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Presence and ecological distribution of *Mus "spretoides"*[1] and *Mus musculus domesticus* in Israel
Circum-Mediterranean vicariance in the genus *Mus*

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Abstract

Described the presence of *Mus "spretoides"* in Israel by morphometric and biochemical analyses. 792 specimens of *Mus* are morphologically studied. These animals were live-trapped or came from museums or owl pellets from all over Israel. By then, distributions of both *Mus "spretoides"* and *Mus musculus domesticus* were established: *Mus "spretoides"* ranges in strictly Mediterranean environments while *Mus musculus domesticus* occurs also in semi-arid environments. Partly competitive exclusions of *Mus "spretoides"* from human dwellings and of *Mus musculus domesticus* from natural environments appear in sympatric area.

The typical Mediterranean range and ecology of *Mus "spretoides"* allows to demonstrate a clear vicariance around the Mediterranean Sea between this eastern species and *Mus spretus* which occurs in the western part of the Mediterranean Basin.

Introduction

Biochemical genetics allows for the recognition of four species of mice in Europe (Bonhomme et al. 1978, 1983; Thaler et al. 1981). Likewise it allows for the establishment of discriminative interspecific morphological criteria in the genus *Mus* on the basis of biochemically discriminated material (Darviche and Orsini 1982; Orsini et al. 1983). Thus, the boundaries of the European species have been established, as well as, their ecological features and distributions.

In Israel, only the house mouse *Mus musculus domesticus* (sensu Thaler et al. 1981) has been described until now (Harrison 1972). The house mouse is common in all areas around the Mediterranean Sea. In this species, the great length of the tail, relative to the length of the body and head as compared to other European species of mice, makes it easy to recognize in the field.

In this study, we report the finding of a short-tailed mouse in Israel which demonstrates the presence of two sympatric species in this part of the Mediterranean Basin. The present study provides original data on the presence and on the range of *Mus "spretoides"* in Israel, the ecological features of the distribution of the two partly sympatric species of mice and the micro ecological partition of the habitat between them.

[1] The oriental Mediterranean mouse has been described under various names. Due to the absence in the international nomenclature of a clear definition of this species (see taxonomy section of the present paper), authors use *Mus "spretoides"* for commodity throughout this paper.

Material and methods

Material

Apart from the few animals which were live trapped (N = 27), we also studied 242 specimens from all over Israel (deposited at Tel Aviv University Museum and the Hebrew University Museum in Jerusalem). In addition, we analyzed the proportion of both mice (523 mice) in owl pellets involving 12 localities.

Inter-species discrimination

Biochemical study: The trapped animals were dissected and their organs (plasma, hemolysate, kidney, liver, heart) stored at −80 °C. They were subsequently submitted to standard routine protein electrophoresis procedure as described in Pasteur et al. (1987).

Morphological study: The inter-specific discrimination is based on the method of Orsini et al. (1983). Briefly, the recognition of the species is based on:

1. The index of head plus body length/tail length (HB/T) measured on live animals. This measurement is perfectly discriminative between both species and allows for recognition by sight with a little training.
2. The zygomatic index on skulls (ZI: Width of Malar process anterior part/width of Zygomatic arch upper part, Fig. 1). ZI appears to be the best discriminatory parameter among those given by Orsini et al. (1983).

These authors developed this method for Greek and Bulgarian material. Israeli material is first analysed for these two parameters.

Micro-ecological studies

A correspondence analysis, as described by Benzecri et al. (1976) was performed, comparing the proportion of both species in raptor pellets, collected from sites that varied in environmental features.

The proportion of mice for the pellet collections of each location has been calculated from the ZI distribution. The ZI distributions of both species show a small overlap. The average of the two species distribution means was calculated: all the material presenting a ZI above this average was classified as *Mus "spretoides"* and all below as *Mus musculus domesticus*.

We have established 5 categories of specific proportions of the two mice within owls pellets collections as summarized in Table 1.

The correspondence analysis was performed on these categories (each site collection is treated itself as an unactive individual), using the environmental features of the pellet locations as variables. The owl *(Tyto alba)* possesses a small hunting area of 4 km^2 around the nest (Libois 1984). The general features of the environment of the raptors hunting areas is determined by the presence (or lack thereof) of human dwellings (Variable H), agricultural field (A) and natural environment which is unexploited by man (U), and by the location of the hunting area in Mediterranean climatic zone (M) and in the zone of mice sympatry (S).

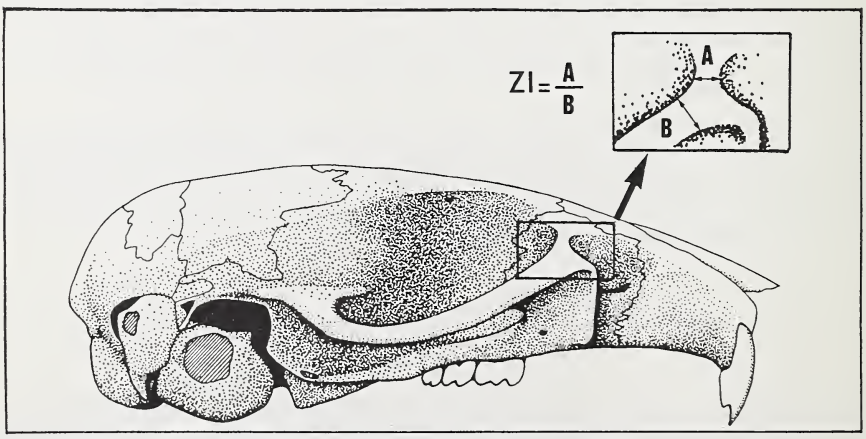

Fig. 1. ZI parameter

Results

Biochemical discrimination

14 individuals could clearly be identified as *Mus "spretoides"* whereas remaining 13 others were to be assigned to *Mus musculus domesticus* without ambiguity according to the diagnostic locus (Car: Carbonic anhydrase) already described for Eastern European mice (Bonhomme et al. 1983). The Israeli samples of the two species were not significantly differing from other Eastern European conspecific populations from a genetical standpoint.

Table 1. **Established categories of specific proportions of *Mus "spretoides"* and *Mus musculus domesticus* within owls pellets collections**

Category	Proportions of *Mus musculus domesticus*	Proportions of *Mus "spretoides"*
V1	0–20 %	80–100 %
V2	20–40 %	60–80 %
V3	40–60 %	40–60 %
V4	60–80 %	20–40 %
V5	80–100 %	0–20 %

Morphological discrimination

For the HB/T index, only entire animals (trapped ones) could be used. In spite of the small sample size, it is possible to see that discrimination is feasible by this parameter (Table 2). The divergence between European *Mus "spretoides"* described by Orsini et al. (1983) and Israeli one for this parameter comes essentially from the lengthening of the tail in Israeli material (mean 62.1 mm vs 54.4 mm in Europe; $t = 4.42$, $df = 42$, $p < 0.01$).

Table 2. **Values of discriminatory parameters, H + B/T and ZI, for *Mus musculus domesticus* and *Mus "spretoides"***

		Greece Bulgaria*			Israel		
		n	$\bar{x}$	σ	n	$\bar{x}$	σ
H + B/T	*M. "spretoides"*	35	1.49	.10	14	1.28	.08
	M. m. domesticus	15	1.07	.03**	13	1.03	.03**
ZI	*M. "spretoides"*	45	.74	.10	47	.80	.10
	M. m. domesticus	22	.47	.05**	52	.52	.07**

* From Orsini et al. 1983. ** $p < .05$

Concerning the ZI index, Figure 2 presents the histogram of the results obtained with the 792 Israeli mice measured for this parameter. It does not represent a normal distribution (Kolmogorov-Smirnov test: $D = 0.12$, $N = 792$, $p < 0.01$), but rather a bimodal one.

Later, we calculated the average of this trait for each species only for live trapped mice and for museum specimens. For this last category, we used only individuals for which tail, head and body measurements had been recorded, and these were clearly determined by this characteristic as belonging to one of the two species (Table 2). ZI is very discriminatory, too, and may be also used on museum pellet material.

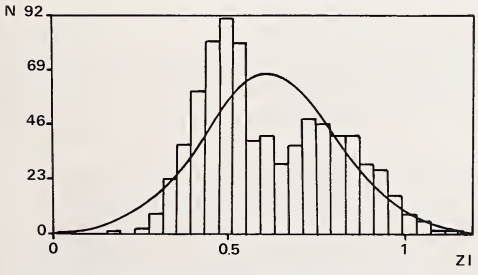

Fig. 2. ZI parameter distribution in mice in Israel

Distribution and habitat of both species of mice in Israel

Mus musculus domesticus occurs throughout Israel, whereas *Mus "spretoides"* occurs on the western coastal plain, hills and

Fig. 3 (left). Presence of *Mus musculus domesticus* (○) and *Mus "spretoides"* (●) in Israel; (1 to 12): Location of owl pellet collections; (---) Annual 400 mm rainfall curve. – *Fig. 4 (right).* Mice ZI distribution within owl pellet collections from 12 locations studied and brief description of the raptors hunting area for each location

mountains of northern Israel. Humidity apparently plays an important role in the distribution of *Mus "spretoides"*, which has its southernmost boundary correlated with the annual 400 mm rainfall curve, which corresponds to the Mediterranean climatic limit (Fig. 3).

Figure 3 shows that these two species are found sympatrically in the Mediterranean climatic zone.

Mus "spretoides" was trapped in two kinds of environments: sandy dunes beaches and, up to an altitude of 500 m, in bushes (especially correlated with *Pistacia lentiscus*). No trapping at higher altitudes was done. This species has never been found in human dwellings which are usually inhabited by *Mus musculus domesticus*. We have not succeeded in trapping the former in cultivated fields, but it may occur there. *Mus musculus domesticus*

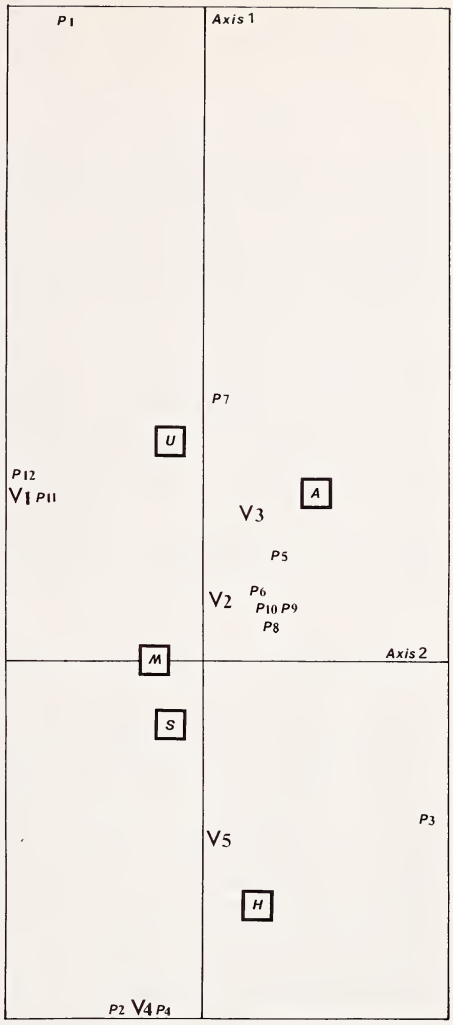

Fig. 5. Axis 1,2 plan of the correspondence analysis (the two first extracted factors account respectively for 68 % and 27 % of the explanation); V1 to 5: both mice proportions categories in pellets (active individuals of the analysis); P1 to 12: pellet collections (unactive individuals in the analysis); H, A, U, M, S variables (described in text)

was trapped indoors in the zone of sympatry (Mediterranean climatic zone) and outdoors in the northern Negev desert (N = 8), where no *Mus "spretoides"* occurs.

Figure 4 presents the distribution of ZI of the material derived from owl pellets. The result of the Correspondence Analysis is shown in Figure 5. This associates V4 and V5 proportions (more than 60 % of *Mus musculus domesticus*) with human dwellings, V2 and V3 (between 20 and 60 % of *Mus musculus domesticus* and between 40 and 80 % of *Mus "spretoides"*) with agricultural fields and natural environments and V1 (more than 80 % of *Mus "spretoides"*) with natural environments.

The presence of the two species is strongly correlated with the habitats: *Mus musculus domesticus* occurs in human settlements and agricultural areas (points 2 to 10), whereas *Mus "spretoides"* occurs in agricultural areas and natural environments (points 6 to 12).

The calculation of the percentage of each mice in the total number of prey in owl pellets was possible for 4 points (Table 3).

Table 3. **Percentage of both species of *Mus* in the total number of prey of owl pellets (see location on fig. 3)**

	Percentage of both mice (N)	Percentage of *M. m. domesticus*	Percentage of *M. "spretoides"*
Point 3	16.8 (57)	15.8	1.0
Point 6	42.9 (51)	18.9	24.0
Point 7	15.5 (63)	7.4	8.1
Point 10	14.7 (33)	3.3	11.4

Discussion

Taxonomy

In the last 20 years, *Mus "spretoides"* has been described under various names by several authors. According to the distribution and the ecological, morphological and biochemical features, it seems that all of these authors described the taxa referred to as *Mus "spretoides"* in the present paper. This species has also been called *Mus abboti* (Marshall and Sage 1981), *Mus "4A"* (Bonhomme et al. 1983), *Mus "spicilegus* sud" (Orsini et al. 1983), *Mus "spicilegus tataricus"* (Marshall 1986), *Mus "macedonicus"* (Thaler 1986), or even when its specific status was not clearly recognized, as *Mus "musculus spicilegus"* (Ondrias 1965) or *Mus "hortulanus macedonicus"* (Petrov and Ruzic 1983). Given this great confusion, and according to the fact that clear of type specimens of *Mus abboti* is still to be done, and that all other names could lead to a confusion with its northernmost sibling species (the so-called mound-builder mouse), we prefer to use for commodity *Mus "spretoides"* (Bonhomme et al. 1984) throughout this paper.

Mus "spretoides" has already been described in Bulgaria and Cyprus (Orsini et al. 1983), Greece (Ondrias 1965), Turkey and Iran (Darviche et al. 1979). *Mus musculus domesticus* has been described in the Middle-East, Western Europe, Africa, and America (see Bonhomme 1986 for a review). No study ever revealed any hybrids between these two species in nature. Interspecific breeding, however, is possible under laboratory conditions: Offspring are viable, but F1 males are sterile (Bonhomme et al. 1984).

Habitat partition between *Mus "spretoides"* and *Mus musculus* domesticus in Israel

It appears that there is a correlation between the presence of *Mus musculus domesticus* and *Mus "spretoides"* respectively with human settlements and unexploited environment.

Nevertheless, to assess the presence of permanent feral populations (occurring outdoors throughout the year) for *Mus musculus domesticus,* we consider the percentage of this species in the total number of prey in owl pellets. In Europe, this percentage, in regions where this species is strictly commensal, varies between 1 % to 5 % (Contoli and Sammuri 1978; Barbieri et al. 1975; Lovari et al. 1976; Libois 1984; Chaline et al. 1974). In Southern France, in the Mediterranean climate where *Mus musculus domesticus* is both permanently feral and commensal, its proportion in raptors prey varies from 10 to 30 % (Libois 1984). In some places in Israel it can reach 15.5 % (point 3) or 18.6 % (point 6), and thereby could establish the occurrence of feral permanent populations of the house mouse there. In the zone of sympatry, that is the Mediterranean climate, the feral populations of *Mus musculus domesticus* may occur only in agricultural fields or in close proximity to human settlements, whereas only *Mus "spretoides"* can be found completely independantly of human dwellings (poins 11 and 12). When they occur sympatrically, these two species seem to have established a partition of the environment, and the only place of syntopy could be in cultivated fields.

We noted the presence of feral *Mus musculus domesticus* populations in the northern Negev desert, where we caught 8 feral animals more than two kilometers from the first settlement, or at point 1 (Fig. 2). So, this species occurs as feral populations in semi-arid natural environments where *Mus "spretoides"* is missing but not in Mediterranean zones of sympatry with *Mus "spretoides"*. Also, the occurrence of feral populations of the house mouse in Mediterranean environments in Europe (Orsini et al. 1982) suggests that, in Israel, this species is partly competitively excluded from such type of natural environments by *Mus "spretoides"*.

Besides, we noted a longer tail for *Mus "spretoides"* in Israel, comparing with European material. The inverse relation between tail size and latitudes may be an example of Allen's

rule which states that, within closely related species, the colder environment, the shorter the appendages (reviewed for mice in Barnett 1965). By living in human dwellings, where their micro-environment is buffered, *Mus musculus domesticus* may not follow Allen's rule.

Circum-Mediterranean vicariance in the genus *Mus*

Our study clearly shows the Mediterranean distribution of *Mus "spretoides"* in Israel. The Mediterranean feature of the distribution of this species is confirmed by its northern distribution: Greece, Bulgaria, Turkey and Iran (see Orsini et al. 1983 for a review). There, the northern limit of its distribution also corresponds to the limit of the Mediterranean climate. So, this species appears to be Mediterranean on all its known Eurasian distribution (Fig. 6). Harrison (1972) gives measurements of mice from the Middle East and we note that he reports short-tailed mice in Israel, Lebanon and Syria, but not in Jordan and Saudi Arabia. These data seem to indicate that there is a junction between northern and southern areas of *Mus "spretoides"* still under Mediterranean climate. Marshall and Sage (1981) described a short-tailed mouse in Egypt, but finally assigned this animal to *Mus musculus domesticus* (Marshall 1986). So *Mus "spretoides"* does not seem to extend beyond the Mediterranean climate southwards. In Greece and Bulgaria it seems to slightly range out of the Mediterranean zone.

Such a sympatry between *Mus musculus domesticus* and another Mediterranean species of *Mus* occurs in the western part of the Mediterranean region. There, *Mus spretus* occurs as a strictly feral and Mediterranean species (Fig. 6), and is found in shrubs and beaches while *Mus musculus domesticus* is both feral and commensal. So, the partition of habitat in the western Mediterranean Basin is basically very similar to that in Israel. Ecological features concerning the relation between *Mus musculus domesticus* and *Mus spretus* are better known than with *Mus "spretoides"*. Ecology (Orsini 1982), behavior (Cassaing 1984), population dynamics (Cassaing and Croset 1985), water balance (Sicart et al. 1985), metabolic cold adaptation (Auffray 1988) of these species have comparatively been studied. They confirm the Mediterranean feral nature of *Mus spretus,* as compared with the house mouse. *Mus spretus* is better adaptated to dryness, badly adaptated to cold temperatures, is aggressive and territorial. By contrast, *Mus musculus domesticus* is accustomed to nomadism or aggregative population structures in the sympatric zone of Southern France. Nevertheless, in Israel, some divergences seem to appear in the competition pattern between *Mus musculus domesticus* and the feral species of mice, in this case *Mus "spretoides"*. Indeed, in the Middle-East, *Mus musculus domesticus,* found in semi-arid zone where the feral species is missing, seems to be better adapted to dryness than *Mus "spretoides"*.

It would be valuable to undertake physiological and ethological studies on the pair *Mus musculus domesticus/Mus "spretoides"* to better determine the ecological proximity between this last species and *Mus spretus,* but also to approach the ecological disparities between eastern and western populations of *Mus musculus domesticus* in the Mediterranean Basin.

Both *Mus "spretoides"* and *Mus spretus* are strictly Mediterranean species. Mediterranean climatic zones around the Mediterranean Sea are discontinuous areas. The biggest interruption is the Lybian-Egyptian desertic coast, Cyrenaica being a biogeographic "Mediterranean island". The Mediterranean climate is neither characteristic of the Italian Riviera nor the Po Delta, so the Italian Peninsula can also be considered as a barrier strictly for Mediterranean species. These two interruptions cut the Mediterranean Basin into two biogeographic zones, the occidental (Southern France, Iberic Peninsula and Maghrebi Coast) and the oriental (from Yugoslavian to Israeli Coast and an extension to Iran).

A very clear vicariance between *Mus spretus* and *Mus "spretoides"* is established between these two parts of the Mediterranean Basin. Nevertheless, the Italian Peninsula

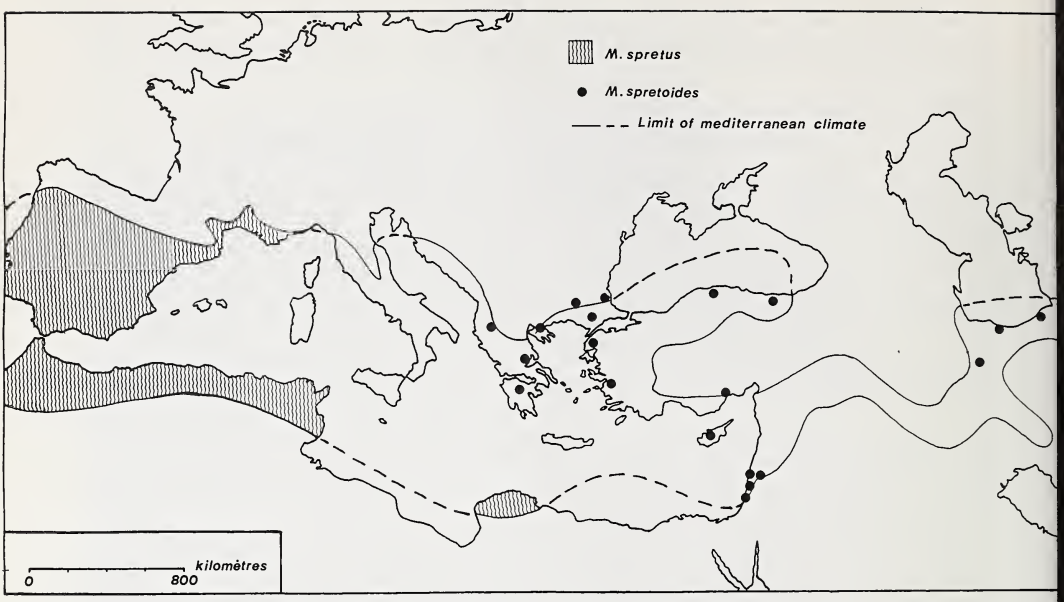

Fig. 6. Circum-Mediterranean distribution of *Mus spretus* and *Mus "spretoides"* (modified from Orsini 1982 and Orsini et al. 1983)

remains free of these two feral mice. On the other hand, Cyrenaica harbors *Mus spretus* (Marshall and Sage 1981). This could be explained by the colonization of *Mus spretus* through northern Africa, at a time when the Sahara was hospitable. After the desertification, an isolated population of *Mus spretus* could have remained as a refuge in this zone. The circum-Mediterranean parcelling out and species vicariance are also illustrated by the distribution of some other mammals, such as *Meriones* and *Crocidura* (see Cheylan 1988 for a review).

The discovery of a new species of mice in Israel is also very interesting from a paleontological point of view. Indeed, Israel presents numerous paleontological and archeological sites from the Lower Pleistocene. Only *Mus musculus* lineage has been described since the Pleistocene (Tchernov 1968, 1986). The presence of the two actual species in this region should occur as a result of two lineages, one for each species. Thaler (1986) stresses the need to study late paleontological material with a biometric discriminatory method complemented by biochemical studies on actual material. The morphological method used in this study on extant material may also be applied to fossil material. The dating of the appearance of the two species and of their colonization of the Middle-East should then be viewed through the perspective of competition in time, and the effects of human appearance on the feral and the commensal species of mice.

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Zusammenfassung

Vorkommen und Verbreitung von Mus "spretoides" und Mus musculus domesticus in Israel
Circum-Mediterrane Vikarianz im Genus Mus

Das Vorkommen von *Mus "spretoides"* in Israel wird morphometrisch und biochemisch belegt. Insgesamt wurden dazu 792 *Mus*-Individuen untersucht, die teils lebend gefangen wurden, teils aus Museen oder Gewöllen aus ganz Israel stammten. Danach ist *Mus musculus domesticus* weiter verbreitet, auch in semiariden Gebieten, wogegen *Mus "spretoides"* auf mediterrane Habitate beschränkt ist. Bei sympatrischem Vorkommen wird offensichtlich durch die Konkurrenz der jeweils anderen Art *Mus musculus domesticus* aus dem Freiland, *Mus "spretoides"* hingegen von menschlichen Siedlungen ausgeschlossen.

Im Mittelmeerraum ist *Mus "spretoides"* die östliche Vikariante der westmediterranen *Mus spretus*.

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