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Habitats selected by the endangered Greater Rhea (*Rhea americana*) – implications for conservation

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Abstract. The abundance and spatial distribution of species are influenced by the distribution and availability of resources. The objective of this study was to evaluate habitat selection by a wild population of Greater Rhea (*Rhea americana*) in El Palmar National Park, Entre Ríos, Argentina, and the adjacent agroecosystem. Sightings and signs (i.e. faeces, footprints) of Rheas and environmental variables were recorded every 45 days from April 2011 to March 2012 at 51 sites. The associations between the habitat selected by Rheas and landscape elements were analysed by means of generalised linear mixed models and generalised linear models. A total of 301 sightings were made, at 57% of the sampling sites. Habitat use was linked with environmental variables but differed with time of year (breeding vs non-breeding season). For much of the year, Rheas selected sites with a simple landscape structure, open and low vegetation, such as grasslands, crops and firebreaks, which facilitate movements of birds, and near waterbodies. In the breeding season, Rheas selected dense grassland sites. To manage and conserve this species, it is recommended that areas of open grassland free of shrubs are preserved and expanded and that grassland corridors are created to connect fragmented patches of grassland.

Additional keywords: GIS, national parks, spatial use, wild species, wildlife management.

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Introduction

For individual organisms, not all environments and sites are equally suitable for occupation, and animals choose from the available habitats and sites within an environment (Morris 1996). Such habitat selection is a process over multiple scales and a consequence of two decisions: where to live and establish a home-range and where to shelter and forage within that home-range. The study of habitat selection by species and the combination of resources (availability, type and quantity of food, water, and shelter) and the physical and ecological environment (temperature, precipitation, presence of predators and competitors) that promote the occupation of habitats by individuals or populations are essential to developing management guidelines for the conservation of organisms.

In South America, large areas of native temperate grasslands, owing to their suitable soil types and weather, have been transformed to agricultural land, cultivated mainly with Soybean (*Glycine max*) (Baldi *et al*. 2006). Worldwide, grasslands are little protected and, especially in the Argentine Pampas, changes in the use and management of land have resulted in fragmentation of grasslands, reduction in the distribution and abundance of specialist grassland birds, and increased avian mortality resulting from the use of pesticides (Maitz and Dickman 2001; Bilenca and Miñarro 2004; Baldi *et al*. 2006; Filloy and Bellocq 2007; Codesido *et al*. 2011, 2012). In particular, in El Palmar National Park, Entre Ríos, Argentina, the exclusion of cattle and fire suppression after the creation of the reserve in 1965 appears to have promoted an increase in shrub and tree cover and loss of the grasslands typical of this zone, with subsequent negative effects on grassland birds (APN 1994; Goveto *et al*. 2005; Batista *et al*. 2014).

The Greater Rhea (*Rhea americana*) is a ground-dwelling Neotropical ratite, distributed from eastern and central Brazil and the Bolivian Chaco south through Paraguay, Uruguay and northern and central Argentina, to the Río Negro province of Argentine Patagonia (Blake 1977; Bazzano *et al*. 2002; Martella and Navarro 2006; De Azevedo *et al*. 2010). Rheas mainly inhabit grasslands but also occupy other habitats, both natural and anthropogenic, including savannas, open woodlands, shrublands, saline marshes, croplands, pasture and forest plantations (del Hoyo and Elliot 1992; De María 1994; Martella *et al*. 1996; Bazzano *et al*. 2002; Bellis *et al*. 2004*a*, 2004*b*; Comparatore and Yagueddú 2007; Giordano *et al*. 2008, 2010; Roldán *et al*. 2009; De Azevedo *et al*. 2010; Juan *et al*. 2013). The species is classified as Near Threatened globally (IUCN 2016) and Endangered in Argentina (López-Lanús *et al*. 2008), mainly as a result of modification, fragmentation and loss of habitat caused by the intensification of agricultural practices, in turn causing spatial isolation and loss of genetic variability (Bouzat 2001; Reboreda and Fernández 2005; Martella and Navarro 2006; Giordano *et al*. 2008). Despite the value of natural and protected areas for the conservation of biodiversity, most studies of the ecology of Greater Rheas have been in agroecosystems or semi-natural grasslands (Bellis *et al*. 2004*a*, 2004*b*; Herrera *et al*. 2004; Comparatore and Yagueddú 2007; Giordano *et al*. 2008; Juan *et al*. 2013). The objective of this study was to evaluate the habitat selection of a wild population of Greater Rheas in El Palmar National Park and the adjacent agroecosystem in order to determine the preferred habitat of this species.

Methods

Study area

The study was carried out in Entre Ríos, Argentina, in El Palmar National Park (EPNP; 31°55′S, 58°16′W) and an adjacent agroecosystem (Fig. 1). EPNP covers an area of ~8500 ha, lies within an important bird area (Di Giacomo and Abril 2005; López 2006) and is a designated Valuable Grassland Area of Argentina (Bilenca and Miñarro 2004). EPNP supports 11 broad vegetation types, defined by their soil types and floristic composition (Ruiz Selmo *et al*. 2007): gallery forest (629 ha, 7% of the total area), dry woodland (119 ha, 1%), shrubland with trees (681 ha, 8%), sandy areas with scarce vegetation (7 ha, 0.08%), open grassland (376 ha, 4%), semi-dense grassland (756 ha, 8%), dense grassland (2951 ha, 35%), flooded grassland (798 ha, 9.4%), open palm forest (677 ha, 8%), semi-dense palm forest (879 ha, 10%) and dense palm forest (629 ha, 7%).

The agroecosystem (AGR hereafter) is a privately owned farm bordering the national park (31°55′S, 58°18′W), and covers a total of 5400 ha. The study was concentrated in an area of 1526 ha adjacent to EPNP, composed of Soybean crops (36% of the study area), mature *Eucalyptus* plantation (3–5 m tall; 21%), *Sorghum* crops (23%), pasture (11%) and young *Eucalyptus* plantation (ploughed and with plants <1.5 m tall; 9%). Hunting is prohibited on the property.

Sightings and indirect signs of Rheas

Data on Rheas were collected at sampling sites along fixed transects over two consecutive days every 45 days from April

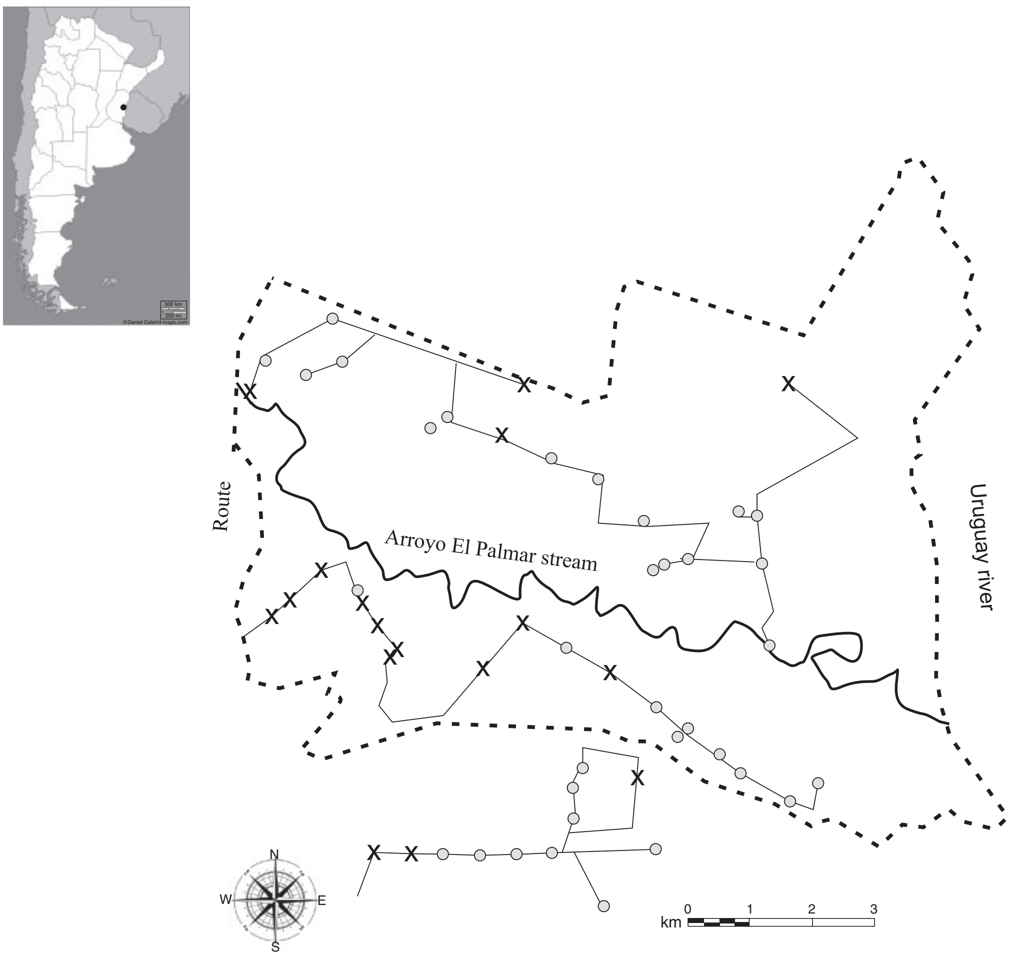

Fig. 1. The study area in Entre Rios, Argentina (inset) and map of sites with presence (grey circles) or absence (black crosses) of Greater Rheas (direct sighting or indirect sign) in the El Palmar National Park (EPNP; boundary shown by dotted line) and in the agroecosystem (transect below the southern limit of the EPNP).

2011 to March 2012 ($n = 9$ sampling periods). January–September was classified as the non-breeding period, and October–December the breeding period (Reboreda and Fernández 2005). Three fixed transects that were sampled each sampling period were established running roughly west–east using existing unpaved routes (Fig. 1): one 12 km long in the north of EPNP (NZ); one 14 km long in the south of EPNP (SZ); and one 11 km long in the AGR. The routes were used by EPNP or AGR personnel only. The northern and southern zones of EPNP (NZ and SZ) were separated by a stream (Arroyo El Palmar) that also runs west–east and that may act as a barrier to the movement of Rheas and interchange of populations.

Sampling points were located every 1–2 km along each of the three transects. A few additional points where Rheas were observed between the sampling points were also sampled and followed over the study period. There were 20 sampling points along the transect in the NZ, 19 in the SZ and 12 in the AGR. At each sampling point, two observers, with binoculars, walked slowly in opposite directions perpendicular to the axis of the transect into the surrounding vegetation for 500 m, and recorded the number of Rheas sighted, group-size, and their distance and direction from the sampling point on the transect. At each sampling point, searches for fresh Rhea footprints and faeces, as an indirect indicator of the presence of Rheas, were conducted for 10–15 min within an area of ~$30 \times 30\,m^2$ centred on the sampling point (faeces were collected for other studies). Both observers walked in parallel, 4 m apart, to survey the area.

Footprints were classified as: 0, no footprints; 1, one or two footprints or tracks of footprints belonging to one or two individuals; 2, comprising 3–7 footprints or tracks that could be recognised as belonging to different individuals (differentiated by size and direction of the footprints); and 3, >7 footprints or tracks that could be recognised as belonging to different individuals. The ground of every vegetation community is sandy or bare and footprints were easily detected. Faeces were classified as: 0, absence of faeces; 1, from one to three faeces; 2, comprising 4–11 faeces; and 3, >12 faeces. The size of Rhea faeces meant they were easily observed in any vegetation community independent of vegetation cover. The classification was developed before the start of the study to create a quantitative indirect variable that was easy to determine in the field.

Environmental variables

The 11 broad vegetation types were assessed individually and also grouped into two categories: open and closed environments. The open environments had low to moderately tall vegetation and absence of shrubs, and included the sandy areas, open grassland and semi-dense grassland. The closed environments had moderately tall to tall vegetation in the mid-stratum and shrubs or other woody plants, and included the gallery forest, dry woodland, shrubland with trees, dense grassland, and the dense, semi-dense and open palm forest. The flooded grassland was omitted from this classification because it is an aquatic environment not used by Rheas.

Satellite images of the study area (Google Earth), mapping of the vegetation types (Ruiz Selmo *et al*. 2007), and the location of the transects and sites were integrated in a geographical information system (GIS; ESRI 1999). Based on these maps and using Patch Analyst 2.2 (Elkie *et al*. 1999), a total of 35 variables for EPNP and eight variables for AGR were quantified for each site as an estimate of landscape structure (Turner and Gardner 1991) that included the proportion and perimeter lengths of vegetation types (Tables 1 and 2). Many of the variables (details in Table 1) were quantified within a circular sampling window 1000 m in diameter generated at each site (area $0.78\,km^2$). This area is ~20% of the estimated minimum home-range that satisfactorily meets the requirements of an individual Greater Rhea (Giordano *et al*. 2010).

Data analysis

The difference in the number of sites at which Rheas were detected (based on direct sightings or indirect observations) between the study transects (NZ, SZ, AGR) was compared using a Chi-square test, and the difference in the number of sites at which Rheas were detected between seasons (breeding, non-breeding) was compared using a Kruskal–Wallis test (Zar 1996). Further, the group-size in each sampling period was compared between zones and seasons by means of a Kruskal–Wallis test (Zar 1996).

To determine habitat selection by Greater Rheas, generalised linear mixed models (GLMM, using the sampling point as a random effect) and generalised linear models (GLM) with binomial or Poisson error structures were used to assess the presence of Rheas (both direct sightings and indirect observations) and number of Rheas (direct sightings) against landscape variables and breeding or non-breeding period (Tables 1 and 2) (McCullagh and Nelder 1989; Nicholls 1991; Crawley 1993; Zuur *et al.* 2009). Significance of the random effect was tested based on change of deviance between models with and without the random effect; random effect was removed from the final model when it did not improve the explained variance (Zuur *et al.* 2009). GLMMs were conducted using the lme4 (Bates *et al.* 2015) and MASS packages (Venables and Ripley 2002) within the software R (R Core Team 2013) and GLM developed using the BASE package within R. A Spearman correlation was performed to identify associated explanatory variables ($P < 0.05$; Tables S1 and S2, in supplementary material available online) to avoid the inclusion of redundant variables in the models (Zar 1996). The landscape variables chosen were those with clear ecological meaning and association with Greater Rheas, such as indicators of the availability of food and shelter (Austin 2007). The variables were added in the analysis by means of a forward stepwise procedure and were kept in the model if statistically significant (Zuur *et al.* 2009). The dependent variables were: presence of faeces, category of faeces, presence of footprints, category of footprints, presence of individuals and number of individuals observed for each site in each month. A principal components analysis (PCA) using a correlation matrix was performed to identify groups of associated dependent variables to avoid, or reduce the number of, redundant models (Legendre and Legendre 1998; Table 3). Based on the PCA, variables were selected that were easily observable in the field and constituted direct or indirect evidence of the occurrence of Rheas.

To determine model explanation of observed data we compared predicted and observed values of the dependent variable

Table 1. Variables measured at each sampling site in the El Palmar National Park (EPNP)
In descriptions below, 'window' refers to the circular sampling area of 0.78 km^2 around each sampling point in which the variables were quantified

Variable name	Variable description
Vegetation type	A category based on the floristic composition and soil type at the sampling point
Altitude (Al)	Height of sampling point above sea level (m)
Zone	Location within either northern (NZ) or southern (SZ) zone of the EPNP
Month	Sampling month ($n = 9$ sampling periods)
Season	Breeding (October–December) or non-breeding (January–September)
Area of each vegetation type (VTA)	Area of patches of each vegetation type within each site window (ha)
Number of patches (NP)	Number of vegetation types within window
Average size of patches (ASP)	A measure of average size of patches of vegetation types within window (ha); calculated as the sum of area of each vegetation type within the window divided by the number of vegetation types
Edge density (ED)	A measure of edge effect within a window (m ha^{-1}); calculated as the sum of the perimeters of each vegetation type divided by the total area of the window
Edge density of vegetation types combined in open and closed categories (EDoc)	A measure of the edge effect within a window, including open and closed environmental categories of vegetation; calculated as the sum of perimeters of each vegetation type divided by the number of vegetation types
Average patch perimeter (APP)	A measure of the edge effect within window (m ha^{-1}); calculated as the sum of the perimeters of open and closed categories of vegetation type divided by the area of the window
Mean shape index (MSI)	A measure of complexity of landscape structure within a window; calculated as the sum of the perimeters of each vegetation type divided by the square root area of each vegetation type within window, adjusted by the constant 0.25 divided by the number of vegetation types
Mean perimeter area ratio (P/A)	A measure of complexity of landscape structure within a window; calculated as the sum of ratios between the perimeter and area of each vegetation type divided by the number of vegetation types in the window
Distance to waterbody (DWB)	Minimum distance from sampling point to nearest body of water (including Uruguay River and Arroyo El Palmar stream) (m)
Distance to main stream (DMS)	Minimum distance from sampling point to main stream (Arroyo El Palmar) (m)
Distance to route (DRo)	Minimum distance from sampling point to national route bordering western limit of EPNP (m)
Distance to the edge of EPNP (DL)	Minimum distance from sampling point to nearest limit of EPNP (m)
Distance to river (DRi)	Minimum distance from sampling point to Uruguay River located to east of EPNP (m)
Distance to patches of open vegetation types (DoP)	Minimum distance from sampling point to nearest patch of open environment (m)
Distance to firebreak (DF)	Minimum distance from sampling point to nearest firebreak (a wide strip of unvegetated land to prevent fires from spreading uncontrolled) (m)
Proportion of vegetation types – closed (PETc)	Proportion of window composed of closed vegetation type
Proportion of vegetation types – open (PETo)	Proportion of window composed of open vegetation types
Proportion of gallery forest (PGF)	Proportion of window composed of gallery forest
Proportion of open grasslands (POG)	Proportion of window composed of open grassland
Proportion of semi-dense grasslands (PSG)	Proportion of window composed of semi-dense grassland
Proportion of dense grasslands (PDG)	Proportion of window composed of dense grassland
Proportion of lowland (PL)	Proportion of window composed of lowland
Proportion of open palm (POP)	Proportion of the window composed of open palm
Proportion of semi-dense palm (PSP)	Proportion of window composed of semi-dense palm forest
Proportion of dense palm (PDP)	Proportion of window composed of dense palm forest
Number of patches combined in open and closed vegetation types within site window (NPoc)	Number of vegetation types in open and closed categories within window
Average size of patches combined in open and closed vegetation types (ASPoc)	A measure of landscape structure and size of patches of open and closed vegetation types within window
Average length of perimeter of patches combined in open and closed vegetation types (APPoc)	A measure of edge effect within site window (m); calculated as sum of perimeter of each vegetation type combined in open and closed categories divided by number of categories

(*continued next page*)

Table 1. (*continued*)

Variable name	Variable description
Mean shape index combined open and closed environment types (MSIoc)	A measure of complexity of landscape structure within site window; calculated as sum of perimeter of each vegetation type divided by the square root area of vegetation type within a window, adjusted by the constant 0.25 divided by the number of vegetation types
Mean perimeter : area ratio of combined vegetation types in open and closed vegetation types (P/Aoc)	A measure of complexity of landscape structure within window; calculated as the sum of the ratios between perimeter and area of each vegetation type divided by the number of vegetation types

Table 2. Variables measured at each site in the agroecosystem adjacent to the El Palmar National Park (EPNP)
In descriptions below, 'window' refers to the circular sampling area of 0.78 km^2 around each sampling point in which the variables were quantified

Variable name	Variable description
Altitude (Al)	Height of sampling point above sea level (m)
Month	Sampling month ($n = 9$ sampling periods)
Season	Breeding (October–December) or non-breeding season (January–September)
Distance to edge of EPNP (DL)	Minimum distance from sampling point to nearest edge of EPNP (m)
Distance to route (DR)	Minimum distance from sampling point to national route bordering western limit of EPNP (m)
Distance to the grassland grazed by cattle (DGC)	Minimum distance from sampling point to nearest grassland grazed by cattle (m)
Distance to Soybean crop (DSC)	Minimum distance from sampling point to nearest Soybean crop (m)
Distance to *Eucalyptus* plantation (DEP)	Minimum distance from sampling point to *Eucalyptus* plantation (m)

Table 3. Dependent variables associated (positively or negatively) with each of the first three axes of the principal component analysis
Significant associations are highlighted in bold (Pearson $r > 0.3$). Category of footprints: 0, no footprints; 1, comprising 1–2 footprints or tracks of footprints belonging to one or two individuals; 2, comprising 3–7 footprints or tracks that could be recognised as belonging to different individuals. Category of faeces: 0, absence of faeces; 1, from 1–2 faeces; 2, from 4–11 faeces; 3, ≥12 faeces

Dependent variable	Axis 1	Axis 2	Axis 3
Category of footprints	**0.4258**	**–0.3340**	0.2258
Presence of footprints	**0.4002**	**–0.3610**	0.1586
Number of individuals observed	**0.3548**	**0.4836**	0.0865
Presence of individuals	**0.3446**	**0.3942**	–0.0438
Category of faeces	0.2342	–0.1140	**–0.6495**
Presence or absence of faeces	0.2277	–0.1027	**–0.6587**
Eigenvalues	3.6370	2.0790	**1.6670**
Proportion explained	0.4540	0.2590	**0.2080**

(percentage of concordance) of binary dependent variables (e.g. presence of faeces), and tested the change of deviance between final models and the null model by Chi-square tests when the variable is not binary (Zuur *et al.* 2009).

Analyses were performed for the EPNP and AGR separately because each has different management and landscape composition and so models for each had to include different independent variables (Tables 1 and 2).

Results

Direct and indirect signs of Rheas

In total, 301 Greater Rheas were sighted (direct observations) at 29 (57%) of the 51 sampling sites (mean of 38 Rheas per sampling period (month), s.d. 13.9, minimum 22, maximum 64). The proportion of sites at which Rheas were recorded differed between the EPNP zones and the AGR, with Rheas recorded at most sampling sites in the AGR (92% of points in AGR), and at fewer sites in the NZ (65%) and SZ (26%) of the EPNP ($\chi^2 = 130.54$, $P = 0.0001$). In EPNP, the sites with Rheas were concentrated in the east of the SZ, and distributed more evenly throughout the NZ. There was no significant difference in the proportion of sites with sightings of Rheas between the AGR and the two zones of EPNP (Kruskal–Wallis: $H = 0.11$, $P = 0.74$).

There were no significant differences detected in the size of the groups between EPNP zones and the AGR (median group-size: NZ = 2 birds; SZ = 1 birds; AGR = 2.5 birds; Kruskal–Wallis: $H = 1.63$, $P = 0.41$) or between the breeding and non-breeding periods (median group-size: breeding = 3 birds, non-breeding = 4 birds; Kruskal–Wallis: $H = 0.17$, $P = 0.66$). However, the largest group was observed in the AGR (38 individuals, cf. maximum of 11 in the NZ and 7 in the SZ) and in the non-breeding season (38 individuals, cf. maximum of 10 in the breeding season).

We detected signs of Rheas at 34 (67%) of the 51 sites (Fig. 1), all but two of which were sites where Rheas were sighted (signs were recorded at two sites in the SZ of EPNP, close to the AGR where Rheas were not sighted). There were slight but non-significant differences in the proportion of sites with signs of Rheas between zones in EPNP and the AGR ($\chi^2 = 5.14$, $P = 0.07$). Within EPNP, signs of Rheas were observed at 64% of sites, including a higher percentage of sites in the NZ (80%) than in the SZ (47%) ($\chi^2 = 4.17$, $P = 0.04$; Fig. 1). In the AGR, signs of Rheas were recorded at 75% of the sites.

Habitat selection

The PCA of dependent variables showed associations among many of them (Table 3). The presence of faeces and the number of individuals sighted were included in the EPNP models as dependent variables because they are easily observable in the field and represent direct and indirect observations of birds.

El Palmar National Park

Most direct sightings and indirect signs of Rhea were in the NZ of EPNP, in circular windows with less complex landscape structure and, in the breeding season, in dense grassland (Tables 4 and 5). Further, the number of sample points with faeces was greater near waterbodies than elsewhere (Table 4). Lastly, larger groups (sightings and indirect signs) were detected near firebreaks and at sites with lower proportions of dense grassland and of closed environment types (Table 5).

Agroecosystem

Overall, 41% of individuals observed were detected in Soybean crops (crops and crop residues), 37% in young *Eucalyptus* plantations (ploughed and with plants <1.5 m tall), 12% in mature *Eucalyptus* plantations (3–5 m high) and associated firebreaks, and 9% in grazing pasture. Rheas were neither sighted nor detected indirectly in Sorghum crops.

The probability of detecting faeces and individuals was greater in sites located near Soybean crops and *Eucalyptus* plantations (Tables 4 and 5). Additionally, based on the presence of faeces,

Table 4. Multiple regression mixed models (GLMM) for presence or absence of faeces as a function of explanatory variables in the El Palmar National Park (EPNP) and the agroecosystem (AGR)

Variance explained by the random effect (sites) was 6% for EPNP ($P < 0.05$) and 3.5% for AGR ($P < 0.05$); percentage of concordance between observed and predicted values was 85.5% for EPNP and 73.3% for AGR; s.e., standard error

Explanatory variable	Estimate	s.e.	*z*	*P*
EPNP				
Intercept	2.6149	0.6471	4.041	<0.0010
Southern zone	–1.9105	0.3348	–5.705	<0.0010
Breeding season	–2.3147	0.6022	–3.843	<0.0010
Proportion of closed environment types	–0.0559	0.0182	–3.067	0.0022
Proportion of dense grassland	0.0208	0.0152	1.364	0.1725
Distance to main stream	–0.0343	0.0135	–2.533	0.0113
Mean shape index	–0.0493	0.0155	–3.176	0.0014
Breeding season × proportion of dense grassland	0.0863	0.0275	3.136	0.0017
AGR				
Intercept	1.5617	0.4037	3.868	<0.0010
Distance to *Eucalyptus* plantation	–0.0009	0.0004	–2.549	0.0108
Breeding season	–0.8905	0.4870	–1.829	0.0674
Distance to Soybean crop	–0.0015	0.0004	–3.139	0.0017

Table 5. Multiple Regression Models (GLM) for the number of individuals as a function of environmental variables in the El Palmar National Park (EPNP) and the agroecosystem (AGR)

The random effect (sites) was not included in the models because the change of deviance did not improve the explained variance. Variance explained by the model 24.0% for EPNP and 25.5% for AGR. Model significance: PNEP $\chi^2 = 271.5$ (d.f. = 8, $P < 0.0001$); AGR, $\chi^2 = 129.9$ (d.f. = 2, $P < 0.0001$). s.e., standard error

Explanatory variable	Estimate	s.e.	*z*	*P*
EPNP				
Intercept	2.6828	0.1505	9.540	<0.001
Southern zone	–0.6743	0.0758	–8.889	<0.001
Breeding season	–1.3901	0.1717	–8.095	<0.001
Distance to firewall	–0.0174	0.0033	–5.145	<0.001
Proportion of dense grasslands	0.0056	0.0042	1.314	0.189
Proportion of semi-dense grassland	–0.0163	0.0032	–4.996	<0.001
Proportion of closed environment types	–0.0166	0.0038	–4.287	<0.001
Mean shape index	–0.0193	0.0035	–5.551	<0.001
Breeding season × proportion of dense grassland	0.0479	0.0068	7.011	<0.001
AGR				
Intercept	0.0220	0.0519	40.868	<0.001
Distance to Soybean crop	–0.0006	0.0001	–5.887	<0.001
Distance to *Eucalyptus* plantation	–0.0006	0.0001	–7.229	<0.001

fewer numbers of points with indirect signs were detected in the breeding season (Table 4).

Discussion

The present study confirms the use of modified agroecosystems by Greater Rheas and has increased knowledge of habitat selection in a natural protected area, about which little was known despite the great value of such areas in the conservation of biodiversity. In the study area, Greater Rheas were more frequently detected in modified, cultivated habitats of the AGR than in natural habitats in EPNP. This differential use may relate to the availability of food throughout the year in the agroecosystem provided by the Soybean crops and the presence of open areas that allow ready movement of individuals associated with the low herbaceous ground-layer within *Eucalyptus* plantations, at the edges of crops and along firebreaks (Bazzano *et al*. 2002; Goveto *et al*. 2005; Martella and Navarro 2006; Comparatore and Yagueddú 2007; de Azevedo *et al*. 2010). In the AGR, Rheas were strongly associated with areas located near Soybean and *Eucalyptus* plantations, where they had a combination of food resources and refuge from predators. In EPNP, Rheas were mainly detected in open habitats, such as grasslands lacking shrubs, and tended to avoid closed habitats, such as palm forests with an understory of shrubs or trees. Overall, Rheas selected less complex and open habitats, landscapes with simple form and structure, and areas with a low proportion of closed vegetation types and near waterbodies. These results are consistent with previous studies showing that Rheas need open spaces, sites with low density of canopy cover and shrubs, and landscapes with a simple matrix of vegetation types and high connectivity among patches (Herrera *et al*. 2004; De Azevedo *et al*. 2010). The proximity to waterbodies observed in this study is consistent with the results of Herrera *et al*. (2004), who proposed that Rheas select these areas because they provide good food resources, in particular, abundant herbaceous plant species.

Rheas were recorded in small groups or as solitary individuals in the breeding season, as reported in other studies (Reboreda and Fernández 2005; Carro and Fernández 2008; Giordano *et al*. 2008). In the non-breeding season, as a result lower levels of intraspecific competition (Carro and Fernández 2008), larger groups were detected than in the breeding season, especially in the AGR. In the breeding period, Rheas were found in dense grassland, possibly because this provides a safer environment for reproduction, with the species vulnerable to predation by mammals during incubation (Bazzano *et al*. 2002; Bellis *et al*. 2004*a*, Reboreda and Fernández 2005).

Rheas were detected throughout most of the AGR and NZ of EPNP (although the intensity of detection differed). However, in the SZ of EPNP, Rheas were concentrated in the eastern part. This south-eastern region consists of large areas of open grassland with large boulders, allowing better mobility and connection between different patches than elsewhere in the SZ. The central and western regions of the SZ comprise a matrix of dense vegetation, including large proportions of grassland dominated by shrubs and palm forest with woody understory, which could inhibit movement of birds. It is also worth noting that the AGR and EPNP are not isolated, and fences do not act as total barriers to movement of Rheas (Herrera *et al*. 2004). A group of seven adult Rheas was observed to move through a six-wire fence that divides EPNP and AGR in a sector where there was a gap of at least 40 cm between the lowest wire and the ground.

Conclusions

This work provides valuable information on the habitat requirements of the Greater Rhea, which need to be considered for management and conservation of the species. The main recommendations resulting from this study are the need to preserve and expand open areas of grassland free of shrubs and the preservation or creation of grassland corridors to connect patches of suitable vegetation within the national park. It is also necessary to develop management strategies in consultation with the managers of the agroecosystem bordering the national park, for example, by installing fencing with fewer wires to facilitate movements of Rheas in the landscape or by maintaining wider firebreaks in *Eucalyptus* plantations and maintaining or expanding areas of grassland, potentially by grazing cattle.

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