



# Wild small mammals in intensive milk cattle and swine production systems



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## ABSTRACT

Some rodent species are considered important pests around the world because they cause economic losses and sanitary problems. Although rodents are found in many different environments, they select habitat patches where resources are available. There is scant information regarding community composition and habitat distribution of small mammals in dairy and pig production systems. The aim of this research was to compare the composition of wild small mammal communities between intensive dairy and pig farms and to describe their distribution among habitats within the farms in northeast Buenos Aires province, Argentina. The intent is to contribute to management strategies of small mammals in these production systems. Ten pig farms and eight dairy farms were sampled seasonally during one year. Cage and Sherman live traps were set in five habitats within the farms. A total of 505 small mammals (270 in dairy farms and 235 in pig farms) were captured in 7026 cage trap-nights and 7333 Sherman trap-nights. In both production systems, the rodents captured included the dominant murines: *Rattus norvegicus*, *R. rattus* and *Mus musculus*, native sigmodontines: *Azodon azarae*, *Calomys laucha* and *Oligoryzomys flavescens* and the native caviid *Cavia aperea*. The opossums *Didelphis albiventris* and *Lutreolina crassicaudata* were also captured. The introduced murines used mainly human buildings, food storage sheds and animal sheds, whereas native species were more common in the vegetated environments among dwellings. A recommendation for control of pest rodent species would be to apply rodenticides only in dwellings to avoid accidental poisoning of non-target native species. Further studies on the damage produced by small mammal species and their role in the disease transmission in these production systems are necessary to identify management priorities.

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## 1. Introduction

In this work we compare the composition of wild small mammal communities in intensive dairy and pig farms, and their distribution among habitats within the farms to develop management strategies for small mammals in these production systems.

Animal species occurring within the same region select different habitat patches from the options available (Cody, 1985), including those in agricultural settings. Differential selection allows species to coexist (Pulliam, 1988; Abramsky et al., 1990; Darmon et al., 2012). The community structure and the population abundance of each species depend on local conditions, the

landscape context, historical events and evolutionary processes (Pimm and Rosenzweig, 1981; Pimm et al., 1985; Rosenzweig and Abramsky, 1986; Ricklefs, 1987; Kotliar and Wiens, 1990; Levin, 1992; Wiens et al., 1993). Small mammals select habitats and microhabitats, occupying mainly patches where resources are available (Braithwaite and Gullan, 1978; Van Deventer and Nel, 2006), suggesting that these animals perceive differences in patch quality and structure (Dueser and Shugart, 1978; Simonetti, 1989).

Synanthropic small mammals depend on food resources provided by humans (McKinney, 2006). Thus, small mammals such as some rodents and opossums are common in livestock production systems where food resources to feed livestock are abundant (Rowe and Swinney, 1977; Collins and Wall, 2004; Gómez Villafaña et al., 2004; Kijlstra et al., 2008; Leirs et al., 2004). Some rodent species are considered nuisance pests because they cause economic losses (Kravetz, 1991; Singleton et al., 1999; Drummond, 2001). In rural areas, particularly in livestock production systems, damage includes consumption and

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contamination of animal food, and structural damage to building components and equipment, all of which results in a decrease in production (Timm, 1987; Villa and Velasco, 1994). Rodents also cause sanitary problems since they are primary transmitters, reservoirs and mechanical vectors of more than 20 diseases (Webster and Macdonald, 1995; Glass, 1997). Opossums are considered a potential link between wild and domestic habitats for the transmission of zoonotic diseases (Gómez Villafañe et al., 2004; Pérez Carusi et al., 2009) since they have been documented carrying zoonotic etiological agents (Potkay, 1977; Potkay, 1977; Schweigmann et al., 1999; Gomes et al., 2003; Bodini Santiago et al., 2007; Pérez Carusi et al., 2009) and have been found in many environments, including forests, rural, domestic and peridomestic habitats (Cabrera and Yepes, 1960; Hunsaker II, 1977; Contreras, 1983; Gómez Villafañe et al., 2004) both in Australia and the Americas (Wynne and McLean, 1999). Problems associated with small mammals led to the implementation of chemical control measures but in many production systems problems still persist (Singleton et al., 1999). The persistence of these problems is likely due to the high reproductive potential of these animals, especially when conditions are favorable (Aplin et al., 2003; Ylönen et al., 2003; Gómez Villafañe et al., 2005).

Ecological studies on wild small mammals living on pig and dairy farms are scarce. There are many studies of small mammals on pig farms focusing on infectious diseases (e.g., Le Moine et al., 1987; Weigel et al., 2007; Friedman et al., 2008; Kijlstra et al., 2008; Van de Giessen et al., 2009), while studies of community composition and habitat use are rare (e.g., Leirs et al., 2004). To the best of our knowledge only two studies on small mammal composition on dairy farms have been reported in the last 40 years (Rowe and Swinney, 1977; Rowe et al., 1983). In the Pampas in central Argentina communities of small mammals have been studied in production systems such as poultry farms and agroecosystems, as well as in natural grasslands and urban environments. In these systems and environments, both native and introduced species of small mammals are present. The native species include six sigmodon species (*Oligoryzomys flavescens*, *Akodon azarae*, *Calomys laucha*, *C. musculus*, *Necromys obscurus* and *Oxymycterus rufus*), one caviid (*Cavia aperea*), and three opossums (*Lutreolina crassicaudata*, *Didelphis albiventris* and *Monodelphis dimidiata*), and the introduced species are the three commensal murines (*Mus musculus*, *Rattus norvegicus* and *R. rattus*) (Mills et al., 1991; Busch and Kravetz, 1992; Bilenca and Kravetz, 1995b; Miño et al., 2001; Gómez Villafañe and Busch, 2007; Miño et al., 2007; Pérez Carusi et al., 2009; Muschetto et al., 2011). The small mammal composition, relative abundances of each species and their habitat distribution are different among systems (Dalby, 1975; Hodara et al., 2000; Castellarini et al., 2003; Castillo et al., 2003; Gómez Villafañe and Busch, 2007; Miño et al., 2007; Andreo et al., 2009; Cavia et al., 2009; Gomez et al., 2009). Although pig and dairy farms are important in the Pampas, small-mammal communities in these production systems have not been studied in this area (Ribicich et al., 2005). Knowledge about the composition of small-mammal communities and their habitat distribution in production systems is essential to optimizing rodent management, protecting non-target species and minimizing transmission of rodent-borne diseases to humans and livestock.

## 2. Materials and methods

### 2.1. Study area

Fieldwork was conducted in Marcos Paz, General Las Heras, Exaltación de la Cruz and San Andrés de Giles (northeast of Buenos Aires province, Argentina (34° S, 58.5° W)). The study area is located in the Rolling Pampa, a subdivision of the Pampas region

(Soriano et al., 1991). The climate is temperate, with a mean annual temperature of 17.4 °C (IGM, 1998). It is the main agricultural area and one of the most important dairy production areas in Argentina. Almost all the original grasslands have been replaced by grain crops and natural or implanted pastures for raising livestock, consisting mainly of horses and dairy cattle (Soriano et al., 1991; Bilenca and Miñarro, 2004). The study area is a rural landscape also characterized by the presence of poultry and pig farms, both of which have increased significantly in numbers in recent years. Pig farms in this area account for 80% of the national pig production (Ribicich et al., 2005).

### 2.2. Production systems studied

On all the farms used for the study, cows were milked twice daily with milking machines. The milk was then stored directly in cold tanks. While milking, cows fed on nutritionally balanced food and then grazed on pastures, which were the main source of their diet. After each milking, farmers washed the dairy shed to ensure satisfactory hygienic conditions to prevent milk contamination and disease transmission. As a result, wastewater flowed into a drainage channel about 1.5–2 m wide, which usually ended into a pond located close to the shed. This wastewater contained cattle feces, hair and urine, along with substances used to sanitize the dairy shed. Storage sheds with food spread on the floor or in bags, silos and/or silage bags were common, providing ad libitum food sources to synanthropic mammals. Also, other buildings such as houses or warehouses were common. On most farms, the farmer's house was nearby the dairy shed. Vegetation growing spontaneously around the dwellings was used to feed cows, sheep and/or goats when present, as well as horses used to manage cattle. Because of grazing, vegetation was usually not mowed. However, the height, type of vegetation and vegetation cover varied among dairy farms and depended on the seasonality and type of management performed by the farmers. Poisoning was the only management action used against rodents. Personnel responsible for operating the farms were employees and all management decisions on each farm were made by the owners, managers or other professionals such as veterinarians or agronomists.

Intensive pig farms considered in this study consisted of indoor breeding in sheds, because free rearing for commercial purpose is forbidden (Res. No. 225/1995, SENASA, 1995). Pig age classes were held in different types of sheds since each age class has special management requirements. As on dairy farms, pig farms also included food storage sheds or silos, other buildings (houses, warehouses, offices) with spontaneous vegetation growing around, as well as pig sheds with their respective drainage channels. Food sources were also present ad libitum in all sheds, mainly in feeders, but also spilled on the floor. Pig sheds were also washed with water frequently and on some pig farms septic tanks were present. Drainage channels carried the wastewater from the pig sheds into a pond for wastewater treatment. This wastewater contained remnants of food eaten by pigs, together with pig feces, hair and urine. Drainage channels both in dairy and pig farms sometimes filled up with organic material and had to be emptied and thus often deepened. Soil removed from these channels was then subsequently placed alongside the drainage channel itself, resulting in dirt mounds where spontaneous tall herbaceous vegetation often grew to over 1 m height (Lovera, unpublished results).

Unlike dairy farms, pig farms rodent infestations were a major concern due to the threat of Trichinosis transmission to pigs, since Trichinosis is endemic in Argentina and can be carried by rodents. As a result, some pig farms frequently used chemical products for rodent control, applied by the farmers or by pest control companies. Nevertheless, there were periods in which farms

remained untreated because farmers could not afford the cost of treatment.

Both production systems were typically surrounded by crops, grasslands and/or pastures for livestock.

### 2.3. Trapping procedure

Trapping surveys were conducted on 10 pig farms and eight dairy farms from December 2008 to November 2011. Each farm was sampled for four consecutive seasons. Five habitats were surveyed on pig and dairy farms: 1. animal sheds (dairy and pig sheds), structures in which pigs or cows were present, either continuously as in pig sheds or intermittently at dairies in which cows were taken for milking twice daily; 2. food storage sheds or silos, structures used to store food; 3. human buildings, dwellings with high human activity not used to store food, such as houses, machinery sheds, warehouses and offices; 4. vegetated areas around dwellings; 5. drainage channels deepened over time, and subsequent nearby dirt mounds with tall herbaceous vegetation. Not all habitats were present on all the farms.

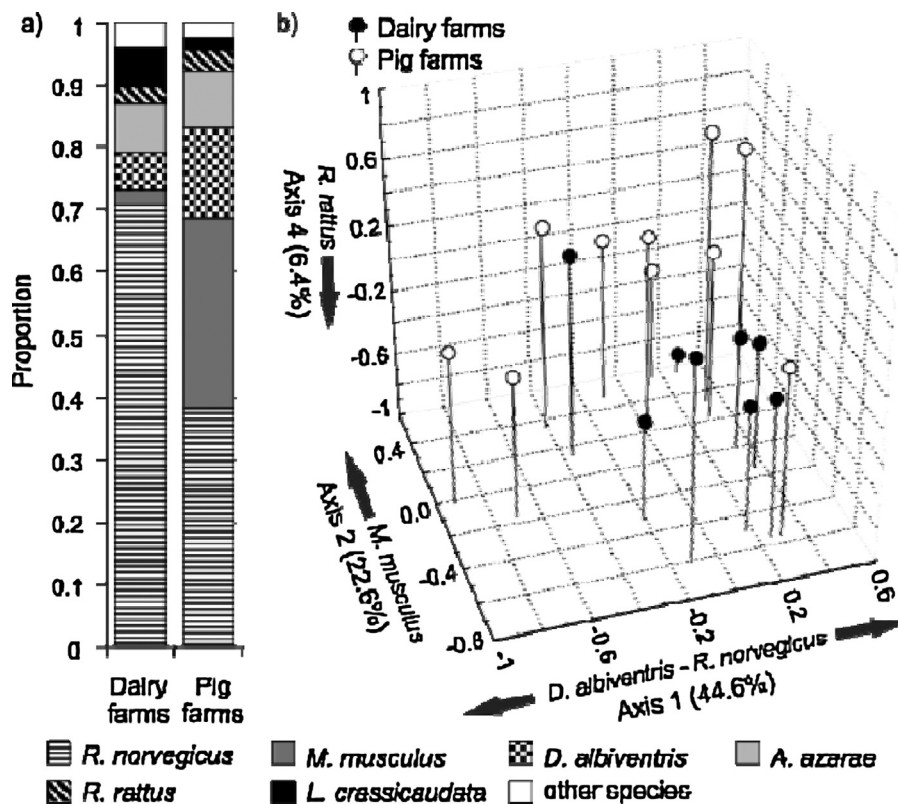
Individual small mammals were captured using cage live traps ( $15 \times 16 \times 31$  cm) baited with beef and carrot, and Sherman traps ( $8 \times 9 \times 23$  cm) baited with a mixture of peanut butter, bovine fat and rolled oats. The two types of traps were set adjacent to each other every 10 m along trap lines of 50–100 m with 1–3 replicates per habitat depending on the farm structure. The location of traps was the same in each survey. Traps were active for three consecutive nights and checked daily in the morning. Captured individuals were identified to species and date and trap location were recorded. Animals were sacrificed to collect tissue samples for parasitological studies.

### 2.4. Data analysis

The abundance of each species was estimated based on trap success. Trap success was calculated for each trapping session for each environment, season and farm as the number of individuals captured/number of trap-nights. The number of sprung traps without captures was considered as 0.5 trap-nights (Cavia et al., 2012). When more than one trap line was placed in an environment within a farm, all captures and traps for this environment were pooled to estimate trap success.

To compare the small mammal community structure between the two production systems, a Principal Components Analysis (PCA) was performed on mean annual trap success for each species captured on each of the 18 farms. Trap success data were transformed using Hellinger standardization according to Borcard et al. (2011), prior to PCA. Principal Components (PCs) were computed from the covariance matrix (Legendre and Legendre, 2012). This analysis was performed using the *vegan* package (Oksanen et al., 2013) from the R software, version 3.0.1 (R Core Team, 2013). A Multivariate Analysis of Variance (MANOVA) was conducted on farm PCs' scores to determine if the two production systems were separated in the PCA space. A backward stepwise procedure was used to obtain the simplest MANOVA model using Infostat software (Di Rienzo et al., 2008).

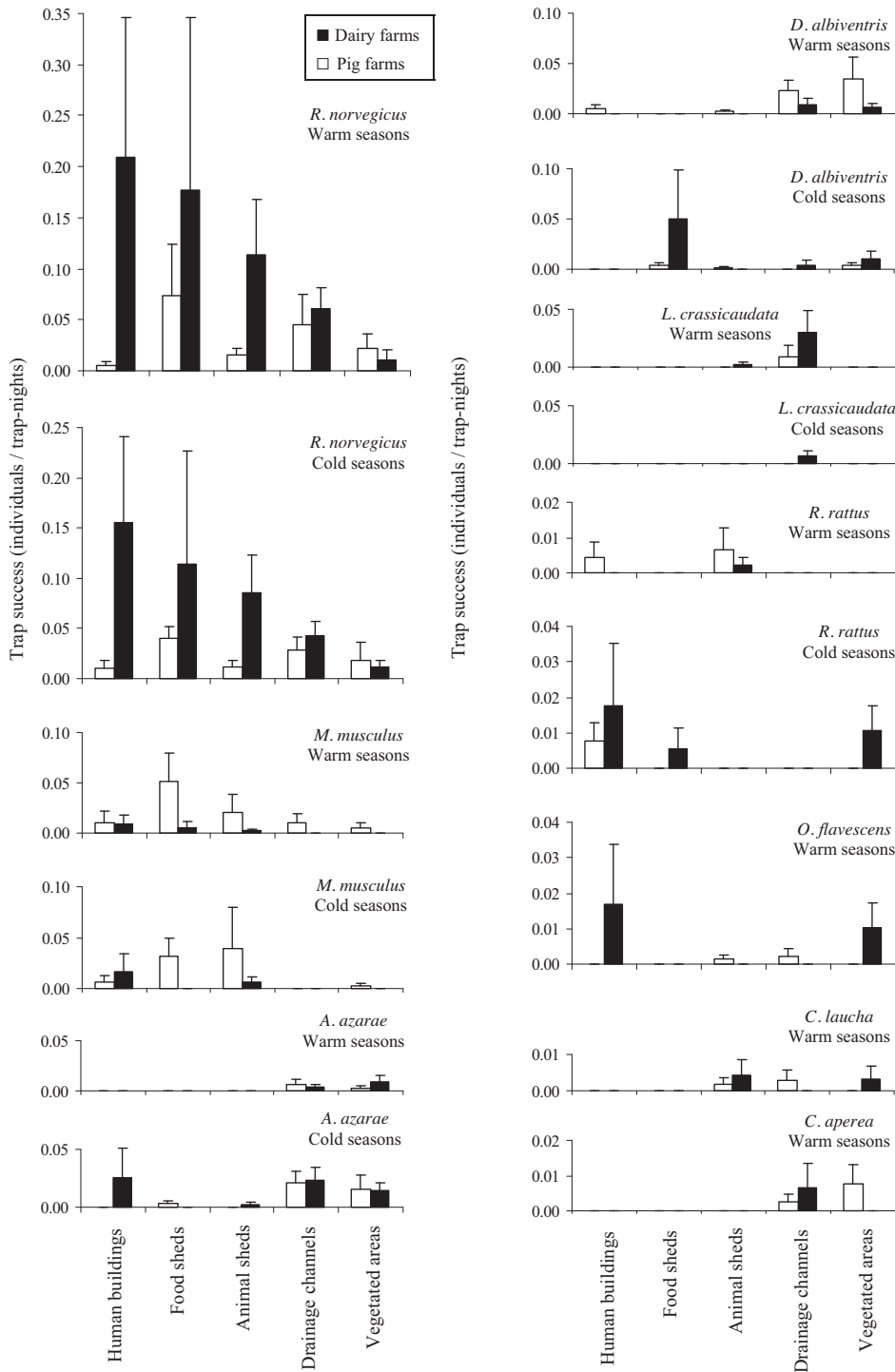
To analyze the spatial distribution of each species among environments, the abundances were compared among the five habitats and the two production systems, taking into account possible seasonal and year effects. For this, Generalized Linear Mixed Models (GLMM) with binomial error structure, a logit-link function and the Laplace approximation method were used (Bolker et al., 2009; Zuur et al., 2009; Crawley, 2012). We included farms as a random effect to account for variation in trap success among



**Fig. 1.** (a) Small mammal species in dairy and pig farms of the northeast of Buenos Aires province (Argentina). *C. laucha*, *O. flavescens* and *C. aperea* were pooled (other species) because of the small number of captures. (b) Principal Components Analysis on mean annual trap success of the nine species captured. The value of the proportional variance explained for each Principal Component retained by the MANOVA analysis is stated in parentheses. The arrows show the direction of association to species-specific trap success (with Pearson  $r > |0.5|$ ).

farms. Candidate models for trap success included all possible combinations of the main effects of the production system, season, habitat and their interactions, and the effect of the year of the study. The effect of the year of the study was not evaluated in the interactions with the other factors. The effect of the production system was evaluated as a two-level fixed factor (dairy and pig farms), the effect of habitat as a five-level fixed factor, and the effect of year as a three-level fixed factor. We were forced to group

the four seasons in two levels: warm seasons (summer and spring) and cold seasons (winter and autumn) because the number of captured individuals in each trapping session did not reach the minimum requirement for this statistical analysis. Thus, the season effect was included as a two-level fixed factor. When the dispersion factor was larger than 1.5, we used GLMM with penalized quasi-likelihood to correct over-dispersion (Zuur et al., 2009). Initially, we fitted the full model and then simplified the model by dropping



**Fig. 2.** Mean trap success (individuals/trap-nights) and standard errors of each species, in dairy (black bars) and pig (white bars) farms, in five habitats in warm and cold seasons. For *O. flavescens*, *C. laucha* and *C. aperrea* only the warm seasons are shown because no individuals were captured in the cold seasons. Note that graphs of the species less captured are at a different scale (*R. rattus*, *O. flavescens*, *C. laucha* and *C. aperrea*) than species captured more often (*R. norvegicus*, *M. musculus*, *A. azarae*, *D. albiventris* and *L. crassicaudata*).



the non-significant higher-order interactions or terms from the model (Zuur et al., 2009), with subsequent model comparison. Only the simplified best-fit model is reported. Significance of the random effect was also tested, based on change of deviance between models with and without the random effect (Zuur et al., 2009). GLMM were conducted using the *lme4* (Bates et al., 2013) and *MASS* packages (Venables and Ripley, 2002) from the R software (R Core Team, 2013). *A priori* multiple comparisons were performed using the *multcomp* (Hothorn et al., 2008) and *car* (Fox and Weisberg, 2011) packages from the R software (R Core Team, 2013).

### 3. Results

A total of 505 individuals (270 in dairy farms and 235 in pig farms), belonging to two different small-mammal groups (Rodentia and Didelphimorphia), were captured with a trapping effort of 7333 Sherman trap-nights and 7026 cage live trap-nights. Rodents captured included introduced murines: *R. norvegicus* ( $n=281$ ), *R. rattus* ( $n=17$ ) and *M. musculus* ( $n=86$ ), the three native sigmodontines: *A. azarae* ( $n=41$ ), *C. laucha* ( $n=6$ ) and *O. flavescens* ( $n=7$ ) and the native caviid *C. aperea* ( $n=6$ ). Opossums *D. albiventris* ( $n=41$ ) and *L. crassicaudata* ( $n=20$ ) were also captured. All species were captured both on dairy and pig farms, and murines represented more than 70% of the total captures in both production systems (Fig. 1a). *R. norvegicus* was the dominant species in both systems and although *M. musculus* was poorly represented on dairy farms it was second most frequently captured on pig farms (Fig. 1a).

The first four PCs explained 88% of the association among trap success of the captured species. PC1 separated farms with high trap success of *R. norvegicus* and low trap success of *D. albiventris* (Pearson  $r=0.75$  and Pearson  $r=-0.99$ , respectively) from farms which exhibited the opposite pattern. PC2 separated farms with high trap success of *M. musculus* (Pearson  $r=0.91$ ) from farms with low trap success of this species, while PC3 separated farms with low trap success of *A. azarae* and *O. flavescens* (Pearson  $r=-0.74$  and Pearson  $r=-0.59$ , respectively) from farms with high trap success of both species. PC4 separated farms with low trap success of *R. rattus* (Pearson  $r=-0.65$ ) from farms with high trap success of this species. According to the backward stepwise procedure, the simplest MANOVA model retained PC1, PC2 and PC4 ( $F_{3,14}=3.83$ ,  $p=0.034$ ), indicating that the abundances of *R. norvegicus*, *R. rattus*, *M. musculus* and *D. albiventris* differed between dairy and pig farms (Fig. 1b). There were fewer *M. musculus*, as well as more *R. rattus* at equal abundances of *R. norvegicus* on dairy farms than on pig farms which exhibited the opposite pattern. The PCA also separated two pig farms (on the left side of PC1 axis, Fig. 1b) with high abundance of *D. albiventris* and low numbers of *M. musculus*, *R. rattus* and *R. norvegicus*. Using these three PCs, the MANOVA assigned correctly 16 of the 18 sampled farms according to their type of production system.

*R. norvegicus* was the only species found in all habitats in the two production systems. This species tended to be captured mostly during the warm seasons ( $p=0.067$ , Fig. 2). The simplest model obtained for this species showed that abundance patterns among habitats differed between types of production system (Table 1). On dairy farms, *R. norvegicus* trap success was lower in vegetated areas than in food storage sheds or silos and dairy sheds (*a priori* comparisons,  $z=3.13$ ,  $p=0.014$ ,  $z=3.08$ ,  $p=0.016$ , respectively) and showed a similar tendency in human buildings ( $z=2.63$ ,  $p=0.060$ ). In contrast, on pig farms, similar abundances were found among habitats ( $p>0.05$  for all pairs of comparisons). Furthermore, trap success was higher in human buildings on dairy farms than in human buildings on pig farms ( $z=2.76$ ,  $p=0.026$ ) and higher in dairy sheds than in pig sheds ( $z=2.56$ ,  $p=0.046$ ).

**Table 1**

Summary of the GLMM simplest-model for trap success of *R. norvegicus*, *M. musculus*, *A. azarae* and *D. albiventris*. The effects of production system, habitat, seasons and year were analyzed. Farms were included as a random effect. Only significant effects are reported (see text). Table entries state the corresponding statistics:  $z$ -values for binomial errors and  $t$ -values for quasi-binomial errors with degrees of freedom,  $p$  values, and change in deviance for the random effect. For each model the explained deviance ( $R^2$ ) is stated.

Factor	Statistics	$p$
<i>R. norvegicus</i> model ( $R^2=0.15$ )		
Intercept	$t_{104} = -7.11$	<0.001
Production system: habitat	$t_{104} = 2.79$	0.006
Farm	Change in deviance: $\chi^2_1 = 174.70$	<0.001
Dispersion parameter	2.54	
<i>M. musculus</i> model ( $R^2=0.21$ )		
Intercept	$t_{52} = -3.07$	0.003
Production system: habitat <sup>a</sup>	$t_{52} = -2.02$	0.048
Farm	Change in deviance: $\chi^2_1 = 94.22$	<0.001
Dispersion parameter	2.23	
<i>A. azarae</i> model ( $R^2=0.09$ )		
Intercept	$z = -12.62$	<0.001
Seasons	$z = 3.01$	0.003
Farm	Change in deviance: $\chi^2_1 = 11.13$	0.001
Dispersion parameter	1.36	
<i>D. albiventris</i> model ( $R^2=0.09$ )		
Intercept	$z = -5.58$	<0.001
Production system: habitat <sup>b</sup>	$z = -2.79$	0.005
Farm	Change in deviance: $\chi^2_1 = 16.76$	<0.001
Dispersion parameter	1.52	

<sup>a</sup> *M. musculus* habitat: animal sheds, human buildings and food storage sheds or silos.

<sup>b</sup> *D. albiventris* habitat: food storage sheds, drainage channels and vegetated areas.

*R. rattus* was captured in all the habitats except in drainage channels (Fig. 2). Trap success was similar among human buildings and animal sheds, the two production systems, and the three years of the study. Differences between seasons and in the other environments could not be tested due to the low numbers of captures.

*M. musculus* was captured mainly in human buildings, food storage sheds or silos and animal sheds (Fig. 2). On dairy farms, *M. musculus* was not captured in drainage channels or vegetated areas, whereas on pig farms a small number of individuals were captured in these habitats (Fig. 2). *M. musculus* showed no seasonal differences in trap success ( $p>0.05$ ). On pig farms, trap success was greater in food storage sheds or silos than in human buildings and pig sheds ( $z = -3.41$ ,  $p=0.002$  and  $z=2.32$ ,  $p=0.050$ , respectively), and showed a tendency of a higher trap success in pig sheds than in human buildings ( $z = -2.28$ ,  $p=0.054$  and Table 1). On dairy farms, trap success was similar among habitats ( $p>0.05$  for all comparisons). Trap success in the three habitats was similar in both types of production system ( $p>0.05$  for all comparisons).

*A. azarae* was captured mainly in vegetated areas and drainage channels (Fig. 2). Trap success in the other three habitats was low (only five individuals were captured in the cold seasons) (Fig. 2). *A. azarae* was captured more frequently during the cold seasons both in vegetated areas and in drainage channels (Table 1).

*O. flavescens*, *C. laucha* and *C. aperea* were only captured during cold seasons and in low numbers (Fig. 2), representing less than 4% of the total captures (Fig. 1a). These three native species were captured in vegetated areas and drainage channels. *O. flavescens* was captured also in human buildings and pig sheds. *C. laucha* was captured also in animal sheds (Fig. 2).

On pig farms, the opossum *D. albiventris* was captured mainly in food storage sheds or silos, drainage channels and vegetated areas, and few individuals were captured in pig sheds and human

buildings, whereas on dairy farms, *D. albiventris* was not captured in those habitats (Fig. 2). Trap success showed a different pattern among habitats between seasons in each production system (Fig. 2). However, this interaction could not be tested. *D. albiventris* abundance among habitats differed between dairy and pig farms (Table 1). On dairy farms, *D. albiventris* trap success was greater in food storage sheds than in drainage channels and vegetated areas ( $z=2.58$ ,  $p=0.026$  and  $z=2.50$ ,  $p=0.033$ , respectively). On pig farms, trap success was similar among the three habitats ( $p>0.05$  for all cases, Fig. 2). This opossum showed similar trap success among the three habitats when compared between both types of production systems ( $p>0.05$  for all cases, Fig. 2).

The other opossum, *L. crassicaudata*, was mostly found in drainage channels and only one individual was recorded in a dairy shed (Fig. 2). The trap success of this opossum showed no differences between production systems in drainage channels ( $p>0.05$ , Fig. 2), or during the three years of the study ( $p>0.05$ ).

#### 4. Discussion and conclusions

This survey demonstrated for the first time a rich assemblage of nine introduced and native small mammal species in dairy and pig farms in Argentina. However, not all the species of the study area were present in both production systems. Although *C. musculus* or *O. rufus* occurred on poultry farms (Mills et al., 1991; Busch and Kravetz, 1992; Bilenca and Kravetz, 1995b; Busch et al., 2006; Miño et al., 2007; León et al., 2013), we did not find these species. Dairy and pig farms were characterized by high anthropic activity, high livestock densities and consequently a great amount of food available to wild small mammals. The environment within the farms was highly heterogeneous, with a variety of diverse and contrasting habitats such as vegetated areas and drainage channels, both with tall herbaceous vegetation. Although the farms were relatively small (with areas of around  $4.27 \pm 1.17$  ha) where small mammals could move among available habitats, habitat selection was different among species. This selection produced spatial segregation that allowed the species to coexist in these systems (Kotliar and Wiens, 1990; Levin, 1992; Wiens et al., 1993).

Species composition and relative abundance on pig and dairy farms were similar to those on poultry farms, where the introduced murines have been found to be the dominant species, accompanied by some native species (Gómez Villafañe et al., 2001, 2004; Gómez Villafañe and Busch, 2007; León et al., 2009). Different seasonal patterns of abundance were observed: *R. norvegicus* and *M. musculus* showed similar abundances in the two seasons, the native rodent species showed higher abundance in the cold seasons than in the warm seasons, and the opossum *L. crassicaudata* showed higher abundance in the warm seasons than in the cold seasons. In contrast, *R. rattus* and *D. albiventris* did not show clear seasonal patterns of abundance. Although our removal of individuals could have affected the seasonal patterns of abundance, the seasonal patterns observed in this study are consistent with those reported for these species in the study region (see below). Therefore, removal sampling appeared to have no sustainable effect on population size, probably due to compensatory population growth and/or immigration of individuals from surrounding habitats. Otherwise, no differences in the species abundance were detected among years, suggesting that the populations were stable throughout the study period. Native species and introduced murines also differed in their spatial distribution among environments. The introduced murines used mainly human buildings, food storage sheds and animal sheds, whereas native species were more concentrated in the vegetated environments. To avoid accidental poisoning of non-target species, since some native species are not pests, rodenticides to control

murine pest rodents should be applied only in human buildings, food storage sheds and animal sheds. However, some authors have documented that when rodents are removed from dwellings there is an increase of immigration movements from surrounding habitats, which might increase the risk of diseases transmission (Douglass et al., 2003). Therefore, future studies on these aspects are required.

The dominance of *R. norvegicus* (Rowe and Swinney, 1977; Webster et al., 1995; Stojcevic et al., 2004; Backhans and Fellström, 2012) and *M. musculus* (Rowe and Swinney, 1977; Rowe et al., 1983; Backhans and Fellström, 2012) observed in the two production systems has been documented on other farms around the world. In Buenos Aires, these two species are also dominant in chicken sheds on poultry farms (Gómez Villafañe and Busch, 2007; Miño et al., 2007; León et al., 2009). The similarity in the small mammal composition on dairy and pig farms compared to poultry farms could be related to the fact that they are all intensive domestic animal production systems with similar environmental characteristics. Poultry farms are also characterized by high animal densities, great amounts of food available to wild small mammals and plentiful poultry sheds surrounded by vegetated areas. This arrangement seems to provide food, shelter and habitat conditions that suit similar small-mammal communities.

Human buildings, animal sheds and storage food sheds were somewhat different between dairy and pig farms, leading to differential abundance patterns of *M. musculus* and *R. norvegicus*. As pig farms are usually much larger than dairy farms (mean pig farms area:  $6.84 \pm 1.72$  ha; mean dairy farms area:  $1.08 \pm 0.17$  ha), they have more and larger animal sheds and food is more abundant than on dairy farms. Perhaps most importantly, pigs are present continuously inside pig sheds while cows are inside for only a few hours per day. Consequently, there is less animal and personal movement in dairy sheds than in pig sheds. Therefore, *R. norvegicus* may prefer dairy sheds over pig sheds. Human buildings and food storage sheds had similar characteristics in the two production systems. On dairy farms, in these two habitats as well as in animal sheds, the high abundances of *R. norvegicus* compared to the abundances of *M. musculus* could be explained by competitive dominance of *R. norvegicus* over *M. musculus* (McCartney & Marks, 1973 in Yom-Tov et al., 1999) or even predation by *R. norvegicus* on *M. musculus* (Moors, 1900 in Yom-Tov et al., 1999). In contrast, on pig farms, trap success of *M. musculus* and *R. norvegicus* was similar among human buildings, food storage sheds and animal sheds. The higher number of dwellings on pig farms could help *M. musculus* find places to avoid spatial overlap with *R. norvegicus*. Although *R. norvegicus* was mostly captured in three habitats, it used all habitats in both production systems probably because its high abundances forced some individuals to live in suboptimal habitats inside the farms.

Vegetated areas and drainage channels seemed to be similar in their structure for rodents between the two production systems. It is interesting that *M. musculus* was scarce while *A. azarae* was abundant in vegetated areas and drainage channels. Since *M. musculus* has been reported to be a poor competitor and more restricted to commensal habitats than *A. azarae* (Busch et al., 2005), this difference in abundance between the two species could be related to interspecific competition between them. The high abundance of *A. azarae* in vegetated areas and drainage channels was probably related to the dense cover of tall herbs (Lovera, unpublished data), which is selected by this native species (Mills et al., 1991; Busch and Kravetz, 1992; Bilenca and Kravetz, 1995b; Frascina et al., 2009).

*R. rattus* is also competitively subordinate to *R. norvegicus* (Barnett, 1958), which could explain why this species was rare in the two production systems. *R. rattus* is more likely to inhabit environments that lack *R. norvegicus*. Studies in urban areas and on

poultry farms also support the avoidance idea (Gómez Villafañe and Busch, 2007; Cavia et al., 2009; Yom-Tov et al., 1999).

Neither *M. musculus* nor *R. norvegicus* showed seasonal variations in abundance, in agreement with other studies conducted in poultry farms (Gómez Villafañe and Busch, 2007; Miño et al., 2007). The lack of seasonal variation in murines was contrary to that observed in the native rodent species, which were more abundant during the cold seasons. The higher abundance during the cold season was typical for the seasonal variation reported in crop borders and poultry farms (Mills et al., 1991; Busch and Kravetz, 1992; Bilenca and Kravetz, 1995a; Gómez Villafañe et al., 2001; Miño et al., 2007). On the studied farms, the supply of food and water inside buildings were constant, the environmental conditions were mild throughout the year, and the number of refuges was high as in other production systems like poultry farms (Gómez Villafañe and Busch, 2007). The absence of variation in seasonal abundance in *R. norvegicus* and *M. musculus* is probably a consequence of stable conditions, which could allow yearlong breeding. Native species, in contrast, are subject to seasonal variation of resources such as vegetation cover (Jacob, 2008), insect and seed abundance (Cittadino et al., 1994; Lima et al., 2002) and may also be affected by low temperature and other adverse climatic conditions (Crespo, 1966; Castellarini and Polop, 2002).

The opossum *L. crassicaudata* was more abundant during the warm seasons than during cold seasons. This could be related to its period of reproductive activity, which begins and ends during the warm seasons (Regidor et al., 1999; Pérez Carusi et al., 2009). In a Natural Reserve in this region, Muschetto et al. (2011) also found fluctuations in seasonal abundance, but reported higher peaks in trap success in autumn than in spring. We would expect the same seasonal pattern in *D. albiventris*. Considering the seasonal variations in the vegetated environments, we observed higher abundances in the warm seasons than in the cold seasons. These opossums are often nomadic (Hunsaker II, 1977) which can bias trap revealed habitat selection. In this study, *D. albiventris* used mostly environments with vegetation and water, but was also captured in food storage sheds, indicating an association with habitats where food is available. *L. crassicaudata* was associated mainly with drainage channels, consistent with reports that state that opossums are very common in areas with permanent water (Hunsaker II, 1977; Regidor et al., 1999). It would be interesting to analyze the effect of *L. crassicaudata* on small rodents, since some authors consider this opossum a frequent predator of small rodents (Streilein, 1982; Díaz and Barquez, 2002).

Some of the species considered here are introduced rodent pests that damage crops, stored goods, and infrastructure and can transmit zoonotic diseases. Although it is unclear if opossums of the family Didelphimorphia are pests in Argentina, they are locally troublesome in hen houses and poultry farms (Jackson, 1988; Pérez Carusi et al., 2009). On both poultry farms and the dairy and pig farms studied here, farmers perceived them as plagues due to the extensive damage they generate, and because they attack both domestic and other production animals within farms.

Understanding aspects of the biology and ecology of pest species, such as habitat use of commensal rodents, is crucial to managing damage properly as well as to understanding the dynamics of rodent-borne diseases and to minimize disease transmission (Mills, 1999). Here, we identified the small mammal species present in pig and dairy production systems in central Argentina. Our results may help to decrease both rodent and opossum damage and disease risk as well as to protect non-target species. However, to identify risk associated with wild small mammal infestation in dairy and pig farms, damage produced by introduced and native species as well as their role in disease transmission should be studied. Our results indicate that (1)

murines should be controlled in all habitats or only in dwellings if native non-target species are of concern; and if necessary (2) native rodent species should be controlled in vegetated habitats, mainly during the cold seasons, and (3) opossums should be controlled in vegetated habitats mainly during the warm seasons. Nevertheless, it should take into account that individuals that survive control actions could quickly recover its population because of its high reproductive potential (Aplin et al., 2003; Macdonald et al., 1999) and, as mentioned, the removal of animals may increase immigration movements and consequently disease transmission (Douglass et al., 2003). Future studies should also identify environmental factors that favor small mammal pest populations, and would help prevention and control management decisions.

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