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Seasonal variations in small mammal-landscape associations in temperate agroecosystems: a study case in Buenos Aires province, central Argentina

Abstract: We studied the associations between small mammal assemblages and patterns of land use and landscape structure, and their seasonal variations in temperate agroecosystems. We collected barn owl, *Tyto alba*, pellets from nest sites located in the Pampean region included in Buenos Aires province (36 sites in winter and 29 in summer). We used Google Earth and SAC-C imagery classification to describe land use and landscape structure around pellet collection sites. In winter, we found a significant relation between the relative abundances of small mammal species and landscape variables. Landscape accounted for 33.2% of variance in species data. *Calomys* spp. were relatively more abundant in sites with higher winter crops cover, while *Akodon azarae* and *Oligoryzomys flavescens* increased their relative abundances in sites with more grassland cover. The commensal rodents *Mus musculus* and *Rattus* spp. were relatively more abundant in sites with higher urban cover, or near households and grain storage facilities. We found no significant small mammal-landscape association in summer. Our results are in agreement with previous studies showing that land use patterns may influence small mammal assemblages. Moreover, our results also show that seasonality plays a major role modulating the intensity of these small mammal-landscape associations in temperate agroecosystems.

Keywords: agricultural intensification; land use; owl pellets; Pampas; sigmodontine rodents.

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Introduction

The replacement of natural systems by agroecosystems introduces important changes in land use patterns and landscape structure (Vitousek et al. 1997, Foley et al. 2005). Although the establishment of an agroecosystem is mainly regarded as a homogenizing process (Wood et al. 2000), baseline differences in geomorphology, climate and soil types, as well as politic divisions among different areas of the same region could produce different land use patterns and landscape structures (Weibull et al. 2003).

Land use patterns and the landscape structure affect species abundances by modifying habitat and food availability and altering dispersion processes (Atauri and de Lucio 2001, Robinson and Sutherland 2002, Poudevigne and Baudry 2003, Donald 2004). Moreover, landscape elements may undergo seasonal changes in their structure, phenology, and disturbance regime, affecting not only local abundances but also the distribution of different species among habitats (Law and Dickman 1998). In agroecosystems, the effects of seasonality on biotic communities may be exacerbated by the coupling of natural seasons and farming practices (Benton et al. 2003). For example, the natural drop in vegetation cover observed

toward fall in temperate grasslands is magnified by the harvest of annual crops (Ghersa and León 2001).

Several faunal groups have shown responses to changes in land use and landscape structure in agroecosystems, including birds, lizards, earthworms, butterflies, and beetles (Hendrix et al. 1992, Atauri and de Lucio 2001, Weibull et al. 2003, Blevins and With 2011). In particular, small mammals have proven to be sensitive to changes in land use and landscape structure associated with agroecosystems (Gorman and Reynolds 1993, Delattre et al. 1998, Love et al. 2000, Jacob 2003, 2008, Millán de la Peña et al. 2003, Butet et al. 2006, Heroldová et al. 2007). In rodents, short-term effects caused by farming practices, such as mowing and harvesting, promote several responses ranging from behavioral responses to local extinction of populations (Jacob 2003, Cavia et al. 2005, Hodara and Busch 2009).

In the temperate grasslands of the Pampas in central Argentina, the impact of productive activities on biodiversity can be traced back to the settlement of Spanish colonies in the first half of the XVIth century, when extensive grazing by introduced cattle altered the community structure of native grasslands (Soriano et al. 1992). Records of small mammals clearly indicate major changes in the small mammal assemblage since the 16th century, including the first records of *Calomys* spp. Waterhouse 1837 and the reduction of the relative abundance of *Akodon azarae* (Fischer 1819, Pardiñas et al. 2010).

During the 20th century, agricultural expansion in Buenos Aires province introduced further changes in land use and landscape structure (Ghersa et al. 1998), and many studies addressed the effects of farming practices and seasonality on small mammal populations and their habitat associations (Busch et al. 1984, de Villafañe et al. 1988, Mills et al. 1991, Busch and Kravetz 1992, Bilenca and Kravetz 1995, 1998, 1999, Ellis et al. 1997). Mills et al. (1991) described two distinct patterns in annual fluctuations of rodent populations. Opportunistic species, largely limited to crop fields (i.e., *Calomys* spp.), maintain relatively stable populations during most of the year, and suffer a precipitous drop in population numbers after crop harvest. More successful competitors (i.e., *A. azarae*), occupying mostly the more stable crop field borders and other naturally vegetated areas, increase their population numbers during their breeding season and have their peak at the end of the fall, and then drop as a result of harsh environmental conditions during winter.

Over the last 20 years, Buenos Aires province has witnessed an accelerating agricultural expansion, as cropped area increased by 50% between 1988 and 2008 (INDEC 1988, 2009, Baldi and Paruelo 2008). The effects of this recent agriculturization on biodiversity have been the focus of numerous studies, detecting changes in both birds (Filloy and Bellocq 2007, Codesido et al. 2008, 2011, Schrag et al. 2009) and mammal assemblages (Abba et al. 2007, Bilenca et al. 2007, 2009). However, there are no regional studies linking land use and landscape structure with small mammal assemblages, nor exploring the role of seasonality in this small mammal-landscape association. In this article, we describe the associations between small mammal assemblages and land use patterns and landscape structure in the Pampas of Buenos Aires province, central Argentina, and analyze their seasonal variations.

Materials and methods

Study area

The Pampas are part of the Río de la Plata grasslands, the largest complex of temperate grassland ecosystems in South America (750,000 km^2; Soriano et al. 1992). The Pampas included in Buenos Aires province (277,000 km^2; Figure 1) are classified into four ecological units, which can be distinguished according to differences in geomorphology, soils, drainage, physiography, and vegetation: the Rolling Pampa, the Southern Pampa, the Flooding Pampa, and the Inland Pampa (Soriano et al. 1992; Figure 1). Mean annual temperature varies from 13°C in the south to 17°C in the north, and mean annual precipitation varies from 600 mm in the southwest to 1200 mm in the northeast.

Land use patterns also vary along the province: in the Rolling Pampa, agriculture has replaced most of the native vegetation and covers about 75% of the land, whereas in the Flooding Pampa grasslands or pastures prevail (>85%). The Southern and the Inland Pampas have a mixed production system with both agriculture and animal husbandry (Baldi and Paruelo 2008). In the Rolling, Inland, and Flooding Pampas, summer crops (soybean *Glycine max* Linnaeus 1753, and maize *Zea mays* Linnaeus 1753) are predominant, whereas in the Southern Pampa winter crops (i.e., wheat *Triticum aestivum* Linnaeus 1753) prevail (INDEC 2006). The small mammal assemblage of the Pampas includes at least 12 rodent species, four marsupials, and one carnivore (Mills et al. 1991, Busch and Kravetz 1992). The most abundant and more widely distributed species are the native sigmodontine rodents *Calomys laucha* (Fischer 1814), *Calomys musculinus* (Thomas 1913), *Akodon azarae*, *Oligoryzomys flavescens* (Waterhouse 1837), and *Holochilus brasiliensis*

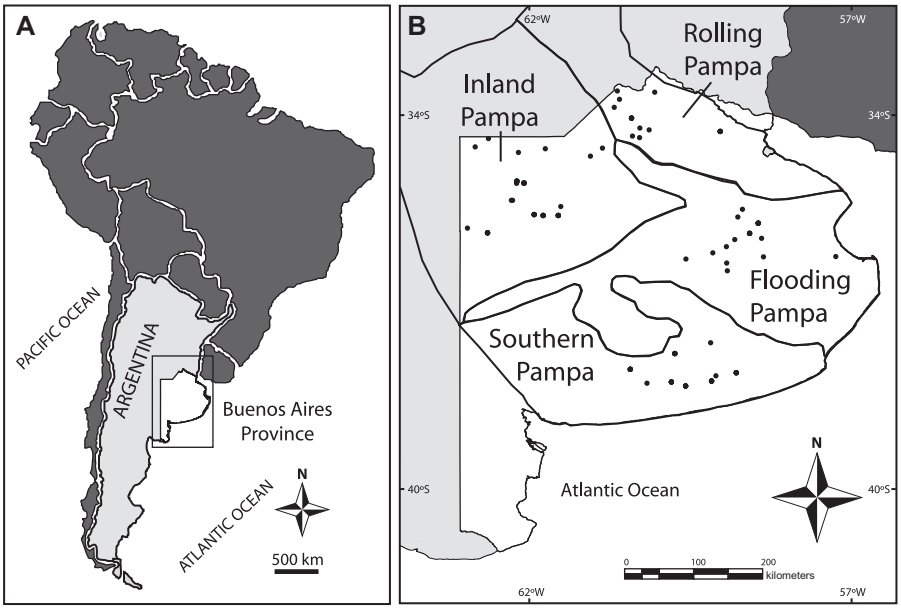


Figure 1 Study area.
(A) Location of the study area. (B) Map of the study area indicating the pellet collection sites and the four units of the Pampean region included in Buenos Aires province, Argentina.

(Desmarest 1819), and the introduced commensal rodents *Mus musculus* Linnaeus 1758, *Rattus rattus* Linnaeus 1758, and *Rattus norvegicus* (Berkenhout 1769) (Teta et al. 2010).

Small mammal records

We collected fresh barn owl [*Tyto alba*, Scopoli 1769 (Aves, Tytonidae)] pellets during winter (July and August 2006–2007) and summer (January and February 2007–2008) from nest sites distributed in the four ecological units of the Pampean region included in Buenos Aires province (n=36 and n=29 nest sites for winter and summer, respectively; Figure 1). The barn owl is a cosmopolite raptor, and it is known to be a specialist predator focusing almost exclusively on small mammals within their home range (The Barn Owl Trust 2009). The home range of the barn owl varies from 0.5 to 6 km in diameter (Taylor 2004); for the purpose of this study, we will consider a mean value of 2 km, centered in the pellet collection site. The analysis of owl pellet samples is an extremely valuable tool for mammalogists (Yalden and Morris 1990), which has already been used to track changes in small mammal relative abundances, both spatially and temporally in temperate agroecosystems (Love et al. 2000, Millán de la Peña et al. 2003, González Fischer et al. 2011). The latitude and longitude of each site was recorded with a GPS. The pellets were processed following the method described by Longlan (1985). Mammalian prey was identified to the lowest taxonomical level possible by examination of the skulls and dentaries. Osseous remains were identified by comparison of voucher specimens deposited in museum collections and also by a literature review. Mammal taxonomy followed Wilson and Reeder (2005), with modifications according to D'Elía et al. (2008).

Land use and landscape characterization

We estimated the area occupied by each cover class (winter crops, summer crops, grasslands, urban, water bodies) within a 2 km radius around each roosting site, using the LART (2004) classification. The classification method was based on the analysis of normalized difference vegetation index temporal series derived from MMRS SAC-C images (October–November 2003 and May–June 2004; spatial resolution: 175 m). In addition, we used field surveys and very high spatial resolution images (supported by the Google Earth system) in order to determine the presence or absence of households and grain storage facilities within 2 km from each pellet collection site. We also used imagery supported by the Google Earth system to trace landscape elements in order to calculate mean paddock area around owl pellets collection sites, using Scion Image for Windows 4.0 software (Scion Corporation 2010). Because in many cases paddocks were not entirely

included within the 2 km radius that we used to describe land use patterns, we considered instead a 5 km radius for paddock size estimation.

Statistical analysis

We performed two separate redundancy analyses (RDAs; Leps and Smilauer 1999) for summer and winter, respectively, using CANOCO for Windows 4.5 software, in order to analyze the associations between small mammal species and land use and landscape structure. Only those small mammal species that were found in all four units of the Pampas were considered for the analyses, in order to avoid any confounding biogeographic effects in the interpretation of small mammal-landscape associations (Pereira et al. 2006). We considered the pellet collection sites as the cases for the RDA and the percentages of the small mammal species as the response variables. The explanatory variables included for the analyses were (1) the percentages of each cover class (winter or summer crops for winter and summer, respectively; grassland, water bodies, and urban), (2) mean paddock area, and (3) the presence of households and grain storage facilities. In both cases, the angular transformation for proportions was applied to the species percentages, the analysis was centered and standardized by species, and we tested the significance of the first and of all canonical axes by means of a Monte Carlo permutations test (499 unrestricted permutations; Leps and Smilauer 1999).

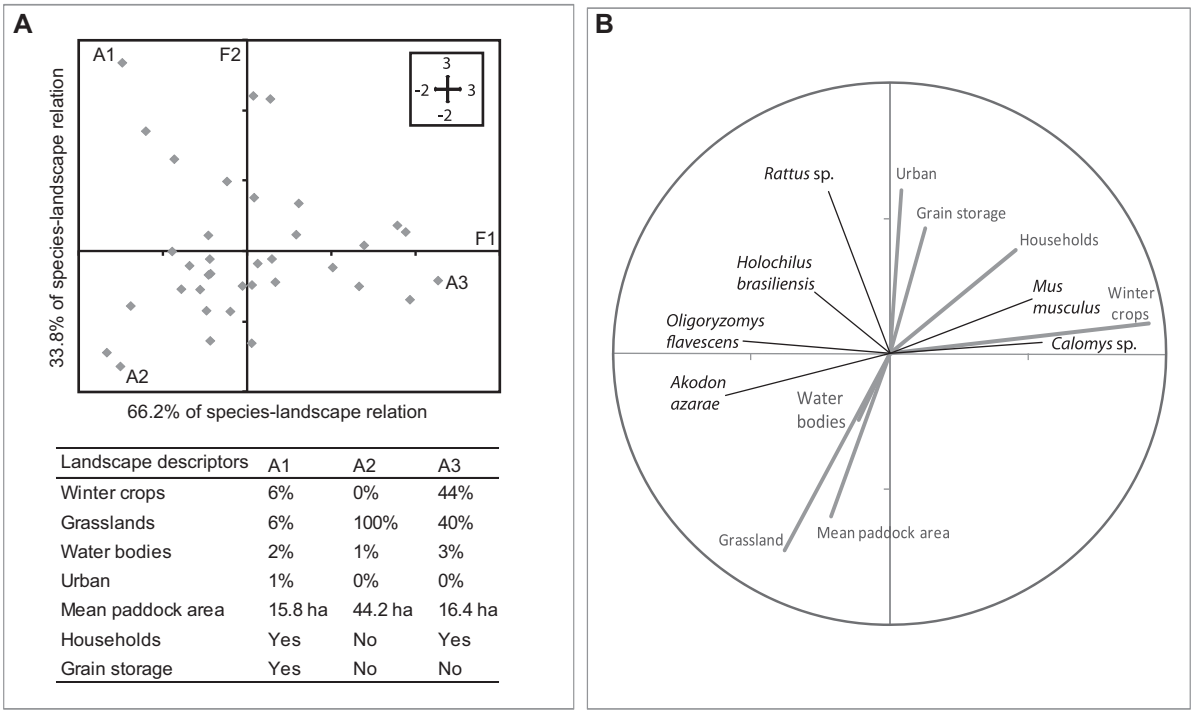
Results

We collected a total of 31,054 small mammals including at least 11 species (20,785 individuals in winter and 10,269 in summer; Table 1). Only six species were found in all four ecological units and accounted for >95% of the individuals recorded in each unit: *Calomys* spp., *Akodon azarae*, *Oligoryzomys flavescens*, *Mus musculus*, *Holochilus brasiliensis*, and *Rattus* spp. Other species found, but not considered for the analysis, were *Monodelphis dimidiata* (Wagner 1847), *Necromys lasiurus* (Lund 1840), *Necromys obscurus* (Waterhouse 1837), *Oxymycterus rufus* (Fischer 1814), and *Reithrodon auritus* (Fischer 1814) (Table 1).

In winter, we found a significant relation between the relative abundances of small mammal species and land use and landscape variables (RDA, Monte Carlo permutations test for the first and all canonical axes, $p=0.014$ for both tests; Figure 2). Land use and landscape accounted for 33.2% of variance in species data. The first and second canonical axes accounted for 66.2% and 24.3% of the species-landscape relation, respectively (Figure 2). The first axis separated sites according to agricultural intensification, so that sites with higher winter crop areas had higher scores than sites dedicated to animal husbandry. The second axis separated sites according to anthropic disturbance, so that nesting sites with higher urban cover and smaller paddocks, located nearer to households and grain storage facilities, obtained higher scores. *Calomys* spp. were relatively more abundant in sites with more winter crop area, whereas in sites with more grassland

	Southern pampa		Flooding pampa		Inland pampa		Rolling pampa	
	Winter (n=8645)	Summer (n=2974)	Winter (n=3297)	Summer (n=1543)	Winter (n=5725)	Summer (n=3350)	Winter (n=3097)	Summer (n=2370)
Common species								
Calomys spp.	85%	83%	67%	63%	75%	71%	63%	74%
Akodon azarae	5%	7%	17%	23%	9%	14%	12%	12%
Oligoryzomys flavescens	5%	3%	15%	14%	15%	14%	23%	12%
Mus musculus	2%	3%	0%	0.2%	0.3%	1%	1%	1%
Holochilus brasiliensis	0.1%	0.3%	0.1%	0%	0.1%	0.4%	0.2%	0.3%
Rattus spp.	0.02%	0%	0.2%	0.1%	0.1%	0.1%	0.5%	0.3%
Total for common species	97%	97%	100%	100%	100%	100%	99%	99%
Other species								
Reithrodon auritus	+	+	+	+	-	-	-	-
Monodelphis dimidiata	+	+	+	-	-	-	+	+
Necromys lasiurus	+	-	-	-	-	-	+	+
Oxymycterus rufus	+	-	+	-	-	-	+	+
Necromys obscurus	+	+	-	-	-	-	-	-

Table 1 Percentages of the six common species (species found in all ecological units) and the presence of the other species for each one of the four ecological units of the Pampean region included in Buenos Aires province, Argentina.
n, number of small mammals; +, species found in the ecological unit; -, species not found in the ecological unit.



Landscape descriptors	A1	A2	A3
Winter crops	6%	0%	44%
Grasslands	6%	100%	40%
Water bodies	2%	1%	3%
Urban	1%	0%	0%
Mean paddock area	15.8 ha	44.2 ha	16.4 ha
Households	Yes	No	Yes
Grain storage	Yes	No	No

Figure 2 Graphical interpretation of the RDA between species percentages and land use and landscape descriptors for winter samples. (A) Site scores for the first and second canonical axes (F1 and F2, respectively). A table with land use and landscape descriptors for three extreme sites is included for illustration purposes. (B) Bi-plot for species (black lines) and landscape variables (gray lines), showing their correlation with the first and second canonical axes.

cover, small mammal assemblages were characterized by high percentages of *Akodon azarae* and *Oligoryzomys flavescens*. *Mus musculus* and *Rattus* spp. were relatively more abundant in sites with higher urban cover in the rural landscape, and in those sites near households and grain storage facilities (Figure 2).

However, we found no significant small mammal-landscape association in summer (RDA, Monte Carlo permutations test for the first and all canonical axes; $p=0.43$ and $p=0.36$, respectively; data not shown).

Discussion

In this article, we provide the first comprehensive study of the associations between small mammal assemblages and land use patterns and landscape structure at a regional scale in the temperate agroecosystems of Buenos Aires province, central Argentina. We showed that the landscape context may have an influence in shaping small mammal community structure, and that this small mammal-landscape association is modulated by seasonal effects.

Our results are in agreement with both ecological and paleoecological studies showing that in the Pampean region small mammal communities are characterized by higher proportions of *Calomys* spp. in sites with anthropogenic disturbance and intensification of agriculture, and with high percentages of *Akodon azarae* and *Oligoryzomys flavescens* at the opposite extreme of the intensification gradient (de Villafañe et al. 1988, Mills et al. 1991, Busch and Kravetz 1992, Bilenca and Kravetz 1995, Bilenca et al. 2007, Pardiñas et al. 2010 and references therein, Gonzalez Fischer et al. 2011). In addition, the association found between commensal species (*Mus musculus* and *Rattus* spp.) and grain storage facilities and households included in the rural landscape is consistent with studies describing the presence of these species in intensified production facilities (i.e., poultry farms; Gómez Villafañe and Busch 2007, Miño et al. 2007) and urban areas (Cavia et al. 2009).

Seasonality is a major driver in both natural and modified ecosystems, altering resources availability and affecting the migration, reproduction, and behavior of different species (Begon et al. 2006). In agroecosystems, the effects of seasonality on biotic communities may be exacerbated by the coupling of natural seasons and farming practices (Benton et al. 2003). Small mammal assemblages in the agroecosystems of Buenos Aires province are known to be hierarchically structured by interspecific competition, and species tend to be spatially segregated (Mills et al.

1991, Busch and Kravetz 1992). Studies describing seasonality of small mammal populations and their habitats have found that in winter, when rodent populations are at their peak and resources are scarce, the larger *Akodon azarae* occupies the more favorable crop field borders, restricting the smaller *Calomys* spp. to the interior of the crop fields. However, in summer, low rodent densities and high resources availability reduce interspecific competition, enabling *Calomys* spp. to colonize crop field borders, where it coexists with *A. azarae* (Ellis et al. 1997, Bilenca and Kravetz 1998, 1999). This shift from strong competition and spatial segregation in winter to reduced competition in summer could explain the shift form a stronger small mammal-landscape association in winter to a lack of association between the relative abundances of small mammal species and land use and landscape variables in summer.

In this article, we showed that land use patterns and landscape structure are responsible for some of the differences among small mammal assemblages in the temperate agroecosystems of the Pampas, and that seasonality plays a major role in small mammal-landscape associations. Future trapping studies could enlighten us about the processes behind these patterns, by describing the small mammal assemblages found in each one of the landscape elements and the seasonal variations of different species abundances in each one of them.

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