

Quantifying the intersexual and interspecific morphometric variation in two resembling sympatric lacertids: *Iberolacerta horvathi* and *Podarcis muralis*

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Abstract. *Podarcis muralis* and *Iberolacerta horvathi* are sympatric, frequently syntopic, lacertids through the entire range of *I. horvathi* and very similar in their general body size and shape, as well as in most ecological traits. We morphologically compared adults from the area of sympatry using biometric measurements and performed analyses to investigate their sexual size and shape dimorphism. A total of 34 males and 24 females of *I. horvathi*, and 25 males and 23 females of *P. muralis*, all adult individuals, were measured. Both species showed sexual size dimorphism with females being longer (snout-vent length, SVL) than males. After SVL correction (ANCOVA), head width, length and height and mass showed to be sexually dimorphic in both species. Males carry relatively wider, longer and higher heads and were heavier than conspecific females. *I. horvathi* heads were more flattened than those of *P. muralis* and *P. muralis* were heavier than *I. horvathi*. Both species displayed the same pattern of sexual dimorphism regarding body size, head size and shape not only in direction but also in magnitude. All results confirm that both species are very similar in studied biometric characters and, together with their ecological similarities, these suggest in absence of other factors they are likely to interact when living together.

Keywords. Biometric characters, sexual dimorphism, southern Slovenia, *Podarcis muralis*, *Iberolacerta horvathi*, Lacertidae

INTRODUCTION

The Common wall lizard (*Podarcis muralis*) and Horvath's rock lizard (*Iberolacerta horvathi*) are sympatric and frequently syntopic lacertids through the entire range of *I.*

horvathi (Tiedemann, 1997). The range of latter as known today extends from pre-alpine and alpine part of north eastern Italy, to north western Slovenia (Lapini et al., 2004; Rassati, 2010) and southern Austria (Cabela et al., 2007), and Dinaric Alps of central and southern Slovenia and Velebit in Croatia (De Luca, 1989; Krofel et al., 2009). Allotopic *I. horvathi* populations are only known from high elevations where *P. muralis* is absent; in the north of its distributional range above 900 m a.s.l. (e.g., Lapini et al., 1993; Cabela et al., 2007). Both species are said to be very similar in their general body size and shape, the average snout-vent length of adults being between 55-65 mm (e.g. De Luca, 1989; Aleksić and Ljubisavljević, 2001). Reproductively, *I. horvathi* is monoestrous while *P. muralis* may lay a second clutch when conditions are favourable (Lapini et al., 1993; Capula et al., 1993). The dietary niches of both species are highly overlapping (De Luca, 1992; Richard and Lapini, 1993). In the area of sympatry both species start their activity period in March/April and go to hibernation in October/November, exhibiting the diurnal activity pattern typical of lacertids in temperate zone (De Luca, 1992; Lapini et al., 1993). The overall habitat use of both species is also highly similar (Cabela et al., 2007). They mostly occupy rocky habitats with sparse vegetation or open rocky screes in forests. On the microhabitat scale, some differences in slope and vegetation cover selection between species have been detected, *I. horvathi* tending to use more rocks and vertical surfaces than *P. muralis* (Arnold, 1987; Lapini et al., 1993; Cabela et al., 2007). Moreover, similarity in the overall appearance between both species has frequently led to misidentification in the past (e.g. Brelih, 1954; De Luca, 1989). To determine the species it is usually necessary to catch or make a close-up photograph of the individual to see the position of rostral and fronto-nasal scales that are frequently in contact in *I. horvathi* and separated in *P. muralis* (e.g. Arnold et al., 2007). Because of that, recent intensive studies discovered unknown populations of *I. horvathi* in many parts of its range where the species had previously been misidentified as *P. muralis* or not recorded yet (Lapini et al., 2004; Žagar, 2008 a, b; Krofel et al., 2009; Cafuta, 2010; Rassati, 2010).

Sexual dimorphism in size and shape occurs in most species of lacertids. Size (snout-vent length and body mass) can be either male- or female-biased (e.g., Kaliontzopoulou et al., 2007; Kratochvíl et al., 2003) and males in most species have bigger and wider heads and longer limbs (e.g. Herrel et al., 1996). Such sexual differentiation in lacertids is hypothesised to be derived from different selection pressures: males having bigger head proportions to have a firm grasp of a female's trunk during copulation and females having longer trunks to hold the eggs (Kaliontzopoulou et al., 2007, 2008 a, b). In the case of *P. muralis*, instances of both male-biased (Strijbosch et al., 1980; Barbault and Mou, 1988; Braña and Ji, 2000; Allan et al., 2006; Bruner and Constantini, 2007; Gracceva et al., 2008; Aleksić et al., 2009) and female-biased (Gracceva et al., 2008; Kaliontzopoulou and Carretero, unpublished) sexual dimorphism have been described. In contrast, for *I. horvathi* a single comparative study of sexual dimorphism published so far showed a female-biased sexual size dimorphism (De Luca, 1989) as described for some other species of this genus (e.g. for *I. galani*; Arribas et al., 2006).

The main aim of our study is to reveal morphometric (dis)similarity in two very resembling species of lacertids, *P. muralis* and *I. horvathi* living in the area of sympatry. In the past, most comparisons of size and shape of both species only referred to descriptive, often qualitative data and were not targeted to biometric characters in order to detect

possible subtle interspecific differences. We aimed to compare differences at intra- (intersexual) and interspecific level in order to evaluate morphological divergences of considered sympatric lacertids. For the first time, we quantitatively investigate biometric characters of these two species from a sympatric area in southern Slovenia. Intersexual differences in size and shape in lacertids are a result of sexual selection rather than resulting from niche segregations (Carretero, 2004) and therefore we expect it exists in both species.

MATERIAL AND METHODS

Study area and individuals studied

Lizards were captured at 19 localities in the sympatric area of *P. muralis* and *I. horvathi* in Kočevsko region, Southern Slovenia (45°28'37"N, 14°48'34"E) in spring and summer periods between 2007 and 2010 (Fig. 1). The maximal distance between locations was 30 km that ensured similar environmental conditions. Climate was moderate continental and mountainous influenced by Mediterranean, inland and Atlantic ocean (Kordiš, 1993) with total annual precipitation of 1600 to 1800 mm and mean temperature in July 17.9 °C and in January -2.8 °C (Puncer, 1980). Typical habitats of both lacertid species in the region are natural or artificial rock cliffs with no or sparse vegetation and rocky outcrops on the forest edge (Žagar, 2008 a). Sampling sites were chosen to have similar microhabitat characteristics. All individuals caught were measured and photographed, and released afterwards on the same location. Sex was verified by inspection of colouration, cloacal region and femoral pores.

Biometric characters

To quantify intra- and interspecific differences we measured six biometric characters: snout vent length (SVL), head length (HL) from the tip of the snout to the posterior border of the collar, pileus length (PL), head width (HW), head height (HH), and mass (M) (only for specimens caught in 2010, measuring scheme after Kaliontzopoulou et al., 2007). All linear measurements were taken to the closest 0.1 mm, using digital callipers and mass was measured to the closest 0.1 g, using scale with a hook type Pesola max. 30 g.

Statistical analysis

Variables were logarithmically transformed to meet the assumptions of normality and homogeneity of variances. Considering that sexual dimorphism either in size (SSD) or in shape (SShD) is common in lacertids (see Introduction) sex was taken into account in all analyses. Differences in SVL were tested through a two-way ANOVA with sex and species as factors. Differences for the other measurements were relativized to SVL by using a two-way ANCOVA design with sex and species as factors and SVL as covariate for size correction. All statistical analyses have been done using Statistica 10 (STATSOFT, 2011).

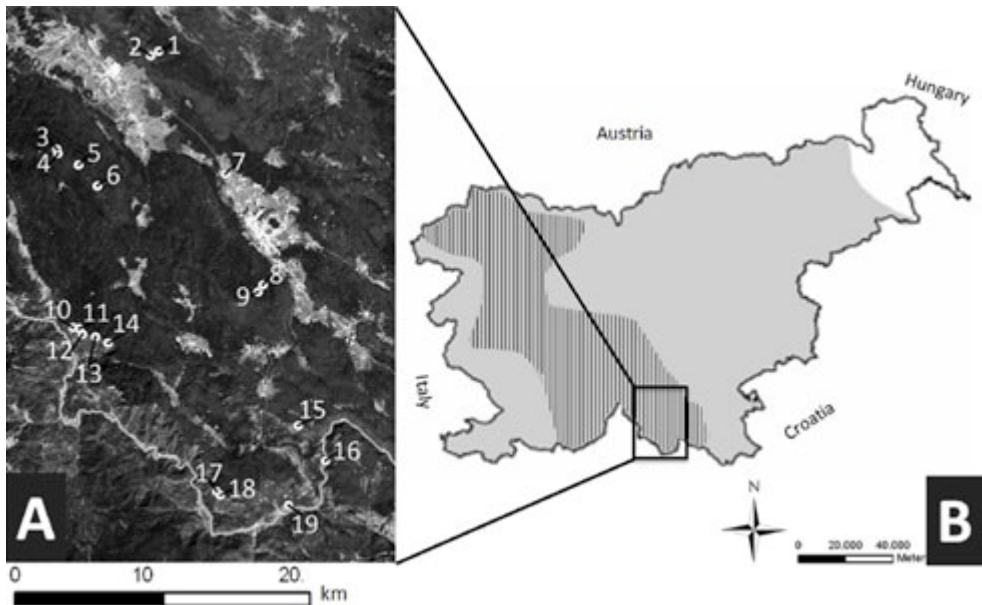


Fig. 1. Locations of the sampling sites (A) of Common wall lizards (*Podarcis muralis*, numbers 1, 2, 7-9, 16 and 19) and Horvath's rock lizards (*Iberolacerta horvathi*, numbers 3-6, 10-15, 17 and 18) and the location of the study area in Slovenia (B) with distributions of both species (*P. muralis* in grey and *I. horvathi* in black stripes).

RESULTS

A total of 34 males and 24 females of *I. horvathi*, and 25 males and 23 females of *P. muralis*, all adult individuals, were measured (Tab. 1). Both species showed sexual size dimorphism with females being longer (SVL) than males, but no interspecific differences either in SVL or in sexual dimorphism were found (Tab. 1 and 2). After size correction (ANCOVA), only PL did not show to be dependent on sex, but HW, HL, HH and M proved to be sexually dimorphic in both species (Tab. 2). In fact, males of both species had relatively wider, longer and higher heads and were heavier than the conspecific females (Tab. 1). Moreover, for both sexes, *I. horvathi* heads were more flattened than those of *P. muralis* and *P. muralis* were heavier than *I. horvathi* but no interspecific differences were found for the remaining variables (Tab. 2).

DISCUSSION

Our results comparing body size, head size and head shape of adult *P. muralis* and *I. horvathi* from the area of sympatry, indicated both sexual dimorphism and (limited) interspecific variation which were independent one from another. We have also confirmed that species were similar to each other in their external appearance. Considering each sex

Table 1. Descriptive statistics of biometric characters for two species of lacertids, *Podarcis muralis* and *Iberolacerta horvathi*, from southern Slovenia. For each variable next values are given: Mean±SD, Min-max and n (numbers of individuals). Legend: SVL – snout-vent length, HH – head height, PL – pileus length, HL – head length, HW – head width and M – mass.

Variable	<i>Iberolacerta horvathi</i>		<i>Podarcis muralis</i>	
	Males	Females	Males	Females
SVL	53.46±3.90	58.30±4.27	54.71±4.62	58.85±3.36
	43.7-60.0	48.2-65.9	41.9-62.8	50.1-64.6
	34	24	25	23
HH	6.37±0.38	6.19±0.38	6.96±0.88	6.87±0.66
	5.7-7.0	5.5-6.9	4.5-8.5	5.3-8.2
	19	23	25	23
PL	13.29±1.73	12.57±0.80	14.14±1.00	13.24±0.80
	10.7-21.4	10.5-13.8	11.9-15.6	11.5-14.8
	33	24	25	23
HL	19.72±1.55	18.83±1.32	20.10±1.48	18.82±1.58
	16.7-23.0	16.1-21.4	17.1-22.5	13.3-21.3
	34	24	25	23
HW	8.96±0.91	8.71±0.71	9.14±0.81	8.43±0.39
	7.0-10.5	6.9-9.8	7.0-11.0	7.6-9.2
	33	24	25	23
M	4.25±0.58	4.01±0.83	4.26±1.11	4.55±0.90
	2.8-5.3	2.5-5.5	1.5-6.3	2.5-5.5
	19	23	25	23

Table 2. Results of AN(C)OVA comparisons for species and sex (variables are SVL corrected, except SVL) for two species of lacertids, *Podarcis muralis* and *Iberolacerta horvathi*, from southern Slovenia. Legend: SVL – snout-vent length, HH – head height, PL – pileus length, HL – head length, HW – head width and M – mass.

Variable	Denominator	Species		Sex		Species*sex				
	df	F	df	P	F	df	P	F	df	P
SVL	105	1.20	1	0.2730	30.0	1	<0.0001*	0.20	1	0.6939
HH	89	35.00	1	<0.0001*	15.83	1	0.0001*	0.01	1	0.9173
PL	104	0.0006	1	0.9813	2.29	1	0.1337	1.23	1	0.2705
HL	105	0.04	1	0.8390	64.06	1	<0.0001*	0.31	1	0.5759
HW	104	1.73	1	0.1911	67.33	1	<0.0001*	3.30	1	0.0723
M	89	5.45	1	0.0220*	25.79	1	<0.0001*	2.43	1	0.1225

separately, there were no significant differences in body size and some head dimensions between the species, except for the head height (see Tab. 2). However, *I. horvathi*'s heads tended to be more flattened, whereas the heads of *P. muralis* have a higher arc. Flatness of *I. horvathi* heads has been reported already before and is a trait that is often used in general description of this species (e.g. Radovanović, 1951; Mršić, 1997; Arnold and Ove-

den, 2002, Cabela et al., 2007; Lapini et al., 1993, 2004). Flat head was also described as a general trait for all species of genera *Iberolacerta* (Arnold et al., 2007). Most of the species from genera *Podarcis* and *Iberolacerta* use crevices as escape sites and their body and heads are moderately to very depressed (Arnold and Oveden, 2002).

Both species also displayed the same pattern of sexual dimorphism regarding body size, head size and shape not only in direction but also in magnitude. Females had longer snout-vent lengths whereas males carried relatively bigger heads in all dimensions but length. In the family Lacertidae, considerable lability in the direction of sexual size dimorphism have been found both between (reviewed in Cox et al., 2007) and within species where either males or females are bigger depending on the population (Roitberg and Smirina, 2006 a, b; Roitberg, 2007) in response to geographic variations in the relative contributions of sexual, fecundity and natural selection forces (Kaliontzopoulou et al., 2010 a, b). Across populations of lacertids, size (snout-vent length and body mass) was described to be either male-biased with males having larger body sizes (Vogrin, 2005; Kaliontzopoulou et al., 2007; Brecko et al., 2008; Kaliontzopoulou et al., 2008 a; Aleksić et al., 2009), or female-biased with females having larger size dimensions on account of a longer trunk (Kratochvíl et al., 2003; Liu et al., 2008). More specifically in the case of *P. muralis*, the direction of the sexual size dimorphism observed in our study (females longer than males) was not always found. Namely, in some populations no significant difference in snout-vent length between adults of the two sexes was observed (Barbault and Mou, 1988; Srijbosch et al., 1980; Allan et al., 2006) whereas in others even there was the opposite trend, males being longer than females (Gracceva et al., 2008), than showed here. The results from this study corroborate that interpopulation variability in sexual size dimorphism is very high in *P. muralis*.

On the other hand, comparing data for *I. horvathi* with the only extensive morphometric study previously carried out for this species, our study show similar trends: females were significantly larger in snout-vent length than males (De Luca, 1989). However, in the study of De Luca (1989), data of females and males from two populations were pooled together which posed doubts on the reliability of the results since inter-population variation in lacertids is known to be high and snout-vent length tends to be sexually dimorphic in lacertid lizards (i.e. Kaliontzopoulou et al., 2010 a, b). Hence, it is crucial to size-adjust other morphological traits before comparing them (Kratochvíl et al., 2003). More populations of *I. horvathi*, as well as of *P. muralis*, should be studied in the future to recognize if different patterns of sexual size and shape dimorphisms are exhibited in different populations.

Regarding the sexual shape dimorphism, there were head shape differences in both species with males having relatively wider and higher (but not longer) heads. For *I. horvathi*, Bischoff (1984) and De Luca (1989) already suggested a similar pattern. Likewise, mostly all morphometric studies of *P. muralis* populations also found the same trend, e.g. males having larger heads adjusted to snout-vent length than females (Gracceva et al., 2008) or males having larger jaw sizes and larger heads than females (Aleksić et al., 2009). The direction of sexual shape dimorphism in the head robustness is common to whole family Lacertidae in which males have wider and bigger relative head measurements and also longer limbs (Herrel et al., 1996; Kratochvíl et al., 2003; Bruner et al., 2005; Vogrin, 2005; Kaliontzopoulou et al., 2007; Kaliontzopoulou et al., 2008 a; Ljubisavljević et al., 2008; Aleksić et al., 2009). Although the direction in shape sex dimorphism is common, its magnitude is highly variable between species (Verwajen et al., 2002; Kaliontzopoulou

et al., 2007; Ljubisavljević et al., 2008), but even though, in our case almost no differences in the amount of sexual shape dimorphism were detected between both species living in the area of sympatry. Actually, the analysis revealed that sexual dimorphism was in general higher (significant differences in all but one biometric characters) than species variation (significant differences only in head height and relative body mass, Tab. 2).

Summarizing, the lacertids *P. muralis* and *I. horvathi* show remarkable similarities not only in general size and shape (and in colouration; De Luca, 1989; Arnold and Oveden, 2002), but also in their sexual dimorphism patterns. Our study comparison of inter- and intraspecific sexual dimorphism patterns from localities in the sympatric area confirmed that *P. muralis* and *I. horvathi* are very similar. Together with their ecological similarities these facts suggest that, in absence of other factors, they are likely to be in interaction when living together. With our analysis we could not yet identify what type of interspecific interaction is present between both species, but most probably acts as interference which is commonly found in predator guilds (e.g. Carothers and Jaksić, 1984; Robinson and Terborgh, 1995; Linnell and Strand, 2000), and even in lacertids (Downes and Bauwens, 2002, 2004). In this perspective, results suggest potential for competition between species since interspecific effects in sympatric populations were not expressed in morphological, i.e. coevolved divergences. Perhaps such effects are expressed in other phenotypic or ecological adaptations, e.g. spatial segregation or resource partitioning (Tokeshi, 1999) that need to be investigated in the future. Thus, biometric comparisons could provide a first evaluation of competitive potential between lacertids of similar size belonging to the same predator guild (Valverde, 1967). If interspecific size differences are smaller than intraspecific, i.e. sexual dimorphism, this might suggest species to be potential competitors. On the other hand, equal or larger interspecific size differences could indicate already coevolved niche differentiation and consequently lower competition potential, i.e. "ghost of competition" pattern (Begon et al., 2006). Multipopulation comparison of sexual dimorphism and morphological divergence between both species in allopatry and sympatry should be carried out to test the hypotheses of character displacement and relaxation of interspecific competition (Butler et al., 2007).

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