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EFFECTS OF LAND USE ON THE DISTRIBUTION OF THREE SPECIES OF ARMADILLOS IN THE ARGENTINEAN PAMPAS

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We evaluated the effects of land use on the distribution of 3 sympatric species of armadillos, *Chaetophractus villosus*, *C. vellerosus*, and *Dasypus hybridus*, on 34 farms in the eastern Pampas. We characterized 4 soil and vegetation variables around each burrow located during surveys of these farms, and related burrow abundance to 10 variables used to characterize each farm. *C. vellerosus* was the most specialized, using primarily native woodlands and areas with calcareous soil. *D. hybridus* was associated with natural grasslands and avoided cultivated pastures, and was negatively related to the number of dogs that lived on the farms. *C. villosus*, the most abundant species, was found in all 4 types of habitats, but its distribution depended on the intensity of hunting on each farm.

Key words: Argentina, armadillos, *Chaetophractus vellerosus*, *Chaetophractus villosus*, conservation, *Dasypus hybridus*, distribution, ecology, Pampas

Armadillos (order Cingulata, family Dasypodidae) are one of the characteristic groups of medium-sized mammals of South America. Together with anteaters and sloths in the order Pilosa, they comprise a group known as xenarthrans, with 31 species, 38% of them threatened by extinction (Fonseca and Aguiar 2004). This percentage is higher than that in many other orders of mammals, including carnivores (27%) and cetaceans (33%—Mace and Balmford 2000). However, xenarthrans have not received the same attention as those more charismatic orders.

We investigated 3 species of armadillos that differed in conservation status. *Chaetophractus villosus* (big hairy armadillo) is a widespread and abundant species that is frequently persecuted because it is considered a pest. *C. vellerosus* (little hairy armadillo) also is a species of low conservation concern. However, we studied a small and isolated population of this species in eastern Buenos Aires Province (Carlini and Vizcaíno 1987; Crespo 1974) that deserves special attention because it occupies a small zone with intensive human activity. *Dasypus hybridus* (southern long-nosed armadillo) is considered "near threatened" and it is likely to qualify as endangered in the near future. These statuses were assigned both at global (Fonseca and Aguiar 2004) and local (Díaz and Ojeda 2000) levels.

We used regression analyses to identify the main effects of land use on the distribution of these 3 species of armadillos at a landscape and local level in rural areas of the Pampas plain. We conducted our study in a typical area of the Pampas plain. The area included 2 principal ecosystems, grasslands and a woody community called "talar." The native Pampas grassland was a community once dominated by grasses (Poaceae) of the genera *Stipa*, *Piptochaetium*, and *Aristida* (Cabrera and Zardini 1978) but intense human practices have altered the ecosystem (Ghersa et al. 1998).

MATERIALS AND METHODS

Study area.—Our study was carried out in the eastern part of the Pampas grasslands of Argentina between 34°58′S, 57°47′W and 35°30′S, 57°12′W. The weather is moderately warm and humid with mean annual temperature of 16.2°C and 1,035 mm of annual precipitation. The annual prevailing wind intensity is about 12 km/h, predominantly from the east and secondarily from the northeast and northwest (Hurtado et al.

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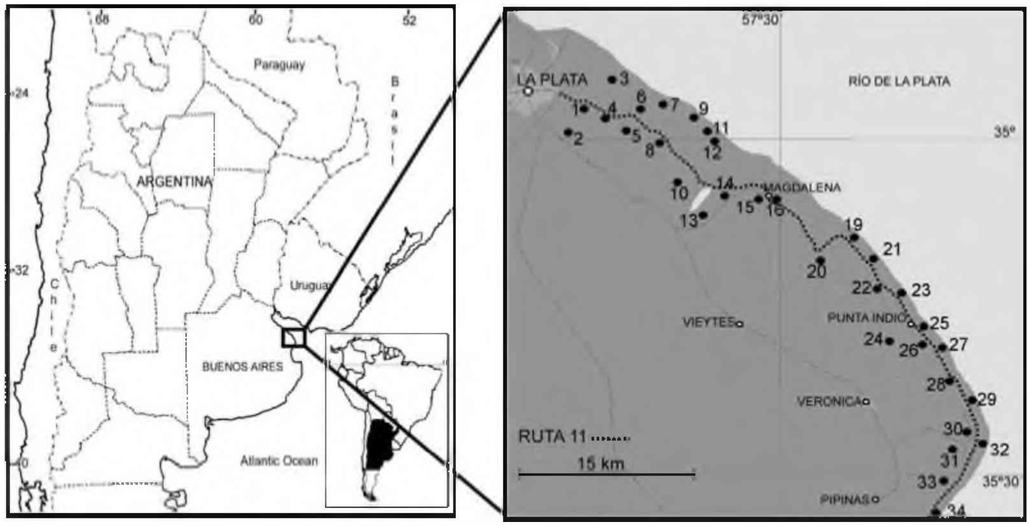

Fig. 1.—Geographic location of the study area in eastern Buenos Aires Province, Argentina, including the 34 localities surveyed.

2003). The study area was fragmented into units of private farms. Farms were considered the unit of land use.

Data collection and statistical analyses.—We randomly selected 34 farms distributed approximately evenly throughout our study area (Fig. 1). General information on each farm was collected from 1:25,000 maps and satellite images, and by interviewing the owners and employees of the farms. For each farm we determined 10 variables: distance to the main city (La Plata, capital of Buenos Aires province); total area of the farm (ha); number of land divisions in the farms/total area; hectares of pastures/total area; hectares of grassland/total area; hectares of exotic woodland/total area; hectares of native woodland/total area; number of cattle on each farm; intensity of hunting, quantified to 4 levels (0 [interviewed people indicated no hunting in the fields, and no signs of hunting were found, that is, no animals killed by hunters, spent bullets, or shells], 1 [hunting once per month but hunting signs were not found], 2 [hunting twice a month and at least 1 sign of hunting was found], and 3 [interviewed people hunted all species of armadillos and hunting signs were found]); and number of dogs living on the farm.

From December 2003 to October 2004, approximately 70 ha of each farm were surveyed for sign (burrows and holes) of armadillos. Two observers walked in a straight line, 20 m apart, and observed 10 m to both sides of each line, locating burrows. The direction of the transect was selected at random. Observers walked for 5 h at a speed of 3.5 km/h, controlled with a global positioning system. The same approach has been used to estimate the habitat use of numerous different species of burrowing animals (e.g., Breininger et al. 1994; Burke 1989; Carter and Encarnaçao 1983; González et al. 2001; King 1955; Mc Donough et al. 2000; Moller et al. 1997; Schaller 1983). Two types of burrows were identified for the 3 armadillo species: complex structures or home burrows, and simple structures or foraging holes (Abba et al. 2005). Many small or partial foraging holes were not included in the analysis because they could be the result of the activity of other medium-sized mammals present in the region (skunks, foxes, and other species).

Features that allowed discrimination of burrows between species were width and shape of the entrance, as well as direct observations of animals digging. The width of the entrance was used because width showed significant differences among the 3 study species (analysis of variance: $F = 75.087$, $d.f. = 2, 136$, $P < 0.000001$, Tukey post hoc tests all $P < 0.00004$). The shape of the cross section of a burrow and its entrance is in gross accordance with the shape of a cross section of the body of the burrower (Krieg 1929); thus, the burrows of *Dasypus* have subcircular entrances whereas those of the *Chaetophractus* species are ellipsoid.

When a burrow or a hole was found, the following variables were measured. The 1st variable was type of vegetation in a circle of 5-m radius around the burrow (grassland, pasture, native woodland, and exotic woodland). Grassland was a mixture of native species of grasses with foreign and exotic species of different herbaceous plants (mainly *Cynara cardunculus*, *Carduus acanthoides*, *Lolium perenne*, *Festuca arundinacea*, *Phalaris aquatica*, and *Trifolium repens*—León et al. 1984), and was used mainly for livestock husbandry. Pastures were cultivated grasses (commonly *Lotus*, *Melica*, and *Paspalum*) and also were used for livestock husbandry. Native woodland, or talar, was a subclimax community of xeric species (Cabrera 1949; Parodi 1940). This community developed in a narrow fringe area of mid-to-late Holocene beach ridges and extends along the northeastern margin of the Pampas plain. These coastal deposits form elongated hills up to 6 m above the surrounding plain, largely composed of marine mollusc shells (Cavallotto 2002). Talar resembles low woodland with shrubby trees 3–6 m high, with a low-vegetation substrate of shrubs and herbs. The dominant species are xeric plants; in general, the principal species is tala (*Celtis tala*), accompanied by *Jodina rhombifolia*, *Acacia caven*, *Scutia buxifolia*, *Schinus longifolia*, and *Sambucus australis* (Cabrera 1949; Parodi 1940; Vervoorst 1967). Exotic woodlands were relatively small patches of introduced trees including *Eucalyptus* and *Populus*. The 2nd variable was type of soil (calcareous or humus). Soils were differentiated by color and texture, following the descriptions of the Soil Survey

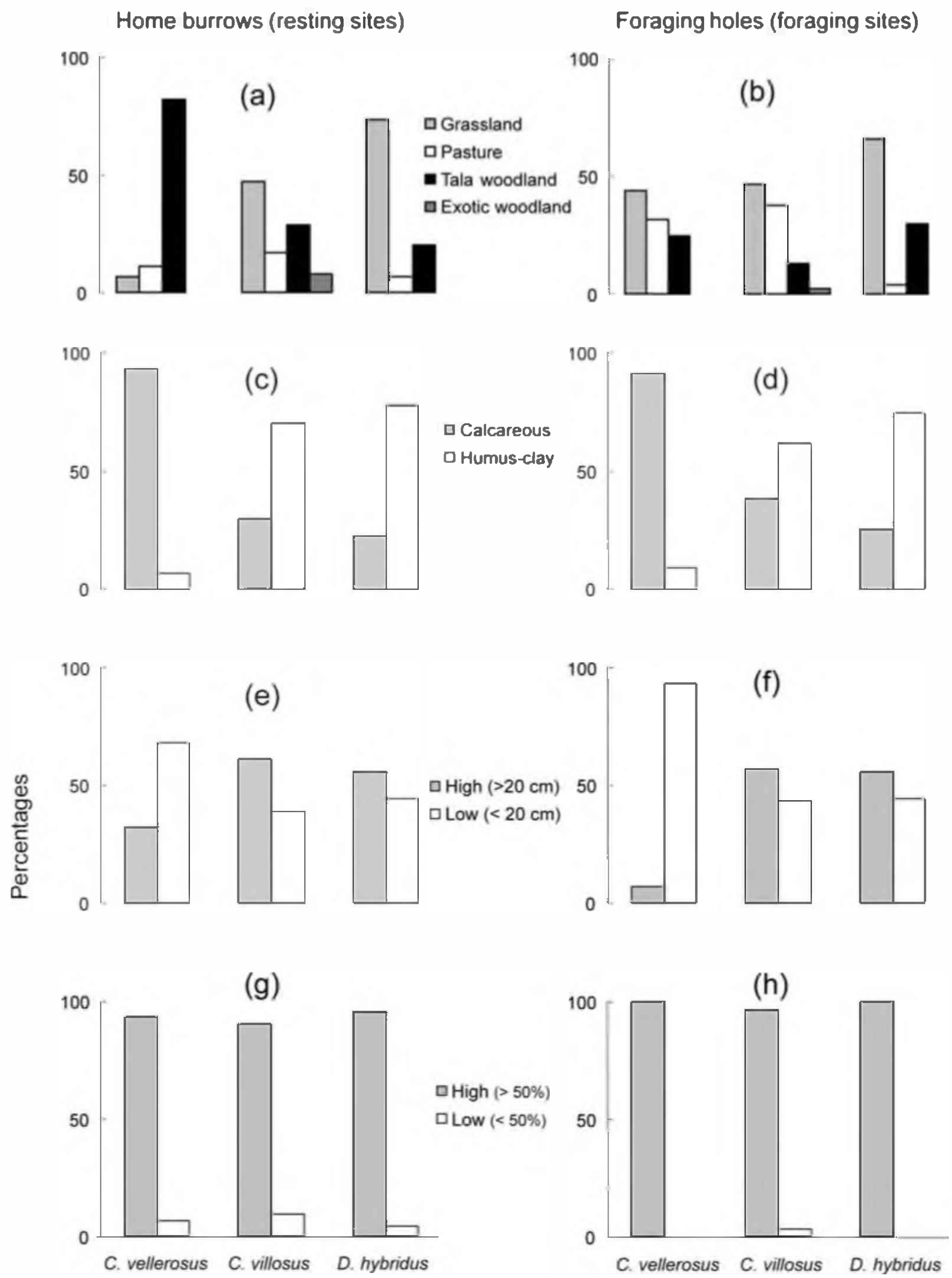

FIG. 2.—a, c, e, g, and i) Percentages of occurrences of home burrows and b, d, f, h, and j) foraging holes of the 3 species of armadillo, in relation to environmental variables: a and b) habitat type, c and d) soil, e and f) vegetation height, and g and h) vegetation cover.

Staff (1999). The 3rd variable was plant cover (high [>50%] or low [<50%]), which was determined following the Braun Blanquet (1979) method. The 4th variable was plant height (high [>20 cm] or low [<20 cm]), determined as an average of plant heights measured at 5 points in a circle of 5-m radius around the burrow or hole.

Habitat niche breadth was estimated using the Shannon–Wiener index (H),

$$H = -\sum p_j \log p_j,$$

where p_j is the proportion of individuals found in or using resource j, and overlap in habitat was estimated using the simplified Morisita index (C),

$$C = 2\sum p_{ij}p_{ik} / \left(\sum p_{ij}^2 + \sum p_{ik}^2\right),$$

where p_{ij} and p_{ik} are the proportion of resource i of the total resources used by the 2 species (Krebs 1989).

In the analyses of factors affecting the distribution of armadillos between farms, we applied a principal component

TABLE 1.—Results of the principal component analysis (PCA). The table shows the values of the scores obtained for each independent variable for each factor. Italic type indicates values > 0.7.

	PCA factor			
Variable	1	2	3	4
Distance to main city	*0.83*	0.10	−0.13	0.01
Total area of the farm (ha)	0.10	0.01	*0.81*	0.13
Number of land division in the farms/total area	*−0.76*	−0.21	−0.39	−0.05
Hectares of pastures/total area	−0.52	0.42	−0.36	0.38
Hectares of grassland/total area	0.30	*−0.94*	0.11	0.05
Hectares of exotic woodland/total area	−0.11	−0.01	−0.04	−0.68
Hectares of native woodland/total area	0.29	*0.82*	0.21	0.04
Number of cattle on each farm	0.01	0.01	*−0.78*	0.23
Intensity of hunting	0.07	0.19	0.09	*0.75*
Number of dogs living on the farm	*−0.84*	0.28	0.07	0.01
Eigenvalue	2.4	1.9	1.6	1.3
Percentage of variance explained	23.9	19.3	16.3	12.6

analysis to the 10 variables estimated for each farm. Variables with factor loadings greater than 0.7 were considered to contribute high scores to the component. We then conducted 3 multiple regression analyses to determine the effect of environmental variables on the distribution of each species at a landscape level. We used the first 4 factors of the principal component analysis as independent variables and the number of burrows per species as dependent variables.

RESULTS

Signs (burrows and holes) of armadillos were found in 88.2% ($n = 30$) of the 34 farms surveyed. A total of 3,260 signs were found. *C. villosus* was the most abundant species, with 1,660 signs located, and was present on 88.2% of the farms. A total of 825 signs of *C. vellerosus* and 775 signs of *D. hybridus* were found in 23.5% and 44.1% of the farms, respectively. We conducted separate analyses of local habitat variables for home burrows (Figs. 2a, 2c, 2e, and 2g) and foraging holes (Figs. 2b, 2d, 2f, and 2h). Home burrows can be used as an index of resting sites, whereas foraging holes comprise indirect evidence of foraging by armadillos.

The frequency distributions of soil and vegetation variables associated with both burrows and foraging holes differed among species. Burrows of *C. vellerosus* were located primarily in tala woodlands, and this species was the most specialized in burrow location (H = 0.26). *C. villosus* was the most generalized in burrow location (H = 0.53), but had most burrows located in grassland. *D. hybridus* also specialized in burrow location (H = 0.31), but in contrast to *C. vellerosus*, most burrows were located in grassland (Fig. 2a). As a consequence, the overlap in habitat use was relatively low between *C. vellerosus* and *C. villosus* (C = 0.56) and between *C. vellerosus* and *D. hybridus* (C = 0.34), but was high between *C. villosus* and *D. hybridus* (C = 0.90).

Chaetophractus vellerosus changed its pattern of habitat association when searching for food (Fig. 2b). This species showed a wider range of use of vegetation types (H = 0.46),

TABLE 2.—Multiple regression analyses of the number of signs in relation to the 4 main factors of the principal component analyses conducted with the data collected in 30 farms. Columns correspond to species of armadillos, factor of the principal component analysis, standardized (β) and nonstandardized (B) regression coefficients (weights), their standard errors, and statistical significance. The arrows indicate the partial regression coefficients that were statistically significant ($P < 0.05$) for each species.

Armadillo species		Factor	β	*SE*	B	*SE*	*t*-test	*P* value
Chaetophractus villosus		1	0.01	0.17	0.21	8.21	0.03	0.98
		2	0.06	0.17	2.88	8.21	0.35	0.72
		3	0.07	0.17	3.41	8.21	0.42	0.68
	→	4	0.42	0.17	20.40	8.21	2.48	0.01
		1	0.19	0.16	12.91	10.41	1.24	0.22
C. vellerosus	→	2	0.48	0.16	31.97	10.41	3.07	0.01
		3	0.10	0.16	6.88	10.41	0.66	0.51
		4	0.04	0.16	2.90	10.41	0.28	0.78
Dasypus hybridus	→	1	0.34	0.17	20.32	10.23	1.99	0.05
		2	−0.13	0.17	−7.71	10.23	−0.75	0.45
		3	−0.09	0.17	−5.33	10.23	−0.52	0.60
		4	0.02	0.17	1.48	10.23	0.14	0.88

whereas the other 2 species showed patterns similar to those for burrow sites, with *D. hybridus* showing the narrowest range of foraging sites (H = 0.33). Overlap in habitat use while foraging differed from overlap for burrow sites: there was a very high level of overlap between the 2 species of *Chaetophractus* (C = 0.97), as well as for the other 2 pairwise comparisons (C = 0.85 for *C. vellerosus* and *D. hybridus*, and C = 0.80 for *D. hybridus* and *C. villosus*).

For the rest of the local variables, the 3 species showed similar patterns between burrows and foraging sites. *C. vellerosus* was primarily associated with calcareous soils, whereas signs of the other 2 species were more frequent in humus soils (Figs. 2c and 2d). *C. vellerosus* also differed from the other 2 species in that frequency of its signs was low in tall vegetation (Figs. 2e and 2f). All 3 species were almost absent from areas with low plant cover (Figs. 2g and 2h).

The first 4 factors of the principal component analysis conducted for the comparison among farms explained 72.0% of the variation in the data. Table 1 shows the values of the scores obtained for each independent variable for each factor. Factor 1 had high positive values for distance to the city, and high negative values for number of dogs and number of fields/total area. Factor 2 had high positive values for percentage of hectares with native woodland, and high negative values for percentage of hectares with grasslands. Factor 3 had high positive values for total area of the farm and high negative values for number of cattle. Factor 4 had high positive values for intensity of hunting.

The results of the multiple linear regressions between the distributions of the 3 species of armadillos and the 4 principal component analysis factors are summarized in Table 2. Significant relationships were found with factor 4 for *C. villosus*, factor 2 for *C. vellerosus*, and factor 1 for *D. hybridus*. In other words, *Dasypus* correlated positively with distance to the main city and negatively with the number of dogs and fields per hectare, *C. vellerosus* correlated positively with the availability of native woodland, and *C. villosus* correlated negatively with the intensity of hunting.

Discussion

We sampled the distribution of signs of 3 species of armadillos in a portion of the most modified region of Argentina (A.P.N. 1998; Bertonatti and Corcuera 2000). In the Pampas plain, wildlife must unavoidably live under human pressure, so it is of great conservation concern to identify the specific anthropogenic variables that correlate with the distribution of each species. In the analysis within farms, the 3 species of armadillos appeared to show a relative segregation in habitat use, assuming that the density of home burrows is an expression of habitat use. In the comparison among farms, the distribution of signs of each species correlated with few and different aspects of land use and anthropogenic impact.

Chaetophractus vellerosus was the most specialized in burrow location, primarily using the native woodlands, normally composed of a tree called tala. However, *C. vellerosus* appeared to move to adjacent grassland while searching for food. For all activities, this species appeared to be associated with areas with calcareous soil. *C. vellerosus* occupies mostly arid and semiarid environments in the center of Argentina and appears to be adapted to dig in loose soil (Cabrera 1958; Crespo 1944, 1974; Greegor 1980, 1985; Wetzel 1982). The Pampas plains are characterized by rich, humus soils used for agriculture and cattle, and the coastal calcareous fringes are isolated islands for this species. From the conservation point of view, the future of the coastal population of *C. vellerosus* appears to be linked to the future of the tala woodlands.

Dasypus hybridus appeared to be dependent on natural grassland and avoided cultivated pastures. Its presence correlated negatively with the distance to the main city in the region. It also was sensitive to the number of dogs that lived on the farms. These 2 results are probably related because in the city there are large populations of free-roaming feral dogs from which many animals disperse toward the adjacent rural areas. There are reports of packs of feral dogs attacking wildlife and even domestic livestock in the rural areas surrounding La Plata (see Beade et al. 2000). Therefore, the decrease in numbers of *D. hybridus* when approaching La Plata could be at least in part a consequence of the impact of dogs.

Chaetophractus villosus, the most abundant species, was found in all 4 types of habitats. Its distribution among farms depended on the intensity of hunting within these properties. Local people eat these armadillos, but they also hunt them as pests. Massoia (1970) included it on a list of mammalian species that destroy the soil and pastures of the Pampas and promoted eradication campaigns. Other complaints are related to burrow construction and the risk to cattle and horses of broken legs when they step on the burrows.

In summary, the 3 species of armadillos survive in a highly altered environment. However, their presence appears to be affected by different human impacts. For *C. vellerosus*, it appears to be necessary to protect the native woodlands. For *D. hybridus*, conservation actions should be directed toward the reduction of dog populations and preservation of grassland. For *C. villosus*, the most important consideration is the control of hunting activity. Although very preliminary, these results also suggest a pattern of habitat segregation between the species, which may facilitate their coexistence.

Resumen

En este trabajo se evaluó el efecto del uso de la tierra sobre la distribución de 3 especies simpátricas de armadillos, *Chaetophractus villosus*, *C. vellerosus* y *Dasypus hybridus*, en 34 establecimientos agropecuarios de noreste de la región pampeana. Se documentaron 4 variables relativas a la vegetación y el suelo alrededor de cada cueva y se relacionó la abundancia de las cuevas con 10 variables que caracterizaban a cada establecimiento. *C. vellerosus* fue la especie más especialista, usando primariamente los montes nativos y áreas con suelo calcáreo. *D. hybridus* se asoció positivamente con los pastizales naturales y rechazó las pasturas implantadas, y está negativamente relacionada con la cantidad de perros que viven en los establecimientos. *C. villosus*, fue la especie más abundante y se la encontró en los 4 tipos de hábitat, sin embargo su distribución dependió de la intensidad de caza registrada en cada establecimiento agropecuario.

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