Age and growth of *Schizothorax waltoni* (Cyprinidae: Schizothoracinae) in the Yarlung Tsangpo river, China

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**ABSTRACT**

To better understand the biology of *Schizothorax waltoni*, the age structure and growth characteristics of *S. waltoni* were examined. The standard length (SL) range was 41–642 mm and the body weight (BW) range was 1.1–3788 g. Otoliths continually grew with increasing SL and increasing age, but asymmetrically over time. One annulus was formed each year, between April and July. Estimated age range was 4–37 yr for males, 4–40 yr for females, and 1–9 yr for those of undetermined sex. The SL–BW relationship was described as $BW = 1.365 \times 10^{-3} SL^{2.564}$ for females, $BW = 1.238 \times 10^{-3} SL^{2.999}$ for males, and $BW = 3.664 \times 10^{-3} SL^{2.800}$ for undetermined specimens. The von Bertalanffy function was used to model the observed length-at-age data as $Lt = 644.3 \{1 - \exp \left[-0.084(t - 0.247)\right]\}$ for females, and $Lt = 586.2 \{1 - \exp \left[-0.084(t + 2.250)\right]\}$ for males. Females grew faster than males. Knowledge of this species’ characteristics of slow growth and a long life will be useful for establishing reasonable management practices for its conservation.

1. Introduction

The subfamily Schizothoracinae is the predominant group of endemic fishes living in high-elevation rivers and lakes on the Qinghai-Tibetan Plateau (Cao et al. 1981). They are characterized by restricted distributions, slow growth rates, low fecundity, and late maturity, which may result from their surrounding rigorous environment (Chen & Cao 2000). These life-history characteristics make them more vulnerable to intense exploitation (Buxton 1993). These species have been subjected to intensive anthropogenic pressures such as indiscriminate fishing, habitat modification resulting from dam construction, and biological invasions (Huo et al. 2012).

*Schizothorax waltoni* (Cyprinidae, Schizothoracinae), generally known as marinka baileyova, is an endemic fish to Tibet. It is distributed only in the middle reaches of the Yarlung Tsangpo River and is of economic importance in this region (Chen & Cao 2000). Despite the *S. waltoni* population supporting a valuable fishery, little is known about the biology and ecology of this species. To date, there has been only one study of *S. waltoni*. Qiu and Chen (2009) estimated the age of *S. waltoni* using otoliths, but the standard length (SL) range was only 202–580 mm and the body weight (BW) range was 96–2256 g. The estimated age range was 4–28 yr for all specimens and the maximum observed age was only 18 yr for males and only 28 yr for females in their study, owing to difficulties in collecting sufficient samples of smaller and larger specimens and the need to develop appropriate methods for ageing older fish. This ageing problem often led to age underestimation, resulting in overly optimistic estimates of growth and mortality rates, which can contribute to overexploitation of a population or species (Campana 2001). The growth model estimates are greatly affected by the lack of very young or old individual, extra space in juveniles (age classes 1–4) (Cailliet & Goldman 2004).

Accurate estimates of age and growth are prerequisites for understanding population dynamics and maintaining sustainable yields in fisheries (Campana & Thorrold 2001). Anal scales (Tsao & Wu 1962; Zhao et al. 1975; Ren & Sun 1982), vertebrae (Lal & Mishra 1980), and opercles (Sunder 1985) have all been used to determine age in previous studies of schizothoracine fishes. Recent studies have demonstrated that schizothoracine age can be estimated reliably from the sections of lapillus otoliths (Huo et al. 2012; Ma et al. 2010; Chen et al. 2006). For *S. waltoni*, sectioned lapillus showed a clear pattern of alternating opaque and hyaline zones (Qiu & Chen 2009).

Some researchers focused on relationships of otolith size with fish size and age, and suggested that age can be estimated from the otolith weight and fish length (Boehlert 1985). Experimental studies using fish of known ages showed that for juveniles, the otolith growth is in fact isometric with somatic growth (Secor & Dean 1989), but for slowly growing individuals, otoliths grow asymmetrically through time, having relatively heavy otoliths for their body size, which might be attributed to an increase in otolith thickness (Reznick et al. 1989).
The overall goal of our study was to characterize the age and growth of *S. waltoni* in the Yarlung Tsangpo River of Tibet, China, by a large number of specimens with a wide *SL* and *BW*. The specific research content included: (1) to verify the annual periodicity of the growth increments in otoliths, (2) to determine age structure of the population through otolith analysis, and (3) to model the growth for both sexes of the population.

### 2. Material and methods

#### 2.1. Collection of samples

The *S. waltoni* individuals were obtained from the Yarlung Tsangpo River and its tributaries (Xiang Qu and Nyang Qu) monthly from August 2008 to August 2009 by means of floating gillnets, bottom gillnets, and trap nets (Figure 1). The standard length (*SL*) of each fresh specimen was measured to the nearest 1 mm using a tapeline, and body weight (*BW*) was measured to the nearest 0.1 g with an electronic balance. Specimens were classified as male, female, or undetermined sex by macroscopic examination of gonads. Lapillus otoliths were extracted from each fish, washed with 95% ethanol, air-dried, and then stored in labelled tubes.

#### 2.2. Otolith preparation

The terms anterior, posterior, dorsal, ventral, proximal, and distal faces refer to the position of the otolith corresponding to its original orientation in the fish (Reñones et al. 2007, Figure 2). To study otolith size and growth, the following measurements were made in a sample of 1061 whole otoliths (Figure 2): length (*OL*: maximum anterior-posterior distance), breadth (*OB*: dorsal-ventral distance at the widest point), thickness (*OT*: distal-proximal maximum distance), and weight (*OW*: measured after being dried at 60°C for 24 h) (Reñones et al. 2007). *OL* and *OB* were measured to the nearest 0.01 mm using Image-Pro Plus software (version 6.0; Media Cybernetics, USA) after taking photos with Leica Application Suite (Leica EZ4D dissecting microscope). The *OT* was measured to the nearest 0.01 mm with digital calipers and *OW* to the nearest 0.1 mg with an electronic balance.

A lapillus was mounted with the proximal face on a glass slide using nail polish, ground from the distal face using wet sandpaper (600–2000 grit) and polished with alumina paste (3 μm) until the core was visible under a compound microscope. Then the otolith was removed from the glass slide by dissolving the polish with acetone, and the section was re-affixed with the polished surface down, ground, and polished until the core was exposed again (He et al. 2008).

Figure 1. Sampling locations of *S. waltoni* in the Yarlung Tsangpo River.

Figure 2. Proximal (b), distal (a), and dorsal (c) faces of a whole lapillus under a dissecting microscope with reflected light, from an 8-yr old *S. waltoni* (338 mm standard length (*SL*)). The axes along which the otolith length (*OL*) and breadth (*OB*) were measured are indicated. The otolith (c) was placed inside digital calipers to measure the thickness (*OT*). Scale bars = 0.5 mm.
2.3. Marginal increment ratio (MIR)

A marginal increment ratio (MIR) analysis was used to verify the period of opaque zone formation in the otoliths. Monthly variations of the MIR (1–8 annuli) were established using the following equation:

\[
\text{MIR} = (R - R_n) (R_n - R_{n-1})^{-1},
\]

where \( R \) is the otolith radius, \( R_n \) is the distance from the focus to the outer edge of the last annulus formed, and \( R_{n-1} \) is the distance from the focus to the outer edge of the penultimate complete annulus (Haas & Recksiek 1995). Measurements were conducted along the anterior growth axis using an image analysis system (Leica Application Suite EZ, Heerbrugg, Switzerland) with a direct data feed between the dissecting microscope (Leica EZ 4D) and a computer.

2.4. Age estimation

Each fish was assigned to an age class assuming 1 March as the birth date, which approximately corresponds to the peak spawning season (which occurs in March, unpublished data). When a fish sampled after the assumed birth date had no new ring mark, the annulus should plus 1 in the age estimation (Granada et al. 2004).

Otolith readings were made along the anterior growth axis. The reader had no prior knowledge of the length and sex before the age estimation. All ages were determined twice by the same interpreter after a considerable time (3 wk). Readings were only accepted if both counts by the same examiner were in agreement. If the two readings differed, then the otolith was recounted, and the final count was then accepted as the agreed age. If the 3rd reading had no consensus with either of the previous two readings, the sample was discarded.

The index of the average percentage error (IAPE) and coefficient of variation (CV) were calculated to measure the ageing precision between the two readings. The equations (Campana 2001) are expressed as follows:

\[
\text{IAPE}_j = \frac{1}{N} \sum_{j=1}^{N} \left( \frac{\sum_{i=1}^{R} |X_i - X_j|}{X_j} \right) \times 100\% , \quad \text{and}
\]

\[
\text{CV} = \frac{1}{N} \sqrt{\frac{\sum_{j=1}^{N} (X_j - \bar{X})^2}{\sum_{j=1}^{N} (X_j - \bar{X})}} \times 100\% ,
\]

where \( N \) is the number of fish aged, \( R \) is the number of times each fish was aged, \( X_j \) is the \( j \)th age determination of the \( j \)th fish, and \( \bar{X} \) is the mean age calculated for the \( j \)th fish.

2.5. Environmental factors

To discuss the relationship between the water temperature and the deposition of the opaque zone, water temperature was measured and recorded twice a day (8:00 and 20:00) at Xigaze, the middle reaches of Yarlung Tsangpo River. The mean values each month were used in our analysis.

2.6. Data analysis

Relationships of otolith dimensions with fish length and age were studied by linear regression analysis. Relationships between \( BW \) and \( SL \) were estimated independently for females and males using a power regression analysis, described by \( BW = a \times SL^b \), where \( a \) and \( b \) are parameters. The traditional von Bertalanffy growth function (von Bertalanffy 1938) was used to fit the observed length at age of \( S. \) waltoni: \( L_t = L_\infty (1 - \exp (-k (t - t_0))) \) where \( L_t \) is the length at age \( t \), \( L_\infty \) is the asymptotic length, \( k \) is the growth coefficient, \( t \) is the age (year from birth), and \( t_0 \) is the age at length 0. The growth performance index was calculated using the equation of Munro and Pauly (1983): \( \Phi = \log_{10} k + 2 \log_{10} L_\infty \). \( \Phi \) was used to compare growth parameters obtained in this study with those reported by other authors for schizothoracine fishes.

The \( BW-\text{SL} \) relationship and von Bertalanffy function were calculated by a non-linear regression analysis (the Levenberg–Marquardt method; Levenberg 1944). The difference in the \( BW-\text{SL} \) relationship between the sexes was compared by an analysis of covariance (ANCOVA). Deviation of the allometric coefficient, \( b \), from the theoretical value of isometric growth (\( b = 3 \)) was tested by a \( t \)-test (Pauly 1984). A residual sum of squares analysis (ARSS) was used to determine whether any significant difference existed in the von Bertalanffy equations for males and females (Chen et al. 1992).

The data were presented as the mean ± standard deviation (SD). Differences were regarded as significant when \( p < 0.05 \). The analysis was carried out using SPSS 18.0 (Chicago, IL, USA), Origin 8.0 (Originlab, Northampton, USA), Microsoft Excel 2003 (Redmon, WA, USA), and Photoshop CS2 Extended (Adobe, San Jose, USA).

3. Results

3.1. Length–frequency distributions and \( SL-BW \) relationship

The \( SL \) of specimens’ range was 41–642 mm, and the \( BW \) range was 1.1–3788.1 g. Of the 1118 \( S. \) waltoni sampled, 448 were females with \( SL \) of 151–642 mm, 377 were males with \( SL \) of 176–499 mm, and 293 were the undetermined sex with \( SL \) of 41–303 mm. Length–frequency distributions significantly differed between males and females (Kolmogorov–Smirnov test, \( D = 3.556, p < 0.05 \)) (Figure 3). \( SL \) of captured fish was mainly 100–500 mm (88%), and females were significantly larger than males.

The \( SL-BW \) relationships are plotted separately for males, females, and undetermined sex in Figure 4. No statistically significant difference was detected for \( SL-BW \) relationships between males and females by both the slopes and the intercepts (ANCOVA, \( F = 0.226, p > 0.05 \)). So, all the individuals were pooled together. The regression equations were shown as follows:

Female \( BW = 1.365 \times 10^{-5} SL^{2.984} \) \((R^2 = 0.990, n = 448)\),

Male \( BW = 1.238 \times 10^{-5} SL^{2.999} \) \((R^2 = 0.974, n = 377)\),

Undetermined sex \( BW = 3.664 \times 10^{-5} SL^{2.800} \) \((R^2 = 0.993, n = 293)\); and

Total \( BW = 2.274 \times 10^{-5} SL^{2.996} \) \((R^2 = 0.995, n = 1118)\).

The allometric index value (\( b \)) obtained from the function significantly differed from 3 for undetermined specimens (\( t \)-test,
\[ t = 14.528, \ p < .05 \] and exhibited no statistical difference from the theoretical value of isometric growth \( (b = 3) \) for females (t-test, \( t = 1.079, \ p > .05 \)) and males (t-test, \( t = 0.055, \ p > .05 \)).

3.2. Age validation and annual periodicity

Under polarized transmitted light, alternate, concentric opaque and hyaline bands were observed in the anterior area of the otolith, which facilitated the reading of growth markers.

For otolith sections with 1–8 annuli, monthly changes of the MIR gradually increased from July to February, and appeared to peak at 0.871 in February followed by a gradual decrease to 0.124 in May (Figure 5). Significant differences were found in MIR values among months (one-way ANOVA, \( F = 11, \ p < .001 \)). Tukey's post-hoc pair-wise comparisons revealed that the MIR between April and July significantly differed from that from September to March (\( p < .05 \)). These results indicated that the opaque band of the otoliths was laid down once a year between March and July.

3.3. Relationships between otolith dimensions and fish length/age

The relationships between otolith dimensions (OL, OB, OT, and OW) and fish length/age are shown in Figure 6. The lines of best fit between OL/OB/OT/OW and SL/age were power functions. The growth rate of OL/OB/OT declined as SL/age increased, that is, OL/OB/OT increased with increasing SL at a fixed rate up to a size of 400 mm or 15 yr, and at a slightly slower rate thereafter. OL was the best predictor of fish length \( (R^2 = .963) \) and age \( (R^2 = .905) \). Otoliths dimensions were more highly correlated with fish length than age. Variability in the data substantially increased for all variables beyond 450 mm SL or 20 yr.

3.4. Age structure

Sectioned otoliths of \( S. \ waltoni \) showed the typical pattern observed in teleosts under transition light, with an alternating sequence of broad opaque and narrow hyaline bands that became progressively narrower and of similar widths as the number of bands increased (Figure 7). Of the 1118 simples of otoliths examined, there were successfully read for a total of 1061 specimens, only 57 (approximately 5.1%) were discarded due to fragmentation and unidentifiable annulus deposition. Age estimates had low IAPE (0.49%) and CV (0.65%), reflecting concordance in the readings and thus intrinsic reliability. The estimated age range was 1–40 yr. Assigned ages of fish for the undetermined sex were in the range 1–9 yr, for males the range was 4–37 yr, and for females the range was 4–40 yr. Standard lengths-at-age of the 1061 specimens are presented in Table 1.
3.5. Growth

The mean length-at-age did not significantly differ between sexes for age classes 5–8 (two-sample t-test, all p > .05). Therefore, the length-at-age data of undetermined specimens (except for two 9-yr-old individuals) were included in the von Bertalanffy models for both sexes. The von Bertalanffy functions fitted to the observed length-at-age are given as follows:

\[ L_t = 586.2 \left(1 - e^{-0.084(t + 2.250)}\right) \] (\(R^2 = .970\)) for males and,

\[ L_t = 644.3 \left(1 - e^{-0.084(t - 0.247)}\right) \] (\(R^2 = .966\)) for females.

The growth curve based on the observed length-at-age data between sexes described a general trend of relatively slow growth (Figure 8). The growth trajectories of male and females were very similar up to age 8, and then the growth trajectories began to diverge as females grew substantially faster than males with increasing age. The growth performances indices (Ø) of *S. waltoni* were 4.5432 for females and 4.4605 for males.

4. Discussion

It has been argued that otolith size is highly correlated with fish size, because they are both controlled by the same metabolic processes (Gauldie 1988). Otoliths, as measured along various
axes, show asymmetrical growth through time, but nevertheless grow throughout the life of the fish (Fowler 1990). Asymmetries occur in otolith growth because the new material is mainly deposited on the distal face of the otolith which thickens the structure, particularly in slow-growing, long-lived species (Boehlert 1985; Reñones et al. 2007). Such a growth pattern might affect the application of back-calculation which assumes that otolith growth is isometric with somatic growth through time (Campana 1990). In the present study, otoliths grew symmetrically along the three axes, but the growth rate slightly declined after the SL longer than 400 mm.

Pino et al. (2004) reported that otolith weight could be correlated with the age of some fish, and it may be a useful, simple tool for rapidly estimating the age of individuals (Araya et al. 2001). However, in some studies, the increased variability of OW in older fish indicated that this variable may produce less-reliable age estimates in older fish (Tuset et al. 2004). Gunn et al. (2008) and Ma et al. (2010) pointed out that OW was an imprecise predictor of age beyond 10 or 15 yr. In the present study, a similar trend was observed, with variability of OW in S. waltoni significantly increasing beyond 450 mm SL or 20 yr.

Application of the precision measures (IAPE and CV) presented satisfactory consistency in age determination between the two readings, because the estimated value was below the precision point of 5.5% established by Campana (2001) for ageing studies.
Although the exact mechanisms of growth increment formation are poorly understood, they are thought to involve some exogenous and endogenous factors, which may include temperature, season, feeding, and reproductive cycles (Beckman & Wilson 1995; Morales-Nin 2000; Tserpes & Tsimenides 2001; Grandcourt et al. 2006; Liu et al. 2009). In this study, deposition of the opaque zone in otoliths of *S. waltoni* occurred in the spring and early summer, whereas the hyaline zone was formed in the winter months. A similar phenomenon in Scizothoracinae fishes has been demonstrated for *O. stewartii* (Jia & Chen 2009; Huo et al. 2012), *P. dipogon* (Li et al. 2009), *S. waltoni* (Qiu and Chen 2009), and *O. o’connori* (Ma et al. 2010). Deposition of the opaque zone occurs between March and July, corresponding well to the reproductive activity and water temperature changes, and deposition of the hyaline zone occurs during winter months, when there is reduced metabolic activity. Formation of the opaque zone in otoliths of *S. waltoni* appeared to be closely associated with the abrupt increase in seasonal water temperature in April–July and August. Moreover, formation of the opaque zone in otoliths of *S. waltoni* may be partially related to reproductive cycle. Peak reproductive activity may promote a redirection of energy to reproduction, with a consequent reduction in somatic growth, which could possibly affect the physiology of otolith growth. Similar influences by water temperature and reproduction on other fishes were observed in past studies (Morales-Nin & Ralston 1990; Mann & Buxton 1997; Pajuelo et al. 2003; Bustos et al. 2009; Beckman & Wilson 1995). Thus, formation of the annulus in otoliths of *S. waltoni* could be due to an interaction between water temperature and reproduction.

The maximum ages estimated for *S. waltoni* in this study were 40 yr for females and 37 yr for males. Li and Chen (2009) recorded 45 yr for females and 24 yr for males of *P. dipogon* based on an interpretation of sectioned otoliths. Chen et al. (2009) found 18 yr for females and 16 yr for males of *S. younghusbandi younghusbandi* by means of otoliths. Yao et al. (2009) obtained 24 yr for females and 18 yr for males of *S. o’connori* using otoliths. Ma et al. (2010) reported 50 yr for females and 40 yr for males of *S. o’connori* based on otolith observations. Huo et al. (2012) reported 25 yr for females and 17 yr for males of *O. stewartii* based on otolith observations. Those studies including the present paper confirm that relatively high longevity is a common trait in scizothoracine fishes and the females live longer than males.

Cailliet and Goldman (2004) reported that growth model estimates are greatly affected by the lack of very young or old individuals, extra space in juveniles (age classes 1–4) collected from traps provided a meaningful estimate of the VBGF parameter, *t₀*. More data points from juvenile fish would tend to shift *t₀* values higher and closer to 0 (Paul & Horn 2009). Since the mean length-at-age exhibited no significant difference between sexes up to an age of 8 yr, the length-at-age data of undetermined specimens were used to fit models for both sexes (Peres & Haimovici 2004). Moreover, the presence of several specimens of >600 mm SL also provided a reliable estimate of the other VBGF parameter, *Lₘₐₓ* (644.2 mm for females, which was larger than the maximum observed size of 642 mm).

Regarding the estimation of VBGF parameters, a low estimate of *k* and a high *Lₘₐₓ* indicated that *S. waltoni* is a slow-growing, long-lived fish. Females attained a bigger size (*Lₘₐₓ*) than males. Comparing our results of the growth of *S. waltoni* with those from the previous study (Table 2), the *Lₘₐₓ* obtained in our study was lower than the study by Qiu and Chen (2009) in the Yarlung Tsangpo River (Table 2), the *Lₘₐₓ* obtained in this study was lower, but the *k* value was higher. Differences among all of the estimated parameters could be attributed to several factors: (1) different environmental conditions (such as altitude and water temperature) (2) different size distributions (probably caused by different types of sampling gear), and (3) different age groups employed to fit the VBGF function (groups whereas here in individuals were age of 4 to 28).

The von Bertalanffy growth coefficient (*k*) is a useful index to address the potential vulnerability of stocks to excessive mortality (Musick 1999). Comparing the parameters of several Schizothoracinae fishes, Li and Chen (2009) suggested that they are slow-growing species with *k* values of around 0.1. Slow-growing, long-lived fishes tend to be particularly vulnerable to excessive exploitation and exhibit rapid stock collapse, after which population turnover may be lower than expected, and their responses to rehabilitation measures slower than predicted (Musick 1999). In this study, the estimated maximum age was 40 yr, and the *k* value was well below 1, indicating that *S. waltoni* is a very slow-growing, long-living species. The growth traits of *S. waltoni* may be adaptations to cold water temperatures and food deficiencies on the
Qinghai-Tibetan Plateau (Chen et al. 2009). Therefore, it is necessary to establish science-based management of this resource to guarantee its sustainable use. Fishery regulations for S. waitoni should aim to prevent growth overfishing through minimum landing sizes, and also prevent recruitment overfishing by protecting the oldest population components especially in the spawning season.

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