Altitudinal effects on the life history of the Anatolian lizard (*Apathya cappadocica*, Werner 1902) from southeastern Anatolia, Turkey

Serkan GÜL[1],*, Nurhayat ÖZDEMİR[1], Aziz AVCI[2], Yusuf KUMLUTAŞ[3], Çetin ILGAZ[3]

[1]Department of Biology, Faculty of Arts and Sciences, Recep Tayyip Erdoğan University, Rize, Turkey
[2]Department of Biology, Faculty of Arts and Sciences, Adnan Menderes University, Aydın, Turkey
[3]Department of Biology, Faculty of Science, Dokuz Eylül University, Buca, İzmir, Turkey

Abstract: Altitudinal gradients are an important variable in testing the life history traits (e.g., longevity, age at maturity, and body size) of organisms. In this study, the life history traits of the Anatolian lizard *Apathya cappadocica* were examined from 3 populations from different altitudes (Kilis, 697 m; Şanlıurfa, 891 m; Diyarbakır, 1058 m) from southeastern Anatolia, Turkey. Age structure was determined by using skeletochronology. Males in all populations were the larger sex; therefore, the populations showed male biases that were negative by the sexual size dimorphism index. Males in Diyarbakır (high altitude) were also younger than males in the other populations. There were no significant differences between the males and females of all 3 populations in terms of either age or snout–vent length except in the Şanlıurfa population, in which males were larger than females. Life history traits of *A. cappadocica* across altitudinal gradients may be affected by climatic factors, as males from the middle altitude population in Şanlıurfa, which inhabits a warmer and more arid environment, tended to be larger than males and females in Kilis and Diyarbakır.

Key words: Age structure, *Apathya cappadocica*, life history traits, lizard, skeletochronology, Turkey

1. Introduction

Distinct life history characters of lizards define body size, age at sexual maturity, and number of offspring produced (Pianka and Vitt, 2003). These characteristics are vitally important to individuals, and variation in any one of these characteristics can have a significant influence on the overall fitness and survival of an individual (Chamberlain, 2011). Traditionally, life history traits are quantified in terms of age and body size. Both of these measurements have unique implications for a given life history trait (Davidowitz et al., 2005; Wilbur and Rudolf, 2006). Age and body size of individuals are 2 standard characteristics that many researchers (Chen et al., 2011; Gül et al., 2011; Liao et al., 2011; Liao and Lu, 2011; Chen et al., 2012; Lou et al., 2012; Özdemir et al., 2012; Altunışık et al., 2013; Huang et al., 2013; Gül et al., 2014) have used to quantify life history traits. Many environmental factors (e.g., altitude, climate) can affect variation in age structure, body size, and life history traits (Adolph and Porter, 1993; Guarino et al., 2010; Oufiero et al., 2011).

Altitudinal gradients as an environmental factor are an important variable in order to test ecological and evolutionary processes in the life history of organisms (Körner, 2007). Several studies have shown that altitudinal comparisons in age structure and body size of both amphibians and reptiles are especially useful for comparative ecology (Esteban et al., 2004; Chen et al., 2011; Gül et al., 2011; Liao et al., 2011; Liao and Lu, 2011; Lou et al., 2012; Özdemir et al., 2012; Cajade et al., 2013; Huang et al., 2013 for amphibians; Roitberg and Simirina, 2006a, 2006b; Guarino et al., 2010; Tomasevic et al., 2010; Arakelyan et al., 2013; Gül et al., 2014 for lizards).

The family Lacertidae consists of 2 subfamilies and a total of 42 genera (Pyron et al., 2013). *Apathya* is a small genus in the subfamily Lacertinae that includes *Apathya cappadocica* (Werner, 1902) and *A. yassujica* (Nilson, Rastegar-Pouyani, Rastegar-Pouyani & Andren, 2003) (Arnold et al., 2007; Ilgaz et al., 2010; Kapli et al., 2013). *A. cappadocica* is found in the central, eastern and southeastern Anatolian regions of Turkey and also has distribution in northern Syria, northern Iraq, and northwestern Iran (Baran et al., 2012). Since there has been no study on the age structure and growth of *A. cappadocica* that indicates distribution in a limited area, we focus on the life history of populations of the species living at different altitudes in southeastern Turkey.

* Correspondence: serkan.gul@erdogan.edu.tr

In the present study, we basically address 2 questions: (1) Is there any difference between the sexes in terms of age structure and body size within and between populations? (2) How do different altitudinal gradients affect age structure and body size?

2. Materials and methods

2.1. Study samples and collection sites

A total of 56 specimens (23 ♂♂ and 33 ♀♀) of *A. cappadocica* were used for skeletochronological analysis from 3 populations (Kilis, Şanlıurfa, and Diyarbakır) in southeastern Anatolia, Turkey (Figure 1). Specimens that had already been collected and deposited in the Fauna and Flora Research Center of Dokuz Eylül University (Buca, İzmir) were used for this study. All specimens had been captured in mid-April in 2005 and 2006. The snout–vent length (SVL) of each individual was measured using a dial caliper with 0.01 mm of precision.

Kilis (697 m, 36°43′6.24″N, 37°7′16.39″E) is located between the middle section of the Euphrates and the Mediterranean coastal region in southeastern Anatolia. The weather is hot and dry in the summer, while winters are mild and rainy in Kilis (Aydın, 2011). Mean annual temperature, precipitation, and humidity of Kilis are 16 °C, 515 mm, and 54.6%, respectively (http://www.meteor.gov.tr/).

Şanlıurfa (891 m, 37°09′04″N, 38°47′34″E) is a city in southeastern Anatolia about 80 km east of the Euphrates River. Şanlıurfa has a very hot climate in the summer months. The highest temperatures in the summer months generally reach 39 °C. The winter months are cool and wet, while spring and autumn months are mild and also wet (Kaya, 2011). The mean annual temperature and precipitation in Şanlıurfa are 18.3 °C and 457.3 mm.

Şanlıurfa has a mean annual humidity of 47.8% (http://www.meteor.gov.tr/).

Diyarbakır (1058 m, 37°54′51.88″N, 40°5′50.56″E) is the largest city in southeastern Anatolia on the edge of the Tigris River, one of the largest rivers of the Middle East. Climate conditions of Diyarbakır are more similar to the climatic structure of the Mediterranean region. The summer months are hot and dry; however, the winter months are not as cold as in the eastern Anatolian region (Varol et al., 2010). The mean annual temperature and precipitation of Diyarbakır are 15 °C and 490 mm. In addition, it has 56.1% mean annual humidity (http://www.meteor.gov.tr/).

2.2. Skeletochronological protocol

Skeletochronology is basically the use of periodic growth lines in bones to estimate age. Each growth line in long bones such as the humerus and femur or phalanges represents 1 year of life (Pellegrini, 2007). These are called lines of arrested growth (LAGs). These lines in amphibians and reptiles are a result of low metabolism and no growth, associated with seasonal climate changes (Castanet, 1993). In order to determine ages, the standard protocol that was applied by Gül et al. (2014) was used. According to this protocol, LAGs were counted on transverse sections of the middle part of the phalangeal diaphyses using a portion of the second phalanx from the third toe of the hind foot. After digits were dissected, the phalangeal bones were kept under water for 24 h and were decalcified in 5% nitric acid for 2 h. Later, they were immersed in water again for 12 h. Cross-sections (18 μm) of the middle part of the phalangeal diaphysis were prepared using a freezing microtome and stained with Ehrlich's hematoxylin (Figure 2). Cross-sections were treated with glycerol for observation under a light microscope.
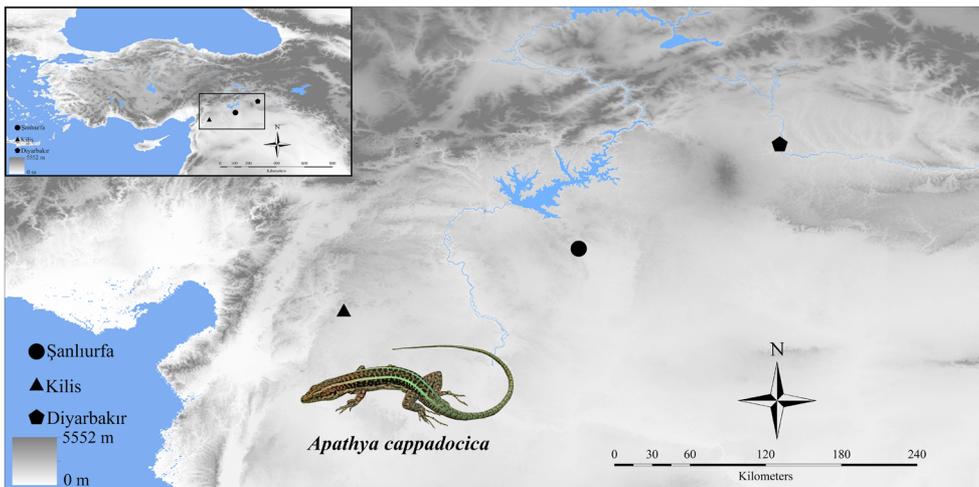
Figure 1. Geographic distribution of *Apathya cappadocica* populations from different altitudes in southeastern Anatolia, Turkey.
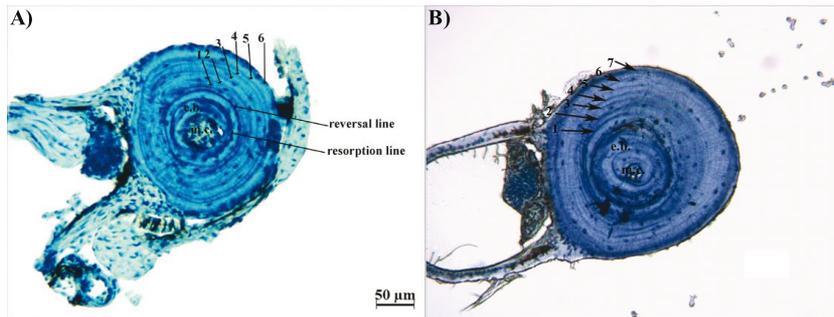
Figure 2. A) Cross-sections (18 μm) at the diaphysis level of a phalanx of *Apathya cappadocica* in Diyarbakır (SVL: 61.82; ♀); B) *Apathya cappadocica* in Şanlıurfa (SVL: 70.86; ♀). The LAGs are indicated by black arrows (m.c. = marrow cavity, e.b. = endosteal bone).

2.3. Statistical analysis

All data were tested for normality using the Kolmogorov–Smirnov test and for homogeneity of variances using the Levene test. According to the test distribution type of variables, independent sample t-test and one-way analysis of variance (ANOVA) were used to compare variables between sexes and populations. The strength and direction of the relationship between age and SVL were tested using Pearson's correlation coefficient (r). Regression analysis was performed by using the quadratic model, which has the highest R^2 value. All analyses were performed using SPSS 21 (IBM SPSS Statistics for Windows, Armonk, NY, USA).

We used the sexual dimorphism index (SDI) of Lovich and Gibbons (1992), in which SDI = [(size of larger sex / size of smaller sex) ± 1], to estimate sexual size dimorphism (SSD). SDI was arbitrarily defined as positive if females were larger and negative if males were larger.

3. Results

LAGs of cross-sections of the phalangeal bones were readily identified in all specimens. Although endosteal bone that originates at the perimeter of the marrow cavity

was seen in almost all samples, no problems occurred in calculating the LAGs. Descriptive statistics of age and SVL are summarized in the Table. Age at maturity was calculated as 2 years for both sexes in all populations.

Males in all populations were larger than females; therefore, the populations showed a male bias that was negative by the SSD index (Table). While a significant difference was not found between males in terms of SVL (one-way ANOVA, P > 0.05) in all populations, the difference was significant in terms of age (one-way ANOVA, F = 10.422, P < 0.01). According to Tukey's honestly significant difference (HSD) test, Kilis and Şanlıurfa males were not different from each other (Tukey's HSD, P > 0.05), but males in the Diyarbakır population were different from males of both Kilis and Şanlıurfa (Tukey's HSD, P < 0.05). Males in Diyarbakır were younger than males in the other populations. On the contrary, the difference in SVL in the females of all 3 populations was significant (one-way ANOVA, F = 6.736, P < 0.01), whereas there was no significant difference between the females of the 3 populations in regards to age (one-way ANOVA, P > 0.05). In Tukey's HSD test, SVL of females in Kilis and Şanlıurfa populations was significantly

Table. Descriptive statistics of age and SVL and SSD indices, and coordinate information for *Apathya cappadocica* populations.

Populations	Sex	N	Minimum–maximum SVL	Mean SVL (±SD), mm	Minimum–maximum age	Mean age (±SD), years	SSD	Latitude	Longitude	Altitude
Kilis	M	6	59.88–82.10	72.13 (±8.55036)	5–7	5.8333 (±0.75277)	−0.001	36.83	36.79	697 m
	F	14	61.86–80.00	72.0157 (±6.21647)	4–7	5.5714 (±0.85163)				
Şanlıurfa	M	9	64.00–83.52	72.2489 (±7.43658)	4–6	5 (±0.70711)	−0.132	37.18	38.64	891 m
	F	12	57.62–71.10	63.7867 (±4.02846)	4–7	5 (±0.95346)				
Diyarbakır	M	8	58.40–85.86	69.9775 (±11.42511)	3–5	4.1250 (±0.64087)	−0.07	37.87	39.88	1058 m
	F	7	57.26–79.48	65.4429 (±8.04162)	3–6	4.8571 (±1.34519)				

different from that of each other (Tukey's HSD, P < 0.05). Females in the Kilis population were larger than those of the Şanlıurfa population (Table). However, females in the Diyarbakır population were not different from females of Kilis and Şanlıurfa with respect to SVL (Tukey's HSD, P = 0.06, P = 0.83, respectively).

A significant difference could not be found between females and males in terms of either SVL (independent t-test t = 0.034, P = 0.454; t = 0.876, P = 0.088, respectively) or age (independent t-test t = 0.650, P = 0.455; t = −1.376, P = 0.057, respectively) in the Kilis and Diyarbakır populations. In addition, no significant difference was found between sexes in the Şanlıurfa population in relation to age (independent t-test t = 0.000, P = 0.413), but the difference in SVL was significant between females and males (independent t-test t = 3.357, P < 0.05). Males in Şanlıurfa were larger than females (Table).

The correlation between age and SVL was not statistically significant in either females (Kilis: n = 14, r = 0.478, P = 0.084; Diyarbakır: n = 7, r = 0.702, P = 0.078) or males (Kilis: n = 6, r = 0.632, P = 0.178; Diyarbakır: n = 8, r = 0.381, P = 0.352). On the other hand, there was a significant correlation between age and SVL in females (n = 12, r = 0.642, P < 0.05) and males (n = 9, r = 0.750, P < 0.05) in the Şanlıurfa population. A quadratic regression model was found suitable for the statistical relationship between age (x) and SVL (y). According to this model, a mathematical function was used for females (y = 83.424 − 10.241x + 1.22x^2, R^2 = 0.496, P < 0.05) and males (y = 93.844 − 16.970x + 2.486x^2, R^2 = 0.594, P < 0.05) in the Şanlıurfa population (Figure 3).
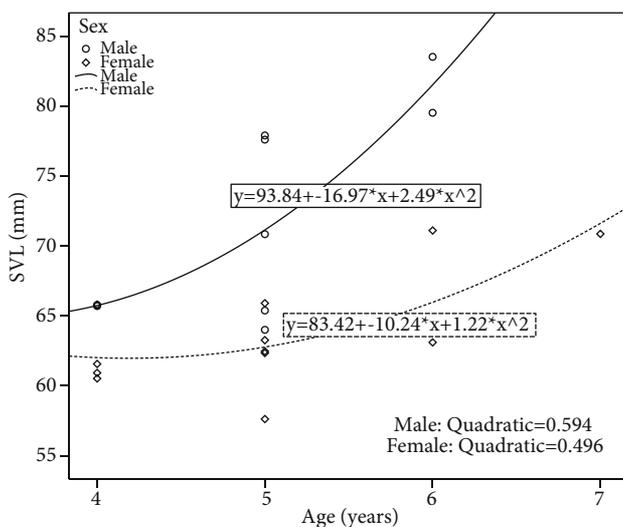
Figure 3. Mathematical relationship between SVL and age in females and males of *Apathya cappadocica* in Şanlıurfa.

4. Discussion

The SVL represents the body size differentials between males and females in sexual dimorphism; therefore, it is the most important distinguishing character for many species of the family Lacertidae (Arribas, 1996). Most species of lacertid lizards are male-biased in terms of body size and head dimensions (Kaliontzopoulou et al., 2007). Our study points out the life history traits of *A. cappadocica* across altitudinal gradients from 3 populations in southeastern Anatolia, Turkey, and the results of this study showed that the males of this species were larger than females in 3 populations (male-biased SSD). Our results support Rensch's rule. According to this rule, when males in animals are larger than females, the pattern of SSD variation increases with increasing body size of individuals (Fairbairn, 1997). As a general rule, animals from high altitudes and northern latitudes live longer than those from low altitudes and southern latitudes, and they also exhibit larger body size in cooler climates (Sears and Angilletta, 2004). Furthermore, lizards in low altitudes are expected to have a smaller mean body size than individuals in high altitudes (Roitberg and Smirina, 2006a), but this situation did not occur in our results. On the contrary, female individuals of *A. cappadocica* from a low altitude (Kilis; 697 m) were larger than individuals from a middle altitude (Şanlıurfa; 891 m), but this was not statistically significant in female individuals of Diyarbakır. In addition, the Şanlıurfa population statistically indicated a strong male-biased SSD. Many studies have produced results similar to our results. For example, Oufiero et al. (2011) reported that *Sceloporus* lizards from warmer and more arid environments tended to be larger. In addition, the body sizes of *Gallotia atlantica atlantica* and *G. a. mahoratae* males from the eastern Canary Islands were generally larger than those of females (Molina-Borja, 2003). Similarly, Chi-Yun et al. (2009) stated that males of *Japalura swinhonis* living in Taiwan were significantly larger than females in terms of body size. Furthermore, Üzüm et al. (2014) reported that the mean SVL of *Acanthodactylus boskianus* males was meaningfully greater than that of females. In addition, patterns of geographic variation in SSD were indicated as male-biased by Roitberg (2007) for *Lacerta agilis exigua* and *L. a. boemica*.

The patterns of SSD variation may occur as a result of abiotic and biotic environmental factors, because SSD in lizards may be explained by differences in the SVL, climate (e.g., temperature, precipitation), phylogenetic relationships, and age structure between females and males (Roitberg, 2007). For example, the cold-adapted sagebrush lizard (*Sceloporus graciosus*) has a larger body size in individuals from populations that are found at low altitudes, which undergo longer periods of activity than individuals in populations found at high altitudes, which undergo shorter periods of annual activity (Sears

and Angilletta, 2004), because at high altitudes, *S. graciosus* shows faster rates of growth in a relatively cool environment than lizards at lower altitudes and warmer environmental temperatures (Sears and Angilletta, 2004).

In addition, Sears and Angilletta (2004) stated that lizards at high altitudes start their first activities (1 year) at a smaller size, but grow faster to reach the same sizes as lizards at low altitudes according to the age of maturity (3 years). The shorter activity period in a cooler climate should reduce the risk of predation, unfavorable temperature conditions, and lower food availability (Roitberg and Smirina, 2006b). However, our results showed that *A. cappadocica* living at a low altitude (Kilis) displayed quicker growth rates comparatively in warmer environments than cooler environments (Diyarbakır). Moreover, maximum length of life was 7 years for females in the population from Kilis (697 m) and Şanlıurfa (891 m), 7 years for males in Kilis and 6 for males in Şanlıurfa (891 m), and 6 for females and 5 years for males in the Diyarbakır population (1058 m) at different altitudes (Table). Gül et al. (2014) similarly stated that *Darevskia rudis* individuals from lower altitudes exhibited clearly higher mean SVL and ages than those from higher altitudes; maximum longevity was 8 years for males and females of *D. rudis* in the population from a low altitude. In addition, Guarino et al. (2010) reported that length of life in population of *L. agilis*, which lives at high altitudes (1790–1890 m), was only 4 years for males and 3 for females. They stated that

length of life might be directly affected by environmental temperatures. Life history traits of *A. cappadocica* across altitudinal gradients may be affected by climatic factors, as males from the high-altitude population at Diyarbakır (annual mean temperature 15 °C) living in a colder and more arid environment tended to be younger than males in Kilis and Şanlıurfa (annual mean temperatures of 16 and 18 °C, respectively).

In conclusion, we observed patterns of altitudinal gradients in mean age, longevity, and body size among the *A. cappadocica* populations. Our results indicated that differences in terms of SVL and age between sexes of *A. cappadocica* across altitudinal gradients might be based on climate and altitude, as males of *A. cappadocica* at a high altitude (Diyarbakır) were younger than males at middle (Şanlıurfa) and low (Kilis) altitudes. Although the Şanlıurfa population was at a middle altitude, it showed a robust male bias, unlike the other populations (Kilis and Diyarbakır). This situation probably occurred as a result of temperature, as Şanlıurfa had the highest annual mean temperature.

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