

## Sexual dimorphism and female reproduction in the multi-ocellated racerunner *Eremias multiocellata* (Lacertidae)\*

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**Abstract** Reproductive success and morphological traits are intimately linked in lizards. We collected adult multi-ocellated racerunners *Eremias multiocellata* from a population in Inner Mongolia (northern China) to quantify sexual dimorphism and female reproductive characteristics of this poorly studied viviparous, lacertid lizard, testing for the prediction that the evolution of sexual dimorphism is promoted by between-sex differences in reproductive success relating to adult morphological traits. Adults are sexually dimorphic in head size but not in body size, with males having longer and wider heads than do females of the same body length. Females ovulate from May to June and, under laboratory conditions, they give birth to young from late June to late July. Litter size ranges from two to four young. Litter mass is positively correlated with female SVL, but female SVL only explains a small portion (approximately 19%) of variation in litter mass. Both litter size and neonate mass are not correlated with female SVL. Neonate mass is negatively correlated with relative fecundity (litter size relative to female SVL), suggesting a trade-off between size and number of offspring in *E. multiocellata*. Overall, selective pressures towards large male and large females are both relatively weak in *E. multiocellata*, and the evolution of sexual dimorphism in head size results mainly from between-sex differences in reproductive success relating to adult head size [Acta Zoologica Sinica 52 (2): 250–255, 2006].

**Key words** Reptilia, Lacertid, Multi-ocellated racerunner, *Eremias multiocellata*, Sexual dimorphism, Female reproduction, Size-number trade-off

## 密点麻蜥的两性异形和雌性繁殖\*

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**摘要** 蜥蜴繁殖成功率与其形态特征有密切的关系。作者在内蒙古乌拉特后旗采集密点麻蜥 (*Eremias multiocellata*), 定量研究该种形态特征的两性异形和雌性繁殖特征, 检验与成体形态特征相关的两性繁殖成功率差异是否能促进两性异形的进化。密点麻蜥成体个体大小无显著的两性差异, 但头部大小两性差异显著; 雄性个体的头长和头宽均大于体长相同的雌性成体。繁殖雌体于五、六月份排卵; 在实验室条件下, 雌体在六月下旬至七月下旬之间产仔。该种雌体年产单窝仔, 每窝 2–4 仔。窝仔重与雌体体长呈正相关, 但雌体体长仅能解释很少一部分 (约 19%) 窝仔重的变异。窝仔数和幼仔重均与雌体体长无关。幼仔重与相对生育力 (相对于雌体体长的窝仔数) 呈显著的负相关, 表明该种蜥蜴存在后代数量–大小之间的权衡。密点麻蜥雄体和雌体向较大体型方向进化的选择压力均相对较弱, 与成体头部大小相关的两性繁殖成功率的差异是导致该种蜥蜴头部大小两性异形进化的主要原因 [动物学报 52 (2): 250–255, 2006]。

**关键词** 爬行纲 蜥蜴科 密点麻蜥 两性异形 雌性繁殖 卵数量–大小权衡

The multi-ocellated racerunner *Eremias multiocellata* is a viviparous, lacertid lizard. The lizard

shows a preference for arid or semi-arid districts covered by sparse vegetation, and its distributional range

Received Aug. 28, 2005; accepted Nov. 25, 2005

\* This study was funded by the grants from Nanjing Normal University and the local government of Zhejiang Province for the Key Discipline of Zoology

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covers Xinjiang, Qinghai, Inner Mongolia and western Liaoning in northern China, Mongolia, eastern Kirgizstan as well as southern Tuvin District in Siberian Russia (Zhao and Adler, 1993; Zhao, 1999). The food consists mainly of insects, their larvae and spiders, and lizards are particularly fond of various beetles and these often form a large part of their diet in the wild (Zhao, 1999).

Although there is much anecdotal information on diet, litter size, male reproductive cycle and morphology of the species (Liu and Geng, 1995; Liu and Li, 1995; Liu et al., 2005; Zhao, 1999), there is little quantitative data, especially on topics such as sexual dimorphism and female reproduction. To date, there has been no statistical analysis of sexual dimorphism of *E. multiocellata*, although some empirical data on morphological traits are available (Zhao, 1999). There has been no detailed examination of the reproductive ecology of *E. multiocellata*, although incidental information indicates that this viviparous lizard produces a single litter of 1–4 young per breeding season between June and August, with mating occurring just prior to ovulation in May (Zhao, 1999; Liu et al., 2005).

To obtain more detailed information, we study a population of *E. multiocellata* in Wulatehouqi (41°27'N, 106°59'E), Inner Mongolia, northern China. Based on morphological measurements taken for adult lizards collected from the field and females giving birth to young under the laboratory conditions, we present data on sexual dimorphism and female reproduction for the population, and make comparisons, where possible, with other species of lacertid lizards to test for the prediction that the evolution of sexual dimorphism is promoted by between-sex differences in reproductive success relating to adult morphological traits (Cooper and Vitt, 1989; Hews, 1990; Mouton and Van Wyk, 1993).

## 1 Materials and methods

A total of 83 adult lizards [SVL (snout-vent length) > 51 mm; Liu et al., 2005] were collected by hand or noose in mid-May 2005. All of these were used for the collection of morphological data. Measurements (to the nearest 0.01 mm) taken for each lizard include SVL, tail length (TL), head length (HL, from the snout to the anterior edge of the tympanum), and head width (HW, taken at the posterior end of the mandible). These measurements were taken simply because comparable data on more than ten species of other lizards have been available to us (e.g., Ji et al., 1998, 2002a, 2002b; Ji and Du, 2000; Lin and Ji, 2000; Du and Ji, 2001).

After measurements were taken, twenty-six lizards were released to the site originally collected,

and the remaining 60 lizards were transported to Hangzhou, where females were individually palpated to assess their reproductive conditions and were marked by toe-clipping in a unique combination for future identification. Ten males and 10 females with yolking or recently ovulated follicles were housed individually 100 × 60 × 40 (length × width × height) cm<sup>3</sup> plastic cages, the bottom of which was filled with 20 cm of fine sand and pieces of clay tiles. Mealworms (larvae of *Tenebrio molitor*) and water enriched with vitamins and minerals (Nekton-Rep, Nekton-product) were provided *ad libitum*. These cages were placed in a room where ambient temperatures were never higher than 28°C and the room lights were programmed to create a 12 light:12 dark cycle. A 250-W light bulb, suspended at one end of each cage (20 cm above the cage floor), created a thermal gradient from room temperatures to 55°C for 12 h daily. Lizards were exposed to a natural light cycle and some direct sunlight, and were able to regulate body temperature behaviorally during the photophase.

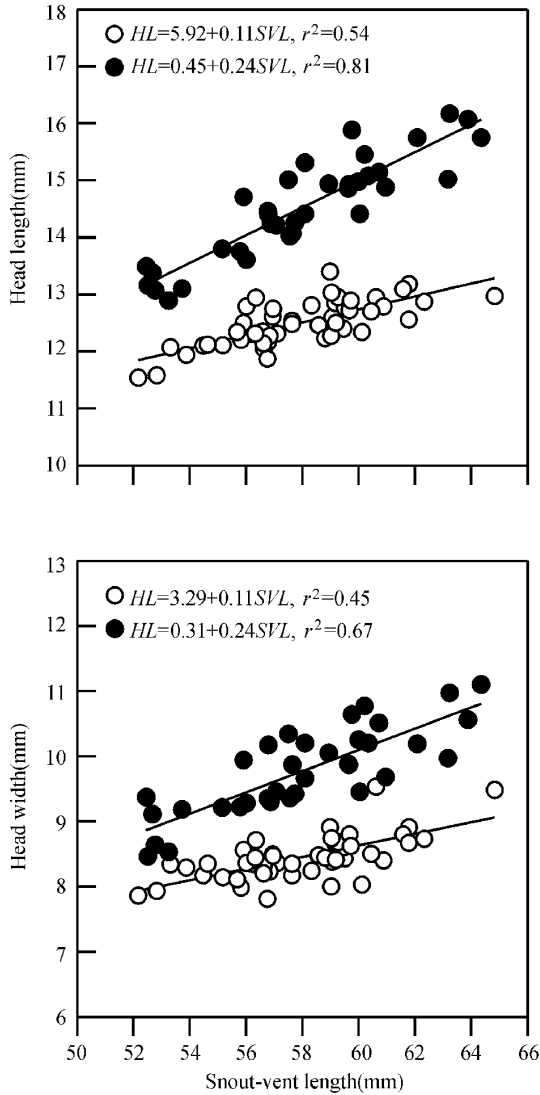
We checked the cages at least twice daily for newborns, and immediately measured and weighed them after birth. Females giving birth during the same period were isolated from each other using 30 × 20 × 20 cm<sup>3</sup> cages so that newborns could be allocated accurately to the mother. Postpartum females were individually measured for SVL and weighed. We calculated relative litter mass (RLM) by dividing litter mass by the postpartum female mass (Shine, 1992), and relative fecundity by using the residuals derived from the regression of litter size on maternal SVL (Olsson and Shine, 1997).

Five females producing abnormal litters with various numbers of fully developed dead young, stillborns, or unfertilized eggs were excluded from statistical analyses. All data were tested for normality (Kolmogorov-Smirnov test) and homogeneity of variances (Bartlett test), and loge-transformation was performed when necessary to satisfy conditions for parametric tests. Throughout this paper, values are presented as mean ± 1 standard error, and the significance level is set at  $\alpha = 0.05$ .

## 2 Results

The largest male and female we recorded were 70.5 and 66.4 mm SVL, respectively, but mean values for adult SVL did not show sexual size dimorphism (unpaired two-tailed *t*-test,  $t = 0.27$ ,  $df = 81$ ,  $P = 0.79$ ). ANCOVA with SVL as the covariate revealed that the rates at which head length ( $F_{1,79} = 26.56$ ,  $P < 0.0001$ ) and head width ( $F_{1,79} = 9.46$ ,  $P < 0.003$ ) increased with increasing SVL were both greater in males than in females (Fig. 1). ANOVA analyses on residuals derived from the regressions of

HL and HW on SVL revealed that the sexes differed in both head length ( $F_{1, 81} = 538.68$ ,  $P < 0.0001$ ) and width ( $F_{1, 81} = 309.73$ ,  $P < 0.0001$ ). Males had longer and wider heads than did females of the same body length (Fig. 1).



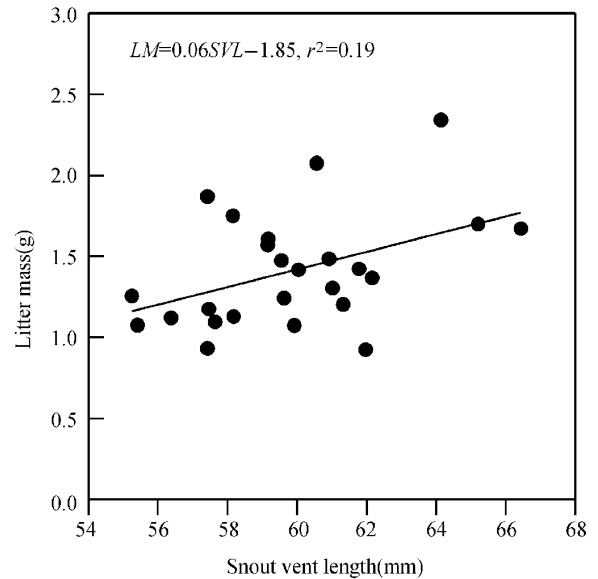
**Fig. 1** Linear regressions of head length and head width on SVL in adult *E. multiocellata*

Solid dots: males. Open dots: females. The regression equations are indicated in the figure. See text for statistical analyses.

Females larger than 55 mm SVL produced a single litter per breeding season. Of the 30 females maintained in the laboratory, fourteen (approximately 47%) had ovulated when they were collected, and the remaining 16 ovulated in the laboratory from mid-May to early June. Females under the laboratory conditions gave birth to young from late June to late July. Litter size determined for 25 litters ranged from two to four young (Table 1). Litter mass was positively correlated with female SVL ( $r = 0.44$ ,  $F_{1, 23} = 5.43$ ,  $P < 0.03$ ; Fig. 2), whereas litter size ( $r = 0.23$ ,  $F_{1, 23}$

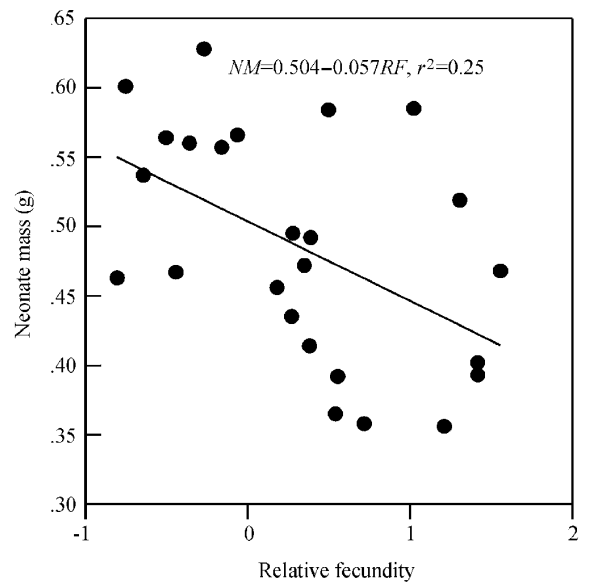
**Table 1** Descriptive statistics of reproductive traits of female *E. multiocellata* ( $n = 25$ )

	Mean	Standard error	Range
Snout-vent length (mm)	59.9	0.6	55.3–66.4
Postpartum body mass (g)	4.5	0.1	3.4–6.1
Litter size	3.0	0.2	2–4
Litter mass (g)	1.4	0.1	0.9–2.3
Neonate mass (g)	0.49	0.02	0.36–0.63
Relative litter mass	0.36	0.02	0.22–0.54



**Fig. 2** Linear regression of litter mass on female SVL in *E. multiocellata*

The regression equation is indicated in the figure. See text for statistical analyses.



**Fig. 3** The trade-off between size and number of offspring in *E. multiocellata*

Each data point represents one litter. The regression equation is indicated in the figure. See text for the definition of relative fecundity and statistical analyses.

$= 1.33$ ,  $P = 0.26$ ) and neonate mass ( $r = 0.21$ ,  $F_{1, 23} = 1.08$ ,  $P = 0.31$ ) were not. Neonate mass was negatively correlated with relative fecundity ( $r = -0.50$ ,  $F_{1, 23} = 7.63$ ,  $P < 0.02$ ; Fig. 3).

### 3 Discussion

Adults of *E. multiocellata* are sexually dimorphic in head size but not in body size (SVL). Head size is larger in males than in females of the same body size in *E. multiocellata*, which is consistent with the results reported for numerous other species of lacertid lizards worldwide (e. g., Braña, 1996; Huang, 1998; Ji et al., 1998; Zhang and Ji, 2000; Xu and Ji, 2003). Within lacertid lizards, however, the ways through which sexual dimorphism in head size arises seem to vary among species. For example, female *Takydromus septentrionalis* (northern grass lizard) increasingly sacrifice head growth for rapid growth in SVL to realize the greater potential reproductive output from a larger body size, whereas males exhibit an increasingly rapid growth of the head (Zhang and Ji, 2000). On the contrary, sexual dimorphism in head size arises mainly because of the increasingly rapid growth of the head in males in *Eremias brenchleyi* (upland racerunner; Xu and Ji, 2003). The detailed way through which sexual dimorphism in head size arises in *E. multiocellata* is currently unknown, because of the lack of morphological data on juveniles. However, as in other species of lacertid lizards (Braña, 1996; Huang, 1998; Zhang and Ji, 2000; Xu and Ji, 2003), adult males do exhibit an increasingly rapid growth of head size in *E. multiocellata*.

Fighting amongst males for the possession of females never takes place in *E. multiocellata*. A male wishing to mate seizes a reproducing female in his jaws by some part of her body and then maneuvers until he has got hold of her by the flank, usually near the groin. Clearly, the head size is important for male *E. multiocellata* to increase their reproductive success by subjugating females but not males.

Within the two species of *Eremias* lizards we have studied, female *E. brenchleyi* (mean RCM = 0.38; Ji et al., unpubl. data) produce heavier clutches than do female *E. multiocellata* (RLM = 0.36; Table 1) of the same body size (both length and mass). Interestingly, adult females of the former species have shorter and narrower heads than do adult females of the latter species when variation in SVL is removed using ANCOVA ( $P < 0.01$  for both HL and HW). What can be inferred from this comparison is that females with smaller heads have an increased potential to produce larger clutches or litters. Thus, our data provide a support for the prediction that reproductive output and morphological traits are intimately

associated in female lizards (Vitt and Congdon, 1978; Cooper and Vitt, 1989; Shine, 1992; Braña, 1996).

Body size of *E. multiocellata* shows no significant SVL dimorphism, which is consistent with the results reported for other lacertid lizards such as *T. septentrionalis* (Ji et al., 1998; Zhang and Ji, 2000), *T. hsuehshanensis* (Hsuehshan grass lizard; Huang, 1998) and *E. brenchleyi* (Xu and Ji, 2003) without field observations of male-male combat behavior. Sexual size dimorphism (SSD) is assumed to evolve in lizards mainly because of between-sex differences in reproductive success relating to adult body size (Cooper and Vitt, 1989; Hews, 1990; Mouton and Van Wyk, 1993). Theoretically, fecundity selection favors large females and sexual selection favors large males. The two selective pressures could cancel each other out and, consequently, result in a lack of SSD between males and females. In *E. multiocellata*, however, selective pressure towards increased male size is relatively low, because the species lacks significant male-male combat behavior. Moreover, *E. multiocellata* is unlike numerous other lacertid lizards in that litter size (fecundity) is not correlated with female SVL (Liu et al., 2005) and that female size (SVL) explains only a very small portion (19%) of variation in litter mass (reproductive output) in the species. These findings suggest that selective pressure towards increased female size is also relatively low in *E. multiocellata*. Most probably, less pronounced male-male combat behavior as well as less pronounced physical constraints from female size on fecundity and reproductive output are the main reasons that explain why adult *E. multiocellata* lack SSD.

Female *E. multiocellata* exhibit some flexibility in timing of reproductive events but, in the field, most give birth in the warmest months (July and August; Zhao, 1999; Liu et al., 2005). Females in this study, however, gave birth from late June to late July. Lizards in nature are subject to unpredictable weather (and thus, basking opportunities) and food availability. However, under laboratory conditions, the unlimited food availability and the suitable thermal environments allow developing embryos to be free from the negative effects of the potential constraints imposed on pregnant females in nature. Thus, the difference in birth date between offspring produced in the laboratory and in the field, although not surprising, adds evidence that environmental factors may influence the rate of embryonic development in viviparous lizards (Robert and Thompson, 2001; Wapstra et al., 2004).

Our data confirm that female *E. multiocellata* produce a single litter per breeding season (Zhao,

1999; Liu et al., 2005). Under the laboratory conditions, most adults can survive for at least two years, with all adult females reproducing annually. Accordingly, we conclude that *E. multiocellata* exhibits iteroparity. Large female *E. multiocellata* on average allocate more resources to reproduction than do small females, although female SVL only explains a small portion of variation in litter mass. Females with larger litters produced smaller offspring, so there must be a trade-off between size and number of offspring in *E. multiocellata*. Based on available data, such a trade-off can be detected in some species [e. g., *Lacerta agilis* (sand lizard); Olsson and Shine, 1997; *T. septentrionalis*; Du et al., 2005b] but not in others [e. g., *Podarcis muralis* (common wall lizard); Ji and Braña, 2000]. As in *T. septentrionalis* (Ji et al., 1998; Du et al., 2005a) and *P. muralis* (Ji and Braña, 2000), variation in offspring size as a function of female SVL was not found in *E. multiocellata*. This result coupled with the size-number trade-off presumably add evidence for the prediction from the classical model (Smith and Fretwell, 1974) that the trade-off between size and number of offspring should lead to the evolution of optimally sized offspring.

**Acknowledgements** We are grateful to DING Guo-Hua, GUO Li, HAN Jun, LU Hong-Liang and ZHANG Jian-Long for their help during the research.

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