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 carinicauda) 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 $L_\infty$ and $K$, the parameters of the von Bertalanffy growth function (VBGF), which has the form:

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

where $L_t$ is the mean size (here in diameter) at age $t$ of the animals in question, $L_\infty$ 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).

![FIGURE 1](http://example.com/figure1.png)

**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).

1[www.fishbase.org](http://www.fishbase.org)
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).

| Species (common and scientific names) | Length (SL or CL) range (cm) | Number of individuals measured |
|---------------------------------------|-----------------------------|--------------------------------|
| **Class Actinopterygii**               |                             |                                |
| Osbeck’s grenadier anchovy Callia mystus | 4.0–21.0                   | 2508                           |
| Grey’s grenadier anchovy Callia grayii | 4.7–30.4                   | 290                            |
| Big head croaker Collichthys lucidus   | 1.9–15.6                   | 928                            |
| Trewavas croaker Johnius trewassae     | 2.4–18.5                   | 405                            |
| Goby Chaetodipterus hexanema           | 2.0–12.4                   | 765                            |
| Goby Odontamblyopus lacpeidei          | 2.8–22.8                   | 275                            |
| Three-lined tongue sole Cynoglossus abbreviatus | 7.2–32.0       | 256                            |
| Tongue sole Cynoglossus saboga         | 7.7–22.0                   | 244                            |
| **Class Malacostraca**                |                             |                                |
| Japanese mantis shrimp Oratosquilla oratoria | 0.5–4.4              | 1995                           |
| Coastal mud shrimp Solenocera carascomis | 0.6–3.4              | 386                            |
| Shiba shrimp Metapeneaus joyneri       | 0.9–4.8                    | 628                            |
| Periscope shrimp Atypopeneaus stenodactylus | 0.4–2.1            | 317                            |
| Southern rough shrimp Trachypeneaus curvisrostris | 0.2–3.6          | 452                            |
| Shrimp Parapeneaus cus tilrostris      | 0.5–5.5                    | 332                            |
| Spear shrimp Parapeneaus hardwicki     | 0.6–6.4                    | 803                            |
| Smoothshell shrimp Parapeneaus tenella  | 0.4–3.3                    | 320                            |
| Whiskered velvet shrimp Metapeneaus 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 cannicouida    | 0.5–4.0                    | 248                            |

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 $L_{\text{inf}}$ 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):

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

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., $L_{c}$, $L_{\text{inf}}$, M/K, and F/K), the estimated B/B₀ 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 (Lc), the asymptotic length (L∞), 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∞ 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∞ and Z/K. The Lopt is calculated from L∞ 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) Alphehus japonicus, (C) Palaemon annandalei, and (D) Palaemon carinicouda. The left panels estimate the length at 50% first capture (Lc), the asymptotic length (Linf), 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 Linf 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 Linf and Z/K. Lopt is calculated from Linf 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                          | \(L_{\text{max}} \) (cm) | \(L_{\text{inf}} \) (cm) | \(B/B_0\) | \(B/B_{\text{MSY}}\) | Status              | Interval scale (cm) |
|---------------------------------|--------------------------|--------------------------|-----------|----------------------|---------------------|---------------------|
| **Class Actinopterygii**        |                          |                          |           |                      |                     |                     |
| Coilia mystus*                  | 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*            | 15.6                     | 15.6                     | 0.13      | 0.34                 | Overexploited       | 0.50                |
| Johnius trewavasae*             | 18.5                     | 18.7                     | 0.15      | 0.42                 | Overexploited       | 0.50                |
| Chaetopristis hexanema*         | 12.4                     | 12.3                     | 0.49      | 1.30                 | Non-fully exploited | 0.50                |
| Odontobutis ocellata*           | 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*          | 4.4                      | 4.4                      | 0.76      | 2.10                 | Non-fully exploited | 0.20                |
| Solenocera caricicorina         | 3.4                      | 3.45                     | 0.83      | 2.20                 | Non-fully exploited | 0.25                |
| Metapenaeus joynieri*           | 4.8                      | 5.01                     | 0.43      | 1.20                 | Fully exploited     | 0.40                |
| Atypospenaeus 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 californiensis    | 5.3                      | 5.25                     | 0.10      | 0.26                 | Overexploited       | 0.20                |
| Parapenaeopsis hardwickii*      | 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                |
| Alpheus japonicus               | 2.0                      | 2.06                     | 0.13      | 0.37                 | Overexploited       | 0.10                |
| Palaeomon annandalei            | 2.0                      | 2.07                     | 0.11      | 0.31                 | Overexploited       | 0.10                |
| Palaeomon canalicuina           | 4.0                      | 3.91                     | 0.18      | 0.50                 | Overexploited       | 0.25                |

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

Results based on the value of \(B/B_{\text{MSY}}\); non-fully exploited status was assigned where \(B/B_{\text{MSY}} > 1.2\), fully exploited status where \(0.8 \leq B/B_{\text{MSY}} \leq 1.2\), and overexploited status where \(B/B_{\text{MSY}} < 0.8\) (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 \(L_{\text{inf}}\) were saved in another “.csv” format file. More details and R-code3 are available (Froese et al., 2018).

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 greyi in Engraulidae and the big head croaker C. lucidus in Sciaenidae require more attention (Table 2). C. greyi was listed as Least Concern in 2012 (Vidhyavilaskar, 2012). It inhabits the waters near the mouths of the rivers and is a commercially important species in Fujian waters. C. greyi 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. greyi 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

3See http://oceanrep.geomar.de/43182/
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 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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