Acta Theriologica 44 (2): 113–122.
PL ISSN 0001–7051

The *Sorex araneus* group in the northern Iberian System (Spain): a contact zone between *S. coronatus* and *S. granarius*?

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López-Fuster M. J., Ventura J., García-Perea R. and Gisbert J. 1999. The *Sorex araneus* group in the northern Iberian System (Spain): a contact zone between *S. coronatus* and *S. granarius*? Acta Theriologica 44: 113–122.

Available information on the distribution of the European species of the *Sorex araneus* group in the Iberian Peninsula suggests that the Iberian System (north-central Spain) might be a sympatric area between *S. coronatus* Millet, 1828 and *S. granarius* Miller, 1910. With the aim to assess this hypothesis, multivariate analyses based on 16 skull and mandible parameters were carried out on 78 shrews from the Iberian System. A preliminary specific determination was performed on 57 specimens using a discriminant function established in a previous study. Two further discriminant functions based on skull and mandible variables respectively were constructed from the sample analysed and both provided an identical classification of the specimens, although slightly different from that of the preliminary determination. In order to summarize the morphometric interspecific relationships a principal components analysis was performed. Results obtained confirm the presence of *S. coronatus* and strongly suggest that of *S. granarius* and of a contact zone between both species in the Iberian System. In this area both species share the same general habitats, occupying oro- and supramediterranean bioclimatic levels. Taking into account the distributional pattern reported for *S. araneus* and *S. coronatus* in sympatric areas, and considering the convergence in size observed between *S. granarius* and *S. coronatus* in the Iberian System, we suggest that in this contact zone both species might have a parapatric distribution, due most probably to microhabitat segregation.

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Key words: *Sorex coronatus*, *Sorex granarius*, morphometrics, Iberian System, Spain

Introduction

Since the establishment of *Sorex coronatus* Millet, 1828 as a sibling species of *S. araneus* (Meylan 1964, Ott 1968, Meylan and Hausser 1978), and the raising of *S. granarius* Miller, 1910 to the species rank (Hausser *et al.* 1975), many studies have sought to clarify the distribution and ecological requirements of these three shrews, which constitute the European members of the *S. araneus* group (Hausser *et al.* 1985). According to available data, the distribution of the three species in the Iberian Peninsula can be outlined as follows: the common shrew, *S. araneus,* is restricted to the eastern Pyrenees and Catalan Pre-Pyrenees, the Millet's shrew, *S. coronatus,* extends from the Pyrenees to Galicia in the West, and the Iberian shrew, *S. granarius,* stretches from the Central System to the mouth of the Tajo river and northwards to Galicia (see López-Fuster and Ventura 1996, and references therein). The Iberian System, a zone of great biogeographical interest, is located in north--central Spain (Fig. 1) and emerged between the sedimentary basins of the Ebro and Duero rivers, constituting a transitional montane zone between the Cantabrian mountains in the North, and the Central System, in the South. It has acted both as a barrier and as a bridge to potential migrations resulting from climatic changes during glaciar and interglaciar periods (Lagos 1990). In the Iberian System, published data are scarce but seem to suggest that this area constitutes a contact zone between *S. granarius* and *S. coronatus*. Thus, Garzón-Heydt *et al.* (1971) mention the presence of *S. araneus pyrenaicus* (read *S. araneus* group) in the Sierras of Demanda and Cebollera, Hausser (1990a, b) reports *S. coronatus* and *S. granarius* in Barbadillo del Pez (province of Burgos), and more recently Meijide Calvo *et al.* (1996) attribute specimens from the province of Soria, which includes part of the Iberian System, to *S. coronatus*. In these studies specimens were classified by means of morphological characters. Nevertheless, the only unequivocal manner of identifying these *Sorex* species is by genetic methods and, therefore, the specific membership of these forms in the Iberian System has not been demonstrated faithfully.

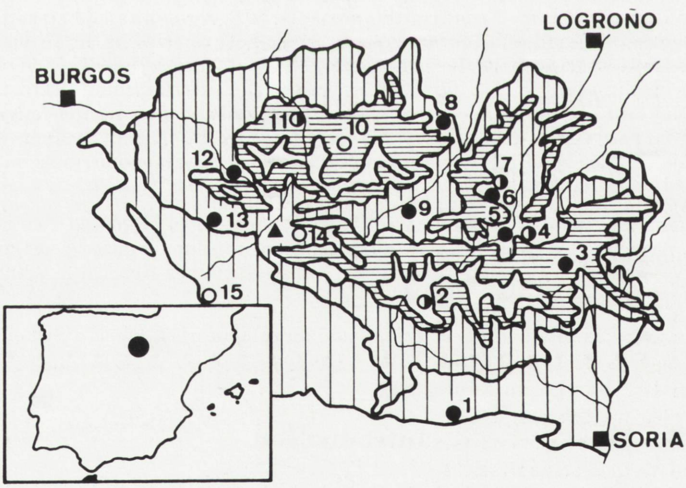

Fig. 1. Location and distribution of *Sorex coronatus* (●) and *S. granarius* (○) in the Iberian System. (◑): potential contact zones according to this study. (▲): a potential contact zone in Barbadillo del Pez, according to Hausser (1990a, b). Numbers correspond to locations listed in Table 1. Striped areas: supramediterranean level (sparce vertical lines: dry oak forest; dense vertical lines: wet oak forest; horizontal lines: beech forest); white areas: oromediterranean level (juniper trees).

In the absence of biochemical, karyological, and mitochondrial DNA data, multivariate analysis of cranial characters can provide a good approach to the identification of the European species of the *Sorex araneus* group (eg Hausser and Jammot 1974, Loch 1977, Hausser 1984, Mys *et al.* 1985, Turni and Müller 1996). In this paper we present new data on the distribution of *S. coronatus* and *S. granarius* in the northern Iberian System, based on discriminant and principal components analyses using skull and mandible variables. Additionally, karyological analysis was performed on one specimen.

Material and methods

The sample analysed consisted of 78 shrews from the Iberian System, belonging to the European group of *Sorex araneus*. Most specimens ($n = 76$) are kept in the collections of the Estación Biológica de Doñana (Seville) and the Museo Nacional de Ciencias Naturales (Madrid), and correspond to samples collected in 14 locations between 1969 and 1980. Two additional specimens, captured in Viniegra de Abajo (province of Logroño) in 1995, are deposited in the Department of Animal Biology (University of Barcelona). The geographic location of the sites is shown in Fig. 1. The following variables were measured with a digital caliper to 0.01 mm: TCL – total cranium length, CBL – condylo-basal length, RL – rostral length, SCL – skull case length, SBL – staphylion-basion length, UDS – length of upper dental series, P^4-M^3 – P^4-M^3 length, IOW – interorbital width, ZW – zygomatic width, PGW – postglenoid width, IAL – incisor-angle length, ML – mandibular length, AL – articular length of the mandible, LDS – length of lower dental series, M_1-M_3 – M_1-M_3 length, CH – coronoid height (Fig. 2).

Taking into account the geographical distribution of the European species of the *S. araneus* group in the Iberian Peninsula (cf López-Fuster and Ventura 1996), the specimens analysed could be assigned to either *S. coronatus* or *S. granarius*. Since no intersexual difference in the cranial parameters has been detected in either of the two species (Mys *et al.* 1985, and own data) and shrews do not grow significantly after leaving the nest (Pucek 1970, Vogel 1972), sex and age were not considered in the statistical analyses. A preliminary specific determination was conducted on 57 specimens (values were missing in 14 specimens), applying a discriminant function constructed from Iberian specimens, representing much of the distribution range of both species, and based on three mandibular parameters

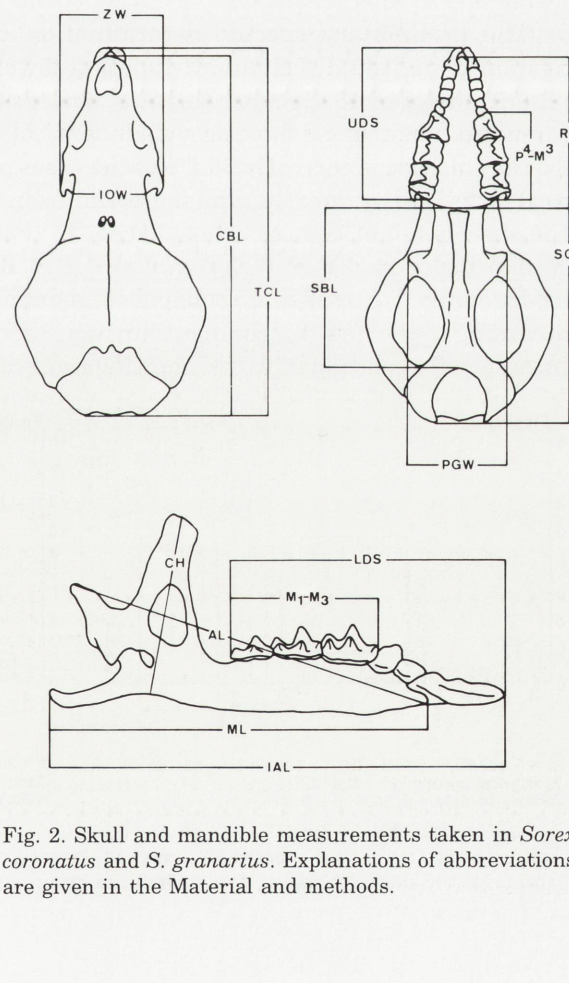

Fig. 2. Skull and mandible measurements taken in *Sorex coronatus* and *S. granarius*. Explanations of abbreviations are given in the Material and methods.

(López-Fuster and Ventura 1996). Since this function includes one dental measurement (LDS), animals with noticeable tooth-wear (n = 7) were excluded from the analysis. In addition, the morphology of the skull (cf Miller 1912, Hausser *et al.* 1975) and certain dental features (cf Dannelid 1989) were examined. Moreover, one of the two specimens from Viniegra de Abajo was identified by chromosome analysis. The shrew was karyotyped by synchronized cell cultures from tail fibroblasts. G-banded mitotic preparations were obtained by Seabright's modified trypsin technique (1971).

Since the Iberian System might be a contact zone between *S. coronatus* and *S. granarius*, and morphometric differentiation between both species in sympatric areas is quite difficult (Hausser 1984, López-Fuster and Ventura 1996), new discriminant analyses were performed to confirm the specific membership of the specimens classified previously. After fitting several models (stepwise and direct methods) two new discriminant functions were obtained by stepwise procedure, based on either skull or mandible variables. In addition, these analyses allowed us to classify those animals which could not be included in the specific determination and those with missing data for any predictor variable as we replaced the missing value with the corresponding variable mean. Phenetic affinities among individuals were assessed by principal components analysis (PCA) on the correlation matrix of standardized data. Interspecific differences for each character were tested by Student's t-test. Statistical analyses were performed using the SPSS programs (Norusis 1995).

Results

The preliminary specific determination of 57 individuals from the Iberian System using the discriminant function developed by López-Fuster and Ventura (1996) classified 43 specimens as *S. coronatus* and 14 as *S. granarius*. The two new functions constructed here provided identical classifications of the specimens (Fig. 3): they classified correctly 96.5% of the cases previously grouped, reassigned two *S. coronatus* to *S. granarius*, and increased from 2 to 4 the number of locations where the species might coexist. Thus, except in these 4 sites (Table 1, Fig. 1), either *S. coronatus* (n = 8) or *S. granarius* (n = 3) were present in most locations. Additionally, we applied a principal components analysis to the specimens grouped according to the new discriminant functions in order to summarize the morphometric interspecific relationships by identification of several orthogonal components. In

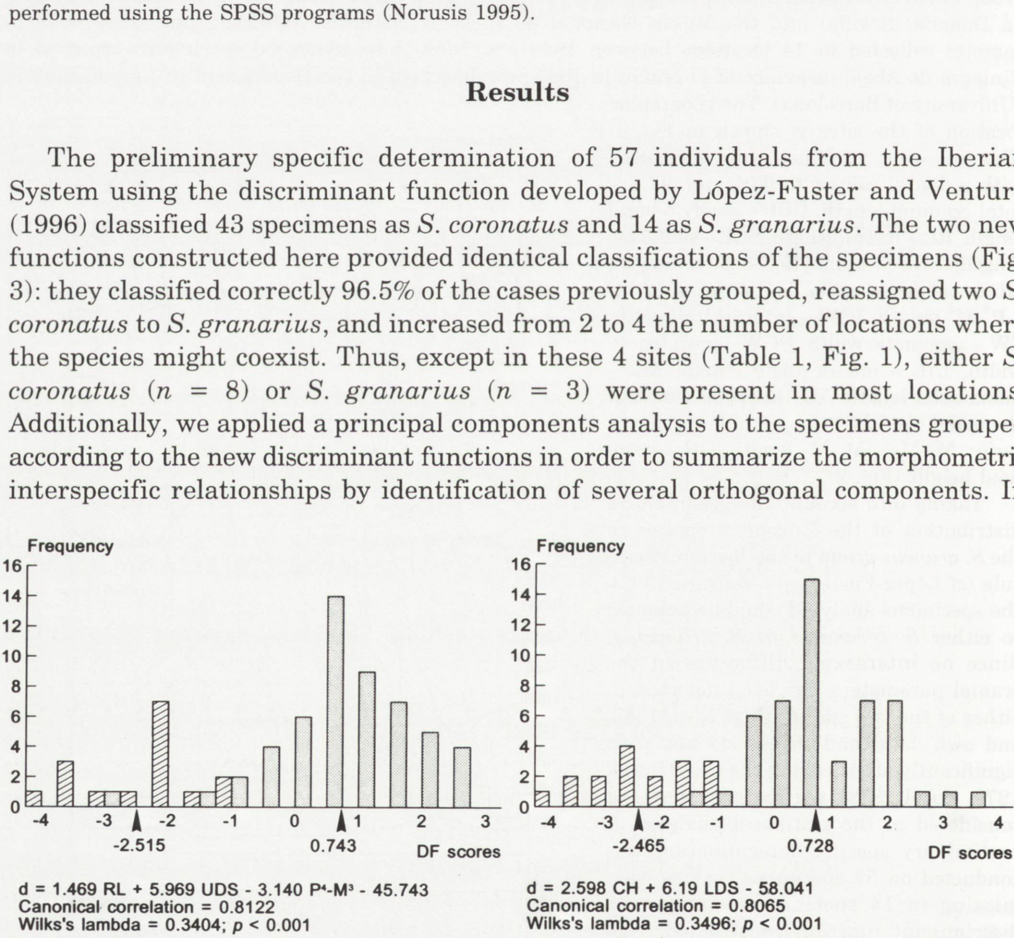

Fig. 3. Histograms of the discriminant scores of *Sorex coronatus* (dotted bars) and *S. granarius* (striped bars) from the Iberian System. Arrows indicate group means.

Table 1. Specific identity of specimens studied from each location, classified according to the discriminant functions. *S.c.* – *Sorex coronatus*, *S.g.* – *S. granarius*. Asterisk indicates the specimen determined karyologically. Location numbers correspond to Fig. 1. Altitude in meters above see level.

No.	Location	*S.c.*/*S.g.*	Altitude
1	Abejar	3/0	1138
2	Laguna Negra	4/2	1740
3	Puerto Piqueras	1/0	1710
4	Lumbreras	7/1	1183
5	Villoslada	6/0	1071
6	Ortigosa	1/0	1069
7	El Rasillo	23/4	1101
8	Tobía	1/0	680
9	Viniegra de Abajo	2*/0	881
10	Rio Oja, Demanda	0/1	1000
11	Fresneda de la Sierra	1/1	989
12	Pineda de la Sierra	1/0	1211
13	San Millán	2/0	1068
14	Huerta de Abajo	0/1	1100
15	Carazo	0/9	1133

conducting the analysis, variables concentrating considerable amounts of missing data (TCL, CBL, SCL, SBL) were removed, after verifying that this procedure was not critical to the analysis. Three unrotated principal components with eigenvalues greater than 1 were extracted, which accounted for 71.5% of the total morphometric variance (Table 2). The first factor (PC I) was positively and significantly correlated ($p < 0.001$) with all cranial dimensions and therefore it was used as an indicator of skull size; the second (PC II) and third (PC III) factors were highly and positively correlated with PGW ($p < 0.02$) and IOW ($p < 0.001$) respectively. Projection of the principal components scores for the first three axes (Fig. 4) showed a reasonably good separation between both species, with positive scores on PC I for the specimens attributed to *S. coronatus* and negative scores for those assigned to *S. granarius;* conversely, factor scores for PC II and PC III overlapped between both species and did not contribute substantially to the interspecific separation. The pattern of ordination of the specimens in the factor space agreed on the whole with the results obtained by the discriminant analyses, so that bivariate plots of PC I and both skull and mandible discriminant scores provided a complete separation between *S. coronatus* and *S. granarius* in the area studied (Fig. 5). Considering the interspecific discrimination obtained by the multivariate analyses as being realistic, basic descriptive statistics for both species in the area studied were calculated (Appendix I). Differences between mean values were statistically significant for all

Table 2. Character loadings on the first three principal components.

Variable	Principal components I	II	III	Communality
RL	0.857	-0.104	-0.118	0.759
UDS	0.786	-0.280	-0.335	0.883
P^4-M^3	0.747	-0.164	-0.190	0.621
IOW	0.431	0.020	0.618	0.567
ZW	0.595	0.414	-0.080	0.531
PGW	0.475	0.673	-0.295	0.765
IAL	0.858	-0.204	-0.030	0.778
ML	0.823	0.006	0.292	0.763
AL	0.777	0.178	0.345	0.755
LDS	0.786	-0.280	-0.335	0.809
M_1-M_3	0.732	-0.352	0.222	0.709
CH	0.672	0.425	0.093	0.641
Eigenvalue	6.434	1.144	1.005	
Variance explained	53.6%	9.5%	8.4%	

characters ($p<0.001$; SBL: $p<0.003$), except for IOW. When statistical comparisons with the nearest populations of *S. coronatus* (Navarre and Basque Country; López--Fuster 1983, López-Fuster and Ventura 1987) and *S. granarius* (Guadarrama, Central System; Gisbert *et al.* 1988) were possible, results revealed that, in general terms, the mean values obtained for the specimens of the Iberian System were significantly smaller for the former species (12 out of 14 skull and mandible variables showed significant differences: TCL, CBL, SCL, UDS, P^4-M^3, IOW, ZW, IAL, AL, LDS, M_1-M_3, CH; $p < 0.01$) and slightly larger for the latter (significant differences in two out of the six mandibular parameters: IAL, LDS: $p < 0.05$).

The karyotype of one male from Viniegra de Abajo consisted of 23 chromosomes (2Na = 20; NFa = 40), corresponding to *S. coronatus* (see eg Hausser *et al.* 1985). This specimen was also assigned to *S. coronatus* by multivariate analyses.

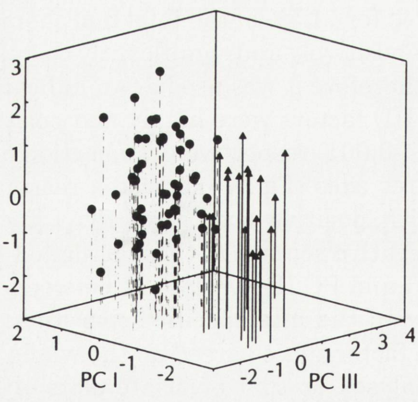

Fig. 4. Three-dimensional scatter diagram of the individual scores onto the first three principal components axes (PC). Predicted group: (●) *Sorex coronatus*; (▲) *S. granarius*.

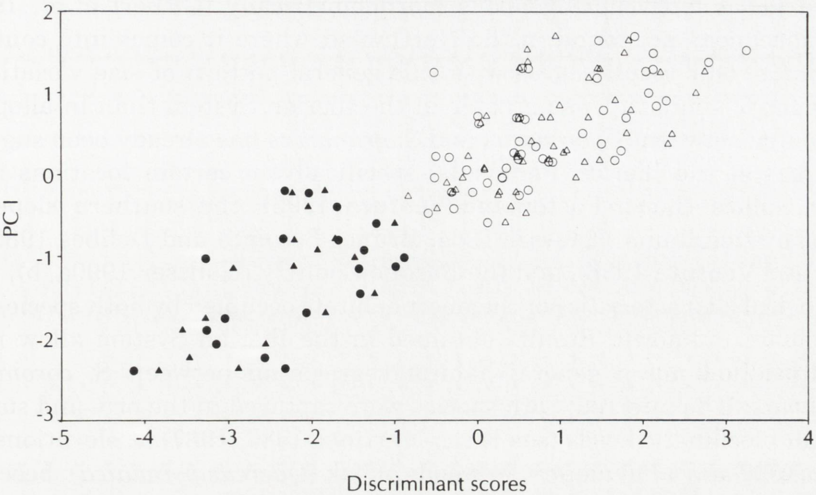

Fig. 5. Bivariate plot of the first principal components scores (PCI) and the skull (triangles) and mandible (circles) discriminant scores. Open symbols: *Sorex coronatus*; filled symbols: *S. granarius*.

Discussion

Chromosomal analysis allows us to confirm, for the first time, the presence of *S. coronatus* in the Iberian System. Moreover, while the specific determination of the specimens obtained by applying multivariate methods to morphometric characters can only be considered as being hypothetical, we also tentatively conclude the occurrence of *S. granarius* and of a contact zone between the two species in the Iberian System. These results are consistent with the findings of Hausser (1990a, b) and Hausser *et al.* (1985), which suggest the existence of a sympatric area between both species in north-central Spain. Nevertheless, no discussion on this subject is provided by these authors. An evaluation of the morphological characteristics of the cranium (see Miller 1912, Hausser *et al.* 1975) and dentition (see Dannelid 1989), which have been identified as differential for both species, fit quite well with the results obtained by multivariate methods, although the specific determination cannot be achieved using these morphological traits alone.

Since morphometric differences between the European species of the *Sorex araneus* group are, in the first place, a function of eco-geographical conditions (Hausser *et al.* 1985), a convergence in size in sympatric areas is to be expected. In this way, a clinal size variation has been demostrated for *S. coronatus* in Spain (Nores 1979, Hausser 1984, López-Fuster and Ventura 1987): the species becomes smaller from East to West, so when it meets the large-sized *S. araneus* and the small-sized *S. granarius*, respectively, they are similar in size. Likewise, although

S. granarius is fairly homogeneous morphometrically (Gisbert *et al.* 1988), the largest specimens are found in the Northwest, where it comes into contact with *S. coronatus*. Our results agree with this general pattern of size variation, since morphometric similarity was greater in the Iberian System than in allopatry.

Sympatry between *S. coronatus* and *S. granarius* has already been suggested in other areas of the Iberian Peninsula, specifically in certain locations in north-western Galicia (López-Fuster and Ventura 1996), the southern slopes of the Cantabrian mountains (Hausser 1984, Brunet-Lecomte and Delibes 1988, López--Fuster and Ventura 1996), and the Basque Country (Hausser 1990a, b), although the ecological characteristics of the microhabitats occupied by both species in these areas remain unknown. Results obtained in the Iberian System allow neither a clear altitudinal nor a general habitat segregation between *S. coronatus* and *S. granarius* to be inferred: both species were captured in the oro- and supramediterranean bioclimatic levels (see Rivas-Martínez 1983, 1987) at elevations ranging between 1000 and 1740 meters, in woods of oak (*Quercus pyrenaica*), beech (*Fagus sylvatica*) or juniper (*Juniperus nana*). Although *S. granarius* was not trapped in sites below 1000 meters or in groves of gall-oaks (*Quercus faginea*), the presence of the species in this zone cannot be discarded. In fact, in the Central System, where the closest populations of this species are found, the Iberian shrew is located at altitudes between 500 and 2000 meters, occupying also the supra- and the oromediterranean bioclimatic levels (see Gisbert *et al.* 1988). Thus, the geoclimatic characteristics of the sites occupied by both shrews in the Iberian System are quite similar, suggesting that they share the same habitats. If, according to Hausser (1984), the morphological differences between *Sorex* species that share the same ecological niche are related to adaptation to local differences, a segregation in the microhabitats occupied by *S. coronatus* and *S. granarius* in the Iberian System might be expected, which would permit their local coexistence in this contact zone. In fact, Neet and Hausser (1990) present evidence that in sites where both *S. araneus* and *S. coronatus* appear, there is a partitioning of the available microhabitat, so that *S. araneus* selects colder and more humid habitats with thicker litter cover than does *S. coronatus*. It has been suggested that this habitat segregation appears as a response to the presence of the competitor and is maintaned by interspecific territoriality (eg Neet 1989, Neet and Hausser 1990, Rossier *et al.* 1992). Although a similar parapatric distribution between *S. coronatus* and *S. granarius* in the Iberian System may be assumed, further studies of the characteristics of the microhabitats inhabited by these shrews are needed to validate this hypothesis.

Acknowledgements: We thank J. Barreiro (Museo Nacional de Ciencias Naturales, Madrid) and J. Cabot (Estación Biológica de Doñana, Seville) for granting us access to the collections under their care. We are also grateful to Dr J. Navlet (Universidad de Alcalá de Henares) for karyotyping a shrew, R. Fernández and R. A. Baquero (Madrid) for their assistance in the field, L. de Ambrosio (Madrid) for helping with figure 1, and R. Rycroft (SAL, Barcelona) for improving the English text. We also thank two anonymous referees for their comments and criticisms on an earlier draft of the manuscript.

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Received 7 November 1997, accepted 28 October 1998.

Appendix I. Basic descriptive statistics of *Sorex coronatus* and *S. granarius* in the Iberian System.

Variable	*S. coronatus*					*S. granarius*				
	n	$\bar{x}$	SD	Min	Max	*n*	$\bar{x}$	SD	Min	Max
TCL	37	19.04	0.28	18.26	19.55	12	17.98	0.45	17.32	18.56
CBL	36	18.23	0.34	17.60	18.93	12	17.43	0.49	16.57	18.02
RL	50	8.16	0.15	7.83	8.60	18	7.74	0.15	7.48	8.05
SCL	36	10.53	0.17	9.92	10.81	11	10.04	0.30	9.41	10.39
SBL	38	8.45	0.20	8.10	8.83	11	8.20	0.30	7.61	8.70
UDS	50	8.17	0.15	7.80	8.50	18	7.65	0.15	7.40	7.89
P^4-M^3	50	4.51	0.12	4.16	4.97	18	4.34	0.12	4.13	4.57
IOW	45	3.65	0.13	3.40	3.90	15	3.59	0.14	3.37	3.81
ZW	43	5.31	0.16	5.01	5.64	13	5.00	0.21	4.72	5.38
PGW	40	5.32	0.13	5.06	5.58	14	5.15	0.14	4.89	5.44
IAL	45	12.07	0.22	11.61	12.53	15	11.54	0.23	11.19	11.91
ML	45	9.69	0.17	9.35	10.04	15	9.40	0.24	8.97	9.85
AL	51	9.46	0.18	9.13	9.80	19	9.19	0.23	8.70	9.57
LDS	48	7.62	0.14	7.35	7.96	19	7.21	0.14	6.93	7.41
M_1-M_3	50	3.69	0.08	3.50	3.82	19	3.61	0.10	3.47	3.84
CH	51	4.51	0.13	4.16	4.81	19	4.34	0.14	4.07	4.60