Stock Assessment Using LBB Method for Eight Fish Species From the Bohai and Yellow Seas

Yibang Wang[1,2], Yuanchao Wang[1,3], Shude Liu[4], Cui Liang[1,5], Hui Zhang[1,5,6]* and Weiwei Xian[1,5,6]*

[1] CAS Key Laboratory of Marine Ecology and Environmental Sciences, Institute of Oceanology, Chinese Academy of Sciences, Qingdao, China, [2] Qingdao University of Science and Technology, Qingdao, China, [3] University of Chinese Academy of Sciences, Beijing, China, [4] Shandong Hydrobios Resources Conservation and Management Center, Yantai, China, [5] Laboratory for Marine Ecology and Environmental Science, Qingdao National Laboratory for Marine Science and Technology, Qingdao, China, [6] Center for Ocean Mega-Science, Chinese Academy of Sciences, Qingdao, China

Eight common and commercially important marine fishes from coastal and offshore areas of Shandong Province, China, were assessed using the "Length-based Bayesian Biomass" estimator (LBB) method. These species were *Scomber japonicus* (chub mackerel), *Sebastiscus marmoratus* (false kelpfish), *Hexagrammos otakii* (fat greenling), *Thryssa kammalensis* (kammal thryssa), *Gadus macrocephalus* (Pacific cod), *Setipinna taty* (scaly hairfin anchovy), *Sillago sihama* (silver sillago), and *Lophius litulon* (yellow goosefish). LBB is a new and powerful, yet simple, approach to evaluate a fisheries' status using length and frequency data. Shandong Province's coastal areas, adjacent to the Yellow and Bohai Seas, are an important fishing ground of China, where the 2018 catch of three of these species, yellow goosefish, chub mackerel, and Pacific cod, yielded up to 57,200, 21,100, and 1330 tons, respectively. The ratios of current relative to unexploited biomass (B/B_0) is smaller than the relative biomass that can produce MSY (B_{MSY}/B_0) in eight stocks save for silver sillago, indicating overfishing. Also, the sizes at first capture were well below the optimal, suggesting that larger mesh sizes would be beneficial. Our study provides evidence that LBB is an efficient method to evaluate the fishery resources in the Yellow and Bohai Seas, especially when length frequencies are the only available data. Also, LBB provided evidence useful for the management of the costal fishery resources of Shandong Province.

Keywords: Bohai and Yellow Seas, LBB method, overfishing, stock assessment, fishery resources

INTRODUCTION

For capture fisheries, China ranked first among the world's fishing countries in terms of quantity, and their capture production was up to 15,373,196 tons (FAO, 2019). With the increasing impact of human activities on the Marine ecosystem, the fish community has undergone considerable changes, and the resources of dominant economic species have been declining continuously. It was apparent that fishing individuals were younger, of lower quality, and smaller (Li et al., 2012). Shandong Province is adjacent to the Yellow Sea and the Bohai Sea, and it has economically important coastal fishing grounds (Tang and Ye, 1990) that are among the oldest in China (Lü et al., 2012). The

increasing impact of human activities on the marine ecosystem of Shandong's waters, especially overfishing, has caused a noticeable decline in fishery resources, including once-abundant species (Fu et al., 2007).

Scomber japonicus (chub mackerel), *Gadus macrocephalus* (Pacific cod), *Setipinna taty* (scaly hairfin anchovy), and *Sillago sihama* (silver sillago) have been the most important economic species in China, but their resources have presented a downward trend because of excessive fishing pressure (Huang et al., 2013; Cai et al., 2014; Xu et al., 2017; Yi and Chen, 2019). Since the 1970s, fishing intensity on chub mackerel has steadily increased, but the total catch of chub mackerel in East China and Yellow Seas has been on the decline; however, strong inter-year fluctuations have been documented (Yi and Chen, 2019). Pacific cod is one of the most important marine resources in northern China, where it is mainly caught in the Yellow Sea, with an annual catch that reached as high as 26,000 tons (Tang and Ye, 1990); the trend has, however, been gradually decreasing (Xu et al., 2017). For over a decade, starting in the early 1970s, the catch of scaly hairfin anchovy has steadily increased, partly compensating for the declining catches of more valuable species (Gu, 1990). However, since the 1980s, it has been on the decline because of excessive fishing pressure (Cai et al., 2014). Silver sillago is an economically important fish in China, but its yield is gradually declining (Zhang et al., 2018), and the species' biomass appears to be depleted (Du et al., 2009). As a local species, the *Hexagrammos otakii* (fat greenling) resources were destroyed (Feng and Han, 1998). In these waters, there has been a decline in fat greenling in both species diversity and the number and size of fish caught (Feng and Han, 1998). Similarly, *Sebastiscus marmoratus* (false kelpfish) experienced a sharp decline in natural resources due to long-term fishing (Yan et al., 2018). However, as an offshore small pelagic fish, the production and economic status of *Thryssa kammalensis* (kammal thryssa) were relatively improved (Yao et al., 2003). Kammal thryssa is a pelagic fish that is a vital fishery resource both economically and ecologically (Park et al., 2015). *Lophius litulon* (yellow goosefish) became one of the main aquatic products exported by China (Lin and Zheng, 2004). Therefore, it is necessary to carry out effective resource assessments and concerns need to be devoted to the sustainable use of fishery resources.

LBB is a length-based Bayesian biomass (LBB) estimation method for analyzing length frequency data from exploited fish or invertebrate populations in which all relevant parameters are estimated synchronously using Bayesian Monte Carlo Markov Chain (MCMC) approach (Froese et al., 2018). In this contribution, we have presented the LBB method as applied to eight common commercial fishes from the coastal waters of Shandong Province. The goal here is to provide an evidential basis for the protection and management of fishery resources in this area.

MATERIALS AND METHODS

Data Sources
Samples were collected in the coastal waters of Shandong between 35°–38° 30′ N and 118°–124° E, and a total of 177 resource

survey stations were set up, with trawling time of 1 h per station and towing speed of 3 kn. Fish samples were obtained using single bottom trawlers (30.6 × 8 m) with a cod end (mesh size: 30 mm) from October 2016 to August 2017. Samples were taken to a laboratory for further analysis, including species identification and a standard-length measurement. All collected fish were identified to species level, and scientific and common names were verified using FishBase[1], as summarized in **Table 1**. The LF data are presented in the **Supplementary Material**.

In this study, all analyses were performed using the R-code (LBB_20.R), which can be downloaded from http://oceanrep. geomar.de/44832/, including a New User Guide, whose various recommendations were followed.

General Description of the LBB Method
The LBB estimator is a new approach to estimate stock status using length-frequency data (Froese et al., 2018). The LBB method is applicable to species that grow throughout their lives, as do most commercially exploited fish and invertebrates. These species required no input apart from length-frequency (LF) data. The LBB estimates several parameters for one or several LF samples representing the population in question, including asymptotic length (L_{inf}), mean length at first capture (L_c), relative natural mortality (M/K), and relative fishing mortality (F/M) (Froese et al., 2018, 2019).

Here, we have only given the basic and final formulas, and we have referred to Froese et al. (2018) for details.

In LBB, it is assumed that the growth in length follows von Bertalanffy (1938) growth equation in the form given to it by Beverton and Holt (1957), i.e.,

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

where L_t is the length at age t, L_{inf} is the asymptotic length, K is the rate at which L_{inf} is approached, and t_0 is the theoretical age at zero length (Froese et al., 2018).

When the fish are fully selected by the gear, the curvature of the right side of catch samples is a function of total mortality ($Z = M + F$) relative to K. This curve is expressed by the equation

$$N_L = N_{L_{start}} (\frac{L_{inf} - L}{L_{inf} - L_{start}})^{Z/K} \tag{2}$$

where N_L is the number of survivors to length L, N_{Lstart} is the number at length L_{start} with full selection, i.e., from which all individuals entering the gear are retained by the gear, and Z/K is the ratio of the total mortality rate Z to somatic growth rate.

The lengths affected by partial selection are, for each species, a function of the fishing gear (here assumed to be a trawl or another gear with a trawl-like selection curve), as given by the ogive described by Eq. 3:

$$S_L = \frac{1}{1 + e^{-a(L-L_c)}} \tag{3}$$

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

---

[1]www.fishbase.org

Scientist name	Common name	Min (mm)	Max (mm)	Class interval	Numbers	L_{inf} prior (cm)	Z/K prior	M/K prior	F/K prior	L_c prior	*Alpha* prior
Scomber japonicus	Chub mackerel	55	303	10	764	34.5	10	1.5	8.74	11.2	55.9
Sebastiscus marmoratus	False kelpfish	35	114	10	96	15.3	5.5	1.5	3.95	7.14	39.3
Hexagrammos otakii	Fat greenling	40	255	15	1115	27.1	5.3	1.5	3.8	10.7	25.7
Thryssa kammalensis	Kammal thryssa	50	115	5	266	13.9	5	1.5	3.51	6.12	83.7
Gadus macrocephalus	Pacific cod	10	445	20	975	45	5.4	1.5	3.89	9.18	24.6
Setipinna taty	Scaly hairfin anchovy	12	222	10	1402	26.5	4.3	1.5	2.82	8.67	20.2
Sillago sihama	Silver sillago	51	147	5	115	14.8	1.6	1.5	0.0994	8.42	46.3
Lophius litulon	Yellow goosefish	11	494	10	1248	52.9	5.7	1.5	4.25	18.4	16.2

The parameters of the selection ogive are estimated at the same time as L_{inf}, L_c, α, M/K, and F/K by fitting

$$N_{L_i} = N_{L_{i-1}} \cdot \left(\frac{L_{inf} - L_i}{L_{inf} - L_{i-1}} \right)^{\frac{M}{K} + \frac{F}{K} S_{L_i}} \qquad (4)$$

and

$$C_{L_i} = N_{L_i} \, S_{L_i} \qquad (5)$$

where L_i is the number of individuals at length i, L_{i-1} is the number at the previous length, C refers to the number of individuals vulnerable to the gear, and all other parameters are as described above (Froese et al., 2018).

Finally, the following equation describes the framework for approximating stock status from L_{inf}, M/K, F/K, and L_c (Froese et al., 2016). First, given the estimates of L_{inf} and M/K, L_{opt}, i.e., the size at which cohort biomass is at maximum, can be obtained from equation (6):

$$L_{opt} = L_{inf} \left(\frac{3}{3 + \frac{M}{K}} \right) \qquad (6)$$

Based on Eq. (6) and a given fishing pressure (F/M), the mean length at first capture, which maximizes catch and biomass (L_{c_opt}), can be obtained from

$$L_{c\_opt} = \frac{L_{inf}(2 + 3\frac{F}{M})}{(1 + \frac{F}{M}) \, (3 + \frac{M}{K})} \qquad (7)$$

Estimates of L_{c_opt} are used below to calculate a proxy for the relative biomass that can produce MSY (Froese et al., 2018).

The estimate of $F/M > 1$ confirms that the stock is overfished, while the estimate of $B/B_0 < 0.5$ indicates that the current biomass is extremely low. The ratios L_{mean}/L_{opt} and L_c/L_{c_opt} were below unity, suggesting truncated length structure and fishing of too small individuals. The ratio of the 95th percentile length to asymptotic length L_{95th}/L_{inf} was close to unity (>0.9), suggesting that at least some large fish were still present.

The relative biomass and the length at first capture estimated by LBB can then be used directly for management of data-poor stocks:

If relative stock size B/B_0 is smaller than B_{MSY}/B_0, catches should be reduced.

If the mean length at first capture L_c is smaller than L_{c_opt}, fishing should start at larger sizes.

RESULTS

The results of our application of the LBB methods to eight fish species in the waters of Shandong Province are presented below, first by species and then in general terms.

Chub Mackerel (*S. japonicus*)

Chub mackerel is distributed in the Indian and Pacific oceans as well as the East China and Yellow Seas. This species reaches a maximum length of 64 cm (see text footnote 1) and is a valued commercial fish in the coastal waters of China. The estimate of $F/M = 5.4$ confirms that chub mackerel is greatly overfished, while the estimate of $B/B_0 = 0.033$ indicates that the current biomass of chub mackerel is extremely low, i.e., that it has declined by 97% from its original level (**Figure 1A**). The estimate of $L_{95}/L_{inf} = 0.88$ implies that large individual should be very rare to non-existent, which is supported by the ratios L_{mean}/L_{opt} (=0.59) and L_c/L_{c_opt} (=0.49); these ratios are both below unity, implying a truncated length structure and fishing of individuals that are too small.
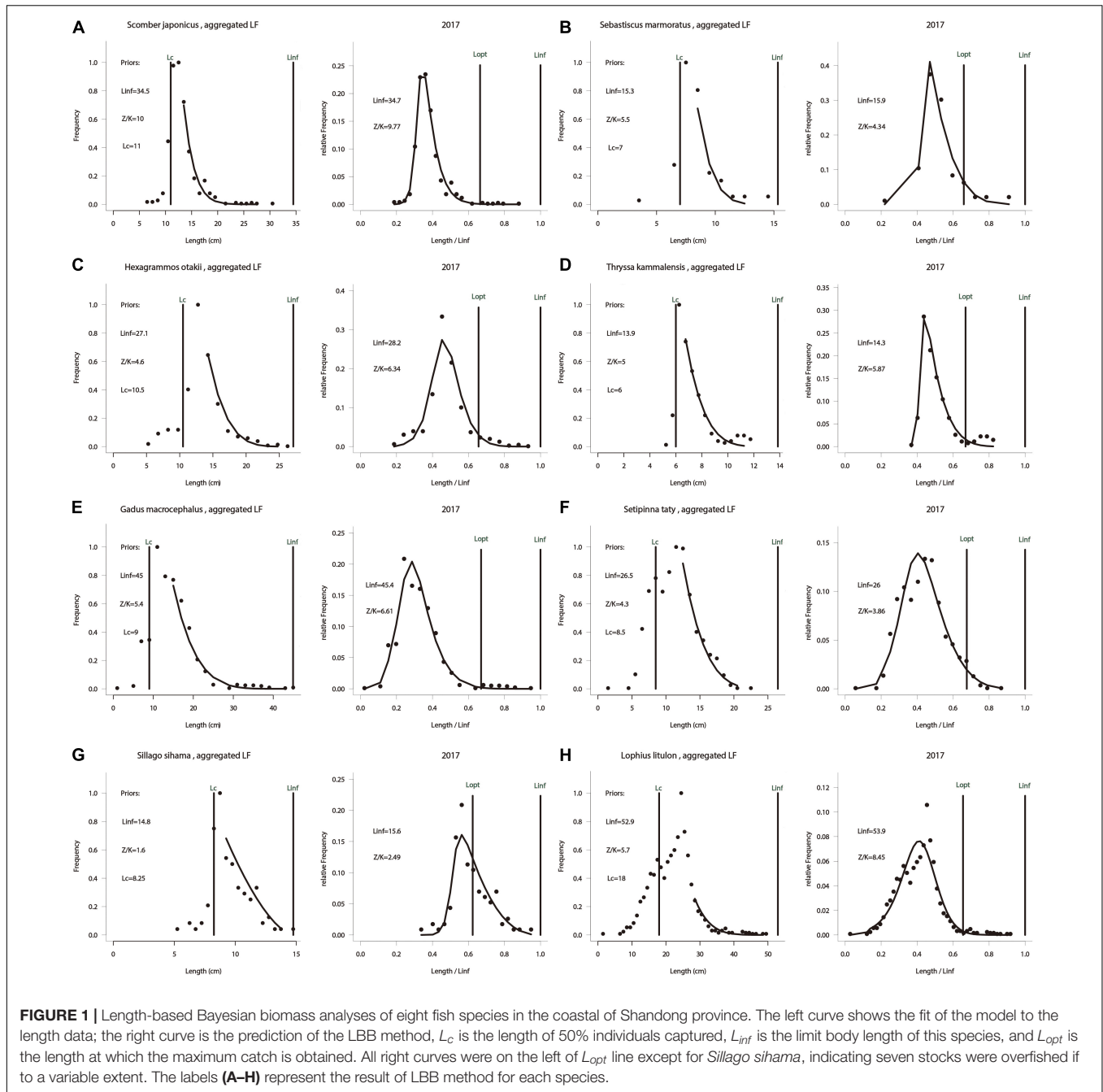
False Kelpfish (*S. marmoratus*)

False kelpfish is a species distributed in the Western Pacific, and these fish reach a maximum length of 36.2 cm (see text footnote 1). The parameters F/M (= 1.8) and B/B_0 (= 0.18) indicate that the low biomass for false kelpfish is primarily due to fishing pressure (**Figure 1B**).

Fat Greenling (*H. otakii*)

Fat greenling, which reaches a maximum length of 57 cm (see text footnote 1), is distributed in the Northwest Pacific, including Japan and from the southern Korean Peninsula to the Yellow Sea. There has been a decline in both species diversity and in the number and size of fish caught, confirmed in this study, by the ratios F/M (= 2.6) and B/B_0 (= 0.12) and by our estimates of L_{mean}/L_{opt} (=0.77) and L_c/L_{c_opt} (=0.66) (**Figure 1C**).

Kammal Thryssa (*T. kammalensis*)

Kammal thryssa is a widespread species in the Indo-West Pacific. It reaches a maximum length of 15.0 cm (see text footnote 1). In this study, the F/M (=2.9) indicates that this fish is under increasing fishing pressure. The ratio B/B_0 (=0.1) is very low, suggesting that its standing biomass is undergoing a sharp decline. Similarly, the parameters L_{mean}/L_{opt}

FIGURE 1 | Length-based Bayesian biomass analyses of eight fish species in the coastal of Shandong province. The left curve shows the fit of the model to the length data; the right curve is the prediction of the LBB method, L_c is the length of 50% individuals captured, L_{inf} is the limit body length of this species, and L_{opt} is the length at which the maximum catch is obtained. All right curves were on the left of L_{opt} line except for *Sillago sihama*, indicating seven stocks were overfished if to a variable extent. The labels **(A–H)** represent the result of LBB method for each species.

(= 0.77) and L_c/L_{c_opt} (= 0.66) are below unity, suggesting a truncated length structure and fishing of individuals that are too small (**Figure 1D**).

Pacific Cod (*G. macrocephalus*)

Pacific cod, which reaches 120 cm (see text footnote 1), is widely distributed in the North Pacific Ocean, including the area from the western Pacific to the Yellow Sea. The parameters F/M (= 3.5), B/B_0 (= 0.043), L_{mean}/L_{opt} (= 0.51), and L_c/L_{c_opt} (= 0.37) indicate that overfishing has depleted the species (**Figure 1E**).

Scaly Hairfin Anchovy (*S. taty*)

Scaly hairfin anchovy, which reaches a maximum length of 15.3 cm (see text footnote 1), is widely distributed in the Indo-West Pacific and along most of China's coastline, notably in the Bohai Sea. In this study, the ratios F/M (=1.7) and B/B_0 (=0.16) suggest that this species is suffering from overfishing pressure (**Figure 1F**) and a low biomass.

Silver Sillago (*S. sihama*)

Silver sillago, which reaches a maximum length of 31 cm (see text footnote 1), is widely distributed in the Indo-West Pacific,

including China's coasts, from the Bohai Sea in the North to the South China Sea. This study estimated ratios F/M (=0.37) and B/B_0 (= 0.62). This suggests that fishing pressure may not be the major cause for the decrease in biomass of silver sillago. The parameters L_{c95}/L_{inf} (=0.95), L_{mean}/L_{opt} (=1), and L_c/L_{c_opt} (=1.1) are close to 1 (>0.9), suggesting that large fish are still present (**Figure 1G**).

Yellow Goosefish (*L. litulon*)

Yellow goosefish, reaching a maximum length of 150 cm (see text footnote 1), is distributed in the Northwest Pacific, including Japan, Korea, and the Yellow and East China Seas. The ratios F/M (= 4.4) and B/B_0 (= 0.06) indicate that yellow goosefish are suffering from overfishing pressure, and the biomass for this species is very low (**Figure 1H**).

Eight fish stocks in the coastal areas of Shandong Province, for which abundant data were available, were analyzed by the LBB method. The priors for the eight fish stocks, including asymptotic length, L_{inf}, Z/K, M/K, F/K, L_c, and α, are given in **Table 1**.

The results for the eight fish stocks obtained by the LBB method are presented in **Figure 1**. All eight stocks showed a similar trend; the top of the curve of relative frequency to L/L_{inf} was situated the left of L_{opt} and stayed away from the limit body length.

Three parameters (Z/K, L_{95th}/L_{inf}, and B/B_0) of eight stocks were all below unity, and three ratios (L_{mean}/L_{opt}, L_c/L_{c_opt}, and B/B_{MSY}) were also < 1, except for silver sillago. Both F/M and F/K were > 1. Detailed information for each parameter is given in **Table 2**.

DISCUSSION

The ratios L_{mean}/L_{opt} and L_c/L_{c_opt} were below unity in seven of the eight stocks, suggesting truncated length structure and fishing of too small individuals. The ratio of the 95th percentile length to asymptotic length L_{95th}/L_{inf} was close to unity (>0.9) in five of eight stocks, suggesting that at least some large fish were still present. The ratio B/B_0 was smaller than B_{MSY}/B_0 in all eight stocks, except for *S. sihama*, suggesting the fish species included in this study are being overfished. Furthermore, the relative biomass (B/B_0) for the eight species in Shandong's coastal seas evaluated here was 0.16 on average, which indicated a depletion rate of 84%. The result was consistent with the 84% average depletion reported by Zhai and Pauly, 2019.

The results given by the LBB method were compared with other research (**Table 3**). It was found that there were few studies on fishery resource assessments in coastal waters of Shandong. The assessments of *S. marmoratus* and *G. macrocephalus* were not reported in recently years. The studies on the other species, except for *S. sihama*, were consistent with our results that fishery resources of these species in this area were overfished.

For *S. japonicus*, our result was confirmed by the results of Yi and Chen (2019), who believed that the species was overfished in 2015 (**Table 3**). Thus, we strongly recommend that the intensity of fishing for *S. japonicus* in this area can be reduced, especially for larvae. For *H. otakii*, our result corresponded to other published research (Wang et al., 2018), where Beverton-Holt Y/R analysis was used to assess the resource of *H. otakii* in Shandong, with the result showing overfishing (**Table 3**). Reducing fishing pressure on this species would allow it to recover. Our result is also consistent with the study published by Li et al. (2015) in

TABLE 2 | Estimates of eight fish species for 2017 given by LBB.

Scientist name	L_{mean}/L_{opt}	L_c/L_{c_opt}	L_{95th}/L_{inf}	B/B_0	B/B_{MSY}	F/M	F/K	Z/K	Assessment
Scomber japonicus	0.59	0.49	0.88	0.033	0.091	5.4	8.3	9.77	Collapsed
Sebastiscus marmoratus	0.8	0.61	0.91	0.18	0.49	1.8	2.8	4.31	Grossly overfished
Hexagrammos otakii	0.82	0.73	0.93	0.12	0.35	2.6	4.6	6.34	Grossly overfished
Thryssa kammalensis	0.77	0.66	0.82	0.1	0.28	2.9	4.4	5.86	Grossly overfished
Gadus macrocephalus	0.51	0.37	0.95	0.043	0.12	3.5	5.1	6.61	Grossly overfished
Setipinna taty	0.72	0.57	0.87	0.16	0.44	1.7	2.4	3.87	Grossly overfished
Sillago sihama	1	1.1	0.95	0.62	1.7	0.37	0.67	2.48	Healthy
Lophius litulon	0.74	0.67	0.92	0.06	0.17	4.4	6.9	8.46	Grossly overfished

TABLE 3 | Comparison of fishery resource assessment studies for eight fish species.

Scientific name	Assessment method	Assessment result	Comparison with this study	References
Scomber japonicus	Pella-Tomlinson Model	Overfished	Consistent	Yi and Chen, 2019
Sebastiscus marmoratus	None	None	None	None
Hexagrammos otakii	Beverton-Holt Y/R analysis	Overfished	Consistent	Wang et al., 2018
Thryssa kammalensis	Fisheries resource survey	Overfished	Consistent	Ren et al., 2002
Gadus macrocephalus	None	None	None	None
Setipinna taty	Fisheries resource survey	Overfished	Consistent	Zhang et al., 2004
Sillago sihama	Beverton-Holt Y/R analysis	Overfished	Inconsistent	Liu et al., 2010
Lophius litulon	Fisheries resource survey	Overfished	Consistent	Li et al., 2015

which they found that *L. litulon* was suffering from overfishing, especially in the Yellow Sea (**Table 3**). In this study, our results suggested that *S. taty* is suffering from overfishing pressure and a low biomass, thus confirming the results of Zhang et al. (2004); they believed that it has been grossly overfished, and its juveniles have been severely damaged (**Table 3**). Thus, local governments should take measures to ease the decline of the species, such as reducing the intensity of fishing in the area and limiting the size of the nets. Similarly, Ren et al. (2002) suggested that *T. kammalensis* have been overfished, which is consistent with our results (**Table 3**). However, no models have been used to evaluate the resources of *T. kammalensis* in coastal areas of Shandong. Here, the taxonomic status of the species is unclear, and the name used here is tentative (Munroe and Nizinski, 1999). For *S. marmoratus*, this result is similar to other published studies, e.g., Yan et al. (2018), where the authors just mentioned that false kelpfish was overfished. Unfortunately, there is no research on resource assessment of *S. marmoratus* in coastal areas of Shandong. Similar issues face *G. macrocephalus*, and measures should be taken to limit the fishing of it, as this would allow its population to recover. While *S. sihama* was different, our result suggests that large fish are still present. However, Liu et al. (2010) used Beverton-Holt Y/R analysis to evaluate the resources of *S. sihama* in the waters of Beibu gulf in China, resulting in overfishing (**Table 3**), but the assessment in Shandong has not been reported.

CONCLUSION

Seven of the eight stocks examined in this study are overfished species in the Yellow and Bohai Seas and are trending toward miniaturization. As a result of long-term overfishing, the structure of fisheries resources in coastal areas of Shandong has been changed, i.e., scaly hairfin anchovy and kammal thryssa are no longer the dominant stock in this area; instead, the dominant stock are Pacific cod, fat greenling, and yellow goosefish. More seriously, chub mackerel of Shandong is on the verge of collapse due to chronic overfishing.

Fishery managers should provide species-specific size limits and enforce specific mesh sizes for fishing nets to help rebuild the fish populations. However, increasing mesh size would be difficult to implement (Liang and Pauly, 2017). Thus, we also suggest that the fishing intensity should be reduced by limiting the number, type, and time of fishing boats in Shandong's waters.

The LBB method needs no data other than body length and frequency to evaluate the fish resources in a certain area, which solves the problem that the resources cannot be evaluated due to the lack of available data in some areas. In contrast, the LBB method is not accurate enough in resource assessment because it just inputs length and frequency data. If the LBB method

is used in combination with other models, the results may be more reliable.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

ETHICS STATEMENT

Our manuscript was based on survey cruise data, and no live vertebrates or higher invertebrates were involved, thus we believe an ethical review process was not required for our study.

AUTHOR CONTRIBUTIONS

YW analyzed the LF data and completed the first draft. YW provided guidance on data analysis and structure of the manuscript. SL provided the original length data. WX and HZ modified the manuscript. CL offered suggestions on the analysis and revised the manuscript again. All authors contributed to the revision of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.00164/full#supplementary-material

REFERENCES

Beverton, R. J. H., and Holt, S. J. (1957). *On the dynamics of exploited fish populations. Ministry of Agriculture, Fisheries and Food*, Series II, XIX. London: Fishery Investigations, 533.

Cai, S., Xu, S., Song, N., Gao, T., and Zhang, Z. (2014). Mitochondrial DNA control region structure and length polymorphism analysis of *Setipinna tenuifilis. Acta Hydrobiol. Sin.* 38, 980–986. doi: 10.7541/2014.145

Du, T., Huang, Y., and Cao, J. (2009). A preliminary study on the temporary cultivation of *Sillago sihama. Anim. Breed. Feed* 10, 15–17.

FAO (2019). *FAO Yearbook*. Rome: Fishery and Aquaculture Statistics 2017.

Feng, Z., and Han, H. (1998). Rational utilization of *Hexagrammos otakii* resources. *J. Dalian Fish. Univ.* 13, 24–28.

Froese, R., Winker, H., Coro, G., Demirel, N., Tsikliras, A. C., Dimarchopoulou, D., et al. (2018). A new approach for estimating stock status from length frequency data. *ICES J. Mar. Sci.* 75, 2004–2015. doi: 10.1093/icesjms/fsy078

Froese, R., Winker, H., Coro, G., Demirel, N., Tsikliras, A. C., Dimarchopoulou, D., et al. (2019). On the pile-up effect and priors for Linf and M/K: response to a comment by hordyk et al. on "A new approach for estimating stock status from length-frequency data. *ICES J. Mar. Sci.* 76, 461–465. doi: 10.1093/icesjms/fsy199

Froese, R., Winker, H., Gascuel, D., Sumaila, U. R., and Pauly, D. (2016). Minimizing the impact of fishing. *Fish Fish.* 17, 785–802. doi: 10.1111/faf.12146

Fu, X., Song, T., Dai, G., Wang, Y., Lu, S., Guan, H., et al. (2007). Status and issues of marine fishery resources in Shandong province and the strategies for its sustainable exploitation. *Trans. Oceanol. Limnol.* 2, 164–170. doi: 10.13984/j.cnki.cn37-1141.2007.02.024

Gu, H. (1990). Feeding habits and food composition of scaly half-fin anchovy. Setipinna taty (C et V) in the Bohai Sea. *Chin. J. Oceanol. Limnol.* 8, 280–289. doi: 10.1007/BF02849668

Huang, Y., Du, T., and Huang, H. L. (2013). A study on artificial breeding of *Sillago sihama* Forskål. *J. Guangdong Ocean Univ.* 33, 15–21.

Li, F., Xu, B., and Wang, B. (2012). Fish community diversity during spring and autumn in the Yellow Sea off the coast of Shandong. *Biodiv Sci.* 20, 207–214. doi: 10.3724/sp.j.1003.2012.08239

Li, Z., Shan, X., Jin, X., Dai, F., and Lu, H. (2015). Interannual variations in the biological characteristics, distribution and stock density of anglerfish *Lophius litulon* in the central and southern Yellow Sea. *Acta Hydrobiol. Sin.* 26, 4007–4015. doi: 10.5846/stxb201310262585

Liang, C., and Pauly, D. (2017). Growth and mortality of exploited fishes in China's coastal seas and their uses for yield-per-recruit analyses. *J. Appl. Ichthyol.* 33, 746–756. doi: 10.1111/jai.13379

Lin, L., and Zheng, Y. (2004). Preliminary research on stock of *Lophius litulon* in the East China Sea region. *Mar. Fish* 26, 179–183.

Liu, J. D., Zhu, L. X., and Lu, H. S. (2010). Estimation of growth and mortality parameters of the silver sillago (*Sillago sihama*) in Beibu Gulf. *J. Zhejiang Ocean Uni.* 29, 64–69.

Lü, Z., Li, F., Xu, B., and Wang, B. (2012). Fish community diversity during spring and autumn in the Yellow Sea off the coast of Shandong. *Biodiversity Sci.* 20, 207–214. doi: 10.3724/SP.J.1003.2012.08239

Munroe, T. A., and Nizinski, M. (1999). "Engraulidae. Anchovies," in *FAO Species Identif. Guide Fish. Purp*, eds K. E. Carpenter, and V. H. Niem, (Rome: FAO), 1698–1706.

Park, J. M., Huh, S.-H., and Baeck, G. W. (2015). Feeding habits of kammal thryssa *Thryssa kammalensis* (Bleeker, 1849) in the coastal waters of Gadeok-do. *Korea. Anim. Cells Syst.* 19, 350–358. doi: 10.1080/19768354.2014.907206

Ren, Y., Liu, Q., Li, Q., and Chen, Y. (2002). Biological characteristics of some small species in *Engraulidae* and *Clupeidae*. *JOL* 1, 69–74. doi: 10.13984/j.cnki.cn37-1141.2002.01.010

Tang, Q., and Ye, M. Z. (1990). *Exploitation and Conservation of Offshore Fishery Resources in Shandong Province*. Beijing: China Agriculture Press.

von Bertalanffy, L. (1938). A quantitative theory of organic growth (inquiries on growth laws. ii). *Hum. Biol.* 10, 181–213. doi: 10.2307/41447359

Wang, J. Q., Liu, S. D., Tang, Y. L., Yang, W. Z., and Fang, G. J. (2018). Growth, mortality and resource evaluation of *Hexagrammos otakii* inhabiting the artificial reef area of Lidao. Shandong Province. *Periodical. Ocean Univ. China* 48, 51–59.

Xu, Y., Liu, X., Shi, B., and Wang, B. (2017). Domestication of wild broodstock and early development of Pacific cod (*Gadus macrocephalus*) *J. Prog.Fish. Sci.* 38, 159–167.

Yan, Y., Liu, Y., Shi, Y., Xie, Y., Deng, P., and Yuan, X. (2018). Preliminary study on indoor artificial breeding technology of *Sebastes marmoratus*. *Fish. Sci. Technol. Inform.* 45, 322–326.

Yao, S., Yong, L., Bo, Z., and Qisheng, T. (2003). Food consumption, growth and ecological conversion efficiency of *Thryssa kammalensis*, determined by eggers model in laboratory. *Acta Hydrobiol. Sin.* 23:1216.

Yi, W., and Chen, X. (2019). Establishment of Pella-tomlinson model for east china and yellow sea *Scomber japonicus* based on environmental factors. *J. Guangdong Ocean Univ.* 39, 49–55.

Zhai, L., and Pauly, D. (2019). Yield-per-recruit, utility-per-recruit and relative biomass of 21 exploited fish species in China's coastal seas. *Front. Mar. Sci.* 6:724. doi: 10.3389/fmars.2019.00724

Zhang, M. H., Wang, Y., and Zhang, J. (2004). Studies on the growth and death character of *Setipinna taty* in the South of Bohai Sea. *J. Zhejiang Ocean Univ.* 23, 31–36.

Zhang, N., Du, W., Wang, Z., Huang, Y., Du, T., and Dong, Z. (2018). Screening of reference genes for Real-time PCR in different tissues from *Sillago sihama*. *J. Guangdong Ocean Univ.* 38, 8–14. doi: 10.3969/j.issn.1673-9159.2018.05.002