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Allometry and sexual dimorphism of the Nile Softshell Turtle (*Trionyx triunguis*): male-biased size and conserved body shape

Salim Can Akçinar & Ertan Taşkavak

Department of Marine and Inland Water Sciences and Technology, Faculty of Fisheries, Ege University, Bornova 35100 İzmir, Türkiye

Present Address: Department of Marine and Inland Water Sciences and Technology, Faculty of Fisheries, Ege University, Bornova 35100, İzmir, Türkiye

Corresponding author: Salim Can Akçinar, ORCID 0000-0003-1369-8332, e-mail: can.akcinar@ege.edu.tr

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Abstract. The Mediterranean subpopulation of the Nile softshell turtle (*Trionyx triunguis*) is critically endangered, yet fundamental demographic and morphological parameters remain unresolved. This study aimed to evaluate sexual size and shape dimorphism, and ontogenetic growth trajectories using a dataset of 264 individuals in the Dalaman population in Türkiye. We found a significant male-biased sexual size dimorphism, with adult males averaging approximately 8% larger in straight carapace length (SCL) than females. However, multivariate and size-adjusted analyses revealed a highly conserved body shape, demonstrating that despite absolute size divergence, overall somatic morphology remains functionally monomorphic across adult sexes. Furthermore, allometric growth analysis identified total tail length as the primary secondary sexual characteristic for differentiating males, characterized by a distinct rapid hyperallometric elongation between 40.8 and 48.0 cm SCL. Consequently, the specific size-class thresholds identified provide field researchers with practical, non-invasive metrics to rapidly assess population structure. While males can be identified by tail elongation that extends the cloaca beyond the posterior carapace margin (> 40.8 cm SCL), individuals lacking this trait should only be confidently assigned as female at sizes exceeding 48 cm SCL. Ultimately, providing these actionable baseline parameters will directly support accurate population assessments and targeted conservation management.

Key words. Testudines, Trionychidae, morphometrics, secondary sex characters, sexual size dimorphism, tail length.

Introduction

Sexual dimorphism represents a significant macroevolutionary pattern among reptiles, including Testudines, and reflects divergent selective pressures acting on males and females (Shine 1994, Fairbairn 1997, Cox et al. 2007, Regis & Meik 2017). Understanding these patterns provides key information about the distribution, movement, behaviour and reproductive strategies of species (Agha et al. 2018), which play a central role in ecology and conservation. Within Testudines, the direction and magnitude of sexual size dimorphism (SSD) exhibit substantial variation, serving as fundamental metrics for comparative ecological and evolutionary studies (Lovich & Gibbons 1992). Female-biased SSD appears to be the ancestral state and remains dominant in approximately 66% of species, a trend primarily driven by fecundity selection to maximize clutch size and egg volume (Berry & Shine 1980, Gibbons & Lovich 1990, Stephens & Wiens 2009, Ceballos et al. 2013). Conversely, male-biased SSD frequently emerges in lineages where male-male combat dictates mate access and provides a reproductive advantage to larger individuals (Berry & Shine 1980). The degree of dimorphism in these male-larger clades often increases with overall species body size, adhering to the macroevolutionary trend known as Rensch's Rule (Fairbairn 1997, Ceballos et al. 2013). Minimal SSD or size monomorphism is rare in freshwater species but common in marine turtles, as the energetic costs of long-distance swimming likely constrain size divergence (Figgener et al. 2022).

Although divergent selective pressures often drive disparities in absolute body size, the physical environment strongly constrains the evolution of organismal shape. Terrestrial tortoises, for instance, often evolve highly domed and sexually dimorphic shells to accommodate larger clutches without incurring significant locomotor penal-

ties (Willemsen & Hailey 2003, Bonnet et al. 2010). In contrast, hydrodynamic drag restricts aquatic turtles, and many aquatic species exhibit hypoallometric shell development during late ontogeny, resulting in relative reductions in shell width and height to minimize drag (Fairbairn 1997, Pfaller et al. 2010, Ennen et al. 2015). Therefore, natural selection for hydrodynamic efficiency often constrains shape divergence and promotes a streamlined and functionally monomorphic shell profile across both sexes, a pattern most distinctly observed in highly pelagic marine turtles (Chelonioidea) (Stayton 2019, Figgener et al. 2022). Exploring how sexual selection for size interacts with natural selection for shape in large aquatic taxa remains essential for establishing accurate morphological baselines and demographic parameters.

Sexually dimorphic traits emerge through divergent ontogenetic trajectories. Evaluating the divergence of these paths can be used for estimating the onset of sexual maturity (Klingenberg 1998, Pélabon et al. 2014). This is particularly relevant for taxa lacking epidermal scutes, such as the Trionychidae, where traditional annulus counting is inapplicable. Given this limitation, inferring maturity from size-based morphological measurements and the emergence of secondary sexual characteristics provides a critical framework for defining life-history stages. In Testudines, these secondary characteristics differentiate during puberty and stabilize in adulthood (Berry & Shine 1980, Gibbons & Lovich 1990). Quantifying these morphological shifts is a standard proxy used to assign both sex and maturity status in wild populations (Ennen et al. 2015, Brito et al. 2022). A widespread marker of this transition is the hyperallometric elongation of the male tail, which shifts the cloacal vent distally beyond the plastron margin to facilitate successful copulation (Webb 1962, Rovatsos et al. 2017). Historically, these transitions were estimated using visual inspection of scatterplots (Casale et al. 2005), non-linear least-squares fitting for asymptotic growth models (Kennett 1996, Morales-Mérida et al. 2024), and traditional allometry. Applying these allometric and visual approaches to scuteless taxa facilitates the estimation of morphological transitions, effectively delineating the ontogenetic shift from juvenile to adult stages.

Serving as a valuable model to address these gaps, the Nile softshell turtle, *Trionyx triunguis* (Forskål, 1775), is a large trionychid inhabiting African river systems and the coastal eastern Mediterranean (van Dijk et al. 2017). Despite the Mediterranean subpopulation being listed as Critically Endangered (IUCN 1996), quantitative data regarding its ontogeny and morphology remain scarce. Previous research has focused on distribution, population size, reproduction, and genetics (Atatür 1979, Gidis et al. 2011, Güçlü et al. 2011, Akçınar & Taşkavak 2017, Eniang et al. 2024). As such, fundamental demographic parameters remain unresolved. To date, no study has quantitatively assessed the true extent of sexual size and shape dimorphism using robust morphometric methods or estimated maturation thresholds for this species.

In this study, we used morphometric data collected during a three-year population survey in the Dalaman region of Türkiye to provide a comprehensive analysis of ontogenetic scaling and sexual dimorphism in *T. triunguis*. Our research addresses three primary objectives: (i) to assess the magnitude and direction of SSD to determine if this population deviates from the typical female-biased freshwater pattern; (ii) to evaluate morphometric shape variation to determine if the sexes exhibit a conserved body shape; and (iii) to identify the size threshold at which secondary sexual characteristics emerge by analysing ontogenetic shifts in allometric growth.

Materials and methods

Study site and sampling

We sampled *T. triunguis* in the Dalaman region, Muğla, Türkiye, during the summer months (June to September) of 2009 to 2011 as part of a population estimation study (see Akçınar & Taşkavak 2017 for more details). For the present analyses, we included only first-time captures with complete morphometric measurements to avoid pseudoreplication from recaptures. Turtles were captured using baited hoop traps deployed at 16 locations across brackish marsh and channel habitats associated with Kükürt and Küçükdalyan Lakes and the Tersakan Channel. Traps were partially submerged in shallow near-shore waters and checked daily (soak time ≈ 12–14 h). Captured turtles were measured and weighed on site and released at their capture locations.

Data collection

For each individual, we measured straight carapace length (SCL), straight carapace width (SCW), straight plastron length (SPL) using waterproof vernier callipers (± 0.1 mm); curved carapace length (CCL) with a measuring tape; and total tail length (TTL) with a rigid transparent ruler (± 1 mm). Total tail length was defined as the distance from the midline of the posterior plastron margin to the tip of the tail. Body mass (W) was recorded using a hanging scale (precision ± 50 g; maximum load 50 kg). All measurements were performed by a single researcher to minimize observer bias.

Sex determination was based on external morphology. Individuals larger than approximately 45 cm SCL with elongated tails and cloacal openings extending beyond the posterior carapace margin were classified as males, while those lacking these features were classified as females (Fig. 1B, C). Relatively smaller individuals lacking secondary sexual characteristics were classified as unsexed/juveniles (U) (Fig. 1A). These juveniles typically displayed a dark olive background with bright yellowish spots on the carapace and distinctive ventral blotch patterns, resembling juvenile patterns observed in other softshell turtles (Webb 1962, Ernst & Barbour 1989, Bonnet et al. 2010, Rovatsos et al. 2017).

Statistical analyses

We compared $\log_{10}$-transformed trait dimensions between sexes using Student's or Welch's t-tests (depending on variance homogeneity), calculating effect sizes with Hedges' g and applying the Bonferroni correction to control for multiple comparisons.

To distinguish size from shape, we performed Principal Component Analysis (PCA) on the scaled, $\log_{10}$-transformed adult morphometrics. To isolate body shape from caudal dimorphism, we ran a primary PCA including all traits and a secondary PCA excluding total tail length (TTL). Differences in multivariate group centroids along the principal axes were assessed via MANOVA (Pillai's trace). Additionally, size-adjusted structural proportions and body mass were evaluated using ANCOVA (Type III Sums of Squares) with straight carapace length (SCL) as the covariate, reporting estimated marginal means (EMMeans).

We examined allometric relationships using Ordinary Least Squares (OLS) regression on $\log_{10}$-transformed data for females (F), males (M), and unsexed/juveniles (U). Departures from isometry ($b_{iso} = 1$ for linear traits; $b_{iso} = 3$ for mass) were evaluated using two-tailed t-tests. Differences in allometric trajectories among demographic groups were compared using Analysis of Covariance (ANCOVA) to assess slope heterogeneity and elevation shifts.

All analyses were performed in R v4.4.2 using the packages FactoMineR, factoextra, rstatix, car, effsize, and emmeans.

Results

Sample demographics and size dimorphism

We measured six morphometric traits in 264 *T. triunguis* individuals (147 males, 69 females, and 48 unsexed/juveniles). The largest male measured 78.7 cm SCL, whereas the largest female measured 65.6 cm SCL (Table 1). The smallest male exhibiting a cloacal vent extending beyond the carapace margin measured 45.7 cm SCL. Conversely, the largest female retained the vent entirely within the carapace margin. Most males and females measured between 45 and 66 cm in SCL, and six individuals (five males, one female) exceeded 66 cm SCL (Fig. 2). Males were significantly larger than females across all absolute morphometric measurements (t-test, $p < 0.001$ Bonf. Corr.; Table 1). Shell traits (CCL, SCL, SCW, SPL) and body mass (W) demonstrated moderate to large effect sizes between sexes (Hedges' $g \approx 0.6–0.9$) and yielded male-to-female ratios ranging from 1.05 to 1.17, translating to an average male-biased size divergence of approximately 8% in SCL. As expected, tail length exhibited pronounced dimorphism, with male total tail length (TTL) measuring approximately 1.5 times longer than that of females ($p < 0.001$; Hedges' $g = 3.13$).

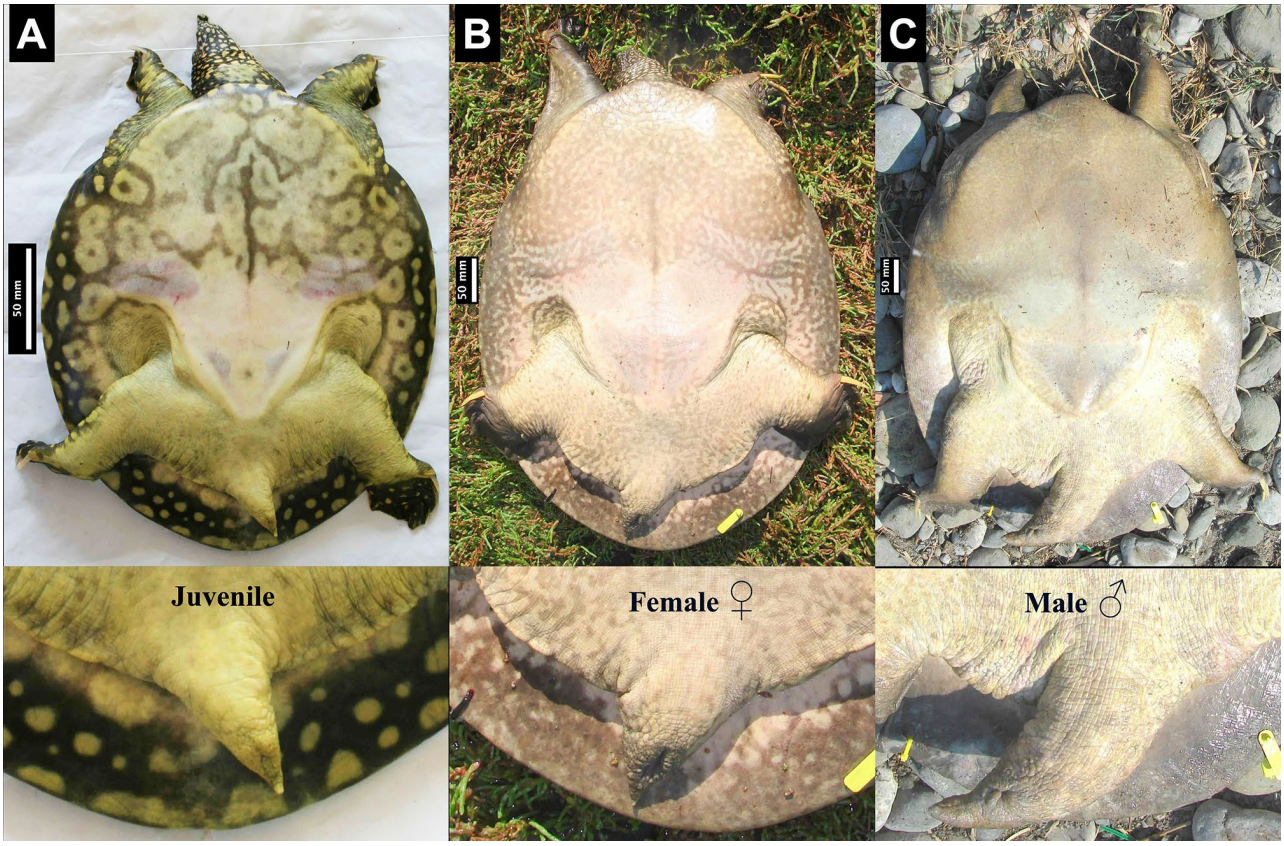

Figure 1. Ventral and close-up tail views of (A) unsexed/juvenile (SCL = 23 cm), (B) female (SCL = 54 cm), and (C) male (SCL = 68 cm) *T. triunguis* showing tail and cloacal differences used for sex determination (scale bars = 50 mm).

Table 1. Descriptive statistics (Mean ± SD, range) and univariate comparisons (t-test) of measured traits for *T. triunguis* by sex and ontogenetic stage. Degrees of freedom (df) for total tail length (TTL) and mass are reduced because Welch's t-test was applied due to unequal variances between sexes (Levene's test $p < 0.05$). All other traits met the assumption of homoscedasticity and were evaluated using Student's t-test (df = 214). ***Significance levels for Bonferroni corrected $p < 0.001$.

	Descriptive statistics			Comparison (females vs. males)			
Trait	Unsexed/Juv. (n=48)	Females (n=69)	Males (n=147)	Ratio (M:F)	t (df)	Hedges' g	Direction
CCL (cm)	38.1±5.8 (21.9–48.8)	56.9±4.5 (47.0–69.7)	60.7±5.2 (50.0–80.2)	1.067	5.38 (214) ***	0.78	M > F
SCL (cm)	35.4±5.2 (20.2–43.7)	52.7±4.6 (44.6–65.6)	56.9±5.2 (45.7–78.7)	1.079	5.95 (214) ***	0.86	M > F
SCW (cm)	29.5±4.1 (17.5–36.1)	41.9±3.4 (35.1–50.2)	44.1±3.5 (36.1–54.6)	1.052	4.36 (214) ***	0.63	M > F
SPL (cm)	25.5±4.1 (14.4–34.9)	37.4±2.9 (31.1–45.7)	39.4±3.3 (32.7–50.9)	1.053	4.35 (214) ***	0.63	M > F
TTL (cm)	10.9±2.2 (5.4–18.5)	18.0±2.7 (12.2–27.2)	26.6±2.8 (19.4–35.4)	1.489	20.47 (104) ***	3.13	M >> F
Mass (kg)	4.1±1.7 (0.7–7.9)	13.4±3.2 (7.4–22.1)	15.9±4.3 (8.3–35.3)	1.173	4.56 (152) ***	0.65	M > F

Table 2. Size-adjusted morphological comparisons between adult male and female *T. triunguis*. Results are derived from analyses of covariance (ANCOVA) on log-transformed traits using straight carapace length (SCL) as the covariate. Estimated marginal means (EMMean) are back-transformed to original units. R^2: model fit. Bold values indicate significance ($p < 0.05$).

Trait	n♂	n♀	R^2	Body size (SCL) $F_{1,214}$ (p)	Sex $F_{1,213}$ (p)	Sex × SCL $F_{1,212}$ (p)	EMMean♂ (95% CI)	EMMean♀ (95% CI)	Direction
CCL	147	69	0.96	3195.16 (<0.001)	2.56 (0.11)	2.44 (0.12)	59.17 (58.98–59.36)	59.38 (59.07–59.69)	♂ ≈ ♀
SCW	147	69	0.84	874.76 (<0.001)	1.23 (0.27)	1.35 (0.25)	43.10 (42.86–43.34)	43.71 (43.31–44.11)	♂ ≈ ♀
SPL	147	69	0.80	628.52 (<0.001)	0.02 (0.90)	0.01 (0.94)	38.52 (38.27–38.76)	38.93 (38.52–39.35)	♂ ≈ ♀
TTL	147	69	0.89	350.69 (<0.001)	13.88 (<0.001)	9.52 (0.002)	25.84 (25.53–26.16)	19.05 (18.67–19.44)	♂ > ♀
Mass	147	69	0.90	1434.86 (<0.001)	3.30 (0.07)	3.00 (0.09)	14.35 (14.15–14.55)	14.94 (14.60–15.29)	♂ ≈ ♀

Morphometric shape variation

Principal component analysis (PCA) of the adult morphometric dataset (N = 216) showed that PC1 explained 87.0% of the total variance and represented overall body size. The primary size-independent shape axis (PC2) explained 8.3% of the variance and was dominated by TTL (86.3% contribution; Fig. 3A). Adult males and females differed significantly in the multivariate morphospace (MANOVA: $F_{2, 213}$ = 461.4, Pillai's trace = 0.812, $p < 0.001$). Removing TTL from the PCA markedly reduced sex separation along the shape axis. In this restricted model, PC1 increased to 94.1% of the total variance, while PC2 decreased to 2.6% (Fig. 3B). MANOVA remained significant for the TTL-excluded model ($F_{2, 213}$ = 15.6, Pillai's trace = 0.128, $p < 0.001$). Consistent with this multivariate overlap, size-adjusted analyses of covariance (ANCOVA) with SCL as a covariate detected no significant intersexual differences in shell proportions or body mass (all $p > 0.05$; Table 2). In contrast, TTL remained significantly larger in males even after size adjustment ($F_{1, 212}$ = 13.88, $p = 0.0002$), yielding estimated marginal means of 25.8 cm for males and 19.1 cm for females.

Allometric relationships and ontogeny

Regression analyses of $\log_{10}$-transformed traits on SCL demonstrated distinct ontogenetic shifts in growth trajectories (Table 3). Shell traits in juveniles scaled isometrically ($b \approx 1$) but shifted to hypoallometry in adults ($b < 1$), indicating a relative decrease in shell width and length with increasing body size. Adult slopes were statistically indistinguishable across shell traits ($p > 0.05$), with sex-specific differences limited to SCW elevation ($F_{1, 212}$ = 5.34, $p = 0.021$). Comparisons of regression slopes (Table S1) confirmed that males and females differed significantly from juveniles in nearly all the linear shell traits ($p < 0.05$), except SCW and TTL for females.

Tail length exhibited the most distinct ontogenetic shift among the measured traits, serving as the primary secondary sexual characteristic for male differentiation (Fig. 4). Visual inspection of the regression plot revealed that while juvenile tail growth is relatively steady, males invest heavily in tail growth as they approach reproductive maturity. This shift toward rapid, hyperallometric tail elongation became visually apparent between approximately 40.8 and 48 cm

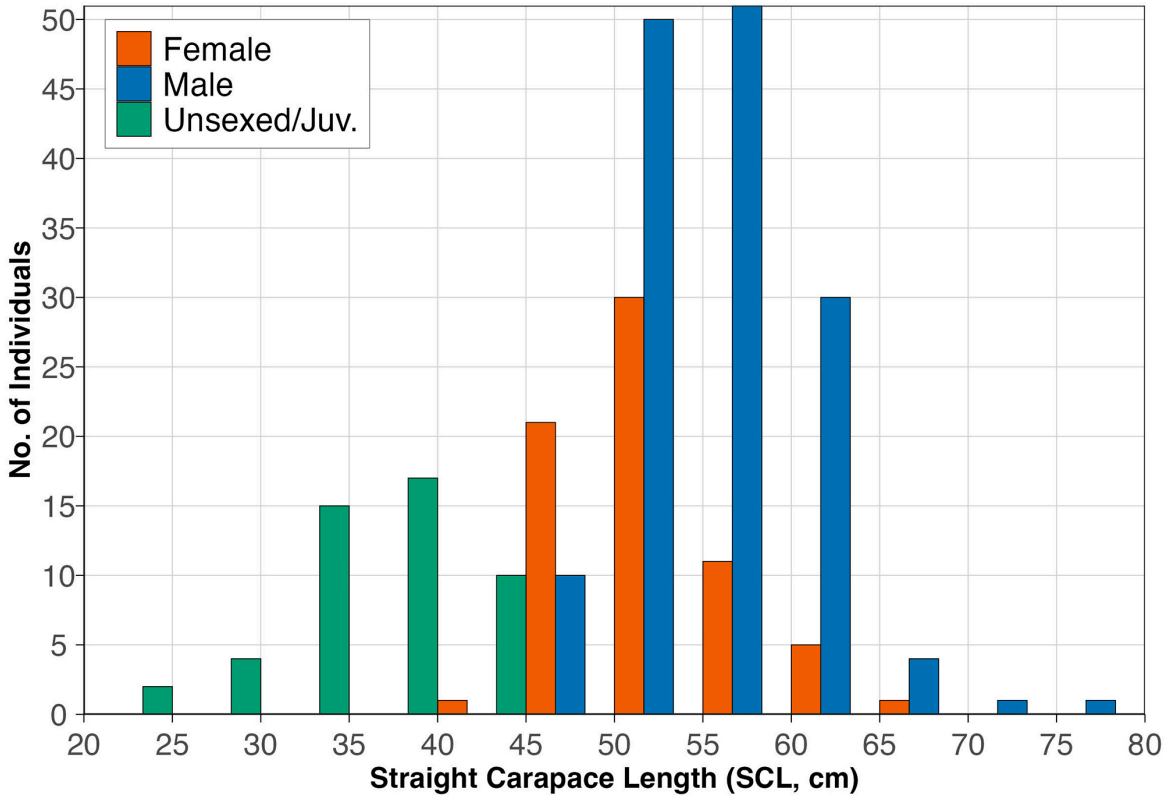

Figure 2. Size-class frequency distribution for males (n = 147), females (n = 69), and unsexed/juveniles (n = 48) of *T. triunguis* in Dalaman, Türkiye (2009 and 2011).

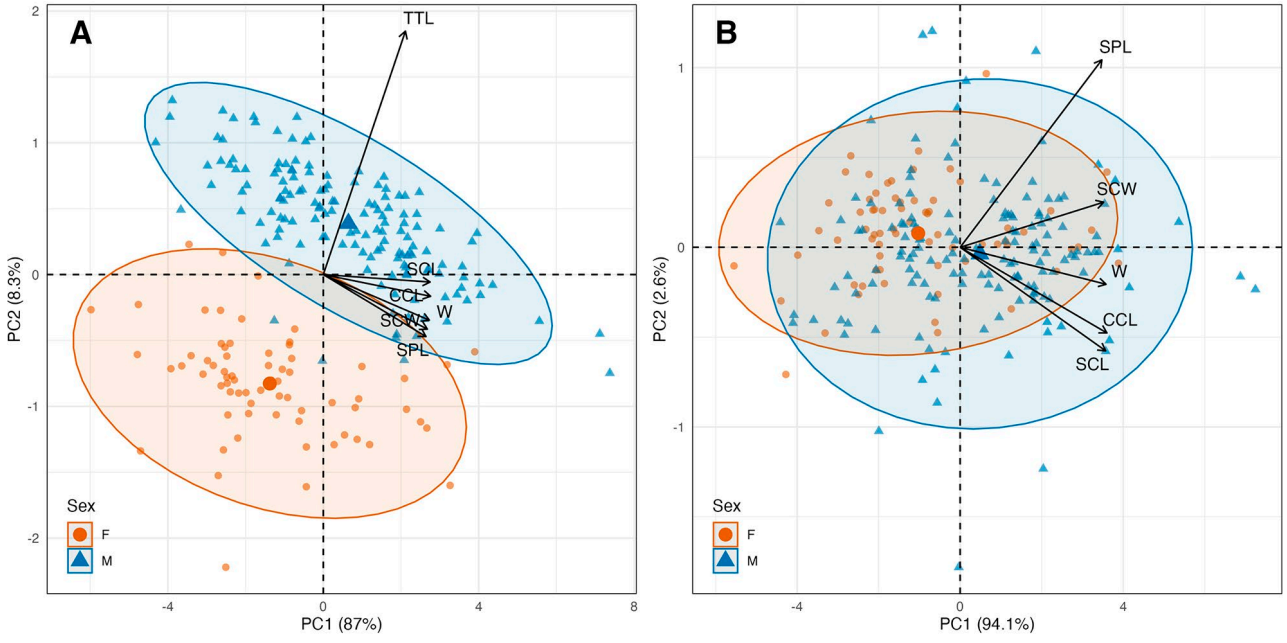

Figure 3. Multivariate morphological variation between adult male (blue triangles) and female (orange circles) *T. triunguis*. (A) Principal component analysis (PCA) including all morphometric traits with PC1 and PC2 accounting for 87.0% and 8.3% of the variance, respectively. (B) PCA excluding total tail length (TTL) with PC1 and PC2 accounting for 94.1% and 2.6% of the variance, respectively. Shaded ellipses represent 95% confidence intervals.

Table 3. Allometric relationships between SCL and log-transformed morphometric traits in *T. triunguis*. Sex: females (F), males (M), unsexed/juveniles (U). Slope [95% CI]: allometric coefficient; Int.: intercept; allometry type: deviation from theoretical isometry (slope = 1 for linear, 3 for body mass (W)). Significance of deviation from isometry: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Trait	Sex	n	Slope [95% CI]	R^2	Int.	Allometry type
CCL	F	69	0.88 [0.82, 0.95]	0.93	0.23	Hypo-***
	M	147	0.94 [0.90, 0.97]	0.96	0.14	Hypo-***
	U	48	1.00 [0.95, 1.06]	0.96	0.03	Isometry
SCW	F	69	0.87 [0.77, 0.97]	0.83	0.12	Hypo-**
	M	147	0.80 [0.74, 0.86]	0.83	0.23	Hypo-***
	U	48	0.92 [0.87, 0.98]	0.96	0.04	Hypo-**
SPL	F	69	0.82 [0.73, 0.91]	0.84	0.16	Hypo-***
	M	147	0.83 [0.75, 0.90]	0.76	0.14	Hypo-***
	U	48	1.03 [0.95, 1.11]	0.93	-0.19	Isometry
TTL	F	69	1.35 [1.09, 1.61]	0.61	-1.07	Hyper-**
	M	147	0.97 [0.86, 1.08]	0.66	-0.28	Isometry
	U	48	1.21 [1.04, 1.39]	0.81	-0.84	Hyper-*
Mass	F	69	2.56 [2.34, 2.79]	0.88	-3.30	Hypo-***
	M	147	2.81 [2.66, 2.97]	0.9	-3.74	Hypo-*
	U	48	2.94 [2.76, 3.12]	0.96	-3.96	Isometry

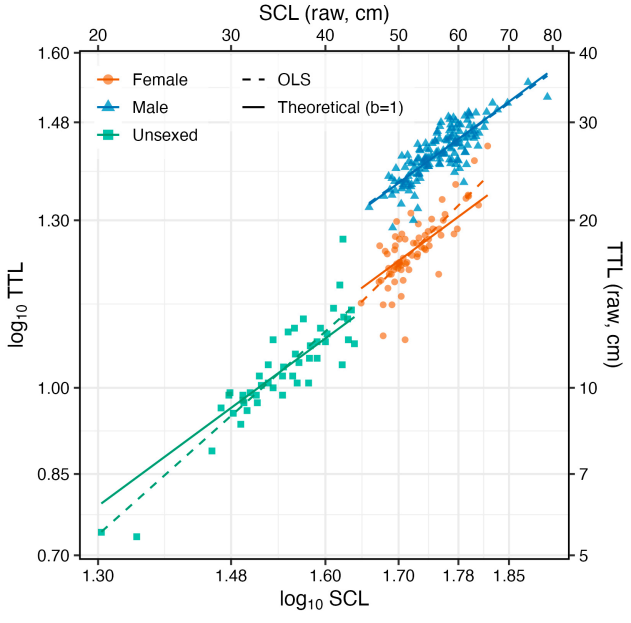

Figure 4. Ontogenetic allometry of *T. triunguis* tail length (TTL) vs. straight carapace length (SCL). Sex-specific OLS regressions (dashed) vs. theoretical isometry (b = 1, solid).

SCL. Beyond this transitional size range, the male trajectory distinctly separated from that of females and juveniles, allowing for definitive morphological sex identification.

Discussion

Sample demographics and size dimorphism

Our morphological assessment of the Dalaman *T. triunguis* population revealed a male-biased sexual size dimorphism (SSD), with adult males averaging approximately 8% larger than females in body size (SCL). The largest male and female recorded in our dataset had SCL values of 78.7 cm (CCL = 80.2 cm) and 65.6 cm (CCL=69.7 cm), respectively. Similar-sized individuals were observed from Gabon (CCL = 83 cm) and Dalyan and Dalaman (CCL = 75.5 cm) without specifying sex (Gramentz 1990, Gramentz 1993). Sex-specific morphological studies are based on a limited number of specimens documenting the presence of large males. The largest documented specimen to date (108.4 cm SCL) was a male captured as trawl bycatch in the Gulf of Iskenderun (Taşkavak & Akçınar 2008). Similarly, a recent study of the Dalaman population (n = 7) suggested potential male-biased dimorphism, where males (n = 5, mean CCL = 54.2 cm; 17.35 kg) were larger and heavier than the sampled females (n = 2, mean CCL = 39.5 cm; 6.7 kg) (De Kock et al. 2026). While these few findings suggest male-biased size dimorphism, interpretations require caution. In our study, this relatively small magnitude of male-biased SSD was driven by a small number (n=5) of large males. However, the male-biased sex ratio aligns with observations from African *T. triunguis* populations (Eniang et al. 2024). Ultimately, documenting the specific direction and magnitude of this divergence (Lovich & Gibbons 1992) establishes the foundational parameters necessary for comparing this population against broader macroevolutionary patterns and informing future demographic studies.

Additionally, the emergence of male-biased SSD in this large-bodied species aligns with the broader macroevolutionary expectations of Rensch's Rule, which notes that in clades exhibiting male combat, dimorphism often favours males and scales positively with species size (Fairbairn 1997, Ceballos et al. 2013). Broadly, this male-biased divergence represents a relatively rare occurrence among highly aquatic freshwater turtles. In contrast to most aquatic taxa, including well-studied North American trionychids such as *Apalone* species, which exhibit extreme female-biased SSD to accommodate larger clutches (Plummer 1977, Robinson & Murphy 1978, Gibbons & Lovich 1990), the Dalaman population appears to be aligned with those semi-aquatic lineages, such as Chelydridae (snapping turtles) and Kinosternidae (mud turtles), where sexual selection favours larger males (Berry & Shine 1980, Agha et al. 2018). Within the family Trionychidae, the only other known exception to this female-biased trend is *Pelodiscus sinensis*, which also exhibits male-biased SSD (Liu

et al. 2024). Crucially, documenting this relatively rare male-biased divergence provides essential sex-specific size parameters that will directly support future demographic modelling and life-history evaluations.

Morphometric shape variation

Although our findings indicate a male-biased difference in absolute size, our multivariate morphological assessment demonstrated that body shape divergence is largely constrained. Excluding the sexually dimorphic tail length from analysis substantially reduced size-independent shape variance and resulted in near-complete multivariate overlap between the sexes. This overlap indicated that the biological effect of allometric shape dimorphism was negligible compared to the extreme tail dimorphism. Carapace and plastron proportions scaled similarly between males and females. This conserved body aligns with broader eco-morphological patterns observed in highly aquatic turtles. Unlike terrestrial tortoises, which can evolve highly domed and sexually dimorphic shells without locomotor penalties (Bonnet et al. 2010), aquatic species are restricted by the physical drag of their environment. Recent global-scale analyses confirm that the shell shapes of aquatic turtles are severely limited by the need for efficient movement in water, resulting in highly conserved morphologies with little variation (Xiao et al. 2023). Furthermore, because large aquatic turtles face reduced predation pressure, they prioritize flatter, streamlined carapaces to minimize energy consumption during extensive movements (Xiao et al. 2023). This functionally monomorphic shell profile across both sexes in *T. triunguis* is consistent with the constraints described for highly pelagic sea turtles (Stayton 2019, Figgener et al. 2022). Recognizing this highly conserved body shape, despite absolute size divergence, provides a vital structural baseline for future ecological monitoring.

Allometric relationships and ontogeny

Understanding the development of these traits requires examining growth trajectories across life stages. Using a broad size distribution (20.2 to 78.7 cm SCL) and substantial sample size (n = 264) of our dataset, we integrated juvenile and adult measurements to evaluate these ontogenetic transitions. Because the Mediterranean subpopulation is critically endangered, we avoided invasive or semi-invasive sex determination methods to comply with ethical and logistical constraints. Instead, we estimated male sex and maturation thresholds by utilizing hyperallometric tail elongation and the displacement of the cloaca beyond the posterior carapace margin. This structural transformation is a highly conserved secondary sexual characteristic across Testudines, allowing the male cloaca to bypass the female's carapace margin during the copulation (Webb 1962, Rovatsos et al. 2017).

In *T. triunguis*, tail length and accompanying cloacal vent position serve as the primary secondary sexual characteristics by which males can be reliably differentiated. Visual inspection of the allometric growth trajectories (Fig. 4) revealed that males invested heavily in tail growth as they approached reproductive maturity. This distinct shift toward hyperallometric tail elongation became apparent between approximately 40.8 and 48.0 cm SCL. Interestingly, the upper end of this transitional size range aligns with theoretical expectations for turtle maturation, where adult morphology typically stabilizes at approximately 65% of maximum carapace length (Hermanson & Evers 2025). In our dataset, 65% of the maximum observed size (78.7 cm) was approximately 51 cm, closely matching the completion of this visually inferred allometric shift. Similar size-linked morphological transitions have been documented in *Caretta caretta* (Casale et al. 2005) and *Dermatemys mawii* (Bishop et al. 2021). Furthermore, establishing this specific size at maturation is critical for understanding the underlying mechanics of SSD in this species. In turtles, the direction and magnitude of SSD are heavily influenced by bimaturism – differences in the age or size at which each sex matures (Lovich et al. 2014). By identifying the 40.8 to 48.0 cm SCL maturation threshold for males, our baseline data provides the valuable morphological parameters required for future demographic studies to investigate how maturation timing drives the male-biased SSD observed in this population.

Conclusion

Our results provide a comprehensive morphometric baseline for the Critically Endangered Mediterranean subpopulation of *Trionyx triunguis*. We demonstrated that SSD in this population was distinctly male-biased, with adult males averaging approximately 8% larger than females in SCL. Despite this absolute size divergence, overall somatic body shape remains highly conserved and monomorphic between the sexes. Furthermore, we identified relative tail length as the primary secondary sexual characteristic for differentiating males, characterized by a distinct allometric shift toward rapid elongation between 40.8 and 48.0 cm SCL. Because traditional scute-based aging is inapplicable to the Trionychidae family, identifying these size-linked morphological transitions provides a critical non-invasive metric for field researchers. To ensure consistent demographic predictions, individuals within the 40.8 to 48.0 cm SCL range should be treated cautiously as transitional. Turtles lacking tail elongation, where the cloacal vent remains within the carapace margin, should only be confidently assigned as female at sizes exceeding 48 cm SCL. In practice, providing these practical baseline parameters will directly support accurate population assessments and targeted conservation management for this species.

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