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THE WATER FROGS (ANURA: RANIDAE) OF TURKEY: A MORPHOMETRIC VIEW ON SYSTEMATICS

ULRICH SINSCH[1], HANS SCHNEIDER[2], UĞUR KAYA[3] AND HÜSEYIN ARİKAN[3]

[1]*Institut für Biologie, Universität Koblenz-Landau, Universitätsstr. 1, D-56070 Koblenz, Germany*

[2]*Institut für Zoologie, Universität Bonn, Poppelsdorfer Schloss, D-53115 Bonn, Germany*

[3]*Ege Üniversitesi, Fen Fakültesi, Biyoloji Bölümü, Zooloji Anabilim Dalý, 35100 Bornova Ýzmir, Turkey*

The morphometric variation among 138 water frogs collected in Turkey at twelve localities extending from the Mediterranean coast in the south to the Black Sea coast was analysed using principal component and discriminant analyses. The water frog sample was heterogeneous and included two diagnosable morphs. Comparison with specimens from the type localities of *Rana bedriagae* (Damascus, Syria) and *R. ridibunda* (Atyrau, Kazakhstan) demonstrated that the most common water frog taxon in Turkey is *R. bedriagae*. The second morph was restricted to Ulubey, near Ordu, and was not conspecific with either *R. bedriagae* or *R. ridibunda*. It was, however, morphometrically closer to *R. bedriagae* than to *R. ridibunda*. As we were unable to locate an extant population of frogs which resembled the preserved sample from Ulubey, the taxonomic status of these morphometrically distinct water frogs remains unresolved. The large water frogs of the Anatolian Lakes District were indistinguishable from *R. bedriagae* in size-adjusted shape, but their maximum size exceeded that of *R. bedriagae* from all other localities by about 30 mm. We therefore provisionally refer to them as *R. bedriagae caralitana*. Reliable taxonomic recommendations require further information on independent character complexes such as advertisement calls and allozymes.

Key words: morphometry, *Rana bedriagae, R. bedriagae caralitana, R. ridibunda*, systematics

INTRODUCTION

Water frog systematics and biogeography of the Balkans and the Middle East have undergone considerable changes during the the past two decades (e.g. Schneider, Sofianidou & Kyriakopoulou-Sklavounou, 1984; Joermann, Baran & Schneider, 1988; Schneider & Sinsch, 1992; Sinsch & Schneider, 1996). At first the water frogs of this region were all referred to as *Rana ridibunda* PALLAS, 1771 (Boettger, 1888). Now, we know that the water frog fauna of this region (excluding the Mediterranean islands) comprises at least five species: *Rana balcanica, R. bedriagae, R. epeirotica, R. lessonae* and *R. ridibunda* and several types of hybrid (Schneider *et al.*, 1984; Schneider *et al.*, 1992; Schneider *et al.*, 1993; Sinsch & Schneider, 1996; Schneider & Sinsch, 1999). Nevertheless, our knowledge of the water frogs of Turkey and their biogeography remains limited because many regions are unexplored and taxonomic assignments are often uncertain.

Since the late 19th century Turkey was thought to be inhabited by the lake frog *Rana ridibunda* (Boettger, 1888; Werner, 1902, 1904; Bodenheimer, 1944; Mertens, 1952; Günther, 1991). This traditional view has been adopted in many faunistic, morphological and serological studies (Baran, 1981, 1984; Arıkan, 1983, 1990; Yılmaz, 1984; Atatür & Yılmaz, 1986; Baran *et al.*, 1992; Kaya, 1996; Kumlutaş, Tosunoğlu & Göçmen, 1999; Tok, 1999; Tok, Atatür & Ayaz, 2000). Consequently, reviews of the diversity of the herpetofauna of Turkey reiterate this point of view (Başoğlu & Özeti, 1973; Kasparek & Kasparek, 1990; Leviton *et al.*, 1992; Baran & Atatür, 1998).

The one-species concept was first modified by Arıkan (1988) who proposed that water frogs of the Lake Beyşehir region represent a new subspecies, *R. ridibunda caralitana*, because they differ from the other water frogs by the orange-coloured skin of wide parts of the venter and the legs and by their large snout-vent length. This striking coloration had already been observed by Kosswig (cf Bodenheimer, 1944). During the past decade several studies have focused on the geographical range of the new subspecies (Atatür, Arıkan & Mermer, 1989/90; Arıkan 1990; Arıkan *et al.*, 1994; Arıkan, Olgun, Çevik & Tok, 1998; Budak, Tok & Ayaz, 2000; Jdeidi, Bilgin & Kence, 2001). A recent mtDNA-based study of only 10 frogs from six localities suggests a remarkable degree of genetic differentiation among water frogs, but data are too scarce for reliable taxonomic conclusion (Plötner *et al.*, 2001).

Bioacoustic analyses of the advertisement calls of Palaearctic water frogs yielded results which did not agree with the assignment of water frogs in Turkey to *R. ridibunda*. Joermann, Baran & Schneider (1988) demonstrated that advertisement calls of water frogs from

Correspondence: U. Sinsch, Institut für Biologie, Universität Koblenz-Landau, Universitätsstr. 1, D-56070 Koblenz, Germany. *E-mail*: Sinsch@uni-koblenz.de

the Aegean coast (İzmir, Dalaman) had the same temporal structure as those from Israel (Nevo & Schneider, 1983), but differed from those of water frogs from the Balkans. Extensive comparative studies of the vocalizations of water frogs in the Middle East and adjacent regions including the type localities of *R. ridibunda* at Atyrau (Kazakhstan) and *R. bedriagae* at Damascus (Syria) finally provided evidence that Israel, Syria, the Nile delta of Egypt and the studied regions of Turkey are inhabited by the Levantine frog, *R. bedriagae* (Akef & Schneider, 1989; Schneider & Sinsch, 1992, 1999; Schneider, 1997*a,b*, 1999). Further bioacoustic surveys extended the geographical range of *R. bedriagae* in Turkey (Schneider & Sinsch, 2001).

The species status of *R. bedriagae* and the assessment of its geographical range is not only based on bioacoustics. Electrophoretic studies on allozymes (Nevo & Filippucci, 1988; Sinsch & Eblenkamp, 1994; Sofianidou, Schneider & Sinsch, 1994) and comparative morphometrics (Sinsch & Schneider, 1999) provided further characters which distinguish *R. bedriagae* from *R. ridibunda.* In particular, the morphometric study extended its range to many more sites in Syria, Jordan and Turkey. The combined evidence suggests that *R. bedriagae* is widely distributed in the Middle East (Sinsch & Schneider, 1999).

The morphometric evidence of the presence of *R. bedriagae* at Alanya and Lake Beyşehir (Turkey) is inconsistent with the conclusions drawn from other morphological studies. The nominate form of *R. ridibunda* is claimed to inhabit the northern Aegean islands as well as those of the Sea of Marmara and the Black Sea (Baran 1981), Turkish Thrace (Yılmaz, 1984), the southern Lakes district (Atatür, Arıkan & Mermer, 1989/1990), four more regions of Turkey (Atatür, 1990), the Datça peninsula (Tok, 1999) and Dalaman on the Aegean coast (Tok, Atatür & Ayaz, 2000). Some of the contradicting taxonomic assignments may be due to the fact that the studied water frogs have not been compared with animals from the type localities of *R. bedriagae* and *R. ridibunda.* However, data may also indicate that *R. bedriagae* is not the only water frog species of Turkey. Initial bioacoustic data suggest that *R. ridibunda* occurs in the Kızılırmak River at Gülşehir, central Turkey (Schneider & Sinsch, 1999). *R. ridibunda* is likely to be present in regions in which climate is unfavourable for *R. bedriagae*, such as Turkish Thrace and the Black Sea coast (Schneider & Sinsch, 2001). Consequently, we used morphometric data on water frogs collected at twelve localities extending from the Mediterranean coast in the south across the country to the Black Sea coast to test the hypothesis that more than one water frog species inhabits Turkey. Principal component and discriminant analyses were applied to detect and to quantify local features of the populations studied in Turkey. To enable a reliable taxonomic assignment to either *R. bedriagae* or *R. ridibunda,* we included reference populations (also from the corresponding type localities) of both species in the analysis.

MATERIAL AND METHODS

Water frogs (n=138) were collected in Turkey at the following localities (Fig. 1): (1) Alanya (Antalya), n=22; (2) Lake Beyşehir (Konya), n=32, type locality of *Rana ridibunda caralitana* Arıkan, 1988; (3) Yakaköy near Dinar (Afyon), n=14; (4) Lake Işıklı at Beydilli (Denizli), n=9; (5) Lake Eber at Çayırpınar (Afyon), n=6; (6) Çifteler (Eskişehir), n=5; (7) Balçıkhisar, ca. 30 km north of Çifteler (Eskişehir), n=12; (8) Lake İznik at Çakirca (Bursa), n=8; (9) Karasu (Adapazarı), n=5; (10) Kızılırmak at Bafra (Samsun), n=5; (11) Ulubey (Ordu), n=16; (12) Turna Suyu (Ordu), n=4. Ten external morphological characters were measured with calipers to the nearest 0.1 mm: (1) snout-vent length (SVL); (2) callus internus length (CIL); (3) digitus primus length (DPL); (4) femur length (FEMUR); (5) tibia length (TIBIA); (6) foot length (FOOT); (7) head width at eye position (HEADeye); (8) maximal head width (HEADmax); (9) snout-eye distance (SNOUT-EYE); (10) tympanum diameter (TYM). Comparisons of these water frogs with species that are known to inhabit neighbouring states were made by comparing the morphometrics with corresponding measurements of reference samples of *Rana bedriagae* CAMERANO, 1882 (n=94) and of *R. ridibunda* PALLAS, 1771 (n=55) which were shown to be homogeneous in Sinsch & Schneider (1999). The reference samples included individuals from the type locality of *R. bedriagae* at Damascus, Syria, and from the type locality of *R. ridibunda* at Atyrau, Kazakhstan. Localities, numbers and sex of specimens and their assignment to museum collections are summarized in Appendix 1.

All measurements were taken by one of us (H. Schneider) from either preserved frogs or from live frogs that were captured and released at the capture site. We tested data (principal component scores, ratios) for a potential bias between preserved and living material in

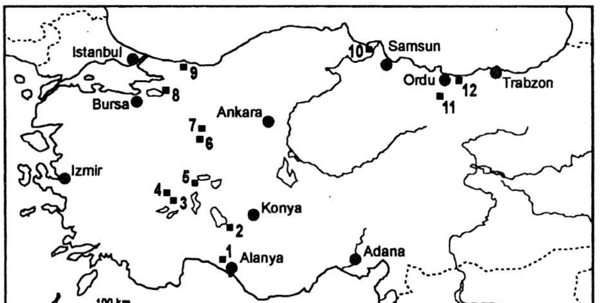


FIG. 1. Map of localities. 1 Alanya (Antalya); 2 Lake Beyşehir (Konya, type locality of *Rana ridibunda caralitana* Arıkan, 1988); 3 Yakaköy, Dinar (Afyon); 4 Lake Işıklı at Beydilli (Afyon); 5 Lake Eber at Çayırpınar (Afyon); 6 Çifteler (Eskişehir); 7 Balçıkhisar, ca. 30 km north of Çifteler (Eskişehir); 8 Lake İznik at Çakırca (Bursa); 9 Karasu (Adapazarı); 10 Kızılırmak at Bafra (Samsun); 11 Ulubey (Ordu); 12 Turna Suyu (Ordu).

TABLE 1. Principal component analysis of the data set on 138 water frogs from Turkey consisting of ten log10-transformed, standardized morphometric variables. The association (=component weights) of single variables to the derived three principal components representing a total of 94.4% of total variance is presented.

	PC 1	PC 2	PC 3
Eigenvalue	8.87	0.32	0.25
Variable:			
SVL	**0.331**	0.044	-0.002
CIL	**0.295**	**0.236**	**-0.894**
DPL	**0.300**	**-0.549**	-0.140
FEMUR	**0.318**	-0.089	0.195
TIBIA	**0.328**	-0.080	0.126
FOOT	**0.319**	**-0.223**	0.153
HEADeye	**0.327**	-0.078	0.114
HEADmax	**0.328**	0.080	-0.006
SNOUT-EYE	**0.320**	-0.044	0.112
TYMP	**0.292**	**0.750**	**0.280**

the sample collected at Lake Beşyehir, but the observed deviations with respect to size- or shape-related measures did not reach statistical significance. We therefore assumed that preservation did not affect the parameters used for this analysis and pooled data irrespective of preservation state.

Before applying multivariate statistics all morphometric distances were $\log_{10}$-transformed. As sexual dimorphism was limited to differences in size

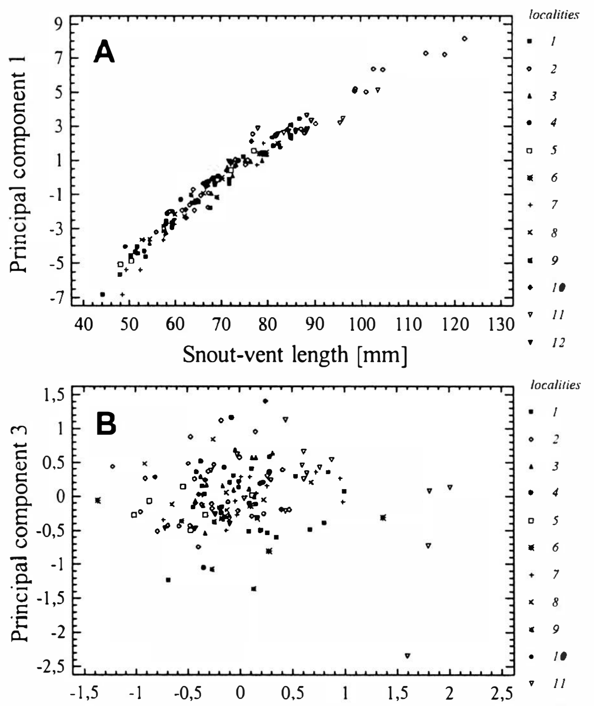


FIG. 2. Morphometric variation among the water frogs from 12 localities (see Fig. 1) in Turkey. (A) Size-related variation; (B) Shape-related variation. Details on the principal component analysis are given in Table 1.

(Table 7), we pooled single measurements into three data sets irrespective of sex: (1) frogs only from Turkey; (2) frogs from Turkey + *R. bedriagae*; (3) frogs from Turkey + *R. ridibunda*. Each data set was subjected to principal component analysis to explore the morphometric variability independent of taxonomic assignment, i.e. to test for homogeneity of the sample and to reduce the information to statistically unrelated factors. The first principal component (PC1) of morphometric data generally describes differences in size, but size effects may be present in subsequent principal components representing shape (Humphries *et al.*, 1981). The second, third and subsequent components are related to aspects of shape. Slopes and intercepts of regression lines describing the size-PC1 relationship were compared using ANOVA. Discriminant analysis was applied to maximize the differences among predefined groups, i.e. water frogs from Turkey, *R. bedriagae* and *R. ridibunda*. Using the rate of correct classification, we obtained a quantitative measure of the morphological differentiation among the groups/species (Schneider & Sinsch 1992).

RESULTS

Morphometric Variation Among Water Frogs From Twelve Localities in Turkey

Most of the morphological variability (88.7%) within the data set of 138 water frogs was caused by variation in size, i.e. PC1 (Table 1, Fig. 2A). The allometric relationship between PC1 and snout-vent length did not differ among frogs from different localities. However, maximum size was largest in the sample from Lake Beyşehir (122.4 mm), intermediate in that from Ulubey (103.9 mm), and smallest in the other ten samples (72.2-88.4 mm). With respect to shape, the frogs from Ulubey varied considerably from all others (including those from the neighbouring localities Kızılırmak at Bafra and Turna Suyu) with respect to their scores on PC2, which accounted for 3.2% of total variation (Fig. 2B). PC2 was strongly loaded by the variable tympanum diameter (Fig. 3C), but also by the variables representing foot morphology (DPL, FOOT, CIL; Table1). Thus, principal component analysis suggested that the data set tested was not homogeneous with respect to shape-related variables. The discriminant analysis lent further support to the supposed sample heterogeneity: five significant discriminant functions were derived (Table 2). Successful classification of individuals to their actual population exceeded the rate of random assignment (8.33%) by a factor of four to ten, suggesting the existence of particular local characteristics. In four populations (Lake Eber at Çayirpinar, Çifteler, Karasu and Ulubey) classification success was 80% or more (Table 2C). Specifically, the scores of the Ulubey frogs showed little overlap with the distributions of those from the other regions. In contrast, the frogs from Lake Beşyehir only yielded a classification success of 44% (>5 times the probability of random assignment).

TABLE 2. Significant discriminant functions based on ten $\log_{10}$-transformed morphometric variables to distinguish among water frogs from 12 localities in Turkey (see Fig. 1). In (C) the values shown are actual (1st row) and predicted (2nd row) localities.

(A) *Statistical significance:*

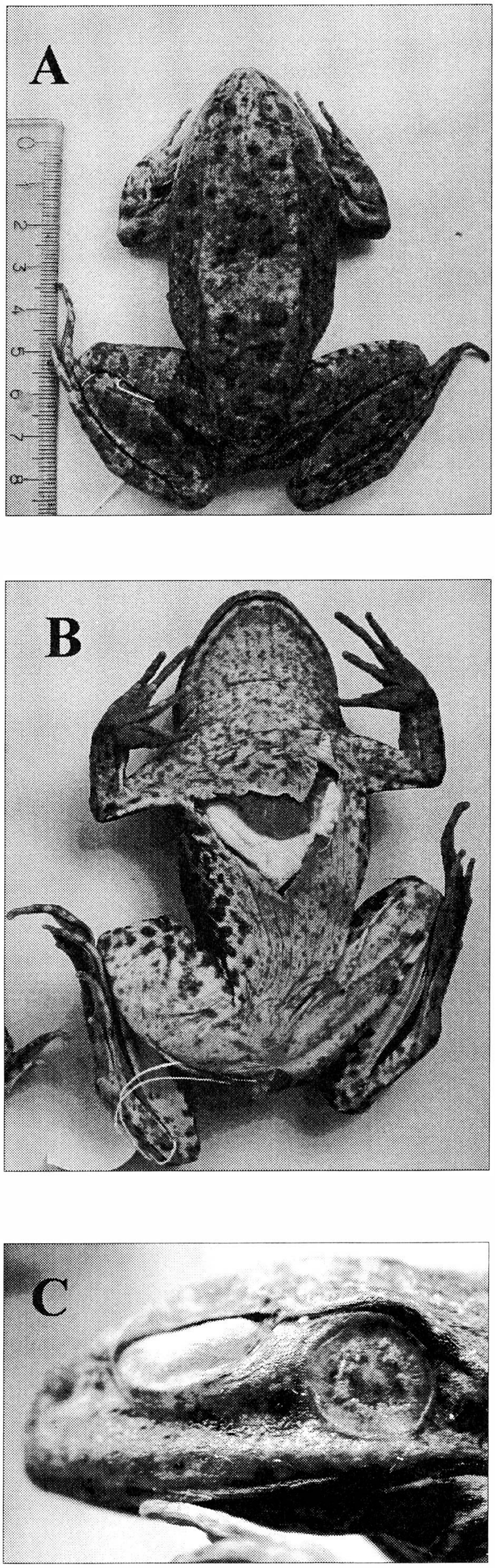
Discriminant function	Eigenvalue	Relative Percentage	Canonical Correlation	Wilks Lambda	χ^2	df	*P*
1	1.61	41.7	0.786	0.063	348.7	110	<<0.0001
2	0.96	24.8	0.699	0.164	227.6	90	<<0.0001
3	0.50	13.0	0.578	0.322	142.9	72	<<0.0001
4	0.28	7.2	0.467	0.483	91.6	56	0.0019
5	0.20	5.1	0.406	0.618	60.6	42	0.0315

(B) *Unstandardized coefficients of the significant discriminant functions:*

	Discriminant functions				
	1	2	3	4	5
SVL	0.09	-34.77	18.46	21.67	-17.11
CIL	10.35	1.63	-2.33	-3.26	-12.38
DPL	0.40	11.36	8.14	4.96	-3.72
FEMUR	-24.20	-18.87	9.51	-15.24	-2.73
TIBIA	8.99	10.99	-33.32	36.15	29.67
FOOT	11.81	14.79	4.22	-10.86	-16.67
HEADeye	-8.74	3.68	26.86	-6.69	2.36
HEADmax	16.68	3.22	-27.49	-30.56	18.18
SNOUT-EYE	-13.39	20.86	0.89	0.28	11.30
TYM	7.83	-11.40	3.28	4.52	-2.38
CONSTANT	-6.90	15.46	-12.02	-11.26	-10.80

(C) *Classification success:*

	1	2	3	4	5	6	7	8	9	10	11	12
1	15	-	-	-	-	4	2	-	1	-	-	-
	68.2%					18.2%	9.1%		4.6%			
2	1	14	4	5	4	-	-	2	1	1	-	-
	3.1%	**43.8%**		12.5%	15.6%	12.5%			6.3%	3.1%	3.1%	
3	1	-	10	1	1	-	-	-	1	-	-	-
	7.1%		**71.4%**		7.1%	7.1%				7.1%		
4	-	2	1	5	1	-	-	-	-	-	-	-
		22.2%	11.1%	**55.6%**		11.1%						
5	1	-	-	-	5	-	-	-	-	-	-	-
	16.7%				**83.3%**							
6	-	-	-	-	-	4	-	-	-	-	-	1
						80.0%						20.0%
7	3	1	-	-	-	2	4	1	-	-	1	-
	25.0%	8.3%				16.7%	**33.3%**	8.3%			8.3%	
8	-	1	-	-	-	-	-	6	-	-	-	1
		12.5%						**75.0%**				12.5%
9	-	-	-	-	1	-	-	-	4	-	-	-
					20.0%				**80.0%**			
10	-	-	-	2	-	-	-	-	-	2	-	1
				40.0%						**40.0%**		20.0%
11	-	2	-	1	-	-	-	-	-	-	13	-
		12.5%		6.3%							**81.2%**	
12	-	-	-	1	1	-	-	-	-	-	-	2
				25.0%	25.0%							**50.0%**



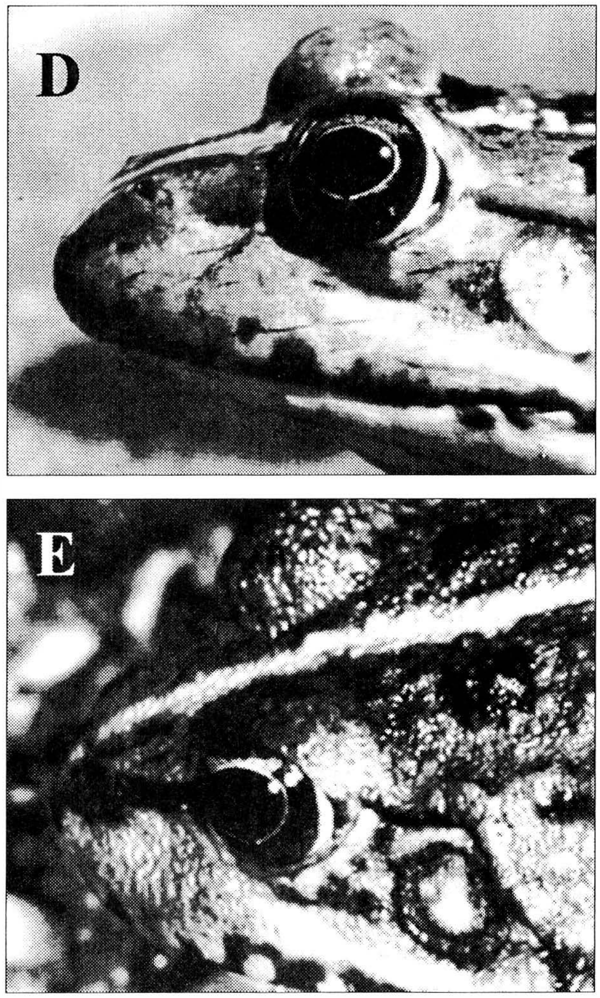


FIG. 3. Female water frog collected at Ulubey, Turkey (A-C), *Rana bedriagae* from Hadera, Israel (D) and *Rana ridibunda* from Valtos, Greece (E).

TABLE 3. Principal component analysis of the data set on 138 lake frogs from Turkey and 94 *Rana bedriagae* from Syria, Jordan, and Israel consisting of ten $\log_{10}$-transformed, standardized morphometric variables. The association (=component weights) of single variables to the three principal components representing a total of 93.9% of total variance is presented.

	PC 1	PC 2	PC 3
Eigenvalue	8.72	0.41	0.25
Variable:			
SVL	**0.332**	-0.084	0.093
CIL	**0.299**	0.127	**-0.822**
DPL	**0.308**	0.007	**-0.321**
FEMUR	**0.314**	**-0.357**	0.199
TIBIA	**0.332**	-0.034	0.093
FOOT	**0.323**	0.032	0.048
HEADeye	**0.327**	**-0.225**	0.112
HEADmax	**0.331**	0.010	0.022
SNOUT-EYE	**0.317**	-0.155	**0.256**
TYMP	**0.274**	**0.879**	**0.290**

TABLE 4. Significant discriminant functions based on ten $\log_{10}$-transformed morphometric variables to distinguish among water frogs from 12 localities in Turkey and *Rana bedriagae*. In (C) the values shown are actual (1st row) and predicted (2nd row) localities.

(A) *Statistical significance:*

Discriminant Function	Eigenvalue	Relative Percentage	Canonical Correlation	Wilks Lambda	χ^2	df	*P*
1	1.44	51.0	0.769	0.124	458.7	120	<<0.00001
2	0.59	20.9	0.610	0.302	262.7	99	<<0.00001
3	0.27	9.5	0.460	0.481	160.8	80	<<0.00001
4	0.17	5.9	0.378	0.610	108.6	63	0.0003
5	0.14	4.8	0.346	0.711	74.8	48	0.0080

(B) *Unstandardized coefficients of the discriminant functions:*

	Discriminant functions				
	1	2	3	4	5
SVL	12.18	22.52	-22.63	6.00	20.55
CIL	5.25	1.78	3.56	8.62	4.07
DPL	1.36	-15.72	-9.80	3.68	0.59
FEMUR	-16.36	13.07	-4.92	11.02	-11.75
TIBIA	-4.04	4.45	17.26	-51.13	28.07
FOOT	12.86	-20.03	3.03	18.37	0.60
HEADeye	-3.86	-9.64	-23.42	5.98	-3.90
HEADmax	13.67	3.13	42.03	-4.84	-25.33
SNOUT-EYE	-19.64	-13.13	-0.71	-10.48	-16.91
TYM	8.57	12.08	-11.43	4.43	-1.54
CONSTANT	-15.99	-6.71	8.46	19.44	-7.59

(C) *Classification success:*

	1	2	3	4	5	6	7	8	9	10	11	12	*R. bedriagae*
1	12	-	1	-	-	3	2	-	-	-	-	1	3
	(54.6%)		(4.6)			(13.6%)	(9.1%)					(4.6%)	(13.6%)
2	-	15	5	5	4	3	-	-	1	1	1	-	2
		(46.9%)		(15.6%)	(15.6%)	(12.5%)	(9.4%)			(3.1%)	(3.1%)	(3.1%)	(6.3%)
3	-	-	9	1	2	1	-	-	1	-	-	-	1
			(64.3%)	(7.1%)	(14.3%)	(7.1%)			(7.1%)				(7.1%)
4	-	3	2	3	1	-	-	-	-	-	-	-	-
		(33.3%)	(22.2%)	**(33.3%)**		(11.1%)							
5	-	-	-	-	5	-	-	-	-	-	-	-	1
					(83.3%)								(16.7%)
6	-	-	-	-	-	4	-	-	-	-	-	1	-
						(80.0%)						(20.0%)	
7	3	1	-	-	-	2	3	1	-	-	1	-	1
	(25.0%)	(8.3%)				(16.7%)	**(25.0%)**	(8.3%)			(8.3%)		(8.3%)
8	-	1	-	-	1	-	1	5	-	-	-	-	-
		(12.5%)			(12.5%)		(12.5%)	**(62.5%)**					
9	-	-	-	-	1	-	-	-	3	-	-	-	1
					(20.0%)				**(60.0%)**				(20.0%)
10	-	-	-	1	2	-	-	-	-	2	-	-	-
				(20.0%)	(40.0%)					**(40.0%)**			
11	-	1	-	-	-	-	-	-	-	-	15	-	-
		(6.3%)									**(93.8%)**		
12	-	-	-	1	1	-	-	-	-	-	-	2	-
				(25.0%)	(25.0%)							**(50.0%)**	
R. bedriagae	15	1	2	5	4	5	9	7	5	-	-	8	33
	(16.0%)	(1.1%)	(2.1%)	(5.3%)	(4.3%)	(5.3%)	(9.6%)	(7.5%)	(5.3%)			(8.5%)	**(35.1%)**

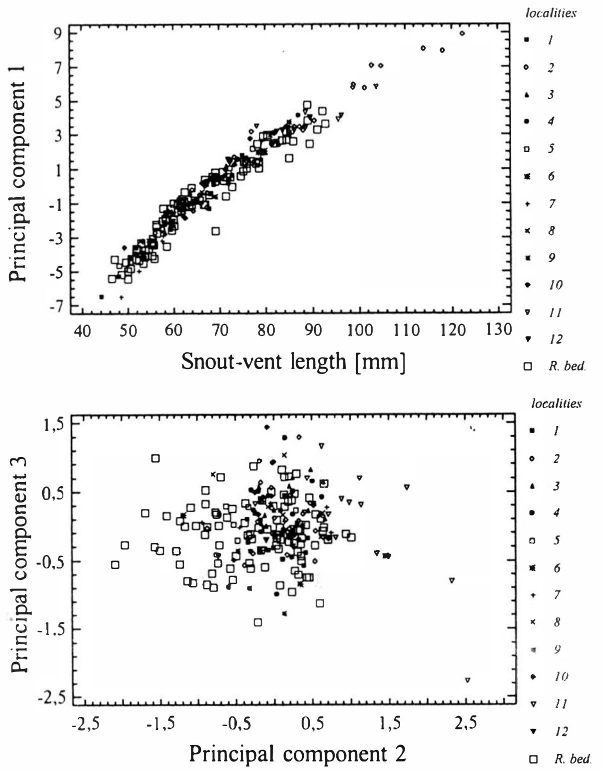


FIG. 4. Morphometric variation among the water frogs collected at 12 localities in Turkey and *Rana bedriagae* from Syria, Jordan and Israel. (A) Size-related variation; (B) Shape-related variation. Details on the principal component analysis are given in Table 3.

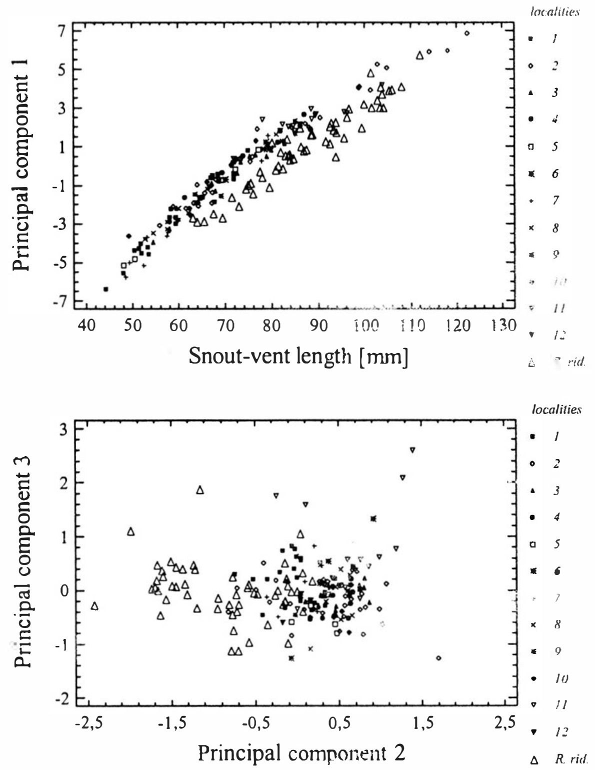


FIG. 6. Morphometric variation among the water frogs collected at 12 localities in Turkey and *Rana ridibunda* from Khazakstan, Armenia and Greece. (A) Size-related variation; (B) Shape-related variation. Details on the principal component analysis are given in Table 5.

TAXONOMIC IDENTIFICATION OF WATER FROGS IN TURKEY

Initially, we compared the features of the frogs from Turkey with those of *R. bedriagae* that inhabit Syria, Jordan, Israel and Egypt (Table 3). The size-related PC1 accounted for 87.2% of total variance of the pooled data set (Fig. 4A). The comparison of regression lines demonstrated that the relationship SVL/PC1 did not differ between the frogs from Turkey and *R. bedriagae* from outside Turkey (ANOVA: intercepts $P>0.05$; slopes $P>0.05$). The shape-related PC2 and PC3 (accounting for 4.1% and 2.5% of total variance, respectively) yielded a complete overlap of scores between *R. bedriagae* and all frogs from Turkey, except for those from Ulubey (Fig. 4B). Again, PC2 mainly represented tympanum features. Discriminant analysis yielded five significant discriminant functions (Table 4). The classification success of the individuals into their actual population again exceeded the rate of random assignment (7.69%) by 3.3-12.2 times, but decreased in most samples due to the presence of *R. bedriagae*, as the morphological variability of this large sample covered most of the variation range of populations in Turkey (Table 4C). The only notable exceptions to this rule were the frogs from Ulubey, which

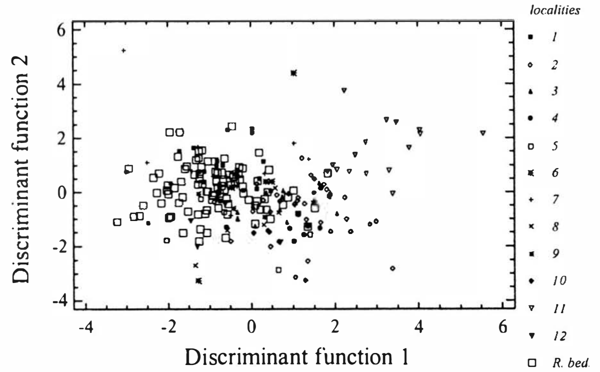


FIG. 5. Distinction among water frogs collected at 12 localities in Turkey and *Rana bedriagae* from Syria, Jordan and Israel by discriminant functions. Details on the discriminant analysis are given in Table 4.

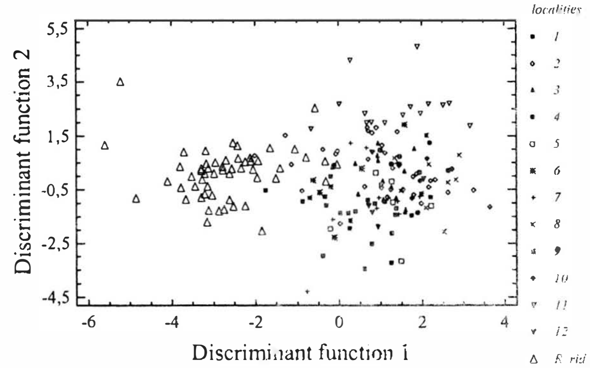


FIG. 7. Distinction among water frogs collected at 12 localities in Turkey and *Rana ridibunda* by discriminant functions. Details on the discriminant analysis are given in Table 6.

TABLE 5. Principal component analysis of the data set on 138 water frogs from Turkey and 55 *Rana ridibunda* from Kazakhstan, Armenia, and Greece consisting of eight log10-transformed, standardized morphometric variables (HEADeye and FOOT were not measured in Kazakhstan and Armenia). The association (=component weights) of single variables to the derived 3 principal components representing a total of 93.4% of total variance is presented.

	PC 1	PC 2	PC 3
Eigenvalue	6.64	0.54	0.30
Variable:			
SVL	**0.373**	-0.069	0.011
CIL	**0.345**	-0.003	-0.125
DPL	**0.305**	**0.718**	**-0.560**
FEMUR	**0.362**	**-0.353**	-0.005
TIBIA	**0.372**	-0.150	-0.021
HEADmax	**0.378**	0.017	0.014
SNOUT-EYE	**0.365**	-0.240	-0.129
TYMP	**0.323**	**0.455**	**0.809**

increased their classification success. While all other populations showed a remarkable degree of overlap with the scores of *R. bedriagae* - indicating conspecificity - the frogs from Ulubey were certainly distinct (Fig. 5). In contrast, the frogs of Lake Beyşehir appeared to be extraordinary large *R. bedriagae*.

In a second step, we compared the external morphology of the frogs from Turkey with those of *R. ridibunda* from Kazakhstan, Armenia and Greece (Table 5). PC1 accounted for 83.0% of total variance of the pooled data set (Fig. 6A). The comparison of regression lines demonstrated that the relationship SVL/PC1 significantly differed between the frogs from Turkey and *R. ridibunda* (ANOVA: intercepts $P<0.00001$; slopes $P>0.05$). The shape-related PC2 and PC3 (accounting for 6.7% and 3.7% of total variance, respectively) did not resolve clear differences, but the overlap area of scores was very small between the frogs from Turkey and *R. ridibunda* (Fig. 6B). Discriminant analysis yielded five significant discriminant functions and confirmed that none of the water frog samples from Turkey was assignable to *R. ridibunda* (Table 6, Fig. 7). Remarkably, scores of the frogs from Ulubey fell outside the range of both *R. ridibunda* and the other populations from Turkey.

DISCUSSION

The morphometric data obtained along a transect including 12 localities from the Mediterranean coast to the Black Sea coast clearly confirms that a large area of Turkey is inhabited by the Levantine frog *R. bedriagae*. As expected from previous studies, the water frogs inhabiting 11 out of the 12 localities were morphometrically indistinguishable from *R. bedriagae* collected at the type locality and further sites in Syria, Jordan and Israel. Bioacoustic and morphometric studies have already provided evidence that the assignment of the water frogs of the Mediterranean coast of Turkey to *R. ridibunda* is inappropriate, and should be changed to *R. bedriagae* (Joermann, Baran & Schneider, 1988; Schneider & Sinsch, 1992; 1999; Sinsch & Schneider, 1999). Recently, Jdeidi, Bilgin & Kence (2001) accepted this conclusion, although their multivariate study on the morphometry of water frogs from Turkey did not include reference populations of either *R. bedriagae* or *R. ridibunda* from outside Turkey. The convincing evidence from bioacoustics (Schneider & Sinsch, 1992, 1999), morphology (Sinsch & Schneider, 1999; this study) and allozymes (Beerli, Hotz & Uzzell, 1996) should finally eliminate the generalization that the water frogs in Turkey are *R. ridibunda*, and lead to a common acceptance of *R. bedriagae* as the predominating water frog species in this country.

The water frogs inhabiting the Lakes district including Lake Beyşehir (Arıkan, 1988; Atatür, Arıkan & Mermer, 1989/90; Arıkan, Özeti, Çevik & Tosunoğlu, 1994; Arıkan, Olgun, Çevik & Tok, 1998; Jdeidi, Bilgin & Kence, 2001; Budak, Tok & Ayaz, 2000) differ from the water frogs from all other sites studied in terms of maximum size (Table 7) and the striking orange colouration of the ventral skin (Schneider, 2001). These features were used by Arıkan (1988) to establish the subspecies *R. ridibunda caralitana*. Bioacoustic evidence (Schneider & Sinsch, 1999) and morphometrics (Sinsch & Schneider, 1999; this study) clearly demonstrate that species assignment has to be altered to *R. bedriagae*.

Do these frogs deserve their own taxonomic status? External coloration is very variable in water frogs, and this character alone would probably not justify subspecific status. The slight, but detectable morphometric divergence found in this study and also noticed by Jdeidi, Bilgin & Kence (2001) is basically the result of size effects in the discriminant analysis. Frogs from Lake Beyşehir with a SVL below 90 mm cannot be distinguished from *R. bedriagae*. Nevertheless, it remains unresolved whether the ability to grow to the observed large size is genetically fixed or reflects a phenotypic response to environmental conditions. The taxonomic implications of specific karyological features detected by Alpagut & Falakalı (1995) in these frogs are unclear. The haplotypes (mtDNA) of frogs collected in Alanya (typical *R. bedriagae* in external morphology) and in Beyşehir were so similar that Plötner *et al.* (2001) considered both forms as pertaining to the same taxon. In conclusion, evidence available so far may indicate an early stage of the speciation process, but it is a matter of discussion whether local differentiation has already progressed to a level which justifies an own taxonomic status. The suggestion of Jdeidi, Bilgin & Kence (2001) to assign species status is certainly not justified. However, if subspecific status is accepted, the Beyşehir frogs should be referred to as *R. bedriagae caralitana*.

The morphometric comparison of water frogs from Ulubey, in the district of Ordu (Black Sea coast), with *R. bedriagae* and *R. ridibunda,* yielded an unexpected

TABLE 6. Significant discriminant functions based on eight $\log_{10}$-transformed morphometric variables to distinguish among water frogs from 12 localities in Turkey and *Rana ridibunda*. In (C) the values shown are actual (1st row) and predicted (2nd row) localities.

(A) *Statistical significance:*

Discriminant Function	Eigenvalue	Relative Percentage	Canonical Correlation	Wilks Lambda	χ^2	df	*P*
1	3.25	64.9	0.875	0.058	517.1	96	<<0.00001
2	0.95	18.9	0.698	0.246	254.4	77	<<0.00001
3	0.34	6.8	0.503	0.479	133.4	60	<<0.00001
4	0.18	3.6	0.392	0.642	80.4	45	0.0009
5	0.13	2.7	0.344	0.759	50.2	32	0.0216

(B) *Unstandardized coefficients of the discriminant functions:*

	Discriminant functions				
	1	2	3	4	5
SVL	-38.34	19.23	-3.24	-22.25	26.16
CIL	6.73	6.77	3.35	1.94	10.21
DPL	10.15	-3.89	-7.63	-11.09	-0.38
FEMUR	-16.66	-19.69	18.58	-8.69	-17.39
TIBIA	22.78	12.32	-17.07	8.69	1.25
HEADmax	5.58	1.31	0.86	38.83	-9.90
SNOUT-EYE	-0.75	-14.35	-13.94	-1.20	-12.99
TYM	10.58	9.70	15.29	-10.46	-6.46
CONSTANT	30.38	-18.83	12.66	7.03	3.02

(C) *Classification success:*

	1	2	3	4	5	6	7	8	9	10	11	12	*R. ridibunda*
1	14 **(63.6%)**	-	-	-	2 (9.1%)	2 (9.1%)	2 (9.1%)	-	-	-	-	1 (4.6%)	1 (4.6%)
2	-	6 **(18.8%)**	5 (15.6%)	4 (12.5%)	3 (9.4%)	2 (6.3%)	4 (12.5%)	-	4 (12.5%)	1 (3.1%)	-	-	3 (9.4%)
3	1 (7.1%)	1 (7.1%)	7 **(64.3%)**	1	1 (7.1%)	1 (7.1%)	1 (7.1%)	- (7.1%)	1	- (7.1%)	-	-	-
4	-	1 (11.1%)	1 (11.1%)	4 **(44.4%)**	1	- (11.1%)	-	1	1 (11.1%)	- (11.1%)	-	-	-
5	1 (16.7%)	1 (16.7%)	-	-	3 **(50.0%)**	-	-	1	- (16.7%)	-	-	-	-
6	-	-	-	-	-	3 **(60.0%)**	-	-	-	-	-	-	-
7	3 (25.0%)	2 (16.7%)	-	1 (8.3%)	-	-	4 **(33.3%)**	1	1 (8.3%)	- (8.3%)	-	-	-
8	-	1 (12.5%)	-	-	1 (12.5%)	-	-	5 **(62.5%)**	-	1 (12.5%)	-	-	-
9	-	1 (20.0%)	-	-	1 (20.0%)	-	-	-	2 **(40.0%)**	-	-	1 (20.0%)	-
10	-	-	-	1 (20.0%)	-	-	-	1 (20.0%)	-	2 **(40.0%)**	-	1 (20.0%)	-
11	-	2 (12.5%)	-	-	-	-	-	-	-	-	14 **(87.5%)**	-	-
12	-	-	-	-	1 (25.0%)	-	-	1 (25.0%)	-	-	-	2 **(50.0%)**	-
R.ridibunda	1 (1.8%)	1 (1.8%)	-	-	-	3 (5.5%)	-	-	1 (1.8%)	1 (1.8%)	-	-	48 **(87.3%)**

TABLE 7. Distinctive morphological features of five water frog groups: *Rana bedriagae* (Turkey: localities 1, 3-9, 12), *R. bedriagae* (outside Turkey), *R. bedriagae* (caralitana, locality 2), *R. spec.* (locality 11), and *R. ridibunda* (outside Turkey). Data are given as sex-specific mean, corresponding standard error and range. P_{sex} denotes significance of difference between sexes; different letters indicate significant differences at the 0.05 level (Multiple range test with Bonferroni correction).

	Rana bedriagae						*R.* spec.		*R. ridibunda*	
	inside Turkey		outside Turkey		*caralitana*					
	males *n*=71	females *n*=19	males *n*=41	females *n*=53	males *n*=10	females *n*=21	males *n*=11	females *n*=5	males *n*=35	females *n*=20
SVL	65.2±1.3^{a}	71.6±2.2^{a}	62.3±1.3^{a}	69.1±1.9^{a}	77.4±5.0^{b}	82.4±4.4^{b}	83.9±1.0^{b}	95.0±2.7^{c}	83.5±1.6^{b}	95.2±2.9^{c}
[mm]	44.2-85.0	57.4-88.4	47.1-78.5	46.4-92.8	55.9-104.9	61.7-122.4	78.0-88.7	89.5-103.9	63.1-99.4	69.5-112.1
P_{sex}	0.0201		0.0061		>0.05		0.0003		0.0004	
Tympanum	5.7±0.1^{b}	6.2±0.2^{b}	5.3±0.1^{a}	5.7±0.1^{a}	6.5±0.3^{b}	6.8±0.3^{b}	8.4±0.4^{c}	8.2±0.4^{c}	6.0±0.1^{b}	6.4±0.2^{b}
[mm]	4.2-7.5	4.7-8.7	4.2-6.9	4.6-8.1	4.9-7.8	5.0-8.8	6.9-11.6	7.4-9.2	4.5-7.9	4.5-7.8
P_{sex}	>0.05		0.0105		>0.05		>0.05		>0.05	
Leg length/	1.54±0.01^{a}	1.48±0.02^{a}	1.54±0.01^{a}	1.52±0.01^{a}	1.51±0.01^{a}	1.52±0.02^{a}	1.49±0.02^{a}	1.39.2±0.03^{b}	1.48±0.01^{a}	1.44±0.01^{b}
SVL	1.26-1.80	1.33-1.62	1.34-1.70	1.25-1.69	1.38-1.62	1.43-1.70	1.41-1.61	1.27-1.45	1.42-1.53	1.41-1.52
P_{sex}	0.0052		>0.05		>0.05		0.0099		>0.05	
Tibia/femur	1.09±0.01^{a}	1.08±0.02^{a}	1.07±0.02^{a}	1.06±0.01^{a}	1.10±0.02^{a}	1.09±0.01^{a}	1.10±0.02^{a}	1.16±0.04^{a}	1.01±0.01^{b}	1.00±0.01^{b}
	0.80-1.30	0.93-1.21	0.91-1.26	0.88-1.26	0.96-1.16	1.01-1.15	1.02-1.16	1.04-1.26	0.85-1.13	0.90-1.09
P_{sex}	>0.05		>0.05		>0.05		>0.05		>0.05	
Callus/	0.30±0.01^{a}	0.31±0.02^{a}	0.30±0.01^{a}	0.31±0.01^{a}	0.31±0.02^{a}	0.29±0.01^{a}	0.34±0.02^{b}	0.36±0.03^{b}	0.37±0.01^{b}	0.36±0.01^{b}
1st finger	0.23-0.43	0.23-0.39	0.24-0.37	0.21-0.38	0.23-0.38	0.20-0.38	0.22-0.50	0.32-0.45	0.24-0.53	0.27-0.46
P_{sex}	>0.05		>0.05		>0.05		>0.05		>0.05	

result. As *R. ridibunda* inhabits Armenia (Schneider & Egiasarjan, 1989, 1991; Schneider & Sinsch, 1992; Sinsch & Schneider, 1999), it seemed reasonable to assume that the geographical range of these frogs also extends to Turkey, specifically to the Black Sea coast and thus to Ulubey. The geographical distance between Ulubey and Hankavan – the study site near Lake Sevan in Armenia – is about 570 km. Nevertheless, the multivariate analyses of morphometric data leaves no doubt that the water frogs collected at Ulubey are neither conspecific with *R. ridibunda* or *R. bedriagae*. They are easily distinguished from *R. bedriagae* and *R. ridibunda* by a larger tympanum diameter (Fig. 4, Table 7). There is also non-morphological evidence that water frogs from Ulubey are different from those of other regions in Turkey. In his comparative study on water frogs from Lake Beyşehir, Lake İznik (north-west Turkey), Malatya (eastern Anatolia) and Ulubey, Arıkan (1990) analysed features of external morphology and of blood cells. The Ulubey frogs differed from the other three samples studied (*R. bedriagae*) in the number of erythrocytes and leucocytes as well as with respect to DNA-content.

Taken alone, these observations seem to indicate that the water frogs from Ulubey represent a new taxon. However, considering that these frogs were collected in 1984 (by Yilmaz), one of us (H. Schneider) visited the village of Ulubey in May, 2001. No water frog was heard calling or captured during this visit. Thus, the present status of the water frog population near Ulubey is unclear; it may have gone extinct. Turna Suyu – about 30 km distant from Ulubey – was the nearest site at which water frogs were found during our visit. To our surprise, neither these frogs nor those from Kızılırmak at Bafra – about 220 km distant from Ulubey – morphometrically resembled those of the Ulubey sample, but were clearly conspecific with *R. bedriagae*. There are at least two alternative hypotheses to explain these contradictory observations: (1) the water frog population from Ulubey consisted of ordinary *R. bedriagae* which were altered in response to an unknown environmental impact (e.g. pesticides); (2) the Ulubey frogs represent a new taxon, more closely related to *R. bedriagae* than to *R. ridibunda*. If the second hypothesis is true, we would expect to find other frog populations in the region of Ordu which share the characteristics of the Ulubey frogs.

The most surprising result of our morphological survey is the fact that we were unable to establish the presence of *R. ridibunda* in Turkey. The same was true for a preliminary mtDNA-analysis of 10 frogs collected at six sites in Turkey (Plötner *et al*., 2001). The external morphology of all frogs strongly deviated from that of western *R. ridibunda* in Thrace (Greece) and eastern *R. ridibunda* in Armenia. However, a parallel bioacoustic survey (Schneider & Sinsch) which will be published in a separate paper, yielded different results. At several central and northern localities frogs morphometrically assigned to *R. bedriagae* gave advertisement calls assignable to *R. ridibunda*, whereas at southern and western localities morphometric and bioacoustic assignment coincided. Thus, the analysis of more than one character complex seems to be neccessary to fully appreciate the biogeography of the water frogs in Turkey and to propose a reliable taxonomic reassessment.

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APPENDIX 1

Geographical origin of specimens examined morphometrically. The numbers of the localities in Turkey refer to Fig. 1; details on the geographical locations of the reference populations of *R. bedriagae* and *R. ridibunda* are given in Sinsch & Schneider (1999). Institutional abbreviations are as follows: SMF, Senckenberg Museum Frankfurt; ZDEU, Zoology Department, Ege University; ZFMK, Zoologisches Forschungsinstitut und Museum Alexander Koenig, Bonn.

TURKEY

1. *Alanya* (Antalya). Sample 1: 5 males, 5 females, ZFMK 40192-40201, collected in April 1983. Sample 2: 1 male, 1 female, unpreserved, collected by H. Schneider in April 1994. Sample 3: 10 males, unpreserved, collected by H. Schneider in April 1996.
2. *Lake Beyşehir* (Konya, type locality of *R. ridibunda caralitana* Arıkan, 1988). Sample 1: 2 males, 10 females, ZDEU 2/982-1 to -12, collected by H. Arıkan in April 1981. Sample 2: 4 males, 4 females, ZDEU 8/982-1 to -8, collected by H. Arıkan in April 1982. Sample 3: 1 male, 1 female, unpreserved, collected by H. Schneider in April 1994. Sample 4: 2 males, 8 females, unpreserved, collected by H. Schneider in April 1996.
3. *Yakaköy*, 7 km northwest of Dinar (Afyon). Sample 1: 5 males, unpreserved, collected by H. Schneider in June 1998. Sample 2: 9 males, unpreserved, collected by H. Schneider in May 1999.
4. *Beydilli*, Lake Işıklı (Denizli). 2 males, 7 females, unpreserved, collected by H. Schneider in May 1999.
5. *Çayırpınar*, Lake Eber (Afyon). 6 males, unpreserved, collected by H. Schneider in June 1998.
6. *Çifteler* (Eskişehir). 4 males, 1 female, unpreserved, collected by H. Schneider in June 1998.
7. *Balçıkhisar*, ca. 30 km north of Çifteler (Eskişehir). 9 males, 3 females, unpreserved, collected by H. Schneider in May 1999.
8. *Çakırca*, Lake İznik (Bursa). Sample 1: 1 male, unpreserved, collected by H. Schneider in June 1998. Sample 2: 7 males, unpreserved, collected by H. Schneider in May 1999.
9. *Karasu* (Adapazarı). 5 males, unpreserved, collected by H. Schneider in June 1998.
10. *Kızılırmak* at Bafra (Samsun). 3 males, 1 female, 1 juvenile, unpreserved, collected by H. Schneider in May 2001.
11. *Ulubey* (Ordu). Small pond at the entrance to the village. 11 males, 5 females, ZDEU 2/984-1 to 16, collected by İ. Yılmaz in April 1984.
12. *Turna Suyu* (Ordu). 4 males, unpreserved, collected by H. Schneider in May 2001.

1. REFERENCE POPULATIONS OF *RANA BEDRIAGAE*:

Syria:

Jebel el Ansariye. 1 male, 3 females, ZFMK 60901-6904.

Ar Raqqah. 1 male, 3 females, SMF 75349-75352, collected by H. Martens

Nahr al-Habur. 4 males, 2 females, SMF 73715-73717, 73721, 73723-73724, collected by H. Martens in October 1988.

Abu Kemal, Euphrates River. 4 males, ZFMK 61785-61788.

Bahrat Khatuniyah. 1 male, 3 females, SMF 75467-75470, collected by H. Martens.

Barada River, surroundings of Damascus (type locality of *R. bedriagae*). 1st sample: 1 male, SMF 5900, collected by H. Simon 1882; 2nd sample: 4 males, 2 females, SMF 75688-75689, 75693-75696, 75699, collected by H. Martens.

Quanwat, Jebel Al-Arab. 2 males, 3 females, SMF 75610-75613, collected by H. Martens

Mzeirib. 4 males, 8 females, SMF 75644-75655, collected by H. Martens.

Jordan:

Zarqa. 4 males, 2 females, SMF 76454-76459.

Wadi Wala. 6 females, SMF 76469-76474.

Israel:

Birket Ata, Hadera. 4 males, 5 females, ZFMK 52836-52844, collected by E. Nevo in 1992.

Jericho. 11 males, 17 females, ZFMK 52836-52844 and unpreserved, collected by E. Nevo in 1992.

2. REFERENCE POPULATIONS OF *RANA RIDIBUNDA*:

Kazakhstan:

Atyrau, formerly Guryev (type locality of *R. ridibunda*). 2 males, 2 females, unpreserved, collected by H. Schneider and E. M. Egiasarjan in May 1990.

Armenia:

Hankavan. 19 males, 11 females, unpreserved, collected by H. Schneider and E. M. Egiasarjan in May 1990.

Greece:

Ardas, Thrace. 2 males, 1 female, unpreserved, collected by T. S. Sofianidou in March 1990.

Valtos, Thrace. 12 males, 6 females, unpreserved, collected by T. S. Sofianidou in March 1990.