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An exceptionally high frequency of melanism in a population of viviparous lizards *Zootoca vivipara* in southwestern Germany

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Different adaptations such as polychromatism, changes in inter- and intraspecific behaviour, or physiological adaptations potentially increase survival and reproduction success. Melanism is a common expression of polychromatism found in many reptiles (e.g., Kuriyama et al. 2020). Melanism in reptiles might have an advantage for thermoregulation and various studies have demonstrated that melanistic ectotherms may heat up more quickly than their non-melanistic relatives (e.g., Gibson & Falls 1979), but the thermoregulatory advantage hypothesis is controversially discussed and still is vaguely supported (e.g., Gvozdik 1999, Clusella Trullas et al. 2007). Apparently melanistic phenotypes of snakes and lizards are more frequent at higher altitudes than in lowland situations (Luiselli 1992, Clusella Trullas et al. 2007, Alho et al. 2010, Recknagel et al. 2018). Also, physiological differences are often correlated with a form of polychromatism, i.e., melanistic morphs of the Italian wall lizard, *Podarcis sicula* (Rafinesque, 1810),were found to have a lower ectoparasite load than non-melanistic conspecifics (Monti et al. 2013, Baekens & van Damme 2018), but showed an enhanced level of α-MSH acting as an antagonist of the melanocortin receptor and likely triggering a higher resistance to ectoparasites.

Melanistic individuals have been found in different regions and genetic lineages throughout the extensive distributional range of viviparous lizard *Zootoca vivipara* (Lichtenstein, 1823) (e.g., Recknagel et al. 2018). Although variable phenotypes are known for *Z. vivipara* (e.g., Dely & Böhme 1984) melanistic morphs are most common, yet in Central Europe, they still are rarely reported, and appear to occur at very low proportions in nature (see Glandt 2001). Herein we report on high numbers of melanistic common lizards, *Z. vivipara*, from a natural population inhabiting peat swamps located in southwestern Germany (Upper Swabia, Baden-Württemberg state). We compare our findings with previous reports and discuss potential reasons for such a high rate of melanism.

We examined a total of 48 viviparous lizards, *Z. vivipara,* captured at the Haidgauer raised bog (c. 47°55'00.8" N, 9°51'53.1" E) of the "Wurzacher Ried", a high moor with open undisturbed wet peatland (e.g., Poschlod et al. 2007) at altitudes of around 650 m a.s.l. All lizards were collected between 1992 and 1994 by means of barber pitfall traps set on six plots, originally intended to sample ground beetles (Jansen et al. 1998), with a solution of ca. 4% unbuffered formaline, were then transferred to 70% ethanol, and later stored in the herpetological collection of the State Museum of Natural History Stuttgart (SMNS) with accession numbers SMNS 15201-15248. We measured snout–vent lengths (snout tip to cloaca, in mm) using digital callipers (Mituyo, Japan), and identified their age classes, sexes, coloration type and scutellation type following Voipio (1991). The degree of melansim of *Z. vivipara* follows the descriptions of melanistic phenotypes of Recknagel et al. (2018). We regarded individuals with a fully dark grey to black venter and a darker brown to black dorsum as melanistic. Some darkly pigmented individuals still showing hints of the normally-coloured phenotype on the dorsum and having a highly melanin-based or complete black venter we classified as semi-melanistic (see also Vroonen et al. 2013). All lizards were also checked for the presence of regenerated

tails and their ectoparasite load (ticks and mites, see Wu et al. 2019). If sample size permitted it we compared SVL between different phenotypes using univariate t-tests. SVL was tested for normal distribution with graphical methods and with the Anderson-Darling test. Statistical analysis was carried out with Prism 6.0 for Macintosh following Sokal & Rohlf (1981) with Alpha set at 0.05.

A total of 48 viviparous lizards *Zootoca vivipara* were obtained from pitfall traps between April and October at the study site at the Wurzacher Ried. We found a high rate of melanistic lizards (overall proportion of 33%) distributed across all age classes, but mostly among adults (see Table 1). Regardless of their polychromatism all lizards shared pileus scale-type A (after Voipio 1992), i.e., the internasal shield was separated from the frontals by two prefrontal scales (see Fig. 1). Fully melanistic lizards across all age classes appeared dorsally dark brownish to completely black, lacking any pattern, and were also coloured dark greyish to completely black ventrally (Figs 2A, D). The general appearance of semi-melanistic individuals resembled the normal chromatotype with visible linear or reticulated black paravertebral lines that were much darker, however (Fig. 2B), and some semi-melanistic lizards had a typical light cream-white gular colouration and a completely black venter. The dorsal coloration of 'normal' *Z. vivipara* (47.9% of the total sample) ranged from medium to dark brown with either the typical dark or/and brighter paravertebral lines and several dark spots in-between, whereas the ventral coloration was the typical cream-white (Figs 2C, E). We recorded six melanistic females out of ten (40%) and four melanistic adult males out of 16 individuals (25%), moreover, nine semi-melanistic lizards (six adult and two subadult males and one subadult female, see Table 1) were detected. The two melanistic females and males were on average larger than the normal chromatotypes (49.5 vs. 46.3 mm SVL in females and 43.6 vs. 40.3 mm SVL females, see Table 1). All adult and subadult melanistic lizards were slightly, but not significantly, larger than the normal chromatotypes (45.1 vs. 42.2 mm, t-test = 1.686, df = 21). The smallest melanistic juvenile (age class 0+) had a SVL of 19.5 mm. Ten out of 48 lizards (21% of all age classes) had regenerated tails, four of these were melanistic. Seven out of 48 lizards (14% including all age classes) had an ectoparasite load of ticks only.To the best of our knowledge this is the first quantitative evidence of melanistic *Z vivipara* in southwestern Germany subsequent to the record of a single melanistic female (Klunzinger 1903) collected near

Figure 1. Dorsal view of the head of a melanistic female viviparous lizard, *Zootoca vivipara* (SMNS 15218), exhibiting pileus scale-type A after Voipio (1992). I = internasal, PF = prefrontals, F = frontals. Scale bar: 5 mm.

Table 1. Sex, age class, mean size (snout–vent length, SVL, ± standard deviation, SD) and frequency of melanistic, semi-melanistic, and "normally" coloured viviparous lizards, *Zootoca vivipara*, at the Wurzacher Ried.

age	sex	morph	N	SVL±SD (mm)	melanism frequency (%)
adult (26)	female	melanistic	6	49.5±5.5	38.5
		semi-melanistic	–	–	
		"normal"	4	46.3±2.2	
	male	melanistic	4	43.6±4.1	
		semi-melanistic	6	42.6±2.7	
		"normal"	6	40.3±2.4	
subadult (5)	female	melanistic	1	37.1	20.0
		semi-melanistic	1	37.7	
		"normal"	–	–	
	male	melanistic	1	32.8	
		semi-melanistic	2	35.2±0.9	
		"normal"	–	–	
juvenile (17)		melanistic	4	21.7±2.6	23.5
		semi-melanistic	–	–	
		"normal"	13	23.6±2.8	

Isny in 1880 (SMNS 975) and some more recent records of adult melanistic lizards in the Altdorfer forest in Upper Swabia. Most findings of melanistic viviparous lizards refer to high altitudes, i.e., 1,400 to 1,500 m a.s.l. at the Gailtal Valley (Carinthia, Austria, Recknagel et al. 2018) or to the Bavarian Alps at 1,680 m (Malkmus 1976), whereas the study site at Wurzacher Ried in Upper Swabia lies at a moderate altitude of around 650 m a.s.l. Previous reports identified melanistic lizards at much lower proportions, e.g., two out of 62 (3.2%) or two out of 197 individuals (1%, see also the overview in Recknagel et al. 2018), whereas 10 out of 26 adult lizards were melanistic at our study site.

The habitat itself might also contribute to the high frequency of melanism among viviparous lizards with regard to the thermoregulatory advantage hypothesis. The Wurzacher Ried covers more than 1,700 ha of moorland, including the nearly pristine Haidgauer raised bog surrounded by transition mires and various fen types with several smaller lakes and ponds (Poschlod et al. 2007). As the Haidgauer raised bog has a fairly low annual average temperature of 7°C with minima of -7°C, the increased frequency of lizard melanism in such a relatively cold and wet environment potentially indicates a selection towards a thermoregulatory advantage. Noteworthy also is that syntopic common adders (*Vipera berus*) have a high degree of melanism at the same site (see Fritz et al. 2007). However, the thermoregulatory advantage hypothesis has been sustainably proven neither for an increased reproductive success nor for benefitting the locomotion of viviparous lizards yet (compare also Moreno Azócar et al. 2020), because previous records of single individuals or small sample sizes did not allow for any quantitative testing (compare also Gvozdik 1999). On the other hand, the dark moor underground of the core area of the Wurzacher Ried might simply select naturally for darker lizards and ultimately promote the existence of dark chromatotypes. The extraordinary high number of melanistic lizards at the Wurzacher Ried should motivate future comparative re-

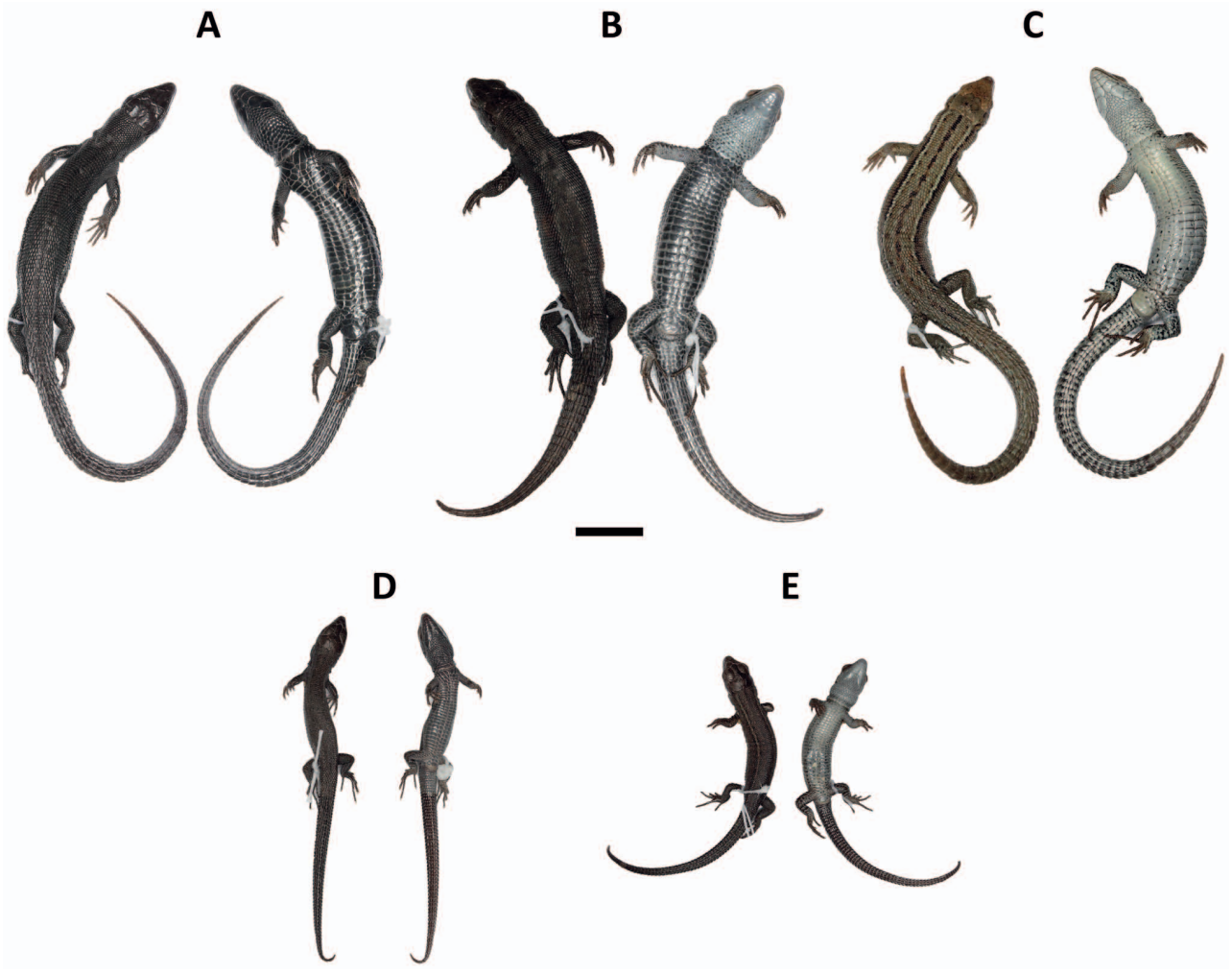

Figure 2. Dorsal and ventral views of three types of polychromatism of viviparous lizards, *Zootoca vivipara*, at the "Wurzacher Ried". (A) melanistic female (SMNS 15217), (B) semi-melanistic male (SMNS 15221), (C) "normally" coloured male (SMNS 15219), (D) melanistic juvenile (SMNS 1539), and a (E) "normally" coloured juvenile (SMNS 15240). Scale bar: 10 mm.

search tackling some of the key questions of the adaptive significance of melanism in viviparous lizards (see Recknagel et al. 2018).

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