Morphological variation in Tyrrhenian
Emys orbicularis revisited

Anja Schulze, Uwe Fritz

Museum für Tierkunde, Staatliche Naturhistorische Sammlungen, A.-B.-Meyer-Bau, Königsbrücker Landstr. 159, 01109 Dresden, Germany
e-mail: anja.schulze3@stud.uni-rostock.de; fritz@snsd.de

The European pond turtle, *Emys orbicularis* (L., 1758), was considered monotypic by most authors for more than a century (e.g., Boulenger, 1889; Siebenrock, 1909; Wermuth and Mertens, 1961, 1977; Ernst and Barbour, 1989). In the past decade a complicated taxonomic differentiation was detected, resulting in the recognition of up to 13 subspecies. Until now, many studies focusing on taxonomy in this species were based on simple descriptive statistics and color and pattern characters (see reviews in Fritz, 1998, 2001). Phylogeographic investigations (Lenk et al., 1999), using sequence data of the mitochondrial cytochrome *b* gene, produced largely congruent results.

A major difference between both approaches concerns some populations from the western Mediterranean. Fritz (1995) described the subspecies *Emys orbicularis galloitalica* from southern France and the Tyrrhenian coast of the Italian peninsula (type locality: Département Var, France), and two further subspecies from Sardinia (*E. o. capolongoi*) and Corsica (*E. o. lanzai*), acknowledging mainly differences in coloration and ecology. Whereas on Corsica dark colored specimens predominate, most specimens from Sardinia are lighter colored. In the mainland subspecies *E. o. galloitalica* both types occur at approximately the same frequency. Hence, Fritz (1995) speculated that the populations on Corsica and Sardinia might have undergone a genetic bottleneck, resulting in the selection of different genotypes on each island.

Emys orbicularis galloitalica, *E. o. capolongoi* and *E. o. lanzai* are characterized by a shared distinct mitochondrial haplotype, which differentiated in pre-Pleistocene times from other lineages. However, no sequence differences of the mitochondrial cytochrome *b* gene were found between the three subspecies (Lenk et al., 1999), leading to considerations about the validity of *E. o. capolongoi* and *E. o. lanzai* (Zuffi, 2000).

Here we reanalyze morphological data of *E. o. galloitalica*, *E. o. capolongoi* and *E. o. lanzai*, in part based on the same specimens and measurements as in Fritz (1995). In addition, data of several live turtles were included, studied in 1995 and 1996 by UF during excursions to southern France (Département Var), northern Sardinia, and western Corsica (see appendix).
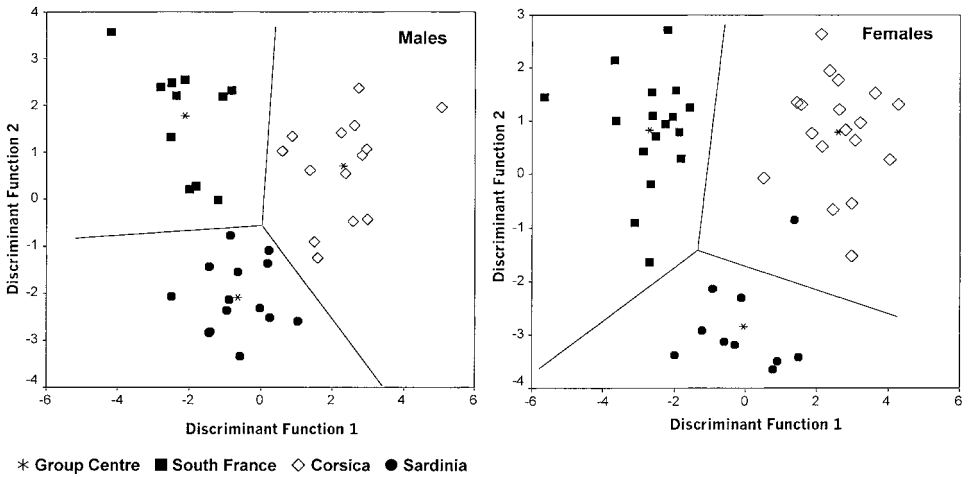
Figure 1. Scatter diagrams of the canonical discriminant function for *Emys orbicularis* from southern France (males: $n = 11$, females: $n = 17$), Corsica (males: $n = 14$, females: $n = 18$), and Sardinia (males: $n = 14$, females: $n = 10$), based on 19 characters.

All specimens were measured by UF. All measurements are straight line measurements to the nearest 0.1 mm, taken with calipers (see detailed definitions and figures in Fritz, 1995). Data evaluation was performed with discriminant function analysis (Mahalanobis distance) as implemented in SPSS 7.5. This operation includes forward and backward stepwise processing. The following characters were assessed:

(1) Maximum carapacial length — CL; (2) maximum carapacial width — CW; (3) maximum shell height — SH; (4) maximum plastral length — PL; lengths of median seams between plastral scutes: (5) intergular length — GuL, (6) interhumeral length — HumL, (7) interpectoral length — PecL, (8) interabdominal length — AbdL, (9) interfemoral length — FemL, (10) interanal length — AnL; (11) width of plastral forelobe — FLW; (12) width of plastral hindlobe — HLW; (13) snout length — SL; (14) head length — HL; (15) head height — HH; (16) head width — HW; (17) nuchal length — NuL; (18) nuchal width — NuW; (19) number of enlarged scutes at the distal edge of the left foreleg — ScuN. Besides these mensural and meristic characters, the sex of the specimens was noted. Only fully adult specimens were used for statistical analyses to avoid an influence of allometric growth. Incomplete data sets were excluded, so that our samples numbered 11 males and 17 females for southern France (Département Var), 14 males and 18 females for Corsica, and 14 males and 10 females for Sardinia.

As a clear sexual dimorphism is known in European pond turtles (Fritz, 2001), data were processed for each sex separately (for mean and standard deviation values see tab. 1). We compared the following settings: (1) males from southern France, Corsica and Sardinia and (2) females from southern France and both islands.

Parameters for the two discriminant analyses involving all 19 characters are given in table 2, non-standardized discriminant coefficients for the three geographical samples in table 3.

(1) Males from southern France, Corsica and Sardinia. All samples (100%) were reclassified correctly (fig. 1). Stepwise discriminant analysis selected only HL and NuW as optimal character combination. With these two characters alone, 73% of males from southern France, 86% of the Corsican males and 79% of the Sardinian males could be reclassified correctly.

(2) Females from southern France, Corsica and Sardinia. Like males, the samples of female pond turtles are very well separated by canonical discriminant function (fig. 1).

Table 1. Mean and standard deviation of characters analyzed for *Emys orbicularis* males and females from southern France (Département Var), Corsica and Sardinia. Means are in mm, with the exception of the scute counts (ScuN). For abbreviations see text.

	S France, males n = 11		S France, females n = 17		Corsica, males n = 14		Corsica, females n = 18		Sardinia, males n = 14		Sardinia, females n = 10	
	mean	s	mean	s	mean	s	mean	s	mean	s	mean	s
CL	124.7	6.3	129.2	7.1	123.6	5.4	132.0	6.1	117.9	10.0	125.2	10.0
CW	98.4	5.9	101.1	5.4	96.7	4.6	104.4	5.8	93.4	5.8	99.3	7.9
SH	43.4	2.1	53.7	3.4	45.0	2.4	54.6	3.5	42.3	3.5	50.9	5.7
PL	101.5	30.9	124.1	7.3	108.3	5.2	126.2	7.3	104.7	7.3	119.0	11.4
GuL	18.2	1.0	20.5	2.0	18.7	1.0	22.8	1.8	18.4	1.8	20.4	2.2
HumL	10.4	1.9	12.2	1.9	9.7	1.1	11.8	1.3	9.1	1.3	11.5	1.4
PecL	18.7	1.9	20.6	1.9	17.9	1.8	20.2	2.0	17.0	2.0	19.6	2.7
AbdL	16.2	1.3	19.1	1.8	17.4	1.3	20.0	2.3	16.0	2.3	19.2	1.7
FemL	11.8	1.8	14.5	1.9	12.6	2.0	14.3	1.3	11.1	1.3	12.9	2.7
AnL	30.2	2.1	34.0	3.5	28.9	2.2	34.7	2.0	29.6	2.0	33.2	2.7
FLW	57.3	3.2	61.5	4.2	55.3	2.3	65.6	3.1	54.2	3.1	60.8	5.0
HLW	65.2	3.8	71.4	4.7	64.9	3.2	75.9	4.2	62.7	4.2	71.8	7.1
SL	9.5	0.9	9.3	0.7	9.9	0.7	10.2	1.0	9.2	1.0	9.4	0.8
HL	30.3	1.5	30.7	1.6	32.5	1.4	33.3	2.0	29.0	2.0	29.2	2.6
HH	9.9	1.1	9.8	0.8	9.8	0.8	10.0	0.9	9.1	0.9	9.5	0.5
HW	22.5	1.1	23.9	1.2	23.4	1.6	23.6	1.2	21.0	1.2	22.1	1.9
NuL	7.6	1.2	7.7	0.8	6.4	0.8	6.8	0.7	7.4	0.7	7.4	1.3
NuW	4.2	1.0	3.7	1.0	2.6	0.5	3.2	0.9	2.7	0.9	3.1	0.5
ScuN	8.1	0.7	7.7	0.9	7.6	0.7	7.7	0.7	7.9	0.7	8.2	0.4

Table 2. Parameters of the three discriminant analyses involving all 19 morphometric characters. SF: southern France; C: Corsica; S: Sardinia.

	Function	Eigenvalue	% Variance	Cumulative %	Canonical Correlation
Males (SF, C, S)	1	3.626	56.1	56.1	0.885
	2	2.837	43.9	100.0	0.860
Females (SF, C, S)	1	5.801	69.9	69.9	0.924
	2	2.497	30.1	100.0	0.845

	Test of Function	Wilks-Lambda	Chi^2	df	P
Males (SF, C, S)	1 vs 2	0.056	77.665	38	<0.001
	2	0.261	36.308	18	<0.001
Females (SF, C, S)	1 vs 2	0.042	104.579	38	<0.001
	2	0.286	41.317	18	<0.001

All specimens from Corsica and southern France were correctly reclassified (100%); for Sardinia 90% of the specimens were properly regrouped.

Table 3. Canonical discriminant coefficients (non-standardized) for *Emys orbicularis* from southern France (Département Var), Corsica and Sardinia.

Character	Males		Females	
	Function 1	Function 2	Function 1	Function 2
CL	−0.1292	0.0219	−0.0727	−0.3066
CW	−0.0734	−0.4457	0.2388	−0.0823
SH	0.1389	−0.1785	0.0891	0.1315
PL	0.0151	−0.0208	−0.5384	−0.0923
GuL	0.6046	−0.3659	0.5110	0.2139
HumL	0.2030	0.3727	0.4269	0.1767
PecL	0.3100	0.4347	0.2107	0.3619
AbdL	0.3578	0.1498	0.7655	0.0034
FemL	0.2942	−0.1294	0.2266	0.3075
AnL	−0.1268	−0.1461	0.1561	0.3067
FLW	−0.2987	0.6959	0.1984	0.1588
HLW	−0.0782	−0.1763	0.0582	−0.4992
SL	−0.3169	−0.1271	1.0706	−0.6160
HL	0.3929	0.8494	0.5422	1.2442
HH	−0.3615	−1.2405	0.3186	0.7057
HW	0.4411	0.8998	−0.9651	0.7329
NuL	−0.0673	0.3422	−0.0767	0.1870
NuW	−0.4748	1.1940	−0.2256	0.3277
ScuN	−0.8715	0.0104	0.5820	0.0999
Constant	5.8486	−17.5582	−24.6639	−10.1907

Stepwise discriminant analysis demonstrated SL, HL, HW and HLW to be the best character combination for group discrimination. Using only these characters, 100% of the females from southern France, 94% of the females from Corsica and 90% from Sardinia were correctly reclassified.

Discussion.   In both settings, HL turned out to be among the most powerful characters for distinguishing between the geographical samples. The importance of head length was already highlighted by Fritz (1995) in his diagnosis of *Emys orbicularis lanzai.* Using discriminant function analysis with cross-validation and stepwise discriminant analysis, most specimens from the three geographical samples (1) southern France, representing the subspecies *Emys orbicularis galloitalica*, (2) Corsica (*E. o. lanzai*) and (3) Sardinia (*E. o. capolongoi*) were correctly reclassified. This underlines the distinctiveness of these populations, regardless whether they are treated as subspecies or not. *Emys orbicularis* is known from Corsica since the Middle Pleistocene (Hervet and Salotti, 2000). The oldest fossils on Sardinia are younger and originate from Upper Pleistocene deposits (Tyrrhénien, Caloi et al., 1981). Together with the morphological differences in color and pattern (Fritz, 1995) and the results presented here, this argues for a long unique evolutionary history of the populations on Corsica and Sardinia and a high degree of differentiation. These findings have to be taken into account in all conservation and management plans for Mediterranean *Emys orbicularis*.

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Appendix

Specimens examined (museum acronyms follow Leviton et al., 1985 except MHNM = Muséum d'Histoire naturelle Marseille and MTD = Museum für Tierkunde Dresden):
Emys orbicularis galloitalica (southern France, Département Var): males: MHNM 15:1975B, MNHN 1993-5801 plus 9 live specimens; females: MHNM 15:1975A, MNHN 1993:5803-4, MTD 34287, NMBA 21186, ZSM-LM 5031:2 plus11 live specimens.
Emys orbicularis lanzai (Corsica, France): males: MZUF 7701-7703, 22088, 22092, 35645-35646, 35649-35651, 35653, 35659, 35663-35664; females: MZUF 7704, 13968, 13970, 13972, 19095, 22085-22087, 22089, 35655, 35666, 35669, 35671-35672, SMF 47280-47281, SMNS 5492 plus 1 live specimen.
Emys orbicularis capolongoi (Sardinia, Italy): males: MZUF 30579, 30581, NMW 14698, 14699:2, RMNH 3356:1-2, SMF 43328-43329, ZFMK 55578-55580 plus 3 live specimens; females: NMW 14697, 14699:1, 21428:1-2, NMBA 22420, SMF 59593, SMNS 7854 plus 3 live specimens.