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A skeletochronological study of age, growth and longevity in two freshwater turtles, *Emys orbicularis* and *Mauremys rivulata*, from Mediterranean Turkey (Reptilia: Testudines)

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We estimated growth parameters of *Emys orbicularis* and *Mauremys rivulata* in Mediterranean Turkey with the skeletochronological method, using specimens drowned in fyke nets. In adult *E. orbicularis*, the median age was 8 years in males and 10 years in females. The median age of adult *M. rivulata* was 10 years for both sexes. Both species reach sexual maturity at an age of 5–7 years. No difference was found in age composition between the sexes.

Keywords. Skeletochronology; humeral diaphysis; growth; longevity; *Emys orbicularis*; *Mauremys rivulata*; Southwestern Anatolia

Introduction

The European Pond Turtle, *Emys orbicularis* (Linnaeus, 1758), is distributed from Northern Africa, Southern, Central, and Eastern Europe, the Caucasus to Western Asia, while the distribution range of the Western Caspian Turtle, *Mauremys rivulata* (Valenciennes 1833), extends from the Balkan Peninsula over some Aegean and Mediterranean islands to the Middle East (Fritz et al., 2009; Van Dijk et al., 2014). In many parts of their ranges, both species occur together in various freshwater habitats such as swamps, marshes, ponds, lakes and rivers (Fritz 2001, 2003; Wischuf & Busack, 2001). Whereas the ecology and life history characteristics of both species have been studied in the European part of their distribution range (see e.g. Fritz 2001, 2003; Schneeweiss, 2004; Wischuf & Busack, 2001), there is limited information on age structure, age at maturity, growth, and longevity of the populations in the southern part of their distribution (Auer & Taşkavak, 2004; Erol, 2010). Our aim was to determine age and growth rates of *E. orbicularis* and *M. rivulata* in the Mediterranean Region of Turkey, to contribute to our understanding of some life history traits of these two freshwater turtles.

Material and Methods

In the course of a study on *Emys orbicularis* and *Mauremys rivulata* in southern and southwestern Anatolia conducted between 2010 and 2014, we found many dead specimens of both species which had drowned in fisherman fyke nets. We collected the humeral bones from these dead specimens to estimate the age structure and growth of turtles. We collected a total of 36 *E. orbicularis* (14 juveniles, 10 males, 12 females) in the provinces of Isparta, Muğla, and Burdur, and 23 *M. rivulata* (4 juveniles, 10 males, 9 females) in the provinces of Muğla, Mersin, and Hatay.

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The straight carapace length (SCL) and plastron length (PL) were measured with a special tortometer to the nearest 1 mm. Sex was determined by secondary sex characteristics (e.g. plastron concavity, tail type, distance of cloaca to body, iris colouration). The smallest turtle (male) with secondary sex characteristics measured 122 mm SCL for *E. orbicularis* and 100 mm SCL for *M. rivulata*; individuals with a lower SCL were considered juveniles.

The humerus of the left forelimb of each dead turtle was dissected and preserved in 70% alcohol for further analysis. The humerus bones were fixed in neutral buffered formalin and decalcified by Osteomoll®, Merck Millipore, for 2-4 hours according to the size of bone. The transverse sections (15-20 µm) were prepared using a freezing microtome, and all sections were stained with Mayer haematoxylin for 10 minutes and then examined under a light microscope. For each humerus, we selected a minimum of three cross-sections at the mid-diaphyseal level, with the smallest marrow cavity. The lines of arrested growth (LAGs) were counted by K.Ç. and M.K., who had previous experience with this technique. In all cases, the observers were blind to the identification of the individuals. All mount preparations were photographed with a Euromex Image Focus (vers. 4.0) Imaging System.

As suggested by Kleineberg and Smirina (1969), the first convergence in the distance between the LAGs was considered as the sign of reaching sexual maturity. In addition, the skeletochronological data were compared with growth rings using the largest plastral scutes (generally pectoral or abdominal) (Germano & Bury, 1998) by two observers (D.A. and K.Ç.), and the lower number was recorded. The method allowed a count up to 151 mm SCL for *E. orbicularis* and 109 mm SCL for *M. rivulata* due to the decay of growth rings.

Normality of the SCL and PL distribution for the sexes was tested using the Kolmogorov-Smirnov D test. Since they were distributed normally (Kolmogorov-Smirnov D test, $P_{SCL} \geq 0.701$ and $P_{PL} \geq 0.585$ for *E. orbicularis*; $P_{SCL} \geq 0.603$ and $P_{PL} \geq 0.860$ for *M. rivulata*), a parametric t-test was used for comparison. The non-parametric Mann-Whitney U-test was used to compare the medians, and Spearman's rank correlation was used to estimate the relationship between SVL and age due to data which were not normally distributed ($P \leq 0.05$). PAST statistical program was used in all statistical analyses (Hammer, Harper, & Ryan, 2001). The significance level was set at 0.05.

Growth was estimated by a modified von Bertalanffy's equation (1938), as previously used in several studies on reptiles (Roitberg & Smirina, 2006; Guarino, Gia, & Sindaco, 2010). The modified growth formula used was $SCL_t = SCL_{max} - (SCL_{max} - SCL_0)e^{-k(t)}$, where k is the Brody growth rate coefficient (units are yr^{-1}); t is the number of growing seasons experienced (age); SCL is the average straight carapace length in the age groups calculated; SCL_{max} is the average straight carapace length at maximum age; and SCL_0 is the average SCL at hatching. The SCL at hatching, approximately 25 mm for *E. orbicularis* (Ernst & Barbour, 1989; Fritz, 2001) and 33 mm for *M. rivulata* (Ernst & Barbour, 1989), follows literature reports. SCL_{max} , K , and their 95% confidence intervals were estimated through the non-linear least-square regression method using the FSA package (Ogle, 2012) in R version 3.0.2 (R Development Core Team, 2015). The age distribution curves between species were compared by analysis of covariance (ANCOVA), with age as dependent variable, the species as factor and the SCL as covariate.

Results

For *Emys orbicularis*, the mean Straight Carapace Length (SCL) was 77.3 mm (45.5–108.0 mm; $N=14$; $SD=20.8$) for juveniles, 130.4 mm (122–138 mm; $N=10$; $SD=6.01$) for males, and 146.8 mm (134–160 mm; $N=12$; $SD=8.53$) for females. In *Mauremys rivulata*, the mean SCL was 85.7 mm (74–94 mm; $N=4$; $SD=8.42$) for juveniles, 149.0 mm (100–191 mm; $N=10$; $SD=22.27$) for males, and 178.1 mm (161–198 mm; $N=9$; $SD=13.11$) for females. In both species, females have larger SCL ($P < 0.01$ for *E. orbicularis* and $P < 0.03$ for *M. rivulata*).

Mean Plastron Length (PL) was 70.3 mm (38.6–102 mm; $SD=5.55$) in juveniles, 116.2 mm (108–124 mm; $SD=5.86$) in adult males and 140.6 mm (128–155 mm; $SD=8.33$) in adult females of *Emys orbicularis*. In *Mauremys rivulata*, the mean PL was 70.5 mm (62–79 mm; $SD=7.23$) in juveniles, 125.1 mm (93–168 mm; $SD=22.06$) in

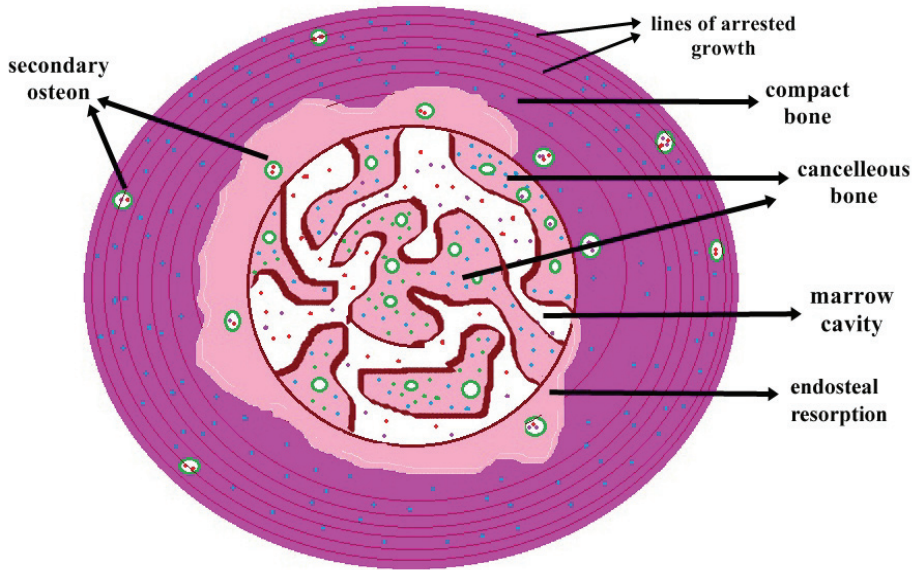


Figure 1. Schematic view of the cross-section of a hypothetical freshwater turtle humerus.

adult males and 160.3 mm (143–182 mm; SD= 13.55) in adult females. In both species, PL is thus larger in females than in males ($P < 0.01$ in both species).

It was found that compact and cancellous bone constitutes the structure of the bone in both species (Figure 1). The marrow cavity was largely or entirely covered by the cancellous bone. The cancellous bone consists of large trabeculae. This bone was poorly vascularized, and contained secondary osteons. The compact bone is found on the outer surface of bone. It preserves primary bone structure, and is called lamellar zonal type bone. It is less vascularized, and secondary osteons were observed as irregularly shaped in juvenile individuals, whereas they were not observed in adult individuals.

Secondary osteons were surrounded by cementum lines. These lines stain strongly basophilically, and can thus easily be distinguished from the other components of the bone (Figure 2). We observed only secondary osteons, and did not see the primary osteons on the bone surface. When compared with the compact bone, it was seen that there was a larger number of vascular canals on these trabeculae in both juvenile and adult individuals.

The new bone was formed from the inner surface to outer surface of the bone, and thus endosteal resorption then occurred widely around the marrow cavity. When cancellous bone progressively expanded towards the compact bone, it gave rise to partial or complete destruction of one or two growth lines in the adult individuals (Figures 3-4). It was observed that bone marrow was completely covered by cancellous bone, and the compact bone preserved primary bone structure in adult individuals older than 9 years. In these individuals, it was seen that vascularization decreased and secondary osteons disappeared on the surface of the compact bone. We did not find any differences between species with regard to histological structure of the bone.

In all humeral cross-sections, well-defined LAGs were observed in *E. orbicularis* and *M. rivulata*. The LAGs are generally in the form of thin and darkly stained concentric chromophilic rings and are located outside the cancellous bone. On the basis of the

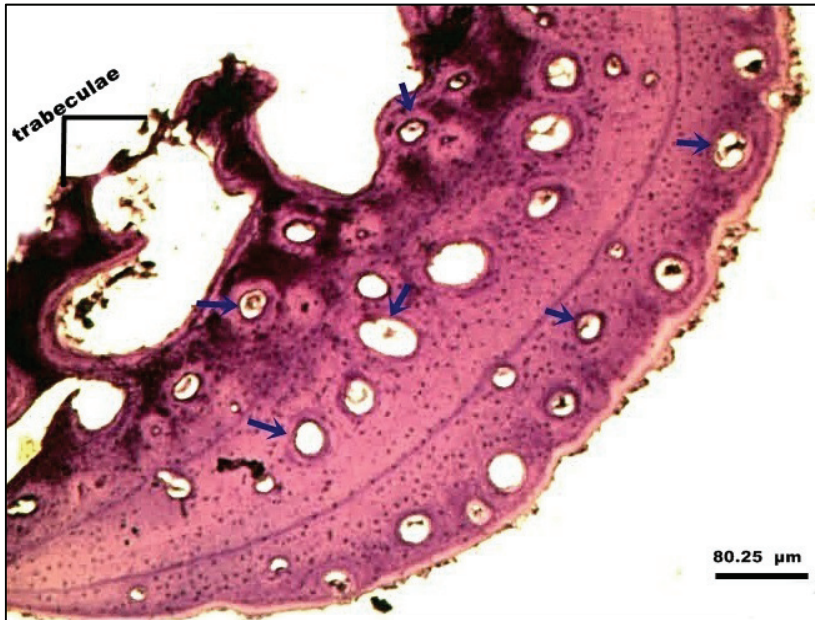


Figure 2. Humerus cross-section of juvenile *E. orbicularis* (SVL=86 mm). The arrows indicate the cementum lines around the secondary osteons. Irregularly shaped vascular spaces can be seen on the compact bone.

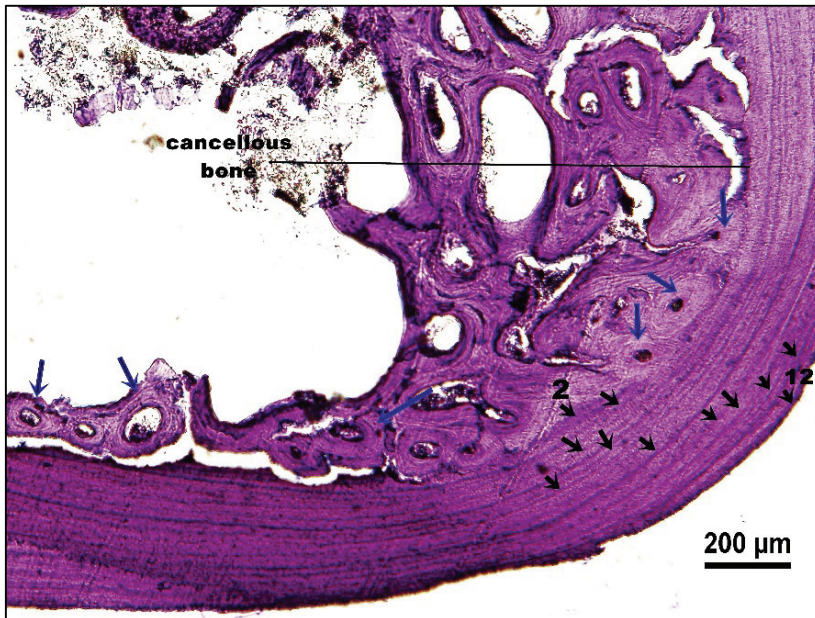


Figure 3. Humerus cross-section of a 12 year old male of *Mauremys rivulata* (SVL=145 mm). The blue arrows indicate the secondary osteons located on the boundary between cancellous and cortical bone. The first growth line was destroyed due to expansion of the cancellous bone (Black arrows: lines of arrested growth).

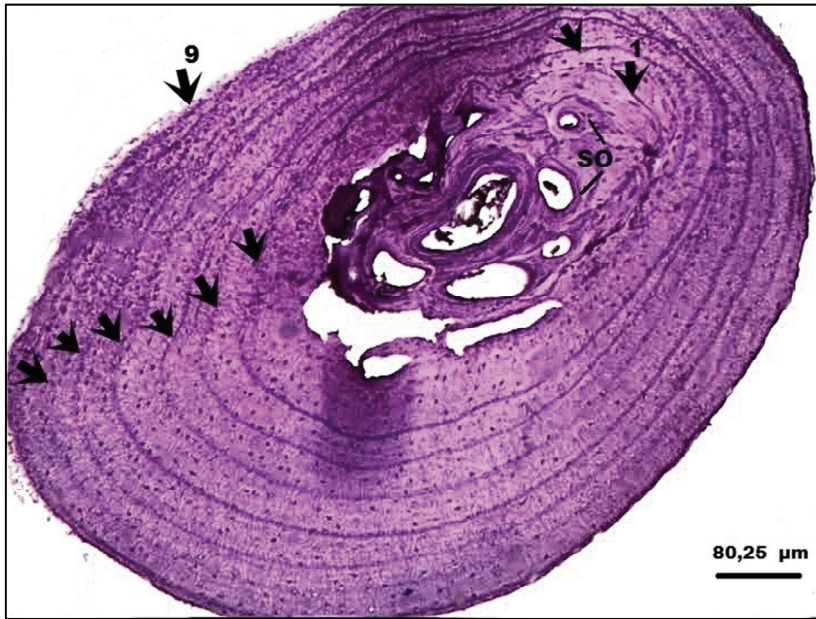


Figure 4. Humerus cross-section of a 9 year old male of *Emys orbicularis* (SVL: 133mm). The cancellous bone widely occupied the bone marrow, and the first and second growth lines were partly resorbed due to the endosteal resorption (Black arrows: lines of arrested growth, SO: secondary osteons).

osteometric analysis ($LAG1 \leq \text{mean } LAG1+2SD \leq LAG2$), it was observed that the first LAG was partially or completely resorbed by endosteal resorption in all individuals.

In *E. orbicularis*, the age distribution ranged from 1 to 12 years; the median age was 3 yrs (range= 1-5) in juveniles, 8 yrs (5-9) in males, and 10 yrs (5-12) in females (Figure 5a). When compared in terms of age structure, no statistically significant difference was observed in the age between the sexes (Mann-Whitney U test; $P < 0.03$). The individuals reach sexual maturity at an age of 5-6 yrs, with females reaching maturity later than males.

The median age of *M. rivulata* was calculated at 4 yrs (3-6) for juveniles, 10 yrs (6-12) for males, and 10 yrs (8-12) for females (Figure 5b). Both sexes reach sexual maturity at an age of 5-7 yrs, with no statistically significant difference in age composition observed between the sexes (U test; $P < 0.97$).

A comparison of the skeletochronological and growth ring counts revealed largely identical numbers of humeri and growth rings on plastral scutes, corresponding to the age of individuals. Our results demonstrated that growth rings could easily count up to 11 yrs for *E. orbicularis* and 12 yrs for *M. rivulata* in Southern Anatolia.

We observed that SCL and age were highly correlated in *E. orbicularis* (Spearman's correlation coefficient, $r=0.95$, $P < 0.001$) and *M. rivulata* ($r=0.63$, $P < 0.001$). According to the von Bertalanffy formula, the estimated asymptotic SCL for *E. orbicularis* was estimated as 161.4 mm (SE= 6.03, Confidence Interval [CI]= 149.1-173.6) and growth coefficient k as 0.24 (SE=0.03, CI= 0.17-0.30) (Figure 6). The values for *M. rivulata* were calculated as 220.1 mm (SE= 8.44, CI= 144.7-395.4) and 0.14 (SE= 0.15, CI= 0.16-0.44) (Figure 6). When comparing age structure of the two species, we found that the growth rate is faster in *E. orbicularis* (ANCOVA: intercept, $F_{2,56}=8.77$, $P=0.004$;

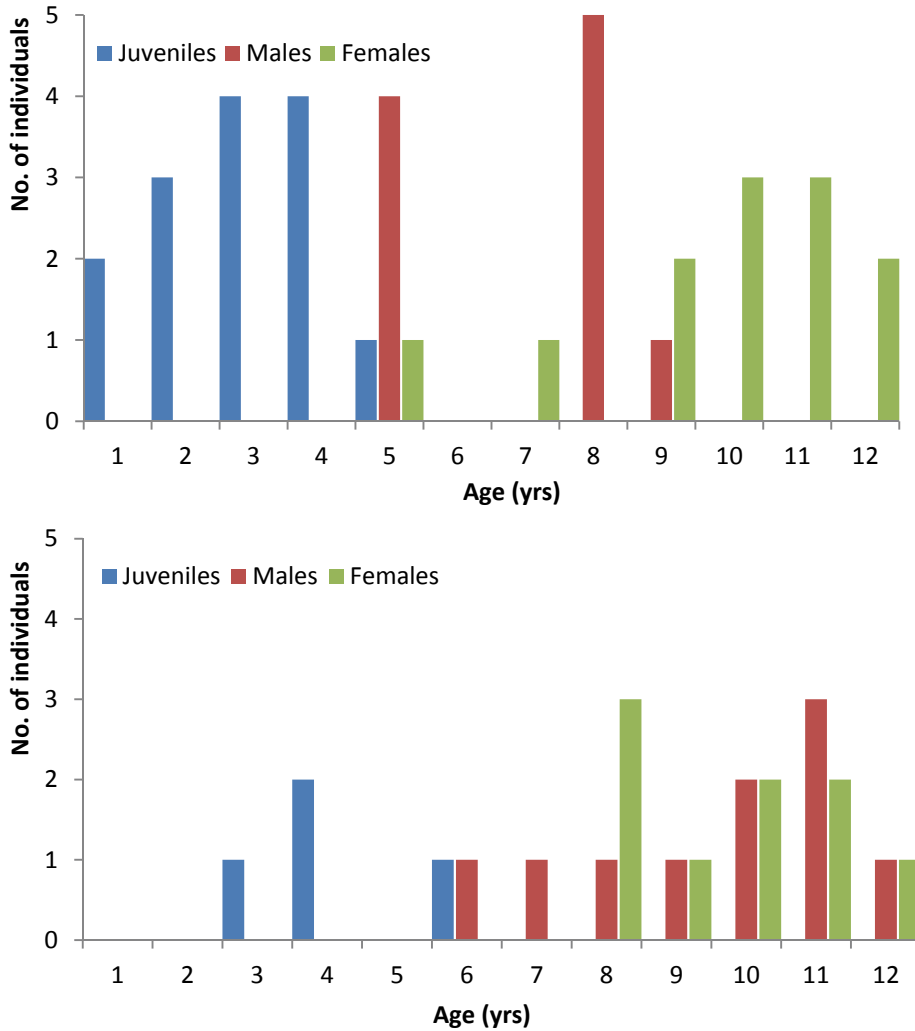


Figure 5. Age structure of *Emys orbicularis* (above) and *Mauremys rivulata* (below) from Mediterranean Turkey.

species interactions, $F_{2,56}=0.21$, $P=0.648$; SCL interactions, $F_{2,56}=152.84$, $P<0.001$), although the age structure is quite similar.

Discussion

The body size and growth rates of freshwater turtles could be affected by several environmental factors, including thermal regimes (Germano & Bury, 2009). *E. orbicularis* is considered as a long-living turtle and some authors reported that the longevity is more than 70 yrs or even 120 yrs (Biegler, 1966; Fritz & Günther, 1996). In the north-easternmost population of *E. orbicularis* in Germany, the age ranged between 8 and 30 yrs, males reached a higher age than females, and a considerable part of the population was over than 50 yrs (Schneeweiss, 2004).

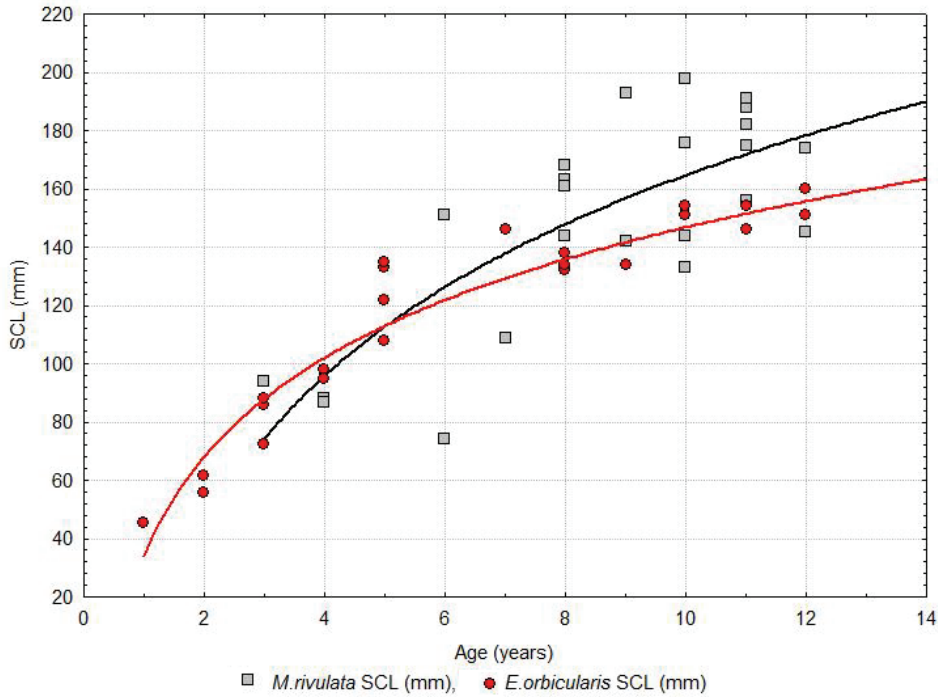


Figure 6. The growth curves of *Emys orbicularis* [$SCL_t = 161.4 - (161.4 - SCL_0)e^{-0.24(t)}$] and *Mauremys rivulata* [$SCL_t = 220.1 - (220.1 - SCL_0)e^{-0.14(t)}$] from Mediterranean Turkey.

Mitrus and Zemanek (2004) stated that the mean number of growth rings was 10 yrs (range= 4-15) for males and 14 yrs (11-17) for females in Central Poland. They also found that individuals reach maturity at 11 yrs for males and 12 yrs for females. In Central France, male *E. orbicularis* reach sexual maturity at 12 yrs and females at 17 yrs (Girondot & Pieau, 1993). Moreover, the species is sexually mature at 6 yrs in Spain (Keller et al., 1998), 6-8 yrs in Ukraine (Shcherbak, 1966), and 6-7 yrs in the southernmost Russia (Bannikov, 1951).

In western Anatolia, Auer and Taşkavak (2004) found that *E. orbicularis* males show secondary sexual characteristics at 110 mm SCL and had 7 annuli, and longevity was calculated as 16 yrs. Erol (2010) studied a Central Anatolian (Afyonkarahisar) population of *E. orbicularis* with the skeletochronological method and found a mean age of 5.6 yrs (4-9 yrs) for males and 6.1 yrs (4-9 yrs) in females. Sexual maturity was reached at an age between 4 to 6 yrs. In the population studied by us in southern Anatolia, the longevity of *E. orbicularis* is 12 yrs and turtles reach sexual maturity at 5-6 yrs.

The smallest males of *M. rivulata* had 86 mm SCL and 3 annuli, and the longevity is 16 yrs in western Anatolia (Auer & Taşkavak, 2004). The median age of *M. rivulata* is 11 yrs in Southeastern Europe and the Caspian region (Wischuf & Busack, 2001). In our population in Southern Anatolia, sexual maturity was reached at 5-7 yrs and the recorded longevity is 12 yrs.

In our study, the histological structure of the bones of *E. orbicularis* and *M. rivulata* did not show any differences. In both species, the cancellous bone was preserved in even the oldest individual. It progressively expanded towards the periphery of the bone, but this growth was limited due to the slow growth rate and endosteal resorption. Early

growth lines toward the centre of sea turtle bones often disappeared due to the endosteal resorption which enables expansion of cancellous bone at the core (Zug, Wynn, & Ruckdeschel, 1986). It was seen that the new or secondary bone was formed around the marrow cavity but had not completely displaced the early bone, so compact bone was preserved and growth lines could be easily counted. Only one or two LAGs could not be counted due to the expansion of cancellous bone and resorption of secondary bone. It was observed in *Podocnemis expansa* that the cortical bone of the femur was well vascularized and consisted of rarely distributed primary osteons and a large number of secondary osteons which were abundant in the peri-medullary region (Chinsamy & Valenzuela, 2008). Unlike *P. expansa*, primary osteons were not seen in either the compact or the cancellous bone. Vascularization was poorly detected in *E. orbicularis* and *M. rivulata*. In individuals older than 9 yrs we did not detect secondary osteons in the cortical bone, but they were obtained from cancellous bone in all species.

Schneeweiss (2004) reported that in *E. orbicularis* age could be identified by plastral growth ring counts up to years 16-18. Auer and Taşkavak (2004) estimated the age of *E. orbicularis* and *M. rivulata* with the help of plastral growth rings. On the other hand, this method had some disadvantages such as erosion of the growth rings. The missing rings caused false calculations in ageing studies (Germano & Bury, 1998). The skeletochronology and growth ring count method we adopted could be used successfully in the juveniles of *E. orbicularis* and *M. rivulata* with 1 or 2 years difference. This suggests that the growth ring count method could be easily used for estimating age structure or other life history parameters of both freshwater turtle populations.

The growth and maturation duration of freshwater turtles is influenced by ambient air and water temperatures (Williamson, Spotila, & Standora, 1989; Brown, Bishop, & Brooks, 1994) and often varies with geographic latitude (Iverson et al., 1993). Growth rates of chelonians can be influenced by the physical (e.g. topographic, climatic factors) and biological characteristics of the environment (e.g. population recovery, density dependency factors) (Suryan et al., 2009; Snover et al., 2010). Mitrus & Zemanek (2004) claimed that the sexual maturity age and size of *E. orbicularis* decrease from north to south in its distribution. The climate of Mediterranean Turkey is characterised by hot, dry summers and mild to cool, wet winters. Despite the favourable conditions, both species demonstrate slow growth, whilst *E. orbicularis* (0.24) grows faster than *M. rivulata* (0.14) in Mediterranean Turkey.

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Disclosure Statement

No potential conflict of interest was reported by the author.

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