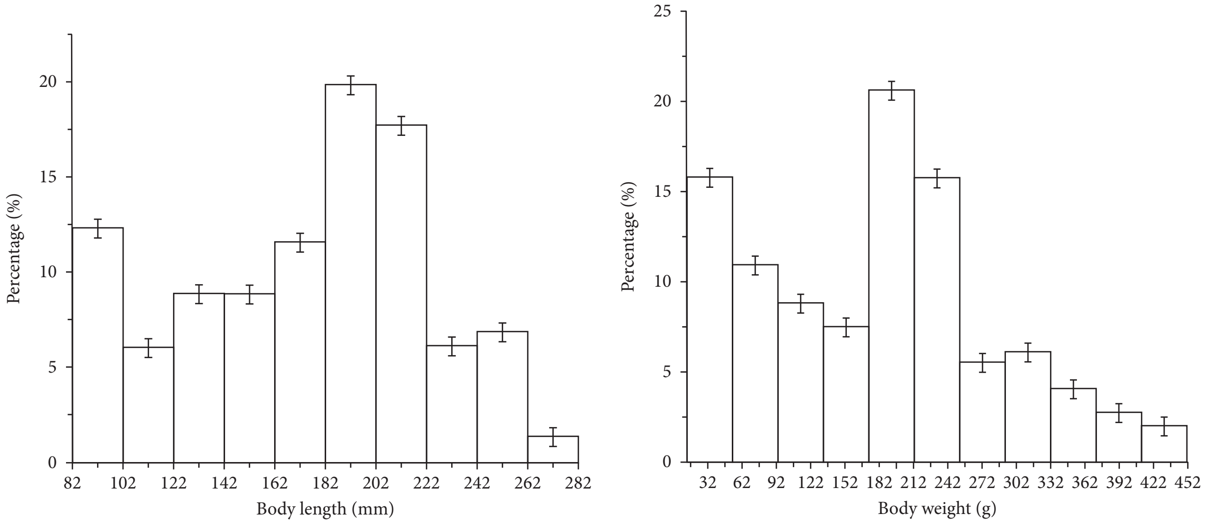
By applying the previously mentioned equation, the growth rate curve can be obtained (Figure 5). As shown in Figure 5, the growth rate of length decreases gradually with age and there is no growth inflection. As the age of *S. schlegelii* increased, its weight growth rate accelerated before declining and there was a growth inflection point. The age of the weight growth inflection can be obtained by applying the equation $d^2W_t/dt^2 = 0$ as follows:

$$\frac{d^2W_t}{dt^2} = 613.69e^{-0.31(t+0.42)}\left[1 - e^{-0.31(t+0.42)}\right]^{0.882}\left[2.882e^{-0.31(t+0.42)} - 1\right] = 0. \tag{17}$$

The result showed that the growth inflection age t was -0.42 or t was 2.99. The value of -0.42 for t is considered meaningless. Therefore, growth inflection age was obtained to be 2.99. This corresponds to a length of 293.64 mm and a weight of 647.48 g.

3.5. Estimation of Mortality and Exploitation Rate

1. Z: According to linear regression analysis, the length-converted catch curve f is depicted in Figure S1. The equation was $\ln(N/\triangle t) = -2.41t + 8.861$ ($R^2 = -0.9102$). Therefore, Z of *S. schlegelii* was 2.41.
2. M: according to Pauly's empirical equation (where $T = 20$°C, $L_\infty = 450$ mm, and $k = 0.31$), M of *S. schlegelii* in Zhangzi Island's waters can be obtained was 0.6335.
3. F: F was 1.7765 (Z-M) for *S. schlegelii* in Zhangzi Island's waters.
4. E: the exploitation rate of *S. schlegelii* in Zhangzi Island's waters $E = F/Z = 0.737$.



(a)

(b)

Figure 2: Composition of the length (a) and weight (b) of *S. schlegelii* in Zhangzi Island's waters.

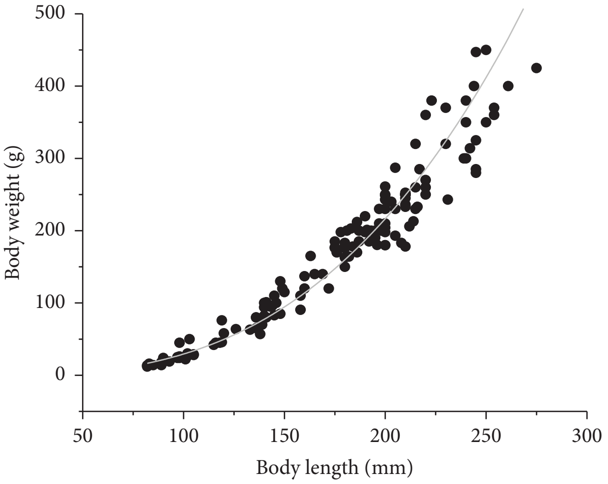


Figure 3: The length-weight relationship of *S. schlegelii* in Zhangzi Island's waters.

3.6. Critical Age. The critical age (T_c) of *S. schlegelii* was 3.8 a on the basis of the equation $T_c = [kt_0 - \ln M + \ln(3k + M)/k]$. The critical length and weight were obtained to be 328.36 mm and 893.52 g, respectively, by substituting T_c into the growth equation.

3.7. Abundance and Biomass Estimation. The length frequency distribution of *S. schlegelii* was utilized to estimate that F_t (instantaneous rate of fishing mortality) at its maximum body length is 0.6335. Based on investigative data, the yield of this species is about 157 t in Zhangzi Island's waters in 2019-2020. The biomass of the *S. schlegelii* samples was set 1/6000 of the yearly yield. It can be deduced that the number of resource (15,169,300 ind.) and steady-state biomass (1470.57 t) (Figure 6, Table S1).

3.8. Fecundity Estimation for S. schlegelii. Due to few individual samples with gonadal maturity above stage III being captured by cage traps, making it impossible to determine the fecundity of the fish. Therefore, the fecundity was assessed using data from spawners collected through angling in April 2019, April 2020, and April 2021 in Zhangzi Island's waters. A total of 31 valid samples (gonadal maturity above stage III) were obtained. By measuring the samples, it is obtained that absolute individual fecundity Fec ranged between 70,867 and 220,353 eggs, with an average *Fec* of 127108 eggs. The individual length relative fecundity Fec_L fluctuated between 253.5 and 534.8 eggs/mm, with an average of 368.4 eggs/mm. Individual body weight relative fecundity Fec_W fluctuated between 121.9 and 218.1 eggs/g, with an average of 171.5 eggs/g.

Various functions were fitted to individual absolute fecundity Fec, length L, and weight W, respectively. The results showed that the best fitting function was a quadratic function [19]. The equation and fitting curves (Figure 7) were as follows.

The individual absolute fecundity-length relationship:

$$Fec = 2.3L^2 - 642.36L + 77943\left(R^2 = 0.8818\right). \tag{18}$$

The individual absolute fecundity-weight relationship:

$$Fec = 0.3468W^2 - 212.21W + 92454\left(R^2 = 0.8728\right). \tag{19}$$

3.9. BPR and YPR Models. It can be calculated that L_c, E, L_c/L_∞, and M/k are 136.59 mm, 0.737, 0.302, and 2.04, respectively. This study plotted two-dimensional analysis for biomass per-recruit (B'/R) and yield-per-recruit (Y'/R) of S. schlegelii at different exploitation rate (E) when Lc/L∞= 0.302 (Figure 8). The isolines of relative yield per recruit (Y'/R)as a function of exploitation rate and Lc/L∞ (Figure 9). Figure 8 demonstrates an initial increase in Y'/R with the exploitation rate, followed by a gradual decrease.

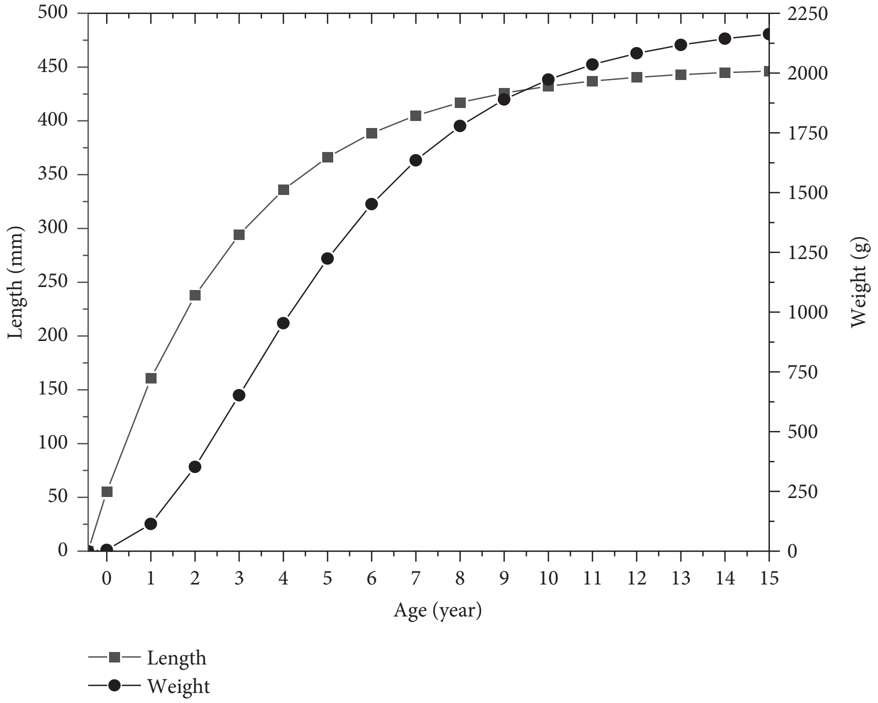


Figure 4: Growth curve for *Sebastes schlegelii* in Zhangzi Island's waters.

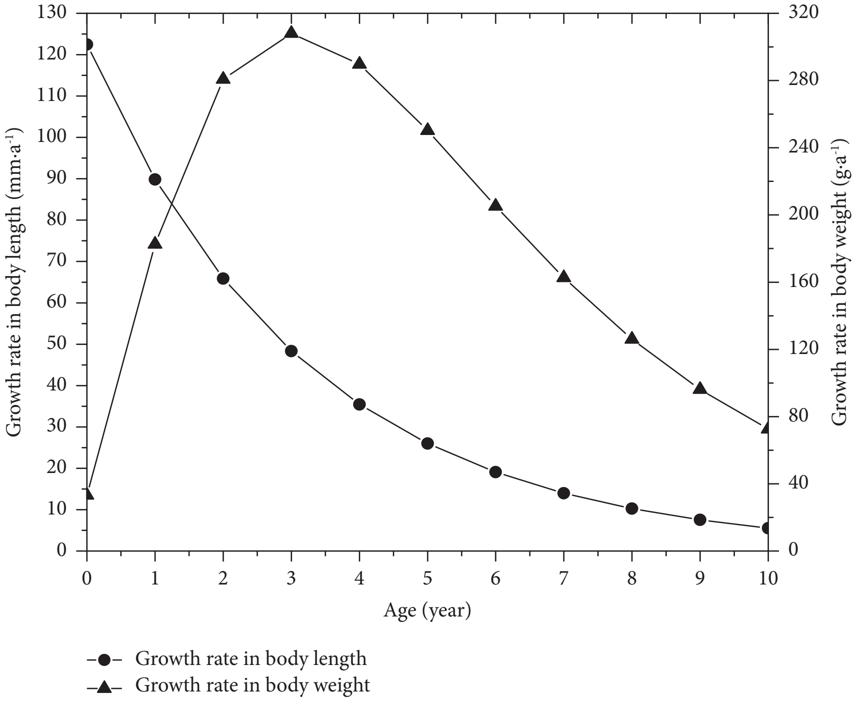


Figure 5: Growth rate curve of *S. schlegelii* in Zhangzi Island's waters.

Meanwhile, B'/R continued to decline consistently. The exploitation rates corresponding to the optimum yield, maximum sustainable yield, and maximum yield obtained were $E_{0.1} = 0.452$, $E_{0.5} = 0.302$, and $E_{\max} = 0.535$, respectively. According to Figure 9, the contour line from blue to red indicates a gradual increase in the Y'/R value. The point "*a*" represents the Y'/R value in the present condition. Point "*b*" corresponds to the maximum Y'/R value obtained when

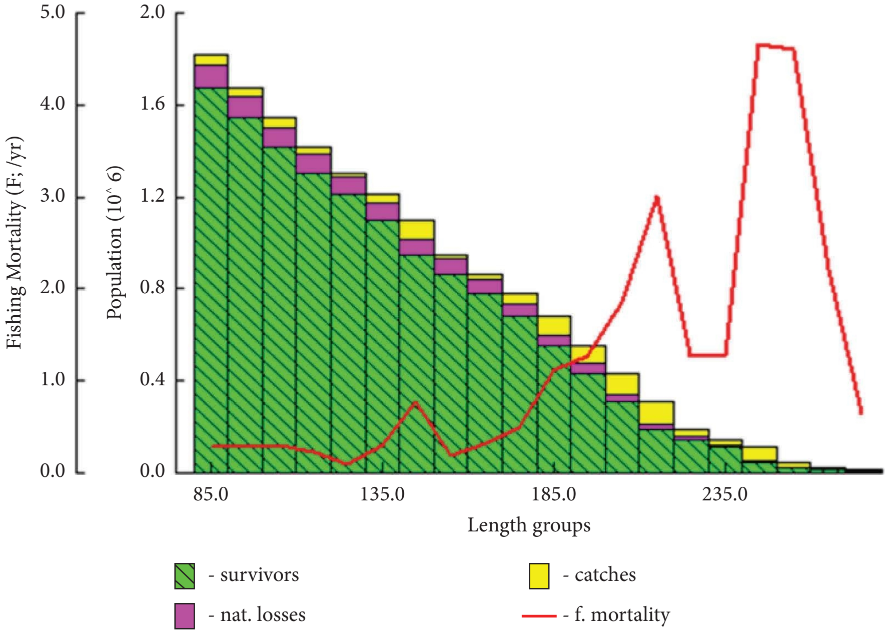


Figure 6: Resource estimation analysis of *S. schlegelii* in Zhangzi Island's waters.

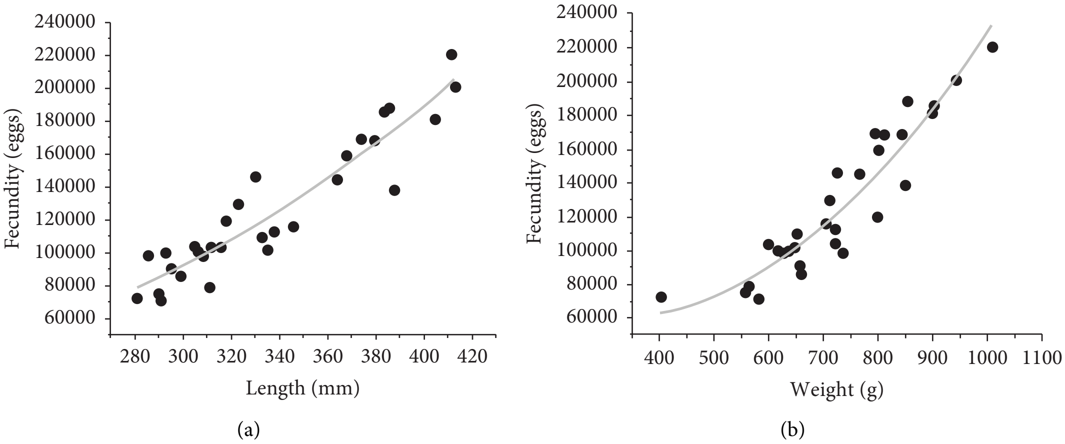


Figure 7: Curve of the individual absolute fecundity-length relationship (a) and individual absolute fecundity-weight relationship (b).

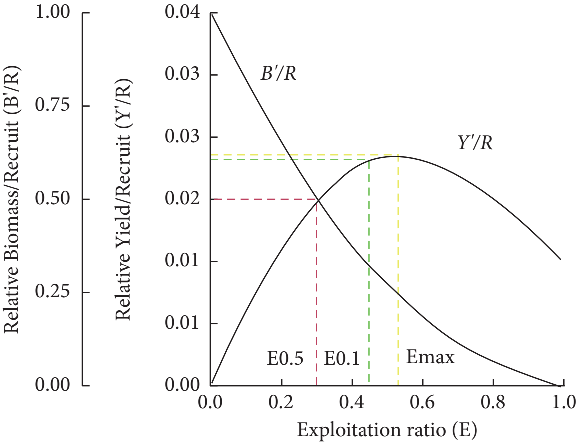


Figure 8: Two-dimensional analysis for biomass per recruit (B'/R) and yield per recruit (Y'/R) of *S. schlegelii* at different E when $L_c/L_\infty = 0.302$.

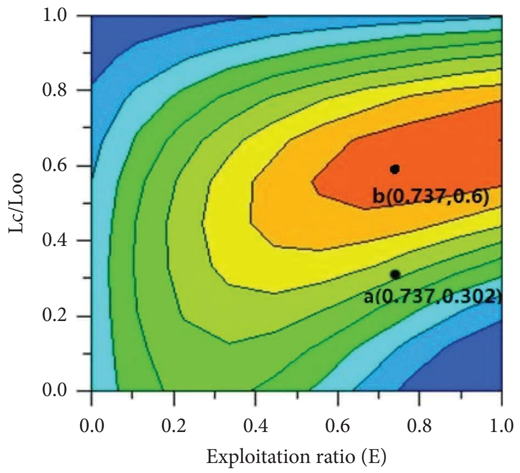


Figure 9: Isolines of relative yield per recruit (Y'/R) as a function of exploitation rate and L_c/L_∞.

changing the catchable size (L_c) under the current exploitation rate. Each loop in the figure represents the Y'/R value. The Y'/R value increases as the color becomes redder and decreases as the color becomes bluer.

3.10. Simulation of Management Strategies for Closed Season. By simulating, this study evaluates the impact of four different management strategies on EPR and SBR values under various *F*. Figure 10 illustrates the disparities between the EPR and SBR values of the different strategies.

By analyzing Figure 10, it is evident that the EPR and SBR values consistently decreased as *F* increased. Furthermore, the rate of decline in these values slowed down as *F* approached 1. Table 3 presents the variations in EPR value and SBR value for various strategies under the current *F* and with the corresponding percentage of the theoretical unexploited maximum value.

Table S2 provides the EPR and SBR as a percentage of the maximum value at the theoretical unexploited state for different strategies. These values are obtained for various *F*. Based on Figure 10(a) and Table S2, it is evident that the EPR value was associated with the extent of overlap between the closed season and the spawning period of *S. schlegelii*. Strategy 2 had the highest EPR due to its complete overlap with the spawning period, followed by Strategy 3 (overlap of 4 months), Strategy 4 (overlap of 3 months), and Strategy 1 (no overlap time). As can be seen in Figure 10(b) and Table S2, SBR values are correlated with the duration of the closed season where *F* is consistent. If the duration of the closed season is longer, the SBR value is larger. Strategy 2 had the largest SBR (with a seven-month closure), followed by Strategy 1 (with a five-month closure), again by Strategy 3 (with a four-month closure), and finally by Strategy 4 (with a three-month closure).

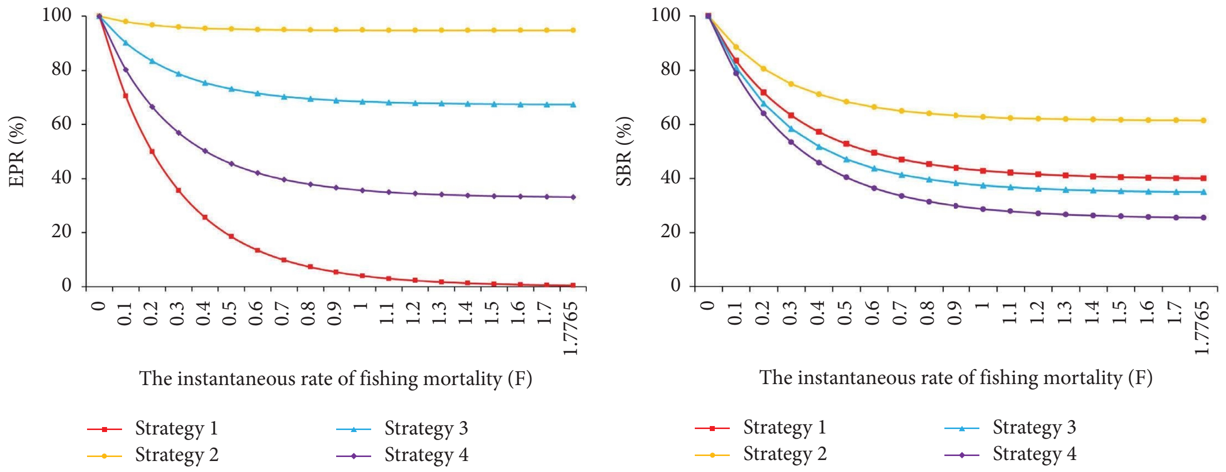
4. Discussion

4.1. Growth Characteristics. The correlation indexes of fish length and weight are important indicators of fish growth. The average length of *S. schlegelii* was 176.33 mm, which was significantly smaller than L_m (225 mm). This finding indicates that the study area contains a greater proportion of juvenile *S. schlegelii*, indicating that the miniaturization of individual organisms is a significant concern. Additionally, L_m was larger than the catchable length (136.59 mm), indicating that fishing is the main reason for individual size miniaturization [21]. Because individual size miniaturization may be primarily caused by the long-term and intensive fishing for fish less than L_m, in length, which increases the survival probability of small individuals of mature fish and maximizes the likelihood of gene transmission from small individuals to their offspring..

In the length-weight relationship, “*a*” can reflect the environmental conditions of the fish and is positively correlated with environmental factors such as bait and hydrological conditions [28]. In this study, the value of parameter “*a*” was 0.00005, which was higher than the value reported by Chen et al. [8]. This difference may be attributed to the favorable environmental conditions in this area, which promoted the growth of *S. schlegelii*.

The parameter of “*b*” represents the variations in body shape of the fish at different developmental stages. In this study, the value of parameter “*b*” was 2.882, which aligns with the results of previous studies [29]. This suggests the population of *S. schlegelii* grows at a uniform rate, with little change in size during the growth stage.

The estimation of the instantaneous natural mortality (M) is considered more rational and precise when the ratio of M to k falls within the range of 1.5 to 2.5. On the other hand, the comparison between Z/k and 3 serves as the foundation for determining the nature of population mortality. The prevailing belief is that natural mortality is thought to account for the majority of total mortality when Z/k is less than 3. When Z/k is greater than 3, fishing mortality is believed to be the primary factor contributing to total mortality [30]. The study found that the value of M/k is 2.04, within the range of 1.5 to 2.5. This indicates that the estimation of M is precise [31]. Additionally, the value of Z/k is 7.77, which is greater than 3. Thus, it can be deduced that fishing is the primary factor contributing to the mortality of the *S. schlegelii* population in Zhangzi Island’s waters.



(a) (b)

Figure 10: Variation of EPR (a) and SBR (b) values of *S. schlegelii* with F under various strategies.

Table 3: Under the current fishing intensity, the EPR and SBR values under different strategies and the percentage of theoretical unexploited maximum value.

	Strategy 1 (%)	Strategy 2 (%)	Strategy 3 (%)	Strategy 4 (%)
EPR (eggs/ind.)	608/0.48	1189991/94.8	84498/67.32	41631/33.12
SBR (g/ind.)	1234/39.96	1897/61.44	1081/35	785/25.43

The growth inflection age, determined by the growth equation, refers to the age at which the rate of fish weight growth is at its highest. In this study, the growth inflection age of *S. schlegelii* corresponded to body length and weight of 293.64 mm and 647.48 g, respectively. These values were significantly higher than those observed in the *S. schlegelii* sample, suggesting that most individuals were captured during a period of rapid growth. It is recommended to exploit fishery resources as much as possible after the growth inflection age [32]. Therefore, it is crucial to establish a suitable catchable size in order to ensure the sustainable exploitation of fishery resources.

The determination of the catchable size generally relies on the individual fish's growth potential and the cohort biomass of the fish as benchmark. From the standpoint of maximizing the fish's capacity for growth, the body length at the age when growth reaches its peak can be identified as the size at which the fish becomes suitable for catching, and this length is 293.64 mm. To maximize the biomass of one generation, the critical length can be defined as the size, and the length is 293.64 mm. Therefore, it is recommended to catch optimum size (294–328 mm) in conjunction with fishery management practice to improve the situation of serious size miniaturization of *S. schlegelii*.

4.2. Status of Resource Utilization.

4.2. Status of Resource Utilization. The exploitation rate is the primary metric that describes the level of utilization of fishing resources [33]. Mehanna posited that the resource is considered to be sustainably utilized when the exploitation rate (E) is below the maximum exploitation rate ($E_{\max}$) as indicated by the curve depicting the relationship between relative yield per recruit and exploitation rate. Conversely, if E exceeds $E_{\max}$, the resource is deemed to be in a state of overexploitation [34]. Figure 8 demonstrates that with the current status of resource exploitation (i.e., L_c of 136.59 mm), the values for $E_{0.1} = 0.452$, $E_{0.5} = 0.302$, $E_{\max} = 0.535$, and $E = 0.737$. This means that E is more than $E_{\max}$, indicating that the resource is being overutilized. As shown in Figure 9, when Y'/R is maximum, $L_c/L_\infty = 0.6$, and L_c is 270 mm. which is obviously larger than the current catchable length (136.59 mm), indicating that the resource of *S. schlegelii* is currently overfished. Therefore, enlarging the mesh size and increasing the catchable length are crucial to ensure the sustainable exploitation of the resource. It is also necessary to scientifically determine the total annual allowable catch (TAC), and the maximum sustainable yield (MSY) is an important reference index used to set the total annual allowable catch. According to the formula of Gulland [35, 36]: $\text{MSY} = 0.5 \times M \times B$, the estimated MSY is 465.80 t for Zhangzi Island's waters. This value can serve as a benchmark for resource management in the area.

4.3. Management Strategies for Closed Season. For the management of fisheries, the biological reference points are important metrics. The concept of biological reference points was first introduced by Schaefer in 1954. Particularly in circumstances where worldwide fishery resources are diminishing, it is frequently employed as a guide for managing and conserving fishing resources. This encompasses the threshold reference points, target reference points, and limit reference points [37]. Biological reference points are determined by relevant models. The model of yield per recruit (YPR) usually uses $F_{0.1}$ and $F_{\max}$ as the reference points; the model of egg production per recruit (EPR) and the model of spawning biomass per recruit (SBR) usually use F that restores the values of EPR and SBR to 25% and 40% as the limiting reference point and the target reference point, i.e., $F_{25\%\mathrm{EPR}}, F_{25\%\mathrm{SBR}}, F_{40\%\mathrm{EPR}}, F_{40\%\mathrm{SBR}}$ [22, 23]. SBR values calculated for Strategy 1 (current management mode) were consistently greater than 40% of the maximum value for the theoretical unexploited state. This may be due to the fact that spawners are well protected because of the long duration of the closed season.

As can be seen from Figure 10, under the current resource utilization mode (Strategy 1), the EPR value accounts for 0.48% of the maximum value at theoretical unexploited state, and the SBR value accounts for 39.96% of the maximum value at theoretical unexploited state, which shows that the egg production of current spawning in Zhangzi Island's waters is seriously underproduced.

The corresponding F when the EPR is restored to 25% and 40% of the theoretical maximum value is 0.407 and 0.265, respectively (Table 4). From Table 4, it can be seen that if the EPR is restored to 25% and 40% of the maximum value at the theoretical unexploited state, F needs to be reduced by 77.09% and 85.08%, respectively. According to Table 4, if Strategy 2 is used, the current F can restore the EPR to 94.8% and the SBR to 61.44%. If Strategy 3 is used, the EPR can be restored to 67.32% and the SBR will be 35%. Finally, if Strategy 4 is adopted, the EPR can be restored to 33.12% and the SBR will be 25.43%. To summarize, when comparing Strategy 1 (the current management mode) with Strategies 2, 3, and 4, all of the latter strategies show various increases in EPR values. Furthermore, all of these strategies surpass the biological limit reference point of $F_{25\%\mathrm{EPR}}$. The above results clearly indicate that the strategies of 2, 3, and 4 have a significant impact on the improvement of *S. schlegelii* resources. Based on a thorough analysis of protecting the reproduction of *S. schlegelii*, ensuring stable income for fishermen, and promoting sustainable resource utilization, it is advised to implement Strategy 3, which involves establishing a closed season from November to February, as the management approach for utilizing *S. schlegelii* resources in Zhangzi Island's waters.

4.4. The Risks of the Assessment. The sampling scheme is considered to be representative, and the mesh size of the fishing gear in this study is 25 mm. Cage traps are considered the main fishing gear used for biological resource surveys in rocky reef waters. Li et al. used cage traps to survey and analyze the biological community structure of five artificial reef areas in the Bohai Sea and Yellow Sea with good results [38]. Zhang et al. also analyzed the population dynamics of *S. schlegelii* using cage traps' sampling and calculated biological reference points in the Xixiakou Marine Ranching in Weihai city [29].

Uncertainty in stock dynamics can lead to discrepancies between estimated management parameters and real values. For instance: (1) the absence of elderly individuals in the sample led to elevated values of total instantaneous mortality (Z) calculated using the length-converted catch curve method; (2) the application of the ELEFAN I module for estimating growth parameters might not accurately reflect the situation given that the cage traps were predominantly utilized in the summer; and (3) the ovaries obtained from fish captured by the cage traps could not be used for fecundity determination due to their stage being below III. Therefore, the fecundity was determined in this study through the analysis of female samples collected via angling in April of 2019, 2020, and 2021 and at least stage III. The purpose of selecting these samples was to provide an example of fecundity during the entire reproductive period, despite the potential for variation from the actual fecundity of the fish. To augment the accuracy of assessments of management parameters, subsequent sampling endeavors would be expanded to include a wider range of sampling durations and magnitudes.

Table 4: Biological reference points for *S. schlegelii* under the current instantaneous rate of fishing mortality (Strategy 1).

$F_{25\%\ \mathrm{EPR}}$	$F_{40\%\ \mathrm{EPR}}$
0.407	0.265

5. Conclusions

The objective of this study is to provide a foundation for fishery management agencies in Zhangzi Island's waters, with the goal of ensuring the sustainable development of *S. schlegelii* resources. Based on the survey data collected, the growth characteristics and population dynamics of *S. schlegelii* were analyzed, and the closed season was simulated using the EPR and SBR models. Following an in-depth review of the findings, the subsequent suggestions were formulated as the conclusive findings of this research. (1) The catchable size of *S. schlegelii* is 294–328 mm. (2) The annual total allowable catch of *S. schlegelii* in Zhangzi Island's waters is about 465.8 t. (3) The closed season is advised to implement in Zhangzi Island's waters from November to February each year. It is critical to consider environmental factors such as suitable water temperature, biological factors associated with the spawning season, and the effects on industry personnel when managing fisheries. This will help the advancement of more rational and scientific approaches to the management of fishery resources. In addition, it is proposed to take further measures with a view to protect the *S. schlegelii* resources in Zhangzi Island's waters. Potential measures to be taken include reducing the number of operational vessels, implementing limitations on trawling operations, and increasing the mesh size of nets. In order to minimize the growth overfishing of *S. schlegelii* in Zhangzi Island's waters, it is recommended to reduce fishing efforts during the breeding season and/or establish a special protection zone. Management measures should be in line with national marine fishery resource conservation measures (including seasonal closures and fishing gear and vessel management) [39]. Improvement of catchable size and reducing fishing intensity are thought to be significant, inter alia.

Data Availability

The data will be made available on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors would like to thank the National Key R&D Program of China (2019YFD0901302) and the Dalian Science and Technology Fund (2021JJ11CG001) for the research funding support.

Supplementary Materials

Figure S1: length-converted catch curve of *S. schlegelii* in Zhangzi Island's waters. Figure S1 shows a plot of the length-transformed catch curve used to solve for the total mortality coefficient (*Z*), with the yellow points in the plot being the discarded points (because they are below the full replenishment age for the species, i.e., not all of the individual fish below that age can be sampled). Table S1: the number of resources and steady-state biomass of *S. schlegelii* in Zhangzi Island's waters. Table S1 shows the number of resources and steady-state biomass of *S. schlegelii* in Zhangzi Island's waters. The data in this table were obtained from the length frequency data by applying the length structure VPA method with FiSAT II software. Table S2: the percentage of EPR and SBR values to the theoretical unexploited maximum under different strategy changes with *F*. Table S2 shows the percentage of EPR and SBR values to the theoretical unexploited maximum under different strategy changes with *F*. The data in this table are calculated from equations (12) and (13) based on the survey data. (*Supplementary Materials*)

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