

# Reproduction and Morphology of the Common Lizard (*Zootoca vivipara*) from Montane Populations in Slovakia

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The common lizard, *Zootoca vivipara* (Lichtenstein, 1823), shows high variation in life histories and morphology across its range, which comprises almost the entire Palearctic region. However, this variation is not congruent with the species phylogeny. This suggests an important role for the environment in shaping the variation in morphology and life histories of this species. As most data on life histories originate from only a small number of populations and does not cover the species' geographic range and phylogenetic diversity, to fill a gap and provide more information for future comparative studies we investigated reproduction and morphology in two montane populations from Slovakia, central Europe. This region is characterized by taxonomic and phylogenetic diversity and both montane and lowland ecological forms of the common lizard occur here. The common lizards from the Slovak populations are sexually dimorphic, with females having larger body and abdomen lengths and males having larger heads and longer legs. Female common lizards start to reproduce at a relatively large size compared to most other populations. This is consistent with a relatively short activity season, which has been shown to be the main factor driving variation in body size in the common lizard. Clutch size was also relatively high and positively correlated with body size, abdomen size and head size. One third of all females attaining the size of the smallest gravid female showed no signs of reproductive activity despite mating opportunities, suggesting that not all females reproduce annually in this population.

**Key words:** morphological variation, reproductive traits, viviparity, sexual dimorphism, central Europe, Sauria, reptiles

## INTRODUCTION

Reproductive traits such as frequency of reproduction, age and size at maturity, fecundity, egg (offspring) size, and mass can vary among species, populations, and also among individuals within a single population (Fitch, 1970; Badyaev, 1997; Seigel and Ford, 2001; Morrison and Hero, 2003). Reptiles show remarkable variation in life history strategies and sources of such variation include environmental and genetic factors individually, and in interacting combinations (Sorci et al., 1996). It has been shown that within-population differences in life history traits (e.g. body size or fecundity) are often the result of plastic responses to local abiotic and biotic factors, such as temperature (Angilletta, 2009), food availability (Ballinger, 1977; Mugabo et al., 2010), the length of the active season (Horváthová et al., unpublished data), precipitation (Marquis et al., 2008; Olalla-Tárraga et al., 2006), or population density (Massot et al., 1992), but direct influence of genetic variation has also been recorded (Smith

et al., 1994; Romano and Ficetola, 2010). Variation in size and age at maturity has important implications for the population dynamics of populations, as it sets the timing for diversion of energy from growth, maintenance and storage to reproduction (Roff, 1992; Adolph and Porter, 1996).

In reptiles, the common lizard, *Zootoca vivipara* (Lichtenstein, 1823), has been of particular interest as it has the widest geographical range of all terrestrial reptiles and it is one of the few reptile species to exhibit reproductive bimodality (Fitch, 1970; Shine, 1985; Surget-Groba et al., 2006), offering an advantage of a broad scale of potential geographic and ecological variation. Several sub-species have been described, based on morphological, karyotypic, and DNA sequence data (Pereleshin and Terentjev, 1963; Lác and Kluch, 1968; Mayer et al., 2000; Arribas, 2009). The common lizard has also been extensively studied in its behavior, phylogeography, and ecology, and many studies have documented temporal and spatial variation in life histories (e.g., Bauwens and Verheyen, 1987; Pilorge, 1987; Heulin et al., 1997; Orlova et al., 2005). Despite substantial phylogenetic structure (Odierna et al., 2001; Surget-Groba et al., 2001), recent comparative analysis has shown that large-scale geographic variation in life history traits (e.g.

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body size and fecundity) is primarily driven by environmental conditions, such as the length of seasonal activity and precipitation (Sorci et al., 1996; Horváthová et al., unpublished data). However, the analyses of patterns of morphological variation identified consistent differences, which presumably are genetic, between oviparous and viviparous populations, as well as between sexes (Šmajda and Majláth, 1999; Guillaume et al., 2006; Jambrich, 2006; Arribas, 2009; Ljubisavljević et al., 2010). Offspring morphology has not been the subject of detailed investigation, but hatchlings are sexually dimorphic (e.g., Le Galliard et al., 2006). However, the trade-off between offspring size and fecundity and variation in sex allocation could generate differences in offspring morphology across and within populations (e.g., Olsson and Shine, 1997; Uller and Olsson, 2005).

Importantly, despite the fact that the species belongs to one of the best-studied reptiles world-wide, broad-scale analyses of the evolution of life histories have been almost entirely lacking from the region of central Europe. This part is characterized by the occurrence of two subspecies, several phylogenetic lineages, and a possible glacial refugium (Lác, 1968; Lác and Kluch, 1968; Surget-Groba et al., 2006; Jandzik, unpublished data). Morphological data is currently available only for populations from Slovakia (Mošanský, 1965; Lác, 1968; Lác and Kluch, 1968; Šmajda and Majláth, 1999; Jambrich, 2006), Czech Republic (Kratochvíl et al., 2003), Poland (Ekner et al., 2008) and hybridizing viviparous and oviparous populations from Austria (Lindtke et al., 2010). Notes on life-history traits (e.g. fecundity and body size) are restricted only to specimens from the abovementioned hybridizing populations in Austria (Lindtke et al., 2010).

To fill this gap, the aim of our study was to examine intra-population variation in reproductive and morphological characteristics of individuals living in two mountain populations from Slovakia, which could be further used in comparative studies.

## MATERIALS AND METHODS

### The study species

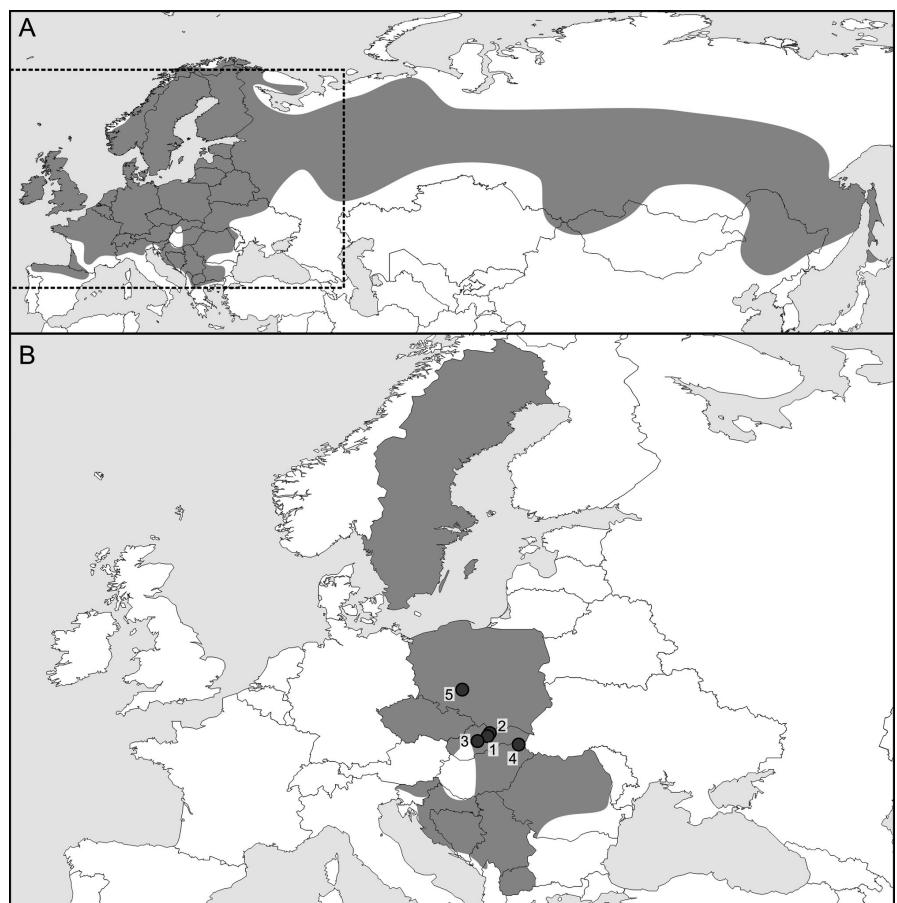
The common lizard is a small insectivorous lizard from the family Lacertidae. The distribution area covers almost the entire Palaearctic region, extending from Ireland in the West, across Europe, as far to the East as Siberia, Sakhalin, and Hokkaido Island in the Pacific Ocean (Fig. 1; Dely and Böhme, 1984; Mayer et al., 2000; Glandt, 2001). It is found in a wide range of humid habitats, from sea level up to about 2500 m altitude. The adults typically reach a snout-vent length (SVL) of 40–60 mm or 45–80 mm in males and females, respectively. It is one of only a few reptiles to exhibit reproductive bimodality (Shine, 1985), with oviparous populations restricted to some areas in the Pyrenees Mountains

(Spain and France, subspecies *Z. v. lousianzi*) and south of the Alps (Austria, Slovenia, and Italy, subspecies *Z. v. carniolica*) (e.g., Heulin and Guillaume, 1989; Heulin et al., 1993; Mayer et al., 2000). Females reproduce once a year, with the exception of oviparous populations in which females commonly lay between one and three clutches per season, and rarely lowland viviparous populations in which females could produce two clutches (Patrick Fitz, unpublished data; Horváthová et al., unpublished data). The reproductive cycle follows a consistent pattern with mating and ovulation in spring, and the young are born in mid to late summer (Bauwens and Verheyen, 1985; Roig et al., 2000). These lizards enter hibernation in autumn, usually in September or October.

In Slovakia, the common lizard occurs in humid habitats at higher altitudes, generally above 600 m a. s. l. (Lác, 1968), but a few populations have also been found in the eastern Slovak lowland (120 m a. s. l.). The unusual occurrence together with some morphological differences led to the description of subspecies *Zootoca vivipara pannonica* (Lác and Kluch, 1968) from this region. Molecular analysis however did not confirm genetic differentiation in mtDNA of this taxon (Surget-Groba et al., 2006) and observed differences may rather represent a result of phenotypic plasticity.

### Data collection and analysis

The study was conducted during June and July 2007 and 2009 in montane localities Šuňava, Kozie Chrbty Mts., (49.133, 20.116; 870 m a. s. l.) and Žiar, Tatra Mts. (49.133, 19.666; 830 m a. s. l.;



**Fig. 1.** (A) Map showing distribution of *Z. vivipara* in dark grey. (B) Enlarged area of Europe with highlighted (in dark grey) regions and localities of origin of the common lizards analyzed in Tables 2 and 3. Numbers of localities: 1, Šuňava, Slovakia; 2, Žiar, Slovakia; 3, Kunešov, Slovakia; 4, Bot'any, Slovakia; 5, Odolanow, Poland.

this population was not sampled in 2009) (see Fig. 1). Individuals from these areas belong to the same mtDNA phylogenetic clade (clade E; Surget-Groba et al., 2006; Jandzik, unpublished data). Males were captured by hand, marked individually by toe-clipping and released after weighing (to the nearest 0.1 g) and measuring body length (SVL), abdomen length (measured as a distance between extremities, DEX), head length (HL), head width (HW), head height (HH), foreleg length (FLL), and hindleg length (HLL; all to the nearest 0.01 mm). Pregnant females were collected and brought to the laboratory. The females were housed individually in plastic cages ( $50 \times 40 \times 30$  cm) filled with the soil and peat moss from the study site. Females were maintained in the laboratory until they gave birth. After parturition, clutch size, clutch weight (sum of all hatchlings in the clutch), hatchling SVL, DEX, HL, HW, HH, FLL, HLL and mass were recorded. Hatchlings and their mothers were released at the place of their capture no more than seven days after parturition.

We used multiple regression analyses to examine relationship between clutch size, body size and hatchling mass. Differences in body size between gravid and non-gravid females were tested with *t*-tests. Small sample size of females from population Žiar (non-gravid  $n = 7$ ; gravid  $n = 8$ ) did not allow the analysis of the differences between populations or individual females. To increase sample size, we pooled morphological and life-history data from population Šuňava ( $n = 9$  in year 2007 and 42 in 2009; we found no between-year variation, data not shown). We used the *t*-test to test to estimate the differences in SVL and the differences between sexes in abdomen length, head measures and leg length were tested with MANCOVA with tests for between-subjects effects. All variables were log-transformed prior to analyses. In the text, we report mean values  $\pm$  standard deviation (SD). All analyses were carried out using SPSS, 13.0 (Chicago, IL).

## RESULTS

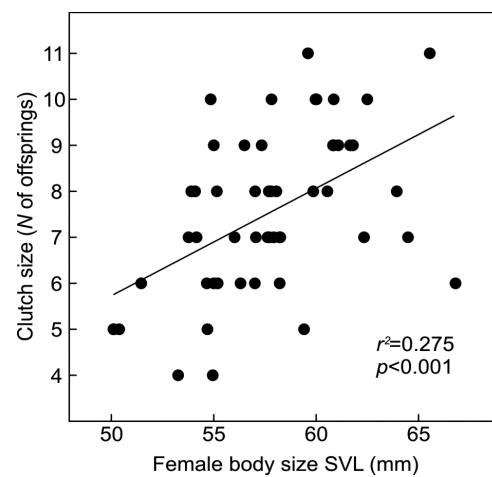
In population Šuňava, the smallest gravid female reached SVL of 50.10 mm, whereas the largest non-reproducing female measured 54.50 mm. Therefore, the size at which females can be considered as sexually mature ranges between ca. 50 and 55 mm in the studied population. The mean body size of reproducing females ( $57.62 \pm 3.8$ ,  $n = 51$ ) was significantly larger than that of non-reproducing females ( $48.36 \pm 3.81$ ,  $n = 22$ ;  $t = -9.551$ ,  $P < 0.001$ ). In the population Žiar, the smallest gravid female measured 56.27 mm and the mean body size of gravid females equaled  $60.36 \pm 4.2$  mm.

Females from population Šuňava produced clutches comprising 4 to 11 offspring, with a mean clutch size of  $7.51 \pm 1.77$  (Table 1). Mean hatchling SVL and mass (calculated for all clutches) were  $19.84 \pm 0.74$  mm and  $0.16 \pm 0.02$  g, respectively (Table 1). Variation in clutch size was largely explained by differences in female SVL ( $r^2 = 0.275$ ,  $df = 50$ ,  $P < 0.001$ , Fig. 2), whereas mean hatchling mass did not account for significant variation ( $r^2 = -0.05$ ,  $df = 50$ ,  $P = 0.074$ ). The relationship between female SVL and hatchling SVL was not significant ( $r^2 = 0.015$ ;  $df = 50$ ;  $P > 0.05$ ).

The correlation between female SVL and mass before and mass after parturition was highly significant (mass before:  $r^2 = 0.667$ ,  $df = 48$ ,  $P < 0.001$ ; mass after:  $r^2 = 0.626$ ,  $df = 48$ ;  $P < 0.001$ ). Female SVL also appeared to be the best morphological predictor of fecundity, as abdomen length and head length explained smaller proportion of variation within clutches (SVL: 27.5%; DEX: 16.5%; HL: 17.5%).

**Table 1.** Reproductive characteristics of the female common lizards (*Z. vivipara*) from two montane populations in Slovakia. Number in parentheses in the locality row refers to the locality number on the map in Fig. 1.

Locality	Šuňava (2007, 2009) (1)			Žiar (2007) (2)		
	Variable	N	Mean $\pm$ SD	Min–Max	N	Mean $\pm$ SD
Maternal SVL (mm)	51	$57.62 \pm 3.8$	50.1–66.81	8	$60.36 \pm 4.2$	56.27–69.31
Female mass before part. (g)	49	$5.45 \pm 1.09$	3.37–7.70	8	$6.23 \pm 0.99$	4.70–7.50
Female mass after part. (g)	49	$3.09 \pm 0.69$	1.75–5.70	8	$3.49 \pm 0.65$	2.80–4.80
Clutch size	51	$7.51 \pm 1.77$	4–11	8	$7.13 \pm 1.46$	5–9
Hatchling mass (g)	364	$0.16 \pm 0.02$	0.14–0.23	55	$0.18 \pm 0.12$	0.16–0.20
Hatchling SVL (mm)	364	$19.80 \pm 0.74$	18.23–21.14	55	$20.18 \pm 0.53$	19.38–20.92



**Fig. 2.** Positive relationship between female body size and clutch size in the population Šuňava.

In population Žiar, the mean clutch size was 7.13 and ranged from 5 to 9 (Table 1). Mean hatchling SVL and mass were  $20.18 \pm 0.53$  mm and  $0.18 \pm 0.12$  g (Table 1).

The descriptive statistics of the morphometric traits in females, males and hatchlings is summarized in Table 2. Adult males and females differ in SVL, with females being the larger sex ( $t_{109} = 9.169$ ,  $p < 0.001$ ). MANCOVA of abdomen length, head size, and leg length (with SVL used as a covariate) showed significant level of sexual dimorphism (Wilks' Lambda  $F(6,102) = 157.915$ ,  $P < 0.001$ ) and tests of between-subject effects showed that females have larger abdomens ( $F(1) = 32.016$ ,  $p < 0.001$ ), while males have larger head length ( $F(1) = 63.282$ ,  $P < 0.001$ ), head width ( $F(1) = 48.877$ ,  $P < 0.001$ ), head height ( $F(1) = 12.304$ ,  $p = 0.001$ ), forelimb length ( $F(1) = 70.537$ ,  $P < 0.001$ ) and hindleg length ( $F(1) = 45.079$ ,  $P < 0.001$ ).

## DISCUSSION

Our results showed that female common lizards from the montane localities Šuňava and Žiar initiate reproduction at a body size of approximately 50–57 mm. This threshold is similar to that observed in montane populations in France (Massif Central, 1400 m a. s. l.; Massot et al., 1992, 2011), however is considerably higher than those reported from other European populations. For example, Heulin (1985) reported the body size of 40–42 mm in French population

**Table 2.** Descriptive statistics of morphometric traits in two montane populations of *Z. vivipara* from Slovakia. *N* – sample size; SD – standard deviation; Min-Max - minimum and maximum value; mass<sup>1</sup> before parturition; mass<sup>2</sup> after parturition; for traits see Material and methods. Number in parentheses in the locality row refers to the locality number on the map in Fig. 1. See Material and methods for the abbreviations of the morphological characters.

Locality	Šuňava (2007, 2009); (1)			Žiar (2007); (2)		
Males	<i>N</i>	Mean ± SD	Min–Max	<i>N</i>	Mean ± SD	Min–Max
SVL (mm)	35	44.72 ± 4.10	36.7–53.22	4	46.08 ± 3.22	41.97–48.94
DEX (mm)	35	21.49 ± 2.13	17.05–24.99	4	21.68 ± 1.65	19.91–23.08
HL (mm)	35	10.02 ± 0.87	8.44–11.85	4	9.96 ± 0.62	13.49–15.89
HW (mm)	35	7.14 ± 0.73	5.2–8.35	4	7.35 ± 0.63	18.28–22.54
HH (mm)	35	5.04 ± 0.78	3.91–8.42	4	5.12 ± 0.40	9.25–10.73
FLL (mm)	35	14.88 ± 1.41	11.65–17.99	4	14.67 ± 0.98	6.72–8.21
HLL (mm)	35	19.52 ± 1.99	15.44–22.53	4	20.18 ± 2.04	4.75–5.58
mass (g)	34	2.34 ± 0.69	1.0–3.70	4	2.48 ± 0.54	1.70–2.90
Gravid females						
SVL (mm)	51	57.62 ± 3.79	50.10–66.81	8	60.36 ± 4.20	56.27–69.31
DEX (mm)	51	32.53 ± 3.57	26.77–40.81	8	33.53 ± 2.98	30.19–40.05
HL (mm)	51	10.60 ± 0.53	9.59–11.61	8	10.71 ± 0.41	9.95–11.34
HW (mm)	51	7.38 ± 0.42	6.20–8.09	8	7.56 ± 0.42	6.92–8.33
HH (mm)	51	5.26 ± 0.42	4.17–6.09	8	5.15 ± 0.21	4.85–5.42
FLL (mm)	51	15.17 ± 0.82	13.50–17.11	8	16.24 ± 1.01	15.17–17.46
HLL (mm)	51	20.67 ± 1.22	17.96–23.41	8	22.05 ± 0.76	21.05–23.40
mass <sup>1</sup> (g)	49	5.45 ± 1.09	3.37–7.70	8	6.23 ± 0.99	4.70–7.50
mass <sup>2</sup> (g)	49	3.09 ± 0.69	1.75–5.70	8	3.49 ± 0.65	2.80–4.80
Nongravid females						
SVL (mm)	24	48.36 ± 3.81	42.58–54.54	7	48.96 ± 6.26	42.89–59.81
DEX (mm)	24	26.4 ± 3.52	21.89–35.27	7	27.01 ± 4.18	22.86–34.80
HL (mm)	24	9.90 ± 0.60	8.90–11.22	7	9.29 ± 0.56	8.77–10.36
HW (mm)	24	6.87 ± 0.56	5.87–7.96	7	6.73 ± 0.45	6.26–7.37
HH (mm)	24	4.93 ± 0.44	4.12–5.73	7	4.76 ± 0.38	4.30–5.26
FLL (mm)	24	14.33 ± 0.95	12.29–16.89	7	14.00 ± 0.58	13.34–14.81
HLL (mm)	24	19.24 ± 1.88	17.08–24.13	7	18.30 ± 1.59	15.94–20.67
mass (g)	24	2.43 ± 0.71	1.50–4.10	7	2.17 ± 0.63	1.50–3.00
Hatchlings						
SVL (mm)	364	19.80 ± 0.74	18.23–21.14	55	20.18 ± 0.53	19.38–20.92
DEX (mm)	364	8.72 ± 0.47	7.38–9.87	55	9.37 ± 0.68	8.78–10.94
HL (mm)	364	5.81 ± 0.17	5.41–6.26	55	5.88 ± 0.09	5.76–6.02
HW (mm)	364	3.68 ± 0.08	3.50–3.84	55	3.80 ± 0.09	3.63–3.91
HH (mm)	364	2.94 ± 0.11	2.74–3.22	55	2.85 ± 0.05	2.80–2.97
FLL (mm)	364	6.91 ± 0.24	6.26–7.55	55	7 ± 0.18	6.72–7.26
HLL (mm)	364	8.63 ± 0.37	7.85–9.20	55	9.06 ± 0.33	8.44–9.42
mass (g)	364	0.16 ± 0.02	0.14–0.23	55	0.18 ± 0.12	0.16–0.20

Paimpont, and a similar value (43–45 mm) was also obtained by Bauwens and Verheyen (1987) in the population Kalmthout in Belgium. Since both populations are located at lower altitudes (Paimpont 50 m a. s. l.; Kalmthout 50 m a. s. l.), such variability may reflect differences in the length of seasonal activity (Horváthová et al., unpublished data). Females from the highland populations in Šuňava and Žiar (or Massif Central), which experience 5.5 months of activity (comparing to 6.5–7 months at low altitudes), may grow slower and mature at larger sizes size and later in life, as has been shown in the lacertid lizard *Lacerta agilis* (Rötberg and Smirina, 2006).

Surprisingly, a relatively large fraction of non-gravid females (33%) attained SVL 50 mm with no signs of reproductive activity (such as the scars in inguinal region as signs of male biting the female during copulation; Heulin, 1988), and without giving birth to offspring later in the lab. Since we

observed adult males quite frequently at the study site, the lack of mating opportunities does not seem to be able to account for this observation. Energy allocated to the reproduction usually represents 28–35% of the energy assimilated during spring (Avery, 1975) which indicates that reproductive investment embodies significant portion of energy budget. Some females may simply not be able to accumulate sufficient energy stores to reproduce in every year (Diller and Wallace, 1984; Reading, 2004) and thus must forestall reproduction to the next season. This is expected to be more common in income breeders, as they depend on energy accumulated during the breeding season (i.e. during vitellogenesis) which has also been implied in common lizard (Avery, 1975; Mugabo et al., 2011). However, our results can also indicate the high variation in timing of maturation in our population, which has also been shown in other montane species (Arribas and Galán, 2005; Bauwens, 1999). Furthermore, observations indicate that females may mate even if they will not later reproduce, perhaps via forced copulations (Olsson, 1995). On the other hand, however, it is also known that females of the common lizard may produce unfertilized eggs even without mating, which suggest a strong pressure on females to mate if they have opportunity, to not risk high cost of not mating (see Bleu et al., 2011).

Positive correlation between female size and clutch size has been confirmed in several populations of the common lizard (Avery, 1975; Bauwens and Verheyen, 1987; Crnobrnja-Isailović and Aleksić, 2004; Liu et al., 2008; Lazareva, 2009). High fecundity linked with large body size is general phenomenon in lizards and may explain sexual dimorphism in this species (fecundity selection hypothesis, Stuart-Smith et al., 2007). The mean clutch sizes of females from populations Šuňava and Žiar were 7.5 and 7.1, respectively, one of the highest ever recorded for this species (Horváthová et al., unpublished data). Comparable values have been reported by Pilorge (1987) and Avery (1975) for French (7.6) and British populations (7.7). Relatively large clutch size has been attributed to high prey abundance and low lizard density at study site (Pilorge, 1987; Horváthová et al., unpublished data). Offspring mass did not explain significant amount of variation in clutch size and was relatively constant within studied populations (0.16 g and 0.18 g). Mean offspring mass of 0.16 g is the smallest recorded for this species, and similar to that of a highland population in France (Pilorge, 1982; Pilorge et al., 1983). The typical mass of most viviparous populations is 0.17–0.18 g (e.g., Pilorge and Xavier, 1981; Bauwens and Verheyen, 1987; Crnobrnja-Isailović and Aleksić, 2004; Liu et al., 2008) and maximum mean values of 0.20 g were recorded by Lindtke et al. (2010), Cavin (1993) and Uller and Olsson (2005). This may suggest that there is a general tendency to produce larger offspring in populations with shorter seasonal activity. In species with a restricted period of growth (e.g., in seasonal environment), the time of hatching could have a strong influence on body size. Females may compensate for the negative effect of short activity period by producing larger offspring (Uller and Olsson, 2010).

We found sex differences in body length, abdomen length, leg length and head length, which is also consistent with the previous studies (Braña, 1993; Barbadillo et al.,

**Table 3.** Variability of morphological traits in the common lizard populations from Central Europe. m-male; f-female; Žoltáková (1976) only means; Dély (1978), Fuhn and Vancea (1961) minimum and maximum value (data pooled for both sexes); Jambrich (2006) locality Šuňava corresponds to subspecies *Z. vivipara vivipara*, locality Bot'any to subspecies *Z. vivipara pannonica*; other studies as min (mean) max value. Number in parentheses in the locality row refers to the locality number on the map in Fig. 1.

Trait	Sex	Fuhn and Vancea (1961)	Lác (1968)	Žoltáková (1976)	Dély (1978)	Šmajda and Majláth (1999)	Jambrich (2006, Šuňava)	Jambrich (2006, Bot'any)	Ekner et al. (2008)	This study (Šuňava, 2007, 2009)
Locality		Romania, no further details	Kunešov, Kremnické Vrchy Mts., Slovakia; 48°43'N 18°52'E; (3)	Eastern Slovakia, many localities	Sweden, Poland, Czechoslovakia, Hungary, Yugoslavia, Romania; many localities	Eastern Slovakia, many localities	Šuňava, Slovakia; 49°01'N 20°07'E; (1)	Bot'any, Slovakia; 48°28'N 22°06'E; (4)	Odolanow, Poland; 51°34'N, 17°40'E; (5)	Šuňava, Slovakia; 49°01'N 20°07'E; (1)
N	m	unspecified	37	77	26	55	31	22	40	35
	f	unspecified	32	76	24	57	40	20	45	75
Snout-vent length (SVL)	m	42–63	41.5 (51.1) 59	50.65	40.2–67	44 (51) 59	43 (49.8) 55	43 (47.6) 58.8	33 (46.1) 56.9	36.7 (44.7) 53
	f	42–63	50 (59.20) 65	55.9	40.4–66.2	44 (55) 67	44.6 (55.1) 65	43.3 (50.4) 62.8	33.8 (51.8) 69	42.6 (55) 66.8
Abdomen length (DEX)	m	–	–	–	–	21 (25) 30	21 (25.2) 28.8	17.2 (22.3) 29	–	17 (21.5) 25
	f	–	–	–	–	22 (31) 41	21.2 (31.8) 40.9	20.9 (26.9) 35.1	–	21.9 (30.6) 40.8
Head length (HL)	m	9–11	10 (11.5) 12.6	10.62	8 (10) 11.5	8.5 (10.5) 12	9.9 (10.7) 12	7.8 (10.1) 12.1	1 (9.8) 12	8.4 (10) 11.9
	f	9–11	10 (11) 12	10.22	8.6–11.4	8 (10) 11.5	9.2 (10.3) 11.6	8.5 (9.5) 10.8	5 (9.8) 15.5	8.9 (10.4) 11.6
Head width (HW)	m	–	7 (7.9) 9	7.03	6 (7.5) 8.5	6 (7.5) 8.5	7 (7.7) 8.5	6.2 (7) 8.2	4 (5.7) 6.7	5.2 (7.1) 8.4
	f	–	6.7 (7.4) 8.2	6.82	5.5 (7) 8	5.5 (7) 8	6.1 (7.1) 7.8	5.8 (6.8) 7.7	3 (5.5) 8	5.9 (7.2) 8.1
Head height (HH)	m	–	–	6.45	4.5 (6) 7	4.5 (6) 7	3.1 (3.5) 4.1	3 (3.3) 3.8	–	3.9 (5) 8.4
	f	–	–	5.95	4.5 (5) 7	4.5 (5) 7	2.5 (3.3) 4.2	2.8 (3.1) 3.5	–	4.1 (5.2) 6.1
Hindleg length (HLL)	m	11.5–16	12.9 (16.1) 17.8	15.04	12.7–18.2	12 (15) 18	14.1 (16.4) 18.2	13.7 (16.1) 19.9	–	11.7 (14.9) 18
	f	11.5–16	14 (15.5) 16	14.18	12.1–17.1	11 (14) 17	13.6 (15.7) 17.1	13.2 (15.3) 17.2	–	12.3 (15) 17.1
Foreleg length (FLL)	m	17–24	17.8 (22.7) 25	22.21	16.8–25.5	16 (22) 25	19.3 (22.2) 24.6	19 (22.1) 25.5	–	15.4 (19.5) 22.5
	f	17–24	20.4 (22) 23.7	21.58	15.5–24.6	16 (20) 24	18.1 (20.7) 24.7	18 (20.2) 23.6	–	17.1 (20.2) 24.1

1995; Šmajda and Majláth, 1999; Gvoždík and Van Damme, 2003; Kratochvíl et al., 2003; Jambrich, 2006; Ekner et al., 2008; Liu et al., 2008). Larger heads in males most likely result from selection on the ability to grasp a female for copulation and inter-sexual selection conferring advantage of a stronger bite force during male-male contests (Herrel et al., 2001; Gvoždík and Van Damme, 2003). On the other hand, larger body size, correlated with larger abdomen, may be driven by fecundity selection, as larger abdomen offers space to accommodate more offspring (Stuart-Smith et al., 2007). In lizards, body size is generally represented by snout-to-vent length (SVL), which also highly correlates with abdomen length (DEX). Both these predictors explained a significant proportion of variation in clutch size in our models. Kratochvíl et al. (2003), however, have pointed out that SVL is a sexually dimorphic trait that scales allometrically in sexes and therefore may not be a proper measure of body size. They proposed head length as an alternative measure for the common lizard, which also showed as an important predictor of fecundity in our analyses, though explaining smaller portion of variation than SVL.

Variability of male and female morphology in highland Slovakia can be compared with other populations from Central Europe (Table 3), where subspecies *Z. v. vivipara* and *Z. v. pannonica* occur. Our findings are generally in agreement with published results, however body size, distance between extremities, and hindleg length are slightly smaller in males (Table 3). Despite the enormous distribution range, morphological variability in general does not correspond to the genetic variation of this species (though studies have only used mtDNA so far, Surget-Groba et al., 2001, 2006). Morphological differentiation is mostly shown in scale numbers, based on which the oviparous subspecies *Z. v.*

*carniolica* and *Z. v. louisianzi* are at least partially well diagnosed (Mayer et al., 2000; Arribas, 2011), whereas there are large overlaps in metric traits between various forms and subspecies (Guillaume et al., 2006; Arribas, 2009, Jambrich and Jandzik, unpublished data). Our results are concordant with this, as we found no significant differences in male and female morphology when compared with other populations across different subspecies (Table 3, Guillaume et al., 2006; Jambrich, 2006; Liu et al., 2008; Arribas, 2009).

Data on hatchling morphometrics are scarce and usually only body size (SVL) is reported. For example, in French lowland population Paimpont the average hatchling SVL was 20.0 mm and 20.3 mm (in two consecutive years; Heulin, 1985), similar to what we recorded in Slovak population Žiar and slightly higher than in population Šuňava. Liu et al. (2008) documented data on body size and head measures of neonates from northeast China, but they are much larger in all examined traits than those analyzed in our study. We cannot exclude a possibility that they were measured several days after birth and the measures may also be affected by differences in sex ratio within the samples. More detailed studies on hatchling morphometrics are thus desired for comprehensive comparisons.

## ACKNOWLEDGMENTS

We would like to thank Tobias Uller and two reviewers for critical reading of the manuscript and valuable suggestions.

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(Received May 15, 2012 / Accepted August 23, 2012)