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## Variation in Body Size and Age Structure of *Stellagama stellio* (L., 1758) (Reptilia: Agamidae) from Turkey

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**Abstract:** Age and body size of 81 *Stellagama stellio* (syn. *Laudakia stellio*) specimens from five regions of Turkey were studied using skeletochronology. Lines of arrested growth (LAGs) in phalanges were used to estimate the age. Snouth vent length (SVL) ranged between 90.05 – 133.14 mm (mean: 109.58 ± 10.26) in males and 86.24 – 130.43 mm (mean: 105.83 ± 10.68) in females. Age ranged between 2-9 (mean: 5.34 ± 1.63) in females and 3-10 years (mean: 5.72 ± 1.82) in males. We did not observe any significant difference in terms of age and SVL between sexes. Intersexual differences in body size were male-biased (SDI = -0.03) but this relation was not statistically significant. A significant difference between the lowland (below 800 m) and mountain (above 800 m) populations was found in respect of SVL, with mountain individuals being larger than the lowland. A significant age difference between lowland and mountain populations was not found. A significant positive correlation was found between age and SVL both in males and females. Individuals reached maturity between 2 and 3 years.

**Key words:** *Stellagama stellio*, skeletochronology, Turkey, body size, age structure

### Introduction

The life cycles of ectothermic animals must be completed within the limits set by seasonality, and the timing of life history events will have a strong influence on fitness (GOTTHARD 2001). Populations are dynamic units precisely adapted physiologically and genetically to their environments. In the ectotherms, the relationship between the chronological and physiological age is affected by some environmental factors such as food availability and ambient temperature (ADOLPH, PORTER 1993, GOTTHARD 2001). The thermal environment restricts the growing season for many organisms. Organisms at low elevations or low latitudes can grow and be active for much of the year, whereas the growing season is shortened at high elevations or high latitudes. The thermal effects on growth can greatly alter life histories (ADOLPH, PORTER 1996). A common consequence is that organisms in cold environments exhibit delayed maturity

and postpone their reproduction until they become older (TINKLE 1970).

Life-history phenotypes in natural populations of lizards are affected by a number of environmental factors (BALLINGER 1983, BERVEN, GILL 1983). In particular, temperature, food availability, and moisture are known to exert proximate influences on lizard life histories (TINKLE 1972, BALLINGER 1977). The mean body temperature of active lizards often varies relatively little despite daily, seasonal, and geographical variation in thermal environments (BOGERT 1949, AVERY *et al.* 1982). Activity is an important link between the thermal environment and lizard life histories. Therefore, activity patterns are a likely target of natural selection (ADOLPH, PORTER 1993). In many cases, lizards may use less than the maximum potential activity time afforded by the thermal environment (SIMON, MIDDENDORF 1976, SINERVO, ADOLPH

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1989, SINERVO, DOYLE 1990), which suggests a compromise between the benefits and costs of activity (ROSE 1981).

The Agamidae is a family of lizards that includes 54 genera and over 330 species, which are widely distributed in Australia and through the Old World and inhabit various habitats within arid, tropical and subtropical regions (MOODY 1980, RASTEGAR-POUYANI, NILSON 2002). The starred agama, *Stellagama stellio* (Linnaeus 1758), formerly in the genus *Laudakia*, was stated as the type species of the new genus *Stellagama* by BAIG *et al.* (2012). The species was ranged from Greece and Turkey to Syria, Lebanon, northwestern Iraq, northern Saudi Arabia, northern and western Jordan, Israel and northern Egypt (AME *et al.* 2013). In Turkey, the species is found in suitable habitats, which may be arid or vegetated, such as sand-dunes and ruins, crevices of terraces, stone walls and stones, the underside of large rocks, and crevices in tree-trunks. Except for the Black Sea coast, the range of the species covers the western, southern, central and south-east regions of Turkey as well as the islands in the Aegean strip of the Anatolia (BARAN *et al.* 1989, GÜL *et al.* 2010).

Data on the longevity and age at sexual maturation in the mountain agamas of the *Laudakia* are scarce (SMIRINA, ANANJEVA 2007). These studies are related to *L. caucasica* (LEDENTSOV, MELKUMYAN 1987, PANOV, ZYKOVA 2003) and *L. stoliczhkana* (SMIRINA, ANANJEVA 2007). Overall, the studies on the formerly known as *L. stellio* are mainly focused on morphol-

ogy, taxonomy, ecology, parasites, physiology and feeding biology (PANOV, ZYKOVA 1997, BRAMMAH *et al.* 2010, Federman, Werner 2007, Baran, Atatur 1998). But there is no study about age structure on *Stellagama stellio* species.

Within this context, the present work is the first study about body size and age structure of *Stellagama stellio*. The objectives of this study were i) to determine the age structure, ii) to examine the altitudinal variation and sex differences for age structure and body size in adults of *Stellagama stellio* living in Turkey.

## Materials and Methods

A total of 81 adult individuals (43 ♂♂ and 38 ♀♀) of *Stellagama stellio* from various altitudes (8-1600 m a. s. l.) and from several regions of Turkey were studied. The regions were as follows: Region (1), Western Anatolia (Çanakkale, Balıkesir, İzmir, Manisa, Muğla); Region (2), South Anatolia (Antalya, Adana, Mersin); Region (3), Central Anatolia (Kayseri, Karaman); Region (4), Southeastern Anatolia (Hatay, Kahramanmaraş, Gaziantep, Adıyaman); Region (5), North Anatolia (Tokat, Amasya, Sinop) (Fig. 1). We used only preserved specimens kept in the herpetological collection at the Section of Zoology, Department of Biology, Çanakkale Onsekiz Mart University, Turkey. The geographic, climatic and environmental variables for localities are presented in Table 1. The snout-vent length (SVL) was measured by a

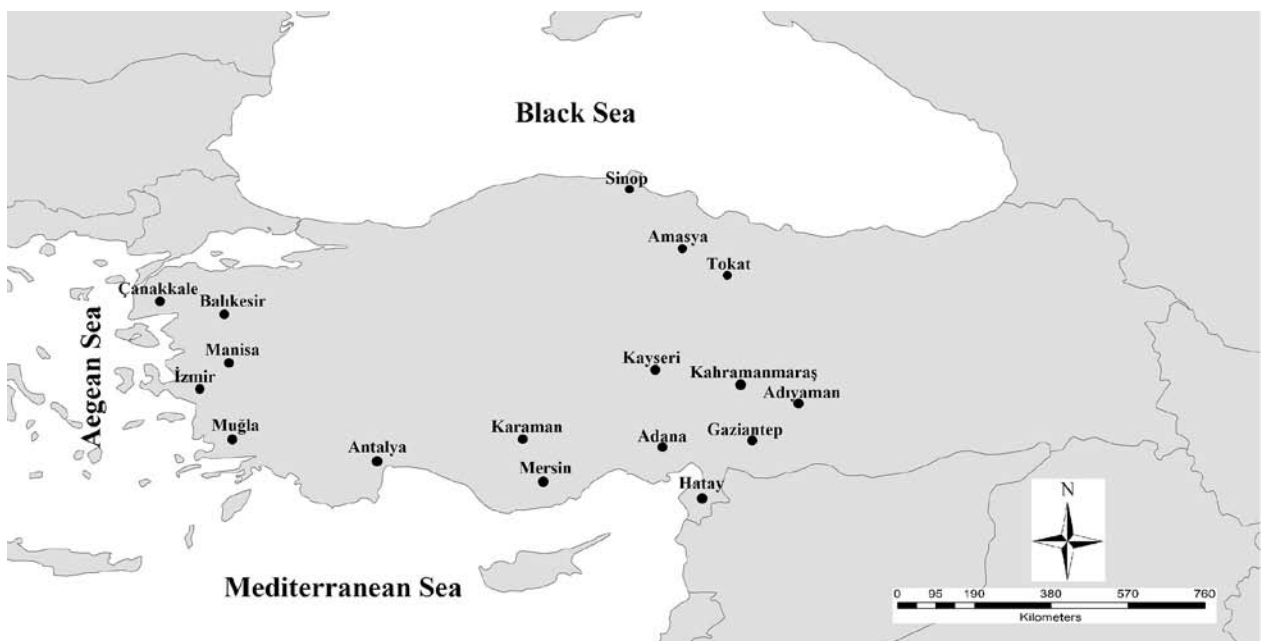


Fig. 1. Map of the sampled breeding sites

**Table 1.** Geographic, climatic and environmental variables in *Stellagama stellio* from five different regions in Turkey

Locality	n	Latitude (N)	Longitude (E)	Altitude (m a.s.l.)	Annual precipitation sum (mm)	Mean annual air temperature (°C)	Regions
Muğla	2	36° 50' 15"	28° 36' 58"	180	1130.5	15	Western Anatolia
Muğla	3	36° 52' 43"	28° 34' 45"	24	1130.5	15	
Muğla	4	36° 40' 0"	29° 8' 49"	50	1130.5	15	
İzmir	5	38° 31' 6"	27° 7' 30"	315	688.3	17.9	
İzmir	1	38° 31' 23"	27° 2' 42"	14	688.3	17.9	
Manisa	2	38° 54' 35"	28° 57' 34"	950	708	17	
Çanakkale	2	39° 29' 25"	26° 20' 11"	220	596.3	15	
Balıkesir	1	39° 26' 30"	28° 3' 46"	300	555.6	14.6	
Antalya	1	37° 3' 50"	30° 11' 10"	1032	1072.8	18.4	South Anatolia
Antalya	2	37° 2' 21"	30° 0' 19"	1600	1072.8	18.4	
Mersin	1	36° 55' 21"	34° 54' 47"	15	568.8	19.3	
Mersin	1	36° 55' 33"	34° 22' 7"	1272	568.8	19.3	
Mersin	6	36° 38' 3"	33° 26' 3"	314	568.8	19.3	
Adana	4	36° 58' 11"	35° 33' 9"	55	636.4	19.1	
Adana	1	36° 58' 11"	35° 38' 35"	60	636.4	19.1	
Kayseri	2	38° 11' 20"	36° 4' 25"	1580	393	10.5	
Karaman	1	36° 38' 35"	32° 39' 0"	1350	326.6	11.9	Central Anatolia
Kayseri	8	38° 30' 32"	35° 11' 16"	1081	393	10.5	
Karaman	2	37° 12' 24"	32° 30' 15"	1500	326.6	11.9	
Gaziantep	2	36° 59' 40"	36° 37' 21"	531	550.8	15.1	South eastern Anatolia
Adıyaman	1	37° 47' 55"	37° 55' 10"	1092	680.3	17.2	
Gaziantep	2	37° 6' 4"	36° 38' 17"	657	550.8	15.1	
Gaziantep	1	37° 7' 49"	36° 52' 3"	708	550.8	15.1	
Kahramanmaraş	1	37° 57' 25"	36° 33' 26"	1470	714.6	16.8	
Gaziantep	3	37° 6' 11"	36° 43' 20"	479	550.8	15.1	
Hatay	1	37° 6' 9"	36° 37' 37"	700	1092.7	18.3	
Hatay	1	35° 54' 9"	36° 5' 45"	665	1092.7	18.3	
Hatay	1	36° 46' 5"	36° 32' 14"	350	1092.7	18.3	
Hatay	4	36° 3' 23"	35° 58' 51"	8	1092.7	18.3	
Hatay	1	36° 42' 59"	36° 30' 26"	299	1092.7	18.3	
Hatay	2	36° 30' 17"	36° 29' 38"	80	1092.7	18.3	
Hatay	1	36° 28' 22"	36° 23' 12"	80	1092.7	18.3	
Hatay	2	36° 5' 16"	35° 57' 33"	12	1092.7	18.3	
Sinop	5	42° 1' 34"	35° 8' 27"	10	674.7	14.1	North Anatolia
Amasya	2	40° 45' 22"	36° 19' 13"	700	461.3	13.6	
Tokat	1	40° 40' 6"	36° 39' 38"	670	443.1	12.5	
Tokat	1	40° 35' 17"	36° 59' 10"	750	443.1	12.5	

digital calliper to the nearest 0.01 mm. The second phalange from second phalanx of the fourth finger of the hind limb was clipped and stored in 70% ethanol for histological analysis.

Age determination was made by skeletochronological analysis (CASTANET, SMIRINA 1990, SMIRINA, ANANJEVA 2007). The digits were dissected, the phalanges were washed in running water for 12 h, then decalcified in 5% nitric acid for 3 h and washed again under running water for 12 h. Cross-sections (18 µm) of the diaphyseal part of each phalange were obtained using a freezing microtome, stained with Ehrlich's haematoxylin and examined under light microscope. We assessed the endosteal resorption of the first LAG (Line of Arrested Growth) by comparing the diameters of eroded marrow cavities with the diameters of non-eroded marrow cavities in sections from the youngest specimens.

On each section, the number of the LAGs was assessed independently by two operators (T. Ergül, N. Özdemir) and their results were compared. The double lines and endosteal resorption did not cause any serious interpretation problems with regard to the age determination, and the operators reached full agreement on all the samples. The distance between two adjoining LAGs is a good indicator of the individual growth in a given year (KLEINENBERG, SMIRINA 1969). Therefore, where we observed an obvious decrease in growth between two subsequent years, we used it to mark the age when sexual maturity had been achieved (RYSER 1988).

Because of the fact that the number of individuals is low in all populations, we pooled all the specimens in one dataset. Both SVL and the age showed normal distribution (Kolmogorov-Smirnov test,  $p > 0.05$ ) for pool data and for males and females considered separately. The equality of variances was assessed by Levene's test ( $p > 0.05$ ). An independent Sample t test was used to compare the variables between sexes, while Pearson's correlation coefficient was computed to infer the pattern of relationships between SVL and the age. The best regression model was selected according to  $R^2$  values. Based on the altitude and climatic data we separated the populations into lowland (at altitudes below 800 m) and mountain (at altitudes above 800 m) populations. Thus, we studied the ecological differences in terms of the age composition and body size. Data analysis was performed by SPSS 18 (for Windows; SPSS, Chicago).

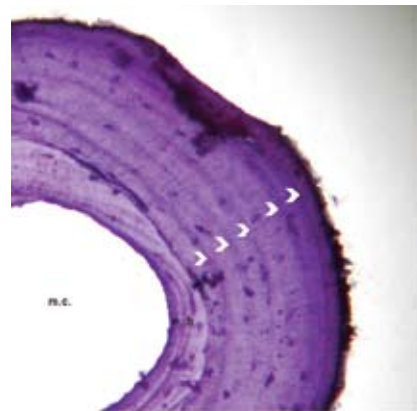
We quantified SSD with the index:  $SDI = (\text{size of larger sex} / \text{size of smaller sex}) - 1$ , arbitrarily expressed as positive if females are larger and negative if males are larger (LOVICH, GIBBONS 1992).

## Results

In all phalangeal cross-sections, the LAGs were clearly marked and relatively easy to count, as it can be seen in Fig. 2. The endosteal resorption, which had created partial erosion of the periosteal bone on the edge of the marrow cavity, was observed in 59.25% of individuals. The SVL ranged from 90.05 to 133.14 mm in males ( $n=43$ , mean:  $109.58 \pm 10.26$ ) and from 86.24 to 130.43 mm in females ( $n=38$ , mean:  $105.83 \pm 10.68$ ). The age was in the range 2-9 (mean:  $5.34 \pm 1.63$ ) in females and 3-10 (mean:  $5.72 \pm 1.82$ ) in males. The maximum age in the males was found in specimens from Muğla (24 m a.s.l.), İzmir (14 m a.s.l.) and Çanakkale (220 m a.s.l.). For the females, the maximum age was found in specimens from Balıkesir (300 m a.s.l.). The maximum age was found in lowland localities in both sexes. For all individuals, the youngest specimens were 2 years old, and for the males 3 years old.

We did not observe any significant difference between the sexes in terms of the age (Independent Sample t test,  $p = 0.329$ ,  $t = -0.982$ ,  $df = 79$ ) and SVL (Independent Sample t test,  $p = 0.112$ ,  $t = -1.607$ ,  $df = 79$ ). The intersexual differences in the body size were male-biased ( $SDI = -0.03$ ) but this relation was not statistically significant.

A significant difference between the lowland (below 800 m) and mountain (above 800 m) populations was found in respect of SVL (Independent Sample t test,  $p < 0.05$ ,  $t = -2.027$ ,  $df = 79$ ), with mountain individuals being larger than the ones in the low altitudes. A significant difference in the mean age between lowland and mountain populations was not found (Independent Sample t test,  $p = 0.73$ ,  $t = 0.35$ ,  $df = 79$ ). When analysing males and females, we did not find any significant difference between the in-



**Fig. 2.** A cross-section (18 µm thick) at the diaphysis level of a phalanx from a male *Stellagama stellio* from Izmir (m.c. = marrow cavity, e.b. = endosteal bone). The five LAGs are indicated by white arrows.

**Table 2.** Descriptive analysis of age and SVL for the localities below and above 800 m a.s.l.

Localities	Mean age $\pm$ SD		Mean SVL $\pm$ SD		Pooled data	
	Female	Male	Female	Male	Mean age $\pm$ SD	Mean SVL $\pm$ SD
Below 800 m	5.62 $\pm$ 1.46	5.73 $\pm$ 1.96	108.13 $\pm$ 9.64	107.95 $\pm$ 10.73	5.58 $\pm$ 1.87	106.43 $\pm$ 11.20
Above 800 m	4.85 $\pm$ 1.83	5.41 $\pm$ 1.16	101.88 $\pm$ 11.57	112.17 $\pm$ 7.47	5.42 $\pm$ 1.28	111.77 $\pm$ 7.39

dividuals inhabiting low and high altitudes, respectively (SVL: Independent Sample t test,  $p=0.08$ ,  $t=1.78$ ,  $df=36$ ; Age:  $p=0.16$ ,  $t=1.41$ ,  $df=36$ ), although the females from the lowland populations showed higher mean values of SVL and age.

We found a correlation between SVL and the altitude in the females (Pearson's correlation coefficient,  $r=0.537$ ,  $p<0.01$ ) and in the pooled data ( $r=0.243$ ,  $p<0.05$ ). The age was also correlated with the altitude in the females ( $r=0.337$ ,  $p<0.05$ ). The data for all groups were summarized in Table 2. The evaluation of the environment effect on the studied parameters in each sex found for the males a single significant correlation between SVL and the annual precipitation ( $r=0.408$ ,  $p<0.01$ ).

Furthermore, a significant positive correlation was found between the age and SVL both in males ( $n=43$ ,  $r=0.684$ ,  $p<0.01$ ) and females ( $n=38$ ,  $r=0.729$ ,  $p<0.01$ ). Simple cubic regression fitted between the age (years: x-axis) and body size (mm: y-axis) for both females ( $y=32.309-4.654*x+0.233*x^2+0.000*x^3$ ,  $R^2=0.417$ ) and males ( $y=17.902-2.102*x+0.092*x^2+0.000*x^3$ ,  $R^2=0.438$ ). The age at which a significant decrease in growth had been detected (based on the thickness of growth rings) was taken as the age of sexual maturity. Individuals reached maturity between 2 and 3 years of age.

## Discussion

Consistent relationships between growth and other life history parameters, such as age at maturity and adult survival, have been established in several reptile taxa (JAMES 1991, SHINE, CHARNOV 1992). The lizard growth rates can be affected by temperature because temperature affects digestive rate and efficiency (CHRISTIAN *et al.* 1983, GRANT, DUNHAM 1990, NOESKE, MEIER 1983, SINERVO, ADOLPH 1989), as well as by water supply (JENSSEN, ANDREWS 1983, STAMPS, TANAKA 1981). In lizards, the annual growth is also positively correlated with their activity (ADOLPH, PORTER 1993). Some lizard species are characterized by low body temperatures during the active periods, prolonged reproductive cycles with long gestation, and vitellogenesis that seems to be linked to envi-

ronmental constraints (IBARGÜENGOYTIA 2004; 2005, PIANTONI *et al.* 2006).

The possibility of age determination in agamas by using the growth layers in phalanges has been shown for *Laudakia caucasica* (LEDENTSOV, MELKUNYAN 1987), and in femur for *Agama impalearis* (EL MOUDEN *et al.* 1997). According to those authors, the longevity of *Laudakia caucasica* in the foothills was 6-7 years, while in the mountains 10-11 years; the maximum age reported for *Agama impalearis* was 5 years. However, based on a long-term mark recapture study of *Laudakia caucasica* by PANOV, ZYKOVA (2003), the maximal age can reach 12-13 years. In this study, the longevity of *Stellagama stellio* was recorded as 9 years for females and 10 years for males similar to that of the mountain populations. Not always the longevity in the mountain populations of various lizard species is higher in comparison with their conspecifics from the lower elevations. The lowland population of *L. agilis* showed a higher mean adult age than some submontane populations in Russia (ROITBERG, SMIRINA 2006). Similarly to that study, our lowland population showed a higher mean age than in the mountain populations. We believe that the length of the activity season determines the main trend and individuals living at higher altitude would exhibit lower longevity.

The individuals of the genus *Laudakia* mature after the second hibernation, i.e. in the third year of life, and their longevity is approximately 4-6 years (ATAYEV 1985, STUBBE *et al.* 1981, ANANJEVA *et al.* 2004). In our study, individuals of *Stellagama stellio* reach sexual maturity in second and third year of their life. We found no differences between lowland and mountain populations with regard to the age at maturity.

Our data showed there was not any significant difference in terms of SVL between males and females. However, the intersexual differences in body size were found to be male-biased (SDI = -0.03) but this relation was not statistically significant. Some authors suggested that the sexual dimorphism has evolved as a result of competition between the sexes for limiting resources, usually food (BEST, GENNERO 1984). Others supposed that sexual selection, medi-

ated by male-male competition for mates, is the primary cause for the sexual dimorphism (HEWS 1990, VITT, COOPER 1985).

The endosteal resorption is a phenomenon that creates an erosion of the periosteal bone on the edge of marrow cavity and can cause the complete loss of one or more periosteal LAGs, and thus can lead to underestimation of the age (CASTANET *et al.* 1993). Several authors suggested that the resorption may be linked to environmental conditions (SMIRINA 1972), for instance, less resorption was observed in populations living at high altitudes in comparison with the resorption in lowland populations (ESTEBAN *et al.* 1996; 1999) or the opposite (CAETANO, CASTANET 1993). The results of this study demonstrated that

the endosteal resorption in bones increased with the body length and age.

We provide here the first demographic data on *Stellagama stellio* from different regions of Turkey. While there is a positive correlation between the age and SVL, it is surprising that age was found to decrease with altitude and the reason for this is still not well understood. That decrease might be symptomatic of some ecological differences in the studied areas. Furthermore, our results suggest that further studies comparing populations at different elevations from a variety of latitudes would be useful in elucidating the potential reasons for the variation of life history and demography in *Stellagama stellio*.

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