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Modeling habitat use of the threatened and endemic mara (*Dolichotis patagonum*, Rodentia, Caviidae) in agricultural landscapes of Monte Desert

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A B S T R A C T

Effective management of natural populations depends heavily on the capacity for understanding and predicting their habitat requirements. For endemic and threatened species like the mara (*Dolichotis patagonum*), this information is extremely necessary for populations survival. I investigated and constructed a mathematical habitat model for the mara, with the capacity to predict the probability of finding animals in a particular environment. In the Monte Desert, maras prefer habitats with low shrub density and high percentage of bare soil. The area used by each couple of maras was 7.73 ha and shows an aggregation pattern. Contrary to expectation, about 94% of these areas were in habitats created by human activities. Grazed, burned and crop areas seem to be prefered by maras when natural open habitat disappear. This information and the results of habitat requirements can be used to monitor the status of mara populations and predict potential population extinctions according to habitat variables.

1. Introduction

Habitat selection studies have been a central issue in ecology over the last three decades (Fretwell and Lucas, 1970; Rosenzweig, 1974, 1981, 1991, 1995; Charnov, 1976). According to this theory, individuals will abandon a patch when its rate of benefit return is lower than the average of the whole group of patches. It means that they will choose those habitats where their fitness is maximized (Rosenzweig, 1981). When individuals select habitat patches, they use some key habitat characteristics, whose identification is fundamental for the comprehension of this process (Busch et al., 2000). A way to identify which environmental factors are important for a species is to analyze the relationship between its habitat selection pattern and the features of its habitat (Ben-Shahar and Skinner, 1988; Kufner and Chambouleyron, 1991).

The Patagonian hare or mara (*Dolichotis patagonum*) is a cavy rodent endemic to the desert plains and shrublands of central-southern Argentina (Taber, 1987; Kufner and Chambouleyron, 1991; Pankhurst, 1998; Campos et al., 2001). Its historical distribution ranges from 32°S on Monte Desert biome to 50°S on Patagonian steppe (Taber, 1987; Campos et al., 2001), and is locally extinct in Buenos Aires Province and in the western portion of Argentina (Campos et al., 2001). Although mara has been categorized as of low risk (UICN, 1996), a large reduction of its populations had been observed over the last 30 years (Diaz and Ojeda, 2000). Major factors affecting mara's populations are habitat loss by changes on land use and over hunting.

Maras prefers open shrub areas with scattered vegetation and sandy soils in the arid regions of Argentina (Garrido and Kovacs, 1982; Taber, 1987; Kufner and Chambouleyron, 1991; Redford and Eisenberg, 1992; Baldi, 2007). Nevertheless, habitats along the extensive mara's geographical range had suffered different degrees of modification as a result of human activities to improve cattle production (e.g. prescribed fire and logging). In some areas, where cattle production is the main human activity, a positive effect on mara's populations can be generated by opening habitat with cattle grazing, as detected by Kufner and Chambouleyron (1991) in Mendoza Province. Nevertheless, dietary overlap with cattle in overgrazed areas can generate an opposite effect on mara's population and threaten the mara's survival, as proposed by Kufner et al. (1992). The process of desertification currently occurring in the Patagonian region, is also an anthropogenic factor that creates areas with high percentage of bare soil (Solá et al., 1995), potentially favorable for maras. In spite of this, the density of maras has diminished in this area (Campos et al., 2001). Natural factors like fire, salt basins and open areas generated by vizcachas (*Lagostomus maximus*) could also provide the kind of habitat required by maras.

The objectives of this work were to describe mara use areas and its relationship with nearest neighbors, to build a habitat model

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capable of predicting the presence of maras, and to explore habitat use in relationship to human land use activities. I expected that 1) being monogamous, the area occupied by a pair of mara would not overlap that occupied by another pair; and 2) the habitat model would select variables related to medium-sized vegetal strata.

2. Materials and methods

2.1. Study area

The study area was located on the southeast of La Pampa Province, Argentina (Fig. 1). The vegetation is typical of the central-eastern Monte Phytogeographic Province (Morello, 1958) and consists of semiarid scrub dominated by creosote bush (*Larrea divaricata*) with mixed shrub patches (e.g. *Condalia microphylla*, *Cercidium praecox*, *Prosopidastrum globosum*, *Chuquiraga erinacea*, *Prosopis flexuosa* var. *depressa*). There is also a herb–grass layer dominated by *Stipa* sp. (Cano et al., 1980). Average annual rainfall is 480 mm (Río Colorado Meteorological Station, 1971–1998, unpub. data). Fieldwork was conducted in three contiguous private ranches (Los Valles, La Legua and Brandimarti) where extensive cattle production is the main activity. Los Valles is a 7500 ha ranch and the other two are 2500 ha each. They are located at 39°11′ south and 63°42′ west.

2.2. Location of mara use and non-use areas

Location of mara use areas was conducted between February and October 2001. Two different methods were used: direct observation of individuals, and indirect observations (presence of burrows, feces, tracks and S-shaped marks left by maras when they drag their anus on the ground). Six visits were made throughout the year to each area potentially used. I considered an area as being used by maras when there were fresh signs in at least five visits, and if animals were observed in at least three visits. The location of each use area was recorded with GPS. Non-use areas were randomly selected at least 200 m away from used areas where absence of individuals and signs was checked around 1 ha from the initial point.

2.3. Size and distance between mara use areas

The presence of fresh feces was used to determine the size of the mara's use area. Each area potentially used by maras was systematically sampled using 20 m-apart line transects, and presence of feces was recorded. An additional 100-m transect was made to confirm absence of feces at the end of each use area. Distance between neighbouring use areas was measured using Clark and Evans (1954) nearest neighbour equation:

$$R = O(\mathrm{r})/E(\mathrm{r})$$

where $O(\mathrm{r})$ is the observed value of the mean distance to the nearest neighbour, and $E(\mathrm{r})$ the expected value of the mean distance to the nearest neighbour if areas were randomly distributed. R varies from 1 (random distribution) to 0 (maximum aggregation).

2.4. Habitat model

Vegetation sampling for habitat modeling was carried out in January 2002 in every mara's use areas and non-use areas. At each site a 100-m-long and 1.7-m-wide transect was used to record habitat characteristics. We recorded 16 habitat variables at every 3 m along this transect: percentage of bare soil, annual grasses, perennial grasses, annual herbs, perennial herbs and litter cover; height of annual herbs, annual grasses, perennial herbs, perennial grasses and shrubs; shrub density and width, tree density, and distance to and width of the nearest dirt road. Shrub and tree density was calculated by dividing total number of individuals along each transect by its total area. Measurements of shrub and tree height and width were made using a 2-m-long graduated pole and a measuring tape. Percentage values of bare soil, litter, grasses, herbs and shrubs were visually estimated by watching through a 5-cm-diameter cylinder at a standard height of 1.4 m.

2.5. Statistical analysis

The SPSS 9.0 statistical programme was used. Normality of each variable was checked using the Shapiro–Wilk statistic. A variable was considered as normal when Shapiro–Wilk statistic was higher than 0.88 (Clark and Shutler, 1999). We used arcsine transformations for percent variables, square root for variables related with height, density, width and distances (Zar, 1999). Four variables (percentage of annual grass, and annual herbs, height of annual grass and annual herbs) were not normally distributed even after transformation. Four variables (height of annual grass, annual herbs, perennial grass

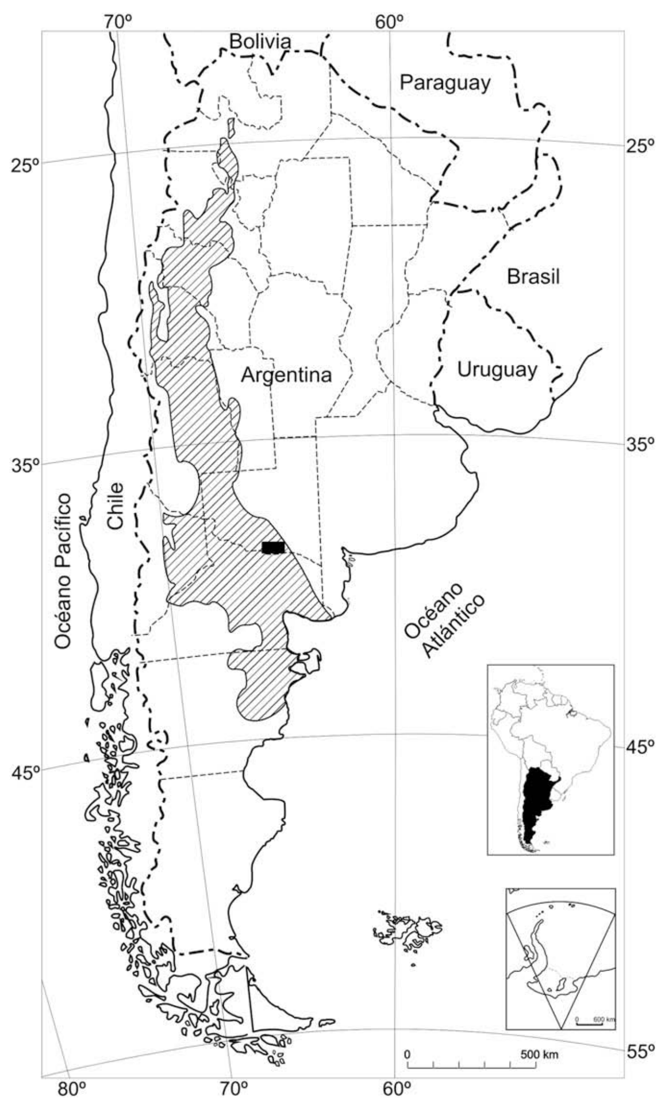

Fig. 1. Location of study site in the southeast of La Pampa Province, Argentina (black box).

and perennial herbs) were averaged to determine mean height of the grass–herb stratum. To obtain the percent cover of the annual grass–herb stratum, the cover of annual grasses and herbs was added. These two new variables were normally distributed.

To reach a suitable relationship between sample size and number of variables, only non-correlated variables (Pearson coefficient: $r \leq 0.7$) were used (Block et al., 1998). Consequently shrub width, shrub height, percent of litter cover, and distance to nearest dirt road were eliminated, leaving only bare soil, percent of perennial grasses, percent of perennial herbs, track width, shrub density, tree density, annual percentages, and height of grass–herb stratum for subsequent analysis.

Univariated logistic regression models were constructed for each variable to verify which one was related to mara's habitat use (Miller et al., 2000; Silva et al., 2007). I used the Wald (Z^2) statistics, with a χ^2 distribution, to test coefficients of significance of univariate regressions (Agresti, 1996; Cumming, 2000). Variables significantly associated with the presence of mara ($p < 0.05$) were used to construct a multivariate logistic regression model. The whole model was compared with reduced ones using Akaike Information Criteria (AIC) (Akaike, 1985). The model with the lower number of parameters (parsimony principle) and the best fit to the data set, i.e. the model with the lower AIC, was selected. The relationship between size of use area and distance to the nearest use area was verified with a regression analysis. Comparisons of habitat characteristic between areas used and not used by maras were made by a Wilcoxon test for paired data (Zar, 1999) using Infostat Statistical Software.

3. Results

3.1. Use areas

Eighteen areas used by maras were found in the study area (Fig. 2). They were classified according to the type of land used into: grazed areas ($n = 6$), burned areas ($n = 2$), plowed areas ($n = 2$), crop areas ($n = 2$), watering points ($n = 2$), dirt roads ($n = 3$), vizcacha burrows ($n = 1$), and unmodified areas ($n = 18$) (an area was regarded as unmodified if during vegetation sampling it could not be included in any of the previous categories, and cattle ware removed at least 4 months before sampling). Most (94.4%) of these areas were located on human-modified habitats. Only the area in vizcacha burrows was on a natural modification of habitat.

3.2. Size of use areas and distance to nearest neighbour

The area used by the mara was 7.73 ha (±1.87 ha) (mean ± SD), and ranged from 0.88 ha to 30.29 ha. The nearest neighbour was 955.55 m (±177.9 m) (mean ± SD), with a minimum of 200 m and a maximum of 3200 m. Clark and Evans (1954) *R* value was 0.032, indicating a grouped pattern of use areas. Regression analysis showed a positive association between size of use areas and distance to nearest neighbour ($p = 0.0026$: $R^2 = 0.62$).

3.3. Habitat model

Only four variables were associated ($p \leq 0.05$) with the presence of mara (Table 1), and they were used to construct the model. Three of these were negatively associated (percent perennial grasses, shrub density and height of grass–herbaceous strata), and the variable percent bare soil was positively associated with mara presence. This whole model was compared with reduced models using AIC, the parsimonious model being the one including high cover of bare soil and low shrub density (Table 2). The final model based on the transformed data set was:

$$P_i = \exp[-12.0989 + 5.3947\ \text{bare soil} - 161.1476\ \text{shrub density}] \div [1 + \exp(-12.0989 + 5.3947\ \text{bare soil} - 161.1476\ \text{shrub density}]$$

with P_i being the probability of habitat *i* being an area used by maras; bare soil being percent bare soil; and shrub density the number of shrubs/m^2 in habitat *i*. The model correctly classified 91.7% of cases according to mara presence–absence, with 94.4% for habitats with maras and 88.9% for habitats without maras.

Fig. 2. Location of mara use areas in the study site.

Table 1
Results of univariated logistic regression analysis for final variables related with mara's habitat use. β coefficient, standard error (SE), Wald's statistic (Z^2) and the associated p value are shown for each variable. *Variables used in multivariate model.

Variable	β	SE	Z^2	P
Bare soil (Bsoil)	3.92	1.6073	5.9481	0.0147*
% Perennial gasses (Pgrass)	−4.3568	2.0561	4.4902	0.0341*
% Perennial herbs (Pherb)	3.4398	3.4149	1.0146	0.3138
Track width (T width)	−2.07E−15	1.2744	0	1
Shrub density (Dshurb)	−96.1902	37.8364	6.4631	0.011*
Tree density (Dtree)	−49.8342	33.0028	2.2801	0.131
Annual percentages (anualt)	−4.4495	2.892	2.3672	0.1239
Height of grass–herb stratum (Hgrass–herb)	−1.4896	0.6422	5.38	0.0204*

3.4. Vegetation structure

Most of the vegetation structure variables were significantly different between areas used and not used by maras, except percent litter and height of perennial herbs (Table 3). Areas used by maras were characterized by a large cover of bare soil and a low percent cover of annual and perennial herbs and grasses, while areas where maras were absent were characterized by taller, denser shrubs and an extensive cover of perennial and annual herbs and grasses (Fig. 3).

4. Discussion and conclusions

The habitat model indicates that the presence of mara can be adequately predicted using bare soil and shrub density variables, which were positively and negatively associated, respectively, with the presence of maras. These habitat characteristics are typical of low strata in open habitats. It is hypothesized that these features allow maras to move more easily than in closed habitats, and be capable of a more effective detection of potential predators or a potential mate (Taber, 1987; Kufner and Chambouleyron, 1991; Baldi, 2007). Notwithstanding early data on habitat use by the mara, this is the first study presenting a habitat model for the endangered and endemic Patagonian hare. The model can be tested along several localities of mara's extensive geographical range, and can be used to predict potential use areas, mainly for conservation efforts.

According to the size of use areas, Taber (1987) found that the daily home range of a mara is 10.25 ha (±5.64 ha), and that distances between areas were 1405 m (±448 m). These values (median values and standard deviation) are similar to those reported in the present study. The technique used in the present study allowed me to determine the minimal area size used by this species. The differences between home range and use area are that home range can be assigned to an individual, while use area for mara, which is monogamous year round, is the area used by a couple and their offspring. While the methods in the current study are applicable to other areas, other techniques such as telemetry should be used to estimate home range size (seasonal or annual), in order to allow a more practical, simple, and precise monitoring of individuals.

The relationship between the spatial distribution of mara use areas and their size shows an aggregation pattern. They accords with my prediction, because there was no overlapping area between neighbouring pairs. In the study area, maras use a wide range of available habitats, varying from large size areas (up to 30 ha) separated by long distances (3200 m) to small patches (0.88 ha) situated very close to one another (200 m). The relationship between patch size and distance to nearest open area is positive. This means that unlike large areas, small patches are closer to dirt track. This could indicate that maras are using either small patches connected by these open areas or large patches disconnected from other use areas. Although patch connectivity could not be analyzed, it is known that maras use roads and trails as corridors, which allow them to move between use areas.

Most of the areas used by maras were located in human-modified habitats such as dirt roads, watering points, and grazed,

Table 2
Comparison between alternative (reduced) habitat models using Akaike's Information Criteria (AIC). The final model is indicated in bold characters.

Habitat model	np	−2 LF	AIC
Bsoil + Pgrass + Hgrass–herb	4	37.701	45.701
Bsoil + Pgrass	3	38.516	44.516
Bsoil + Hgrass–herb	3	38.407	44.407
Bsoil + Dshrub	**3**	**10.757**	**16.757**
g.per.tr + Hgrass–herb	3	41.662	47.662
Bsoil	2	41.384	45.384
Pgrass	2	44.301	48.301
Dshrub	2	14.63	18.63
Hgrass–herb	2	42.351	46.351

Table 3
Comparison of vegetation structure between habitats with maras and without them. Median and standard error (SE) are shown for each variable.

VARIABLE	MARAS		NO MARAS		P
	Median	SE	Median	SE	
% bare soil	31.78	6.76	5.72	2.23	0.002
% annual grass	0	0.41	0.01	0.67	0.002
% peren grass	4.15	2.22	10.8	3.55	0.002
% annual herb	0	0.18	0.04	0.82	<0.0001
% peren herb	0.7	1.18	0.88	0.45	0.004
Height peren grass	5.85	1.55	15.19	4.24	<0.0001
Height peren herb	1.55	0.9	2.29	0.67	0.576
Height annual grass	0	0.75	0.84	1.5	0.008
Height annual herb	0	0.27	0.01	1.33	<0.0001
No bushes	0.49	0.11	3.5	0.35	<0.0001
Height bushes	0.31	0.07	1.25	0.08	<0.0001
Wide bushes	0.36	0.07	1.31	0.12	<0.0001
No tree	0.02	0.01	0.03	0.02	<0.0001
% litter	56.79	7.14	59.79	3.32	0.4

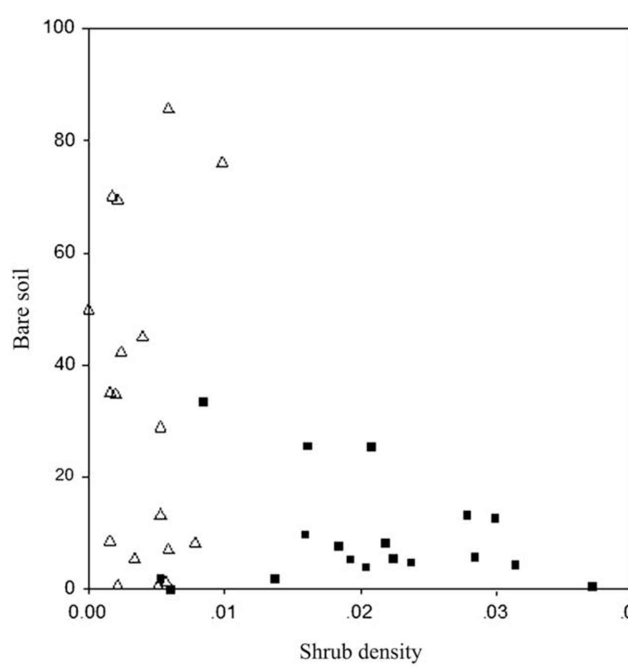

Fig. 3. Vegetation structure for mara's uses (△) and not use areas (■).

burned, cropped and plowed areas. This result seems to indicate that maras prefer artificial habitats. Nevertheless, because of the destruction and loss of natural habitats for maras, often resulting from ranching activities, mara is probably being forced to use open habitats created by humans. The only naturally modified habitat used by mara was open shrub with abandoned vizcacha burrows. Despite being considered an ecosystem engineer (Villarreal, 1999; Machicote et al., 2004), vizcacha are actually being hunted by ranchers because they are thought to cause economic loss through their burrowing activities.

Human activities such as cattle management and road maintenance, and natural factors such as fire and vizcacha burrowing and grazing help to maintain open areas and could potentially be used by maras. While some cattle grazing areas are used by maras, the intensity and period of grazing should be evaluated before confirming whether this activity provides suitable habitats for the mara. Dirt roads were the more common habitats for watching maras because of the bare soil and absence of shrubs. However these habitats are usually frequently used by cars, benefiting capture and hunting of maras. Fire also reduces shrub density and creates open areas (Machicote, 2001). Therefore, fire management practices could create suitable mara habitat. It is critical therefore that further studies are conducted on the effects of fire, vizcachas and cattle activity on mara populations to improve the management of this species.

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