Characterising the peculiar insular population of *Testudo graeca* from La Galite Island (northern Tunisia)

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Abstract

La Galite island is home to a notable population of *Testudo graeca*. These tortoises are larger and heavier than their conspecifics from mainland Tunisia, with a notable sexual size dimorphism. The Sardinian populations are also large and show a high population density. The populations, presumably introduced to Spain and Sardinia, have no ticks like those of La Galite.

The planted pine forest and the resulting habitat change probably represent the main threat to the *T. graeca* population of La Galite, because it alters the structure and composition of the vegetation and can facilitate the occurrence of fires. The dense population of this island should be able to cope with the negative effects of wildfires if they occur no earlier than every 20-30 years. However, these are events whose frequency and intensity may increase due to climate change.

The International Union for Conservation of Nature (IUCN) has classified the species as Vulnerable. The La Galite Protected Area Management Plan should recognize the importance of the *T. graeca* population and designate this island as a reserve to safeguard both a high-quality habitat and a stable tortoise population. Measures to control the growth and expansion of the pine wood should be continue and be intensified.

Key words: Density; size; Spur-thithed tortoise; ticks, weight, wildfire.

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Résumé

L'île de la Galite abrite une remarquable population de *Testudo graeca*. Ces tortues sont plus grandes et plus lourdes que leurs homologues tunisiennes, avec une différence sexuelle de la taille notable. D'autres populations, probablement non-indigènes, en Espagne et en Sardaigne, sont, comme celle de la Galite, exemptes de tiques. Les populations insulaires de Sardaigne sont également de grande taille et ont une densité de population encore plus élevée.
La croissance de la pinède plantée et la modification de l'habitat qui en résulte constituent probablement la principale menace pour la population de la Galite. Si les incendies ne sont pas plus fréquents que tous les 20 à 30 ans, cette population dense devrait être en mesure de faire face à leurs effets.
Toutefois, la fréquence et l'intensité des feux pourraient augmenter en raison du changement climatique.

L'Union internationale pour la conservation de la nature (UICN) a classé l'espèce dans la catégorie "Vulnérable". Le plan de gestion de l'aire marine et côtière protégée de la Galite devrait reconnaître l'importance de cette population et considérer cette île comme une réserve vouée à sauvegarder un habitat de haute qualité et une population stable. Les mesures de contrôle du développement de la pinède doivent être poursuivies et intensifiées.

Mots clés : Densité; incendie, poids; taille; Tortue mauresque; tiques

Introduction

Among Palaearctic tortoises, *Testudo graeca*, Linnaeus 1758, has the most extensive distribution, ranging from southern Europe, including some Mediterranean islands, to northern Africa up to southwestern Asia (Fig. 1), (Graciá et al., 2017). The eastern part of its distribution includes many disjunct populations, while the northern African populations cover a vast range from Morocco to Libya with few geographical discontinuities. In the Mediterranean four lineages have been identified (Fritz et al., 2009): A (Tunisia, eastern Algeria); B (Algeria, northern Morocco); C (Libyan Cyrenaica); and D (Morocco, High Atlas, Souss Valley). The species also occurs in western Sardinia and in the island of Mallorca in the Balearics (Escoriza et al., 2022; Fritz et al., 2007; Fritz et al., 2009), where it was introduced, probably in prehistoric or historic times (Vamberger et al., 2011). In Tunisia, only the A-lineage has been found so far, corresponding to the subspecies *Testudo graeca nabeulensis*. Sardinian populations are assigned to lineage A (Fritz et al., 2009), the haplotypes found on the island are part of the variation detected in Tunisia. The A10 haplotype, currently only known in the Sardinian population, could however be found in Tunisian populations following a broader sampling (Vamberger et al., 2011). The La Galite and Sardinian populations most likely belong to the same lineage and could therefore be ascribed to subspecies *T. graeca nabeulensis*.

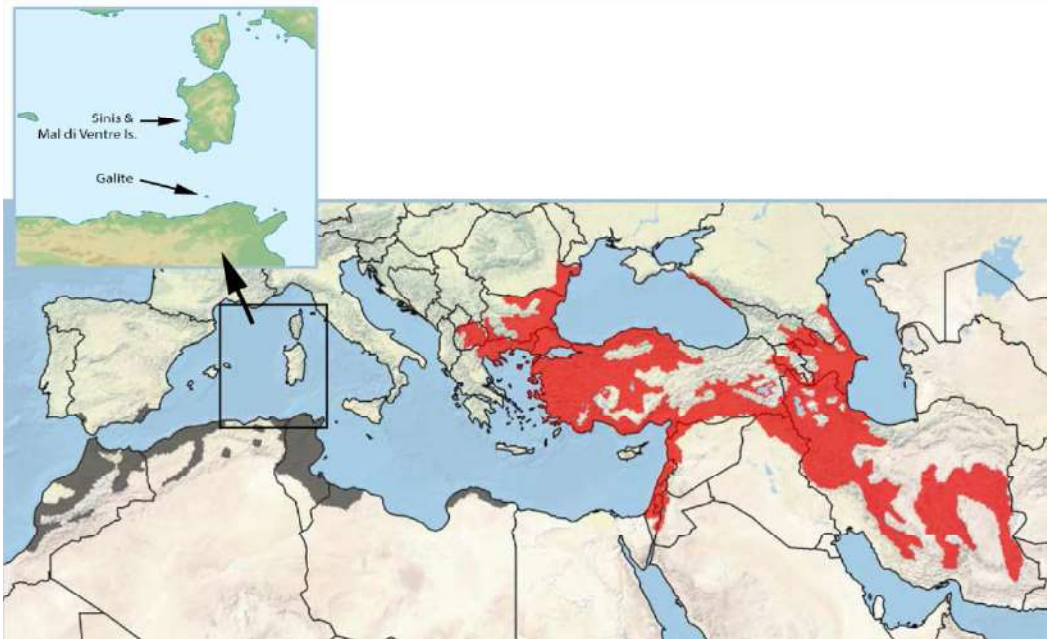

Figure 1: Distribution of *Testudo graeca*; gray = western populations; red = eastern populations, from Escoriza et al. (2022). In detail, the area that includes Sardinia and La Galite Island.

Fig. 1. Carte globale de la distribution indigène estimée de Testudo graeca; en gris sous-espèces occidentales; en rouge sous-espèces orientales, d'après Escoriza et al. (2022). En cartouche, situation de l'île de la Galite et de la région d'Oristano en Sardaigne.

It is known that tortoises have been present on the island of La Galite (northern Tunisia) since the 19th century. Two adults and one juvenile were collected in September 1876 (D'Albertis, 1878) and August 1877 (Issel, 1880) respectively, but these specimens have been lost. In the following century the presence of *Testudo graeca* was reported on the island (Schneider, 1969).
We do not yet know whether this species is native or introduced to the island. Its presence could date back to a Pleistocene land bridge with the Tunisian mainland, older than the Last Glacial Maximum in which La Galite was already isolated from the Continent. The species may also have been introduced in historical times, since the main occupation of this island dates back to the antiquity, with Carthaginian settlements (Chelbi, 2013).
In the Mediterranean, the island populations of *Testudo graeca* are very rare (western Sardinia, and Mallorca), furthermore there are only two small island populations, one on the island of Mal di Ventre (western Sardinia) (Corti et al., 2007) and the other one on La Galite Island (northern Tunisia).

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Morphological, morphometric and density data were collected on La Galite, and observation on ecology are also reported. Considering these characteristics, the population of La Galite was compared with the populations of other islands, with the insular and microinsular populations of Sardinia, using original and literature data.

Methodology

Study site

The Galite Archipelago is located off the northern coast of Tunisia, 21 nautical miles from mainland Tunisia. It consists of the main island La Galite (or Jalta) (752 ha, maximum elevation 391 m a.s.l.) and five surrounding islets: to the south-west, Galiton (30 ha, 158 m), La Fauchelle or Aguglia (13.6 ha, 137 m) and to the north-east, Gallina (3.1 ha, 60 m), Pollastro (0.6 ha, ≈35 m) and Gallo (8.9 ha, 119 m) (Delaugerre et al., 2011). The geological and geomorphological features are described by Oueslati (2016). On the steep slopes of the main island the vegetation is mainly made up of diss grass, *Ampelodesmos mauritanicus*, predominant on the southern slopes and the Mediterranean matoral (fruticetum) on the northern faces. To the north-east of the village, the" plain" is an agro-landscape with the remains of dry stone terraces where pine trees, *Pinus halepensis*, were extensively planted in 2000 (Muracciole in Abbes et al., 2008). In October 2021, a fire destroyed 550 hectares, more than 70% of the island's land area.

La Galite Island belongs to the sub-humid bioclimatic zone (Tlili et al., 2012) and is very often affected by strong winds and storm surges. Recurring bad weather could be considered the main protection of the archipelago. La Galite is a protected marine-coastal area jointly managed by APAL (a government organisation) and MAN (an NGO). The island is owned by the Tunisian army. About 20 people (mostly military) live permanently on the island; fishermen regularly moor in the bays of La Galite. Furthermore, there are often a very small number of visitors (there are no accommodation facilities on the island) and managers of the protected area, as well as some researchers.

Sampling and analyses

Tortoises are found throughout the island, with higher densities in the so called “Plain”. For two days (9-10.09.2013) they were searched by VES (Visual Encounter Surveys) in two areas of the plain. The first is an abandoned agricultural area with diss and mastic (*Pistacia lentiscus*); the second one is an olive grove with undergrowth and some mastic bushes. Both areas cover a total of 3.5 hectares. A total of 320 minutes were dedicated to prospecting and measurements in the morning and late afternoon.

Each individual was sexed. The length (measured in a straight line = CL) and width of the carapace (measured in a straight line = CW) were measured with a calliper. Animals were weighed with a Pesola scale and checked for ectoparasites (such as ticks) on the legs, tail, head, and carapace and photographed (dorsally and ventrally) before release.

For comparison, we used the morphological data of the populations of western Sardinia reported in Corti et al., (2007) (main island: 112 and 92 , Mal di Ventre Island: 20 and 8), field data, and density data from Biaggini et al. (2018).

A thorough review of the available literature was conducted, but unfortunately there is very little reliable data regarding the size and weight of the animals. Many articles, including some recent ones, only provide maximum or mean values without reporting the standard deviation or sample size, others provide data where the sexes have not even been separated.

The non-parametric Mann-Whitney U test was used to compare the size and weight/CL ratio between the populations for which raw data was available (Doñana, La Galite and Sardinia), because some samples were small and normality of distribution could not be assumed. Student's t test was used to compare the carapace length of La Galite tortoises with those from mainland Tunisia reported by Pieh & Perälä (2002) where only the mean, σ and N were reported. The sexual size dimorphism (SSD) in carapace length was calculated according to Carretero et al. (2005) as SSD = 100 x (Xa-Xb)/ Xb, where Xa is the average size of females and Xb is the average size of males. Given the small sample size, the Haldane's coefficient of variation (VH) was used. VH = VP x 1 + 1/4N, where VP = the Pearson coefficient of variation and N the sample size (Haldane, 1955). Population density has been estimated in the field as the number of individuals per hectare.

Results and discussion

Size and weight

On La Galite, 48 individuals were captured, 46 adults (29 males and 17 females) and 2 hatchlings. All measurements are given in Table I and the size class distribution (CL) and weight classes are shown in Fig. 2 and Fig. 3 respectively. Only two juveniles have been sighted, which may reflect more cryptic behaviour and therefore low detectability rather than rarity. The most common size classes are 13-15 cm for males (max 17.5 cm) and 15-18 cm for females (max 19.8 cm) (Table IIA). The weight class 400-600 g is predominant in males (max 670 g) while the weight class 700-900 g is predominant in females (max 1090 g) (Table IIIA). Comparing tortoises from La Galite with those from Sardinia (Tables IIA, IIB), males from La Galite were found to be smaller than those from the island of Mal di Ventre and females from La Galite larger than those from the Sinis (Sardinia, main island).

Table I. Measures of Testudo graeca from La Galite Island. In cm: CL = carapace length; CW = carapace width; Weight in grams.

Tableau I. Mesures des Testudo graeca de la Galite. En cm: CL = Longueur droite de la carapace, CW = Largeur droite de la carapace; Poids en gramme.

age class	sex	CL	CW	Weight	age class	sex	CL	CW	Weight
ad	f	19.8	19.3		ad	f	14.8	11	730
ad	f	16	12		ad	m	13.3	9.2	420
ad	m	10	15		ad	f	14.6	10.3	660
ad	f	19	12		ad	m	12.8	9	390
ad	m	12.5	8.5		ad	m	14.5	10.3	490
juv	/	3.72	3.28	15	ad	m	13.8	10	530
juv	/	3.47	2.88		ad	m	14.5	10.4	560
ad	f	17	12.5		ad	f	14.3	10	550
ad	m	14.5	11.3		ad	m	12.7	9.3	390
ad	m	17.5	12.2		ad	m	13.3	9.8	440
ad	m	13	9.5		ad	f	15.2	10.8	690
ad	m	14	9	420	ad	f	15.1	10.8	635
ad	f	16.5	13	970	ad	f	16	11	810

age class	sex	CL	CW	Weight
ad	m	14.5	10.3	580
ad	m	14	9.9	500
ad	m	13.5	9.5	460
ad	f	15.6	11.4	710
ad	f	16	11.5	820
juv	m	14.6	10.5	540
juv	m	13.3	9.3	460
ad	f	15.6	11	680
ad	m	14.5	11.3	420
ad	m	17.5	12.2	970
ad	m	13	9.5	580
ad	m	14	9	420
ad	f	16.5	13	970
ad	m	14.5	10.3	580
ad	m	14	9.9	500
ad	f	14.8	11	730
ad	m	13.3	9.2	420
ad	f	14.6	10.3	660
ad	m	12.8	9	390
ad	m	14.5	10.3	490
ad	m	13.8	10	530
ad	m	14.5	10.4	560
ad	f	14.3	10	550
ad	m	12.7	9.3	390
ad	m	13.3	9.8	440

age class	sex	CL	CW	Weight
ad	m	14.2	9.3	490
ad	m	13.5	10	450
ad	f	15.2	10.8	690
ad	f	15.1	10.8	635
ad	f	16	11	810
ad	m	14.2	9.3	490
ad	m	13.5	10	450
ad	m	13.3	9.5	460
ad	f	15.6	11.4	710
ad	f	16	11.5	820
ad	m	14.6	10.5	540
ad	m	13.3	9.2	460
ad	f	15.6	11	680
ad	m	12.2	8.8	380
ad	m	13.3	9.2	420
ad	m	14.4	9.8	560
ad	m	14.5	9.8	490
ad	m	12.2	8.8	370
ad	m	15.6	11.4	670
ad	f	17.8	12.6	1090
ad	f	16	12	800
ad	m	12.8	9	380
ad	m	14.7	10.3	600
ad	f	13.5	10.4	540
ad	m	13.8	10	450

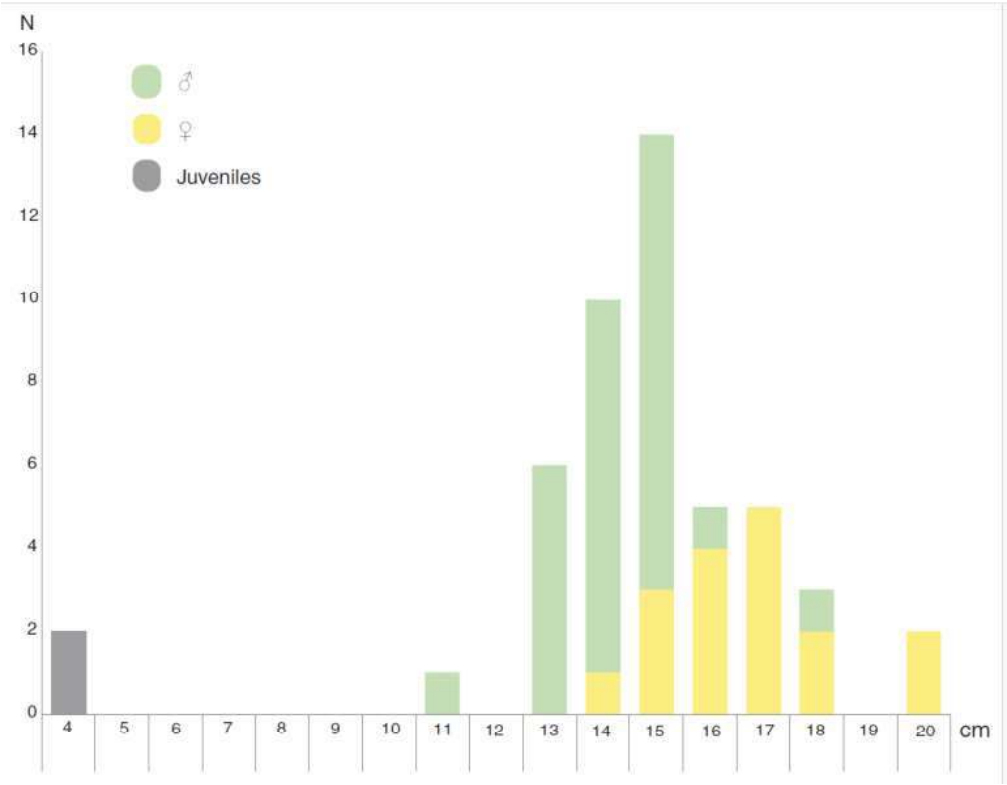

Figure 2: Size class distribution of *Testudo graeca* on the island of La Galite (carapace length in cm). September 2013 N = 48.

Fig. 2. Distribution des classes de tailles des *Testudo graeca* de l'île de la Galite (Longueur de la carapace en cm). Septembre 2013 N = 48.

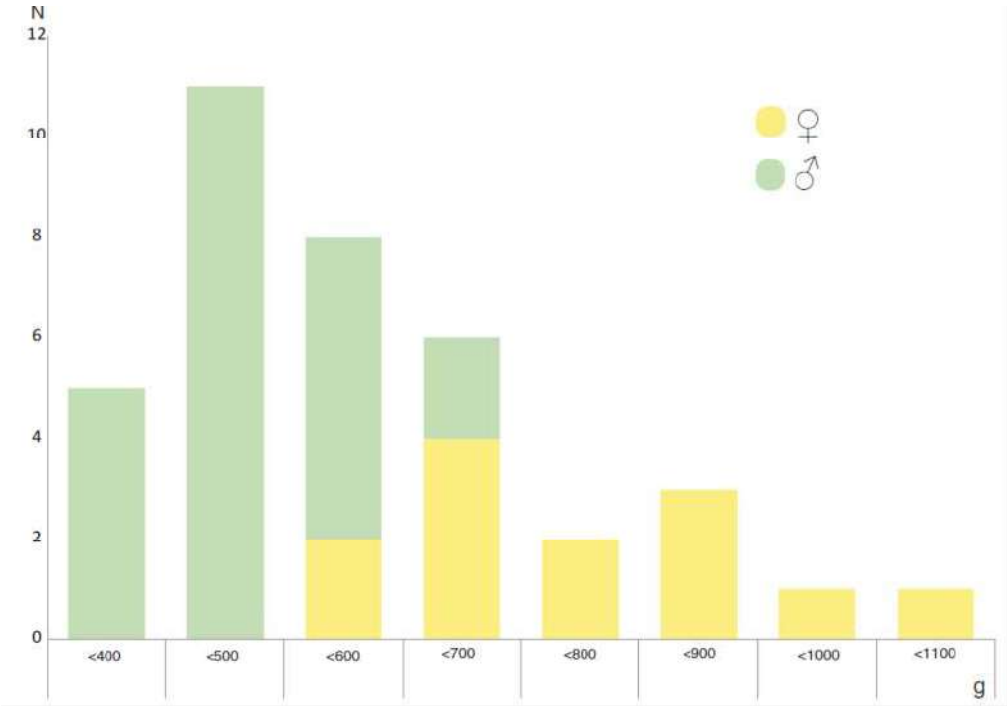

Figure 3: Distribution by weight class (g) in adults of *Testudo graeca* from La Galite. September 2013 N = 37.

Fig. 3. Distribution des classes de poids (g) des *Testudo graeca* adultes de l'île de la Galite. Septembre 2013 N = 37.

Table II.

IIA_ Descriptive statistic of Carapace Length (CL) of adult T. graeca of several western Mediterranean population. VH = Coefficient of variation of Haldane. Data Doñana from Diaz-Paniagua et al. (1996).

IIA_ Statistiques descriptives CL d'adultes de T. graeca de plusieurs populations de Méditerranée occidentale. VH = coefficient de variation de Haldane. Données Doñana (Diaz-Paniagua et al., 1996).

	Galite	Sinis	Malu Entu	Galite	Sinis	Malu Entu	Doñana
N	29	92	8	17	112	20	15
X	137.0	134.0	148.5	160.5	149.4	159.4	171.7
median	138.0	134.5	148.6	160.0	148.5	158.1	173.2
σ	13.04	15.13	9.17	16.24	17.12	8.90	14.55
min	100.0	104.0	138.4	135.0	102.1	146.5	144.9
max	175.0	183.1	167.3	198.0	235.0	181.6	210.8
VH	9.53	11.32	6.37	10.27	11.49	5.65	8.61

IIB_ Comparisons of CL with the Mann Whitney U test. In colour, test significant at p < .05.

IIB_ Comparaisons deux à deux de la CL à l'aide du Test U de Mann Whitney. En couleur, différence significative à *p* < .05.

SCL			
Population	Galite	Malu Entu	
La Galite	/	/	
Mal di Ventre	U = 45	/	
Sinis	U = 1130.5	U = 126	

SCL			
Population	Galite	Malu Entu	Sinis
La Galite	/	/	/
Mal di Ventre	U-= 166.5	/	/
Sinis	U = 573.5	U = 581.5	
Doñana	U = 68.5	U = 64	U = 226

Table III.

IIIA_ Descriptive statistics of the weight of T. graeca adults from the La Galite and Sardinian populations. VH = Haldane coefficient of variation.

IIIA_ Statistiques descriptives du poids d'adultes de T. graeca de populations de la Galite et de Sardaigne. VH = coefficient de variation de Haldane.

	La Galite	Sinis	Mal di Ventre	Galite	Sinis	Mal di Ventre
N	24	92	8	13	112	20
X	476.7	471.3	680.8	745.0	740.1	894.9
median	460.0	490.5	630.5	710.0	708.0	918.5
σ	78.89	130.04	154.63	155.62	203.23	201.53
min	370.0	130.0	550.0	540.0	248.0	143.9
max	670.0	845.0	1020	1090.0	1425.0	1188.0
VH	17.33	27.67	23.42	21.29	27.52	22.80

Compared to tortoises from mainland Tunisia [N = 34; mean 121.0 σ 19.6; N = 58; mean 19.9 σ 21.34; (Pieh & Perälä, 2002, p. 20)] - mainly from the Nabeul area (A. Pieh pers. comm. 2024-01) - T. graeca from La Galite of both sexes are significantly larger (t(61) = -3.0406, P < 0.0035; t(73) = -5.4517, P = 0). Further measurements should be carried out on natural populations on the Tunisian mainland to confirm the tendency of those from La Galite to be larger, as noted by Ben Hassine in Escoriza et al., (2022). For further qualitative comparisons of CL among Mediterranean populations see Fig 4 and 5; see also Semaha et al. (2024).

The tortoises of both sexes from Mal di Ventre were found to be heavier than those from La Galite and Sinis (and their weight is also more variable). Females from Doñana and Mal di Ventre are heavier than those from La Galite and Sinis (Table IIIB). Although this trend seems evident for the of Mal di Ventre Island tortoises, it should still be considered that weight can vary depending on the season and therefore the result of this comparison should be treated with caution.

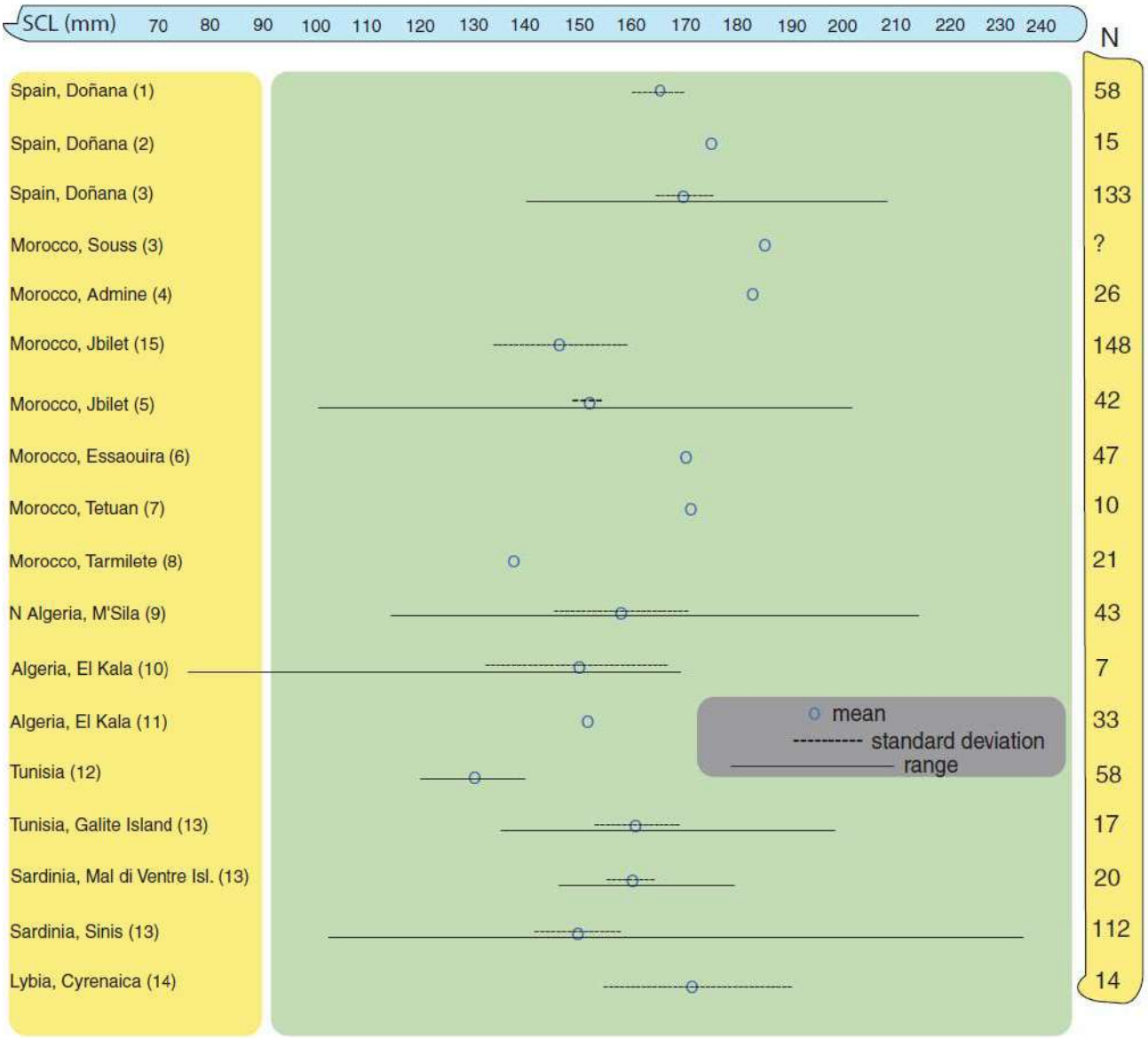

Fig. 4. Carapace length of adult females of Testudo graeca from different Mediterranean populations (in mm).
The numbers in brackets refer to: (1) (Buskirk et al., 2001); (2) (Diaz-Paniagua et al., 1996); (3, 9) (Hadj Aissa et al., 2022); (4, 5, 6) (Carretero et al., 2005); (7,8) (Pieh & Perälä, 2004); (10) (Rouag et al., 2007); (11) (Rouag et al., 2007); (12) (Pieh & Perälä, 2002); (13) this study & (Corti et al., 2007); (14) (Pieh & Perälä, 2002); (15) (Ben Kaddour et al., 2005).

Fig. 4. Longueur de la carapace de femelles adultes de Testudo graeca de plusieurs populations méditerranéennes (en mm).
Les nombres entre parenthèses renvoient aux références: (1) (Buskirk et al., 2001); (2) (Diaz-Paniagua et al., 1996); (3, 9) (Hadj Aissa et al., 2022); (4, 5, 6) (Carretero et al., 2005); (7,8) (Pieh & Perälä, 2004); (10) (Rouag et al., 2007); (11) (Rouag et al., 2007); (12) (Pieh & Perälä, 2002); (13) ce travail & (Corti et al., 2007); (14) (Pieh & Perälä, 2002); (15) (Ben Kaddour et al., 2005).

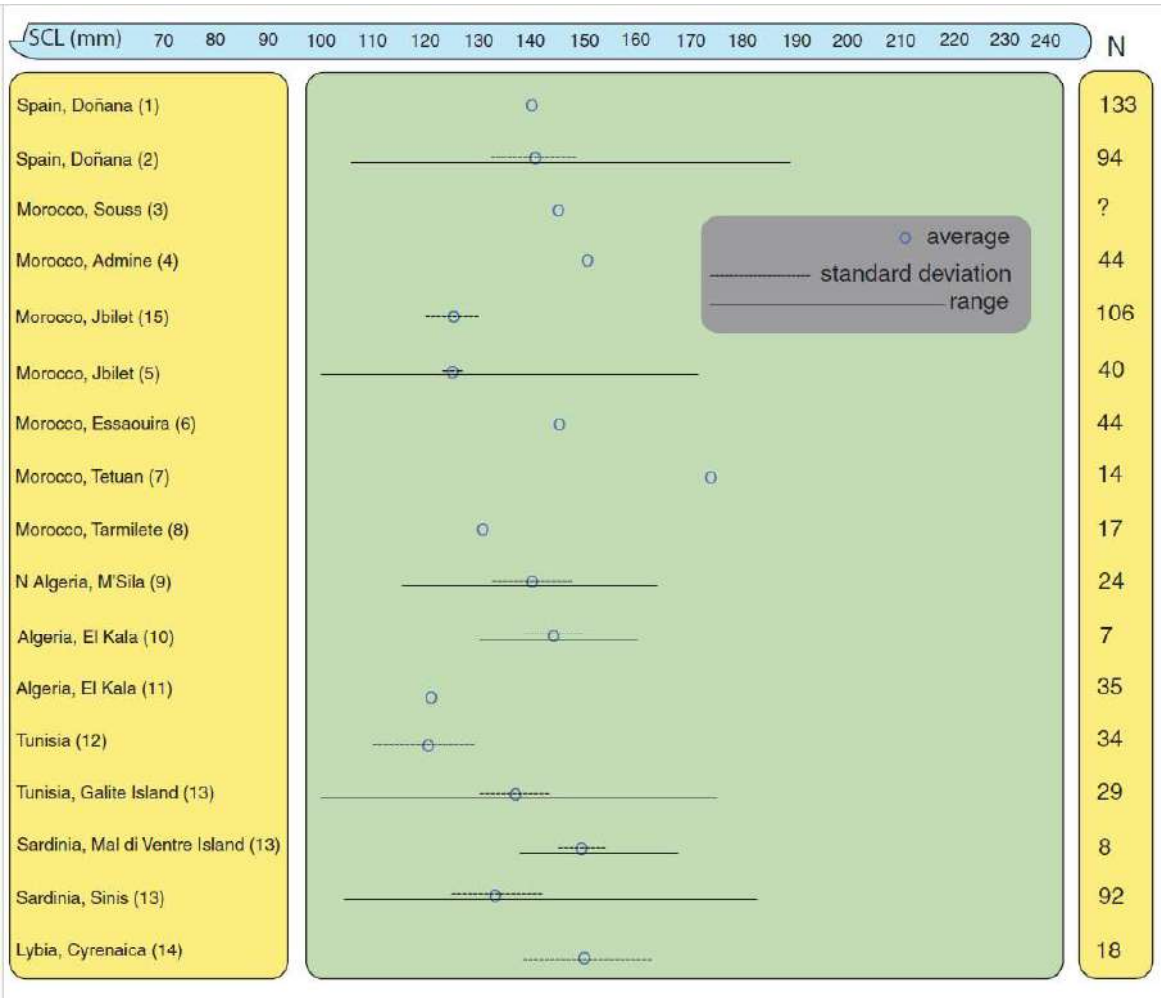

Fig. 5. Carapace length of adult males Testudo graeca from different Mediterranean populations (in mm).
The numbers in brackets refer to: (1) (Buskirk et al., 2001); (3, 9) (Hadj Aissa et al., 2022); (4, 5, 6) (Carretero et al., 2005); (7,8) (Pieh & Perälä, 2004); (10) (Rouag et al., 2007); (11) (Rouag et al., 2007); (12) (Pieh & Perälä, 2002); (13) this study, Tab I & (Corti et al., 2007); (14) (Pieh & Perälä, 2002); (15) (Ben Kaddour et al., 2005).

Fig. 5. Longueur de la carapace de mâles adultes de Testudo graeca de plusieurs populations méditerranéennes (en mm).
Les nombres entre parenthèses renvoient aux références(1) (Buskirk et al., 2001); (3, 9) (Hadj Aissa et al., 2022); (4, 5, 6) (Carretero et al., 2005); (7,8) (Pieh & Perälä, 2004); (10) (Rouag et al., 2007); (11) (Rouag et al., 2007); (12) (Pieh & Perälä, 2002); (13) ce travail Tab I & (Corti et al., 2007); (14) (Pieh & Perälä, 2002); (15) (Ben Kaddour et al., 2005).

IIIB_ Weight comparisons (ratio weight/CL) using the Mann Whitney U test. In colour, significance p < .05. Data Doñana from Diaz-Paniagua et al. (1996).

IIIB_ Comparaisons deux à deux du poids (ratio poids/CL) à l'aide du Test U de Mann Whitney. En couleur, différence significative à p < .05. Données Doñana (Diaz-Paniagua et al., 1996).

N (median)	La Galite	Mal di Ventre	
La Galite 24 (33.79)	/	/	
Mal di Ventre 8 (41.93	U = 10	/	
Sinis 92 (35.18)	U = 1071	U = 97	

N (median)	La Galite	Mal di Ventre	Sinis
La Galite 13 (45.51)	/	/	
Mal di Ventre 20 (58.71)	U-= 39	/	
Sinis 112 (48.31)	U = 678	U = 432	
Doñana 15 (61.97)	U = 11	U = 103	U = 190.5

Sexual size dimorphism

La Galite females are larger than the males, this difference is significantly notable (SSD = 17.4; U = 44, z-= -4.59695, p-value is < .00001), especially when compared with the eastern Mediterranean populations (Algerian, Tunisian, Libyan) (Table IV, Fig. 6); on the other hand, this sexual size dimorphism is within the range of the Moroccan and Spanish populations. In southwestern Asian populations (Iran, Turkey, Abkhazia), SSD is often very low and sometimes even reversed, with larger males (Pestov et al., 2009; Rezazadeh et al., 2014; Türkozan et al., 2005; Türkozan et al., 2023). According to current theories, intraspecific competition, ritual combat between males, as occurs in this species, confers a selective advantage to larger males; on the other hand, larger females have increased fecundity (Diaz-Paniagua et al., 1996). A previous study on this topic (Ben Kaddour et al., 2005) was not very conclusive. Furthermore, the west-east geographical trend, showing a clear reduction or reversal of sexual size dimorphism in the eastern clades, suggests a phylogenetic influence on SSD.

Table IV. Carapace Length in mm of Testudo graeca. SSD = Sexual Size Dimorphism, see methods.

Tableau IV. Longueur de la carapace en mm dans plusieurs populations occidentales de Testudo graeca. SSD = Dimorphisme sexuel de la taille, voir paragraphe Methods.

Location	Lineage	N	Mean	σ	range	N	Mean	σ	range	SSD	source
Spain, Doñana 1	T. g. whitei & T. g. whitei x T. g. marokkensis	58	166.1			133	139.0			19.5	(Buskirk et al., 2001)
Spain, Doñana 2	idem	13 3	169.8	11.30	141.4-210.8	94	140.8	14.40	105.9-191.2	20.6	(Diaz-Paniagua et al., 2001)
Morocco, Souss Valley	T. g. graeca		184.9				145.0			27.5	(Highfield & Bayley, 1996) cited as source by (Hadj Aissa et al., 2022)
Morocco, Admine	T. g. graeca	26	182.7			44	151.0			21.0	(Carretero et al., 2005)
Morocco, Jbilet 1	T. g. graeca	14 8	147.0	25.00		106	125.0	10.00		17.6	(Ben Kaddour et al., 2005)
Morocco, Jbilet 2	T. g. graeca	42	152.2	3.70	100.4-202.0	40	125.3	2.3	101.8-172.2	5.7	(Carretero et al., 2005)
Morocco, Essaouira	T. g. graeca	47	169.7			44	144.0			17.8	(Carretero et al., 2005)
Morocco, Tetuan	T. g. marokkensis	10	170.6			14	174.0			-2.0	(Pieh & Perälä, 2004)
Morocco, Tarmilete	T. g. marokkensis	21	138.5			17	130.4			6.2	(Pieh & Perälä, 2004)
N Algeria, M'Sila	T. g. whitei	43	158.2	24.98	113.2-215	24	140.1	12.50	116.15-166	12.9	(Hadj Aissa et al., 2022)
Algeria, El Kala	T. g. graeca	7	149.0	35.83	76.8-170	7	143.7	10.73	130.3-161.1	3.6	(Rouag et al., 2017)
Algeria, El Kala	T. g. graeca	33	150.7			35	138.4			8.9	(Rouag et al., 2007)
Tunisia	T. g. nabeulensis	58	129.9	21.34		34	121.0	19.61		7.4	(Pieh & Perälä, 2002)
Tunisia, La Galite Island	T. g. nabeulensis	17	160.5	16.24	135-198	29	137.0	13.04	100-175	17.1	This study
Sardinia, Mal di Ventre	T. g. nabeulensis	20	159.4	8.90	146.5-181.6	8	148.5	9.17	138.4-167.3	7.4	This study
Sardinia, Sinis	T. g. nabeulensis	112	149.4	17.12	102.1-235	92	134.0	17.12	104-183.1	11.5	This study
Lybia, Cyrenaica	T. g. cyrenaica	14	172.4	34.14		18	149.4	26.10		15.4	(Pieh & Perälä, 2002, 2004)

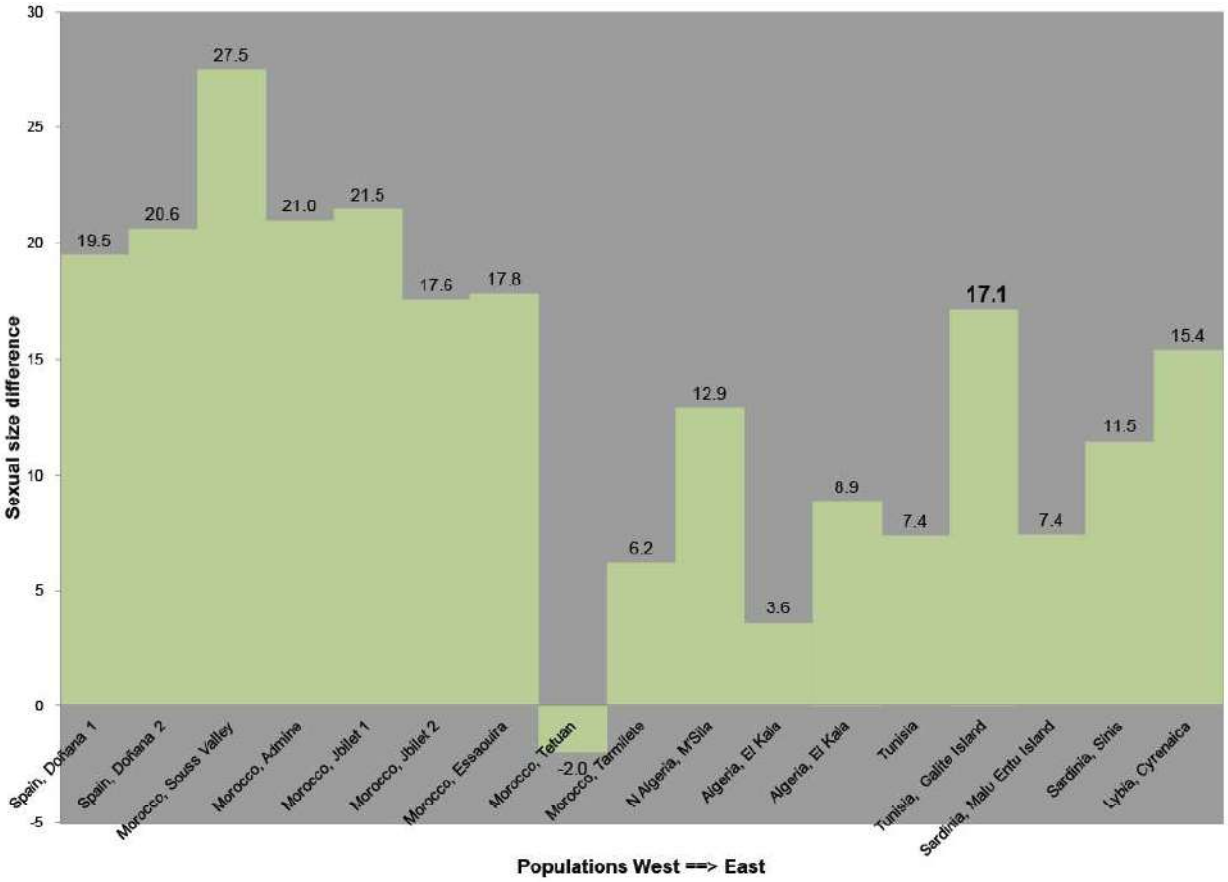

Figure 6: Sexual size dimorphism (SSD) in carapace length in different western populations of *Testudo graeca*. SSD calculation from Carretero et al. (2005) see also MM. Data from Tab IV.

Fig. 6. Dimorphisme sexuel de la taille (SSD) de la longueur de la carapace dans plusieurs populations occidentales de Testudo graeca. Calcul du SSD d'après Carretero et al. (2005), voir aussi le paragraphe méthodes. D'après les données du Tab IV.

Density

The population density of La Galite tortoises is estimated at 13.7 individuals per hectare. This density is higher than that reported for North Africa and Spain, (no data are available for Tunisia), and lower than in Sardinia (Fig. 7). La Galite still seems to be a high-quality habitat for T. graeca, despite the extensive pine plantation.

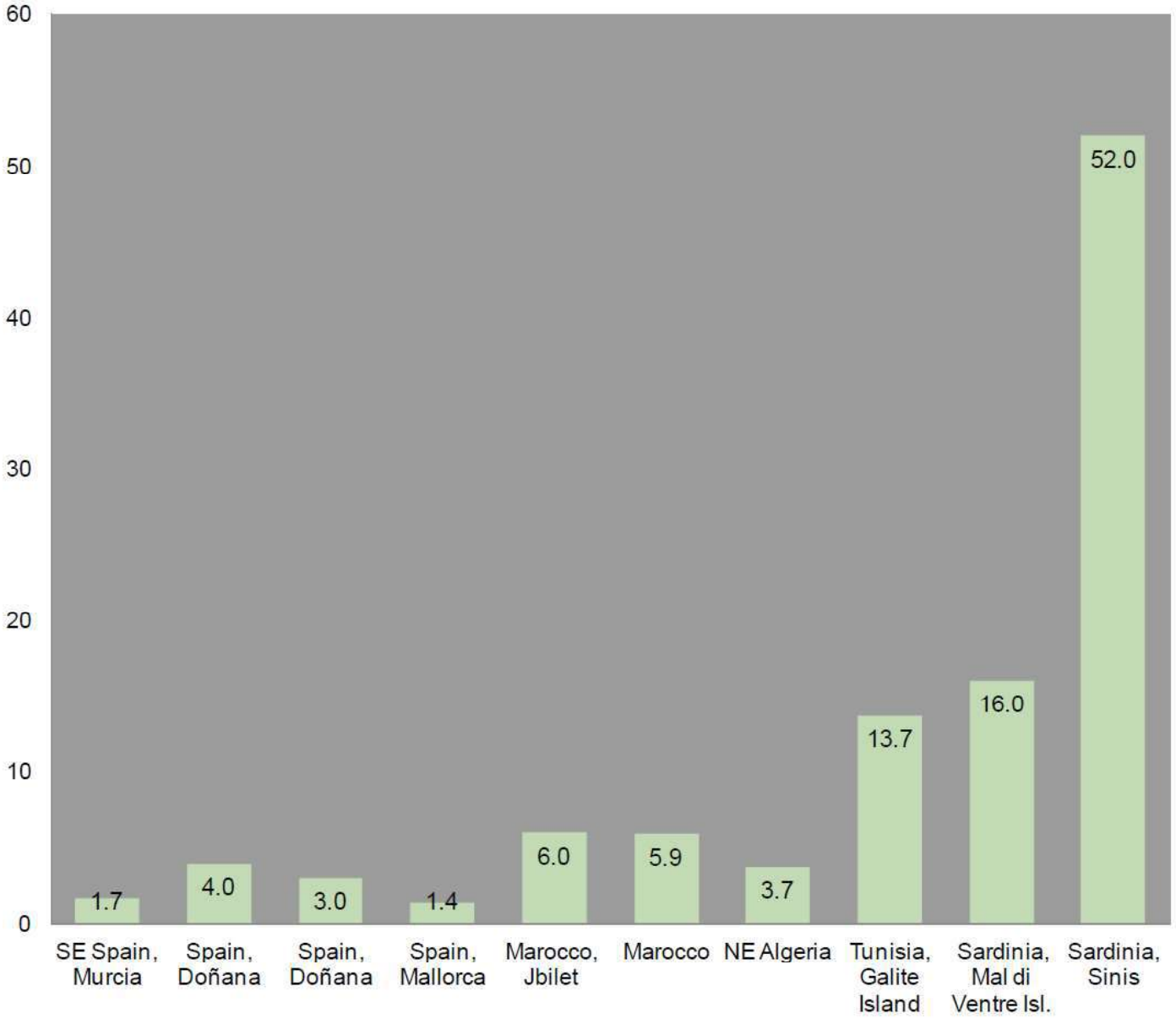

Fig. 7. Population density of Testudo graeca in different populations of the western Mediterranean (estimated number of tortoises per hectare). For: SE Spain (Anadón et al., 2006); Spain, Doñana (Andreu, 1987) (Andreu et al., 2000); Spain, Mallorca Island (Pinya, 2011); Marocco, Jbilet (El Mouden, Ben Kaddour, et al., 2006); Marocco (Ben Kaddour et al., 2006); NE Algeria (Rouag et al., 2007); Tunisia, Galite Island (this study); W Sardinia Mal di Ventre Island (Corti et al., 2007); W Sardinia Sinis (Biaggini et al., 2018).

Fig. 7. Densité de population de Testudo graeca dans plusieurs populations de Méditerranée occidentale (nombre estimé d'individu à l'hectare). Sources: SE Spain (Anadón et al., 2006); Spain, Doñana (Andreu, 1987) (Andreu et al., 2000); Spain, Mallorca Island (Pinya, 2011); Marocco, Jbilet (El Mouden, Ben Kaddour, et al., 2006); Marocco (Ben Kaddour et al., 2006); NE Algeria (Rouag et al., 2007); Tunisia, Galite Island (ce travail); W Sardinia Mal di Ventre Island (Corti et al., 2007); W Sardinia Sinis (Biaggini et al., 2018).

This population has probably been spared by the collection for the international trade of animals that has instead significantly weakened most of the North African populations. Many adult tortoises have been removed from natural populations, although international trade is now banned. However, the collection of animals to sell as souvenirs to tourists or as pets continues. Many tortoise populations also suffer from competition for food with livestock in overexploited environments (El Mouden, Slimani, et al., 2006). In La Galite tortoises, trophic competition with livestock is very low, as there are only few feral goats: 150 goats in 3 herds, 0.25 goat/ha according to Muracciole in Abbes et al. (2008). A large flock of sheep and cattle was established in the late 1990s but it did not last long (Muracciole in Abbes et al., 2008). According to studies conducted in an arid and overgrazed area of Jbilet in Morocco, T. graeca is a rather specialist herbivore. Five plant species accounted for 70% of the material consumed, while very common plant species were actively avoided (El Mouden, Slimani, et al., 2006). The massive pine plantation carried out in the early 2000s is modifying the landscape of La Galite and is likely to significantly alter the structure and composition of the vegetation, to the point of eliminating most plants suitable for tortoises. The fire of October 2021 is expected to further increase the spread of pine and diss grass. This is probably the greatest threat to this important population.

After the fire of 2021, the managers of the protected area (Hassen Zaghdoudi, Apal and Moez Shaiek, Man, pers. comm.) found 180-200 dead tortoises (Fig. 8). This number may have been much higher, and it is likely that many tortoises survived the fire by hiding in the ground, under the rocks or in other shelters. The effects of fires have been studied using long-term data in south-eastern Spain by Rodríguez-Caro et al. (2016). In addition to direct mortality, they suggest that post-fire changes in structure and function of the ecosystem have a major impact on this reptile population (see also Chergui et al., 2019). Sanz-Aguilar et al. (2011) show that most T. graeca populations should be able to withstand the effects of fire if it does not occur more frequently than every 20 to 30 years. This is the case of La Galite, where the last great fire recorded dates back to the 80s (see Fig. S1 where several individuals report signs of fire: pp. 2, 4, 51, 59). In the 19th and 20th centuries, when Italians from the island of Ponza settled there, the agro-pastoral activities were fully developed, leaving no room for fires.

Fig. 8. A burned T. graeca after the La Galite wildfire in October 2021 © H. Zaghdoudi (Apal).

Fig. 8. Tortue mauresque incendiée après le passage du feu sur la Galite en octobre 2021 © H. Zaghdoudi (Apal).

The La Galite tortoises probably have few predators (which represent mainly a danger especially for eggs, hatchlings, and juveniles), such as black rats, birds of prey, corvids.

Figure S1: Catalogue of *Testudo graeca tortoises* from the Island of La Galite

Figure S1 Catalogue des tortues Testudo graeca de l'île de la Galite

Parasites

Ectoparasites like ticks were absent in the 48 animals studied at La Galite and were very rare in the 268 tortoises examined in Sardinia (of which 28 coming from the island of Mal di Ventre). In southern Spain, in Murcia, the prevalence is 0.49% (N = 405 tortoises) and in Doñana, ticks have never been observed in more than 25 years of study (Díaz-Paniagua, 2009). The situation is exactly the opposite in the mainland populations of North Africa. In northern Morocco, the prevalence is 92.5% (N = 296) in the Maamora forest (Segura et al., 2019); 77.6% +/-6.5 (N = 392) in 7 other Moroccan locations (from 33% to 100%) (Laghzaoui et al., 2022); in southern Algeria, 71% (N = 24; Lakehal et al., 2020); in northern Tunisia 66.2% (N = 210; Gharbi et al., 2015); 91% (N = 147; Fares et al., 2019), 91.2% (N = 147; Najjar et al., 2020). The most common tick, *Hyalomma aegyptium*, is a specific host of tortoises and particularly of *Testudo graeca*. Why is there such an obvious discrepancy between the populations of continental North Africa and those of the islands and southern Spain? Could this be a lack of suitable intermediate hosts, given that *H. aegyptium* has a life cycle in 3 hosts, with larvae and nymphs infesting lizards, birds, small mammals and rarely cattle and humans? Or is it the result of transmarine dispersal of tortoises by rafting, where parasites were eliminated from seawater as suggested by Fritz et al. (2009, p. 72)? In any case, macroparasites in general and ectoparasites in particular can regulate host population dynamics by reducing host fitness (Segura et al., 2019). Their absence or rarity could partly explain the high densities of tortoises in Sardinia and La Galite.

Conclusion

The island of La Galite is home to a large population of *Testudo graeca* (Fig. 9) as does Sardinia. Compared to the populations of continental Tunisia, the tortoises of La Galite are larger and do not show ectoparasites. Even in Spanish and Sardinian populations, ectoparasites are rare or even absent.

Fig. 9. Female T. graeca, La Galite Island, May 2006 (© M.J. Delaugerre).

Fig. 9. T. graeca femelle, Ile de La Galite, mai 2006 (© M.J. Delaugerre).

The main threat to the population of La Galite is probably the plantation of pine forests and the resulting habitat change, as well as the susceptibility to fires. The population of *Testudo graeca* could survive the devastating effects of fires as long as they occur every 20-30 years. However, the frequency and intensity of fires could increase with global warming.

The species is classified as Vulnerable by the IUCN (2024), although this assessment needs to be updated. The La Galite Protected Area management plan should officially take into account the importance of the population of *T. graeca* and consider this island as a reserve dedicated to the protection of a quality habitat and a stable population, in addition to the Cap Bon shrubland, as proposed by Escoriza et al. (2022). Measures to control the growth and the spread of pine trees should be continued and intensified. Managers should also ensure that tortoise's collection does not take place.

We hope to be soon able to deepen the taxonomic status of the tortoises of La Galite to understand if they belong to the *T. graeca nabeulensis* A lineage and if the population has been introduced or is native to the island. This large and isolated population is a perfect case study for conducting research on trophic and landscape ecology to study the natural and anthropogenic evolution of vegetation and the effects of climate change.

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Supplementary material(atvs.tn/mat)

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