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Global warming, body size and conservation in a Qinghai-Tibet Plateau lizard

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Global mean temperatures have increased by 0.3–0.6°C since the late 19th century, affecting the physiology, distributions, phenology and adaptations of plants and animals. In the Qinghai-Tibet Plateau, average annual temperatures increased by an average of 0.25°C per decade from the 1970s to the 1990s, and by an average of 0.34°C per decade thereafter. Using museum collections from the 1950s to the 2000s and published references, we tested the hypothesis that body size of the toad-headed lizard *Phrynocephalus vlangalii* in the Qinghai-Tibet Plateau declined between 1954 and 2008 as a response to global warming. However, body size of males and females did not vary significantly between 1954 and 2008, probably due to the reciprocity between higher food availability and earlier age at sexual maturity. We suggest that human activity might result in declining population sizes in the future despite the lack of an apparent current response to changing climates.

Key words: body size, global warming, Qinghai-Tibet Plateau, Toad-headed lizard

INTRODUCTION

Global mean surface temperatures have increased by 0.3–0.6°C since the late 19th century (IPCC, 2001), and global climate change has affected the physiology, distribution, phenology and adaptation of all major groups of animals (Hughes, 2000; Parmesan, 2006). Body size is among the most important morphological traits, and is related to ecological and environmental gradients (Schmidt-Nielsen, 1984; Lomolino & Perault, 2007; Meiri, 2011). Of the environmental factors known to influence body size, temperature is one of the strongest and most pervasive. Bergmann's rule, a negative correlation between body size and temperature, is well documented in many endothermic and ectothermic animals (Ashton et al., 2000; Ashton, 2002; Sacchi et al., 2007; Liao & Lu, 2010, 2012). Over longer time periods, variation in body size has been shown to change predictably in response to recent climate change (Schmidt-Nielsen, 1984; Meiri & Dayan, 2003; Lomolino & Perault, 2007; Oufiero et al., 2011). Accordingly, species and lineages that support Bergmann's rule should evolve towards smaller sizes during episodes of climatic warming. Previous studies revealed that species of birds, lizards and mammals are exhibiting decrease in body size that are linked to climate change (Yom-Tov et al., 2006, 2011; Chamaillé-Jammes et al., 2006; Pincheira-Donoso et al., 2008; Van Buskirk et al., 2010; Gardner et al., 2011). Global climate warming is generally expected to be a major factor influencing biodiversity in the future (Thomas, 2010; Hoffmann & Sgrò, 2011). Thomas et al. (2004) predict that up to 37% of species on Earth might be threatened by extinction because of the ongoing rise in temperature, resulting in distribution shifts and increasing probabilities of population extinction (Peterson et al., 2002; Lovejoy & Hannah, 2005).

The toad-headed lizard *Phrynocephalus vlangalii* is distributed in Qinghai, Gansu, Xinjiang and northwestern Sichuan (Zhao & Adler, 1993). Individuals are typically found in open spaces in arid or semiarid regions covered by sparse vegetation at elevations ranging from 2000 to 4500 m. Recently, it has been suggested that population size and distributional ranges have declined (Jin et al., 2008). In the present paper we use long-term data across 54 years to quantify changes in body size in relation to rising temperatures.

MATERIALS AND METHODS

The Qinghai-Tibetan Plateau is the highest and largest plateau in the world, with an average elevation of 4000 m above sea level and an area of 2.65×10^6 km^2 (Zhang, 1983). The inhabiting biodiversity depends greatly on environmental temperatures, and is considered to be highly sensitive and vulnerable to global climate change (Zheng, 1996). In the Qinghai-Tibet Plateau, average annual temperatures increased by an average of 0.25°C per decade from the 1970s to the 1990s, and by an average of 0.34°C per decade after the 1990s (Wang et al., 2000; Lu et al., 2009).

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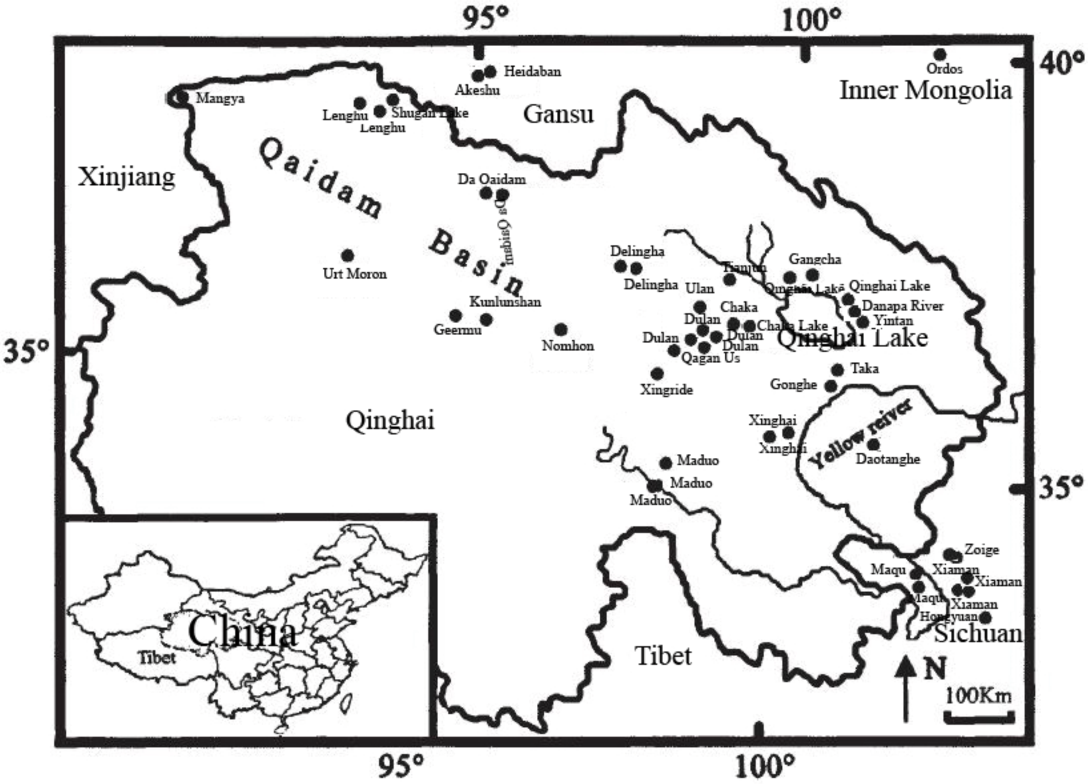

Fig. 1. Topographic map showing the study sites of the sampling 47 populations on Qinghai-Tibet Plateau in China. Black circle indicates a sample population.

Specimens used in the study were collected from 47 locations throughout the species' range in the Qinghai-Tibet Plateau (Fig. 1). We used data on body size of 437 specimens of Zoological Museum in Chengdu Institute of Biology, Chinese Academic of Science. Additionally we retrieved data for 830 individuals from published references (Jin, 2008; Jin et al., 2006). We recorded the month and year of collection, altitude, latitude and longitude for each population (Table 1). Snout-vent length (SVL) and tail length (TL) were measured to the nearest mm using a caliper. Differences in body size in both sexes between museum-preserved specimens and field-captured individuals should be non-significant because the 4% neutral buffered formalin did not significantly change body sizes of all museum-preserved specimens (personal observations). Individuals with SVL above 48 mm were considered as adults (following Zhang et al., 2005).

We used multiple regressions to test the effect of month and year of collection, altitude, latitude and longitude on body size. We accounted for the monthly variation in body size by using the sinusoidal component $\sin(2*\pi*I/12)$, where I=month, and May (the month with highest values for all parameters)=1, June=2, etc. (following Yom-Tov & Yom-Tov, 2005). The SDI was calculated according to Lovich & Gibbons (1992) as SDI=larger sex/smaller sex-1 (SDI is arbitrarily defined as positive when females are larger than males). To identify correlates of body size we used a multiple regression with body size controlled for monthly changes as dependent variable, and latitude, longitude and altitude of the locality of collection as well as year and month of collection as independent variables. Using Pearson correlation coefficients, we estimated the relationships between residual body size and year. $p<0.05$ (two-tailed) was considered statistically significant. All analyses were performed by using Type III sums of squares tests with the SPSS (v.17.0) statistical package.

RESULTS

Females were the larger sex in 24 out of 47 populations, and males were the larger sex in the remaining 23 populations. Population mean SVL ranged from 42.2 to

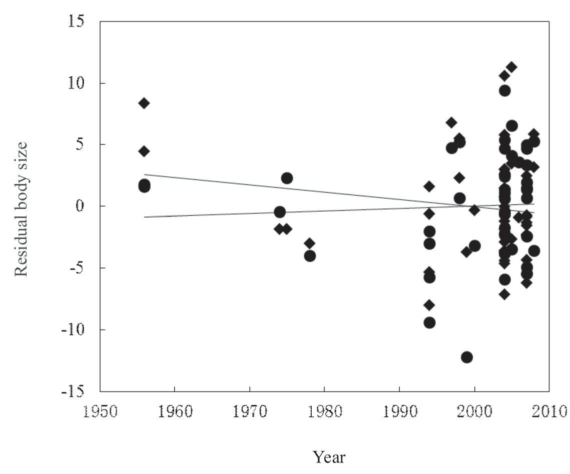

Fig. 2. The relationship between body size (residuals after controlling for month of collection) and year (male: black cycles; female: black rhombus). Each dot represents a single population.

Table 1. *Phrynocephalus vlangalii* study populations (n=47) and their body size attributes. TL: tail length (mm); SVL: snout-vent length (mm); TOM: total offspring mass (g).

Sites	Location	Altitude (m)	Sample size	Males SVL(mm)	Females SVL(mm)	Date	Data sources
Heidaban	39.44°N, 95.11°E	2289	10/10	57.3	60.8	2004.07	Jin et al.(2006)
Lenghu	38.75°N, 93.35°E	2751	9/7	63.3	64.0	2004.07	Jin et al.(2006)
Lenghu	38.74°N, 93.36°E	2756	4/6	55.6	58.2	2004.07	Jin et al.(2006); Jin and Liu (2007)
Nomhon	36.38°N, 96.45°E	2857	6/6	62.6	59.0	2004.07	Jin et al.(2006); Jin and Liu (2007)
Delingha	37.22°N, 97.40°E	2873	17/17	67.3	68.8	2004.07	Jin et al.(2006); Jin and Liu (2007)
Urt Moron	36.82°N, 93.16°E	2894	11/9	56.2	53.6	2004.07	Jin et al.(2006); Jin and Liu (2007)
Maqu	34.95°N, 102.08°E	2926	14/25	57.5	59.7	2004.07	Jin et al.(2006); Jin and Liu (2007)
Ulan	36.93°N, 98.47°E	2929	47/21	55.7	51.1	2004.07	Jin et al.(2006); Jin and Liu (2007)
Xingride	36.01°N, 97.88°E	3074	27/9	59.0	61.2	2004.07	Jin et al.(2006); Jin and Liu (2007)
Mangya	38.35°N, 90.15°E	3174	8/7	60.5	56.4	2004.07	Jin et al.(2006); Jin and Liu (2007)
Qagan Us	36.30°N, 98.08°E	3190	20/17	54.1	59.0	2004.07	Jin et al.(2006); Jin and Liu (2007)
Da Qaidam	37.85°N, 95.42°E	3200	8/8	59.3	55.3	2004.07	Jin et al.(2006); Jin and Liu (2007)
Dulan	36.23°N, 98.11°E	3242	7/14	57.3	57.0	2004.07	Jin et al.(2006); Jin and Liu (2007)
Zoige	33.89°N, 98.11°E	3370	19/18	60.3	54.6	2004.07	Jin et al.(2006)
Zoige	33.89°N, 98.13°E	3470	14/10	58.5	61.2	2004.07	Jin et al.(2006); Jin and Liu (2007)
Maduo	34.75°N, 98.11°E	4250	23/19	54.1	54.5	2004.07	Jin et al.(2006); Jin and Liu (2007)
Maduo	34.75°N, 98.11°E	4565	36/33	52.0	53.8	2004.07	Jin et al.(2006); Jin and Liu (2007)
Daotanghe	36.58°N, 101.82°E	3400	58/34	61.0	68.5	2005.05	Zhang et al. (2005)
Hongyaun	40.01°N, 107.00°E	3500	11/22	53.2	55.9	1978.06	Jiang et al. (1980)
Hongyuan	33.08°N,103.60°E	3500	26/11	53.9	55.2	1978.07	Jiang et al. (1980)
Dulan	36.21°N, 98.16°E	3150	15/17	56.4	53.9	2007.08	Museum measurement
Da Qaidam	37.61°N, 95.37°E	3100	15/16	52.0	48.5	2007.08	Museum measurement
Akeshu	39.38°N,95.02°E	2700	7/5	47.5	49.2	1994.05	Museum measurement
Gangcha	33.07°N, 100.51°E	3200	2/3	58.6	63.7	1998.07	Museum measurement
Xiaman	33.88°N, 102.54°E	3450	9/6	59.2	61.5	1997.08	Museum measurement
Xiaman	33.87°N, 102.55°E	3300	2/2	61.5	57.3	2006.07	Museum measurement
Xiaman	33.87°N, 102.56°E	3400	11/6	52.0	55.1	2000.06	Museum measurement
Chaka	36.65°N, 99.37°E	3200	18/11	55.1	54.0	2007.08	Museum measurement
Kunlunshan	35.88°N, 94.37°E	3700	13/10	49.5	49.2	2007.08	Museum measurement
Geermu	36.38°N, 94.97°E	2800	18/11	49.0	50.4	2007.08	Museum measurement
Shugan Lake	38.90°N, 93.90°E	2800	11/11	59.1	57.2	2007.08	Museum measurement
Shugan Lake	38.88°N, 93.66°E	3250	2/2	42.2	51.0	1999.08	Museum measurement
Qinghai Lake	32.88°N, 97.53°E	3190	13/10	51.6	58.6	2008.06	Museum measurement
Qinghai Lake	32.25°N, 100.25°E	3200	2/3	54.9	58.8	1994.05	Museum measurement
Maduo	35.20°N, 98.97°E	4200	18/7	55.8	52.4	2007.08	Museum measurement
Xinghai	35.80°N, 99.88°E	3600	2/2	59.4	52.4	2007.08	Museum measurement
Xinghai	35.92°N, 100.03°E	3300	12/6	57.8	53.4	2007.08	Museum measurement
Tianjun	38.39°N, 97.47°E	3500	2/2	59.2	55.4	1975.05	Museum measurement
Gonghe	36.17°N, 99.13°E	2850	20/20	55.9	53.2	2007.08	Museum measurement
Taka	36.28°N, 99.44°E	3100	12/6	60.4	61.3	2008.06	Museum measurement
Dulan	36.26°N, 98.15°E	3200	5/7	60.1	58.7	1974.05	Museum measurement
Yintan	36.54°N, 100.28°E	3400	8/7	56.0	59.2	1956.08	Museum measurement
Danapa River	36.24°N, 99.40°E	3290	2/4	56.2	63.1	1956.08	Museum measurement
Chaka Lake	36.46°N, 99.02°E	3670	6/7	53.9	56.6	1994.05	Museum measurement
Delingha	37.26°N, 97.20°E	3200	6/5	51.2	51.9	1994.05	Museum measurement
Dulan	36.48°N, 98.41°E	3060	2/4	63.1	60.5	1998.07	Museum measurement
Maqu	33.95°N, 102.09°E	3430	6/8	61.0	58.2	2005.08	Museum measurement

67.3 mm in males, and from 51.0 to 68.8 mm in females. Multiple regressions revealed that body size of males and females was not related to altitude, latitude, longitude and year of collection (Table 1; male, r^2=0.152, $F_{1, 46}$=1. 471, p=0.220; female, r^2=0.213, $F_{1, 46}$=2.220, p=0.07), but a significant relationship was found between month of collection and body size for both sexes (Table 2). To control for the effects of collection date, residual body size was calculated as the observed body size minus body size predicted by the regressions equation. A non-significant relationship between residual body size and year in both sexes suggested that body size of males and females of did not vary significantly between 1954 and 2008 (Fig. 2; male, r=0.057, p=0.703, n=47; females, r=-0.162, p=0.277, n=47).

DISCUSSION

Global warming was shown to affect the body size of lizards, birds and mammals in most parts of Western

Table 2. Regression coefficients of body size (mm) of toad headed lizard against latitude, longitude and altitude of the locality of collection, year and month of collection. Monthly variation is expressed as Sin (2*π*I/12).

Variables	Male			Female		
	Coefficient	*t*-value	*p*-value	Coefficient	*t*-value	*p*-value
Intercept	-9.728	-0.075	0.941	184.812	1.438	0.158
Latitude	-0.137	-0.265	0.792	-0.514	-1.011	0.318
Longitude	0.207	0.789	0.435	0.174	0.672	0.505
Altitude	-0.001	-0.375	0.709	-0.002	-1.199	0.237
Year	0.026	0.469	0.642	-0.060	-1.078	0.287
Month	-2.093	-2.439	0.019	-2.098	-2.477	0.017

Europe (Sparks et al., 2005; Chamaillé-Jammes et al., 2006; Goodman et al., 2012). We provide, here, the first comprehensive study on the potential effect of global warming on body size by *P. vlangalii* of the Qinghai-Tibet Plateau in China. We provide evidence that no temporal variation in body size took place over the past 54 years despite the increase in temperature observed in our study region (Lu et al., 2009).

Temporal and geographic intraspecific variation in body size may be related to environmental conditions (Pincheira-Donoso et al., 2008). Of the environmental factors known to influence body size, environmental temperature is one of the strongest and most pervasive (Hunt & Roy, 2006). Some studies have shown that body size increases with decreasing environmental temperature in a wide range of taxa conforming to Bergmann's rule (Ashton et al., 2000; Ashton, 2002; Sacchi et al., 2007; Liao & Lu, 2010; Liao & Lu, 2012). Body size variation in reptiles has been related to climatic conditions, both at a geographical (Ashton & Feldman, 2003; Oufiero et al., 2011) and temporal scale (Sinervo & Adolph, 1994; Wikelski & Romero, 2003). For *P. vlangalii*, body size has previously been reported to decrease with increasing altitude and decreasing temperature across an altitudinal scale (Jin et al., 2006), somewhat contradicting the results of the present study. The difference between our results and those of Jin et al. (2006) may relate to environmental temperatures as measured for year of collection, as we found similar temperatures at locations of different altitudes.

Whereas body mass and wing length of birds declined or increased during the second half of the 20th century (Yom-Tov, 2001; Yom-Tov et al., 2002; Van Buskirk et al., 2010), the body sizes in mammals increased over the same period (Yom-Tov & Yom-Tov, 2005; Yom-Tov et al., 2010). Moreover, body lengths of males of both *Rana ridibunda* and *R. lessonae* significantly increased between 1963 and 2003 (Tryjanowski et al., 2006). However, we found a non-significant relationship between change in body size and year of collection in *P. vlangalii* across a 54-year period. Similar results have been observed in the frog *R. esculenta* for the period 1963–2003 in an agricultural landscape in western Poland (Tryjanowski et al., 2006).

Body size shifts in response to climate change can either represent evolutionary responses or constitute phenotypic plasticity (Gienapp et al., 2008). For *P. vlangalii*, adaptive evolution may explain existing patterns of variation in body size (Jin et al., 2008; Jin & Liu, 2008). A proximate determinant of body size could be the availability and quality of food in line with differential growing seasons and temperature-dependent activity budgets that constrain feeding (Ozgul et al., 2009; Ozgul et al., 2010). For ectothermic vertebrates, earlier age at sexual maturity facilitated by high environmental temperature results in smaller adult body size, whereas increasing availability or quality of food results in larger adult body size (Adams & Church, 2008; Liao & Lu, 2012). The reciprocity between age at sexual maturity and food availability in *P. vlangalii* may account for the non-significant change in body size in response to global warming in the Qinghai-Tibet Plateau. This pattern differs for example from *Lacerta vivipara*, for which body size dramatically increased over 18 years (Chamaillé-Jammes et al., 2006).

Global climate changes significantly contributes to the global decline of amphibians and reptiles (Rovito et al., 2009; Fitzpatrick et al., 2010; Bickford et al., 2010). Moreover, species and populations living in higher latitudes or altitudes may be more vulnerable to extinction (Morrison & Hero, 2003; Peterson et al., 2002). Populations of *P. vlangalii* seemed to have remained stable in the recent past (Jin, 2008), but are currently affected by human population growth, urbanisation, environmental pollution and grazing (personal observations).

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