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Intra- and inter-drainage variation in population structure, body condition, shape morphology and sexual dimorphism in *Mauremys leprosa saharica* from southern Morocco

Soumia Loulida[1,2,*], Mohammed Znari [1,2], Mohamed Naimi[2,3], Abdelghani Aabid[1,2]

[1] *Laboratory 'Water, Biodiversity and Climate Change' Cadi Ayyad University, Faculty of Science, Semlalia, Department of Biology, P.O. Box 2390, 40000, Marrakech, Morocco*
[2] *The Natural History Museum of Marrakech, Cadi Ayyad University, 40000, Marrakech, Morocco*
[3] *Polyvalent Laboratory in Research and Development, Polydisciplinary Faculty, P.O. Box 592, 23000, Sultan Moulay Slimane University, Beni Mellal, Morocco*
**Corresponding author*. E-mail: soumialoulida@gmail.com

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Abstract. The Mediterranean pond turtle *Mauremys leprosa* is widely distributed in Morocco. Significant variations could be observed in this species due to the fact that it occupies a vast and environmentally diverse area. Thus, the analysis of population parameters is crucial in elucidating the differences between populations. Differences between individuals may be linked to environmental factors, including many habitat characteristics. In the present study, variation in population structure, body condition, morphology and sexual dimorphism, were examined for the Sahara Desert blue-eyed turtle *M. l. saharica* in southern Morocco from seven distinct localities distributed in four different drainages in southern Morocco. A total of 224 turtles were captured, sexed, weighed and then measured for their carapace and tail dimensions before being released. Among the studied populations, four were dominated by adult individuals (Taakilt: 96%, Oued Guir: 87%, Oued Ziz: 75%, Sidi ElMehdaoui: 70%), two comprised 100% of adults (Oued Noun and Tarmigt) and one population consisted of 50% adults (Lower Draa). The sex ratio was significantly different between populations, being balanced in two populations (Tarmigt and Sidi El Mehdaoui), male-biased in three populations (Oued Zizi, Oued Noun, Lower Draa) and female-biased in the two remaining populations (Oued Guir and Taakilt). Body Condition Index (BCI, g/cm^3) was significantly different among populations but not between sexes, or for the Sex × Locality interaction. The Sexual Size Dimorphism (SSD), females being larger than males, varies among population with the greatest degree observed in Oued Guir population (SSD = 0.41) and the lowest in Sidi El Mehdaoui population (SSD = -0.14). Length-Weight Relation (LWR) shows that *M. l. saharica* has isometric growth for both male and female of Oued Guir and Tarmigt, for female of Oued Ziz, Taakilt, Oued Noun and lower Draa and hypo-allometric for male of Oued Ziz, Taakilt, Oued Noun, Lower Draa and for both male and female of Sidi El Mehdaoui. Morphological variation of carapace is shown in this species associated with population variation among basins. Increased understanding of population characteristics and their fitness status must be considered in conservation and management action plans for the species and its habitat.

Keywords. Structure, morphology, sexual dimorphism, *M. l. saharica*, southern Morocco.

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INTRODUCTION

Freshwater turtle species are still poorly understood, and many species are in decline due to unsustainable trade as well as human alteration of freshwater ecosystems (Palacios et al., 2015). These species are strongly linked to their habitats and consequently greatly affected by their deterioration: fragmentation and degradation. In the arid regions of North Africa, turtles are faced with extreme environmental conditions of arid climate and anthropogenic and climate change-mediated water and land salinization.

The Mediterranean pond turtle, *Mauremys leprosa*, Geoemydidae family, is a freshwater turtle species that mainly inhabits streams and ponds with riparian vegetation (Da Silva, 2002). This turtle species is found in southwestern Europe and northwestern Africa (Da Silva, 2002). In Europe, its distribution is limited almost exclusively to the Iberian Peninsula and includes a small area in southern France in the Eastern Pyrenees. In the northern limit, *M. leprosa* apparently presents a wide distribution although it appears in small and fragmented populations (Llorente et al., 1995; Da Silva and Blasco, 1997; Rivera et al., 2011). Populations in Northwest Africa are often isolated from one another by intervening arid terrain, and a complex pattern of local variation in shell markings has occurred (Bertolero and Busack, 2017). *Mauremys leprosa* tolerates brackish to saline water, and has a high tolerance for polluted freshwater habitats, reduced water levels, and elevated ambient temperatures; carnivorous by preference, it can also feed freely upon vegetation and has been reported ingesting nitrogenous animals (freshwater fish, amphibian larvae…) and human wastes (Bertolero and Busack, 2017). Two subspecies are currently recognized: *M. l. leprosa* (Mediterranean Pond Turtle) (distribution: from northwestern Morocco through the Iberian Peninsula to southern France) and *M. l. saharica* (Saharan Pond Turtle) (distribution: from southern and eastern Morocco through Algeria to northwestern Libya, with scattered populations in the northern Saharan margin).

In Morocco, *M. leprosa* is characterized by a great ecological valence occupying all available aquatic environments (streams, rivers, ponds…) and can tolerate clear, eutrophic, brackish or excessively polluted waters. Across most of its range, *M. leprosa* is currently considered threatened by habitat fragmentation and/or destruction, alien species, pollution, aquifer water extraction, with less significant threats from harvesting for the pet trade (Pleguezuelos and Feriche, 2003; Polo-Cavia et al., 2011) and pathogens (Hidalgo-Vila et al., 2008; Verneau et al., 2011). For these reasons, *M. leprosa* is listed as vulnerable in Europe on the IUCN Red List (version 13.2) (Van Dijk et al., 2004) and is listed in Appendix II of the Berne Convention and in Appendix II and IV of the Habitat Directive (92/43/CEE) (Cox and Temple, 2009). The different threats that the Mediterranean pond turtle faces across its distribution area could lead to an important population stress due to forced adaptations to changing environment contributing thus to marked reductions in the size of populations (Glynn, 1988; Hoffmann and Pearsons, 1991).

The study of population structure is an important parameter of the life history patterns of animals often related to ecological and ethological aspects of the individuals (Peters, 1986; Schmidt-Nielsen, 1984; Roff, 1992; Stearns, 1992). Differences between males and females in body size and morphology (sexual dimorphism) are common among reptiles (Dunham et al., 1988; Shine, 1989; Randriahamazo, 2000). Particularly, body size and sexual dimorphism have been extensively described in turtles (e.g., Berry and Shine, 1980; Iverson, 1985; Gibbons and Lovich, 1990; Lambert, 1995; Zuffi and Gariboldi, 1995; Yasukawa et al., 1996; Ernst et al., 1998; Graham and Cobb, 1998; Willemsen and Hailey, 1999; Zuffi et al., 1999; Ayres and Cordero, 2001; Bonnet et al., 2001; Boone and Holt, 2001). Body size of turtles can vary significantly at the intraspecific level between geographic locations, which is usually explained by phenotypic plasticity, or local adaptation (Gibbons and Lovich, 1990; Rowe, 1997).

Body condition (mass per unit of volume) is an important determinant of an individual animal's fitness. Many authors have addressed the relationship between body condition and ecological parameters such as survivorship, reproductive investment, parasite load or investment in characters used in sexual display in a wide range of studies of amphibians (Reading and Clarke, 1995), reptiles (Bradshaw and Dèath, 1991; Cuadrado, 1998), birds (Carranza and Hidalgo De Trucios, 1993; Dufva, 1996) and mammals (Dobson and Michener, 1995). The variation in morphometric parameters is generally induced by genetic and environmental factors that may have an effect on growth process and then on the species survival (Barlow, 1961; Somers, 1986). Thus, the morphological analysis of intra-population variation is crucial in elucidating the characteristics of a population. The morphological differences among individuals may be linked to environmental factors, including air and water temperatures and other habitat characteristics (Litzgus and Smith, 2010), or to historical factors limiting gene flow among the basins (Clavijo-Baquet et al., 2010). However, turtles and tortoises are known with the existence of morphological differences (Germano, 1993; Packard et al., 1999). Turtles are a model clade for which to study sexual size dimorphism (SSD), as this attribute varies dramatically across species. Sexual Size Dimorphism is a widespread phenomenon among plants and animals that often results from differential selection operating on different body sizes between males and females (Fairbairn, 1997). Biologists generally have explained these differences in terms of sexual selection (Darwin, 1874; Trivers, 1972; Ghiselin, 1974). Body size is among the most frequently used variables used to quantify the sexual dimorphism because it is a fundamental property of organisms in anatomy, ecology, physiology… (Peters, 1986; Calder III, 1996; Cardillo et al., 2005; Lynch, 2007). The standard body size measurement in turtles is the carapace length (CL), a linear measurement of the dorsal shell. Carapace length is often considered as a stable measurement of size across turtles, with little or no apparent seasonal or daily variation (Regis and Meik, 2017). Most turtle species are female-biased in carapace length. Despite this trend, the SSD varies within most families even within genera and species (Lovich et al., 2010). In *M. leprosa*, females are the largest sex. Berry and Shine (1980) suggested that the smaller body size of males in most species turtles could be attributed to the low importance of intrasexual selection processes in turtles. It has been suggested for other species of turtles and tortoises that the small size of one of the sexes can also be related to age at maturity (Gibbons and Lovich, 1990). In *M. leprosa*, males attain sexual maturity at smaller sizes than females (Keller, 1997), and this could be one of the causes of the SSD in this species. Apart from two studies (Meek, 1987; Lovich et al., 2010), there were no investigations on the Saharan and sub-Saharan populations. In this study, we reported on the characteristics of seven Saharan populations (including population structure along with shape morphology, body condition and sexual dimorphism) of *M. leprosa* from southeast to southwest Morocco.

MATERIALS AND METHODS

Study site

The Mediterranean Stripe-necked Terrapins, *M. leprosa*, were collected during spring period from seven sites in southern Morocco (six sites located at different oueds [rivers] belonging to four different drainages: noun, Guir, Ziz, Draa (Lower draa, Taakilt, Tarmigt, and an isolated brackish pond at Sidi El Mehdaoui oasis). The locality of Oued Noun (28°58’20.3”N, 10°13’6.71”W, 198 m a.s.l, about 70 km southwest of Guelmim city (28°59’17”N, 10°03’27”W) on southwestern Morocco. The average of annual rainfall varies between 90 and 120 mm. Maximum and minimum temperatures reach respectively 45 °C and 0.1 °C. The annual average temperature is around 20.5 °C. (The National Meteorological Department, Morocco, 2018). The substrate is dominated by rocks characterized by the presence of shales. The vegetal cover is made of tree species: *Acacia raddiana*, *Tamarix aphylla*, *Phoenix dactylifera* (Palm date) and other plant species such as *Haloxylon scoparium*, *Aizoon canariense*, *Launaea arborescens*, and *Euphorbia officinarum*. The sampling site of Oued Ziz (31°55’42.56”N, 04°18’41.75”W, 1027 m a.s.l) at 7 km north to Erfoud city (31°26’20”N, 04°14’37”W) Southeast Morocco. The average annual rainfall is very low and decrease from north to south ranging from 270 mm at the high atlas ending on the north to 66 mm. Mean annual temperatures are very high and are characterized by strong daily amplitudes (20-50 °C) (The National Meteorological Department, Morocco, 2018). The substrate is rocky with limestone and sandstone. The vegetation is mainly composed of *Acacia*, *Atriplex* and palm date. The Oued Guir site (32°13’59.9”N, 03°56’30.9”W, 1124 m a.s.l) at 22 km south to Gourrama village southeastern Morocco. The rainfall is low, generally poorly distributed over time and space. The monthly temperature represents a striking seasonal variation with an extremely cold winter (January). The summer (July-August) is very hot with mean maximal temperatures up to 41 °C. The National Meteorological Department, Morocco, 2018). The substrate is characterized by rocks occupying stony arid flat areas.The vegetation is in the form of a steppe characterized by the presence of *Acacia* and *Tamarix* and a vegetation consisting mainly of *Stipa tenacissima* tussocks and palm dates.The four last sites are related to the Draa river (Taakilt: 30°37’17.77”N, 06°09’44.62”W, 845 m a.s.l; Tarmigt: 30°52’13.7”N, 06°50’54.0”W, 1152 m a.s.l; Sidi El Mehdaoui (pond): 29°29’03.66”N, 07°59’08.29”W, 453 m a.s.l and Lower Draa: 28°31’6.62”N, 10°56’8.78”W, 58 m a.s.l). The temperatures are high especially between June and September (43 to 50 °C) (The National Meteorological Department, Morocco, 2018), the evapotranspiration is strong especially in summer with the scarcity and the very strong annual and inter-annual variability in precipitations. The substrate is isohumic with brown colour and the texture is sandy-silty on the surface and clay-silty on depth. The vegetation is characterized by an association of *Artemisia herba alba* and *Stipa parviflora* and *Poa bulbosa* with *Festuca spp*. We can also distinguish *Haloxylon scoparium* with *Stipa parviflora* and *Aristida obtusa* (Fig. 1).

Sampling methods

Turtles were collected using hoop traps baited with canned sardines in spring 2017. Upon capture, each individual was weighed (to the nearest 0.1 g) then measured using a Vernier caliper (to the nearest 0.1 mm) for the following shell dimensions (Fig. 2; Muñoz and Nicolau, 2006): Carapace Length (CL), Anterior Width of

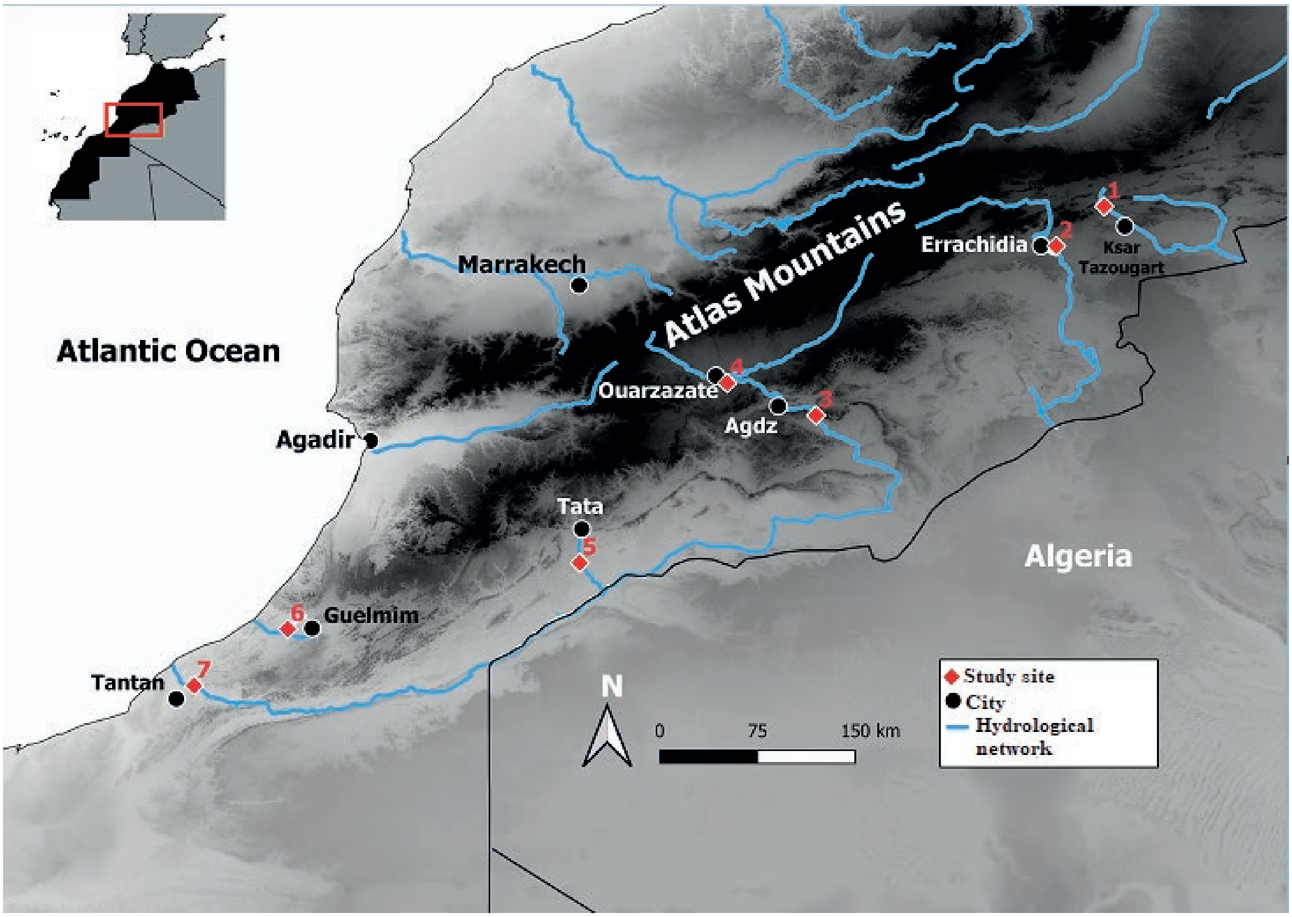

Fig. 1. Map showing the geographic location of the seven study sites in Southeast and Southern Morocco.

Carapace (ACW), Posterior Width of Carapace (PCW), Height of the carapace (H), Plastron Length (PL), Tail Length (TL), Pre-Anal Length (PAL).

Turtle's sex was determined on the basis of the concavity of the plastron (concave in males and flat in females) and confirmed by evaluating the position of the cloaca (located well outside and just at the margin of the carapace, respectively in males and females). For each population, individuals that lacked male secondary sex characteristics and were smaller than the minimum-sized males were considered as juveniles and those that were larger than the minimum-sized males were considered as females. The minimum carapace length of females known to be reproductive (Rowe, 1994) was used as the lower limit for adult female carapace length in each population.

Body Condition Index

We calculated the volumetric Body Condition Index (BCI), which allowed estimating body density as the ratio of the live body mass of the animal to its estimated volume in cm^3. This index expresses the weight status of the individual in relation to its size in terms of body mass loss (wasting), overweight (accumulation of energy reserves) or normal weight (no loss or gain of weight). It was calculated using the following formula (Nagy et al., 2002):

$$\mathrm{BCI} = \frac{mass(g)}{Volume(cm^3)}$$

Where V= volume calculated by equating the shape of the turtle to an ellipsoid using the formula:

$$\mathrm{V} = \pi \times \mathrm{H} \times \frac{(ACW+PCW)}{2} \times CL$$

Sexual Dimorphism Index

The Sexual Dimorphism Index (SDI) defined by Lovich and Gibbons (1992) was used to evaluate the degree of sexual dimorphism in turtles. The Index is sim-

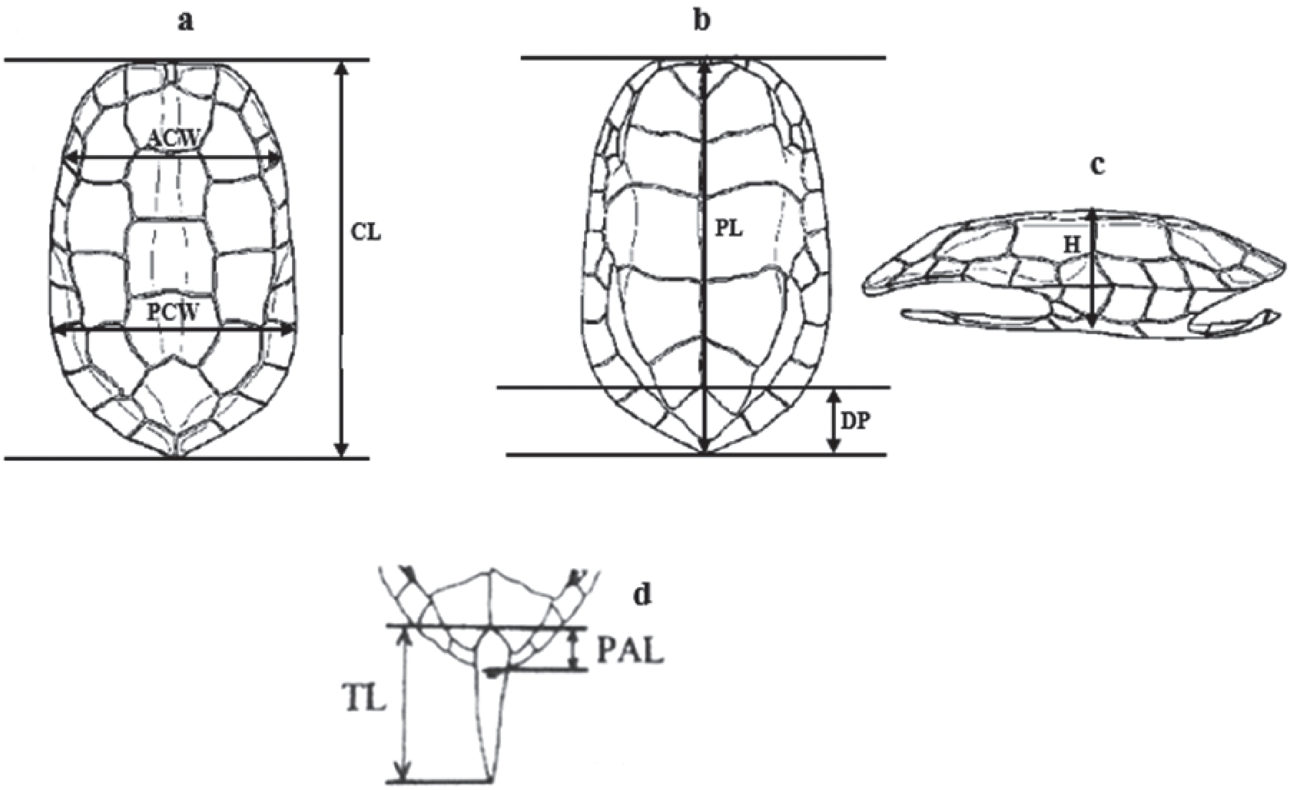

Fig. 2. Main measurements on the carapace. Dorsal (a), ventral (b and d) and lateral (c) views.

ply the ratio between the mean size of the largest sex and the mean size of the smallest sex subtracted by 1 in cases where mean adult female size is larger than mean adult male size. This index is positive when females are larger than males and negative in the opposite case. The SSDI formula is as follows:

$$SDI = \left(\frac{A}{B}\right) - 1$$

Where A is the average size of females and B the average size of males, in the case where females are larger than males (*M. leprosa* case).

Sphericity and Flatness Indices

Sphericity and flatness indices were estimated using Krumbein's Sphericity Index (SI) (Krumbein, 1941) and Cailleux's Flatness Index (FI) (Cailleux, 1947):

$$SI = \left(\frac{qr}{p^2}\right)^{1/3} \text{ and } FI = \frac{p+q}{2r}$$

Where p, q and r were given by CL, CW and CH, respectively. Higher values of sphericity index and lower values of flatness index mean a more domed shell, which entails lower energy barriers between stable and unstable equilibriums.

Statistical analysis

The mean values are given along with their standard deviations and the range of extreme values is eventually indicated. The sex ratio was compared among populations using Pearson Chi-Square (χ^2) test.

Initially, all data were evaluated for normality requirements using the Kolmorov-Smirnov test, in order to determine the application of parametric or non-parametric analyses. A two-way ANOVA was used to compare BCI, SI, and FI among populations. One-factor ANOVAs was used to determine differences in BCI, SI and FI between sexes for each population and among populations. Significant differences among the different populations were determined using a Tukey post hoc test.

One-factor ANOVA was used to compare CL and weight of males and females among populations and Student t-tests were used for comparison of CL and weight between pairs of study populations. Length-weight relations (LWR) were calculated for all localities using the equation $W = aL^b$ (Bagenal and Tesch, 1978) and the growth type is determined: isometric (b = 3), positive allometric (b > 3) or negative allometric (b < 3).

To analyze shape changes filtering allometric effects, we conducted linear regressions between body mass and standard length. Linear variables are usually transformed with a method that removes size and allometric effects. Hence, we transformed linear measurements into size-free new variables with a transformation that considers allometric effects (Lleonart et al., 2000) with the following equation:

$$Z = Y \times (X0 / X)^b$$

Where X0 is the mean standard length. In this case, we chose straight carapace length, but any measure related with size can be used. The X represents the standard length of each individual; Y is the variable to being transformed; b is the allometric coefficient of the variable Y with standard length obtained from a linear regression between the logarithms of Y and X; and Z is the new variable that we used in our statistical analyses.

All statistical analyses were carried out using the STATISTICA software (version 10.0). The statistical significance level was set at 5%.

RESULTS

Distribution by size and body mass

A total of 224 individuals of *M l. saharica* were captured in the seven populations (Table 1). Among the studied populations, and according to the juveniles-to-adults ratios, four populations were dominated by adult individuals (Table 1): Taakilt, Oued Guir, Oued Ziz, Sidi El Mehdaoui and two out of them were made up of 100% adults (Oued Noun and Tarmigt). The other populations consisted of 50%, 29%; 25%, 12.5% and 4.8% of juveniles, respectively in Lower Draa, Sidi El Mehdaoui, Ziz, Guir and Taakilt. Size frequencies based on carapace length are shown in Fig. 3. About 37.5% of the Lower Draa population is composed of individuals smaller than 80 mm *vs.* 12.5%, 0%, 29%, 7.14%, 0% and 16%, respectively in Oued Guir, Oued Noun, Sidi El Mehdaoui, Taakilt, Tarmigt and Oued Ziz. Carapce length and body mass of the visibly mature individuals are summerized for each population in Table 2.

The distribution by size for juveniles was significantly different among population for the following size class: 61-80 (χ^2 = 22.00, df = 6, P = 0.001), 101-120 (χ^2 = 18.00, df = 6, P = 0.006), 161-180 (χ^2 = 18.00, df = 6, P = 0.006); but not different for: 20-40 (χ^2 = 6.00, df = 6, P = 0.423), 41-60 (χ^2 = 8.66, df = 6, P = 0.193), 81-100 (χ^2 = 10.40, df = 6, P = 0.109), 141-160 (χ^2 =12.00, df = 6, P = 0.062). The distribution by size for males differed significantly among the studied population for the size class 80-100 (χ^2 =23.25, df = 6, P < 0.001) and for 181-200 (χ^2 = 35, df = 6, P < 0.001); but it does not differ for: 101-120 (χ^2 =11.58, df = 6, P = 0.072), 121-140 (χ^2 = 9.07; df = 6, P = 0.169), 141-160 (χ^2 = 10.15, df = 6, P = 0.118), 161-180 (χ^2 = 8.00, df = 6, P = 0.238), >200 (χ^2 = 6.00, df = 6, P = 0.423). The distribution by size for females was significantly different among population for: 81-100 (χ^2 =26.33, df = 6, P = 0.002), 101-120 (χ^2 = 18.00, df = 6, P = 0.043), 161-180 (χ^2 =22.80, df = 6, P < 0.001); but not different for: 60-80 (χ^2 =12.00, df = 6, P = 0.062), 121-140 (χ^2 = 6.00, df = 6, P = 0.423), 141-160 (χ^2 = 6.933, df = 6, P = 0.327), 181-200 (χ^2 = 8.20, df = 6, P = 0.223), >200 (χ^2 = 6.00, df = 6, P = 0.423).

Among the studied populations, five populations comprised juveniles, which have the following sizes and body masses (Min-max/Mean ± SD): Lower Draa (57.0-89.5/73.73±10.07, 29.2-97/59.04±22.07), Oued Guir (67.2-79.4/72.8±6.2, 45.1-72.3/57.4±13.8), Sidi EL Mehdaoui (34.9-77.6/66.2±16.05, 9.3-70.0/51.98±23.49), Taakilt (75.9-81.2/78.55±2.65, 66.0-77.0/71.6±5.5) and Oued Ziz (61.8-85.5/77.85±5.96,41.3-89.9/71.71±13.22) (Fig. 3 and 4).

Table 1. Sex/age distribution of turtles *Mauremys leprosa saharica* from seven distant populations in southern Morocco. Sex-ratio: males to females; J-A ratio = Juveniles to Adult ratio.

	Oued Guir	Oued Ziz	Taakilt	Tarmigt	Sidi El Mehdaoui	Oued Noun	Lower Draa
Juveniles	3 (12.5%)	14 (25%)	2 (4.8%)	0	9 (29%)	0	12 (50%)
Males	8 (33.3%)	23 (41.1%)	11 (26.2%)	11 (50.0%)	11 (35.5%)	18 (72%)	7 (29.2%)
Females	13 (54.2%)	19 (33.9%)	29 (69%)	11 (50.0%)	11 (35.5%)	7 (28%)	5 (20.8%)
Total	24	56	42	22	31	25	24
Sex-ratio	1:1.63	1:0.83	1:2.64	1:1	1:1	1:0.39	1:0.71
J-A ratio	1:7	1:3	1:20	0:22	1:2.44	0:25	1:1

Table 2. Carapace length and body mass descriptive statistics for adult males and females from the seven study localities. For each case, values are given as: mean ± SD [sample size] and (min-max).

Locality	Carapace length (mm)		Body mass (g)	
	Males	Females	Males	Females
Oued Guir	114.01 ± 9.78 [8] (105.5 - 128.1)	145.29 ± 28.62 [13] (105.1 - 187.0)	218.04 ± 56.48[8] (175.2 - 303.1)	490.3 ± 279.7 [13] (173.4 - 1010.0)
Oued Ziz	114.45 ± 27.54 [23] (83.6 - 168.4)	131.71 ± 36.12 [19] (90.5 - 196.3)	228.38 ± 170.1 [23] (80.5 - 588.4)	400.17 ± 322.71 [19] (117.5 - 1036.0)
Sidi El Mehdaoui	108.67 ± 16.9 [11] (83.2 - 132.0)	93.19 ± 12.08 [11] (80.6 - 107.8)	193.39 ± 84.6 [11] (89.0 - 323.9)	130.16 ± 50.67[11] (84.9 - 191.0)
Taakilt	118.78 ± 33.36 [11] (90.9 - 198.6)	140.72 ± 35.70 [29] (77.5 - 207.7)	270.81 ± 258.42 [11] (127.0 - 989.0)	479.79 ± 303.26 [29] (82.0 - 1037.0)
Tarmigt	114.1 ± 36.76 [11] (85.0 - 203.4)	151.73 ± 35.47 [11] (97.9 - 210.3)	260.00 ± 289.18 [11] (91.0 - 990.0)	614.54 ± 414.87 [11] (156.0 - 1468.0)
Oued Noun	161.48 ± 35.60 [18] (95.5 - 194.4)	174.45 ± 26.02 [7] (135.7 - 200.6)	591.56 ± 284.00 [18] (122.8 - 816.0)	806.58 ± 319.96 [7] (331.4 - 1014.5)
Lower Draa	149.42 ± 21.09 [7] (128.1 - 184.3)	153.76 ± 15.96 [5] (130.5 - 169.3)	436.35 ± 172.70 [7] (268.4 - 728.6)	548.16 ± 140.67 [5] (320.7 - 634.0)

Sex and juveniles-to-adults ratios

The sex ratio was significantly different among populations (Pearson $\chi^2 = 14.66$, df = 6, P = 0.023). It is male-biased in Oued Guir and Taakilt populations. On the other hand, the sex ratio is female-biased in Ziz, Noun and Lower Draa populations while it is balanced (close to 1) in Tarmigt and Sidi El Mehdaoui (Table 1).

The juveniles-to-adults ratio differed significantly among the different populations (Pearson $\chi^2 = 37.09$, df= 6, P < 0.001). There were no juveniles in Tarmigt (0/22) and Oued Noun (0/25), few in Taakilt (2/40), Oued Guir (3/21), Oued Ziz (14/42) and Sidi El Mehdaoui (9/22). The ratio is well balanced in Low draa: 1 (12/12) (Table 1).

Body Condition Index

BCI did not differ considerably from a normal distribution for all populations (Kolmogorov-Smirnov test: all P values > 0.05) and is significantly different among populations but non-significantly different between sexes (Table 3). The interaction Sex×Locality has no significant effect on BCI (Table 3).

BCI for each population was non-significantly different between sexes for all the studied populations, but significant for Sidi El Mehdaoui ($F_{1,20} = 11.24$, P = 0.003). The BCI was significantly different among populations ($F_{6,170}= 7.44$, P < 0.001). Table 4 shows significant differences (in bold) for each population from Tukey Post-hoc test.

Sexual Dimorphism Index

The SDIs for the studied populations were as follows: Oued Guir = 0.41, Oued Ziz = 0.15, Taakilt = 0.19, Tarmigt = 0.32, Sidi El Mehdaoui = -0.14, Oued Noun = 0.080, Lower Draa = 0.03 (Fig. 5). Significant results of sexual dimorphism using t-test were observed in the following populations: Oued Guir (t-test = -3.492, df = 12; P = 0.003); Oued Ziz (t-test = -1.713, df = 27; P = 0.047); Taakilt (t-test = -1.821, df = 27, P = 0.043) and Tarmigt (t-test = -2.437, df = 19, P = 0.012). The differences were not significant for Sidi El Mehdaoui (t-test = 2.471, df = 14, P = 0.987); Oued Noun (t-test = -1.003, df = 20, P = 0.165) and lower Draa (t-test = -0.407, df = 9, P = 0.344).

Sphericity and Flatness Index

The SI and FI did not significantly depart from a normal distribution (Kolmogorov-Smirnov test, all P values > 0.05). The factorial ANOVA that compared SI and FI between sexes and among the seven populations demonstrated that both indices differed significantly, but the interaction Sex×Locality had no significant effect (Table 3).

The comparison of SI for each population shows that there are significant differences between sexes for Lower Draa ($F_{1,10} = 33.62$, P < 0.001), Sidi El Mehdaoui ($F_{1,20} = 20.09$, P < 0.001), Oued Ziz ($F_{1,40}= 32.20$, P<0.001), Oued Noun ($F_{1,23} = 6.30$, P = 0.019), Taakilt ($F_{1,38} = 7.79$, P = 0.008), and Tarmigt ($F_{1,20}= 7.91$, P = 0.010), but non-significant differences for Oued Guir ($F_{1,19} = 0.01$, P = 0.923). FI differs significantly between sexes in Lower

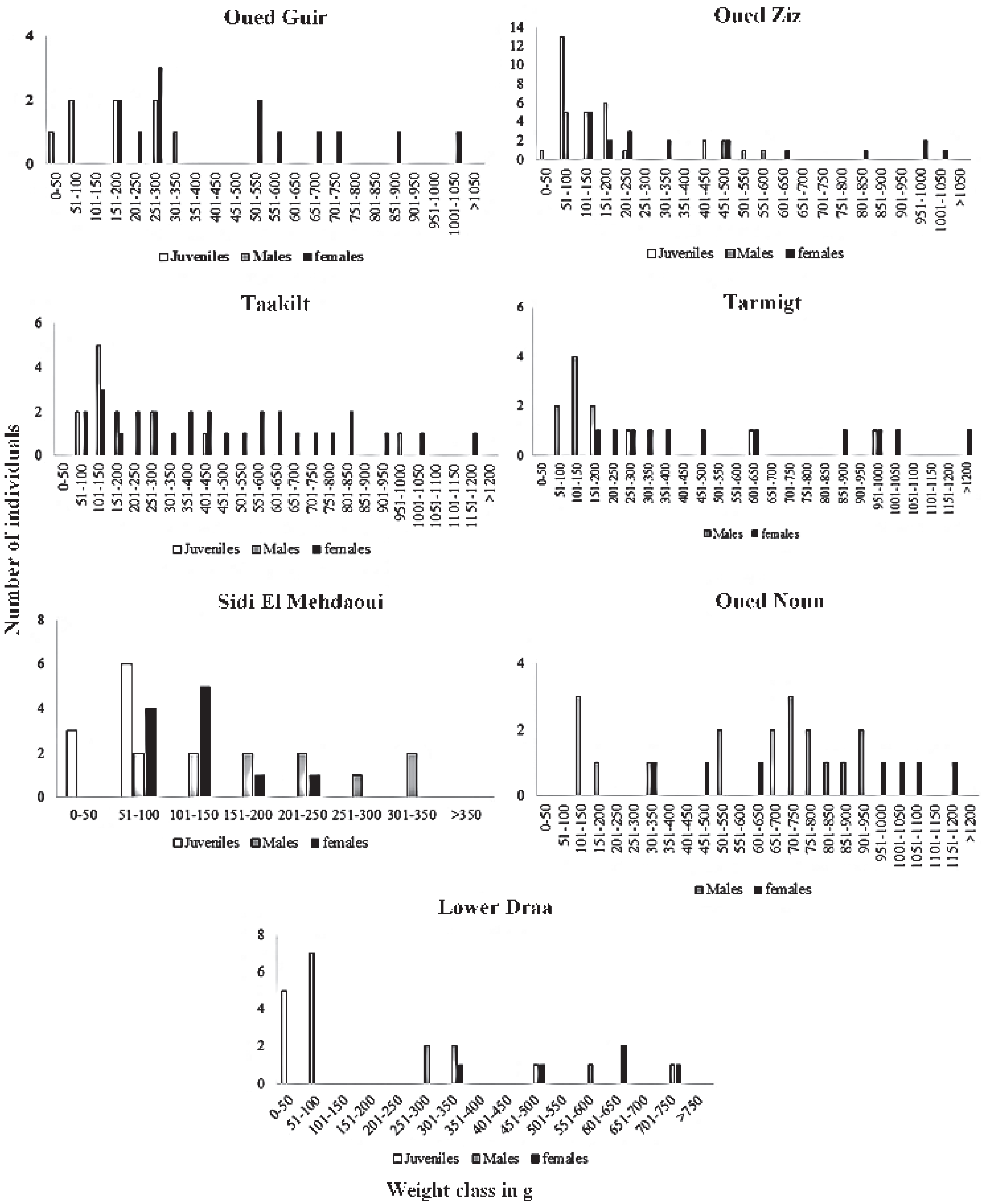

Fig. 3. Distribution by size and sex of individuals from the studied populations of *Mauremys leprosa saharica.*

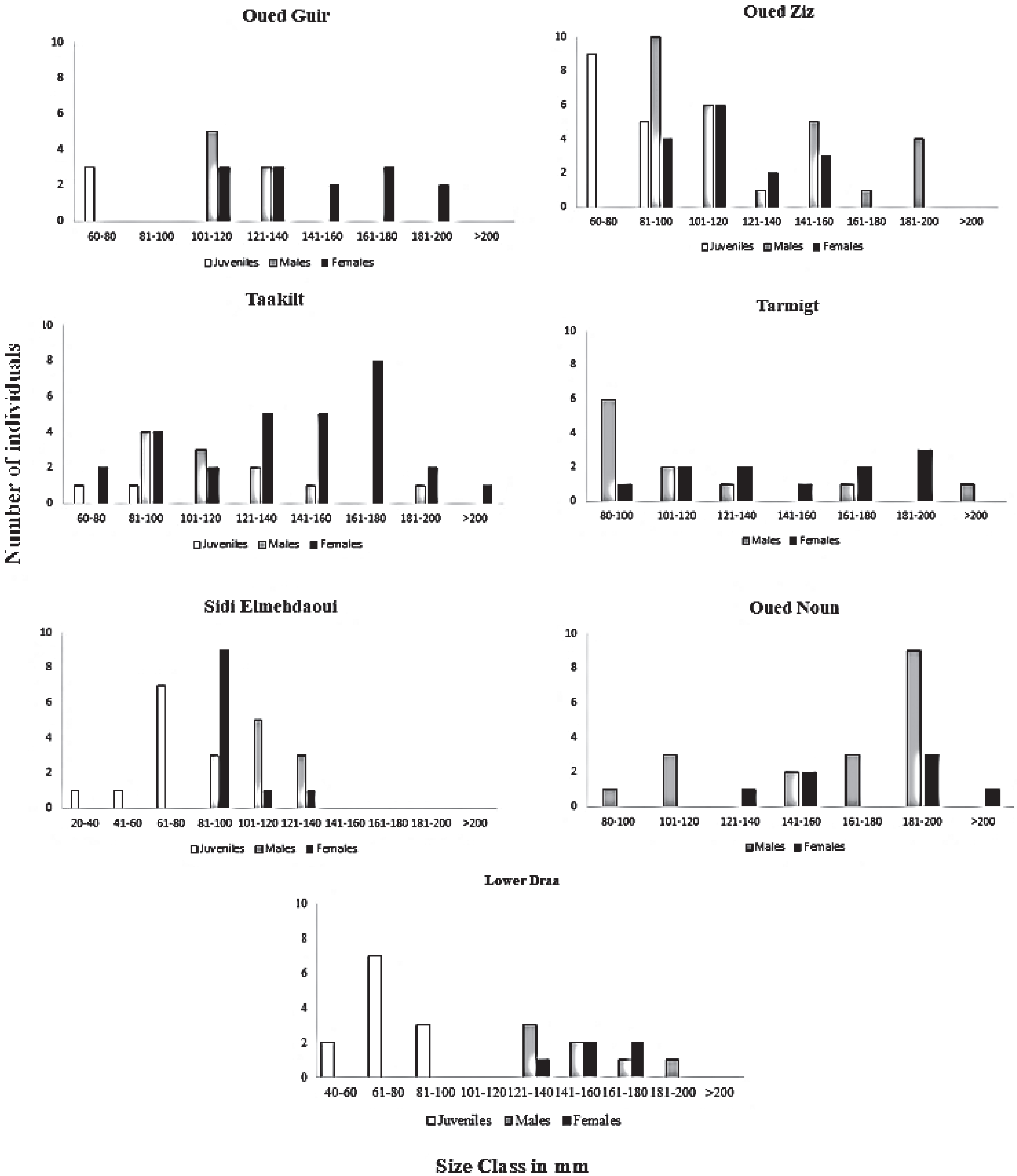

Fig. 4. Distribution by body mass and sex of individuals from the studied populations of *Mauremys leprosa saharica*.

Draa ($F_{1,10}$ = 45.46, P < 0.001), Sidi El Mehdaoui ($F_{1,20}$ = 16.18, P < 0.001), Taakilt ($F_{1,38}$=14.78, P < 0.001), Tarmigt ($F_{1,20}$ = 23.16, P < 0.001), Oued Ziz ($F_{1,40}$ = 22.48, P < 0.001) and Oued Noun ($F_{1,23}$= 5.69, P = 0.025) but non-significant differences in Oued Guir ($F_{1,19}$= 3.72, P = 0.068). Differences among populations in SI and FI were

Table 3. ANOVA for comparison of Body condition Index (BCI), Sfericity Index (SI) and Flatness Index (FI) between sexes, localities and interaction Sex × Locality. Significant effects are bolded; df_{num} and df_{den} represents degrees of freedom for the numerator and denominator of the F stastitic, respectively.

Variable	Effect	df_{num}	df_{den}	F	*P*
	Sex	1	20	0.232	0.630
BCI	**Locality**	6	170	5.034	**<0.001**
	Sex × Locality	6	170	0.377	0.893
	Sex	1	20	31.77	**<0.001**
SI	**Locality**	6	170	3.64	**<0.001**
	Sex × Locality	6	170	1.00	0.425
	Sex	1	20	36.28	**<0.001**
FI	**Locality**	6	170	20.79	**<0.001**
	Sex × Locality	6	170	0.35	0.908

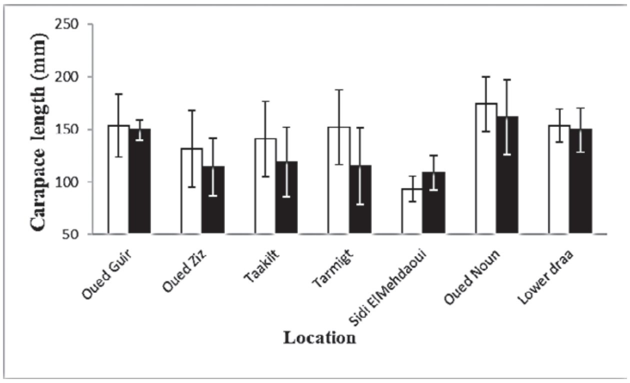

Fig. 5. Means and standard deviations for carapace length of *Mauremys leprosa saharica* from 7 localities in southern Morocco.

significant for both SI ($F_{6,170}$ = 9, P < 0.001) and FI ($F_{6,170}$ = 81.91, P < 0.001). Significant differences among each population are shown from Tukey post-hoc test in Tables 5 and 6.

Comparison of Carapce Length and body mass

There are significant differences in CL and body mass of males among populations (CL: $F_{6,82}$ = 9.993, P < 0.05; body mass: $F_{6,82}$ = 11.452, P < 0.05) and females (CL: $F_{6,88}$ =11.28, P < 0.05; body mass: $F_{6,88}$ = 9.35, P < 0.05). Significant differences were observed in CL between males of the following pairs: Oued Guir-Oued Noun, Oued Ziz-Oued Noun, Taakilt-Sidi El Mehdaoui, Taakilt-Oued Noun, Tarmigt-Sidi El Mehdaoui, Tarmigt-Oued Noun, Sidi El Mehdaoui-Oued Noun and Oued Noun-Lower Draa. For body mass in males, significant differences were observed between Tarmigt-Oued Guir, Tarmigt-Oued Ziz, Tarmigt-Taakilt, Sidi El Mehdaoui-Tarmigt, Oued Noun-Oued Guir, Oued Noun-Oued Ziz, Oued Noun Taakilt, Oued Noun-Sidi El Mehdaoui, Lower Draa-Tarmigt and Lower Draa-Oued Noun (Table 7).

Comparison of CL among populations showed significant differences for females of: Oued Guir-Sidi El Mehdaoui, Oued Guir-Oued Noun, Oued Guir-Lower Draa, Oued Ziz-Taakilt, Oued Ziz-Tarmigt, Oued Ziz-Sidi El Mehdaoui, Oued Ziz-Oued Noun, Taakilt-Sidi El Mehdaoui, Taakilt-Oued Noun; Taakilt-Lower Draa, Tarmigt-Sidi El Mehdaoui, Tarmigt-Oued Noun, Tarmigt-Lower Draa, Sidi El Mehdaoui-Oued Noun, Sidi El Mehdaoui-Lower Draa and oued Noun-Lower Draa. For Body mass in females, significant differences were observed between Taakilt-Oued Ziz, Tarmigt-Oued Ziz, Sidi El Mehdaoui-Oued Guir, Sidi El Mehdaoui-Oued Ziz, Sidi El Mehdaoui-Taakilt, Sidi El Mehdaoui-Tarmigt, Oued Noun-Oued Guir, Oued Noun-Oued Ziz, Oued Noun-Taakilt, Oued Noun-Sidi El Mehdaoui, Lower Draa-Oued Guir, Lower Draa-Taakilt, Lower Draa-Tarmigt, Lower Draa-Sidi El Mehdaoui and Lower Draa-Oued Noun (Table 8).

Length-mass relationships

LMR were calculated for all localities (Table 9). The value of "b" of LMR was found to be significantly differ-

Table 4. Comparison of Body Condition Index (BCI) among populations of *Mauremys leprosa saharica*. P-Values are from Tukey post-hoc test with df = 177. Significant values are bolded.

	Oued Ziz	Taakilt	Tarmigt	Sidi El Mehdaoui	Oued Noun	Lower Draa
Oued Guir	**0.039**	1.000	0.999	0.275	1.000	**0.030**
Oued Ziz		**0.005**	0.056	0.999	**0.015**	0.960
Taakilt			0.999	0.144	0.999	**0.011**
Tarmigt				0.343	0.999	**0.041**
Sidi El Mehdaoui					0.185	0.879
Oued Noun						0.017

Table 5. Comparison of Sfericity Index (SI) among populations of *Mauremys leprosa saharica* from Tukey post-hoc test. P-values are from Tukey post-hoc test with df = 177. Significance is indicated in bold.

	Oued Ziz	Taakilt	Tarmigt	Sidi El Mehdaoui	Oued Noun	Lower Draa
Oued Guir	0.998	1.000	0.999	0.221	0.225	0.990
Oued Ziz		0.997	0.979	0.297	**0.017**	0.999
Taakilt z			0.999	0.105	0.087	0.986
Tarmigt				0.108	0.367	0.958
Sidi El Mehdaoui					**<0.001**	0.871
Oued Noun						0.091

Table 6. Comparison of Flatness Index (FI) among populations of *Mauremys leprosa saharica* from Tukey post-hoc test. P-values are from Tukey post-hoc test with df = 177. Significance is indicated in bold.

	Oued Ziz	Taakilt	Tarmigt	Sidi El Mehdaoui	Oued Noun	Lower Draa
Oued Guir	0.999	**<0.001**	0.542	0.999	**0.001**	1.000
Oued Ziz		**<0.001**	0.547	0.996	**<0.001**	0.999
Taakilt z			**<0.001**	**<0.001**	**<0.001**	**<0.001**
Tarmigt				0.367	0.360	0.733
Sidi El Mehdaoui					**<0.001**	0.999
Oued Noun						**0.017**

Table 7. Pairwise comparison of Carapce length (CL; below matrix diagonal) and body mass (above matrix diagonal) between males of the studied populations, using Student t-tests. Significant differences (P < 0.05) are in bold; degrees of freedom are reported as subscript.

Males		Body mass (g)						
		Oued Guir	Oued Ziz	Taakilt	Tarmigt	Sidi El Mehdaoui	Oued Noun	Lower Draa
CL (mm)	Oued Guir	—	0.105_{46}	-0.836_{22}	**-3.441**$_{20}$	1.266_{29}	**-6.300**$_{16}$	-0.352_{28}
	Oued Ziz	0.235_{46}	—	-1.211_{48}	**-5.486**$_{46}$	1.0372_{55}	**-8.287**$_{42}$	-0.584_{54}
	Taakilt	-0.830_{22}	-1.249_{48}	—	**-2.735**$_{22}$	1.808_{31}	**-4.419**$_{18}$	0.514_{30}
	Tarmigt	-0.886_{20}	-1.296_{46}	-0.104_{22}	—	**5.050**$_{29}$	-1.040_{16}	**3.654**$_{28}$
	Sidi El Mehdaoui	1.401_{29}	1.429_{55}	**2.161**$_{31}$	**2.128**$_{29}$	—	**-8.695**$_{25}$	-1.304_{37}
	Oued Noun	**-4.944**$_{16}$	**-6.873**$_{53}$	**-3.843**$_{29}$	**-3.436**$_{27}$	**-7.060**$_{36}$	—	**5.650**$_{24}$
	Lower Draa	0.087_{28}	-0.110_{54}	0.805_{30}	0.644_{28}	-1.105_{37}	**4.784**$_{35}$	—

Table 8. Pairwise comparison of Carapce length (CL; below matrix diagonal) and body mass (above matrix diagonal) between females of the studied populations, using Student t-tests. Significant differences (P < 0.05) are in bold; degrees of freedom are reported as subscript.

Females		Body mass (g)						
		Oued Guir	Oued Ziz	Taakilt	Tarmigt	Sidi El Mehdaoui	Oued Noun	Lower Draa
LC (mm)	Oued Guir	—	1.6397_{47}	-0.467_{45}	-1.485_{25}	**4.526**$_{34}$	**-2.284**$_{21}$	**2.153**$_{31}$
	Oued Ziz	1.930_{47}	—	**-2.555**$_{62}$	**-3.115**$_{42}$	**2.495**$_{51}$	**-4.412**$_{38}$	0.699_{48}
	Taakilt	-0.427_{45}	**-2.918**$_{62}$	—	-1.352_{40}	**5.0956**$_{49}$	**-2.707**$_{36}$	**2.874**$_{46}$
	Tarmigt	-1.346_{25}	**-3.259**$_{42}$	-7.149_{40}	—	**5.584**$_{29}$	-1.040_{16}	**3.319**$_{26}$
	Sidi El Mehdaoui	**5.029**$_{34}$	**3.003**$_{51}$	**6.071**$_{49}$	**7.222**$_{29}$	—	**-9.892**$_{25}$	**-1.926**$_{35}$
	Oued Noun	**-2.602**$_{21}$	**-4.286**$_{38}$	**-2.496**$_{36}$	**-1.457**$_{16}$	**-10.05**$_{25}$	—	**5.049**$_{22}$
	Lower Draa	**2.504**$_{31}$	1.002_{48}	**3.407**$_{46}$	**3.715**$_{26}$	**-1.630**$_{35}$	**4.749**$_{22}$	—

Table 9. Carapace Length-Body mass relation and growth types for *M. l. saharica* according to localities.

Locality		a	b	r^2	95%CI	Growth type
Oued Guir	M	0.0002	2.953	0.999	2.899-3.006	Isometric
	F	0.0002	2.951	0.997	2.871-3.031	Isometric
Oued Ziz	M	0.0004	2.767	0.986	2.652-2.881	(-) Allometry
	F	0.0002	2.921	0.993	2.855-2.965	Isometric
Taakilt	M	0.0005	2.731	0.994	2.585-2.877	(-) Allometry
	F	0.0004	2.824	0.978	2.664-2.984	Isometric
Tarmigt	M	0.0002	2.899	0.986	2.634-3.164	Isometric
	F	0.0002	2.964	0.987	2.702-3.226	Isometric
Sidi El Mehdaoui	M	0.0007	2.658	0.995	2.561-2.745	(-) Allometry
	F	0.0007	2.672	0.996	2.584-2.759	(-) Allometry
Oued Noun	M	0.0003	2.843	0.988	2.677-3.008	(-) Allometry
	F	0.0002	2.971	0.954	2.223-3.718	Isometric
Lower Draa	M	0.0003	2.822	0.999	2.779-2.865	(-) Allometry
	F	0.0001	3.020	0.996	2.937-3.102	Isometric

ent from 3.0 in *M. l. saharica for* some localities. According to the results, the type of growth for *M. l. saharica* is isometric for both male and female of Oued Guir and Tarmigt, for female of Oued Ziz, Taakilt, Oued Noun and lower Draa and hypo-allometric for male of Oued Ziz, Taakilt, Oued Noun, and Lower Draa and for both males and females in Sidi El Mehdaoui. The analysis of covariance of Log BW with locality as categorical predictor and log CL as continuous predictor revealed a difference among populations for both Males ($F_{6,82}$ = 2863.71, P < 0.05) and females ($F_{6,88}$ = 2658.8, P < 0.05).

DISCUSSION

Several studies have been conducted on the Iberian Population of *M. leprosa* (e.g., Perez et al., 1979; Andreu and Villamor, 1989; Da Silva, 1995). Data on the ecology and biology of this species in Morocco are limited, indeed, with the exclusion of population ecology (Meek, 1987) and on the geographical variation of sexual dimorphism (Lovich et al., 2010). Studies on the population structure of *M. leprosa* are rather rare and only few studies have been done in Spain (Keller, 1997; Alarcos et al., 2008). The only work on the population structure of *M. leprosa* in North Africa is that of Meek (1987), carried out in May-September in the region of Tiznit, Souss valley, Morocco. The population studied by this author in September 1981, was large (sample of 67 individuals) dominated by young animals (60%) with carapace lengths not exceeding 80 mm. However, adults and sub-adults were 4.5 times more abundant than hatchlings. Moreover, in this population, the sex ratio in adults was biased in favour of females (1: 2.12 = 0.47). The total length of the carapace in females is on average higher than that of males (97.1 vs 82 mm) with maximum values of 186 and 149 mm respectively. Two populations in the present study are approximately large as the population of Tiznit (Meek, 1987) (Oued Ziz = 56 and Taakilt = 42) followed by Sidi El Mehdaoui, which was 31 comparatively to the following population that were rather small Tarmigt = 22, Oued Guir = 24, Lower Draa = 24 and Oued Noun = 25 that were rather small.

The sex ratio is variable among the seven populations: it is balanced for Sidi El Mehdaoui and Tarmigt with a value of 1, biased towards males for Oued Ziz (1.21), Oued Noun (2.57) and Lower Draa (1.4) biased towards females for Oued Guir (0.62) and Taakilt (0.39) and the same for the population studied by Meek with a value of 0.47. The differences in sex ratio in the studied populations may be due to either a low impact rate or a difference in the mortality rate between males and females. The sex ratio information is, however, not reliable in explaining the fluctuation in the proportion of males and females and seems to be dependent on the locality or month of capture, reflecting rather different behaviours between the two sexes. Another cause of this variation could be related, as in various other turtle species of the family Geoemydidae, to the phenomenon of sex determinism by temperature (during the incubation of eggs). As in Japan, *M. japonica* (Okada et al., 2010), a species closely related to *M. leprosa*, with incubation temperatures above 29-30 °C, would produce almost exclusively females that could affect sex ratio within natural populations. According to the scenario of a climate change with a tendency to the increase of the temperature, a predominance of females could contribute strongly to the functional disappearance then to the total extinction of some populations.

In Oued Noun, Tarmigt, Oued Guir, Sidi El Mehdaoui and Oued Ziz the juvenile rate varies between 0% and 30%. The value reported by Meek (1987) is approximately similar to those reported for the populations of this study with 25.4%. One population of the seven studied populations which is that of Lower Draa has a rate of juveniles (50%) equal to that of adults (50%). This could indicate a low turnover rate, which may be caused by a high mortality of juveniles due to predation, habitat destruction or drought or to the differences in the minimum size at sexual maturity.

The largest sizes (carapace length) of males and females captured are respectively observed in Tarmigt (203.4 mm) and in Oued Noun (209.6 mm). Busack and Ernst (1980) reported a value for the largest size of CL in Tunisia of 174.5 mm, in Spain it is 114 mm in males and 182 mm in females (Bertolero and Busack, 2017), while in the population studied by Meek (1987), the CL was 146 mm in males and 186 mm in females. The variations observed in the different studied populations could be explained by the variability of habitat and the availability of conditions that allow the animal to grow well, they may also be due to sampling problems. The wide geographic distribution of *M. leprosa* showed that this species is able to be adapted to different habitat conditions ranging from cold/temperate to extremely arid climate and from fresh to brackish waters (Bertolero and Busack, 2017). Studying the condition factors such as the Body Condition Index is very important. The Body Condition Index is the most appropriate parameter to monitor the vitality of populations in different habitat. It was considered as an indicator of past foraging success instead of the ability to cope with environmental pressures that may ultimately impact the population viability (Jakob et al., 1996). In the present study, we found that the BCI was significantly different among populations but not significantly different between sexes among populations, for each studied population and for the interaction sex×population. The observed difference would be mainly attributed to the environmental conditions of turtle habitat (dryness, salinity…) and availability of food resources.

The main differences in shell dimensions between males and females are evident in most turtle species. Thus, it is clear that sexual dimorphism exists, with females being generally larger than males. Berry and Shine (1980) suggested that the smaller body size of males in most freshwater turtles could be the result of a low degree of intrasexual selection processes. In some turtle species, males are larger than females when forced insemination is occurred. The small size of male could facilitate the mobility reducing the costs of their daily/seasonal movements (Bonnet et al., 2011) and hence increased ability to detect females with the most of their available energy devoted to searching for females more than growth (Berry and Shine, 1980). In addition, sexual size dimorphism (SSD) correlates with habitat types, which could affect male mating strategy. It has been suggested for other species of turtles and tortoises that the small size of one of the sexes can also be related to age at maturity (Gibbons and Lovich, 1990). In *M. leprosa*, males attain sexual maturity at smaller sizes than females (Keller, 1997), and this could be one of the causes of the sexual size dimorphism in this species. Lovich et al (2010) noted that SSD was biphasic very unusual phenomenon in turtles, with males and females in one population exhibiting similar body sizes. Intraspecific changes in SSD was also observed for other turtle species by Lovich and Lamb (1995), Iverson (1985), and Yasukawa et al. (1996). The direction of size (large/small or equal) varied according to the sampled population, the growth patterns, mortality at a specific size and possibly to the food availability (Lovich and Gibbons, 1992). In the present study, the SSD varies among populations. The greatest SSD was observed in Oued Guir population (SSD = 0.41) and the lowest in Sidi El Mehdaoui population (SSD = -0.14). The negative SSD values indicate male size bias, whereas positive values indicate female size bias (Lovich and Gibbons, 1992). In the population of Sidi El Mehdaoui, males are even slightly larger than females (males: 108.67 ± 16.9 mm; females; 93.19 ± 12.08 mm) but the opposite case is onserved in in the other studied populations.This latter findings are similar to those for other population in Morocco (Meek, 1987; Lovich et al., 2010) and for those reported by Muñoz (2004) and Muñoz and Nicolau (2006) from the center of the Iberian Peninsula. Lovich et al. (2010) have indeed found, on the basis of the sexual dimorphism index (Lovich and Gibbons, 1992), a geographic variation in the size sexual dimorphism in *M. leprosa* along an environmental gradient in Morocco between the Atlantic coast and the upper Draa to the southeast. The extreme value of the SSD (0.92) assigned by Lovich et al. (2010) to the population of upper Draa is due to the very small sample of the latter. However, the very low value of SSD in the population of Sidi El Mehdaoui may be partly influenced by the possible inclusion of immature specimens as suggested by Gibbons and Lovich (1990).

Estimations of sexual size dimorphism can vary under the influence of several factors: 1) biased samples, 2) inappropriate dimorphism measures, 3) incorrect estimation of size at sexual maturity, 4) geographic variation in growth or body size. These various factors have been cited and discussed in detail by Lovich et al. (2010). These authors deduced, the existence of a positive correlation between the degree of sexual size dimorphism and the productivity of the environment, with the smallest females in oligotrophic environments and the largest in the most productive environments. This suggests that the availability of trophic resources may limit growth in females of *M. leprosa* to such an extent that they acquire sexual maturity at a smaller size and begin earlier to allocate energy resources for egg production. This finding was also reported by Iverson (1985) who suggests that the limitation of food resources was responsible for the geographical variation of the size sexual dimorphism in the red-legged mud turtle, *Kinosternon hirtipes*, of North America.

Previous work has suggested that factors affecting the direction and magnitude of SSD in turtles may include fecundity (Cox et al., 2003). Other works, noted that sexual dimorphism is influenced by the characteristics of habitats as variables differ between localities such as food availability and partitioning and differences in hormone levels (Cox and John Alder, 2005 ; Shine, 1989, Vincent and Herrel, 2007).

Our geometric models of turtles among the studied population based on sphericity and flatness indices of the shell have yielded morphological shape differences among individuals of *M. l. saharica* in the different localities for both sexes, but not for the interaction locality×sex. In freshwater turtles, morphology can vary among populations of the species inhabiting different environmental conditions (Rowe, 1997; Zuffi et al., 2007). Many studies examining intraspecific morphological divergence have focused on the effects of biotic components of the environment, such as resource competition (Adams and Rohlf, 2000; Grant and Grant, 2006; Pfennig et al., 2006; Adams and Collyer, 2007) and the effects of predator–prey interactions (Brönmark and Miner, 1992; Milano et al., 2002; Langerhans and Dewitt, 2004; Eklov and Svanback, 2006; Brookes and Rochette, 2007). However, abiotic or physical features of the environment can also drive phenotypic divergence among intraspecific populations. Despite the potential constraints of a rigid shell, semi-aquatic freshwater turtles have adapted to life in a diverse array of aquatic flow regimes, ranging from ponds and lakes to fast flowing rivers (Ernst et al., 1994). Compared with terrestrial turtles, aquatic turtles possess flatter and more symmetrical shells, both of these characteristics are believed to create a difference between populations of the same species.

Two studies examining intraspecific variation in morphology across different flow regimes have suggested that the shells of freshwater turtles are suited to the hydrodynamic environments in which they are found (Aresco and Dobie, 2000; Lubcke and Wilson, 2007). Aresco and Dobie (2000) presented the first quantitative data, by showing that the shells of river cooters (*Pseudemys concinna*) from lotic sites were flatter than those from lentic sites. Lubcke and Wilson (2007) found that western pond turtles (*Actinemys marmorata*) from lotic habitats were flatter and narrower than those from lentic habitats.

The morphological data variation on *M. leprosa* are not well documented for all the known distribution area of the species. However, morphology of the species is not well investigated and information looking particularly at the variations between populations is almost unknown. Growth of turtles is a process that can changes considerably in response to genetic and environmental factors (Barlow, 1961; Somers, 1986). The results presented in this study shows that LWR has an isometric growth for both male and female of *M. l. saharica* in Oued Guir and Tarmigt, for female of Oued Ziz, Taakilt, Oued Noun and lower Draa but a negative allometric growth for male in Oued Ziz, Taakilt, Oued Noun, Lower Draa and in both male and female of Sidi El Mehdaoui. Few studies have reported *M. leprosa* growth patterns in Morocco (Meek, 1987) and Spain (Keller, 1997; Muñoz and Nicolau, 2006). The differences in growth between and among the different studied populations could be explained by local ecological parameters. Environmental conditions have an important influence on ecology of turtles and are considered to be the principal factors in intra- and interspecific growth differences.

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