Zoological Studies **51**(4): 476-483 (2012)

Zoological Studies

Age, Growth, and Reproduction of *Opsariichthys bidens* (Cyprinidae) from the Qingyi River at Huangshan Mountain, China

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(Accepted December 9, 2011)

Xiao-Yun Sui, Yun-Zhi Yan, and Yi-Feng Chen (2012) Age, growth, and reproduction of *Opsariichthys bidens* (Cyprinidae) from the Qingyi River at Huangshan Mountain, China. *Zoological Studies* **51**(4): 476-483. The age, growth, and reproduction of *Opsariichthys bidens* were studied in a sample of 281 specimens from monthly collections made from May 2009 to Apr. 2010 in Qingyi Stream, Anhui Province, China. The sex ratio of this study population was 1: 1.18 (female: male), which did not significantly differ from 1: 1. The oldest females and males were 5 and 4 yr old, respectively. The dominant age groups were 2 and 3 yr old in both sexes. Annuli on scales were formed in Feb. and Mar. No obvious sexual dimorphism was observed in the length-weight or length-scale radius relationships or in the total lengths back-calculated at each age for either sex. An inflection point occurred in the growth curves given by the von Bertalanffy growth functions for total weight. At this inflection point, females and males were 4.7 and 4.3 yr old, respectively. Both sexes reached sexual maturity at age 2 yr. At this age, total lengths of females and males were 118.1 and 126.5 mm, respectively. The temporal pattern of the gonadosomatic index corresponded to a spawning period that occurred from Apr. to July. Absolute fecundity significantly increased with total length and weight and significantly varied among age groups, whereas no significant variation was observed in relative fecundity in relation to body size. These life-history traits (e.g., the timing of annulus formation, young age structure, temporal pattern of gonad development, and early age at maturity) of *O. bidens* in the studied river are hypothesized to be tightly associated with features of the surrounding environment, such as local hydrological rhythms, unstable habitat conditions, and severe human disturbance. http://zoolstud.sinica.edu.tw/Journals/51.4/476.pdf

Key words: Age, Growth, Reproduction, Life history, *Opsariichthys bidens*.

Opsariichthys bidens (Günther 1983) is a small endemic cyprinid species of East Asia. It is widely distributed in all major river systems in China with the exception of the Qinghai-Tibet Plateau and Xinjiang Uygur Autonomous Region, as well as being found on the Korean Peninsula and in Vietnam's Red River (Chen 1998, Li et al. 2009). This species is commonly found in relatively small streams or tributaries of large rivers, especially in montane streams characterized by a fast-flowing current regime, gravel substrates, and low water temperatures (Li et al. 2010). During breeding, females are often chased by males. The non-viscid eggs are spawned in shallow flowing water with sand or gravel substrates (Jin and Jin 1985). Distinct ontogenetic niche shifts in diet were documented for this species (Jiang et al. 1995, Johansson et al. 2006). Small individuals at < 140 mm in body length are invertivores, feeding primarily on zooplankton, aquatic insects, and shrimp. Large individuals (> 140.0 mm in body length) are piscivores because they can feed on other small fishes (e.g., gobies and small gudgeons) and larvae of large cultured fishes (e.g.,

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silver and bighead carp).

Because of its feeding behavior (i.e., predation on larvae of cultured fish), *O. bidens* was shown to have a harmful influence on reservoir fishery yields (Su et al. 1993, Jiang et al. 1995). However, if its populations are limited in body size (e.g., < 170 mm in body length), *O. bidens* may be beneficial for reservoir fishery yields because it preys on other small fishes but not on larvae of cultured fish (Zhong 1985). *Opsariichthys bidens* is also economically important because it is edible. Therefore, it is possible that this species represents a component of the fishery resources in some montane rivers (Li et al. 2010). In addition, because of its complex ecological behaviors and functions (e.g., its diverse diet), the presence of this species in rivers may contribute to the maintenance of ecosystem balance (Li et al. 2010). Unfortunately, owing to extensive agricultural and industrial production, urban development, and hydraulic engineering construction, most river ecosystems in China are experiencing massive ecological perturbations that may threaten freshwater fishes in these systems (Chen 2005). Li et al. (2010) stated that human impacts have caused a decrease in the *O. bidens* fishery in the Beijiang River in Guangdong Province, southeastern China. These impacts have resulted in smaller body sizes, lower individual abundances, and a narrower distributional range.

Understanding the life history of fishes is fundamental for the scientific protection of fish species and the sustainable use of natural fishery resources (Jia and Chen 2011). Until now; however, information on the life-history traits of *O. bidens* has been scarce. Jin and Jin (1985) and Su et al. (1993) studied the age, growth, and reproduction primarily of populations in reservoirs, i.e., the Tiejia Reservoir in Liaoning Province and the Sandaohe Reservoir in Hubei Province, respectively. For populations inhabiting rivers, only the individual fecundity of *O. bidens* in the Beijiang River in Guangdong Province was documented (Li et al. 2010). To present the life history of this species and its relationship with the surrounding environment in rivers, the age, growth and reproduction of *O. bidens* in the Qingyi River, China were examined in this study.

MATERIALS AND METHODS

Study area

The Qingyi River is located in the northern part of the Huangshan Mountains, Anhui Province, China and flows northeasterly toward its confluence with the lower reach of the Yangtze River. The mainstem of this river is 309 km long. The area of its watershed is 7195 km^2. Because of the local subtropical monsoon climate, the watershed is characterized by asymmetries in seasonal temperature and precipitation. The mean air temperature ranges from -2.1°C (in Jan.) to 27.5°C (in July). The annual mean temperature is 17.8°C. Annual rainfall is abundant, at approximately 2000 mm/yr, but approximately 80% of it occurs during the spring and summer (from Apr. to Sept.), and < 5% occurs during the cold and dry winter (Yan et al. 2011b).

Fish collection

We collected fish using electrofishing at Chenjiadan, near the confluence of the mainstem and a tributary, Huishui Stream, in the middle reach of the Qingyi River. Sampling was conducted monthly during the 3rd wk of each month from May 2009 to Apr. 2010. *Opsariichthys bidens* was sorted, the total length (L, to the nearest 0.1 mm) and total weight (W, to the nearest 0.1 g) were individually measured, and individuals were dissected to determine the sex from visual traits of the gonads. The gonads were removed, scored in 6 maturity stages following Yin (1993), and weighed (gonad weight; GW, to the nearest 0.01 g). Fish were reweighed after removing the internal organs (somatic weight; SW, to the nearest 0.1 g). All specimens and mature ovaries at stages IV and V were preserved in an 8% neutralized formaldehyde solution.

Age

Scales taken between the posterior end of the pectoral fin and the anterior end of the dorsal fin were used for age determination. The scale radius (R, to the nearest 0.1 mm) was measured using Photo Analysis system software, vers. 2.01 (Zhu et al. 2002). The timing of annulus formation was estimated from monthly changes in the marginal increment ratio (MIR) as MIR = $(R - r_{max})/(r_{max} - r_{max-1})$, where R is the scale radius and r_{max} is the length of the outermost annulus.

Growth

The L-W equation was estimated from $W = aL^b$ and the L-R equation from $L = a + bR$, where L is the total length, W is the body weight, R is the scale radius, and a and b are both constants. The back-calculated length (BCL), i.e., the body length at a specific age estimated by back-calculation rather than by measurement (Francis 1990), was examined to estimate the total length at age using the Fraser-Lee equation (Duncan 1980): $L_n = a + (L - a) R_n/R$, where L_n is the L at the formation of the n-th annulus, a is the intercept in the L-R linear function, and R_n is the scale radius of the n-th annulus. Growth curves were fitted to the back-calculated data using the von Bertalanffy growth function (VBGF), a mathematical function widely applied to fish growth (Chen et al. 1992): $L_t = L_\infty(1 - e^{-k\,(t - t_0)})$, where L_t is the predicted length at age t, L_∞ is the mean theoretical maximum length, k is a growth rate parameter, and t_0 is the theoretical age at 0 length.

Reproduction

Maturity was defined as the length or age at which 50% of individuals were mature. $L_{50\%}$ (total length at 50% maturity) and $T_{50\%}$ (age at 50% maturity) were estimated by fitting the binomial maturity data to a logistic function: $P = 100/[1 + e^{(a + bx)}]$, where P is the proportion of mature fish in each 10-mm size interval or each 1-yr age interval, x is total length or age, and a and b are both constants. The length and age at maturity were expressed as -a/b. Breeding timing was determined by following monthly changes in the gonadosomatic index (GSI), an index describing the relative size of the gonads and further indicating the gonad development process by its sequential variation month by month (Yin 1993), calculated as GSI = 100(GW/SW) (in %), where GW and SW are the gonad and somatic weights, respectively. Absolute fecundity (AF) was estimated in terms of the number of whole oocytes, including both transparent and vitelline oocytes, from mature ovaries. Relative fecundity (RF) was calculated as RF = AF/SW, where AF is the absolute fecundity and SW is the somatic weight.

Statistical analysis

χ^2 was used to test for a difference between the observed sex-ratio and 1: 1. An analysis of covariance (ANCOVA) was performed to compare L-W and L-R relationships between the sexes. A one-way analysis of variance (ANOVA) was used to compare total lengths back-calculated among different age groups, GSIs among different months, and the AFs and RFs among different age groups. Differences between the sexes in back-calculated Ls or GSIs were examined by a *t*-test. Statistical significance was accepted at $p < 0.05$.

RESULTS

Age

Annuli on scales of *Opsariichthys bidens* were easily identified; they were characterized by incised patterns defined by the nonparallel arrangement of tracks between the exterior and interior rings. Of the 281 specimens of *O. bidens* collected, 119 were females (73.1-220.9 mm L, 5.3-116.1 g W), 141 were males (74.2-196.6 mm L, 4.7-85.7 g W), and the sex of 21 fish was undetermined. The sex ratio estimated from the sex-identified fish was 1: 1.18 (female: male), which did not significantly differ from 1: 1 ($\chi^2 = 0.93$, *d.f.* = 1, $p > 0.05$). Based on the numbers of annuli on the scales, the oldest females and males were 5 and 4 yr old, respectively. The relative abundances of each age group were 8.77% (1 yr), 57.02% (2 yr), 31.58% (3 yr), 1.75% (4 yr), and 0.88% (5 yr) for females, and 7.97% (1 yr), 47.10% (2 yr), 39.13% (3 yr), and 5.80% (4 yr) for males. The preponderant age groups were 2 and 3 yr for both sexes. The relative abundance of these combined age groups was approximately 85%.

Monthly changes in the MIR indicated that annuli formed in Feb. and Mar. In Feb. and Mar., compared to Jan., the mean MIRs decreased, and ranges of MIRs increased. In Feb. and Mar., some individual MIRs were near 0. The mean MIR began to increase from Apr. to June. Although the mean MIRs in July and Aug. were lower relative to June values, no individual MIR near 0 was observed (Fig. 1).

Growth

The L-W equation was $W = 8 \times 10^{-6}L^{3.05}$ ($R^2 = 0.89$, $n = 119$) for females and $W = 5 \times 10^{-6}L^{3.15}$ ($R^2 = 0.96$, $n = 141$) for males. These equations did not significantly differ between the sexes (ANCOVA, $F = 0.47$, $p > 0.05$). Accordingly, their L-W relationships were combined to give $W = 6 \times 10^{-6}L^{3.12}$ ($R^2 = 0.93$, $n = 260$). The L-R equations for females and males were both linear and were respectively given by L = 0.04R + 38.02 (R^2 = 0.52, n = 119) and L = 0.04R + 30.95 (R^2 = 0.56, n = 141). They were combined to give L = 0.04R + 33.35 (R^2 = 0.55, n = 260) because the difference between the equations for the 2 sexes was not significant (ANCOVA, F = 2.50, p > 0.05).

L_1, L_2, and L_3 from back-calculation were 89.5 ± 10.5, 127.2 ± 14.4, and 154.4 ± 9.3 mm for females and 84.5 ± 12.1, 119.4 ± 14.0, and 149.3 ± 11.9 for males, respectively. For both sexes, the BCLs significantly differed among age groups (one-way ANOVA, *d.f.* = 2, F = 22.34, p < 0.05 for females; *d.f.* = 2, F = 51.27, p < 0.05 for males). Greater BCLs were observed at older ages. Differences between the BCLs at specific ages for the 2 sexes (L_1 (t-test, t = 0.50, p > 0.05), L_2 (t = 0.35, p > 0.05), and L_3 (t = 0.32, p > 0.05)) did not significantly differ.

The VBGFs fitting the length-at-age data were (Fig. 2): $L_t = 246.3[1 - e^{-0.26(t - 0.36)})]$ for females and $L_t = 244.0[1 - e^{-0.31(t - 0.57)}]$ for males.

The VBGFs fitting the weight-at-age data were (Fig. 2): $W_t = 157.4[1 - e^{-0.26(t - 0.36)}]3.05$ for females and $W_t = 165.6[1 - e^{-0.31(t - 0.57)}]3.15$ for males.

Derived from VBGFs in total length and weight, growth rates were as follows (Fig. 3): $dL/dt = 64.04e^{-0.26\ (t - 0.36)}$ and $dW/dt = 40.93e^{-0.26(t - 0.36)}[1 - e^{-0.26(t - 0.36)}]^{3.05}$ for females, and $dL/dt = 75.63e^{-0.31\ (t - 0.57)}$ and $dW/dt = 51.34e^{-0.31(t - 0.57)}[1 - e^{-0.31(t - 0.57)}]^{3.15}$ for males.

The growth acceleration equations were (Fig. 3): $d^2Lt/dt^2 = -16.65e^{-0.26(t - 0.36)}$ and $d^2Wt/dt^2 = 10.64e^{-0.26(t - 0.36)}[1 - e^{-0.26(t - 0.36)}]^{3.05}[3.05e^{-0.26(t - 0.36)} - 1]$ for females and $d^2Lt/dt^2 = -23.45e^{-0.31(t - 0.57)}$ and $d^2Wt/dt^2 = 15.92e^{-0.31(t - 0.57)}[1 - e^{-0.31(t - 0.57)}]^{3.15}[3.15e^{-0.31(t - 0.57)} - 1]$ for males.

As age increased, females and males both showed decreases in the rate of growth in L. However, obvious inflection points occurred in the rate of growth in W. These inflection points corresponded to ages of 4.7 yr for females and 4.3 yr for males (Fig. 3).

Reproduction

Fifty percent of both females and males reached sexual maturity at age 2 yr, the 2nd yr following birth. $L_{50\%}$ was 118.1 mm for females and 126.5 mm for males (Fig. 4).

Both sexes showed significant variations in GSI over time (one-way ANOVA, F = 31.25, p < 0.05 for females; F = 9.87, p < 0.05 for males). During the breeding season, the GSI of the females was significantly greater than that of the males (t-test, p < 0.05). In females, the GSI markedly increased in Apr., remained relatively high (approximately 8.0%) from Apr. to July, and then declined sharply in Aug. (Fig. 5). These findings indicated that the breeding activities of *O.*

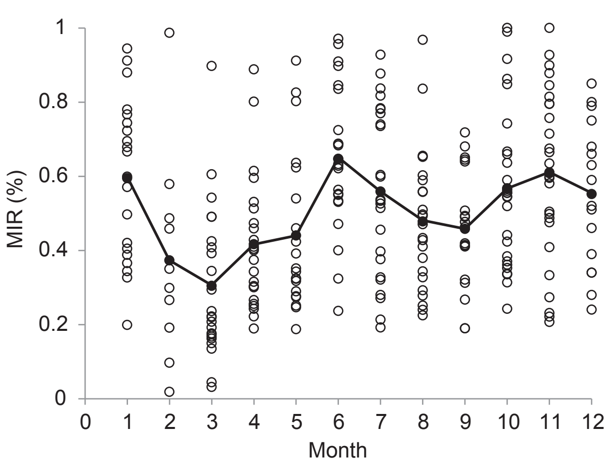

Fig. 1. Monthly changes in the marginal increment ratio (MIR) for *O. bidens* in the Qingyi River, China. Solid circles and the line indicate the mean MIR.

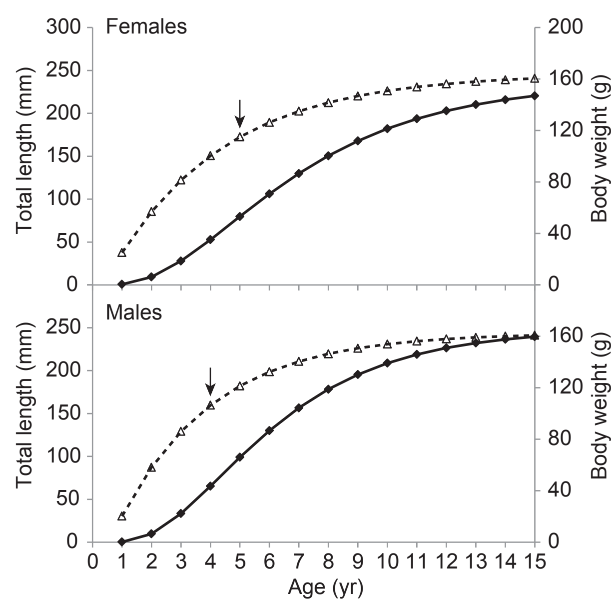

Fig. 2. von Bertalanffy growth function curves fitted to length-at-age and weight-at-age data for female and male *O. bidens* in the Qingyi River, China. Dashed and solid lines indicate the length and weight, respectively. Arrows show the maximum ages observed.

bidens occurred from Apr. to July.

In total, 48 females were used for the fecundity estimation. AF ranged 1145-11,651 eggs, with a mean of 4299 eggs. AF increased with the L and W, as specified by the functions AF = $0.018L^{2.54}$ (R^2 = 0.62, n = 48) and AF = 183.92W + 541.62 (R^2 = 0.55, n = 48), respectively. In addition, AF significantly varied among age groups (one-way ANOVA, F = 23.47, p < 0.05) and increased with increasing age. RF ranged 109-457 eggs/g with a mean of 260 eggs/g and showed no significant difference among age groups (one-way ANOVA, F = 1.21, p > 0.05).

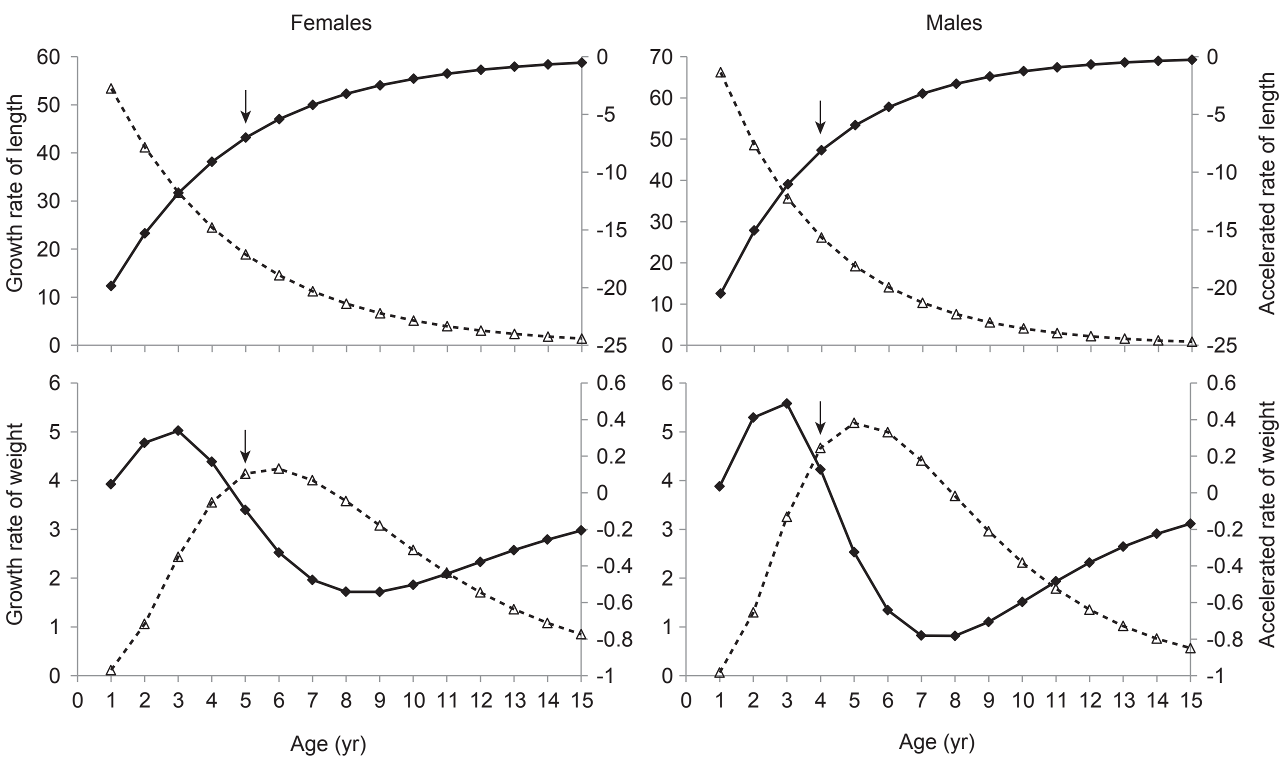

Fig. 3. Curves of the growth rate and its acceleration in the von Bertalanffy growth function of length and weight for *O. bidens* in the Qingyi River, China. Dashed and solid lines respectively indicate the growth rate and its acceleration. Arrows show the maximum ages observed.

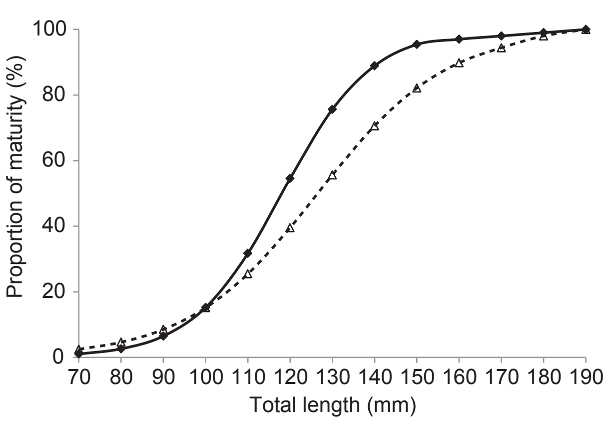

Fig. 4. Percentage contributions of mature female and male *O. bidens* in sequential 10-mm total-length intervals. Solid and dashed lines respectively indicate females and males.

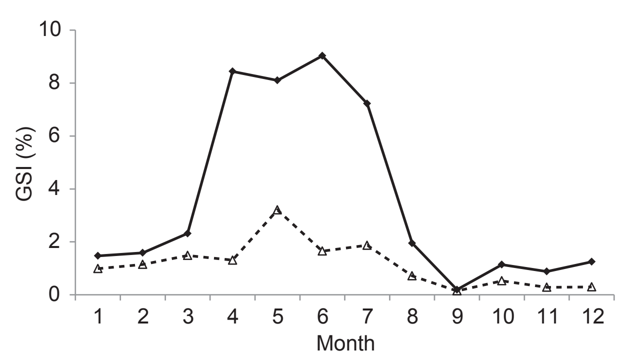

Fig. 5. Monthly changes in the gonadosomatic index (GSI) of female and male *O. bidens* in Qingyi Stream, China. Solid and dashed lines respectively indicate females and males.

DISCUSSION

Annulus formation in fishes is determined by either periodic environmental variations (e.g., seasonal changes in water temperature and food supply) or periodic biological events (e.g., reproduction and migration) (Lowe-McConnell 1987, Yan and Chen 2007, Yan et al. 2010). For riverine fishes, factors influencing annulus formation include low water temperatures, drawdown after floods, and reproductive activity (Welcomme 1979), because these events may induce decreases in the somatic metabolic rates of fishes (Booth and Merron 1996). Our results, based on monthly changes in the MIR, showed that annuli on scales of *Opsariichthys bidens* in Qingyi Stream formed during Feb. and Mar. This result is approximately consistent with the timing of annulus formation by 2 other cyprinid fish in the same river, *Acrossocheilus fasciatus* (Mar.-Apr., Yan et al. 2010) and *Zacco platypus* (in Mar., Yan et al. 2011a). Yan et al. (2010 2011a) related the timing of annulus formation for the 2 fishes to the seasonal pattern of local water temperatures in the Qingyi River. Those authors claimed that locally low water temperatures during the winter (approximately 4°C) could constrain fish somatic growth, whereas relatively high temperatures during late spring (approximately 20°C) could release this constraint. The resulting shift in fish somatic growth induced the formation of annuli during late spring.

Sexual size dimorphism, the body size of males relative to females, reflects the relative influence of natural and sexual selection on both sexes (Shine 1989). Females of many fish species are larger than males. Such a difference induces females to increase their reproductive investment and offspring output (Hedrick and Temeles 1989). Alternatively, if natural selection for female fecundity is weaker than sexual selection, males should be larger than females in mating systems with male-male contests and female choice for larger male size (Pyron 1996). In our study, *O. bidens* did not show significant sexual differences in the length-weight equations, length-scale radius equations, or back-calculated lengths at each age. However, according to Su et al. (1993), some partial external organs of this species show distinct sexual dimorphism. These traits include the shape of fin membranes of the dorsal and anal fins, relative lengths of the 1st-4th branched fin rays of the anal fins, and nuptial tubers on the snout, anal fins, and caudal peduncles. Thus, this species is believed to exhibit sexual dimorphism in some of their external organs but not in body size (especially in characters we measured in this study).

In the sample from the Qingyi River, the oldest female and male *O. bidens* were 5 and 4 yr, respectively. The dominant age groups were 2 and 3 yr for both sexes (approximately 90% of the total abundance). This age structure is almost consistent with those of a population of this species in the Sandaohe Reservoir, Hubei Province (Midwest China) (Su et al. 1993) and of one in the Beijiang River, Guangdong Province (South China) (Li et al. 2010). Growth curves represented by the VBGF for body weight showed an obvious inflection point in somatic-weight growth for both sexes. At that point, females and males were respectively 4.7 and 4.3 yr old. This result suggests that for *O. bidens* in the Qingyi River, the age at the inflection point of somatic-weight growth is similar to the maximum age identified directly by scales. The finding that most individuals (approximately 90% of all fish) are at most 3 yr old suggests that *O. bidens* has a young age structure in the Qingyi River, where fish face many threats from human activities, including dam construction, habitat destruction, water pollution, and overfishing (Yan et al. 2009 2010 2011b).

Our results based on temporal patterns of the GSI showed that *O. bidens* spawned from Apr. to July in the Qingyi River. This result is consistent with observations by Yan et al. (2011a) for another species of the Danioninae, *Z. platypus*, in an identical reach of the Qingyi River. In a study of temporal patterns of the GSI and the egg development process, Yan et al. (2009) showed that *A. fasciatus* spawned from May to Aug. in a headwater tributary (Puxi Stream) of this study river. Despite a limited variation in breeding timing among the 3 species, their approximately similar temporal pattern of the GSI can be explained by the rhythm of the local hydrology in the Qingyi River. In the local subtropical monsoon climate typical of this watershed, most of the annual precipitation occurs from Apr. to Sept. (Yan et al. 2011b). This season of local flooding clearly coincides with the spawning periods of these 3 cyprinids in the Qingyi River. According to Welcomme (1979), the breeding seasons of most fishes in flooding rivers coincide with the local annual flood. Alkins-Koo (2000) explained this flood-related adaptive spawning of fish by observing that flooding can extend the breeding habitat, increase food availability, and avoid crowding and predation pressure. In addition, limited evidence shows that *O. bidens* spawns from May to Aug. in 2 reservoirs, the Tiejia Reservoir in Liaoning Province (Northeast China; Jin and Jin 1985) and the Sandaohe Reservoir in Hubei Province (Midwest China; Su et al. 1993). These findings do not agree with the results of our study. Owing to the lack of comparable information for different populations of this species, such as matched data on populations inhabiting reservoirs and rivers within the same climate area or populations located in an identical type of water body across different climate areas, it is difficult for us to identify whether local factors (e.g., habitat) or regional factors (e.g., climate and hydrology) play a key role in producing the difference between the results of this study and those of Jin and Jin (1985) and Su et al. (1993) regarding the timing of breeding in this species.

Sexual maturity, an important life-history event of fishes, reflects the combined effects of genetic and environmental factors (Stearns 1992). Trade-offs among different life-history variables also affect the age and size at sexual maturity. For example, early maturity could result in shorter longevity, slower somatic growth, and lower absolute fecundity (Heino et al. 2002). Female fish sometimes tend to delay maturity to increase reproductive investment in the future (Roff 1992) and can also exhibit early maturation if somatic growth is restrained by adverse environmental conditions (Stearns and Crandall 1984). In our study, both female and male *Opsariichthys bidens* in the Qingyi River attained maturity at 2 yr and total lengths of 118.1 and 126.5 mm, respectively. Li et al. (2010) reported the same age at maturity for the population of this species in the Beijiang River. In addition, Yan et al. (2009 2011a) showed that both *Zacco platypus* and *Acrossocheilus fasciatus* in the Qingyi River reach sexual maturity at 2 yr. In view of the finding that the 3 documented cyprinids in the Qingyi River (i.e., *O. bidens*, *Z. platypus*, and *A. fasciatus*; the presence of additional cyprinid species is not excluded) all mature at 2 yr, it is perhaps reasonable for us to correlate this life-history strategy these of fishes with their surrounding environments. We hypothesize that their early maturity is an adaptive response to variable and unpredictable environmental factors in the Qingyi River (Yan et al. 2009 2010) as early maturity is considered a reproductive strategy for fishes living in unstable environments (Oliva-Paterna et al. 2002).

Acknowledgments: This study was financially supported by the National Basic Research Program of China (2009CB119200), the Knowledge Innovation Program of the Chinese Academy of Sciences (KSCXZ-YW-Z1023), and the Natural Science Foundation of China (31172120). We are grateful to 2 anonymous referees for their insightful comments on an earlier draft of this manuscript.

REFERENCES

Alkins-Koo M. 2000. Reproductive timing of fishes in a tropical intermittent stream. Environ. Biol. Fish. **57:** 49-66.

Booth AJ, GS Merron. 1996. The age and growth of the greenhead tilapia *Oreochromis macrochir* (Pisces: Cichlidae) from the Okavango Delta, Botswana. Hydrobiologia **321:** 29-34.

Chen Y, DA Jackson, HH Harvey. 1992. A comparison of von Bertalanffy and polynomial functions in modeling fish growth data. Can. J. Fish. Aquat. Sci. **49:** 1228-1235.

Chen YY. 1998. Fauna Sinica, Osteichthyes, Cypriniformes (Middle volume). Beijing: Science Press. (in Chinese)

Chen YY. 2005. Giving promotions to integrated management of river basins and protecting the life river of the Yangtze. China Water Resources **8:** 10-12. (in Chinese)

Duncan KW. 1980. On the back-calculation of fish lengths: modifications and extensions to the Fraser-Lee equation. J. Fish Biol. **16:** 725-730.

Francis R. 1990. Back-calculation of fish length: a critical review. J. Fish Biol. **36:** 883-902.

Hedrick AV, EJ Temeles. 1989. The evolution of sexual dimorphism in animals: hypotheses and tests. Trends Ecol. Evol. **4:** 166-138.

Heino M, U Sieckmann, OR Godo. 2002. Measuring probabilistic reaction norms for age and size at maturation. Evolution **56:** 669-678.

Jia YT, YF Chen. 2011. Age structure and growth characteristics of the endemic fish *Oxygymnocypris stewartii* (Cypriniformes: Cyprinidae: Schizothoracinae) in the Yarlung Tsangpo River, Tibet. Zool. Stud. **50:** 69-75.

Jiang ZQ, XQ Wang, J Liu, SW Yang, DS Zhao. 1995. The food habit of *Opsariichthys bidens* in Biliuhe Reservoir and fishery countermeasure. Fish. Sci. **14:** 35-38. (in Chinese with English summary)

Jin B, KW Jin. 1985. Primary investigation on the biological traits of *Opsariichthys bidens* in Tiejia Reservoir. Fish. Sci. **4:** 8-12. (in Chinese)

Johansson F, P Rådman, J Andersson. 2006. The relationship between ontogeny, morphology, and diet in the Chinese hook snout carp (*Opsariichthys bidens*). Ichthyol. Res. **53:** 63-69.

Li GY, XZ Wang, YH Zhao, J Zhang, CG Zhang, SP He. 2009. Speciation and phylogeography of *Opsariichthys bidens* (Pisces: Cypriniformes: Cyprinidae) in China: analysis of the cytochrome b gene of mtDNA from diverse populations. Zool. Stud. **48:** 569-583.

Li Q, ZJ Lan, J Zhao, LX Chen, LM Zhong, ZS Yi et al. 2010. Study on individual fecundity of *Opsariichthys bidens* of the Beijiang River in Guangdong Province. Sichuan J. Zool. **29:** 440-445. (in Chinese with English summary)

Lowe-McConnell RH. 1987. Ecological studies in tropical fish communities. Cambridge, UK: Cambridge Univ. Press.

Oliva-Paterna FJ, MM Torralva, C Fernandez-Delgado. 2002. Age, growth and reproduction of *Cobitis paludica* in a seasonal stream. J. Fish Biol. **60:** 389-404.

Pyron M. 1996. Sexual size dimorphism and phylogeny in North American minnows. Biol. J. Linn. Soc. **57:** 327-341.

Roff DA. 1992. The evolution of life histories: theory and analysis. London: Chapman and Hall.

Shine R. 1989. Ecological causes for the evolution of sexual dimorphism: a review of the evidence. Q. Rev. Biol. **64:** 419-461.

Stearns SC. 1992. The evolution of life histories. Oxford, UK: Oxford Univ. Press.

Stearns SC, RE Crandall. 1984. Plasticity for age and size at sexual maturity: a life-history response to unavoidable stress. *In* GW Potts, RJ Wootton eds. Fish reproduction: strategies and tactics. London: Academic Press, pp. 13-33.

Su JX, FX Qiu, WX Zhou, CX Xie, WM Wang, CF Chen. 1993. Age, growth, reproduction and diet of *Opsariichthys bidens* in Sandaohe Reservoir. Reserv. Fish. **23:** 15-18. (in Chinese)

Welcomme RL. 1979. Fisheries ecology of floodplain rivers. London: Longman.

Yan YZ, YF Chen. 2007. Changes in the life history of *Abbottina rivularis* in Lake Fuxian. J. Fish Biol. **70:** 959-964.

Yan YZ, LL Guo, XY Xiang, J Tao, YF Chen. 2010. Age and growth of *Acrossocheilus fasciatus* (Barbinae, Cyprinidae) from the Puxi Stream in the Huangshan Mountain, China. J. Freshw. Ecol. **25:** 79-83.

Yan YZ, LL Guo, XY Xiang, YL Xi, YF Chen. 2009. Breeding strategy of *Acrossocheilus fasciatus* in the Puxi Stream of the Huangshan Mountain. Curr. Zool. **55:** 350-356.

Yan YZ, XY Xiang, L Chu, YJ Zhan, CZ Fu. 2011b. Influences of local habitat and stream spatial position on fish assemblages in a dammed watershed, the Qingyi Stream, China. Ecol. Freshw. Fish. **20:** 199-208.

Yan YZ, LL Yan, L Chu, YY Liang, YF Chen, XM Zhang. 2011a. Age, growth and reproduction of *Zacco platypus* in the Huishui Stream. Acta Hydrobiol. Sin. **36:** 1-8. (in Chinese with English summary)

Yin MC. 1993. Ecology of fishes. Beijing: Chinese Agriculture Press. (in Chinese)

Zhong ZX. 1985. Primary investigation on the effect of *Opsariichthys bidens* on reservoir fishery. Inland Fish. **5:** 20. (in Chinese)

Zhu Q, LQ Xia, JB Chang. 2002. Computer identification on otolith microstructure of fish. Acta Hydrobiol. Sin. **26:** 600-604. (in Chinese with English summary)