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BERGMANN'S RULE IS SIZE-RELATED IN EUROPEAN NEWTS (*TRITURUS*)

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The validity of Bergmann's rule – which describes the intraspecific increase in body size with increasing altitude – was studied in a several populations of three European newt species. There was a positive correlation between body size and altitude for smaller-bodied *Triturus vulgaris* and *T. alpestris* species, but no relationship between body size and altitude for the much larger sized *T. carnifex*. Body size therefore plays a role in the application of Bergmann's rule to European newts.

Key words: altitudinal gradient, morphology, *Triturus vulgaris*, *Triturus alpestris, Triturus carnifex*

Bergmann's rule states that there is an intraspecific tendency toward larger body size in cooler environments (Mayr, 1956). However, tests of Bergmann's rule have traditionally relied upon latitude or altitude as a proxy for temperature (Ashton *et al.*, 2000). Originally restricted to mammals and birds (Mayr, 1956), it was recently claimed that Bergmann's rule holds true for amphibians in general, but more clearly for tailed amphibians than for anurans (Ashton, 2002*a*). However, body size data (10 or more location sites) for several populations spread over altitude/latitude gradients are available for only a few species. For instance, among the European newts (*Triturus* spp.), only limited data for *T. alpestris* and *T. marmoratus* have been reported (Miaud *et al*., 2000 and Díaz-Paniagua *et al*., 1996, respectively). More studies, with extensive sampling, of body size variation of amphibians are required to further evaluate the validity of Bergmann's rule for this group.

We collected population body size data for three *Triturus* species to further evaluate Bergmann's rule in amphibians. The sampling locations vary considerably in altitude, but little in latitude (less than 5°). This enables a test of the intraspecific association between body size and altitude while minimizing the possible confounding effect of latitude. Because the three species of *Triturus* differ in body size (maximum total lengths for *T. vulgaris* and *T. alpestris* are about 100 mm, whereas it is about 170 mm for *T. carnifex;* Griffiths, 1996), we also investigated the influence of body size on intraspecific size-altitude body size trends.

Population samples came from Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro and FYR Macedonia. The studied newts came from Dr Georg Dzukic's Herpetological Collection (Institute for Biological Research, Belgrade). Only mature newt individuals, collected during the breeding season, were studied. Due to the sexual dimorphism in newts, which is most prominent in *T. alpestris* (e.g. Kalezic *et al*., 1992), males and females have been treated separately in our study. Our data set was obtained from 39 population samples of *T. vulgaris* (mean no. of specimens per sample±SD: 22.0±3.84 and 22.28±3.68 for males and females, respectively), 19 population samples of *T. alpestris* (24.8±5.3 males and 25.7±5.3 females), and 22 population samples of *T. carnifex* (16.5 ±3.8 males and 17.5±3.4 females). Samples were collected from most of the vertical distributional range recorded for the study species (see Griffiths, 1996). The ranges were: 0-1650 m for *T. vulgaris*, 80- 2100 m for *T. alpestris,* and 0-1550 m for *T. carnifex.*

The snout-vent length (SVL), distance from the snout to the posterior edge of the cloaca, was measured for each specimen from each population. Variation in body size within species, represented by the difference between the minimum and maximum average SVL values of the population samples studied, was as follows: *T. vulgaris* 30.1-43.1 mm and 30.3-44.7 mm (males and females, respectively); *T. alpestris* 37.7 - 48.2 mm in males and 42.5- 55.0 mm in females; *T. carnifex* 103.7-129.7 mm in males and 117.0-146.9 mm in females.

We used simple linear regression analyses to assess the relationship between body size (average SVL values for sampled populations) and altitude for each of the *Triturus* species. Average SVL was significantly positively associated with altitude for *T. vulgaris* (r=0.44, P<0.01 for males; r=0.46, P<0.01 for females), and for *T. alpestris* (r=0.59, P<0.01 for males; r=0.53, P<0.05 for females; Fig. 1). However, the larger-sized *T. carnifex* did not show a significant relationship between SVL and altitude for males (r=0.010, P=0.96) or females (r=0.087, P=0.70; Fig. 1).

To date, the relationship between body size and the tendency of a Bergmann's rule trend has been studied in birds and mammals. While no relationship between the tendency of a Bergmann's rule trend and body size has been found in birds (Ashton, 2002*b;* Meiri & Dayan, 2003), conflicting results have emerged for mammals (Ashton *et al*., 2000 vs. Meiri & Dayan, 2003; Freckleton *et al.,* 2003). Apparently, Bergmann's rule appears to be size-related in European newts. In contrast to the much smaller *T. vulgaris* (this study) and *T. alpestris* (Miaud *et al.*, 2000; this study), large-bodied species (*T. marmoratus*, Díaz-Paniagua *et al*., 1996 and *T. carnifex,* this study), do not show significant relationships between body size and altitude or latitude. Larger-bodied species may not show significant size trends because their large size makes them less sensitive

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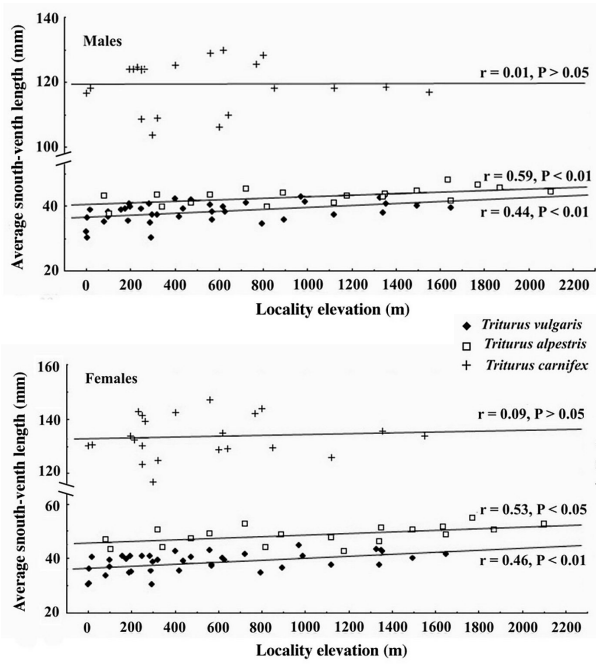

FIG 1. Relationship between body size (snout-vent length) and locality elevation for males and females of *Triturus vulgaris, T. alpestris* and *T. carnifex.*

to environmental differences across populations (e.g. temperature, water availability, difference in activity period). Together with selection acting on different life-history traits correlated with body size, such factors may underlie geographical size variation in amphibians (Ashton, 2002*a;* Morrison & Hero, 2003).

In conclusion, smaller-bodied species of European newts (*T. vulgaris* and *T. alpestris*) increase in body size with altitude, whereas body size for the larger-sized *T. carnifex* does not change with size, suggesting that body size of smaller-bodied salamanders is more influenced by environmental factors. Given that all three species are broadly sympatric over much of their altitudinal ranges, they represent promising candidates for further research aimed at examining mechanisms that generate patterns of body size variation in terrestrial ectothermic vertebrates.

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