

Sexual Dimorphism of the Jilin Clawed Salamander, *Onychodactylus zhangyapingi*, (Urodela: Hynobiidae: Onychodactylinae) from Jilin Province, China

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Abstract Sexual dimorphism in size and shape is common in many organisms, and is a key evolutionary feature. In this study, we analyzed morphometric data of the Jilin clawed salamander *Onychodactylus zhangyapingi*, an endemic Chinese salamander, to examine sexual size and shape dimorphism. The morphometric data included 14 characteristics of 13 females and 11 males and was analyzed using univariate and multivariate methods. Our results showed that sexual dimorphism occurs not only in body size, but also in body shape. Males have a longer snout-vent length than females, a rarely reported pattern of male-biased sexual size dimorphism. Females have a larger space between the axilla and groin than males, while males have longer and larger tails compared to females. The sexual dimorphism in body size and shape can be explained by existing theories, but there is little data for the mating system, behavior, reproduction, or ecology of *O. zhangyapingi*, so further studies are required.

Keywords sexual size dimorphism, clawed salamander, morphometric, Hynobiidae

1. Introduction

The salamanders of the genus *Onychodactylus* are endemic to northeast Asia (Yoshikawa *et al.*, 2008; Poyarkov *et al.*, 2012) and because both the larvae and adults have horny claws, they are called clawed salamanders. For a long time, only two species were recognized in this genus. One is *O. japonicus* (Houttuyn, 1972), widely distributed in Honshu and the Shikoku islands of Japan, and the second is *O. fischeri* (Boulenger, 1886), distributed in the Russian Far East, northeast China and the Korean Peninsula (Kuzmin, 1995; Fei, 2006). Recently, Poyarkov *et al.* (2012) reviewed the systematics, morphology, and distribution of the clawed

salamanders and determined that the two populations of Chinese *Onychodactylus*, which were both regarded as *O. fischeri*, were better described as two new and distinct species: the Liaoning population was named as *O. zhaormii* and the Jilin population as *O. zhangyapingi*.

Sexual dimorphism is a widespread phenomenon throughout the animal kingdom and involves a phenotypic difference between the males and females within a species (Andersson, 1994; Fairbairn, 1997; Kupfer, 2007). The sexual dimorphic characters of the clawed salamander include tail length, shape of tail tip, head width, claw and fleshy skin flaps on hind limbs, black asperities on forelegs and foreleg length (Stejneger, 1907; Dunn, 1923; Sato, 1943; Kuzmin, 1995, 1999; Poyarkov *et al.*, 2012). Sexual differences vary among different species (Poyarkov *et al.*, 2012). Poyarkov *et al.* (2012) reported that secondary sexual characters in *O. zhangyapingi* include fleshy skin folds, tail shape and vent shape;

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morphometric traits show little sexual variation, these traits include a longer tail length, longer and narrower head, shorter snouts, wider chests and shorter interorbital length in males. However, sexual dimorphism can also vary between or among populations (e.g., Kalezic *et al.*, 1992; Serra-Cobo *et al.*, 2000; Stillwell *et al.*, 2007; Stillwell and Fox, 2009; Angelini *et al.*, 2015), because the groups are living under different ecological conditions (e.g., variation in climate, prey resources and vegetation). Poyarkov *et al.* (2012) reported the sexual dimorphism of morphometric characters in *O. zhangyapingi* based on pooled specimens from three localities (for a total of 16 specimens). Here, we explored the sexual dimorphism of morphometric characters in *O. zhangyapingi* based on the Tonghua population. The purpose of this study was to 1) assess sexual dimorphism in *O. zhangyapingi* and to interpret the results in the light of the existing theories; 2) to test if the observations of Poyarkov *et al.* (2012) are consistent with specimens from our study population; and 3) to expand our knowledge of *O. zhangyapingi*.

2. Materials and Methods

A total of 24 adult specimens (13 females, 11 males) of *O. zhangyapingi* were used in this study, which were collected in Laolin, Tonghua County, Jilin Province, China. After capture and arrival at the laboratory, animals were euthanized via submergence in a buffered MS-222 solution and then stored in 10% formalin. The sex was determined directly by body dissection. The specimens were deposited at the Henan University of Science and Technology Museum (HNUSTM). To quantify intersexual differences in morphology, 14 variables (Table 1) were measured with dial calipers to the nearest 0.1 mm from

the right side of each individual.

Because snout-vent length (SVL) is highly collinear with other variables (e.g., Romano *et al.* 2009), it was analyzed with one-way ANOVA but excluded from the subsequent analyses. All original data for the other 13 variables were log10-transformed and tested for normality (Kolmogorov-Smirnov test) and homogeneity of variances (Levene's test). Since the variances were homogeneous, a principal component analysis (PCA) was performed to investigate sexual shape dimorphism using the correlation matrix for a pooled data set. The first principal component (PC), calculated from a set of morphometric measurements, is generally interpreted as an axis of body size variation, when all traits load largely and in the same direction (Reyment *et al.*, 1984; Bookstein, 1985), and the remaining variance describing relative shape differences is expressed in subsequent PCs (Schäuble, 2004). Next, a univariate analyses of covariance (ANCOVA) was conducted, with sex as a factor and PC1 score as a covariate (Guillaumet *et al.*, 2005; Romano *et al.*, 2009) for each morphological variable independently. This analysis allowed us to determine which variables differed between males and females. We additionally applied the analysis of covariance to assess sexual shape dimorphism with an adjustment to SVL. Differences in body shape identified using the above method may not reveal a cryptic dimorphism or could indicate that results are significant, which are not significant after adjustment to SVL.

Data analysis was carried out with SPSS software, version 17.0 (SPSS Inc., Chicago). SSD was calculated using the size dimorphism index (SDI) of Lovich and Gibbons (1992), in which $SSD = (\text{size of the larger sex} / \text{size of the smaller sex}) - 1$, a positive value when males

Table 1 Definitions of the morphological character sets and abbreviations.

Character	Definition
SVL	Snout-vent length: from the tip of snout to the posterior margin of the cloaca
HL	Head length: from the tip of the snout to the gular fold
HH	Head height: height of the head at its highest point
HW	Head width: width of the head at its widest point
SL	Snout length: from the anterior border of eye to the tip of the snout
TL	Tail length: from the posterior margin of the cloaca to the tip of the tail
TH	Tail height: the height of the tail at its highest point
TW	Tail width: the width of the tail at its widest point
IN	Internarial distance: the minimum distance between the external nares
IC	Intercanthal distance: the minimum distance between anterior corners of the eyes
FLL	Forelimb length: from the base of the forelimb to the tip of the longest finger
HLL	Hindlimb length: from the base of the hindlimb to the tip of the longest toe
AGS	Space between axilla and groin: the space between the posterior base of the forelimb and the anterior base of the hindlimb on the same side
CW	Chest width: the minimum distance between left and right axillae

are the larger sex and a negative value when females are the larger sex. Using this index, $SSD = 0$ when the sexes are equal in size, and $SSD > 0$ or $SSD < 0$ indicates that males or females are larger, respectively. Values are presented as mean \pm standard deviation, and the significance level is set at $\alpha = 0.05$.

3. Results

The mean values and ranges for the morphological measurements for *O. zhangyapingi* are presented in Table 2. The mean SVL of males (71.10 ± 3.57) was larger

than of females (65.23 ± 1.96) and the one-way ANOVA clearly showed significant differences in SVL ($F_{1, 23} = 6.196, P < 0.05$), $SDI = 0.09$.

Three principal components were extracted (Table 3). The first principal component (PC1) explained the largest proportion of overall variation (49.985%). All original variables loaded heavily and in the same direction (positively) onto this component. Therefore, the individual scores on PC1 were used to estimate the differences in overall body size. Other PCs (including second and third principal components) explained 50.015% of the differences, and factor scores for these

Table 2 Descriptive statistics of original morphometric characters (mm) in females and males of *O. zhangyapingi*.

Variables	<i>O. zhangyapingi</i>			
	Female (n = 13)		Male (n = 11)	
	mean \pm SE	range	mean \pm SE	range
Snout - vent length (SVL)	65.23 \pm 1.96	50.16–77.26	71.10 \pm 3.57	66.27–77.26
Head length (HL)	14.52 \pm 0.34	12.50–17.10	15.38 \pm 0.86	14.50–17.10
Head width (HW)	10.33 \pm 0.13	9.55–11.21	10.43 \pm 0.72	9.26–11.62
Head height (HH)	5.92 \pm 0.20	4.82–7.45	6.04 \pm 0.69	5.09–7.18
Snout length (SL)	3.77 \pm 0.14	3.15–4.99	3.74 \pm 0.36	3.13–4.22
Tail length (TL)	65.14 \pm 2.53	45.29–77.69	79.50 \pm 5.71	72.55–91.39
Tail height (TH)	5.16 \pm 0.20	3.98–6.47	5.83 \pm 0.52	4.98–6.58
Tail width (TW)	5.11 \pm 0.17	4.21–6.32	6.60 \pm 0.94	5.60–8.80
Internarial distance (IN)	4.82 \pm 0.15	4.06–6.02	5.25 \pm 0.47	4.53–5.80
Intercanthal distance (IC)	5.84 \pm 0.11	5.39–6.57	6.12 \pm 0.39	5.52–6.71
Forelimb length (FLL)	17.51 \pm 0.37	14.89–19.18	18.25 \pm 0.68	17.26–19.09
Hindlimb length (HLL)	20.67 \pm 0.47	17.95–23.54	22.37 \pm 1.05	20.16–23.81
Space between axilla and groin (AGS)	33.76 \pm 1.34	24.79–41.69	35.62 \pm 2.98	32.17–42.15
Chest width (CW)	7.30 \pm 0.21	5.71–8.44	7.89 \pm 0.53	7.35–9.21

Table 3 Factor loadings for the principal components (PC; eigenvectors), eigenvalues and proportion of total variance described by the first three components obtained from PCA on a correlation matrix. Results of ANCOVA with PC1 scores as covariate tests for differences in morphological variables. All variables are log-transformed.

Variables	<i>O. zhangyapingii</i>				
	PC1	PC2	PC3	F	P-value
Head length (HL)	0.849	-0.349	-0.104	0.38	0.544
Head height (HH)	0.259	0.507	0.614	0.086	0.772
Head width (HW)	0.71	0.01	0.445	7.879	0.011
Snout length (SL)	0.463	-0.694	0.332	2.942	0.101
Tail length (TL)	0.861	-0.046	-0.202	6.129	0.022
Tail height (TH)	0.589	0.537	-0.388	1.564	0.225
Tail width (TW)	0.78	0.179	-0.232	10.403	0.004
Internarial distance (IN)	0.717	-0.287	0.308	0.034	0.855
Intercanthal distance (IC)	0.729	0.195	0.279	0.103	0.751
Forelimb length (FLL)	0.742	-0.193	-0.388	0.261	0.615
Hindlimb length (HLL)	0.798	-0.006	-0.193	0.561	0.462
Space between axilla and groin (AGS)	0.87	-0.03	-0.019	8.186	0.009
Chest width (CW)	0.552	0.545	0.141	0.756	0.394
Eigenvalue	6.498	1.639	1.322		
Proportion	49.99%	12.60%	10.17%		

components were retained as the variable body shape. PC1 differed significantly between females and males (ANOVA, $F_{1,23} = 8.981$, $P < 0.05$), but PC2 and PC3 did not differ between sexes (ANOVA, $F_{1,23} = 1.317$, $P > 0.05$; $F_{1,23} = 2.274$, $P > 0.05$, respectively).

Differences in shape between the sexes were also identified by the ANCOVA. The interaction terms of sex and PC1 were non-significant ($P > 0.05$) and could thus be removed from the model for all variables. Four morphological variables (Table 3) were revealed as showing significant differences in body shape: head width (HW), tail length (TL), tail width (TW), and space between the axilla and groin (AGS). Females have larger values for HW and AGS, and males have larger values for TL and TW. The results of ANCOVA, with sex as a factor and SVL as a covariate, found sexual shape dimorphism for TL, TW and AGS.

4. Discussion

Our study demonstrates that sexual dimorphism of *O. zhangyapingi* occurs not only in body size (males are larger than females, as shown in Table 2), but also occurs in body shape (females had longer HW and AGS, while males had longer TL and TW, as shown in Table 3). In contrast to the report of Poyarkov *et al.* (2012) that found sexual dimorphism in tail length, head length and width, snout length, chest and interorbital length, we only observed sexual dimorphism for head width and tail length.

Sexual size dimorphism (SSD), a difference in the average body size between the sexes (Bakkegard and Rhea, 2012), is the most conspicuous sexual character. Three patterns of SSD are present in salamanders (Shine, 1979; Bruce, 1993, 2000). The most widespread pattern is females being larger than males (female-biased SSD). Shine (1979) reported that females are generally larger than males in about 61% of the 79 urodele species. The second pattern is males that are larger than females (male-biased SSD), which has been seldom reported (e.g., Bovero *et al.*, 2003; Bakkegard and Guyer, 2004; Zhang *et al.*, 2014). The third pattern is females equal to males (unbiased SSD). About 20% of salamander species express no dimorphism in body size (Shine, 1979; Fairbairn *et al.*, 2007). For *O. zhangyapingi*, we observed a rarely reported male-biased SSD pattern (males larger than females). SSD is determined by the balance between sexual selection, fecundity selection and natural selection (Fairbairn *et al.*, 2007; Colleoni *et al.*, 2014). Male-biased SSD is often attributed to sexual selection (Monroe

et al., 2015). Sexual selection can increase male-male competition (aggressive behavior and male fighting) and increase mating success (Bruce, 1993; Bakkegard and Guyer, 2004). In urodeles, 86.7% of species engage in male combat (Shine, 1979). Bigger males are also favored because of the female choice of larger males (Halliday and Verrell, 1986). However, there have been no reports about the mating system of *O. zhangyapingi*. Thus, further studies are required to clarify if male combat occurs in *O. zhangyapingi*, and if male-male competition can explain SSD in this salamander.

The sexual dimorphism of the head, including head length, head height and head width, has been observed in some salamanders. Usually, males have larger heads than females (Bovero *et al.*, 2003; Bakkegard & Guyer, 2004; Fontenot & Seigel, 2008; Marvin, 2009; Hasumi, 2010), but there are a few reports of females have larger heads than males in a few cases (Romano *et al.*, 2009; Seglie *et al.*, 2010; Labus *et al.*, 2013; Rastegar-Pouyani *et al.*, 2013). Reproductive roles and ecological selection are associated with sexual dimorphism of the head width. Reproductive roles favors individual intake to maximize energy for reproductive investment (Selander, 1972; Shine, 1979, 1989; Malmgren & Thollensen, 1999; Romano *et al.*, 2012). Ecological selection favors differences in diet (differences in prey size) between the sexes (Godley, 1983; Cooper & Vitt, 1989; Fauth & Resetarits, 1999; Bovero *et al.*, 2003; Fontenot & Seigel, 2008; Seglie *et al.*, 2010), because a wider head can help capture larger prey (Bakkegard and Rhea, 2012). In this study, two different methods have generated different results of sexual dimorphism of the head. According to the data of measurements, we think that the sexual dimorphism of the head is not present in *O. zhangyapingi*, and the result from the method of principal component analysis (PCA) may result from different body size.

The tail of *O. zhangyapingi* shows sexual dimorphism (the length and width of males are longer and larger than in females). Salamander tails are used for energy storage, defense, respiration and reproduction (Bernardo and Agosta 2005; Bakkegard and Rhea, 2012). Bovero *et al.* (2003) reported that the male of *Euproctus asper* captures a female by encircling her tail, and then directly forces the spermathophora into the female's cloaca. Malmgren and Tholleson (1999) found that long tails may improve the performance of males in courtship display. However, the tail is not used in the breeding behavior of *O. fischeri* (Kuzmin, 1995). Thus, energy storage may contribute to the sexual dimorphism of tail length. Females invested more energy into egg production resulting in a shorter

tail, and males invested less in sperm production resulting in the longer tail. Reproduction can explain the sexual dimorphism of tail width (in this study, the tail width is equal to the width of cloaca, because the widest part of the tail is where the cloaca is located). Cloacal shape is a sexually selected trait that increases male reproductive success (Sever, 2003). In urodeles, males often have a larger or noticeably swollen cloaca (e.g., Verrell, 1989; Halliday, 1990; Greven *et al.*, 2004; Kupfer, 2007). Most of the cloacal volume is occupied by glands secreting substances that can often form the spermatophore (Sever *et al.*, 1990), and these cloacal glands become hypertrophied during the breeding season (Sever, 2003).

The trunk length (space between axilla and groin) was greater for females than for males of *O. zhangyapingi*. Fecundity selection has been proposed to explain the sexual dimorphism of trunk length (Hedrick & Temeles, 1989; Griffith, 1990; Jockusch, 1997; Romano *et al.*, 2009). The length of trunk is directly correlated to the volume of the abdominal cavity (Kalezic *et al.*, 1992), and a greater abdominal volume can provide larger internal space for eggs allowing increased reproductive capacity (Shine, 1979; Marvin, 2009).

The population of this salamander is very small, which is consistent with our field survey results. The distribution of *O. zhangyapingi* is restricted to the Linjiang and Tonghua counties of Jilin Province, and the population is threatened by habitat destruction due to logging and other anthropogenic activities near its distribution. Poyarkov *et al.* (2012) suggested that its IUCN red list conservation status is Vulnerable (Vu2a). In this study, the specimen number was small (24 individuals) compared to other similar studies, but we think the specimens from this population fully elaborate the sexual dimorphism in this endangered species.

In conclusion, both sexual size and shape dimorphism are present in *O. zhangyapingi*. These dimorphisms can be explained by existing theories, but a lot of hypotheses remain to be tested. For example, SSD can be attributed to sexual selection, so the mating system of this species should be investigated to explore if there is male-male competition. The shape dimorphism could be the result of reproductive and ecological differences, thus future studies should focus on understanding these differences to explain the observed shape dimorphism.

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