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# Stock Assessment Using the LBB Method for *Portunus trituberculatus* Collected from the Yangtze Estuary in China

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**Abstract:** *Portunus trituberculatus* is an important invertebrate species distributed in the Yangtze Estuary. However, its biomass and enrichment have been affected seriously by ongoing human activity in recent decades. The length-based Bayesian biomass estimator (LBB) is a novel and potent method to estimate the stocks for most commercial fishes and invertebrates in offshore using only length and frequency data. In this study, the results showed that the ratio of current exploited biomass relative to unexploited biomass ($B/B_0$) was smaller than relative biomass capable of producing maximum sustainable yields ($B_{MSY}/B_0$) after handling of the catches of the *P. trituberculatus* collected from the Yangtze Estuary in 2018 using the LBB method. Therefore, this evidence indicated that the biomass of the swimming crab was relatively low as a result of the overfishing in this water area and the catches of the crabs should be controlled at a reasonable level in the future. Meanwhile, LBB is a promising method providing a theoretical basis for the management and protection of fishery resources.

**Keywords:** LBB method; stock assessment; Yangtze Estuary; *Portunus trituberculatus*; fishery resources



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## 1. Introduction

The Yangtze Estuary and its adjacent areas are an important channel for material transportation and exchange between the Yangtze River, the East China Sea and the Yellow Sea [1]. The runoffs from the Yangtze River continuously transport nutrients to the area, making the estuary a habitat and a baiting, fattening and breeding site for many commercial fishes and invertebrates. Therefore, the estuary has become a pivotal fishing ground in China [1]. *Portunus trituberculatus* (Miers, 1876), an edible crab inhabiting the sandy or pebble seafloors throughout the majority of seawaters in China, is the perennial dominant species of invertebrates in the Yangtze Estuary [2]. Over the past few decades, sustained human activity has had serious effects on its biomass and abundance. The catch of *P. trituberculatus* in China had increased significantly from 130,000 tons in 1989 to 490,000 tons in 2018, among which the catch from the Yangtze Estuary and its adjacent areas accounted for about 50% [3]. As an important commercial species in China, the wild biomass of *P. Trituberculatus* has been continuously decreased due to overfishing, pollution and habitats' destruction in the past decades [4,5]. Meanwhile, the swimming crab, with high economic value, was also an important breed of aquaculture. Artificial propagation, restocking and stock enhancement are crucial ways to supply fishery biological resources and restore aquatic ecology [6,7]. The aquaculture yield of the swimming crab also revealed a trend of rapid growth since recorded from 2003, the proportion of which was about 25% of the total catch of swimming crab [3].

Traditional fishery resource assessments require not only value for life history invariant [8] but also, in some cases, catch and effort data [9], length-frequency data or age-structure data [10]. Due to the high cost of data collection and analysis, resource assessments existed for less than 1% of fishery species in the world [11]. Therefore, the lack of survey data for most sea-life made it difficult to assess their maximum sustainable yield (MSY).

The length-based Bayesian biomass estimator (LBB) is a powerful tool only using length-frequency (LF) or width-frequency (WF) data to evaluate the stock status of marine species growing throughout their lives, such as a large number of fishes and invertebrates [12]. Through the analysis of LF or WF data, the LBB theory estimates several parameters for the target species including, but not limited to, asymptotic length/width ($L_{inf}/W_{inf}$), length/width at first capture ($L_c/W_c$), relative natural mortality ($M/K$) and relative fishing mortality ($F/K$) [13,14].

This study presents the LBB method for the analysis of the carapace width of *P. trituberculatus* captured from the Yangtze Estuary. The purpose was to evaluate the size structure of stocks for the swimming crabs in this sea area via derived fishery reference points such as $B/B_0$ and $B/B_{MSY}$, which would be used as the theoretical foundations for managers to take corresponding measures for rationally utilizing the biological resources.

## 2. Materials and Methods

Crab samples were obtained using double bottom trawlers (150.5 × 96.5 m) in the Yangtze Estuary (31°25′N, 122°50′E) in November 2018, with a cod end (mesh size: 200 mm). All captured samples (n = 235) were taken to the laboratory for further analysis, including species identification [14] and a standard measurement of carapace width, defined as the distance between the tips of the posteriormost lateral spines, following Kampouris et al. 2020 [15]. All specimens were identified to species of *P. trituberculatus*.

### *General Descriptionof the LBB Method*

The length-based Bayesian biomass estimator method is an innovative method presented for estimation of size structure and stock status only using length-frequency analysis, in which all relevant parameters are simultaneously analyzed with a Bayesian Monte Carlo Markov chain (MCMC) approach [12].

It is assumed that the growth in length or width of species follows von Bertalanffy's [16] growth equation, in the form given by Beverton and Holt [17], i.e.:

$$W_t = W_{inf}\left[1 - e^{-K(t-t_0)}\right] \quad (1)$$

where $W_t$ is the width at age t, $W_{inf}$ is the asymptotic length, $K$ is the rate at which $W_{inf}$ is approached, and $t_0$ is the theoretical age at zero length [12]. With fully selected by the gear for the crabs, the curvature of the catch in number-at-width curve is a function of total mortality ($Z = M + F$) relative to $K$. This curve is expressed by the equation:

$$N_W = N_{W_{start}}\left(\frac{W_{inf} - W}{W_{inf} - W_{start}}\right)^{Z/K} \quad (2)$$

where $N_W$ is the number of survivors with width $W$, $N_{Wstart}$ is the number at length $W_{start}$ through full selection, from which all individuals entering the gear are retained by the gear, and $Z/K$ is the ratio of the total mortality rate to somatic natural growth rate [12]. When $Z/K$ is equal to $M/K$ and $W_{start}$ is zero, $N_{W\text{start}}$ becomes 1 in the unfished state. Equation (2) can be then simplified to:

$$P_{W/W_{inf}} = \left(1 - \frac{W}{W_{inf}}\right)^{\frac{M}{K}} \quad (3)$$

where $P_W/W_{inf}$ is the probability to survive to length $W/W_{inf}$, which is a function of the $M/K$ where $P_W/W_{inf}$ is the probability to survive to length $W/W_{inf}$, which is a function of the $M/K$ ratio [12].

The widths that are affected by partial selection are a function of the fishing gear (it is assumed to be a trawl or other gear with a selection curve similar to a trawl), as described by Equation (4):

$$Sw = \frac{1}{1 + e^{-a(W - W_c)}} \tag{4}$$

where $S_W$ is the individual proportion retained by the gear at width $W$, and $\alpha$ describes the steepness of the ogive [18,19].

The width corresponding to the gear keeping a certain probability $p$ can be obtained by

$$W_p = \frac{\alpha W_c - \log\left(\frac{1}{p} - 1\right)}{\alpha} \tag{5}$$

where $W_P$ is the width with probability $P$ of being retained by the gear and $W_c$ and $\alpha$ are as defined above [12]. The $P$ value is equal to 0.01, 0.5 or 0.95. The parameters of the selection ogive can be estimated at the same time as $W_{inf,}$ $W_c$, α, $M/K$ and $F/K$ by fitting:

$$N_{W_i} = N_{W_{i-1}}\left(\frac{W_{inf} - W_i}{W_{inf} - W_{i-1}}\right)^{\frac{M}{K} + \frac{F}{K}S_{W_i}} \tag{6}$$

And

$$C_{W_i} = N_{W_i}S_{W_i} \tag{7}$$

where $W_i$ is the number of individuals at width $I$ and $W_{i-1}$ is the number at the previous width, whereas C is the number of individuals vulnerable to gear damage; the other parameters are as mentioned above [12]. By dividing both sides of Equation (7) by the corresponding sums, the samples from different years are normalized and their numbers become compatible, i.e.:

$$\frac{C_{w_i}}{\sum C_{W_i}} = \frac{N_{W_i}S_{W_i}}{\sum N_{W_i}S_{W_i}} \tag{8}$$

Fitting Equation (8) to LF data provides estimates of $M/K$ and $F/K$, which could be combined to give $F/M = (F/K)/(M/K)$. LBB estimation was implemented in Bayesian Gibbs sampler software JAGS, and the statistical language R was used to fit the observed proportional length $P_{Wi}$ with its expected values $\hat{P}_{L_i}$. According to Equation (8), the model predicted width distribution $\hat{P}_{W_i}$ can be expressed as:

$$\hat{P}_{W_i} = \frac{\hat{N}_{W_i}}{\sum \hat{N}_{W_i}} \tag{9}$$

where $\hat{N}_{W_i}$ is a function of the estimable population dynamic parameters $W_{inf}$, $M/K$ and $F/K$ (Equation (7)) and the selectivity parameters $W_c$ and $\alpha$ [12]. Finally, the framework for approximating stock status from $W_{inf}$, $M/K$, $F/K$ and $W_c$ is described by the following equation [20]. Firstly, we considered the estimates of $W_{inf}$, $M/K$ and $W_{opt}$, i.e., the maximum biomass of the cohort can be obtained from Equation (10):

$$W_{opt} = W_{inf}\left(\frac{3}{3 + \frac{M}{K}}\right) \tag{10}$$

Based on Equation (10) and a given fishing pressure ($F/M$), the average width at first capture, maximizing catch and biomass ($W_{c\_opt}$), could be obtained from:

$$W_{c\_opt} = \frac{W_{inf}\left(2+3\frac{F}{M}\right)}{\left(1+\frac{F}{M}\right)\left(3+\frac{M}{K}\right)} \quad (11)$$

Estimates of $W_{c\_opt}$ are used to calculate a proxy for the relative biomass that can produce the MSY [12]. Overfishing occurs when $F/M$ is greater than 1 or the current biomass is significantly low as $B/B_0$ or $B/B_{MSY}$ is less than 0.5. The ratios $W_c/W_{c\text{-}opt}$, $W_{mean}/W_{opt}$ and $W_{95th}/W_{inf}$ are also key indicators in direct proportion to the individual size of the crabs.

The parameters deduced from the LBB method play a vital role in sustainable fishing for the marine resources. For instance, fishing activity should be reduced if $B/B_{MSY}$ or $W_c/W_{c\text{-}opt} < 1$, and on the contrary, catch should be resumed.

All analyses in this study used R code (LBB_20. R); the code can be downloaded from http://oceanrep.geomar.de/44832/ and includes a new user guide, following the guidelines of the various proposals.

## 3. Results

The stocks of *P. trituberculatus* in the Yangtze estuary were analyzed using the LBB method and the results are presented in Figure 1. The priors for the crab stocks, including asymptotic width, $W_{inf}$, $Z/K$, $M/K$, $F/K$, $W_c$, and $\alpha$ are given in Table 1. The data obtained by using LBB method were shown in Table 2. The maximum and minimum of the WF data are 91.7 mm and 20.6 mm, respectively, and the class interval is 5 mm. The ratios $F/M$ (= 1.7) and $B/B_0$ (= 0.18) showed that these invertebrates were suffering overfishing and 82% of their wild resources had been depleted. Meanwhile, the parameters $W_{mean}/W_{opt}$ (= 0.89), $W_c/W_{c\_opt}$ (= 0.72) and $W_{95th}/W_{inf}$ (= 0.91) indicated that the situation of the crabs was not so bad as displayed above, some large crabs were still present in these waters under current fishing pressure.

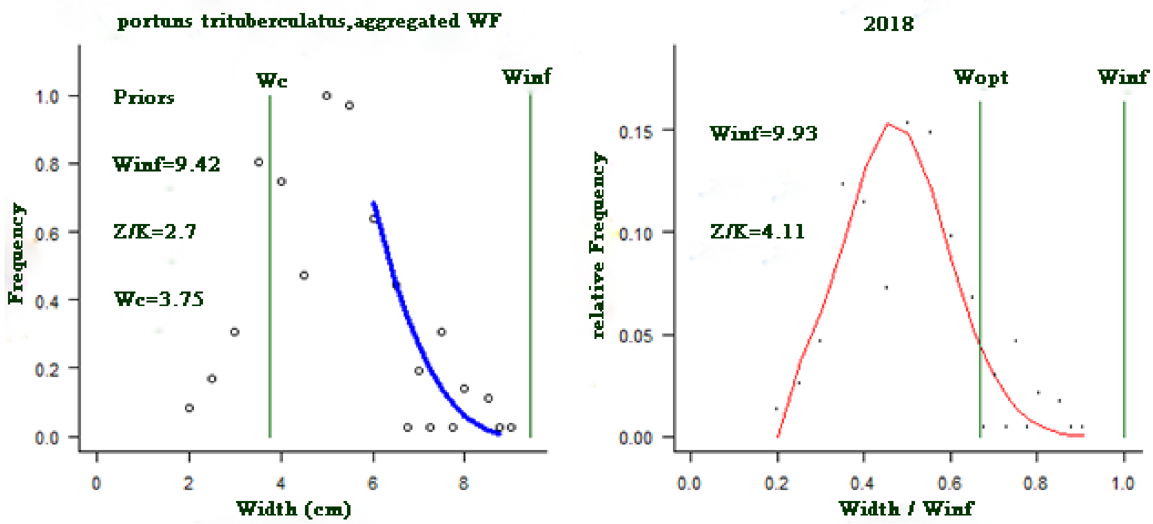


**Figure 1.** The width and frequency results of the length-based Bayesian biomass estimator (LBB) analysis of *Portunustrituberculatus* in the Yangtze Estuary. The left curve manifests the fitness of the model to the width data of the swimming crab, while the right curve is the estimation of the LBB method; the peak point of the right curve is on the left of Wopt and the Z/K in the right curve is greater than the value in the left curve, indicating that overfishing occurs for the species. $W_c$ is the width of 50% of the crabs captured, $W_{inf}$ is the asymptotic width of the *P. trituberculatus* and $W_{opt}$ is the width at which the maximum catch is available.

**Table 1.** Priors of the *P. trituberculatus* given by LBB.

| | $w_{inf}$ Prior(cm) | *Z/K* Prior | *M/K* Prior | *F/K* Prior | $W_c$ Prior(cm) | *Alpha* Prior |
|---|---|---|---|---|---|---|
| *Portunustrituberculatus* | 9.42 | 2.72 | 1.5 | 1.23 | 3.83 | 13.5 |

**Table 2.** Summary of data available for the stock assessments using LBB.

| Scientist Name | $W_{mean}/W_{opt}$ | $W_c/W_{c\_opt}$ | $W_{95th}/W_{inf}$ | $B/B_0$ | $B/B_{MSY}$ | *F/M* | *F/K* | *Z/K* |
|---|---|---|---|---|---|---|---|---|
| *Portunustrituberculatus* | 0.89 | 0.72 | 0.91 | 0.18 | 0.5 | 1.7 | 2.6 | 4.14 |

## 4. Discussion

In China, more than 60 million juveniles of *P. trituberculatus* (stage C2) were released for the first time in Yingkou city, Liaoning Province in 1986–1988 [21]. Due to its remarkable effect, stock enhancement has been gradually extended to the coastal areas of the country, due to which the biomass of the crabs increased significantly and it became the dominant species in the Yangtze Estuary and its adjacent areas again [2,22], which was in accord with the results published by Shen [23]. At present, the natural resources of *P.trituberculatus* in the Yangtze Estuary and its adjacent waters were found to be on the verge of depletion, which is consistent with the research results of Yu et al. [24]. Furthermore, our results corresponded to the research by Panhwar et al. [9], who estimated the biological reference point and maximum sustainable yield of *P. trituberculatus* using length-frequency data and time series of catch and effort data from 2005 to 2016, with the result showing overfishing. Our result was also confirmed by the study of Wang et al. [25] in which they found that the released number of larva crab is the main impact factor for the catch of *P. trituberculatus* in the northern East China Sea using generalized additive models.

On one hand, the wild resources of *P. trituberculatus* are decreasing in the Yangtze Estuary because of long-term overfishing. On the other hand, there is still a growing demand from the people for the crabs as a popular delicacy. Therefore, fishery managers should exercise appropriate regulations in a scientific way to balance the input and the output of the fishery resources—for example, the releasing capacity should be determined systematically, the recapture rate should be controlled and the releasing efficiency must be analyzed reasonably. In addition, reduction in the fishing pressure, adjusting the fishing off season and marine habitat restoration may also play important roles in the conservation of biological resources of the commercial species. Necessary measures should be taken to ensure the sustainability of its population and recover their resources besides the artificial breeding and releasing of the swimming crabs.

Lack of data is the main factor affecting the resource assessment for marine species, especially for China's coastal stocks due to unreliable fishery catch data [26]. Beverton et al. (1957) used the size composition to assess the exploitative stock firstly [17], and the LBB method based on length- or width-frequency data was put forward in 2017 as the development of computer technology [27], which can be used in data-poor fisheries' management. The LBB method has been applied to make stock assessments for eight fish species caught from the Bohai and Yellow Seas by Wang et al. [28]; the results were compared with other research using classical approaches such as the Pella–Tomlinson Model, the Beverton–Holt Y/R analysis and the fisheries resource survey. It was found that although available data were rare, the majority could verify the validity of the LBB method.

The LBB method can estimate the relative stock size of fish and sea life through their length or width in some waters, which gives us a promising approach to assess the resources of sea life with poor data. However, there are not so many studies based on this theory, and its accuracy needs to be verified by more research results; the consequence drawn from this will be more convictive and acceptable when combined and compared with similar approaches.

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