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EFFECT OF LATITUDE AND ALTITUDE ON BODY SIZE IN THE COMMON FROG (*RANA TEMPORARIA*) POPULATIONS

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INTRODUCTION

The mean value of a given trait in a population is determined by genetic factors, environmental influences and the interaction between the two (Falconer and Mackay, 1996; Miaud and Merilä, 2001). When assessing the adaptive potential amongst different populations of a species, the first step is to establish to what degree the observed differences among populations are of genetic or environmental origin (Berven and Gill, 1983). According to Bergmann's rule (Bergmann, 1847) the body size of species increase with latitude/altitude, so that populations in cooler climates tend to be larger than congeners from warmer climates. Bergmann's rule is not generally applicable to amphibians (Adams and Church, 2008), since some species follow the Bergmann's rule whereas other exhibit varying patterns between latitude and altitude (Ashton, 2002; Krizmanic et al., 2005; Laugen et al., 2005; Cvetkovic et al., 2008). Laugen et al. (2005) investigated patterns of body size variation in the common frog (*Rana temporaria)* along a latitudinal gradient and concluded that they are partly genetically determined and existed variation in mean body size does not conform to Bergmann's rule.

The Common Frog (*Rana temporaria*) is the most widespread amphibian species in Europe (Gasc et al., 1997). Its distribution reaches 71^0N in north Scandinavia (Merilä et al., 2000) and can be found even at altitudes above 2600 m (Gasc et al., 1997). The wide altitudinal and latitudinal range and the relatively well-studied life-history of this species, allow longitudinal and altitudinal comparisons over a broad range of conditions. Review of variation in life- history traits between *R. temporaria* population varying in altitude and latitude was made by Miaud and Merilä (2001) and Miaud et al. (1999).

In the present paper we present the altitudinal and latitudinal body size variation among 16 populations of *R. temporaria* testing if the variation pattern is according to Bergmann's rule. As body size indices we used the wet weight (W) and the snout-vent length (SVL). We tested the following predictions: (i) mean body size indices of frog populations from higher latitudes will be significantly larger than those from lower latitudes, and (ii) mean body size indices of *R. temporaria* populations from low altitudes will be significantly higher than those from high altitudes.

MATERIAL AND METHODS

Measurements on *R. temporaria* adults and juveniles from 16 populations were done in Kilpisjarvi, Finland (latitude N 69^0) in 2003, and in Retezat National Park, Romania (latitude N 45^0) in 2004. Latitude and altitude were recorded for each population using a handheld Garmin GPS. Captured individuals were sexed, weighed to the nearest 0.01 g with a portable electronic balance (AccuLab Pocket Pro), and snout-vent length (SVL) was measured to the nearest 0.5 mm with dial-calipers. The data were analyzed with a one-way Anova. In this design W and SVL were entered as dependent variables and populations as fixed factors. Data were log transformed prior to analyses to accomplish assumptions of normality and homogeneity of variance. The normality of data was tested using the Kolmogorov-Smirnov test. All analyses were done using SPSS ver. 10.0 (SPSS Inc., 1999).

RESULTS AND DISCUSSIONS

A total of 391 individuals were measured and weighed, of which 272 juveniles and 119 adults (74 males and 45 females). Both W and SVL were normally distributed (W: D = 5.060, $p < 0.001$; SVL: D = 3.746, $p < 0.001$). Variation of body size indices among the studied populations is presented in tables 1 and 2. The analysis of SVL and W variation in *R. temporaria* populations indicated that both altitude and latitude explain significant amounts of variation in the mean body size indices of both adults and juvenile (Table 3). Evaluation of body size indices variation according to Bergmann's rule showed different patterns. Latitudinal variation patterns in juveniles for both SVL and W were according to Bergmann's rule. In males and females we observed an opposite latitudinal variation pattern for both body size indices. The altitudinal variation pattern of SVL and W was analyzed only for juveniles and was found to be concordant with the pattern described by Bergmann's rule.

Table 1. Variation measures (SD and range) and mean values of SVL on sex and age classes, among 16 populations of *R. temporaria* from Finland and Romania (RL = Retezat low altitude populations and RH = Retezat high altitude populations). M = male, F = female, J = juvenile, SD = standard deviation, min = minimum, max = maximum

Populations	F			M			J		
	Mean	SD	Range (Min –Max)	Mean	SD	Range (Min –Max)	Mean	SD	Range (Min –Max)
Malla 1^{F}	60.05	2.71	57.2-64.6	71.35	1.62	70.2-72.5	36.82	9.87	20.6-51.4
Malla 1.1^{F}	58.90	3.381	55.0 -61.0	-	-	-	36.33	8.57	21.4-50.0
Malla 1.2^{F}	-	-	-	68.26	7.97	59.1-73.6	45.84	5.85	38.3-52.5
Malla 2^{F}	-	-	-	-	-	-	30.15	7.06	26.9-33.4
Stația 20^{F}	68.70	6.93	63.8-73.6	67.79	4.31	62.0-76.5	25.84	6.15	18.5-41.8
Stația 40^{F}	66.80	6.45	56.0-75.0	65.78	3.39	59.6-71.7	28.87	10.08	19.8-50.7
Stația 60^{F}	-	-	-	-	-	-	32.85	7.06	21-40.7
Stația 70^{F}	70.37	5.40	59.8-75.6	-	-	-	24.30	4.59	17.3-52.5
Iezilor Lake^{RH}	79.71	10.80	65.5-91.8	77.37	4.09	66.0-82.5	22.92	8.71	16-54
Secat Lake^{RH}	89.70	11.09	77-97.5	81.00	4.95	77.5-84.5	-	-	
Lăpuşnicul Mare^{RL}	-	-	-	-	-	-	23.14	13.13	15-40
Lunca Berhină^{RL}	-	-	-	-	-		18.03	1.73	15-20
Râul Mare^{RL}	-	-	-	67.92	3.06	63.7-71	23.16	9.06	17-50
Tăul Radeş^{RH}	96.85	11.10	89-104.7	78.76	10.1	63.0-90.5	26.30	0.99	26-27
Tăul Judele^{RH}	68.50	5.65	64.5-72.5	72.40	4.86	64-76	29.70	25.88	11-48

Table 2. Variation measures (SD and range) and mean values of W on sex and age classes, among each of the 16 populations of *R. temporaria* from Finland and Romania (RL= Retezat low altitude populations and RH = Retezat high altitude populations). M = male, F = female, J = juvenile, SD = standard deviation, min = minimum, max = maximum

Populations	F			M			J		
	Mean	SD	Range (Min-Max)	Mean	SD	Range (Min -Max)	Mean	SD	Range (Min -Max)
Malla 1^{F}	23.17	2.29	21-26	40.90	1.69	39.7-42.1	5.98	4.27	1-14
Malla 1.1^{F}	23.57	3.23	20-26	-	-	-	5.61	4.04	1-16
Malla 1.2^{F}	-	-	-	36.06	12.05	22.4-45.2	10.04	3.37	6-14
Malla 2^{F}	-	-	-	-	-	-	3.05	1.34	2-4
Stația 20^{F}	28.45	5.44	25-32	27.61	4.69	20.2-34.6	1.72	1.37	1-6
Stația 40^{F}	28.48	7.09	19-39	30.66	6.77	23-46.1	3.00	3.33	1-12
Stația 60^{F}	-	-	-	-	-	-	3.37	1.86	1-6
Stația 70^{F}	41.70	10.15	26-54	-	-	-	2.14	3.23	0.4-14
Gemenele Lake^{RH}	78.65	25.04	12-105.4	-	-	-	-	-	-
Iezilor Lake^{RH}	57.34	29.60	28.5-112	49.90	10.02	26-67	1.82	3.20	0.3-17.8
Secat Lake^{RH}	56.30	14.98	39.0-65.4	33.95	22.42	18-50	-	-	-
Lăpuşnicul Mare^{RL}	-	-	-	-	-	-	2.32	4.15	0.3-11.5
Lunca Berhină^{RL}	-	-	-	-	-	-	0.54	0.16	0.3-0.7
Râul Mare^{RL}	-	-	-	34.45	4.63	28-37	1.44	3.20	0.4-13.5
Radeş Lake^{RH}	107.95	35.14	83.1-132.8	51.82	21.67	25-82	1.60	0.14	1.5-1.7
Judele Lake^{RH}	35.00	12.72	26-44	35.02	9.02	21-44	5.05	6.85	0.2-9.9

Table 3. The analysis of covariance testing for significant differences in altitude and latitude of SVL and W variation between *R. temporaria* populations from Finland versus Retezat National Park (RNP), and from RNP low altitude versus RNP high altitude populations. N = number of specimens, *P < 0.05, ***P < 0.001, NS = not significant

	SVL					**W**				
	Mean		**N**		**F**	**Mean**		**N**		**F**
F vs RNP	**F**	**RNP**	**F**	**RNP**		**F**	**RNP**	**F**	**RNP**	
Female	65.94	82.06	29	16	-5.71***	31	59.68	29	24	-6.58*
Male	67.58	76.07	32	42	-6.55***	31.75	45.55	32	42	-5.16*
Juvenile	29.01	22.77	197	75	4.58***	3.17	1.80	197	75	2.93*
RH *vs* RL	**RH**	**RL**	**RH**	**RL**		**RH**	**RL**	**RH**	**RL**	
Juvenile	24.42	20.03	40	34	2.04 *	2.18	1.01	40	34	1.74^{NS}

Geographical variation of body size in *R. temporaria* populations is generally ascribed to variations of growth rates as a result of environmental differences. Variations in growth patterns are correlated with other traits and processes such as larval body length at metamorphosis, duration of activity period, resource availability and storage, and mortality caused by predation and disease (Miaud and Merilä, 2001).

There is a well documented general positive relation between condition during the aquatic stage and length at metamorphosis, i.e. amphibian larvae that are large at metamorphosis turn into larger adults (Smith, 1987). Therefore populations from high altitude or latitude should react to adverse conditions (i.e., shorter growth period, low temperature, and limited food resources) by growing larger. In contrast our study indicated that adult frogs showed an opposite response for both body size indices. An explanation for our results could be that small body can provide a thermal advantage in cold climate by allowing more accurate thermoregulation than large one, for example more rapid heat gain. Thus, evolution of larger body size in colder environments appears to be a disadvantageous thermoregulatory strategy (Ashton, 2002; Pincheira-Donoso et al., 2008). Ashton (2002) suggested that rainfall and humidity could be important selective factors behind latitudinal and altitudinal body size trends in adult amphibians. Large individuals have better desiccation tolerance than smaller individuals (e.g. Newman and Dunham, 1994), so this could select for large body size in dry environments. Other explanation for the pattern of body size variation contrary to Bergmann's rule in adults could be the genetically origin of this. Laugen et al. (2005) compared body size variation along a latitudinal gradient among *R. temporaria* adults and juveniles. As metamorphic and adult size are correlated in amphibians, the same pattern of body size variation along a latitudinal gradient indicate that variation of body size could be partly genetically driven. The results of our study do not support the hypothesis that latitudinal and altitudinal variations in body size of *R. temporaria* populations follow Bergmann's rule.

CONCLUSIONS

We found a weak correlation between altitudinal and latitudinal variation in body size and weight and Bergmann's rule. This suggests that the pattern of body size variation in *R. temporaria* results from the interaction of more environmental factors.

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ABSTRACT

The wide domain of distribution, both altitudinal and latitudinal, of the specie *Rana temporaria* allows testing the Bergmann law. This law affirm that the dimensions of individs that belongs to the same specie are larger in the areas with low temperatures and high latitudes, comparing with the warmer area or at low latitudes. Thus we studied intraspecific variation of body length (*Lc*) and weight (*G*) at 15 populations of *R. temporaria* and we testes (i) if the media of body dimensions (*Lc* and *G*) of *R. temporaria* populations from The Reservation Malla, Finlanda (latitude N: 69^0) is meaningful higher than the populations from the National Park Retezat (PNR), Romania (latitude N: 45^0) and (ii) if the media of body dimensions from lower altitudes (average altitude: 1004 m) from PNR is meaningful lower than the media of body dimensions at populations from PNR from higher latitudes (average altitude: 2093m). The low of Bergmann was confirmed both latitudinal and altitudinal by the both measurements at juvenile animals. Latitudinal, the females and males, for *Lc* as well as for *G,* presents an inverse variation than the one suggested by the Bergmann low.

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