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Spatial organization of the mound-building mouse *Mus spicilegus* in the region of northern Bulgaria

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Abstract I studied the spatial associations and distribution of mound-building mice *Mus spicilegus* Petenyi during the breeding period in northern Bulgaria. The most frequent spatial association observed was between a single male and a female. Other associations between two or three males, and between a male and two or three females were also observed. Female social groups were seldom observed. Home ranges of females were exclusive. Male home ranges were larger than those of females. Home ranges of about half of the males overlapped home ranges of one female; the remaining males had home ranges that overlapped home ranges of two adult females. These results suggest that *M. spicilegus* has a variable socioreproductive mating system that is either monogamous or polygynous. The predominance of male-female pairs and solitary females, as well as the exclusive home ranges of females, suggests that monogamy is the preferred mating system [*Acta Zoologica Sinica* 53 (1): 22-28, 2007].
Key words Mouse, *Mus spicilegus*, Mating systems, Sex-ratio, Spatial associations, Home ranges

保加利亚北部地区匈牙利小家鼠的空间组织结构

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摘　要　本文研究了保加利亚北部地区的匈牙利小家鼠在繁殖期的空间关系和分布。这种动物最普遍的空间关系是一雄一雌，也观察到两个或三个雄鼠与一个雌鼠、一个雄鼠与两个或三个雌鼠的组织形式。很少观察到雌性的社群小组。雌鼠之间的巢区没有发现重叠。一般雄鼠的巢区大于雌鼠。有一半雄鼠的巢区与一个雌鼠的巢区相重叠，其他的雄鼠与两个成年雌鼠的巢区相重叠。这些结果表明，匈牙利小家鼠具有多变的社群繁殖婚配体制，即单配制和多配制共存。比较普遍的一雄一雌的配对形式和雌性的独居特性，以及雌性之间巢区的相对独立性，表明单配制是该物种的主要婚配体制［动物学报 53 (1): 22-28, 2007］。
关键词　小家鼠　婚配体制　性比　空间关系　巢区

The mound-building mouse *Mus spicilegus* is a common throughout the steppe zone in Central and Eastern Europe (Orsini et al., 1983; Bonhomme, 1992; Sage et al., 1993; Sokolov et al., 1998). At the beginning of autumn, individuals build complex mounds in which seeds are cached. The mice spend the winter in these mounds. In early spring the mice leave the mound, disperse and reproduce (Naumov, 1940; Orsini et al., 1983; Milishnikov et al., 1998; Simeonovska-Nikolova and Gerasimov, 2000). Studies of captive *M. spicilegus* under laboratory and semi-natural conditions showed that *M. spicilegus* displayed behavioral features characteristic of a socially monogamy: establishment of a strong social bond between females and their familiar male (Patris and Baudoin, 1998); cooperation between males and females in parental care for their young (Patris and Baudoin, 2000); high aggressiveness of female and male mice towards unfamiliar individuals of both sexes (Suchomelová et al., 1998; Patris et al., 2002; Simeonovska-Nikolova, 2003); low reproductive success of the polygynous females (Gouat and Féron, 2005); formation of stable male-female associations in experimental groups (Simeonovska-Nikolova, 2003; Baudoin et al., 2005). Genetic analysis of four autosomal and four X-linked microsatellite loci (Garza et al., 1997) also suggested that individuals in a mound are derived from at least two

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parental pairs which is consistent with monogamy. However, there are insufficient field data to confirm that the mating system of *M. spicilegus* is monogamous.

Simeonovska-Nikolova and Gerasimov (2000) found that during the reproductive period in northern Bulgaria, female mound-building mice had exclusive home ranges, a precondition for social monogamy (Komers and Brotherton, 1997). However, these authors did not define group structure or spatial organization (Baudoin et al., 2005). Even when females live alone, males could adopt spatio-reproductive strategies other than social monogamy (Reichard and Boesch, 2003). For instance male *Peromyscus* spp., have territories that overlap at least one female, often those of one or more neighboring females, resulting in polygynous mating (Wolff, 2003). A recent investigation of spatial associations of *M. spicilegus* in an agricultural field in Hungary demonstrated that polygyny could occur, at least during the beginning of the reproductive period under conditions of female biased sex-ratio and high population density (Gouat et al., 2003a). Additional field data are needed to clarify the spatial organization and mating system of this species. In this connection, the aim of this work was to study the spatial associations of mound-building mice *M. spicilegus* in an agricultural field in northern Bulgaria from spring to autumn. If the species is monogamous, as suggested by many of the above studies, I expected to find exclusive male female associations, with no associations among females or among males, as well as spatial separation of females.

1 Material and methods

The present study was conducted in the Danube Plain in northern Bulgaria (43°21′N, 24°29′E). The climate is continental, with a cold winter and warm summer. The average temperatures vary from −2℃ to 2℃ during winter (December – February) and from 20℃ to 24℃ during summer (June, July and August). Precipitation is 150 mm during summer and 70 mm during winter. Because mound-building mice are mainly found in agricultural fields (Sokolov et al., 1990), the study was conducted in a 1-ha agroecosystem of *Medicago sativa* L, mixed with weeds such as *Andropogon halepensis* (L.) Brot., *Setaria viridis* L. and *Amarantus* sp. The rodent community consisted of 4 species: *Microtus arvalis*, *M. spicilegus*, *Apodemus sylvaticus* and *Apodemus agrarius*. The species identification of *M. spicilegus* in the studied habitat was made using craniometric criteria (Gerasimov et al., 1990; Simeonovska-Nikolova and Gerasimov, 2000).

The field studies were carried out in April – May, June – July, and September of 1992. Studies were conducted for 5 – 7 days for each of these periods. The Capture-Mark-Recapture method was used. A square grid of 100 traps (10-m interval) was established in the study site. The traps (single door and single capture trap, 16 cm × 7 cm × 7 cm) were baited with oat flakes. The traps were checked once a day, in the morning. At first capture individuals were marked by toe-clipping. At each capture the following were recorded: individual number, body mass to 1 g, sex, reproductive condition (females: pregnant, lactating, or perforated vagina; males: scrotal testes). The age of each animal was determined on the base of its body mass and reproductive status (juveniles, ≤9 g; subadults, body mass 10 – 14 g and not in reproductive condition; adults, body mass ≥15 g and in reproductive condition). Males with testes in the scrotal position and females which were pregnant, lactating, or had a perforated vagina were considered as reproductive. Keeping in mind that the visual detection of pregnancy becomes certain only during the last week of gestation (Gouat et al., 2003a), a female was considered to be pregnant, when pregnancy was clearly observed or when its vagina was closed and its body weight exceeded 18 g. The field protocol conformed to the international requirements for ethical conduct towards the animals (Lehner, 1996; Rudran and Kunz, 1996).

Several indices of spacing behavior such as types of spatial associations, recapture rate, latency of first recapture, distance of recapture, frequency of recapture, and home range distribution were analyzed. Many of these indices were adapted from similar studies on *M. spicilegus* (Gouat et al., 2003a; Baudoin et al., 2005) and other rodent species (Gromov et al., 2000; Wu and Yu, 2004). The term "associations" expresses the situations in which two or more mice were captured in the same trap in a given trapping session. "Stable associations" were when the same two or more individuals were recaptured at least once in a given trapping session in the same or at different stations (traps). The latency of first recapture, distance of recapture, and frequency of recapture were represented by the median. The significance of sexual differences between these indices was estimated using a Mann-Whitney U-test at $P < 0.05$.

M. spicilegus home ranges were established by using of the exclusive boundary method, based on 3 – 5 captures per individual and on the presumption that a trap acts at half of the distance between two traps (Nikitina, 1965). The significance of differences between male and female home ranges was estimated by the Mann-Whitney U-test at $P < 0.05$. Home range distribution of female and male *M. spicilegus* was established only for the summer period, when density was high.

2 Results

2.1 Captures, population number and demography

In April – May the number of mound-building mice was relatively low and males dominated the captures (Table 1); 19 mice, 6 females and 13 males, were captured. The population of *M. spicilegus* in spring consisted entirely of adults. Two males were trapped two to three times. Recapture rate was 15.4% for males and 0% for females (Table 2). The distance between the trapping points was 55 m and 95 m, respectively.

In June – July population density of mound-building mice was high and the sex-ratio relatively balanced (Table 1); 99 mice, 42 females and 57 males, were captured (Table 1). All three age classes were represented in the population of *M. spicilegus* (Table 1). Seventeen females and 27 males were trapped from two to five times with similar recapture ratios (females, 40.5%; males, 47.4%; Table 2). All recaptured individuals were reproductively active adults. The median distance between trapping points of females (10 m) was significantly less than that of males (15 m; Mann-Whitney U test: $U = 105.5$, $P < 0.05$; Table 2). Many of the recaptured individuals appeared to be sedentary. Five females and 4 males were recaptured only at the same station and 6 females and 5 males at one of the four nearest stations. Seven recaptured mice, six males and one female, were caught the first time in the previous trapping season in April – May. The distance between spring and summer trapping points was 30 – 50 m.

Table 1 Sex-ratio and age distribution within the *Mus spicilegus* population

Trapping session	Sex ratio		Age distribution					
	Females	Males	Juveniles (< 9 g)		Subadults (10 – 14 g)		Adults (> 15 g)	
			Females	Males	Females	Males	Females	Males
April – May 1992	6	13	–	–	–	–	6(3)	13
June – July 1992	42	57	1	2	2	4	39 (24)	51
September 1992	11	9	–	–	3	6	8 (2)	3

The number of pregnant females is indicated between brackets.

Table 2 Indices of spacing behavior in male and female *Mus spicilegus*

Trapping sessions	Recapture rate-number of recaptured individuals/total number		Latency of first recapture median, min-max values		Distance of recaptures median, min-max values		Frequency of recaptures median, min-max values	
	F	M	F	M	F	M	F	M
April – May 92	0% – 0/6	15.4% – 2/13	0	1(1)	0	55(0 – 95)	0	2(2 – 3)
June – July 92	40.5% – 17/42	47.4% – 27/57	1(1 – 6)	1(1 – 6)	10* (0 – 30)	15* (0 – 70)	3(2 – 5)	3(2 – 5)
September 92	36.4% – 4/11	22.2% – 2/9	2(1 – 3)	2(1 – 3)	0(0 – 10)	0(0 – 10)	2(2 – 3)	2.5(2 – 3)

Recapture rate is expressed in% by calculation of the number of recaptured individuals/ total number of animal captured. The latency is expressed in nights—a value of 1 corresponds to recapture in the night following the first capture, the distance of recaptures is presented in m, and the frequency of recaptures is expressed by the number of recaptures per individual. The data are presented by median, min and max values-in the brackets. The significance of differences revealed by Mann-Whitney U test is shown: $P < 0.05^*$.

In September the number of mice was similar to that in April – May; 20 mice, 11 females and 9 males, were captured (Table 1). In comparison with April – May, however, the population of *M. spicilegus* was composed of subadults and adults (Table 1). Nevertheless, only four adult females and 2 adult males were trapped from two to three times. The recapture ratio was 36.4% in females, and 22.2% in males (Table 2). The four females were first captured in previous trapping sessions.

2.2 Spatial associations and home range distribution

In April – May the following spatial groups were observed: two male-female pairs, four male-male pairs, and one male-two female trio. Two, each, solitary females and males were observed. Females of both female-male pairs and one of the solitary females were pregnant (Table 3).

In June – July the most frequent social group was a male-female pair (11 cases; Table 3). Three male-female pairs were recaptured at least once in successive days in the same or in different trapping points. Four male-female pairs were associated with one or two juvenile individuals. One of the males in one male-female pair was a subadult. Spatial associations were frequently observed also between males (seven pairs and two trios). Only one of the individuals in two male pairs and one in the male trio were subadults. Besides these associations, there were cases in which one male was captured with two or three females, and one female-with two or three males, respectively (Table 3). Eight females and seven males were found to be solitary. Spatial association between females was rare. Only two female pairs were observed (Table 3). In one instance, the female was captured only once with a female, whereas its next captures were with a male and two juveniles. Five solitary females, and all females included in the 19 social groups were pregnant (Table 3). Only two females were subadult: one of the females in the FFFM quartet and one of the solitary females (Table 3).

Table 3　Spatial associations observed during the reproductive period for all animals

Type spatial associations	Spring			Summer			Early Autumn		
	Number of observations	Number of females	Number of males	Number of observations	Number of females	Number of males	Number of observations	Number of females	Number of males
F	2	$2-1^{p}$	0	8	$8-(4), 5^{p}, 1^{sub}$	0	8	$8-(3), 2^{p}, 2^{sub}$	0
M	2	0	2	7	0	$7-(2)$	2		$2-(1), 1^{sub}$
FM	2	$2-2^{p}$	$2-(2)$	11	$11-(5), 11^{p}$	$11-(8), 1^{sub}$	2	2, (1)	2
FF	0	0	0	2	$4-1^{p}$	0			
MM	4	0	8	7	0	$14-(4), 2^{sub}$	1		2^{sub}
MMM				2	0	$6-(3), 1^{sub}$			
FFM	1	2	1	4	$8-(6), 6^{p}$	$4-(4)$			
FFFM				1	$3-(1), 1^{sub}$	$1-(1)$			
FMM				1	$1-1^{p}$	$2-(1)$			
FMMM				2	2	$6-(3)$	1	1^{sub}	$3^{sub}-(1)$
FM + 1/2 Juv				4	$5-(1), 1^{juv}$	$6-(1), 2^{juv}$			
Total	11	6	13(2)	49	42(17)	57(27)	14	11(4)	9(2)

^{p} number of pregnant mice; ^{sub} number of subadults; ^{juv} number of juveniles. The number of recaptured mice is indicated between brackets.

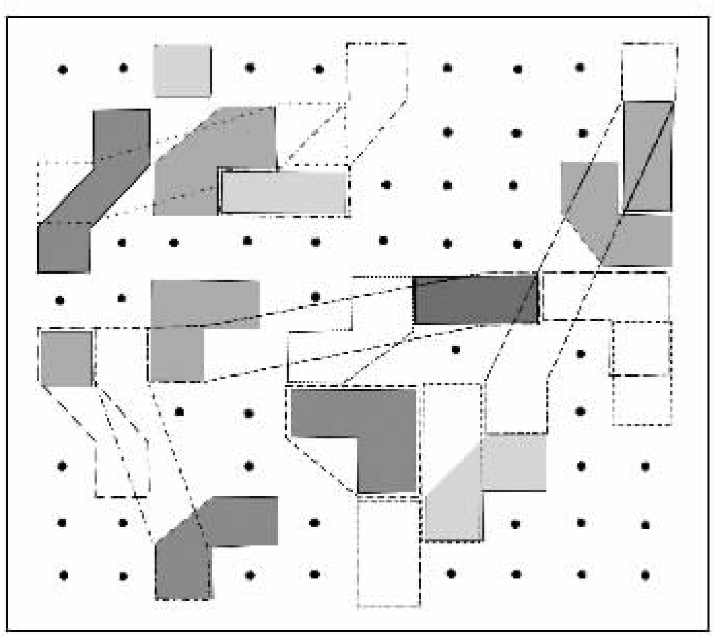

Fig.1　Location of home ranges of male and female *M. spicilegus* in June – July

The home ranges of 12 adult males and 12 adult females, which were captured at least 3 times in that season, are presented. The solid lines represent the borders of female home ranges, which are in grey; the dashed lines—the borders of male home ranges. The dots represent 10-m interval trap stations; stations within home ranges are not plotted.

Home ranges were determined for 12 adult males and 12 adult females which were captured at least three times on the study plot. Male home ranges were significantly larger than those of females: the size of home ranges varied from 100 m^2 to 300 m^2 (median, 250 m^2) in females and from 200 m^2 to 650 m^2 (median, 325 m^2) in males; Mann-Whitney U test: $U = 26.5$, $P < 0.05$. Home ranges of females were exclusive, while those of males overlapped with each other and with the female ranges as follows: In three cases the home range of one male overlapped those of one female in 100%; in two other cases in 60% – 70% (Fig.1). In three cases the home range of one male overlapped those of two females. However, while the overlap with the one female was 60%

– 87%, the overlap with the other one was 33% – 50%. The home range overlap between males was 0 – 50%.

In September two adult females were associated with a single adult male (Table 3). One subadult male was captured with one subadult male, and one subadult female was found to be associated with three subadult males. Eight females (6 adult and 2 subadult) and two males (1 adult and 1 subadult) were found to be solitary. Two of the solitary females were pregnant (Table 3).

3 Discussion

The observed seasonal changes in density and demographic structure of *M. spicilegus* seemed to undergo the seasonal changes in its life cycle. The relatively low population density of mound-building mice in spring is probably due to the food shortage and unfavorable winter conditions as well as increased dispersal at the beginning of the breeding period. High population density of *M. spicilegus* in summer is a common phenomenon in many rodents of temperate regions, and a decline in autumn seems to be connected with the approach of winter and disappearance of adults. The disappearance of adults in autumn for had been reported by other authors (Garza et al., 1997; Milishnikov et al., 1998). Besides, similar observations of seasonal dynamics of density and demographic structure of *M. spicilegus* were reported for this species in the region of Dobrudja (Rumania) by Sutova (1969). In contrast, a female biased sex-ratio and high population density were registered for *M. spicilegus* at the beginning of the breeding period in an agricultural field in the Gyöngyös region of Hungary (Gouat et al., 2003a). Differences in population parameters could affect the spatial organization and mating system of *M. spicilegus* at least at a local level.

In the present study, the most frequent spatial association among adults during the breeding period was between a male and a female, but social groups involving two or three males and a male and two or three females were also observed. Therefore, it appears that social groups are formed by interactions between males and females as well as between males. This tendency was confirmed by home range distribution. Male *M. spicilegus* shared parts of their home ranges with other males. Familiarity is known to play an important role in the social structure of the mound-building mouse (Garza et al., 1997; Patris and Baudoin, 2000; Gouat et al., 2003b). Familiar animals are very tolerant and display cohesive behavior (Gouat et al., 2003b). However, while this behavior is typical inside the mounds, during breeding periods male *M. spicilegus* are very aggressive toward conspecifics (Suchomelová et al., 1998; Simeonovska-Nikolova, 2003). Thus, it could be assumed that males use the shared areas in different periods to reduce encounters. A similar pattern of activity was reported for feral *Mus musculus* (Khokhlova and Krasnov, 1986) and gerbils *Gerbillus dasyurus* (Gromov et al., 2000). The exclusive home ranges of females in summer suggested that during this period females occupied defended territories. It has been demonstrated in laboratory studies that females are very aggressive towards unfamiliar females (Suchomelová et al., 1998; Patris et al., 2002; Simeonovska-Nikolova, 2003). Thus, capture of two females in the same trap probably is more likely evidence of competition between them than of cooperation. Moreover, Baudoin et al. (2005) found that there was no cooperative nesting among female *M. spicilegus* and kinship did not affect female associations. Therefore, potential of monogamy implicates a high level of female competition and dispersal as well as long-term pair bonding (Komers and Brotherton, 1997; Dobson and Jones, 1985; Dobson and Baudoin, 2002; Patris et al., 2002; Baudoin et al. 2005). The exclusive home ranges of females and the predominance of male-female pairs appear to be compatible with a monogamous mating system. Confirmation of this conclusion is also the balanced sex-ratio and separate home ranges of male and female pairs in June – July. Monogamy, however, may occur also in populations with low population density and a male-biased sex-ratio when finding another partner is difficult (Reichard and Boesch, 2003). Thus, the low population density of *M. spicilegus* and male biased sex-ratio in spring may have favoured monogamy. Besides, monogamous species often exhibit strong reproductive cooperation between males and females that last at least until the young are independent of the mother (Dewsbury, 1981). In the present study juveniles were observed in several male-female pairs. Some monogamous species fail to form a new male-female pair after the loss of their mate. For instance only 13.6% of female prairie voles formed a new pair after the loss of their mate (Pizzuto and Getz, 1998). There were a number of single female and male *M. spicilegus* in the present study too.

The significantly greater median distance between trapping points of males in comparison with those of females suggests that males may roam and attempt to mate with multiple females. In addition, the home range distribution in summer showed that some males had home ranges that overlapped those of two adult females, which is typical for a polygynous mating system. Socioreproductive polygyny is the most prevalent reproductive strategy in mammals (Ferron and Oullet, 1989; Gromov et al., 2000; Wolff, 2003). In many rodents, females are randomly distributed and males also have large home ranges that overlap those of several females and other males resulting in polygynous mating (Heske et al., 1995; Wolff, 2003). Considering that some males of *M. spicilegus* can maximize their reproductive success with a socioreproductive polygynous strategy, it seems acceptable that social monogamy may occur as a consequence of males being unable to gain or defend access to several females. The results of this study showed that less than half of the males had home ranges, which overlapped home ranges of two adult females. At the same time, monogamy may occur also when staying with one female provides reproductive benefits to males not otherwise accessible under alternative mating strategies. For instance, comparing reproductive success between monogamous and polygynous females, Gouat and Féron (2005) found that polygyny has a strong negative effect upon the reproductive success of females. The exclusive male-female associations found in the present study confirm these observations.

Based on results of this study, I propose that *M. spicilegus* has a variable socioreproductive mating system, either socially monogamous, or polygynous, as was found in other rodent species. For instance, in the socially monogamous prairie vole, in which densities fluctuate greatly, about half of the males defend a single female whereas the other half exhibit a wandering strategy and attempt to mate with multiple females (Carter and Getz, 1993). A recent investigation on spatial structure of *M. spicilegus* in an agricultural field in Hungary also demonstrated that polygyny may occur during the beginning of the reproductive season under female biased sex-ratio and high population density (Gouat et al., 2003a). Nevertheless, the predominance of male-female pairs and solitary females, as well as the exclusive home ranges of females, observed in the present study suggested that monogamy is the principal mating system in this population of *M. spicilegus*.

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