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Growth, Mortality and Stock Assessment of *Squaliobarbus curriculus* (Actinopterygii: Cypriniformes: Xenocyprididae) from Lanxi Section of Qiantang River, China

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Abstract

Population dynamics parameters and stock status of *Squaliobarbus curriculus* (Richardson, 1846) were analyzed from May to September 2021 in the Lanxi section of Qiantang River. FiSAT II software program was used. The growth coefficient $K = 0.21$ year^{-1}, asymptomatic length $L_\infty = 39.48$ cm, and age at theoretical zero-length $t_0 = -0.74$ years were estimated. The von Bertalanffy growth function was calculated as $L_t = 39.48[1 - e^{-0.21(t + 0.74)}]$. The growth curve for weight had an inflection at 5.86 years, corresponding to 29.61 cm in standard length and 372.29 g in weight. The natural mortality rate (*M*), the fishing mortality rate (*F*), and the total mortality rate (*Z*) were calculated as 0.51, 0.61, and 1.12 year^{-1}, respectively. The exploitation ratio (*E*) was 0.54, which is greater than the value of 0.5 suggested by Gull (1971), indicating a probable state of overdevelopment. The annual average stock number and biomass of *S. curriculus* in the Lanxi section of Qiantang River were 31.86×10^6 individuals and 3656.82 t, respectively.

Keywords

Lanxi Section of Qiantang River, Population Dynamics Parameters, *Squaliobarbus curriculus*, Stock Assessment

1. Introduction

Qiantang River is the largest river in Zhejiang province, with a drainage area of about 55,000 km^2. Besides drinking, it also has power generation, flood control, irrigation, and sightseeing functions. The river was historically rich in fish resources, and fish harvests date back centuries, with the highest take recorded as 5318.2 t in 1960 [1]. However, in recent decades, due to overfishing, biological invasion, environmental damage and the construction of hydropower dams, fish resources have been continuously reduced [1] [2]. To protect and restore the local fish resources in the river, the artificial release has been carried out since 2005, and then fishing strategies, including seasonal bans and restrictions on fishing grounds, have been implemented [1]. In particular, Qiantang River was included in the unified fishing ban system for the southern part of the Yangtze River basin in 2019, which means that all fishing activities except recreational fishing should be banned in the mainstream of Qiantang River from March 1st to June 30th every year.

Squaliobarbus curriculus is an endemic fish in rivers of East Asia Plain, which is widely distributed in various freshwaters in China, but mainly in the Yangtze River basin and its southern water systems [3]. As one of the economic fish, it is very popular due to its delicious taste and rich nutrition. This fish was recorded in Qiantang River several decades ago, but its catch dropped sharply before 2019, accounting for less than 0.5% of the total catch in 2018. To restore the stock of this species in Qiantang River, the government of Zhejiang Province listed it as a directive species for artificial release during the 14th Five-year period, which necessitated ascertaining its population structure and stock status. However, previous studies on the population parameters and resource evaluation of this species mainly focused on the Yangtze River, Jialing River, and Pearl River [3]-[10], and little was on Qiantang River.

In this study, an attempt was made to analyze the population dynamics parameters and stock status of *S. curriculus* in the Lanxi section of Qiantang River. Our findings will describe the characteristics of the population and provide a scientific basis for protecting the fish resources of the river.

2. Material and Methods

2.1. Fish Collection and Measurements

Fish samples were collected monthly by multipanel nylon gillnets ranging in size from 1 cm to 8 cm from May to September 2021 in the Lanxi section of Qiantang River, Zhejiang Province, China (119˚20' - 119˚31'E, 29˚6' - 29˚21'N) (**Figure 1**). Following transportation of the samples to the laboratory, fish samples were immediately measured to the nearest 0.1 cm (standard length, SL; total length, TL) and weighed to the nearest 0.1 g (weight, *W*) simultaneously.

2.2. Length-Weight and Length-Length Relations

The length-weight relation (LWR) was described by the power equation

$$W = aSL^b$$

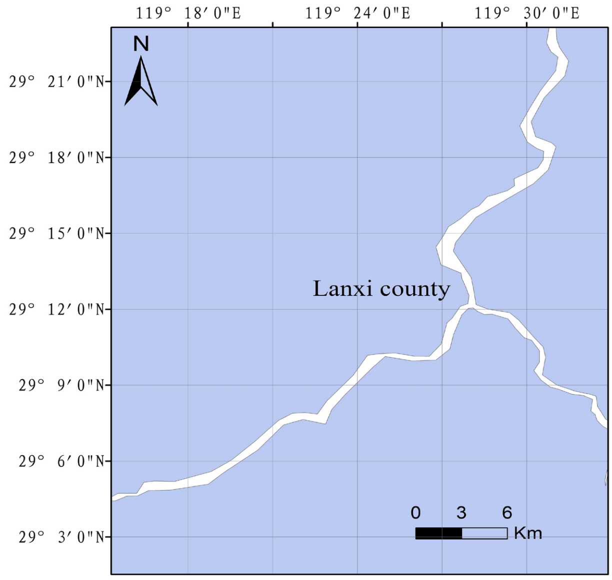

Figure 1. Fish sampling transect in Qiantang River.

where W is the weight (g), SL is the standard length (cm), a and b are the intercept and slope of the equation, respectively. The formula was equipped with a linear regression model based on log-transformed data [11]. The estimated parameter b from LWR was tested for a significant deviation from 3 by using a t-test. The length-length relation (LLR) was determined following the generalized linear regression equation

$$TL = a + bSL$$

where TL is the total length (cm), and other measurements are defined above. The statistical analyses were performed using Excel 2007.

2.3. Growth and Growth Performance Index

The population dynamics parameters in this study were estimated by using FiSAT II software [12], which is a program package developed mainly for the analysis of length-frequency data, but also enables related analyses, of size-at-age, catch-at-age, selection and other analyses. After calculating the group interval of standard length using the methods of Snedecor and Sturges respectively, the average value was adopted as the final group interval used in the FiSAT II software [13] [14].

$$\text{GI-1} = \text{Range}/\left(\text{Range}/SD \times 4\right)$$

$$\text{GI-2} = \text{Range}/\left(1 + 3.322\log N\right)$$

$$\text{GI} = \left(\text{GI-1} + \text{GI-2}\right)/2$$

where GI-1 is the group interval calculated by using Snedecor's method (cm), GI-2 is the group interval calculated by using Sturges's method (cm), GI is the group interval finally used (cm), Range is the total interval of standard length (cm), SD is the standard deviation, N is the number of species.

The theoretical growth parameters, K and L_∞, for the species were estimated from length-frequency data using ELEFAN I [15]. The growth of fish of the given stock was described by fitting von Bertalanffy growth function (VBGF) [16]

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

where L_t is the expected standard length at age of t years (cm), L_∞ is the theoretical standard length at age infinity (cm), K is the growth coefficient (year^{-1}), and t_0 is the age when the length is theoretically zero. Here, the value of t_0 can be calculated using the obtained K and L_∞ by the formula [17]

$$\log(-t_0) = -0.3922 - 0.2752\log L_\infty - 1.038\log K .$$

In addition, the accuracy of the growth performance index (φ') was tested using von Bertalanffy growth performance [18]

$$\varphi' = \log K + 2\log L_\infty$$

The longevity ($t_{\max}$) was determined by the formula [19] below

$$t_{\max} = 3/K$$

2.4. Growth Rate and Growth Acceleration

The first and second derivatives of the LWR equation were calculated to obtain the growth rate and growth acceleration equations of length and weight. The formulas used [20] are as follows

$$\mathrm{d}L/\mathrm{d}t = L_\infty K\mathrm{e}^{-K(t-t_0)}$$

$$\mathrm{d}m/\mathrm{d}t = bm_\infty K\mathrm{e}^{-k(t-t_0)}\left[1-\ \mathrm{e}^{-K(t-t_0)}\right]^{b-1}$$

$$\mathrm{d}^2L/\mathrm{d}t^2 = -L_\infty K^2\mathrm{e}^{-K(t-t_0)}$$

$$\mathrm{d}^2m/\mathrm{d}t^2 = bm_\infty K^2\mathrm{e}^{-K(t-t_0)}\left[1-\mathrm{e}^{-K(t-t_0)}\right]^{b-2}\left[b\mathrm{e}^{-K(t-t_0)}-1\right].$$

where $\mathrm{d}L/\mathrm{d}t$ is the growth rate of standard length, $\mathrm{d}m/\mathrm{d}t$ is the growth rate of weight, $\mathrm{d}^2L/\mathrm{d}t^2$ is the growth acceleration of standard length, $\mathrm{d}^2m/\mathrm{d}t^2$ is *the* growth acceleration of weight, a and b are the intercept and slope of the LWR equation, and other measurements are defined as above. The age of inflecting point (t_i) can be calculated using the formula [20]

$$t_i = (\ln b)/K + t_0 .$$

2.5. Mortality and Exploitation

The annual instantaneous total mortality coefficient (Z) was estimated from a length-converted catch curve by using the FiSAT II software program [21] [22] [23]. The annual natural mortality coefficient (M) was estimated by using Pauly's equation [17]

$$\log M = -0.0066 - 0.279\log TL_\infty + 0.6543\log K + 0.4634\log T$$

where TL_∞ is the theoretical total length at age infinity (cm), and T is the annual mean water temperature (˚C), which was set at 21.5˚C according to historical data. The instantaneous fishing mortality coefficient (F) was calculated by the equation

$$F = Z - M$$

And the exploitation rate (E) was determined by the formula [24]

$$E = F/Z$$

2.6. Fish Catch Estimation

First, the annual total catch number (N_t) was calculated using the formula [14]

$$N_t = x_i \times f_i \times d_i$$

where N_t is the annual total catch number, x_i is the catch per unit effort (CPUE), f_i is the number of operating vessels, which was set as 202 vessels in the section in 2021 according to the statistics of the local fisheries department, d_i is the annual operating time (d), which was calculated as 180 d, excluding the time of fishing closure from March to June, the flooding period (about one month), the cold Chinese New Year and other personal reasons. Then, the mean total catch number (N) of *S. curriculus* was acquired with the equation

$$N = N_t \times \%N$$

where $\%N$ is the individual proportion of *S. curriculus* relative to the number of total catch.

2.7. Stock Estimation

The length-structured VPA module was used for the analysis [21]. The annual catch number of *S. curriculus* is entered into the module, as well as L_∞, K, M, fishing mortality coefficient (F_t) for the maximum length group, the constant a and coefficient b in the LWR. The iterative method was used in the VPA module, and 0.5 was taken as the initial value of F_t. Every time, the overall fishing mortality coefficient F_{ove}, which was used as the next F_t, was determined using the formula below

$$F_{ove} = \sum \left(F_i \times N_i \right) / \sum N$$

where F_i is the mortality coefficient of each length group (year^{-1}), N_i is the stocks of each length group (t). When the F_{ove} is little different from the former, the iterative operation should be completed and the final F_t value is determined [25].

3. Results

3.1. Relative Growth

In this study, 292 individuals of *S. curriculus* were examined for length frequency distribution. The standard length of fish ranges from 14.2 cm to 39.0 cm (mean ± SD 23.56 ± 4.12 cm SL). The fish of 21.4 cm and 23.2 cm size account for 42.8% of the total catch. Smaller size classes were represented by fewer numbers (**Figure 2**).

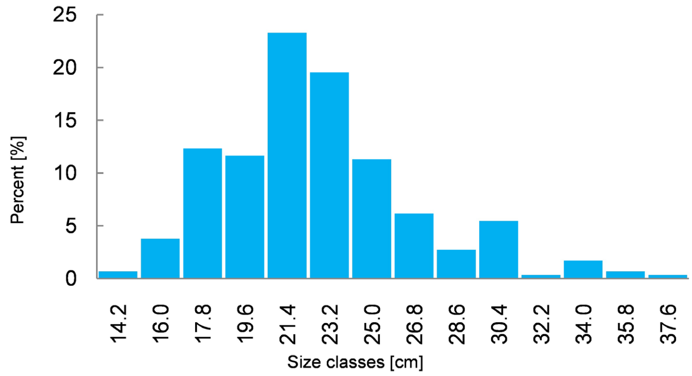

Figure 2. Standard length (SL) frequency distribution of *Squaliobarbus curriculus* sampled in Lanxi section of Qiantang River.

The maximum length (SL) and weight of *S. curriculus* in this study were recorded as 39.0 cm and 868.0 g, respectively. The LWR and LLR estimates were highly significant ($p < 0.01$), yielding $r^2 \geq 0.95$. The value of parameter b in the LWR was consistent with the predicted range of 2.5 - 3.5 [26], and the b value of 2.933 is not significantly different from the theoretical value of 3 (t-test, $p > 0.05$), indicating isometry. The curves of LWR and LLR for all individuals are given in **Figure 3**.

3.2. Growth and Growth Performance Index

The group interval finally used (GI) was 1.8 cm, leading to 14 length groups observed. The calculated growth coefficient (K), asymptomatic length (L_∞) and age at theoretical zero-length (t_0) were estimated at 0.21 year^{-1}, 39.48 cm, and −0.74 years, respectively. The VBGF was described as

$$L_t = 39.48\left[1 - e^{-0.21(t+0.74)}\right]$$

The growth performance index (φ') and longevity (t_{max}) were estimated at 2.51, 14.28 years, respectively.

3.3. Growth Rate and Growth Acceleration

The growth rate curve of length had no inflection, showing a declining trend with age, and also the acceleration of standard length growth kept slowing with age (**Figure 4(a)**). The weight growth curve showed an obvious inflection at 5.86 years, corresponding to the standard length of 29.61 cm and weight of 372.29 g. The weight acceleration decreased with age, reached a minimum and then increased slowly (**Figure 4(b)**).

3.4. Mortality and Exploitation

The annual natural mortality coefficient (M) was estimated to be 0.51 year^{-1}. A length-converted catch curve was utilized for the calculation of the instantaneous total mortality at Z = 1.12 (0.89 – 1.35) year^{-1}, leading to the fishing mortality (F) being 0.61 year^{-1}. Meanwhile, the exploitation rate (E) was determined to be 0.54 year^{-1}.

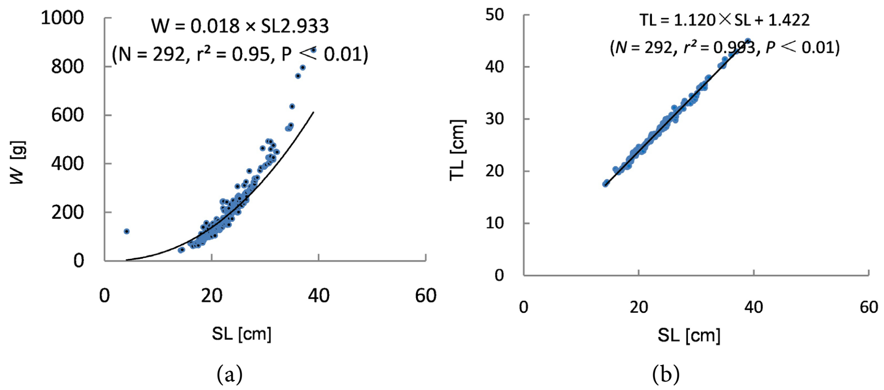

Figure 3. The length-to-weight (a) and length-to-length (b) relations of *Squaliobarbus curriculus* sampled in Lanxi section of Qiantang River.

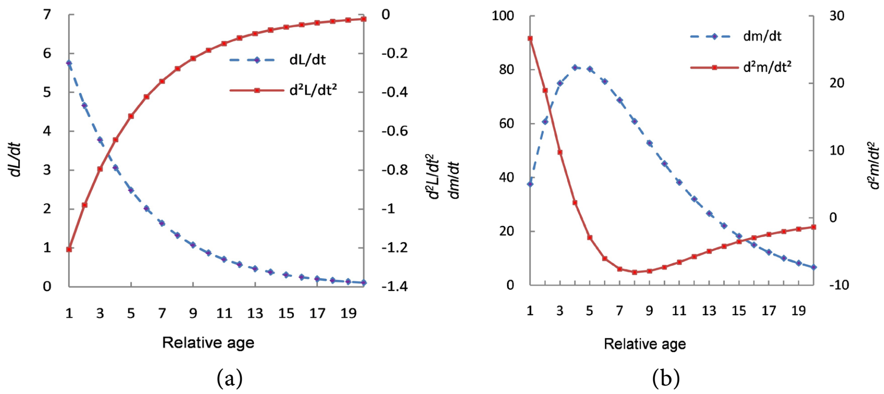

Figure 4. Growth rate and growth acceleration of standard length (a) and weight changing (b) with the age of *Squaliobarbus curriculus*.

3.5. Stock Estimation

Based on data of the CPUE and number of catch cited from Zhang *et al.* (unpublished) [27], that is, 19760 g/(vessel × day) and 260 ind./(vessel × day), the annual total catch number (N_t) was estimated to be 9,453,600. Meanwhile, according to the value of $\%N = 7\%$, the annual total catch number of *S. curriculus* was calculated to be 661,752.

After five iterations, the fishing mortality coefficient for the maximum length group of *S. curriculus* was calculated as 0.023 year^{-1}, which was entered into the VPA module as the final F_t. Subsequently, the annual population of *S. curriculus* was estimated at 31.86×10^6 individuals, with corresponding biomass of 3656.82 t (**Figure 5**).

4. Discussion

4.1. Growth Characteristics of *S. curriculus*

Estimation of fish growth can provide a valuable understanding of its life history, and can be further used to formulate optimum fishing regulations for sustaining stocks [28]. The von Bertalanffy model was generally considered to be the most reliable candidate model for fish stocks in a mathematical sense [29].

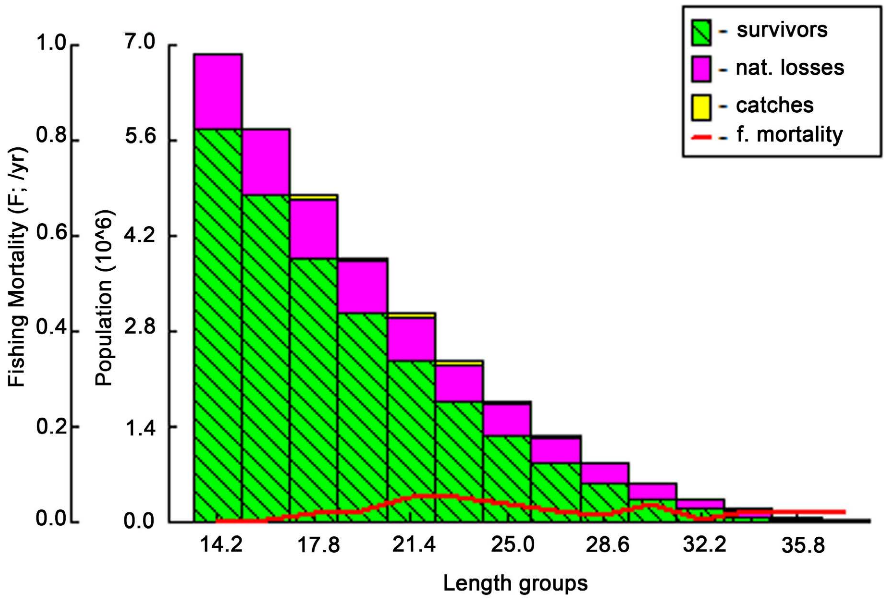

Figure 5. Standard-length structured virtual population analysis for *Squaliobarbus curriculus* collected from Lanxi section of Qiantang River.

In this study, the growth of *S. curriculus* living in the Lanxi section of Qiantang River was evaluated. The coefficient *b* of the LWR was not significantly different from the theoretical value of 3, indicating isometry [26]. The coefficient *b* of the LLR was not within the scope of previous studies listed in FishBase [30]. The inflection point of weight growth curve appeared at 5.86 years, which was later than the estimated value of Wuhu reach of the Yangtze River [6], but virtually the same as that in Fu River [5]. The growth parameters of VBGF here were K = 0.21 year^{-1} and L_∞ = 39.48 cm. The lack of smaller-sized individuals in the catch may affect the growth parameters. The value of K here is close to 0.2, indicating a growth type between fast and slow according to Branstetter's method. In addition, this value was different from that estimated in the Yangtze River (e.g. Fu River, Wuhu reach [5] [6] and other rivers (e.g. Jialing River, the Pearl River) [4] [7] [8] [9]. Other growth performance indexes of *S. curriculus* here were also different from the values reported elsewhere (**Table 1**). Multiple factors such as genetic factors, water temperatures and environmental pressure (such as food organisms), may be responsible for the change [11] [26]. Information about these basic biological parameters is essential to formulate scientific fisheries management policies.

4.2. Resource Utilization and Protection of *S. curriculus*

The usage of fishery resources is related to fish resources, growth, fishing age and fishing intensity, and these factors also determine the status of fish resources. Of these, fishing effort and age/length at opening harvest are subject to human control and are two important tools for fishery management. The objective of fishery management is to maximize sustainable fish production by adjusting these two factors [23].

Table 1. Summary of the population parameters of *Squaliobarbus curriculus* from various sources.

Location	L_∞ (cm)	K (year^{-1})	t_0 (year)	t_i (year)	M (year^{-1})	Z (year^{-1})	F (year^{-1})	E (year^{-1})	Author
	39.48	0.21	−0.74	5.86	0.51	1.12	0.61	0.54	Present Study
Jialing River	67.213	0.146	−0.9925	6.6	/	/	/	/	He and Yang (1997)
Fu River of the Yangtze River	47.29	0.192	−0.6029	5.86	/	/	/	/	Yang *et al.* (2006)
Wuhu Reach of the Yangtze River	32.047	0.2328	−1.911	3.04	/	/	/	/	Guo *et al.* (2009)
Xijiang River Zhaoqing Section of the Pearl River	61.634	0.1359	−0.3961	8	0.1936	0.3379	0.1443	0.427	Zhu *et al.* (2013)
The Left River of the Pearl River	32.55	0.28	−0.515	3.5	/	/	/	/	Han *et al.* (2018)
The Right River of the Pearl River	28.35	0.24	−0.628	3.9	/	/	/	/	Han *et al.* (2018)
Xijiang River of the Pearl River	72.58	0.11	−0.613	9.37	0.16	0.70 - 1.37	0.54 - 1.21	0.77 - 0.86	Li *et al.* (2019)
Xijiang River Fenkai Section of the Pearl River	67	0.51	/	/	0.19	1.51	1.32	0.88	Zhu *et al.* (2020)

L_∞ = theoretical length at age infinity; K = growth coefficient; t_0 = hypothetical length when age is 0; t_i = age of inflecting point; M = natural mortality rate; Z = total mortality rate; F = fishing mortality rate; E = exploitation rate.

The fishing nets mainly used in Qiantang River were multipanel nylon gillnets with a variety of mesh sizes for a long time. Coupled with a large fishing staff, the fishery resources in the river were under great fishing pressure, resulting in a fish resource decline. Due to the sharp decrease of stock for *S. curriculus* before 2018, effective fishery management strategies were urgently needed to restore the resource. It is determined that the breeding season for *S. curriculus* is generally from April to September, with June to July being the peak. The fishing moratorium from May 1st to June 30th every year is one of the main management measures taken by the local fishery department of Lanxi County, and the available fishing time effectively avoids the peak spawning period of *S. curriculus*, which greatly ensures the replenishment of the specie's population resource.

A value of M/K in the range of 1.5 to 2.5 is generally considered reasonable [31], which was also verified in this study. A value of Z/K less than or equal to 3 is considered to be mainly natural mortality, while a value greater than 3 is considered to be mainly fishing mortality [31]. In this study, Z/K was 5.33, indicating the decline of *S. curriculus* was mainly caused by fishing mortality. It can be speculated that the leading cause of the decline of fish stock should be anthropogenic. Furthermore, the exploitation rate (E) of *S. curriculus* was 0.54, which is higher than the value of 0.5 suggested by Gulland [24], indicating this species may be in an overdevelopment state. It was analyzed that the age at the fastest weight growth of this species was 5.86 years when the corresponding standard length was 29.61 cm, however, the average standard length of fish samples here was 23.56 cm, indicating an undersized catch. According to the above results, the local fisheries management department should formulate more reasonable protective measures, such as requiring fishing gears to be of specific types and mesh sizes to avoid catching small juvenile fish that have not been propagated.

For stock conservation, it is also recommended that the fishing size for *S. curriculus* should be larger than that at the age of inflection, that is, the standard length should be larger than 29.61 cm and weight greater than 372.29 g. Research on the reproductive biology of *S. curriculus* in the Lanxi section of Qiantang River should also be studied to provide a scientific basis for its artificial release.

It should be emphasized that this is the first study on the growth, mortality and stock assessment of *S. curriculus* from Qiantang River. Fishery regulations in China forbid the capture of any *S. curriculus* in the river during the fishing closure period, leading to incomplete coverage of annual sampling time and the lack of smaller-sized individuals. However, we believe that this study will greatly contribute to the conservation and management strategies of the species of *S. curriculus* in the future.

5. Conclusion

The growth, mortality and stock assessment of *S. curriculus* in the Lanxi section of Qiantang River, China, were studied by using the FiSAT II software program. The LWR and LLR estimates were highly significant. The fish showed isometry growth according to coefficient b of LWR. The obtained growth and mortality parameters (*i.e.* L_∞, K, F) can be used as inputs in VBGF and other fish stock assessment models (e.g. length-converted catch curve model, length-structured VPA module) to investigate the exploitation and stock status for this species. The exploitation rate was 0.54. The average stock number and biomass of *S. curriculus* in the Lanxi section of Qiantang River were 31.86×10^6 individuals and 3656.82 t, respectively. The population resource of *S. curriculus* was probably overexploited, and the leading cause affecting the population structure of *S. curriculus* in the section was estimated to be anthropogenic (e.g. fishing practices), leading to a decline in the resource. To achieve sustainable utilization of *S. curriculus* resources and mitigate the impacts of human activities on fish stock, control of fishing intensity needs to be implemented in the future, such as increasing minimum length limits.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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