

## ORIGINAL ARTICLE

# Habitat use and demography of *Mus musculus* in a rural landscape of Argentina

Vanina A. LEÓN, Jimena FRASCHINA, Juan S. GUIDOBONO and Maria BUSCH

Department of Ecology, Genetics and Evolution, University of Buenos Aires, Buenos Aires, Argentina

## Abstract

The main goal of the paper was to determine the habitat distribution of the house mouse (*Mus musculus*) within a rural landscape of Buenos Aires province, Argentina. We also studied the seasonal variation in abundance and reproductive activity. The habitats studied were poultry farms, human houses in a small village, cropfields, pastures, cropfield and pasture edges, riparian habitats (streams), railway embankments and woodlots. We captured 817 *M. musculus* and 690 individuals of 5 native rodent species. *M. musculus* was captured in poultry farms, houses, riparian habitats, cropfield and borders, but it showed a significantly higher abundance in poultry farms compared to the other habitats. Its presence outside poultry farms was significantly related to the distance to streams and poultry farms. The mean trapping success index of *M. musculus* did not show significant variations between periods, but the proportion of active males was significantly higher in the spring–summer period than in the autumn–winter period. All captures of *M. musculus* in cropfields, borders and riparian habitats occurred in the spring–summer period. The capture of *M. musculus* in many types of habitats suggests that it can disperse outside poultry farms, and streams may be used as corridors.

**Key words:** abundance variation, habitat distribution, house mice, reproductive activity

## INTRODUCTION

The house mouse [*Mus musculus* (Linnaeus, 1758)] is one of the most widespread mammalian species in the world. The species originated in the northern Indian subcontinent (Boursot *et al.* 1996) and has followed hu-

mans around the world. Despite having wide distribution, *M. musculus* is frequently restricted to commensal habitats (Elias 1988; Singleton *et al.* 2005). However, it is also found in other habitats, such as cropfields, pastures, and natural habitats with low levels of human intervention (Pocock *et al.* 2005; Witmer & Jojola 2006).

*Mus musculus* is considered a pest in urban and suburban areas, where it causes food loss and contamination, damages building structures by gnawing and burrowing, and is a potential threat to both human and animal health through transmission of disease (Timm 1987). *Mus musculus* is widely distributed in Australia and in many other islands, and regularly reaches plague densities in cropfields, usually following above aver-

*Correspondence:* Vanina A. León, Department of Ecology, Genetics and Evolution, University of Buenos Aires, Buenos Aires, Argentina, Intendente Güiraldes 2160, Ciudad Universitaria, C1428EGA, Argentina.  
Email: vleon@ege.fcen.uba.ar

age crop production, which, in turn, is linked to winter-spring rainfall (Singleton *et al.* 2001; MacAllan *et al.* 2003; Pech *et al.* 2003; Ylönnen *et al.* 2003). However, in North America and China, large feral populations of house mice are rare or sporadic, and populations are subdivided into subpopulations inhabiting islands of favorable habitats around human dwellings (Pocock *et al.* 2005; Wu *et al.* 2006).

Understanding how the environment affects *M. musculus* abundance and distribution and the processes that are involved may contribute to the design of management practices to control the population of the species. In countries where *M. musculus* has been introduced, its habitat distribution depends on its requirements for resources and conditions, on its vagility, on biotic interaction as competition and predation, as well as on colonization opportunities, the lack of which may account for its absence in potentially good habitats.

*Mus musculus* is well adapted to human habitats, where it takes advantage of the low abundance of competitors (Pocock *et al.* 2005), although in some cases it may interact with rats (Harris & Macdonald 2007). The competitive rank of *M. musculus* appears to vary depending on the presence and density of other species of rodents (Crespo 1966); while in some areas native rodent species prevent its expansion, in others *M. musculus* successfully invades and eliminates native species (Pefaur *et al.* 1968).

In Argentina, *M. musculus* is frequently found in cities, where it thrives in a variety of habitats, such as human houses (especially in precarious conditions) or parks and vacant areas with weedy vegetation (Castillo *et al.* 2003; Cavia *et al.* 2009). Previous studies suggest that the species is rarely found in agroecosystems, except in intensive breeding farms (Miño *et al.* 2001).

We have previously studied different aspects of the biology of *M. musculus* and their relationship to its control, in agrarian systems, but these studies have been mainly conducted in poultry farms (León *et al.* 2007, 2009, 2010; Miño *et al.* 2007). At present, there is no quantitative information regarding the distribution and abundance of *M. musculus* in non-commensal habitats, such as cropfields, cropfield borders, pastures, woodlots, riparian habitats and railway embankments. There is also little information on the factors limiting the spread of the species. Such information is relevant to assess the potential of this species to become a pest in cropfields.

The aim of the present paper is to test the following hypotheses: (i) *M. musculus* differs from native spe-

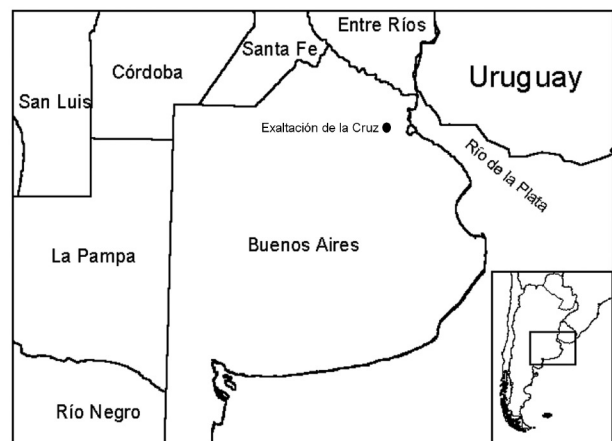
cies in habitat use; (ii) *M. musculus* abundance is higher in peridomestic habitats than in less perturbed habitats by human activity; (iii) *M. musculus* is evenly distributed among poultry farms and among sheds within the poultry farms; (iv) there are no seasonal variations in *M. musculus* abundance in poultry farms; (v) reproductive activity does not differ between the warm and the cold season; and (vi) *M. musculus* captures decrease with increasing distance to poultry farms and when native species are abundant.

## MATERIALS AND METHODS

### Study area

Field work was conducted at the Department of Exaltación de la Cruz, Buenos Aires province, Argentina (34°18'S, 59°14'E; Fig. 1). The study area is located in the Rolling subregion of the Pampean region, and it has a temperate climate with a mean annual temperature of 16 °C and an average annual precipitation of 1000 mm. The maximal temperature occurs in January, while the coldest months are June and July. Although there are seasonal variations in precipitation, there is no dry period (Hall *et al.* 1992).

The original grasslands of the area were highly modified by agriculture and livestock, and by the introduction of trees (Soriano *et al.* 1991). At present, the study area is an agroecosystem with a matrix of cropfields and thin corridors along their edges, roads, railways and ri-



**Figure 1** Location of the Exaltación de la Cruz Department, Buenos Aires province, Argentina.

parian habitats (streams). In these areas, remnants of original plant communities are present, with many exotic species (Bonaventura & Cagnoni 1995). Small patches of woodlots, houses and poultry farms are also present. Other activities in the area are cattle, horse, pig and poultry breeding (Miño *et al.* 2007).

Cropfields are frequently disturbed by agricultural activities, ploughing and herbicide application. Soybean, maize and wheat are the main crops of the area. The borders of cropfields and pastures are longitudinal habitats found along wire fences, usually covered by a weed community. These habitats are less disturbed by agrarian labor and livestock than fields (Busch & Kravetz 1992; Bilenca & Kravetz 1998). Pastures are fields covered with spontaneous vegetation usually supporting livestock. Woodlots are small patches of approximately 0.5 to 2.5 ha, with trees of approximately 5 m high and their juveniles. These woodlots are highly variable according to the dominant tree species. The soil is covered by litter. Riparian habitats are present along small streams, which are dry at some moments of the year and are characterized by spontaneous herbaceous vegetation associated with wet conditions. Railway embankments are longitudinal habitats usually covered by spontaneous herbaceous vegetation and trees.

Poultry farms are devoted to breeding broiler chickens and occupy approximately 1 ha. Most of them have 3 rectangular sheds (Gómez Villafañe *et al.* 2001). Rodent chemical control by anticoagulants is performed in all farms, but not in a systematic way, and, in many cases, there is population recovery between anticoagulant applications (León *et al.* 2009). Therefore, the population of rodents may be limited, but not eradicated (Gómez Villafañe *et al.* 2001). Urban houses are located in a small village with a population of 500, with most people engaged in rural work. Houses are dispersed within small fields, pastures and poultry farms, and most roads connecting them are unpaved.

In the study area, commensal species such as *M. musculus* and *Rattus* spp. are dominant in peridomestic habitats and poultry farms. However, these species are less abundant in cropfields and in other less disturbed habitats (Kravetz *et al.* 1987; Miño *et al.* 2001). In poultry farms, *M. musculus* and *Rattus* spp. are mainly present around poultry sheds, while native species are present in the weedy edges of farms (Miño *et al.* 2007). Other rodent species present in the area are the sigmodontines *Akodon azarae* (J. Fischer, 1829), *Calomys laucha* (G. Fischer, 1814), *Calomys musculus* (Thomas, 1913),

*Oligoryzomys flavescens* (Waterhouse, 1837) and *Oxymycterus rufus* (J. Fischer, 1814) and 1 caviomorph, *Calomys aperea* Erxleben, 1777. In cropfields, *C. laucha* is numerically dominant, whereas in field borders and in less perturbed areas, *A. azarae*, *O. flavescens*, *Oxy. rufus*, *Ca. aperea* and *C. musculus* are more abundant (Mills *et al.* 1991; Busch & Kravetz 1992; Bilenca & Kravetz 1995).

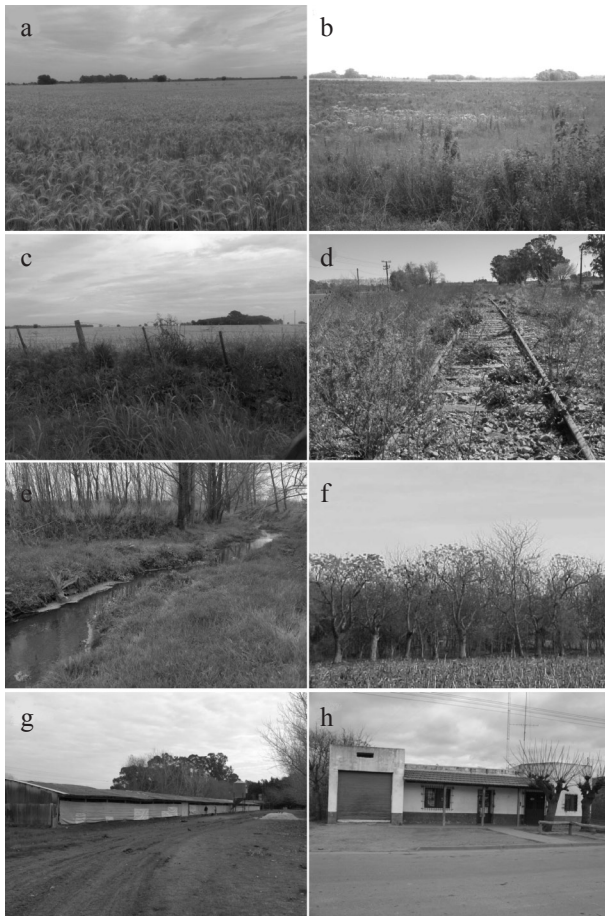
## Rodent sampling

Rodent samplings were conducted from December 2004 to February 2008 in different seasons, with a total of 21 570 trap nights. The peridomestic habitats studied were poultry farms and human houses in 1 small village. Because the houses were scattered within pastures, poultry farms and small cropfields, we considered the abundance of *M. musculus* in each house as independent. The other habitats studied were cropfields, pastures, cropfield and pasture borders, riparian habitats, railway embankments and woodlots (Fig. 2).

The number of sites sampled for each habitat and season are shown in Table 1. In all habitats, except houses and poultry farms, we placed 1 line of 15 Sherman traps spaced at 10 m intervals. In poultry farms, we placed 10 Sherman traps along the external walls of the breeding sheds. We sampled 3 sheds in each farm, except in those that had only 2. We also placed 10 traps along the perimeter of the farm. In all sampled houses, we distributed 15 Sherman traps in the perimeter, garden and around other buildings.

Traps were baited with rolled oats mixed with peanut butter. For each trapping session, we checked each trap in the morning over 3 subsequent days. For each animal captured, we recorded the location and habitat of capture, species, sex, measurements (body and tail length), body weight and external evidence of reproductive condition. We classified those with scrotal testes as reproductive active males, and reproductive active females as those with perforate vagina and those who were lactating and/or pregnant.

Because capture success differed among samplings and habitats, *M. musculus* abundance was estimated using the trapping success index (TSI, number of captures/number of trap nights), as suggested by Mills *et al.* (1991). We grouped data according to season, with a warm period corresponding to spring–summer (September–March samplings) and a cold period corresponding to autumn–winter (April–August samplings).



**Figure 2** Habitats studied (a) cropfields; (b) pastures; (c) cropfield and pasture edges; (d) railway embankments; (e) riparian habitats; (f) woodlots; (g) poultry farms; and (h) human houses.

## Data analysis

### Habitat use

We estimated the TSI for each species captured in each habitat and period. In this analysis, we did not include data from July and August samplings (winter) because they were collected from only 2 farms.

We conducted a principal component analysis (PCA) based on a correlation matrix, which uses standardized variables to describe the distribution of *M. musculus* and native species according to the studied habitats (Infostat 2009). The variables used were the TSI of the 6 species of rodent captured and the 8 studied habitats. The PCA scores for each habitat were calculated using the Infostat program (2009) considering the abundance of each species and their relative contribution to the principal component axes. Trapping sites in which there were no captures of any species were not considered in this analysis.

To compare the abundance of *M. musculus* among habitat types, we estimated confidence intervals of the mean TSI for each habitat. For each pair of habitats, we assumed that abundance was significantly different when the confidence intervals of the TSI did not overlap (Zar 1996). This analysis was conducted because the data did not fulfill the assumption of homogeneity of variances, which is necessary for conducting a parametric or non-parametric analysis of variance (Quinn & Keough 2002).

Analysis of the distribution within each habitat was only conducted for poultry farms because the number of captures in the other habitats was insufficient to conduct statistical analysis. We assessed whether the distribution of captures among farms was different from that

**Table 1** Means and confidence intervals for the trap success index (TSI) of *Mus musculus* in the different habitats studied

Habitat	<i>n</i>	Mean	SE	LL (95%)	UL (95%)
Poultry farms	21	0.0766	0.0682	0.0455	0.1076
Houses	24	0.0065	0.0039	-0.0016	0.0145
Cropfields	60	0.0037	0.0037	-0.0037	0.0111
Pastures	24	0	0	0	0
Cropfield and pasture borders	84	0.0011	0.0006	-0.0002	0.0023
Riparian habitats	24	0.0019	0.0013	-0.0008	0.0045
Railway embankments	24	0	0	0	0
Woodlots	24	0	0	0	0

*n*, number of sites studied for each habitat; LL, lower limit of the confidence interval; UL, upper limit of the confidence interval.

randomly expected as described by the Poisson distribution by means of the variance/mean index. In the present study, if the number 1 is included within the confidence interval of this index, there is random distribution. If the lower limit of the confidence interval is greater than 1, then there is aggregated distribution. However, if the upper limit of the confidence interval is less than 1, there is regular distribution.

The distribution of captures of *M. musculus* among sheds within farms was assessed by comparing the observed number of captures in each shed of every farm with the expected number according to an equal distribution (total number of captures in the farm/number of sampled sheds in the farm) by means of a  $\chi^2$ -test (Zar 1996). We also compared the abundance between internal sheds, those located among other sheds, and external sheds, those neighboring farm perimeters, by means of a *t*-test for paired samples (Zar 1996). When the farm had more than 1 internal or external shed we used the average for each category.

#### *Seasonal variations in abundance and reproductive activity*

We compared the mean abundance in poultry farms between spring–summer and autumn–winter periods by means of an analysis of variance (ANOVA) test (Zar 1996). To assess variations in reproductive activity in poultry farms according to the period, we compared the proportion of active females and males by means of a 2-sided test of difference between proportions (Zar 1996), under the hypothesis of no difference in reproductive activity between warm and cold periods. Furthermore, we also compared pregnancy rates (number of pregnant females/number of reproductively active females) between periods by means of a test of difference between proportions (Zar 1996).

To assess whether the size at reproductive maturation differed between seasons, we compared the mean total body length and the corporal weight of both active and inactive individuals by means of a 1-factor ANOVA test, except for the weight of active males, which was compared by means of a non-parametric Kruskal Wallis test, because data did not fulfill the assumptions of the parametric ANOVA (Zar 1996).

#### *Distance to poultry farms and streams, and the abundance of other rodent species as factors affecting *M. musculus* abundance*

To evaluate whether the captures in cropfields, borders and riparian habitats were related to poultry farm distance, we located the captures in a digitalized map

(Google Earth 2007) and measured the distance to the nearest farm. We also estimated distances to streams, because many of the captures outside poultry farms occurred near streams.

We carried out logistic regressions between *M. musculus* presence in cropfields, pastures, woodlots, borders and riparian habitats (as dependent variables) and the distance to the nearest poultry farm and the nearest stream, and the TSI of native species (as explanatory variables). We used data from all sites situated outside poultry farms and houses where *M. musculus* was captured ( $n = 6$ ) and a random sample from sites where *M. musculus* was absent ( $n = 30$ ). As described in Nicholls (1991), we used a stepwise logistic regression to select the best model, adjusted with an intercept = 0. We first performed an analysis including all variables, and then we entered the variables in a stepwise procedure in an order determined by their contribution to a decrease in deviance with respect to the null model. Remaining variables were those with a significant contribution to the decrease in deviance. The significance of the contribution of the variables to the decrease in deviance was assessed by assuming that the change in deviance is distributed as a  $\chi^2$ -statistic (Nicholls 1991) with  $df = 1$ .

## RESULTS

We captured a total of 817 *M. musculus* individuals, and 690 individuals of 5 native rodent species: *A. azarae* (485), *O. flavescens* (53), *Oxy. rufus* (60), *C. laucha* (63) and *C. musculinus* (29).

### Habitat use

According to the PCA, the first component explained 49% of the variance, with *M. musculus* and *A. azarae* being the variables that contributed the most (Table 2). *M. musculus* was associated with poultry farms and houses and was separated from the other species associated with borders, cropfields, pastures and riparian habitats (Fig. 3). The second principal component explained 23% of the variance, with *O. flavescens* and *C. laucha* being the variables that contributed the most (Table 2). This axis separated the *Calomys* spp. (associated with cropfields and pastures) from the other native species. In contrast, *O. flavescens* was associated with woodlots and railway (Fig. 3).

*Mus musculus* showed a significant higher abundance in poultry farms than all other habitats (Table 1), while native rodent species were scarce in farms (Fig. 4). *Mus musculus* was captured in 5 out of 8 of the habitats stud-

**Table 2** Factor loadings for the 2 first principal components after a principal component analysis on a data matrix with 6 trap success index (TSI) species in the 8 habitats studied

TSI	Components	
	I	II
<i>Aa</i>	0.54 <sup>†</sup>	0.03
<i>Of</i>	$-4.9 \times 10^{-3}$	0.80 <sup>†</sup>
<i>Or</i>	0.50 <sup>†</sup>	0.20
<i>Cm</i>	0.41	-0.12
<i>Cl</i>	0.41	-0.45
<i>Mm</i>	-0.36	-0.33
Eigenvalue	2.93	1.39
% variance	49	23
% cumulative variance	49	72

<sup>†</sup>Loadings > 0.5.

ied. It was captured in all the farms studied, whereas in the other habitats, *M. musculus* was present only in a few sites (12.5% of the houses, 8.3% of the riparian habitats, 3.7% of the borders of cropfields and pastures and 1.7% of the cropfields studied).

*Mus musculus* captures were more evenly distributed among farms, compared to what was randomly expected ( $V/M \pm SE = 0.057 \pm 0.014$ ). Approximately 70% of farms had a TSI < 0.04, while only 1 farm had a TSI higher than 0.30.

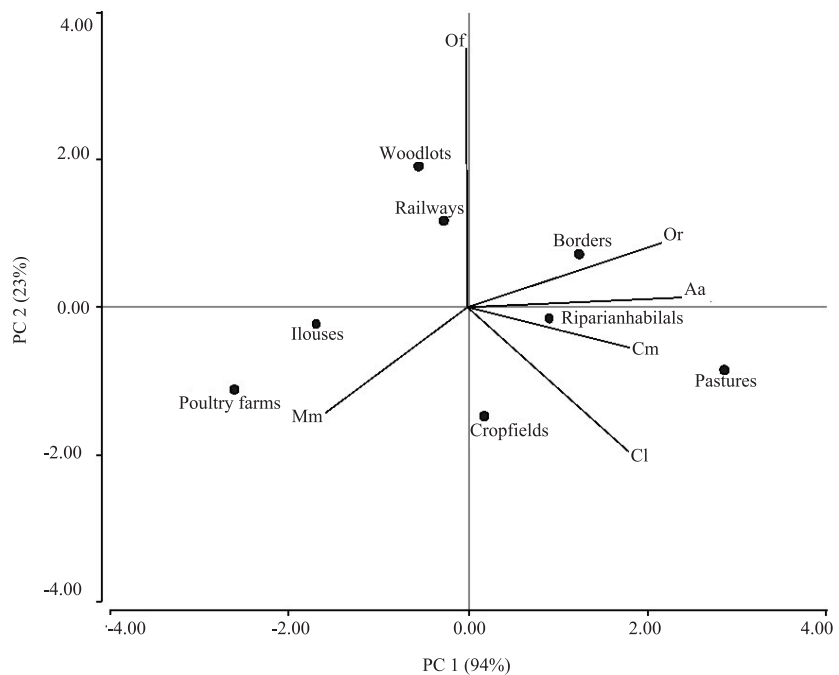
In 73% of the farms, the distribution of captures among sheds did not differ from an equal distribution, and there were no significant difference between internal and external sheds ( $t = -1.0703$ ,  $df = 16$ ,  $P = 0.3004$ ).

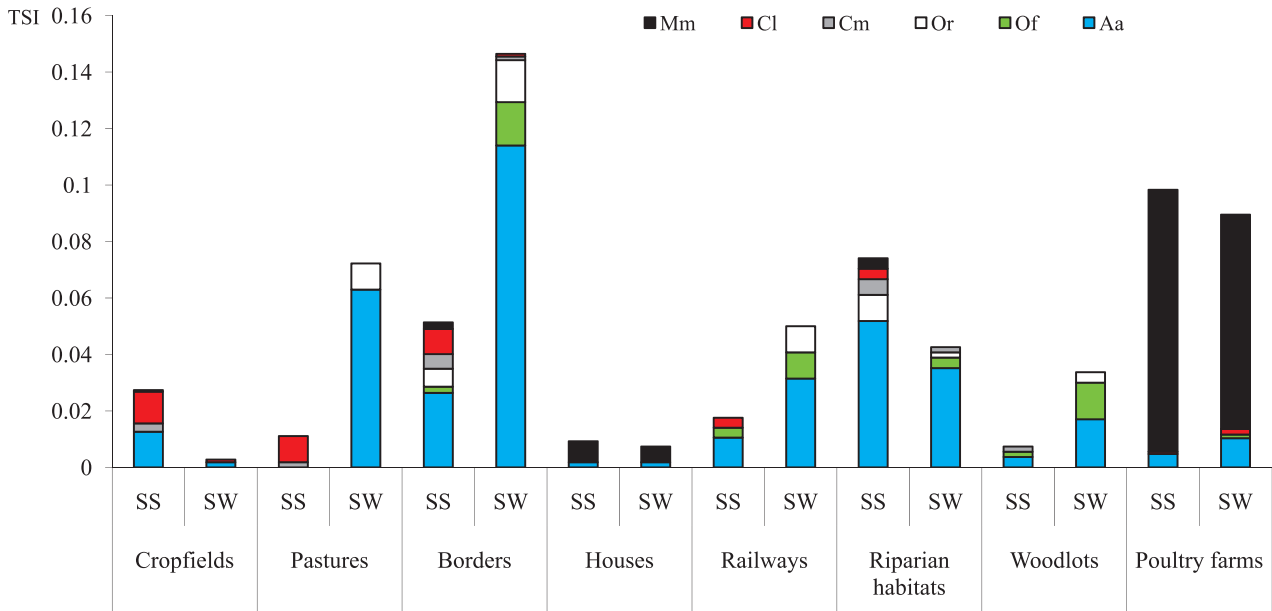
### Seasonal variation in abundance and reproductive activity

In poultry farms, the mean TSI of *M. musculus* did not show significant variation between periods (mean TSI 0.073 and 0.088 for autumn–winter and spring–summer periods, respectively,  $F = 0.75$ ,  $P = 0.42$ ), and there was no consistent trend of variation among seasons (Fig. 5).

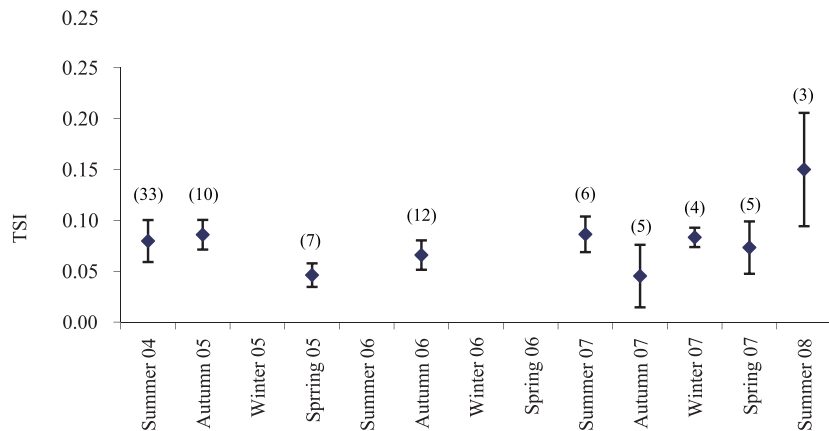
We found reproductively active individuals of both sexes in all months of the year, except for females in August 2007, probably because of the low sample size. However, the proportion of reproductively active males was significantly higher ( $P = 0.0000$ ) in the spring–summer period (0.690) than in the autumn–winter period (0.273). There were differences in the proportion of

**Figure 3** Biplot of principal component analysis (PCA) to describe the distribution of *Mus musculus* and native species abundance (trap success index, TSI) according to the different habitats studied. The species are represented by lines and the centroids of the habitats by full circles. PC1 and PC2: principal component 1 and 2, respectively; the explained variation for each component is shown in parentheses. *Aa*, *Akodon azarae*; *Cl*, *Calomys laucha*; *Cm*, *Calomys musculus*; *Mm*, *Mus musculus*; *Of*, *Oligoryzomys flavescens*; *Or*, *Oxymycterus rufus*.





**Figure 4** Trap success index (TSI) of the different rodent species according to the habitat and period. Data are mean values (the number of replicates is the same as in Table 2). Aa, *Akodon azarae*; Cl, *Calomys laucha*; Cm, *Calomys musculus*; Mm, *Mus musculus*; Of, *Oligoryzomys flavescens*; Or, *Oxymycterus rufus*. SS, spring-summer; AW, autumn-winter.

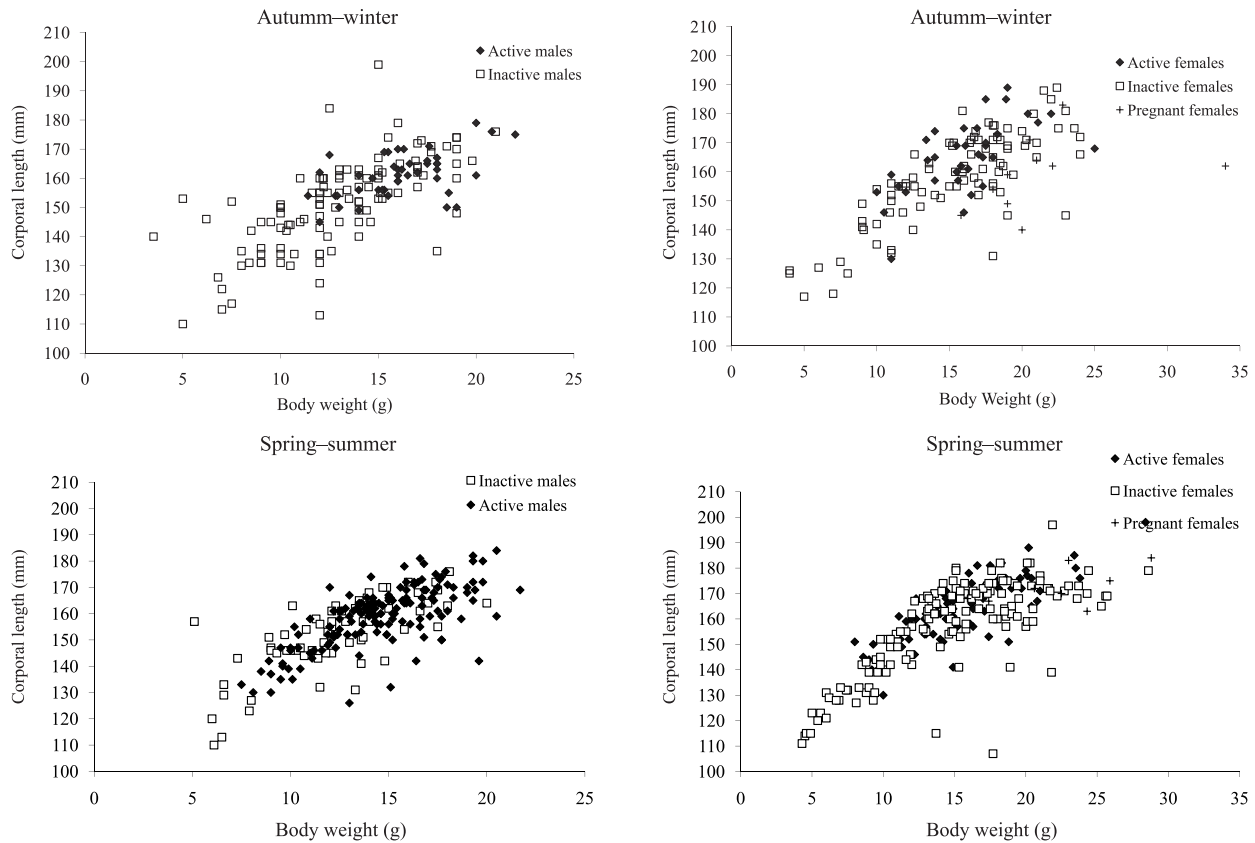


**Figure 5** Mean trap success index (TSI) of *Mus musculus* in poultry farms in each season and year of sampling. The bars indicate standard errors and sample size is shown in parentheses.

reproductively active females between periods (0.377 and 0.331 for spring–summer and autumn–winter, respectively,  $P = 0.395$ ). There were also no differences in pregnancy rates (number of pregnant females/active females) between periods (0.39 and 0.36 in autumn–winter and spring–summer, respectively,  $P = 0.325$ ).

For both periods and sexes, reproductively inactive individuals showed more variation in body weight and length than reproductively active individuals because of the presence of small individuals, whereas the larg-

est values were similar for inactive and active individuals (Fig. 6). There were no differences in body length according to the period in any of the categories considered (Table 3). Reproductively active males were significantly heavier in autumn–winter than in spring–summer (Table 3). This difference was probably due to differences in the minimal values, which were larger in autumn–winter (Table 3). There were no differences in body weight between periods for the other categories (Table 3).



**Figure 6** Corporal length and body weight of female and male *Mus musculus* according to the reproductive status for spring–summer and autumn–winter.

**Table 3** Differences in body length and differences in body weight according to the season for reproductively active and inactive individuals of both sexes

	Period	Min/Max	<i>H</i>	<i>F</i>	<i>n</i>	<i>P</i>
Differences in body length						
Reproductively active females	Spring–summer	130/198		0.150	113	0.7002
	Autumn–winter	130/189				
Reproductively inactive females	Spring–summer	107/197		0.320	232	0.5694
	Autumn–winter	117/189				
Reproductively active males	Spring–summer	88/184	0.99		192	0.3193
	Autumn–winter	145/179				
Reproductively inactive males	Spring–summer	75/176		0.000	176	0.9898
	Autumn–winter	97/199		176		
Differences in body weight						
Reproductively active females	Spring–summer	8/28.4		0.300	113	0.5830
	Autumn–winter	10/25				
Reproductively inactive females	Spring–summer			0.840	232	0.3602
	Autumn–winter	4/28.6				
Reproductively active males	Spring–summer	7.5/21.7		10.39	192	0.0015 <sup>†</sup>
	Autumn–winter	11.4/22				
Reproductively inactive males	Spring–summer	5.10/20		0.62	176	0.4323
	Autumn–winter	3.5/21				

Min/Max = Minimum and maximum value of the variable; *H* = test statistics of the Kruskal–Wallis test; *F* = test statistics of the analysis of variance test and *n* = sample size; <sup>†</sup>significant difference.



**Table 4** The change in the deviance between full and reduced regression models for *Mus musculus* presence outside peridomestic habitats containing the variables: distance to farms, distance to streams, *Akodon azarae* trap success index (TSI) (Aa), *Oligoryzomys flavescens* TSI (Of), *Calomys musculinus* TSI (Cm), *Calomys laucha* TSI (Cl) and *Oxymycterus rufus* TSI (Or); for Model 1 and distance to streams and farms (added sequentially) for Model 2

	Residual deviance	df	Change in deviance	df	P
Model 1					
Null model	48.5203	35			
Distance to farms	32.6269	34	11.8933	1	0.000 <sup>†</sup>
Distance to streams	28.7805	33	7.8464	1	0.005 <sup>†</sup>
Aa	28.4887	32	0.2919	1	0.589
Of	27.6879	31	0.8008	1	0.371
Cm	27.1069	30	0.5810	1	0.446
Cl	26.6415	29	0.4653	1	0.497
Or	23.5397	28	3.1018	1	0.078
Model 2					
Null model	48.5203	35			
Distance to streams	29.5643	34	18.9600	1	0.000 <sup>†</sup>
Distance to farms	28.7806	33	0.7838	1	0.337

<sup>†</sup>Significant difference.

**Table 5** The estimated parameters and approximate standard errors for the model fitted with distance to streams and distance to farms as explanatory variables for the presence of *Mus musculus*; and for the model fitted with only distance to streams as explanatory variable for the presence of *Mus musculus*

Variable	Parameter estimate	SE	df	Student's <i>t</i>	P
Distance to streams	0	0.6434	34	-2.1667	0.037 <sup>†</sup>
	-1.3940				
Distance to farms	-0.2147	0.2507	33	-0.8563	0.398
Distance to streams	-1.6402	0.6013	34	-2.7279	0.005 <sup>†</sup>

<sup>†</sup>Significant difference.

### Distance to poultry farms and streams, and the abundance of other rodent species as factors affecting *M. musculus* abundance

*Mus musculus* individuals captured in cropfields, borders and riparian habitats were males and females, adults and juveniles. According to the logistic regression for the model that included all variables, only the distance to farms and distance to streams were significant (Table 4). To assess the relative contribution of these 2 variables, in a second step, we included only these 2 variables (distance to streams first, Table 4). For both variables, there was a higher probability of *M. musculus* presence at shorter distances (Table 5). According to the difference in deviance explained with respect to the null model after considering the distance to streams, the distance to farms did not have a significant contribution, and, consequently, we fit the final model (that explains

39.06% of the deviance) with the distance to streams (as the explanatory variable) (Table 5).

### DISCUSSION

Our results confirm that in the study region *M. musculus* has only established populations in peridomestic habitats, and that *M. musculus* differs in habitat use to native species. There is a great difference between the population dynamics of *M. musculus* in agroecosystems of Argentina and similar habitats in Australia. In Argentina, its population is scarce, whereas in Australia, *M. musculus* often reaches plague levels and native rodent species are rare or sparsely distributed (Ylönen *et al.* 2002). The existence of an established community of native rodents in agroecosystems of Argentina probably restrains the invasion of *M. musculus* beyond poultry farms (Busch *et al.* 2005), although in this survey we could not confirm the effect of other rodent species on *M.*

*musculus* abundance. The absence of significant results may be due to the small sample sizes of *M. musculus* in cropfields, borders and riparian habitats.

The observed habitat distribution of *M. musculus* may have been the consequence of habitat selection, because *M. musculus* is strongly influenced by food availability (Ylönen *et al.* 2002; Jacob 2008), which is high in poultry farms (Miño *et al.* 2007). However, we cannot disregard that predation risk, which is probably lower in farms than in other habitats, may be determining habitat use (Ylönen *et al.* 2002). In contrast, we observed that human control was greater in houses than in poultry farms (V. Leon, pers. observ.), and this could be an alternative explanation of the lower abundance of *M. musculus* in houses than in poultry farms.

The low abundance of *M. musculus* observed in cropfields, borders and riparian habitats may explain the results of previous work where we found that rodent control in poultry farms is not more successful when anticoagulants are applied at a larger spatial scale (including not only poultry sheds, but also perimeters and surrounding habitats, León *et al.* 2009).

*Mus musculus* was evenly distributed among farms that are widely distributed in the study area, suggesting that this species was able to colonize all the area, but has stable populations only in farms and houses. Each farm may have been colonized independently (e.g. by passive transport by men) or by expansion from particular places. Genetic studies suggest that, although scarce, there are movements among farms. There is no evidence of passive transport (León *et al.* 2010).

Within farms, we did not find differences in abundance according to the location of the sheds (near or far from the perimeter of the farm), suggesting that *M. musculus* populations in farms have a local dynamic that is not strongly influenced by the surroundings (León *et al.* 2007; Miño *et al.* 2007).

*Mus musculus* abundance in poultry farms did not vary between seasons, and there was an approximate 2-fold increase between minimum and maximum values. In contrast, in cropfields, pastures, borders, railways, riparian habitats and woodlots, native rodents showed approximately 25-fold increases in abundance. The absence of a seasonal variation suggests that the population dynamic of *M. musculus* in poultry farms has a different pattern to the population dynamic of native species in other studied habitats, with low numbers in spring, increased numbers during summer and peak numbers in autumn and early winter (Zu-

leta *et al.* 1988; Mills *et al.* 1991). The absence of differences among seasons might be due both to the mild conditions of farms that allow reproduction throughout the year, or to the human effect (rodent control is obligatory for the poultry farms of the area; see <http://www.exaltaciondelacruz.gov.ar>), which stabilizes numbers. Although we found reproductively active individuals in sampled months, the proportion of reproductively active males was higher in the spring–summer period than in the autumn–winter period, when only males with high body weight were reproductively active. These results suggest that climatic conditions have an effect on reproductive activity, but the effect is not strong enough to cause significant difference in abundance (Vadell *et al.* 2010). Females did not show differences in reproductive activity during the studied period. A differential response in reproductive activity and size at maturation between males and females of *M. musculus* was also found in a previous study, where the removal of the dominant *A. azarae* in cropfield borders was followed by higher reproductive activity and lower weight of active *M. musculus* males, but there were no changes in females (Busch *et al.* 2005).

Our data suggests that *M. musculus* disperses outside poultry farms, but the probability of its presence decreases with the increase in distance to these habitats, and riparian habitats could be corridors between farm buildings, as suggested by Maisonnueve and Rioux (2001) for this species in Canadian agroecosystems. The high plant cover of the riparian habitats may reduce predation risk, enhancing survival during dispersal movements (Maisonnueve & Rioux 2001). However, to confirm these results, extended samplings are necessary in non-peridomestic habitats.

The reason why *M. musculus* does not form stable populations in non-commensal habitats remains an open question. Climatic conditions that affect reproduction (as suggested by the differences in reproductive activity in farms during the studied period) in outside conditions may limit abundance and favor competitive exclusion by native species. In poultry farms, the competitive dominance of native species may be reversed. Evidence of the dependence of *M. musculus* on human dwellings is its disappearance from a farm where it was previously abundant when the farm was abandoned and poultry sheds were retired. This farm was invaded by weeds and colonized by native rodent species, which were rare beforehand (León *et al.* 2010).

In summary, we conclude that in the studied agroecosystem, *M. musculus* has established populations only in

poultry farms, and those individuals found in cropfields and borders are probably dispersers. Riparian strips may be used as corridors for dispersing.

## ACKNOWLEDGMENTS

We are greatly indebted to the farm owners who allowed us to work in their properties. We are very grateful to Rosario Lovera and Maria F. Gonzalez (Certified Public Translation) for the revision of the English text. This work was funded by Universidad de Buenos Aires (UBACYT X098) and Agencia Nacional de Promoción Científica y Técnica (ANPCYT, PICT 12303 and 33513) grants.

## REFERENCES

- Bilenca DN, Kravetz FO (1995). Daños a maíz por roedores en la región pampeana (Argentina) y un plan para su control. *Vida Silvestre Neotropical* **4**, 51–7.
- Bilenca DN, Kravetz FO (1998). Seasonal variations in microhabitat use and feeding habitats of the pampas mouse *Akodon azarae* in agroecosystem of central Argentina. *Acta Theriologica* **43**, 195–203.
- Bonaventura SM, Cagnoni MC (1995). La vegetación de los bordes de caminos en agroecosistemas. *Physis* **50**, 63–71.
- Boursot P, Din W, Anand R *et al.* (1996). Origin and radiation of the house mouse: mitochondrial DNA phylogeny. *Journal of Evolutionary Biology* **9**, 391–415.
- Busch M, Kravetz FO (1992). Competitive interactions among rodents (*Akodon azarae*, *Calomys laucha*, *C. musculinus* and *Oligoryzomys flavescens*) in a two-habitat system. I. Spatial and numerical relationships. *Mammalia* **56**, 45–56.
- Busch M, Bilenca DN, Cittadino EA, Cueto G (2005). Effect of removing a dominant competitor, *Akodon azarae* (Rodentia, Sigmodontinae) on community and population parameters of small rodent species in Central Argentina. *Austral Ecology* **30**, 168–78.
- Castillo E, Priotto J, Ambrosio AM *et al.* (2003). Commensal and wild rodents in an urban area of Argentina. *International Biodeterioration and Biodegradation* **52**, 135–41.
- Cavia R, Cueto GR, Suárez OV (2009). Changes in rodent communities according to the landscape structure in an urban ecosystem. *Landscape and Urban Planning* **90**, 11–9.
- Crespo JA (1966). Ecología de una comunidad de roedores silvestres en el Partido de Rojas, Provincia de Buenos Aires. *Revista del Museo Argentino de Ciencias Naturales Bernardino Rivadavia* **1**, 79–134.
- Elias DJ (1988). Overview of rodent problem in developing countries. *FAO, Boletín Fitosanitario* **36**, 107–110.
- Google Earth (2007). Google Earth (Version 5.1.3533.1731) [Software]. Google Inc. Mountain View, CA. Available from URL: <http://www.google.com/earth/index.html>
- Gómez Villafañe IE, Bilenca DN, Cavia R, Miño MH, Cittadino EA, Busch M (2001). Environmental factors associated with rodent infestations in Argentine poultry farms. *British Poultry Science* **42**, 300–307.
- Hall AJ, Rebella CM, Ghersa CM, Culot PH (1992). Field-crop systems of the Pampas. In: Pearson CJ, ed. *Field Crop Ecosystems (Ecosystems in the World)*. Elsevier, Amsterdam, pp. 413–49.
- Harris DB, Macdonald DW (2007). Interference competition between introduced black rats and endemic Galapagos rice rats. *Ecology* **88**, 2330–44.
- Infostat (2009). Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Córdoba, Argentina.
- Jacob J (2008). Response of small rodents to manipulations of vegetation height in agro-ecosystems. *Integrative Zoology* **3**, 3–10.
- Kravetz F, Bellocq M, Busch M, Bonaventura SM, Monjeau A (1987). Efecto de la aplicación de un anticoagulante sobre la comunidad de roedores en campos de cultivo. *Anales del Museo de Historia Natural de Valparaíso* **18**, 153–6.
- León V, Guidobono JS, Busch M (2007). Abundancia de *Mus domesticus* en granjas avícolas, efectos locales vs efectos espaciales. *Ecología Austral* **17**, 189–98.
- León V, Fraschina J, Busch M (2009). Rodent control at different spatial scales on poultry farms in the province of Buenos Aires, Argentina. *International Biodeterioration & Biodegradation* **63**, 113–8.
- León V, Fraschina J, Busch M (2010). Population subdivision of *Mus musculus* in an agrarian landscape: consequences for control. *Canadian Journal of Zoology* **88**, 427–35.
- MacAllan BM, Westman W, Crowther MS, Dickman CR (2003). Reproduction and growth in house mice from cold, hot and thermally moderate environments. In: Singleton GR, Hinds LA, Krebs CJ, Spratt DM, eds. *Rats, Mice and People: Rodent Biology and Management*. ACIAR, Canberra, pp. 346–9.

- Maisonnueve C, Rioux S (2001). Importance of riparian habitats for small mammal and herpetofaunal communities in agricultural landscapes of southern Québec. *Agriculture, Ecosystems and Environment* **83**, 165–75.
- Mills JN, Ellis BA, Mckee KT, Maiztegui JI, Childs JE (1991). Habitat associations and relative densities of rodent populations in cultivated areas of central Argentina. *Journal of Mammalogy* **72**, 470–79.
- Miño MH, Cavia R, Gómez Villafaña IE, Bilenca DN, Cittadino EA, Busch M (2001). Estructura y diversidad de dos comunidades de pequeños roedores en agroecosistemas de la provincia de Buenos Aires, Argentina. *Boletín de la Sociedad de Biología de Concepción* **72**, 67–75.
- Miño MH, Cavia R, Gómez Villafaña IE, Bilenca DN, Busch M (2007). Seasonal abundance and distribution among habitats of small rodents on poultry farms. *International Journal of Pest Management* **53**, 311–6.
- Nicholls AO (1991). Examples of the use of generalized linear models in analysis of survey data for conservation evaluation. In: Margules CR, Austin MP, eds. *Nature Conservation: Cost Effective Biological Surveys and Data Analysis*. CSIRO, Australia, pp. 54–63.
- Pech RP, Davis SA, Singleton GR (2003). Outbreaks of rodents in agricultural systems: pest control problems or symptoms of dysfunctional ecosystems? In: Singleton GR, Hinds LA, Krebs CJ, Spratt DM, eds. *Rats, Mice and People: Rodent Biology and Management*. ACIAR, Canberra, pp. 311–5.
- Pefaur J, Hermosilla W, Di Castri F, González R, Salinas F (1968). A preliminary study of wild Chilean mammals: their distribution, economic value and zoological importance. *Revista Sociedad Médica Veterinaria (Chile)* **18**, 3–5.
- Pocock MJO, Hauffe H, Searle JB (2005). Dispersal in house mice. *Biological Journal of the Linnean Society* **84**, 565–83.
- Quinn G, Keough M (2002). *Experimental Design Data Analysis for Biologists*. Cambridge University Press, UK.
- Singleton GR, Krebs CJ, Davis S, Chambers L, Brown P (2001). Reproductive changes in fluctuating house mouse populations in southeastern Australia. *Proceedings of the Royal Society: Biological Sciences* **268**, 1741–8.
- Singleton GR, Sudarmaji, Jacob J, Krebs CJ (2005). Integrated management to reduce rodent damage to lowland rice crops in Indonesia. *Agriculture, Ecosystem and Environment* **10**, 75–82.
- Soriano A, León RJC, Sala OE *et al.* (1991). Rio de la Plata grasslands. In: Coupland RT, ed. *Natural Grasslands. Introduction and Western Hemisphere*. Elsevier, New York, pp. 367–407.
- Timm RM (1987). Commensal rodents in insulated livestock buildings. In: Richards CGJ, Ku TY, eds. *Control of Mammal Pests*. Taylor & Francis, London, pp. 15–8.
- Vadell MV, Cavia R, Suárez OV (2010). Abundance, age structure and reproductive patterns of *Rattus norvegicus* and *Mus musculus* in 2 areas of the city of Buenos Aires. *International Journal of Pest Management* **56**, 327–36.
- Witmer G, Jojola S (2006). What's up with house mice? –a review. In: Timm R, O'Brien J, eds. *Proceedings of the Twenty-second Vertebrate Pest Conference; 6–9 Mar 2006, Berkeley, USA*. University of California, Davis, pp. 124–30.
- Wu S, Lin Y, Yu H (2006). Population ecology of the southeast Asian house mouse (Muridae: *Mus musculus castaneus*) inhabiting rice granaries in Taiwan. *Zoological Studies* **45**, 467–74.
- Ylönen H, Jacob J, Davies MJ, Singleton GR (2002). Predation risk and habitat selection of Australian house mice *Mus domesticus* during an incipient plague: desperate behaviour due to food depletion. *Oikos* **99**, 284–9.
- Ylönen H, Jacob J, Runcie MJ, Singleton GR (2003). Is reproduction of the Australian house mouse (*Mus domesticus*) constrained by food? A large-scale field experiment. *Oecologia* **135**, 372–7.
- Zar JH (1996). *Biostatistical Analysis*. Prentice–Hall, USA.
- Zuleta GA, Kravetz FO, Busch M, Percich RE (1988). Dinámica poblacional del ratón del pastizal pampeano (*Akodon azarae*) en ecosistemas agrarios de Argentina. *Revista Chilena de Historia Natural* **61**, 231–44.