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Fishery Stock Assessments in the Min River Estuary and Its Adjacent Waters in Southern China Using the Length-Based Bayesian Estimation (LBB) Method

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The Min River Estuary and its adjacent waters, connecting to the East China Sea, is one of the most important fishing grounds in Fujian Province, southern China; however, stock assessments have not yet been conducted. In the present study, the length-based Bayesian estimation method was applied for the first time to assess 20 single-species fishery stocks in the region. Catches of eight fish species from the Class Actinopterygii and 12 shrimp species from the Class Malacostraca were obtained from two commercial demersal trawlers, operated in the Min River Estuary and its adjacent waters, in February, May, August, and November of 2017 and 2018, covering all four seasons. The results showed that eight species were overexploited with an estimated B/B_{MSY} (i.e., the current exploited biomass relative to the biomass producing the maximum sustainable yield) < 0.8 (range from 0.26 to 0.71). Three overexploited fish species (Gray's grenadier anchovy *Coilia grayii*, the big head croaker *Collichthys lucidus*, and the Trevavas croaker *Johnius trewavasae*) are commercially important food species in the region. All four overexploited shrimp species (the shrimp *Parapenaeopsis cultrirostris*, the Japanese snapping shrimp *Alpehus japonicus*, and the Caridean shrimps *Palaemon annandalei* and *Palaemon carinicouda*) are small-sized and have low commercial value. The three-lined tongue sole *Cynoglossus abbreviates*, a commercially important species, was classified as fully exploited ($0.8 \leq B/B_{MSY} \leq 1.2$). Osbeck's grenadier anchovy *Coilia mystus* and the Japanese mantis shrimp *Oratosquilla oratoria*, both commercially important food species in the region, had non-fully exploited statuses ($B/B_{MSY} > 1.2$). The results revealed that some commercially important food fishes are overexploited in the region and that small-sized, non-commercial food species can also be overexploited. There is an urgent need for local and national fisheries authorities to focus on coastal fishery management.

Keywords: commercial trawl fishery, estuarine waters, fishes, shrimps, length-based Bayesian estimation

INTRODUCTION

Stock assessments are essential for managing the fishery resources exploited. The age composition of fisheries catches provide, for many fisheries in, e.g., Europe and North America, the key parameters for stock assessments and evaluations (Fournier et al., 1998; Sparre and Venema, 1998; Mesnil, 2003; Benjamin and Kurup, 2012; Mäntyniemi et al., 2013; Francis et al., 2016; Zhu et al., 2016). However, age studies are time-consuming in fishes and are not feasible in crustaceans such as crabs and shrimps. Thus, length-frequency data, which can be collected easily from catches, have been widely used in stock assessments in both fishes (e.g., Munro, 1983; Fournier et al., 1990; Dennis, 1991; Pauly, 1998; Al-Qishawe et al., 2014; Nadon et al., 2015; Rudd and Thorson, 2018) and crustaceans (e.g., Pauly et al., 1984; Dineshbabu et al., 2007; Haist et al., 2009; Afzaal et al., 2016).

Notably, length-frequency data can be used to estimate L_∞ and K, the parameters of the von Bertalanffy growth function (VBGF), which has the form:
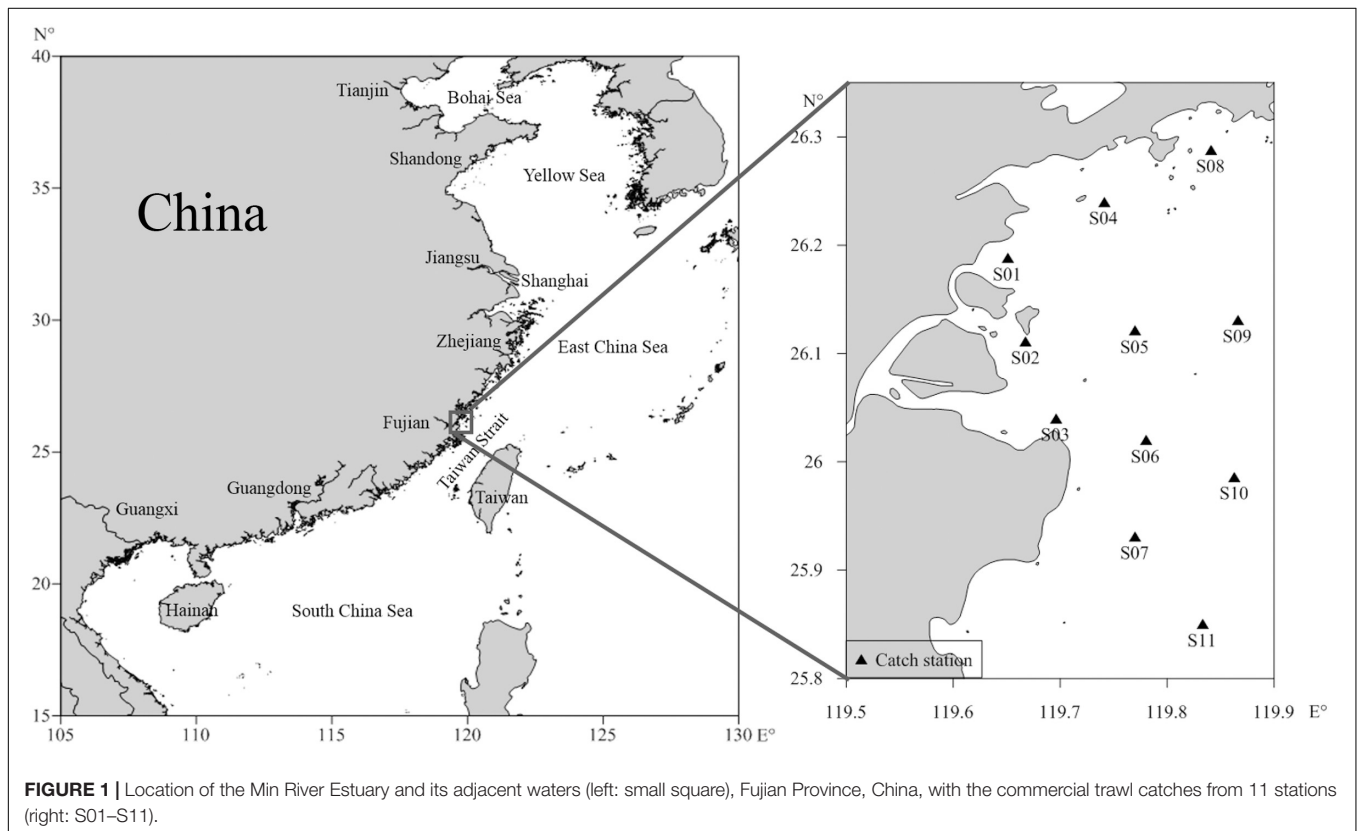
$$L_t = L_{\mathrm{inf}}\left(1 - e^{-K(t-t_0)}\right)$$

where L_t is the mean size (here in diameter) at age t of the animals in question, L_{inf} their asymptotic length, i.e., the mean length attained after an infinitely long time, and K a growth coefficient (here in year^{-1}). Finally, t_0, which cannot be estimated from length-frequency data alone, is the (usually negative) age they would have had at a size of zero if they had always grown in the manner predicted by the equation (which they have not; see, e.g., Pauly, 1998). However, the parameter t_0, which allows the computation of mean length at *absolute* ages, is not required in most stock assessment models (Pauly, 1998). Other important parameters are mean length at the first capture (L_c, i.e., the length at which 50% of the fish are retained by the gear), the instantaneous rates of natural (M) and fishing (F) mortalities, which can be combined into a rate of total mortality ($Z = M + F$) and an exploitation rate ($E = F/Z$), as well as catch and effort time series for some methods.

Recently, a length-based Bayesian estimation (LBB) method was proposed to estimate stock status from length-frequency data, representative of commercial catches (Froese et al., 2018). To minimize the data requirements, the LBB method is not based on the absolute rates of growth and mortality but rather on the ratios of the rates of natural mortality to somatic growth (M/K) and of fishing mortality to somatic growth (F/K). Given representative length-frequency data, the LBB method, after estimating the above ratios, uses them to estimate the ratio of the current exploited biomass relative to unexploited biomass (B/B_0) and relative to the biomass producing maximum sustainable yield (B/B_{MSY}). The relative biomass estimated using the LBB method has been shown to have good validity for species that grow throughout their life span, such as most fish species (Froese et al., 2019)[1].

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[1]www.fishbase.org

FIGURE 1 | Location of the Min River Estuary and its adjacent waters (left: small square), Fujian Province, China, with the commercial trawl catches from 11 stations (right: S01–S11).

China is the largest contributor to the global catch of marine fisheries (FAO, 2018). However, China's marine fisheries resources have tended to be over-exploited since the 1970s, and dramatic declines in catches have occurred in some traditionally important commercial species and stocks (Jin et al., 2015; Kang et al., 2018a). As some of these declines or collapses may be attributed to the absence of strict management measures, fishery stock assessment is required.

Size measurement is the most fundamental and essential requirement in marine fishery resource surveys in China (Jin et al., 2012). This provides a great opportunity to assess commercial fishery stocks in Chinese waters using the LBB method when other parameters are little known. The Min River is the largest river in Fujian Province, and the estuary and its adjacent waters, connecting to the East China Sea, is one of the most important fishing grounds in Fujian Province (Fujian Province Atlas, 2001; **Figure 1**). Fisheries resources in the region have been shown to be declining; however, stock assessment has not yet been conducted, and the biology of most species has not yet been studied (Huang et al., 2010; Kang et al., 2018b). The objectives of the present study are to assess 20 fishery single-species stocks (henceforth, "species") exploited by commercial demersal trawlers in the Min River Estuary and its adjacent waters using the LBB method. The samplings were conducted in all four seasons in 2017 and 2018, and a rapid understanding of the current status of the commercial fisheries was developed based thereon.

MATERIALS AND METHODS

In the Min River Estuary and its adjacent waters (25.80°–26.30°N, 119.60°–119.90°E), two commercial demersal trawlers operated in 11 stations, covering all four seasons (February for Winter, May for Spring, August for Summer, and November for Autumn) in 2017 and 2018 (**Figure 1**). The power and size are 16.2 kW and 4 t for the small trawler, and 202 kW and 122 t for the large one. Both trawlers had mesh sizes of 4.5 cm at the net opening and 2.5 cm at the cod-end. The operating time of each station was around 30 min, and the speed was 3.7–7.8 km/h. The fishing areas have a depth range of 8–13 m and salinity range of 10–13 at Stations 01–03 (near the mouth of the river) and a depth range of 10–26 m and salinity range of 25–31 at Stations 04–11 (off the mouth of the river).

Catches of 20 species, including 8 fishes from the Class Actinopterygii and 1 mantis shrimp and 11 shrimps from the Class Malacostraca (henceforth all called "shrimps"), were collected. Standard length (SL, to 1 mm) and total length (TL, to 1 mm) were subsequently measured for fish species and carapace length (CL, to 1 mm) and standard length (SL, to 1 mm) for shrimp species. For each species, all individuals were measured if there were < 50 at a given station and season; 50 individuals were randomly selected if the sample size > 50 individuals. Eventually, the number of individuals measured ranged from 244 to 2508 for fish species, and from 129 to 1995 for shrimp species; all 20 species included small-sized juveniles and large adults, i.e., there was a wide size range (**Table 1**).

TABLE 1 | Summary of the size range and the number of individuals measured of the 20 fish and shrimp species collected in 2017 and 2018 for stock assessment in the Min River Estuary and its adjacent waters, Fujian Province, southern China.

| Species (common and scientific names)	Length (SL or CL) range (cm)	Number of individuals measured
Class Actinopterygii		
Osbeck's grenadier anchovy *Coilia mystus*	4.0–21.0	2508
Gray's grenadier anchovy *Coilia grayii*	4.7–30.4	290
Big head croaker *Collichthys lucidus*	1.9–15.6	928
Trewavas croaker *Johnius trewavasae*	2.4–18.5	405
Goby *Chaeturichthys hexanema*	2.0–12.4	765
Goby *Odontamblyopus lacepedii*	2.8–22.8	275
Three-lined tongue sole *Cynoglossus abbreviatus*	7.2–32.0	256
Tongue sole *Cynoglossus sibogae*	7.7–22.0	244
Class Malacostraca		
Japanese mantis shrimp *Oratosquilla oratoria*	0.5–4.4	1995
Coastal mud shrimp *Solenocera carssicornis*	0.6–3.4	386
Shiba shrimp *Metapenaeus joyneri*	0.9–4.8	628
Periscope shrimp *Atypopenaeus stenodactylus*	0.4–2.1	317
Southern rough shrimp *Trachypenaeus curvirostris*	0.2–3.6	452
Shrimp *Parapenaeopsis cultrirostris*	0.5–5.3	332
Spear shrimp *Parapenaeopsis hardwickii*	0.6–6.4	803
Smoothshell shrimp *Parapenaeopsis tenella*	0.4–3.3	320
Whiskered velvet shrimp *Metapenaeopsis barbata*	0.6–3.8	299
Japanese snapping shrimp *Alpehus japonicus*	0.4–2.0	129
Caridean shrimp *Palaemon annandalei*	0.3–2.0	167
Caridean shrimp *Palaemon carinicouda*	0.5–4.0	248

SL, standard length for Class Actinopterygii; CL, carapace length for Class Malacostraca.

Length-frequency data (SL for fish species, CL for shrimp species) of each species accumulating from four seasons of two years were input into LBB version 28.0 in R version 3.5.0 software. The M/K prior was generated as 1.5 and the L_{inf} as the maximum length obtained from the present study if the maximum length is unknown (for shrimp species) or the recorded maximum length (fish species from www.fishbase.org) is smaller than that of the present study. The Z/K prior was generated based on the equation (Beverton and Holt, 1957; Quinn and Deriso, 1999):

$$Z = K \frac{L_{inf} - \bar{L}}{\bar{L} - L_c}$$

where $\bar{L}$ is the average length of all individuals of the species measured above. The F/K prior is determined by (Z/K - M/K).

According to the obtained parameters (i.e., L_c, L_{inf}, M/K, and F/K), the estimated B/B_0 and B/B_{MSY} values were generated (Froese et al., 2018). Stocks were classified to different categories
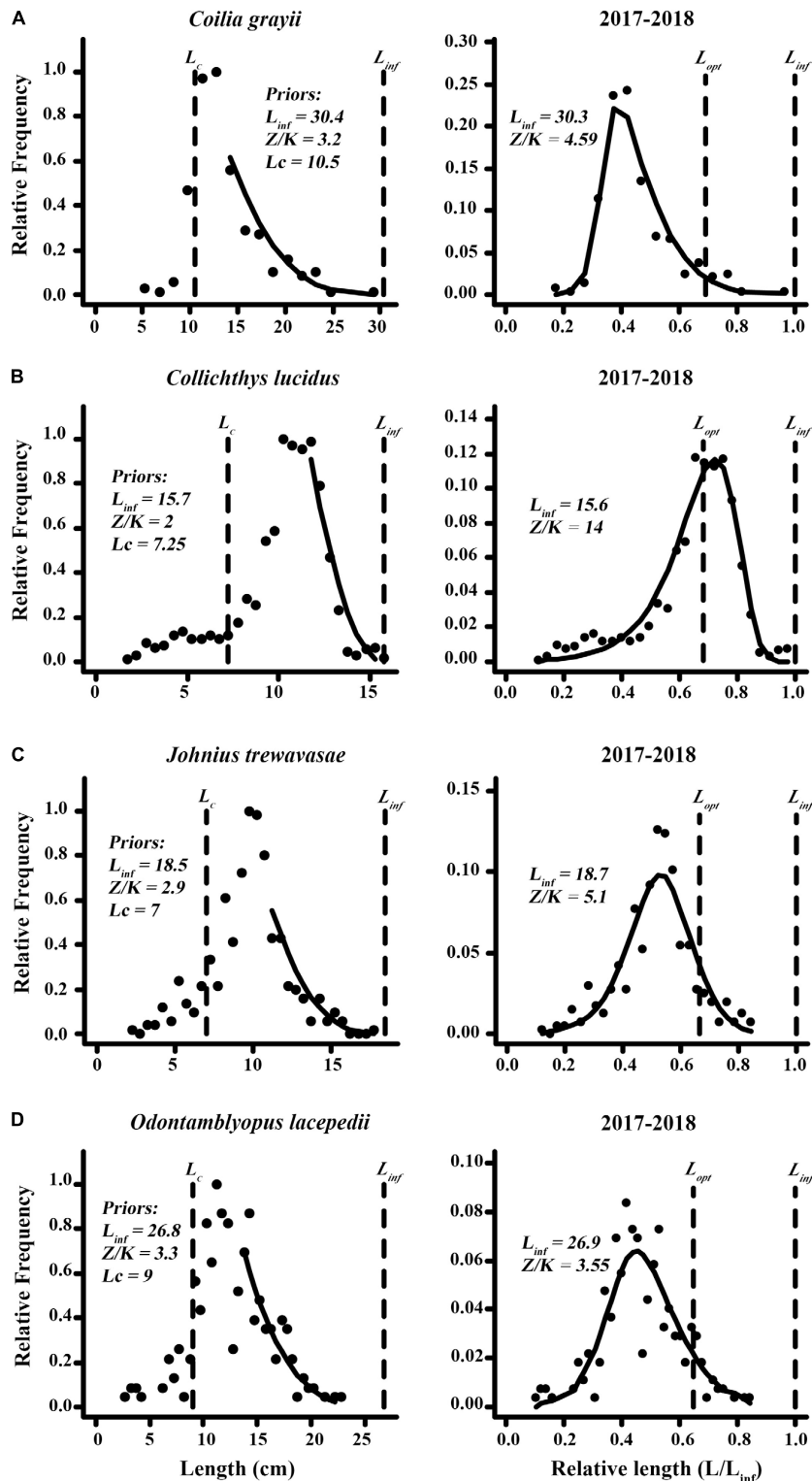
FIGURE 2 | Results of assessment of four fish species with an overexploited stock status in the Min River Estuary and its adjacent waters, Fujian Province, southern China, with length data in 2017 and 2018. **(A)** *Coilia grayii*, **(B)** *Collichthys lucidus*, **(C)** *Johnius trewavasae*, and **(D)** *Odontamblyopus lacepedii*. The left panels estimate the length at 50% first capture (L_c), the asymptotic length (L_{inf}), and the total mortality relative to somatic growth (Z/K) based on the catches of 2017 and 2018 as prior. The curves are fitted to fully selected length classes and provide the estimates of L_{inf} and Z/K. The right panels show the length-frequency data from 2017 and 2018. The curves show the fitness of the LBB master equation and provide the estimates of L_{inf} and Z/K. The L_{opt} is calculated from L_{inf} and M/K, where the biomass of the unexploited stock is maximum.
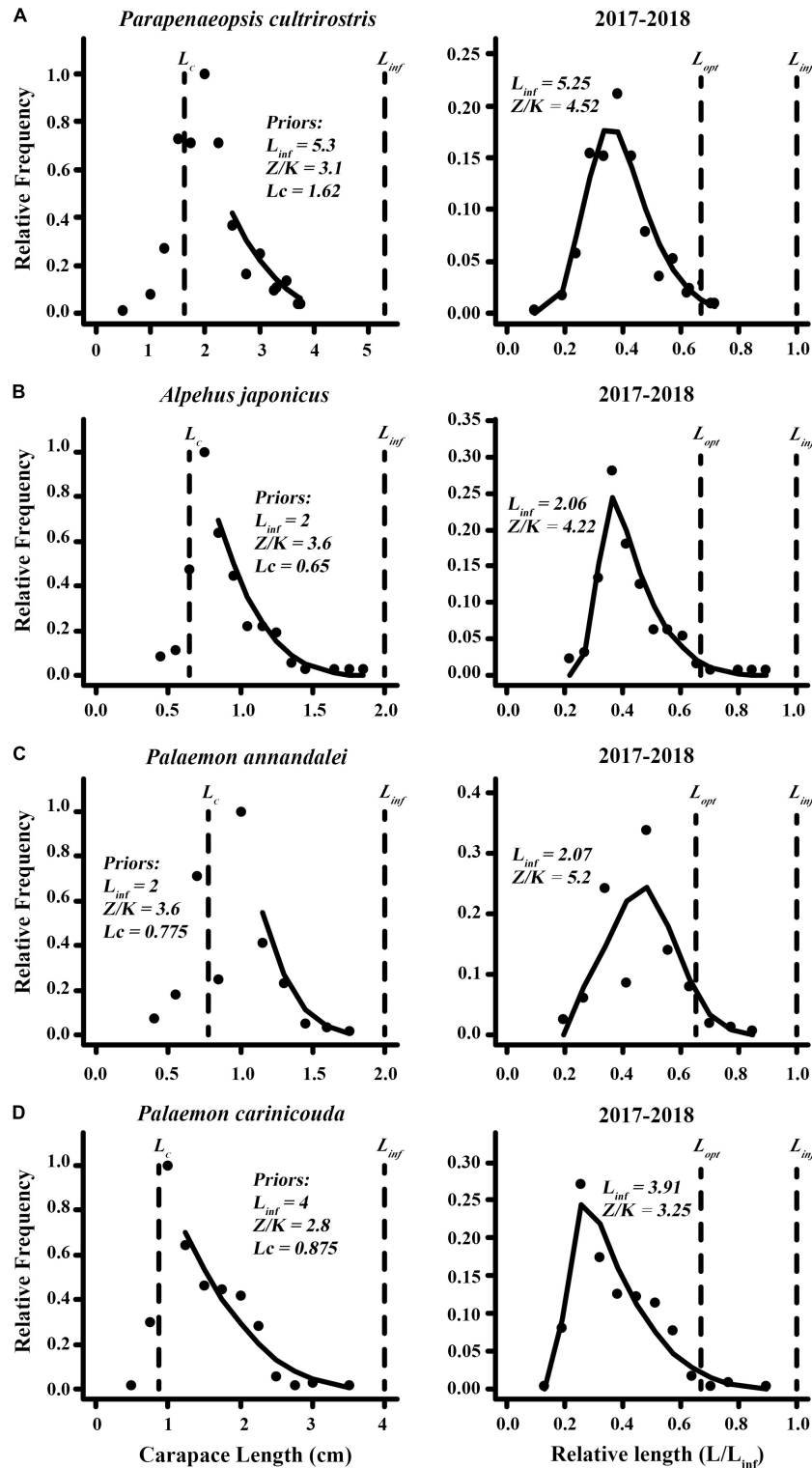
FIGURE 3 | Assessment results of four shrimp species with an overexploited stock status in the Min River Estuary and its adjacent waters, Fujian Province, southern China, with length data in 2017 and 2018. **(A)** *Parapenaeopsis cultrirostris*, **(B)** *Alpehus japonicus*, **(C)** *Palaemon annandalei*, and **(D)** *Palaemon carinicouda*. The left panels estimate the length at 50% first capture (*L*C), the asymptotic length (*L*inf), and the total mortality relative to somatic growth (*Z/K*) based on the catches of 2017 and 2018 as prior. The curves are fitted to fully selected length classes and provide the estimates of *L*inf and *Z/K*. The right panels show the length frequency data from 2017 and 2018. The curves show the fitness of the LBB master equation and provide the estimates of *L*inf and *Z/K*. *L*opt is calculated from *L*inf and *M/K*, where the biomass of the unexploited stock is maximum.

TABLE 2 | Fishery statuses of the 20 species assessed in the Min River Estuary and its adjacent waters, Fujian Province, southern China.

Species	L_{max} (cm)	L_{inf} (cm)	B/B_0	B/B_{MSY}	Status	Interval scale (cm)
Class Actinopterygii						
Coilia mystus[*,θ]	21.0	20.9	0.70	1.90	Non-fully exploited	1.00
Coilia grayii[*]	30.4	30.3	0.10	0.28	Overexploited	1.50
Collichthys lucidus[*,θ]	15.6	15.6	0.13	0.34	Overexploited	0.50
Johnius trewavasae[*]	18.5	18.7	0.15	0.42	Overexploited	0.50
Chaeturichthys hexanema[θ]	12.4	12.3	0.49	1.30	Non-fully exploited	0.50
Odontamblyopus lacepedii[θ]	22.8	26.9	0.26	0.71	Overexploited	0.50
Cynoglossus abbreviatus[*]	32.0	33.3	0.30	0.83	Fully exploited	0.50
Cynoglossus sibogae	22.0	22.2	0.60	1.70	Non-fully exploited	1.50
Class Malacostraca						
Oratosquilla oratoria[*,θ]	4.4	4.4	0.76	2.10	Non-fully exploited	0.20
Solenocera carssicornis	3.4	3.45	0.83	2.20	Non-fully exploited	0.25
Metapenaeus joyneri[*]	4.8	5.01	0.43	1.20	Fully exploited	0.40
Atypopenaeus stenodactylus	2.1	2.13	0.80	2.10	Non-fully exploited	0.10
Trachypenaeus curvirostris	3.6	3.63	0.87	2.30	Non-fully exploited	0.20
Parapenaeopsis cultrirostris	5.3	5.25	0.10	0.26	Overexploited	0.20
Parapenaeopsis hardwickii[*,θ]	6.4	6.67	0.39	1.10	Fully exploited	0.25
Parapenaeopsis tenella	3.3	3.43	0.34	0.91	Fully exploited	0.10
Metapenaeopsis barbata	3.8	3.86	0.38	1.00	Fully exploited	0.25
Alpehus japonicus	2.0	2.06	0.13	0.37	Overexploited	0.10
Palaemon annandalei	2.0	2.07	0.11	0.31	Overexploited	0.10
Palaemon carinicouda[*]	4.0	3.91	0.18	0.50	Overexploited	0.25

[*]Commercial food species; [θ]Species with an index of relative importance (IRI) > 500 in catches of the present study (data not shown here). L_{max}, the maximum length, either standard length or carapace length, from the present study (also see **Table 1**).

based on the value of B/B_{MSY}; non-fully exploited status was assigned where $B/B_{MSY} > 1.2$, fully exploited status where $0.8 \leq B/B_{MSY} \leq 1.2$, and overexploited status where $B/B_{MSY} < 0.8$ (Amorim et al., 2019).

Length-frequency data were adjusted slightly at 0.5, 1.0, and 1.5 cm SL intervals for fish species, and at 0.1, 0.2, 0.3, and 0.4 cm CL intervals for shrimp species. Through such debugging, the interval that made the analysis fit best (i.e., the length-frequency points fall on the trend curve as much as possible) was selected, and the corresponding length-frequency data were saved in EXCEL in ".csv" format. Information such as species name, sampling method, and L_{inf} were saved in another ".csv" format file. More details and R-code[2] are available (Froese et al., 2018).

RESULTS

The dominant length groups of all but one species (the big head croaker *Collichthys lucidus*) were smaller than the length (L_{opt}) that maximizes the biomass of an unexploited cohort (e.g., **Figures 2**, **3**). The estimated L_{inf} values were larger than or equal to the maximum size in the present study (L_{max}) in 15 species, while they were smaller than the L_{max} in only five species (**Table 2**).

The 20 species assessed belonged to one of the three statuses: overexploited, fully exploited, or non-fully exploited (**Table 2**). Eight species (40%), i.e., four fishes and four shrimps, had

[2]See http://oceanrep.geomar.de/43182/

estimated B/B_0 ratios ranging from 0.10 to 0.26 and B/B_{MSY} ratios ranging from 0.26 to 0.71, suggesting overexploited status. Five species (25%), i.e., one fish and four shrimps, were fully exploited, with estimated B/B_0 ratios ranging from 0.30 to 0.43 and B/B_{MSY} ratios ranging from 0.83 to 1.20. Seven species (35%), i.e., three fishes and four shrimps, were non-fully exploited, with estimated B/B_0 ratios ranging from 0.49 to 0.87 and B/B_{MSY} ratios ranging from 1.30 to 2.30.

DISCUSSION

This study is the first time that the LBB method has been used to assess commercial fishery stock status in the Min River Estuary and its adjacent waters, southern China. The results provided valuable information for understanding the current degree of fishery exploitation in the region. Among the four fish species that were overexploited, Gray's grenadier anchovy *Coilia grayii* in Engraulidae and the big head croaker *C. lucidus* in Sciaenidae require more attention (**Table 2**). *C. grayii* was listed as Least Concern in 2012 (Vidthayanon, 2012). It inhabits the waters near the mouths of the rivers and is a commercially important species in Fujian waters. *C. grayii* spawns in the mouth of the Min River every March–June and grows in the estuary year-round or offshore (Qiu, 1984). This is the first report on overexploitation of *C. grayii* stock in China. *C. lucidus*, an important food fish in China, inhabits estuaries and coastal waters down to a depth of 90 m over sandy and muddy

bottoms (Chu and Wu, 1985; see footnote 1). It dominates in the Min River Estuary and its adjacent waters based on the index of relative importance (IRI; Zhang, 2020). A decline in the lengths in commercial catches of *C. lucidus* has been noted; SL ranged from 3.5 to 20.5 cm in 2006/2007, from 3.0 to 16.0 cm in 2015, and from 1.9 to 15.6 cm in 2017/2018 (Wang et al., 2011; Kang et al., 2018b; the present study). The smaller individuals in both *C. lucidus* and *C. grayii* samples indicate the existence of nursery grounds in the Min River Estuary and its adjacent waters. All four overexploited shrimp species are small-sized, benthic or demersal, and of low commercial value.

Among the fully exploited species, the three-lined tongue sole *Cynoglossus abbreviates* in Cynoglossidae and the spear shrimp *Parapenaeopsis hardwickii* in Penaeidae are of local commercial importance. The B/B_{MSY} of *C. abbreviates* was 0.83, close to overexploited status. The abundance of *P. hardwickii* has increased over the past decade; the species was a general species in 2008 (IRI < 100) (Xu and Sun, 2013) and became a dominant species (IRI > 500) in 2017/2018 (Zhang, 2020).

Among the non-fully exploited species, Osbeck's grenadier anchovy *Coilia mystus* in Engraulidae is an important food fish in China and inhabits estuaries and coastal waters (Ni et al., 1999). It was listed as Endangered in 2018 (Hata, 2018). The stock of *C. mystus* in the Yangtze River Estuary, the most abundant region in China, almost collapsed (Liu et al., 2013). In the Min River Estuary and its adjacent waters, less than 600 km distance from the Yangtze River Estuary, *C. mystus* is a dominant species (IRI > 500) (Zhang, 2020); however, the sizes of *C. mystus* in commercial catches has shown a decline over the years from 5.0–26.4 cm SL in 2006/2007 to 7.0–21.0 cm SL in 2015 and to 4.0–21.0 cm SL in 2017/2018 (Wang et al., 2011; Kang et al., 2018b; the present study).

The current stock statuses of the 20 species revealed that some commercially important food fishes are overexploited in the Min River Estuary and its adjacent waters and that small-sized, non-commercial food species can also be overexploited. This is likely due to the non-selective fishery method using small mesh-sized nets employed in commercial demersal bottom fisheries along the coastal waters of China. About 200 species of fishes, crustaceans, and cephalopods have been reported from the Min River Estuary and its adjacent waters (Kang et al., 2018b; Zhang, 2020). It will be a challenge to find a way to continue exploiting the Min River Estuary for its fisheries resources without impacting the biodiversity that makes the estuary so productive. There is an urgent need for local and national fisheries authorities to focus on coastal fishery management.

DATA AVAILABILITY STATEMENT

The datasets analyzed in this article are not publicly available. Requests to access the datasets should be directed to LZ.

ETHICS STATEMENT

The animal study was reviewed and approved by Fuzhou Ocean and Fisheries Bureau of China.

AUTHOR CONTRIBUTIONS

LZ and QR wrote the first draft. ML, QX, BK, and XJ revised the manuscript. LZ, QR, XJ, and ML performed the data analyses. All authors conducted commercial catch sampling and measurement.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.00507/full#supplementary-material

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