An assessment of European bream *Abramis brama* (Linnaeus, 1758) fishery in the downstream of the Irtysh River in China

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\textbf{ABSTRACT}

Per-recruit analyses, with consideration for uncertainty in growth, natural mortality and maturity, were conducted for European bream *Abramis brama* in the downstream section of the Irtysh River in China to assess its status. The Chapman-Robson method produced an estimate of total mortality rate ($Z_{\text{0}}$) of 0.65 year\(^{-1}\). The natural mortality rates ($M$) were estimated as 0.13 and 0.26 year\(^{-1}\), resulting in corresponding estimates of current fishing mortality rate ($F_{\text{cur}}$) of 0.52 and 0.39 year\(^{-1}\), respectively. All the estimates of yield per recruit (YPR), spawning stock biomass per recruit (SSB/R) and corresponding biological reference points (BRPs) were sensitive to $M$. The uncertainty of growth and maturity parameters had limited impacts on the estimates of BRPs, but had a large effect on the YPR and SSB/R outputs. Our findings indicate that *A. brama* may be at higher risk of growth overfishing than those of recruitment overfishing. In addition, increasing the $t_c$ to nine years might ensure that the spawning potential ratios (SPRs) are above the management targets under all ranges of $F$ with comparatively small impacts on YPR regardless of $M$. In addition to providing a basic assessment for *A. brama* in the downstream of the Irtysh River in China, our study presents a comprehensive approach that may be useful for data-limited species in other fisheries.

\textbf{ARTICLE HISTORY}

Received 29 May 2018
Accepted 16 October 2018

\textbf{KEYWORDS}

Per-recruit analysis; stock assessment; mortality; age at first capture; Abramis brama; Irtysh River

\textbf{Introduction}

The Irtysh River originates on the southwestern slope of the Altai Mountains, flowing through Lake Zaysan (Kazakhstan), meeting the Ishim and Tobol rivers before merging...
with the Ob River (Russia) and terminating at the Arctic Ocean (Zhang et al. 2016). The river spans a total of 4,248 km, of which 633 km are in China. The drainage area of the Irtysh River within China is 57,000 km², with a mean annual runoff of $119 \times 10^9$ m³. It remains the second longest river in Xinjiang (Xinjiang Geographic Society 1983). The climate in Xinjiang is cold temperate continental and arid. In comparison with coastal areas of the same latitude, the region has less rain, drier air, longer winters and shorter summers. The rich flora on the banks of the Irtysh River tend to be flooded by rising waters during the flood season each year (Zhang et al. 2016).

The European bream (*Abramis brama*) is a freshwater fish species in the family Cyprinidae, and it is now considered to be the only species in the genus *Abramis*. *A. brama* originated in Europe north of the Alps and Pyrenees, as well as the Balkans. It was introduced in Lake Balkhash of Central Asia from the Ob River basin in 1949, gradually spread into Xinjiang along the Irtysh River in 1963, and became one of the most important commercial and recreational fish of this area (Adakbek et al. 2003). Every spring, a large number of *A. brama* cluster are formed in the downstream section of the Irtysh River in China for breeding; this cluster is readily available to commercial and recreational fishermen. Recent studies indicate that this species is in decline and has been classified as a near threatened fish on the IUCN Red List of Threatened Species (Freyhof and Kottelat 2008). Hence, close attention should be paid to the conservation status of natural populations of *A. brama*.

The biology of *A. brama* has been extensively studied (e.g. Goldspink 1978; Kangur 1996; Treer et al. 2003; Zhang et al. 2016; Zhang et al. 2017). To date, no stock assessment has been conducted for *A. brama* in the Irtysh River nor in its European home range. The surplus production model is regarded as the most convenient and simplest method for the stock assessment of a species (Hilborn and Walters 1992). However, the requirement of long-term catch and relative abundance indices (such as catch per unit effort, CPUE) limits the use of this model to data-poor fisheries (Peixer et al. 2007). The yield per recruit (YPR) and spawning stock biomass per recruit (SSB/R) models offer a valuable alternative for determining the fishery status of a fish stock for which the growth and maturity parameters are available.

Several fishing mortality rate (*F*)-based biological reference points (BRPs) derived from per-recruit analysis have been used to evaluate whether the YPR is optimum or the SSB/R is sufficient for the population to persist. It also provides fisheries managers with the ability to develop harvest policies (Aprahamian et al. 2006; Lin et al. 2015; Huo et al. 2015). The BRPs usually appear in three forms: targets (target reference points, TRPs), thresholds (threshold reference points, ThRPs) and limits (limit reference points, LRP). The TRPs are *F* values that enable fisheries to achieve their desirable states; the LRP are the upper limits of *F* values; if exceeded, fisheries development would be slower or even stagnant, and management actions should be taken immediately. ThRPs are *F* values between the TRPs and LRP and generally used to prevent recruitment overfishing (Williams and Shertzer 2003; Cooper 2006; Tong et al. 2010; Braccini et al. 2015). The combination of these three concepts enables managers to assess the states of fish stocks and fisheries, and to implement the corresponding management measures to ensure continuity in fisheries (Prager et al. 2003).

The BRPs often reflect the combination of several stock dynamics (such as growth, reproduction and mortality) as a single value, which is called a point estimate (Gabriel and Mace 1999). However, point estimates present only the most possible values, whereas a wide range of values and alternative models may exist. Ignoring uncertainties in biological parameters in per-recruit analysis may yield an incorrect estimation of BPRs, and
consequently, the estimation of the fish stock status could be misleading (Chen and Wilson 2002; Lin et al. 2015). Caddy (1993) suggested that the imprecision or uncertainty should be taken into consideration when a per-recruit analysis is developed.

The objectives of this study were to (1) estimate the mortality rates of *A. brama*, (2) evaluate the impacts of uncertainty in per-recruit analyses on the determination of the stock status of *A. brama* and (3) investigate the effectiveness of age at first capture (*t_c*) for conservation of *A. brama* stock in the downstream of the Irtysh River in China.

**Materials and methods**

**Sample collection**

A total of 464 specimens were randomly selected from commercial fishing in the downstream section of the Irtysh River in China from April to October 2013 and April to May 2014 (Figure 1). Fish were caught using trammel nets (inner mesh size 10 cm, outer 23 cm). For each sampled individual, the standard length (*L*) was measured to the nearest 1 mm and body weight (*W*) to the nearest 0.01 g. Specimens were macroscopically classified as male, female or unsexed. Lapillus otoliths were extracted from each fish for age analysis.

**Estimation of mortality**

The Chapman-Robson (CR) method was used to estimate the total mortality rate (*Z*) of *A. brama* and all ages after the age where the peak catch occurred were used (Chapman and Robson 1960).

Two empirical equations were applied to estimate the natural mortality rate (*M*), with the recommendation of Then et al. (2015):

\[
M = 4.899 \cdot t_{\text{max}}^{0.916}
\]
\[
M = 4.118 \cdot K^{0.73} \cdot L_{\infty}^{0.33}
\]

where the parameters of the von Bertalanffy growth function are as follows: *K*, the growth coefficient of 0.123 year\(^{-1}\), *t_0*, the age at zero length of −0.205 year, and *L_\infty*, the asymptotic length of 348.6 cm (Table 1). In addition, *t_{\text{max}}* is the longevity of *A. brama*, which is estimated using the following formula (Taylor 1958):

\[
t_{\text{max}} = \frac{3}{K} + t_0.
\]

Fishing mortality rate (*F*) was calculated as *F* = *Z* − *M*. The estimates of *M* and *F* were assumed to be constant throughout the fish lifespan.

**Per-recruit analysis**

Based on the previous study, there was no significant difference between the growth and maturation of males and females, and the sex ratio (*M*/*F*) was 1.06:1, which showed no significant deviation from 1:1 (Zhang et al. 2017). Hence, yield per recruit (*YPR*) and spawning stock biomass per recruit (*SSB/R*) models were developed for the pooled data. The *YPR* and *SSB/R* were calculated using the following models (Huo et al. 2015):

\[
YPR = \sum_{t=t_c}^{t_t} \left[ L_{\infty} \left( 1 - e^{-K(t-t_0)} \right) \right]^b \frac{S_t F}{S_t F + M} \cdot e^{-M(t_c-t_c)} \cdot e^{-(S_t F + M)(t_t-t_c)} \cdot \left( 1 - e^{-(S_t F + M)} \right)
\]
Figure 1. The sampling locations of *A. brama* in the downstream of the Irtysh River in China.
SSB = \frac{R}{t_k} = \frac{X}{t_k} \cdot \frac{Pt}{C_0} \cdot \frac{Kt}{C_0} \cdot \frac{St}{C_2} \cdot \frac{F}{C_0} \cdot \frac{M}{t_c} \cdot \frac{t_0}{C_4}

SPR = \frac{SSB}{RF} = \frac{SSB}{RF_{t_0}}

where $t_k$ is the maximum observed age; $t_r$ is the age at recruitment, which was the youngest age in the catch; $t_c$ is the age at first capture ($t_s$, $t_r$, and $t_c$ are obtained from age frequency distribution analysis); $K$ is the growth coefficient; $t_0$ is the hypothetical age at zero length; $L_\infty$ is the asymptotic length in the von Bertalanffy growth function; $a$ and $b$ are parameters in the weight–length relationship; $P_t$ is the proportion of mature fish at age $t$; $F$ and $M$ refer to fishing and natural mortality rates, respectively (the parameters used in per-recruit analysis are given in Table 1). SPR is the spawning potential ratio, defined as the ratio of spawner per recruit with a fishing mortality relative to spawners per recruit without fishing; $S_t$ is the gear selectivity coefficient for fish of age $t$ and is set to a 'knife edge' selectivity as follows:

$$S_t = \begin{cases} 
0, & t < t_c \\
1, & t \geq t_c 
\end{cases}$$

**Biological reference points**

To determine the fishery status of *A. brama* stock in the downstream of the Irtysh River, the current fishing mortality ($F_{\text{cur}}$) was compared with four $F$-based BRPs: $F_{\text{max}}$, where the fishing mortality rate produces the maximum $YPR$; $F_{0,1}$, refers to fishing mortality where the slope of the $YPR$ curve is 10% of the slope at the origin (Gulland and Boerema 1973); and $F_{25\%}$ and $F_{40\%}$, are fishing mortality rates at which the SPR is respectively 25% and 40% (Goodyear 1993).

**Sensitivity and management simulations**

The sensitivity of the $YPR$ and $SSB/R$ computations to the variation of $M$ were examined in consideration of the difficulty in obtaining reliable estimates of $M$ for exploited fish...
populations (Sun et al. 2002; Huo et al. 2015). To evaluate the impact of uncertainty of growth and maturity parameters on per-recruit analysis, new parameters were randomly selected from a normal distribution defined by the mean and standard error for each parameter (Zischke and Griffiths 2015). The selected parameters included \( K, L_\infty \) and \( t_0 \) in the von Bertalanffy growth function (VBGF); \( a \) and \( b \) in the weight–length relationship and \( r \) and \( A_{50} \) in the logistic function of first maturity at age (Table 1). A total of 100 model iterations were conducted to investigate uncertainty in stock assessment outputs under the current harvesting scenario (Zischke and Griffiths 2015). Moreover, four different fishery management scenarios from current harvesting were simulated to evaluate the impact of \( t_c \) on \emph{A. brama} fishery. These four scenarios were 3, 5, 9 and 11 years at first capture, respectively. All potential management scenarios were explored with the iterative approach described previously.

Changing \( YPR \) and \( SPR \) were also investigated under various combinations of \( t_c \) and \( F \) using isopleth plot (mean parameters were used), to obtain the best compromise between the conservation of \emph{A. brama} stock and maximizing \( YPR \) and \( SPR \) (Huo et al. 2015).

**Results**

**Mortality**

The age frequency distribution of \emph{A. brama} in the downstream of the Irtysh River in China is presented in Table 2. The Chapman-Robson method produced an estimate of \( Z \) of 0.65 year\(^{-1} \) (Figure 2). Estimates of \( M \) obtained from the use of mean biological parameters in the two empirical equations were 0.13 and 0.26 year\(^{-1} \), and the corresponding estimates of \( F_{\text{cur}} \) were 0.52 and 0.39 year\(^{-1} \), respectively.

**Sensitivity and management simulations**

Per-recruit analysis was conducted at three alternative values of \( M \) (0.13, 0.20 and 0.26 year\(^{-1} \)) within the estimated range. All the estimates of \( YPR \), \( SSB/R \) and corresponding biological references points (BRPs) fluctuated widely with \( M \) (Table 3, and Figures 3 and 4). Under the current harvesting scenario and the three corresponding \( M \), the ranges

| Age | Female | Male | Total |
|-----|--------|------|-------|
| 1   | 0      | 0    | 0     |
| 2   | 0      | 0    | 0     |
| 3   | 2      | 3    | 5     |
| 4   | 7      | 10   | 17    |
| 5   | 6      | 6    | 12    |
| 6   | 13     | 12   | 25    |
| 7   | 50     | 69   | 119   |
| 8   | 45     | 60   | 105   |
| 9   | 28     | 24   | 52    |
| 10  | 6      | 9    | 15    |
| 11  | 10     | 6    | 16    |
| 12  | 9      | 2    | 11    |
| 13  | 1      | 4    | 5     |
| 14  | 1      | 0    | 1     |
| 15  | 3      | 0    | 3     |
| Total | 181 | 205 | 386 |
of \( YPR_{\text{cur}} \) and \( SSB/R_{\text{cur}} \) were 58.0–129.9 g and 212.5–346.2 g, respectively, and both the estimates significantly decreased with the increase of \( M \). Nevertheless, an increased trend in the \( BPR \)s with the increase of \( M \) was observed. The estimates of \( F_{0.1} \) were 0.24–0.35 year\(^{-1} \), and \( F_{\text{max}} \) was 0.48 year\(^{-1} \) with \( M \) of 0.13, and greater than 2 year\(^{-1} \) with \( M \) of 0.20 and 0.26; the ranges of \( F_{40\%} \) and \( F_{25\%} \) were 0.30–0.45 year\(^{-1} \) and 0.57–1.18 year\(^{-1} \), respectively.

The uncertainty of growth and maturity parameters had limited impact on the \( BRP \)s, but had significant effect on the \( YPR \) and \( SSB/R \) (Table 3, Figures 3 and 4). Most of the \( BRP \)s fluctuated over a relatively small range, especially the \( BRP \)s for \( YPR \) model. The maximum fluctuation of \( BRP \)s for \( YPR \) analyses was in S2 with \( M \) of 0.26, the \( F_{\text{max}} \) fluctuates within the range of 0.59 to 0.73 year\(^{-1} \), and \( BRP \)s for \( SSB/R \) in current harvesting scenario with \( M \) of 0.26, the \( F_{25\%} \) fluctuates within the range of 1.09 to 1.29 year\(^{-1} \). However, the estimates of \( YPR_{\text{cur}} \) and \( SSB/R_{\text{cur}} \) fluctuated widely under all simulated scenarios, and the maximum fluctuation of \( YPR_{\text{cur}} \) and \( SSB/R_{\text{cur}} \) was 32.2–129.7 g and 47.6–799.7 g, respectively.

It is apparent that the \( t_c \) could significantly influence the per-recruit analysis, and all estimates of \( YPR \), \( SSB/R \) and \( BPR \)s increased with increasing \( t_c \) under the scenarios simulated in this study (Table 3). For the current harvesting scenario, the \( F_{\text{cur}} \) was higher than all \( TRP \)s (\( F_{0.1} \) and \( F_{40\%} \)) at almost all levels of \( M \), with the exception of \( F_{40\%} \) with \( M \) of 0.26, whereas the \( F_{\text{cur}} \) was lower than the \( F_{25\%} \) and \( F_{\text{max}} \) under almost all levels of \( M \), with the exception of \( F_{\text{cur}} \) slightly higher than \( F_{\text{max}} \) with \( M \) of 0.13. For scenarios S1 and S2, the \( F_{\text{cur}} \) was higher than all \( BRP \)s at almost all levels of \( M \), with the exception of \( F_{\text{max}} \) in S2 with \( M \) of 0.26. In scenarios S3 and S4, the \( F_{\text{cur}} \) was lower than both the \( F_{25\%} \) and \( F_{40\%} \) under all levels of \( M \); and the \( F_{\text{cur}} \) was lower than the \( F_{\text{max}} \) under all levels of \( M \), but larger than the \( F_{0.1} \) in S3 with \( M \) of 0.13 and 0.20, and in S4 with \( M \) of 0.13.

The response of \( YPR \) and \( SPR \) to varying \( t_c \) and \( F \) under three corresponding levels of \( M \) is demonstrated in Figures 5 and 6. With increasing \( F \) within the low levels, \( YPR \)
Table 3. Estimates of YPR, SSB/R and corresponding biological reference points (BRPs) under different fishery management scenarios of A. brama in the downstream section of Irtysh River in China.

| Scenario | t (year) | M | F_{cur} | F_{0.1} (year^{-1}) | F_{max} (year^{-1}) | YPR_{cur} | YPR_{0.1} (g) | YPR_{max} (g) | F_{40\%} (year^{-1}) | F_{25\%} (year^{-1}) | SSB/R_{cur} |
|----------|---------|---|---------|---------------------|---------------------|-----------|----------------|----------------|------------------|------------------|-------------|
| Current  | 7       | 0.13 | 0.52    | 0.24                | 0.48                | 129.88    | 120.15         | 129.96         | 0.30             | 0.57             | 346.17      |
|          | 0.20    | 0.45 |         | 0.29                | >2                  | 84.95     | 78.49          | na             | 0.36             | 0.79             | 265.96      |
|          | 0.26    | 0.39 |         | 0.35                | >2                  | 57.92     | 56.43          | na             | 0.45             | 1.18             | 212.47      |
| S1       | 3       | 0.13 | 0.52    | (0.12–0.13)         | (0.18–0.19)         | (36.23–97.75) | (49.51–126.20) | (51.67–131.96) | (0.12–0.12)     | (0.19–0.19)     | (32.56–80.15) |
|          | 0.20    | 0.45 |         | 0.15                | 0.23                | 52.87     | 56.32          | 59.36          | 0.13             | 0.21             | 51.29       |
|          | 0.26    | 0.39 |         | (0.14–0.15)        | (0.23–0.23)         | (31.35–84.60) | (34.24–89.10) | (35.98–93.93) | (0.13–0.13)     | (0.20–0.21)     | (32.57–80.17) |
| S2       | 5       | 0.13 | 0.52    | 0.17                | 0.29                | 45.83     | 44.07          | 46.81          | 0.14             | 0.22             | 51.30       |
|          | 0.20    | 0.45 |         | (0.17–0.18)        | (0.27–0.29)         | (27.18–73.33) | (26.46–70.06) | (28.03–74.58) | (0.14–0.14)     | (0.22–0.22)     | (32.58–80.19) |
|          | 0.26    | 0.39 |         | (0.17–0.18)        | (0.27–0.29)         | (61.34–159.86) | (62.95–159.64) | (66.56–169.37) | (0.17–0.17)     | (0.27–0.28)     | (90.65–22271) |
| S3       | 9       | 0.13 | 0.52    | 0.34                | >2                  | 141.49    | 131.06         | na             | 0.89             | >2               | 625.59      |
|          | 0.20    | 0.45 |         | (0.33–0.34)        | >2                  | (88.88–218.55) | (82.31–202.52) | (82.31–209.25) | (0.82–0.97)     | >2               | (402.75–954.24) |
|          | 0.26    | 0.39 |         | 0.46                | >2                  | 48.65     | 51.22          | na             | >2               | >2               | (280.19–672.74) |
| S4       | 11      | 0.13 | 0.52    | 0.49                | >2                  | 135.71    | 133.60         | na             | >2               | >2               | 909.66      |
|          | 0.20    | 0.45 |         | (0.48–0.49)        | >2                  | (85.93–207.54) | (84.43–204.70) | (84.43–207.54) | (0.50–0.56)     | >2               | (379.59–898.27) |
|          | 0.26    | 0.39 |         | 0.55                | >2                  | 67.09     | 71.35          | na             | >2               | >2               | 586.19      |
|          | 0.26    | 0.39 |         | 0.62                | >2                  | 35.98     | 42.21          | na             | >2               | >2               | 407.00      |
|          |         |      |         | 0.61–0.62           | >2                  | (22.78–55.02) | (26.64–64.83) | na             | >2               | >2               | (262.93–625.17) |

na: non available.
rapidly increased for most of the range of $t_c$, and the SPR rapidly decreased for low values of $t_c$. The YPR isopleths showed that, under the current $F$, increasing the $t_c$ to between 7 and 9 years would enable YPR to be at relatively high levels regardless of $M$. Maximum YPR could not be obtained by decreasing the $t_c$ to between 1 and 5 years, or increasing the $t_c$ to relatively high levels, even if $F$ is increased to infinity (Figure 5). Moreover, the SPR would be maintained above SPR$_{10\%}$ under all ranges of $F$, when increasing the $t_c$ to nine years (Figure 6). Hence, the $t_c$ to nine years might be able to ensure that the SPR remains above the management targets under all ranges of $F$ with comparatively small impact on YPR regardless of $M$.
Discussion

Natural mortality ($M$) is one of the most important parameters to understanding the population dynamics of a fish species. It directly influences the productivity of a stock and the optimum yield that can be obtained, and is generally believed to be exceptionally difficult to estimate reliably and directly (Kenchington 2014; Then et al. 2015). A number of studies suggested that $M$ is strongly age and size dependent, and may differ significantly among subpopulations (e.g. Lorenzen 1996; Gislason et al. 2010; Kenchington 2014). Nevertheless, most fishery scientists would agree that an invariant $M$ can be an effective representation of mortality across exploited age classes, as obtaining a single value with useful accuracy is challenging enough (Kenchington 2014). Among the $M$ estimators, the direct methods such as mark and recapture, and following individuals through

![Figure 4. Mean estimates (solid line) and 95% confidence intervals (gray shaded area) of spawning stock biomass per recruit ($SSB/R$). Arrows indicate current fishing mortality ($F_{\text{cut}}$). Black dots represent target reference points ($F_{40\%}$). White dots represent target reference points ($F_{25\%}$).](image)
telemetry are considered to be more reliable, whereas these methods are often data intensive and expensive to implement, limiting their application only to those relatively data-rich stocks (Hoenig et al. 1998; Knip et al. 2012; Then et al. 2015). Although the indirect empirical methods are often regarded as being less reliable than those direct estimators, a consensus is that empirical estimators are useful and important, especially for data-limited populations (Brodziak et al. 2011). In this study, we used two empirical methods recommended by Then et al. (2015), three possible values of $M$, believed to encompass the predicted range of target species, were used in per-recruit analysis.

The cross-sectional catch-curve analyses are one of the most commonly used methods for determining the total mortality rate ($Z$) from age-frequency distribution data of a fish

Figure 5. Isotherms describing the response of yield per recruit ($YPR$) to various fishing mortalities ($F$) and age at first capture ($t_c$) for $A. brama$ stock in the downstream section of Irtysh River in China. Red dots represent the current $YPR$. 

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population (Dunn et al. 2002). Among these methods, the Chapman and Robson (1960) estimator and catch-curve regression are generally preferred over the other proposed methods (Ricker 1975), and the Chapman–Robson estimator using all ages after the age of maximum catch occurred was verified to be the most precise and least biased (Smith et al. 2012).

Per-recruit analysis is often used to yield fishing mortality-based biological reference points and can be helpful when the historical fisheries data are unobtainable (Zischke and Griffiths 2015). In this study, we used per-recruit analysis to estimate a traditional target biological reference point $F_{0.1}$ and a limit reference point $F_{\text{max}}$ to compare them with $F_{\text{cur}}$.

Figure 6. Isopleths describing the response of spawning potential ratio (SPR) to various fishing mortalities ($F$) and age at first capture ($t_c$) for A. brama stock in the downstream section of Irtysh River in China. Red dots represent the current SPR.
estimated from the catch-curve method. However, a YPR model only reflects schedules of growth and mortality, and both \( F_{\text{max}} \) and \( F_{0.1} \) are BRPs in the context of growth overfishing (Gabriel and Mace 1999). Hence, BRPs based on YPR model may not be sufficient to ensure sustainability (Gabriel and Mace 1999). As an addition to the YPR analysis, the SSB/R analysis was conducted to estimate reference points (such as \( F_{40\%} \) and \( F_{25\%} \)) to compare them with the \( F_{\text{cur}} \) to evaluate whether recruitment overfishing may occur (Goodyear 1993).

The estimates of YPR, SSB/R and corresponding BRPs fluctuated widely with \( M \), which indicated that the current stock status of \( A. \text{brama} \) in the downstream of the Irtysh River was sensitive to the levels of \( M \). The sensitivity of per-recruit analysis to the level of \( M \) has been reported in a large number of documents (e.g. Sun et al. 2002; Huo et al. 2015). The situations where both the YPR and SSB/R decreased with increasing \( M \), and the BRPs increased with increasing \( M \) might be attributed to higher \( M \) leaving fewer fish to be captured, reducing the yield and mitigating the impact of fishing on the survival of spawners (Sun et al. 2002).

BRPs such as \( F_{0.1}, F_{\text{max}}, F_{25\%} \) and \( F_{40\%} \) have been widely used in developing fisheries management policies. For YPR analysis, the \( F_{0.1} \) was recommended as TRP by many authors (e.g. Mace 1994; Gabriel and Mace 1999; Kirchner 2001; Zischke and Griffiths 2015), and the \( F_{\text{max}} \) was a recognized limit reference point (LPR). Griffiths (1997) and Huo et al. (2015) used \( F_{25\%} \) as ThRP and \( F_{40\%} \) as TRPs for SSB/R analysis. Under the current harvesting scenario, our results based on per-recruit analyses suggested that the \( F_{\text{cur}} \) are higher than almost all TRPs (\( F_{0.1} \) and \( F_{40\%} \)) and lower than the \( F_{25\%} \) and \( F_{\text{max}} \) at almost all levels of \( M \). In addition, the recreational fishery was not considered in the calculation of \( F \), indicating that the \( F_{\text{cur}} \) might be underestimated. Therefore, the \( A. \text{brama} \) population in the downstream of the Irtysh River might be under overfishing. The findings also indicate that, under the current harvesting scenario, \( A. \text{brama} \) may be at higher risk of growth overfishing than of recruitment overfishing, and this phenomenon may be attributed to their slow growth and high selectivity of juvenile fish by fisheries (Zhang et al. 2016; Zischke and Griffiths 2015).

To obtain relatively high yields and spawning stocks, the \( t_c \) should be maintained within reasonable ranges, and these ranges should be determined according to the specific circumstance. The current \( t_c \) of 7 years is approximately equal to the age at first sexual maturity (6.23 years, Table 1), and this might lead to a risky recruitment stock. Our results indicated that increasing the \( t_c \) to 9 years could ensure that the SPR is above the management targets under all ranges of \( F \) with comparatively small impact on YPR regardless of \( M \). The enhancing of the \( t_c \) to 9 years would not increase the YPR to any extent compared with the current YPR, but this measure allows more fish into the age classes which contribute to the spawning stock of this species (Kirchner et al. 2001).

In most fisheries, managers can adjust the level of fishing effort and age or size at first capture (adjust the mesh size in fishery) to achieve the optimum yield or spawning stock (Zhang and Campbell 2002). Although decreasing the fishing effort and increasing the age or size at first capture could be effective measures to conserve the \( A. \text{brama} \) stock in the downstream region of the Irtysh River, increasing age at first capture is preferred. Compared with decreasing the fishing effort, increasing the age or size at first capture may be more efficient and easier to implement, in consideration of the local economic and social conditions. Fishing and grazing are the main sources of income for people who live in this region, and the economy and education in these remote areas are still relatively backward, making it difficult to let them reduce the fishing effort consciously.
Conclusions

We collated biological and fishery information for *A. brama* and provided the first quantitative evaluation of the status of fishery of this species. Our findings indicate that *A. brama* may be at higher risk of growth overfishing than that of recruitment overfishing. Although decreasing both the fishing effort and increasing the age at first capture could be effective measures to conserve the *A. brama* stock in the downstream region of the Irtysh River, we suggest increasing the minimum age limits (increasing mesh sizes of fishing nets) for *A. brama* fishery. Moreover, the fishery should be re-assessed periodically, because its dynamics (e.g. biological characteristic, fishing effort, catch or management measures) might be changing with time. In addition to providing a basic assessment for *A. brama* in the downstream region of the Irtysh River in China, our study provides an approach that may be useful for data-limited species in other fisheries.

Acknowledgments

The authors gratefully acknowledge financial support from China Scholarship Council. The authors would like to thank Feng Wang and Peng Xie for help in sample collection. The authors also thank Kisei Tanaka for his constructive review of the manuscript. This experiment complies with the current laws of the country in which they were performed.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was financially supported by National Science Foundation for Young Scientists of China (No. 31800391), and Special Funds for the Foundation Work of Science and Technology (No. 2012FY112700).

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