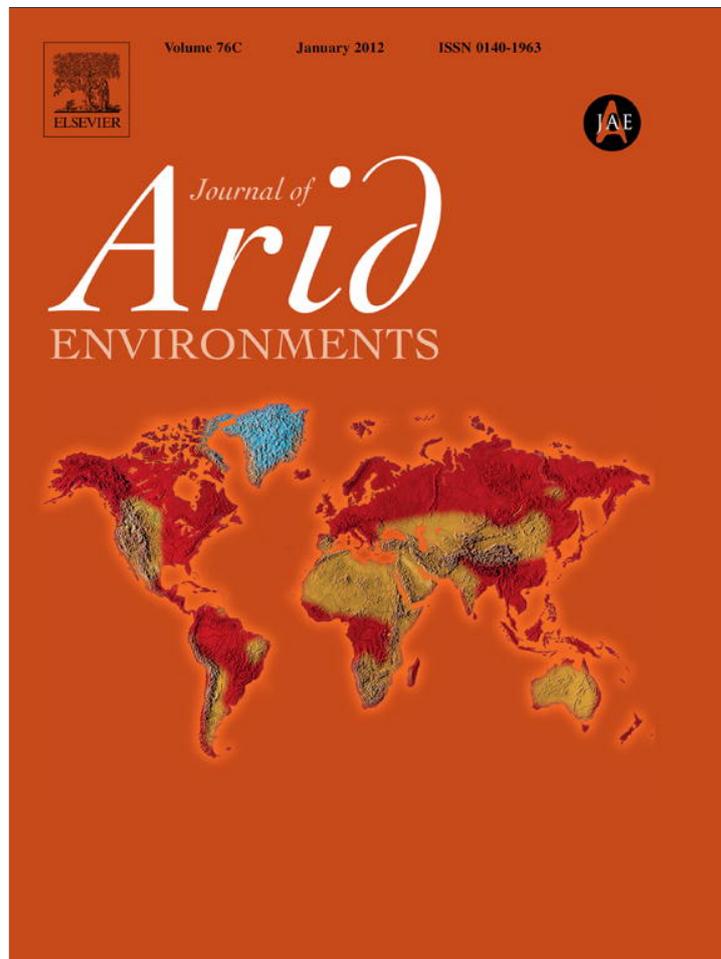


Provided for non-commercial research and education use.  
Not for reproduction, distribution or commercial use.



This article appeared in a journal published by Elsevier. The attached copy is furnished to the author for internal non-commercial research and education use, including for instruction at the authors institution and sharing with colleagues.

Other uses, including reproduction and distribution, or selling or licensing copies, or posting to personal, institutional or third party websites are prohibited.

In most cases authors are permitted to post their version of the article (e.g. in Word or Tex form) to their personal website or institutional repository. Authors requiring further information regarding Elsevier's archiving and manuscript policies are encouraged to visit:

<http://www.elsevier.com/copyright>



Contents lists available at SciVerse ScienceDirect

## Journal of Arid Environments

journal homepage: [www.elsevier.com/locate/jaridenv](http://www.elsevier.com/locate/jaridenv)

## Effects of livestock on the feeding and spatial ecology of Geoffroy's cat

J.A. Pereira<sup>a,\*</sup>, R.S. Walker<sup>a,b</sup>, A.J. Novaro<sup>a,b</sup><sup>a</sup> CONICET – Centro de Ecología Aplicada del Neuquén (CEAN), Casilla de Correos 7, Junín de los Andes (8371), Neuquén, Argentina<sup>b</sup> Wildlife Conservation Society (WCS), Curruhue 395, casa 2 (8371), Junín de los Andes, Neuquén, Argentina

## ARTICLE INFO

## Article history:

Received 28 March 2011

Received in revised form

17 August 2011

Accepted 19 August 2011

Available online 16 September 2011

## Keywords:

Behavioral plasticity

Daily movements

Home-range size

*Leopardus geoffroyi*

Prey selection

Radio tracking

## ABSTRACT

We compared diet composition, prey selection, home-range size, daily movements, and habitat preference of Geoffroy's cats (*Leopardus geoffroyi*) between cattle ranches and an adjacent national park in scrublands of Argentina. Although overall prey abundance was higher in the park than in the ranches, diet composition was similar between sites, and small rodents were the most common prey item found in Geoffroy's cat feces in both sites. Geoffroy's cats selectively preyed on sigmodontines in the ranches throughout the year and in the park during spring, when the abundance of this prey type was the lowest for this site. Mean daily movements of radio-collared Geoffroy's cats in the park were significantly shorter than those of cats in the ranches. Differences in habitat use between sites reflected differences in the availability of different habitat types, and Geoffroy's cats exhibited different patterns of habitat selection according to the site and the scale considered. Changes in home-range size and overlap were also apparent, but the small sample sizes and the short period during which individuals could be monitored may cloud the actual magnitude of these responses. Geoffroy's cats exhibited behavioral plasticity, as the two subpopulations in close proximity had such contrasting trophic and spatial ecology.

© 2011 Elsevier Ltd. All rights reserved.

## 1. Introduction

Livestock accounts for about 20% of total terrestrial animal biomass and the 30% of the earth's land surface that livestock now pre-empt was once habitat for wildlife (Steinfeld et al., 2006). Livestock reduces the density and biomass of plant species, alters their spatial heterogeneity, and decreases habitat productivity (Belsky and Blumenthal, 1997; Kauffman and Pyke, 2001), thus affecting the nutrient cycle, soil erosion, and fire regimens (Belsky and Blumenthal, 1997). These livestock-induced changes, in turn, can alter the density and vulnerability of small mammals, birds, invertebrates, and other prey species of carnivores by affecting availability of food and cover (Hayward et al., 1997; Pia et al., 2003). About 20% of the world's pastures and rangelands, and 73% of those in dry areas, have been degraded to some extent due to livestock activity (Steinfeld et al., 2006). At present, expansion of crops into drier areas is forcing livestock production to even drier lands (Sere et al., 1995). Argentina is following this global trend, with livestock farming increasing by over 19% between 1998 and 2002 in the central semiarid region of the country (INDEC, 2004). If this trend

continues, impacts of livestock farming will intensify, resulting in increased pressure on wildlife and habitats.

Habitat degradation is a major cause of population decline of many species of carnivores (Wilson and Mittermeier, 2009). Some felid species may be more sensitive than others to habitat degradation due to ecological and behavioral differences among species (Gittleman, 1989). However, since most studies on natural history of felids – particularly of small- and medium-sized felids – have been performed in protected landscapes (Nowell and Jackson, 1996), knowledge about the ecological response of different species to potential habitat degradation by livestock is lacking.

The Geoffroy's cat (*Leopardus geoffroyi*) is a small felid (approx. 4 kg) classified as "Near Threatened" (Lucherini et al., 2008), found mostly in arid and semiarid environments from Bolivia to southern Patagonia in Argentina and Chile (Nowell and Jackson, 1996). This felid has been described as an opportunistic predator, and the bulk of its diet in dry areas is composed of small rodents (mainly sigmodontines, subfamily Sigmodontinae) and introduced hares (*Lepus europaeus*) (Johnson and Franklin, 1991; Novaro et al., 2000; Bisceglia et al., 2008). Geoffroy's cats tend to use habitats with dense vegetation and high prey density (Johnson and Franklin, 1991; Manfredi et al., 2006; Pereira et al., 2006).

We studied the effects of livestock management and associated disturbances on the trophic and spatial ecology of Geoffroy's cats by comparing diet composition, prey selection, home-range size, daily

\* Corresponding author. Barrio Cardales Village, UF 90, Ruta 4 km 5.5 – Los Cardales (2814), Campana, Buenos Aires, Argentina. Tel.: +54 11 1567466483.

E-mail addresses: [jpereira@conicet.gov.ar](mailto:jpereira@conicet.gov.ar), [javipereira@yahoo.com](mailto:javipereira@yahoo.com) (J.A. Pereira), [anovaro@wcs.org](mailto:anovaro@wcs.org) (A.J. Novaro).

movements, and habitat preference between cattle ranches and an adjacent protected area in a semiarid scrubland of central Argentina. To relate changes in the cat's trophic and spatial ecology to habitat characteristics that may be affected by livestock, we also measured differences in vegetation structure and prey availability between sites.

## 2. Materials and methods

### 2.1. Study area

The study was conducted from April 2007 to January 2009 in Lihué Calel National Park (37°57'S, 65°33'W, 100 km<sup>2</sup>) and two adjacent cattle ranches (each >50 km<sup>2</sup>), central Argentina. The vegetation is characterized by a mosaic of creosote bush (*Larrea* sp.) flats, grasslands (dominated by *Stipa* spp.), and mixed shrub patches (with *Condalia microphylla*, *Prosopis flexuosa*). Current livestock density (9–21 cows per km<sup>2</sup>) and other management practices (e.g., paddock rotation, vegetation management with fire) are similar between studied ranches and other ranches in the region (J. A. Pereira, unpublished data). Ranchers usually hunt Geoffroy's cats (Pereira et al., 2010). In the national park, livestock is absent and hunting is not permitted.

Mean daily temperatures were 7 °C in winter and 25 °C in summer, and annual rainfall averaged 503.1 mm ( $\pm 172.8$  SD; period 1983–2001; data from the park weather station). However, a prolonged drought occurred during the period 2005–2008 (mean annual rainfall 337.1  $\pm$  19.0 mm). The pampas fox (*Lycalopex gymnocercus*), pampas cat (*Leopardus colocolo*), jaguarundi (*Puma yagouaroundi*), and puma (*Puma concolor*) are potential competitors of Geoffroy's cats in the area.

### 2.2. Habitat structure and prey abundance

To characterize vegetation structure we measured cover of bare soil and cover and mean height of trees, shrubs, and grasses in 10  $\times$  10 m plots (5 in creosote bush scrublands, 5 in xeric forests, and 5 in grasslands) at both the ranches and the park. To maximize the possibility that differences between sites were attributable mostly to the actions of livestock, plots in the park and the ranches were located in areas with similar geomorphology and physiognomy. The cover of each variable was expressed as its relative cover percentage on the plot following Braun-Blanquet (1979), and results for each site were expressed as the average of all plots located in each habitat type.

Based on previous studies, we considered that sigmodontines (see Bisceglia et al., 2011 for details on species), the hystricognath rodent *Ctenomys azarae* (tuco tuco), small birds (mainly passerines), and European hares were the main potential prey for Geoffroy's cats in our study areas. We estimated the seasonal abundances of these prey groups over a year (2008), considering summer (January–February), autumn (April–May), winter (August), and spring (November–December) periods. We operated 7  $\times$  7-trap grids (1 in the creosote bush scrubland, 1 in the mixed scrubland, and 1 in the xeric forest with understory of grassland) with 10 m between traps (H. B. Sherman Traps Inc., Tallahassee, FL) at both sites. Traps were active for 5 consecutive nights, using rolled oats and peanuts as bait. We individually identified captured sigmodontines by natural marks, sex, or toe-clipping, and released them at the capture site. We estimated density of sigmodontines by using the minimum number of individuals known alive, adding a buffer to each grid set at 8 m on each side (representing half of the average maximum distance traveled by captured individuals) and averaging the values obtained in the 3 grids weighted by the coverage area of each habitat type at each site.

Due to the underground activity of tuco tuco, we estimated their relative density by counting active mounds along transects of 300 m  $\times$  10 m (12–14 per season in each site) randomly placed in different habitat types (creosote bush scrubland, mixed scrubland, and grassland). We estimated the abundance of small birds using the variable circular-plot method (Reynolds et al., 1980), recording all individuals seen or heard from the focal point of observation during a 20 min period. We sampled 8 points (3 in the creosote bush scrubland, 3 in the mixed scrubland, and 2 in the grassland) separated by >500 m per season at each site, and analyzed the data using the variable radius method (Estades, 1995) and the program DISTANCE (Laake et al., 1994). We estimated abundance of hares using the line transect method (Buckland et al., 1993), running 4 times per season at each site 3 6-km long transects along secondary roads. Each transect was sampled at night using a spotlight, from a vehicle, and data were analyzed using DISTANCE (Laake et al., 1994). For comparisons of prey densities between sites and among seasons, we used the software CONTRAST (Hines and Sauer, 1989).

### 2.3. Trophic ecology of Geoffroy's cats

We determined the seasonal diet of Geoffroy's cats by analyzing fresh scats collected in the park and in the ranches during the same periods that we were estimating prey abundance. We collected scats from latrines used regularly by Geoffroy's cats (for details see Bisceglia et al., 2008) and examined them following the protocol described in Reynolds and Aebischer (1991). We reported the contribution of different prey items to the diet as percent occurrence (PO = number of times an item was found as percentage of all food items found in all feces) and compared diet composition between sites and among seasons with log-linear analysis of frequencies (Zar, 1996) using the program SPSS, version 15.0 (SPSS, Inc. 2006). We removed from the analyses those categories poorly represented in the diet (Sokal and Rohlf, 1995) and considered only sigmodontines, cavies, tuco tuco, birds, reptiles and arthropods to perform this analysis. We collected and analyzed 31–35 scats per season per site, which contained 63.0  $\pm$  SD 6.8 prey individuals per season in the park and 64.5  $\pm$  9.9 per season in the ranches.

We evaluated prey selection by Geoffroy's cats for the 3 prey groups for which absolute abundances could be determined in the field (sigmodontines, small birds, and hares) using Chi-square tests and Bonferroni confidence intervals (Neu et al., 1974). Because the absolute abundance of tuco tuco was not estimated, selection of this prey item by Geoffroy's cats was only visually evaluated.

### 2.4. Spatial ecology of Geoffroy's cats

We captured Geoffroy's cats in the park and ranches during April–July 2007 and May 2008, using Tomahawk live traps (Tomahawk Live Trap Co., Tomahawk, WI) baited with live domestic pigeons. Captured individuals were immobilized with ketamine (dosage = 5 mg/kg) and medetomidine (dosage = 0.06 mg/kg). We fitted adult individuals with radio-collars with mortality switches (M1940, ATS, Isanti, MN), representing <1.9% of the cats' body weight, and released them at the capture site. Manipulation and care of animals involved during this study followed the American Society of Mammalogists' guidelines (Animal Care and Use Committee, 1998). We radio-collared 13 Geoffroy's cats (10 M, 3 F) in the park and 9 (4 M, 5 F) in the ranches. We included data for 4 Geoffroy's cats (3 M, 1 F) radio-tracked in the park during 2002 (Pereira et al., 2006) to improve the estimation of home-range size and daily movements by increasing sample sizes; weather and habitat conditions in 2002 were similar (398.4 mm of annual rainfall) to those during the current study. Geoffroy's cats in the

park were monitored an average of 98 d (range = 1–467 d), whereas in the ranches they were monitored an average of 174 d (range = 3–388 d).

The locations of Geoffroy's cats were obtained by triangulation from the ground (White and Garrott, 1990), using a hand-held 5-element Yagi antenna and a portable receiver (Telonics, Mesa, AZ). We checked the accuracy of telemetry fixes by using test transmitters (White and Garrott, 1990), obtaining a triangulation error of <120 m in 73% of locations. We located individuals at least 8 times per month, dividing effort between day and night. We assumed independence between consecutive locations by taking locations separated by at least 10 h, a time period sufficient for a Geoffroy's cat to cross its entire home-range (see movements below). We estimated home-range size using the minimum convex polygon (MCP, Harris et al., 1990) method in CALHOME (Kie et al., 1996). We choose MCP because it is more robust than other techniques when the number of fixes is low (Harris et al., 1990). We considered 100% of locations to represent the full area and 50% to represent the core area of an animal's home range (Harris et al., 1990).

By plotting home-range size against the number of location fixes (Harris et al., 1990) we estimated that the minimum number of locations needed to adequately describe home-range size was 18 (Pereira, 2009); thus, we used for this analysis only those animals with  $\geq 18$  locations. Some Geoffroy's cats did not occupy a well-defined territory and dispersed out of the study areas within the first month after their capture. These animals were hence presumed to be transient animals and thus they were not considered for the analysis of spatial ecology. We calculated home-range and core-area size for the remaining individuals and compared home-range size between areas using a Mann–Whitney test. To avoid comparing home range size of cats monitored during periods with different conditions, we split the year in two periods

(autumn – winter and spring – summer) based on the number of individuals monitored during each of them.

We calculated percent home-range and core-area overlap among pairs of Geoffroy's cats as the percentage of the total combined areas that was shared, considering only pairs that were monitored during the same period. We did not test for statistical significance of home-range overlap because number of pairs of overlapping Geoffroy's cats was low.

We estimated daily movements by tracking each animal continuously for 8–36 h, taking locations every 30 min. Minimum distance traveled per unit of time was the straight-line distance between successive locations. The estimated average error ( $n = 24$  measurements) was 55 m, with an error <60 m in 68% of locations. Therefore, we considered as movements only those events which involved a departure of >60 m from the previous location. We assessed differences in movement rate between areas with Student  $t$  tests. Our monitoring regime resulted in an average of 3 24-h tracking sessions per individual (range = 2–4), each with 16–72 locations.

We developed a geographic information system of both study areas based on vegetation information obtained from 5 random transects crossing each area (January–February 2007) and from a Landsat 7 TM satellite image (CONAE, Buenos Aires, Argentina; bands 3, 4, and 5) from February 2007. We performed a supervised classification using the maximum-likelihood decision rule (Lillesand and Kiefer, 1994) using ERDAS IMAGINE 8.4 software (ERDAS Inc., Atlanta, GA). Locations of Geoffroy's cats were converted to a spatial data layer using ARC VIEW 3.2/THEMATIC MAPPER (Environmental Systems Research Institute Inc., Redlands, CA). We linked each Geoffroy's cat location to one habitat type (creosote bush scrubland, mixed scrubland, grassland, low steppe, xeric forest, and others) and investigated habitat use at 2 spatial scales (selection of a home range within the study area and

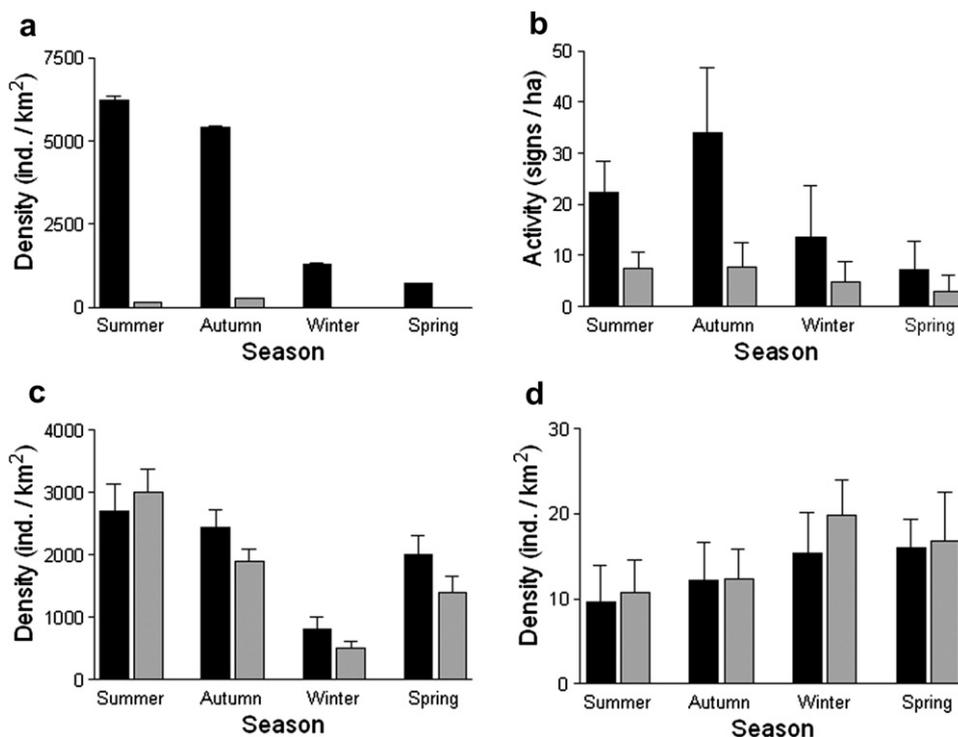


Fig. 1. Seasonal abundance (mean  $\pm$  SD) of (a) sigmodontines, (b) tuco tuco (*Ctenomys* sp.), (c) small birds, and (d) European hares (*Lepus europaeus*) in Lihué Cael National Park (black bars) and adjacent cattle ranches (grey bars), Argentina, in 2008.

**Table 1**  
Seasonal percentage occurrence of prey categories in feces of Geoffroy's cat (*L. geoffroyi*) in Lihué Calel National Park (NP) and adjacent cattle ranches (CR), Argentina, in 2008.

Prey category	Summer		Autumn		Winter		Spring	
	NP	CR	NP	CR	NP	CR	NP	CR
Mammalia								
Rodentia								
Sigmodontinae	22.9	16.7	40.0	27.0	19.9	29.5	31.5	17.5
Caviidae	2.9	3.7	15.0	12.7	5.5	14.1	4.5	4.8
<i>Ctenomys azarae</i>	28.6	18.5	16.7	22.2	41.8	23.1	16.4	19.0
Unidentified	5.7	5.6	0	0	0	0	0	0
Lagomorpha								
<i>Lepus europaeus</i>	0	0	0	0	0	3.8	3.0	0
Other mammals	5.6	3.5	0	1.6	1.8	1.4	0	0
Aves	8.6	9.3	10.0	17.5	5.5	1.3	13.4	12.7
Reptilia	20.0	22.2	8.3	7.9	7.3	9.0	20.7	20.6
Unidentified	0	0	0	0	5.5	2.6	0	6.3
vertebrates								
Arthropoda	5.7	20.5	10.0	11.1	12.7	15.2	10.5	19.1
Number of feces analyzed	33	31	32	31	33	35	32	31

selection of habitat types within the home-range; Johnson, 1980). In the first case, we defined the study area by obtaining the 100% MCP of all locations for all Geoffroy's cats monitored (White and Garrott, 1990), independently for the park and the ranches. Habitat selection at the 2 spatial scales was estimated following Neu et al. (1974). Because relatively few locations were obtained on many animals, data were pooled (White and Garrott, 1990) for all individuals in each site to compare between sites.

### 3. Results

#### 3.1. Habitat structure and prey abundance

We found more grass cover ( $U \leq 1.0, P \leq 0.016$ ), higher grasses ( $U \leq 1.0, P \leq 0.012$ ), and less bare soil ( $U \leq 1.0, P \leq 0.016$ ) in the park than in the ranches in all three habitats. In the xeric forest, shrub cover ( $U = 2.0, P = 0.028$ ) was also higher in the park than in the ranches (Appendix A).

Overall prey abundance was higher in the park than in the ranches. Throughout the study, sigmodontines were on average 98% and tuco tuco 67% more abundant in the park than in the ranches (Fig. 1). The density of small birds was higher in the park than in the ranches ( $\chi^2 > 16.0, d.f. = 1, P < 0.001$ ), except during the summer, when it was higher in the ranches ( $\chi^2 = 232.4, d.f. = 1, P < 0.001$ ; Fig. 1). The density of hares was higher in the ranches than in the park during the winter ( $\chi^2 = 273.9, d.f. = 1, P < 0.001$ ), whereas no significant differences were found between sites in the

remaining seasons ( $\chi^2 < 0.5, d.f. = 1, P \geq 0.461$ ; Fig. 1). In both the park and the ranches, maximum abundances of sigmodontines, tuco tucos, and small birds were in summer and autumn (Fig. 1).

#### 3.2. Trophic ecology of Geoffroy's cats

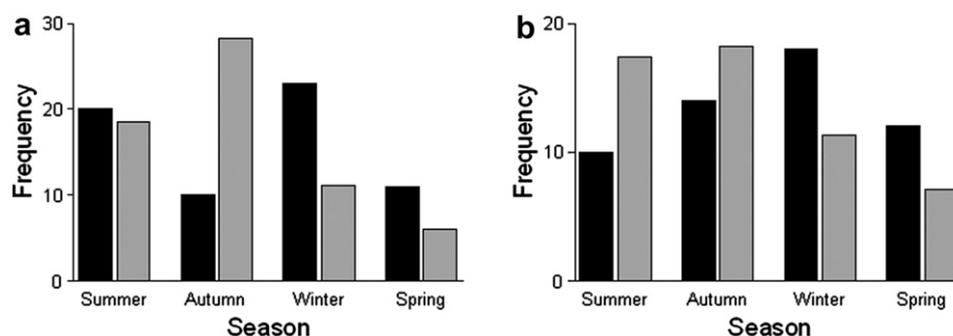
Small rodents (including sigmodontines, tuco tucos, and cavies) were the most frequent food items recorded in both the park and the ranches (>41% of PO in all seasons), whereas birds, reptiles, and arthropods constituted secondary food items (Table 1). The saturated log-linear model indicated that only prey type had a significant effect on diet composition ( $\chi^2 = 84.14, d.f. = 5, P < 0.001$ ), whereas the only significant interaction between factors was season x prey type ( $\chi^2 = 48.93, d.f. = 15, P < 0.001$ ), indicating seasonal differences in prey use. Many food items were consumed differently across seasons. For instance, sigmodontines were consumed more frequently during the autumn, tuco tucos were consumed more frequently during the winter, and reptiles were more used during spring and summer (Table 1).

Geoffroy's cats behaved as selective predators in the ranches throughout the year ( $\chi^2 > 8.5, d.f. = 2, P < 0.02$ ). In this site, sigmodontines were consumed more than expected and small birds and hares less than expected during all seasons, except hares in winter when they were consumed in proportion to their availability. In the park, this felid used all prey items according to their availability ( $\chi^2 \leq 1.8, d.f. = 2, P \geq 0.405$ ), except during spring ( $\chi^2 = 45.7, d.f. = 2, P < 0.01$ ) when sigmodontines were positively selected, birds avoided, and hares used in proportion to their availability. The pattern of selection of tuco tucos appeared to be similar between areas except during the summer, when tuco tucos were used more in-line with their availability in the national park than they were in ranches (Fig. 2).

#### 3.3. Spatial ecology of Geoffroy's cats

Five radio-collared Geoffroy's cats in the park and 1 in the ranches were considered transients, whereas 2 cats (both in ranches) died within 1 month after being caught (1 due to starvation and 1 due to an unknown cause). Thus, our analysis was based on 12 Geoffroy's cats in the park and 6 in the ranches. Combining body weights and measurements from both sites (differences for both sexes between sites were non significant;  $P \geq 0.62$ ), adult males outweighed adult females ( $3.92 \text{ kg} \pm 0.45 \text{ SD}$  vs.  $2.88 \pm 0.35 \text{ kg}, t = 5.57, d.f. = 20, P < 0.001$ ) and were larger (body length;  $920.4 \text{ mm} \pm 39.7 \text{ SD}$  vs.  $844.8 \pm 31.3 \text{ mm}, t = 4.61, d.f. = 20, P < 0.001$ ).

During the autumn – winter period, mean home-range ( $U = 8.00, P = 0.089$ ) and core-area ( $U = 15.00, P = 0.479$ ) sizes



**Fig. 2.** Observed frequency of consumption (black bars) of tuco tucos (*Ctenomys azarae*) by Geoffroy's cats (*Leopardus geoffroyi*) relative to the activity index of tuco tucos (grey bars) recorded in (a) Lihué Calel National Park and (b) adjacent cattle ranches, Argentina, in 2008.

of males in the park ( $207.5 \pm \text{SD } 125.5$  ha) were not significantly different from males in the ranches ( $300.0 \pm 98.3$  ha; Table 2). Home-range and core-area sizes of the two females monitored in the park were 86% and 79% smaller, respectively, than those of the two females monitored in the ranches, but were not statistically evaluated due to the small sample size. During the spring – summer period, too few individuals were monitored (2 in the park and 4 in the ranches) to statistically evaluate differences in home-range and core-area sizes between sites, but males had similar ranges in the park and ranches and females in the ranches had larger ranges than the female in the park (Table 2).

Sixteen pairs of individuals (6 males in the park and 3 males and 2 females in the ranches) had overlapping home ranges. Percent home-range overlap among males in the park was extensive ( $39 \pm 23\%$ , range = 4–69,  $n = 12$  pairs), including an  $18 \pm 16\%$  overlap of core areas for 2 pairs. A transient male was captured within the territory of a resident male (OG23). On the other hand, the home-range overlap between one pair of males in the ranches was only 3% with no overlap of core areas. Two other male dyads maintained home ranges in close proximity but no overlap was detected among them.

During the autumn – winter period, the mean daily movements (MDM) of males in the park were significantly shorter ( $t = 6.62$ ,  $d.f. = 19$ ,  $P < 0.001$ ) than those of males in the ranches (Fig. 3). In the same way, MDM of the single female monitored in the park were significantly shorter ( $t = 2.65$ ,  $d.f. = 7$ ,  $P = 0.032$ ) than those of the two females monitored in the ranches (Fig. 3). During the spring – summer period, males ( $t = 2.62$ ,  $d.f. = 7$ ,  $P = 0.034$ ) and females ( $t = 2.84$ ,  $d.f. = 5$ ,  $P = 0.036$ ) also showed significantly shorter MDM in the park (Fig. 3).

The most abundant habitat type in the park was creosote bush scrubland followed by mixed scrubland and low steppe, whereas in the ranches the predominant habitat type was low steppe followed by creosote bush scrubland and grassland (Appendixes B and C). Overall, differences in habitat use between sites reflected differences in the availability of different habitat types. Home ranges of individuals monitored in the park were composed primarily of creosote bush scrubland and mixed scrubland, whereas in the

ranches they were primarily creosote bush scrubland and low steppe (Appendixes B and C).

Geoffroy's cats exhibited different patterns of habitat preference according to the site and the scale considered. In the park, cats showed no significant preference for any particular habitat type for establishment of home ranges or at the home-range scale (Appendix B). In the ranches, cats did not establish their home ranges at random, and the mixed scrubland was preferred at this scale, whereas at the home-range scale the grassland was preferred and the creosote bush scrubland was avoided (Appendix C).

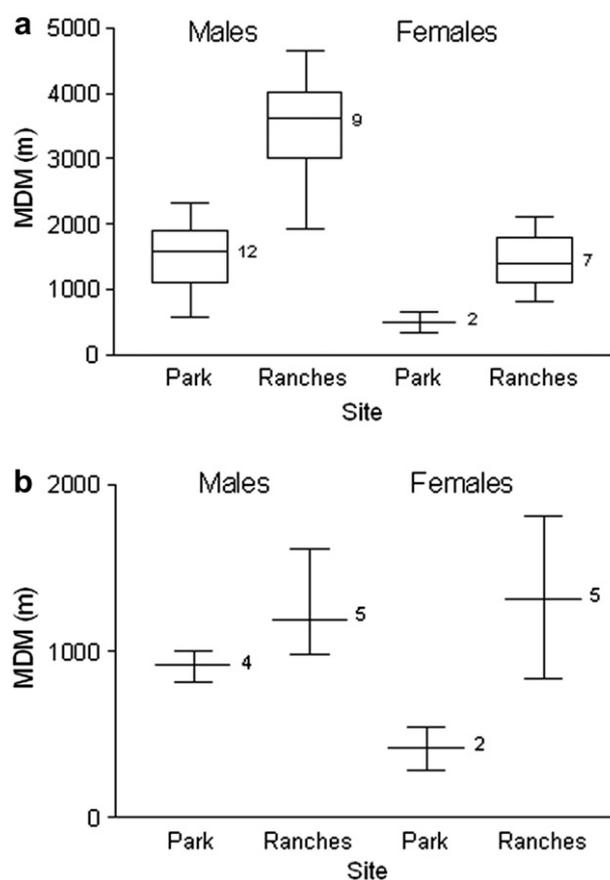
#### 4. Discussion

We found differences in habitat features and prey base, as well as in the spatial and trophic ecology of Geoffroy's cats, between the ranches and the park. The most obvious differences were the higher movement rate in the ranches and a differential pattern of habitat and prey selection between areas. These differences may be related to the presence of livestock in the ranches, although variations in landscape composition between sites may be involved as well.

Differences in movement rates between the ranches and the park could be correlated to home range size, with a higher movement rate of Geoffroy's cats in ranches related to the lower abundance of prey compared to the park. The active search is one of the hunting strategies most used by small- and medium-sized felids (Emmons, 1987; Jedrzejewski et al., 2002), as the encounter rate

**Table 2**  
Seasonal home-range (100% MCP) and core-area (50% MCP) size estimates (ha) for Geoffroy's cats (*L. geoffroyi*) with  $\geq 18$  locations in Lihué Calel National Park and adjacent cattle ranches, Argentina, 2002 and 2007–2008.

Site	Season	Cat/sex	Fixes	100%MCP	50%MCP		
National park	Autumn – Winter	OG01 M	24	371.1	72.6		
		OG02 M	18	60.8	14.2		
		OG03 M	25	176.5	38.3		
		OG04 F	46	24.2	5.2		
		OG20 M	42	212.7	30.1		
		OG21 M	20	218.8	14.2		
		OG22 M	37	305.2	48.6		
		OG23 M	41	417.7	109.4		
		OG24 M	29	79.9	16.9		
		OG25 M	19	169.3	31.2		
		OG42 F	19	68.9	15.3		
		OG46 M	18	62.8	11.6		
		Cattle ranches	Autumn – Winter	OG04 F	24	27.3	6.1
				OG23 M	35	382.4	51.2
				OG29 F	37	158.4	10.8
				OG30 M	21	225.3	5.2
Cattle ranches	Spring – Summer	OG36 M	30	436.4	57.9		
		OG37 F	24	491.9	91.4		
		OG39 M	19	231.1	41.9		
		OG40 M	27	307.3	8.9		
		OG29 F	26	143.9	7.1		
		OG36 M	24	371.7	24.0		
		OG37 F	22	376.2	116.8		
		OG39 M	19	254.3	51.0		



**Fig. 3.** Mean daily movements (MDM) traveled by Geoffroy's cats (*L. geoffroyi*) during (a) Autumn – Winter and (b) Spring – Summer in Lihué Calel National Park and adjacent cattle ranches, Argentina, in 2002 and 2007–2008. Boxes represent the 25–75th percentile range and contain the mean line, whereas capped bars indicate the highest and lowest values. Numbers indicate the number of tracking sessions used to calculate MDM.

with relatively abundant prey (such as small rodents) can be increased when the movement rate of the predator increases. Because foraging effort is closely related to prey availability, greater efforts are needed as prey availability decreases (Liberg, 1984; Jedrzejewski et al., 2002). Geoffroy's cats typically use active search for obtaining small rodents, as was recorded in 47 visual records of individuals during foraging (J. A. Pereira, unpublished data). The increased movement rate of both male and female Geoffroy's cats on ranches was perhaps an attempt to increase the encounter rate with prey, which appeared to be less abundant due to the presence of livestock.

Heavy foraging and constant trampling by livestock severely reduced much of the horizontal and vertical structure of the vegetation in ranches, and these changes may have triggered the decrease in the abundance of small rodents and other herbivores. In the face of this scenario, the preference for grasslands by Geoffroy's cats in ranches could be caused by at least three circumstances. First, the most abundant sigmodontines in ranches are habitat generalists (e.g., *Graomys griseoflavus*) or specialists of open areas (e.g., *Eligmodontia typus*) (Bisceglia et al., 2011). Also, tuco tucos preferred open grasslands and scrublands, even where they are grazed by cattle (data not showed). Thus, even degraded grasslands could be favorable for Geoffroy's cats in terms of prey abundance. Second, loss of vegetation cover and increased bare soil recorded in open habitats could increase the vulnerability of rodents, facilitating their capture. Accordingly, lions (*Panthera leo*; Hopcraft et al., 2005), Canada lynxes (*Lynx canadensis*; Fuller et al., 2007) and leopard cats (*Prionailurus bengalensis*, Rajaratnam et al., 2007) prefer to hunt in habitats where prey are easier to capture as opposed to habitats where prey is more abundant. Third, the use of less structurally-complex habitats such as grasslands may be favored in ranches because of the lower abundance of pumas in those areas (J. A. Pereira, unpublished data), a Geoffroy's cat predator in the region (Pereira et al., 2010). These three factors would allow Geoffroy's cats to acquire the necessary resources through a change in habitat use, exploiting more open sites where structural configuration and level of potential risk are altered due to livestock management. This might be a strong indication of the Geoffroy's cat higher habitat plasticity than previously thought.

Seasonal differences in consumption of sigmodontines and tuco tucos may reflect differences in the relative abundance of these preys and also a behavioral response (prey switching) by the predator. In autumn, when sigmodontines were still relatively abundant in the park, this prey group dominated the Geoffroy's cat diet even though in that season the tuco tucos reached their highest annual relative abundance. By the winter, when the abundance of sigmodontines fell, cats increased the use of tuco tucos although tuco tuco activity also decreased (but not necessarily its abundance). In the ranches, however, the availabilities of sigmodontines and tuco tucos throughout the year may have been too low for the Geoffroy's cat to switch between these preys.

Further, the pattern of prey selection by Geoffroy's cats indicates that this carnivore did not behave as an opportunistic predator with respect to sigmodontines. In the ranches, cats positively selected them throughout the year at the expense of other potential prey such as hares or birds. In the park, Geoffroy's cats consumed sigmodontines in proportion to their availability when the abundance of this prey group was relatively high, but they become selective predators of sigmodontines when their abundance declined in early spring. This evidence suggests that the Geoffroy's cat is a small rodent specialist, as other authors have found (Manfredi et al., 2004; Sousa and Bager, 2008).

Probably due to the locally low abundance of prey, the Geoffroy's cat population studied showed high rates of emigration and mortality (Pereira, 2009). Consequently, from our initial sample of

26 radio-collared cats, 16 individuals (62% of the sample) disappeared from the area within the first four months of monitoring, whereas only four cats provided information on long-term (>1 year) home range. Consequently, changes in home-range size were difficult to assess due to the small sample sizes, the short period during which most individuals could be monitored, and the large variance of the estimates. However, Geoffroy's cats may have decreased their level of spatial overlap in ranches in response to prey scarcity, as occurred with San Joaquin kit foxes (*Vulpes macrotis mutica*; White and Ralls, 1993). To properly assess overlap among home ranges there must be a high level of confidence that all animals within an area are radio-collared (Sandell, 1989), and we had fewer radio-collared males in ranches than in the park. Nevertheless, small sample sizes are typical when population density is low. Although non-collared individuals were present in the ranches during the study (two non-collared animals were recorded opportunistically), we are confident that most of the individuals present in the site were radio-tagged. Mean home-range overlap was extensive in the park, and some individuals even had overlapping core areas. In the ranches, only a few individuals showed home-range overlap, though minimal, and two other pairs remained in close proximity to each other but failed to overlap. These differences could reflect an adjustment to address the decline in food resources, with males increasing their level of territorial exclusion of other males in response to resource scarcity.

The park and ranches exhibited major differences in vegetation structure and prey abundance. Although some of these differences could perhaps be attributed to differences in geomorphology or geology, other studies documenting differences between sites with and without livestock have obtained similar results (Pia et al., 2003; Blaum et al., 2007). To deal with these differences, Geoffroy's cat exhibit behavioral plasticity, as the two subpopulations in close proximity had such contrasting trophic and spatial ecology. This plasticity may help Geoffroy's cats survive in the face of the growing livestock industry, indicating that the conservation of this predator could be compatible with this activity. Other small felids such as the leopard cat also survive in seemingly less suitable habitat by modifying their spatial ecology (Nakanishi et al., 2005). Thus, conservation of Geoffroy's cats in ranches would mostly require reducing poaching and predation by dogs, the most common causes of mortality of this felid in the area (Pereira et al., 2010), instead of other alternatives such as habitat management (i.e., restoration). Lessons about behavior and ecological plasticity of small felids are relevant due to the increasing number of landscapes worldwide where these predators must coexist with human activities.

## Acknowledgments

We thank M. Uhart, V. Rago, H. Ferreyra, and C. Marull for their assistance in capturing cats and F. Alonso, V. Androsiuk, J. Arrabal, S. Bisceglia, F. Bondone, A. Brun, D. Caporossi, A. Caselli, N. Citon, V. Colombo, V. Coronel, S. Costa, V. Chillo, A. Chirife, J. Dopazo, M. Falcón, L. Fortuny, N. Fracassi, F. Gallego, N. Gargiulo, P. Gáspero, E. Infantino, E. Juan, J. Medina, C. Milano, P. Moreyra, E. Muschetto, S. Nussbaum, P. Perrig, J. Rojo, J. Rouaux, N. Scioscia, S. Serrano, M. Tartaglione, P. Teta, and L. Torres for field assistance. We thank M. Romero, H. Erasmus, R. Milne, P. Collavino, R. Culla, and L. Vallejo for field support, N. Fracassi for GIS assistance, P. Perovic, J. Sanderson, D. Villareal, R. Bo, P. Cuello, and R. Quintana for information or equipment provided, and M. Kittlein, K. Hodara, and G. Cueto for statistical advice. Two anonymous reviewers provided valuable comments on early drafts of this paper. We thank Administración de Parques Nacionales and Dirección de Recursos Naturales de La Pampa for research permits. This study was funded by The Rufford Foundation, WCS – Global Health Program, Dirección de Recursos

Naturales de La Pampa, Cleaveland Metroparks Zoo – Cleaveland Zoological Society, Amersfoort Zoo, and Idea Wild.

## Appendix. Supplementary material

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jaridenv.2011.08.006.

## References

- Animal Care and Use Committee, 1998. Guidelines for the capture, handling, and care of mammals as approved by the American Society of Mammalogists. *Journal of Mammalogy* 79, 1416–1431.
- Belsky, A.J., Blumenthal, D.M., 1997. Effects of livestock grazing on stand dynamics and soils in upland forest of the interior west. *Conservation Biology* 11, 315–327.
- Bisceglia, S.B.C., Pereira, J.A., Teta, P., Quintana, R.D., 2008. Food habits of Geoffroy's cat (*Leopardus geoffroyi*) in the central Monte desert of Argentina. *Journal of Arid Environments* 72, 1120–1126.
- Bisceglia, S.B.C., Pereira, J.A., Teta, P., Quintana, R.D., 2011. Rodent selection by Geoffroy's cats in a semi-arid scrubland of central Argentina. *Journal of Arid Environments* 75, 1024–1028.
- Blaum, N., Rossmanith, E., Jeltsch, F., 2007. Land use affects rodent communities in Kalahari savannah rangelands. *African Journal of Ecology* 45, 189–195.
- Braun-Blanquet, J., 1979. *Fitosociología*. H. Blume, Madrid.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., 1993. *DISTANCE Sampling. Estimating Abundance of Biological Populations*. Chapman & Hall, London.
- Emmons, L.H., 1987. Comparative feeding ecology of felids in a Neotropical rain-forest. *Behavioral Ecology and Sociobiology* 20, 271–283.
- Estades, C.F., 1995. Estimación de la densidad de una comunidad de aves del espinal mediante transectos y estaciones puntuales. *Contribuciones Breves. Boletín Chileno de Ornitología* 2, 29–34.
- Fuller, A.K., Harrison, D.J., Vashon, J.H., 2007. Winter habitat selection by Canada lynx in Maine: prey abundance or accessibility? *Journal of Wildlife Management* 71, 1980–1986.
- Gittleman, J.L., 1989. *Carnivore Behavior, Ecology, and Evolution*. Cornell University Press, Ithaca, New York.
- Harris, S., Cresswell, W.J., Forde, P.G., Trehwella, W.J., Woollard, T., Wray, S., 1990. Home range analysis using radiotracking data – a review of problems and techniques particularly as applied to the study of mammals. *Mammal Review* 20, 97–123.
- Hayward, B., Heske, E.J., Painter, C.W., 1997. Effects of livestock grazing on small mammals at a desert cienega. *Journal of Wildlife Management* 61, 123–129.
- Hines, J.E., Sauer, J.R., 1989. Program CONTRAST: a general program for the analysis of several survival or recovery rate estimates. *US Fish and Wildlife Technical Report* 24, 1–7.
- Hopcraft, J.G.C., Sinclair, A.R.E., Packer, C., 2005. Planning for success: Serengeti lions seek prey accessibility rather than abundance. *Journal of Animal Ecology* 74, 559–566.
- INDEC, 2004. Censo Nacional Agropecuario 2002. <http://www.indec.gov.ar> Downloaded on 20 August 2009.
- Jedrzejewski, W., Schmidt, K., Okarma, H., Kowalczyk, R., 2002. Movement pattern and home range use by the Eurasian lynx in Białowieża Primeval Forest (Poland). *Annales Zoologici Fennici* 39, 29–41.
- Johnson, D.H., 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61, 65–71.
- Johnson, W.E., Franklin, W.L., 1991. Feeding and spatial ecology of *Felis geoffroyi* in southern Patagonia. *Journal of Mammalogy* 72, 815–820.
- Kauffman, J., Pyke, D., 2001. Range ecology, global livestock influences. In: Levin, S. (Ed.), *Encyclopedia of Biodiversity*. Academic Press, San Diego, pp. 33–52.
- Kie, J.G., Baldwin, J.A., Evans, C.J., 1996. CALHOME: a program for estimating animal home ranges. *Wildlife Society Bulletin* 24, 342–344.
- Laake, J.L., Buckland, S.T., Anderson, D.R., Burnham, K.P., 1994. *DISTANCE Sampling: Abundance Estimation of Biological Populations – DISTANCE User's Guide*. Colorado Cooperative Fish & Wildlife Research Unit, Colorado State University, Fort Collins, Colorado.
- Liberg, O., 1984. Food habits and prey impact by feral and house-based domestic cats in a rural area in southern Sweden. *Journal of Mammalogy* 65, 424–432.
- Lillesand, T.M., Kiefer, R.W., 1994. *Remote Sensing and Image Interpretation*. John Wiley & Sons, New York.
- Lucherini, M., de Oliveira, T., Acosta, G., 2008. *Leopardus geoffroyi*. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.1. [www.iucnredlist.org](http://www.iucnredlist.org) Downloaded on 26.07.11.
- Manfredi, C., Lucherini, M., Canepuccia, A.D., Casanave, E.B., 2004. Geographical variation in the diet of Geoffroy's cat (*Oncifelis geoffroyi*) in Pampas grassland of Argentina. *Journal of Mammalogy* 85, 1111–1115.
- Manfredi, C., Soler, L., Lucherini, M., Casanave, E.B., 2006. Home range and habitat use by Geoffroy's cat (*Oncifelis geoffroyi*) in a wet grassland in Argentina. *Journal of Zoology (London)* 268, 381–387.
- Nakanishi, N., Okamura, M., Watanabe, S., Izawa, M., Doi, T., 2005. The effect of habitat on home range size in the Iriomote cat *Prionailurus bengalensis iriomotensis*. *Mammal Study* 30, 1–10.
- Neu, C.W., Byers, C.R., Peek, J.M., 1974. A technique for analysis of utilization-availability data. *Journal of Wildlife Management* 38, 541–545.
- Novaro, A.J., Funes, M.C., Walker, R.S., 2000. Ecological extinction of native prey of a carnivore assemblage in Argentine Patagonia. *Biological Conservation* 92, 25–33.
- Nowell, K., Jackson, P., 1996. *Wild Cats. Status Survey and Conservation Action Plan*. IUCN/SSC Cat Specialist Group. IUCN, Gland, Switzerland.
- Pereira, J.A., 2009. Efectos del manejo ganadero y disturbios asociados sobre la ecología trófica y espacial y la demografía del gato montés (*Leopardus geoffroyi*) en el desierto del Monte, Argentina. PhD Thesis, Universidad de Buenos Aires, Buenos Aires, Argentina.
- Pereira, J.A., Fracassi, N.G., Uhart, M.M., 2006. Numerical and spatial responses of Geoffroy's cat (*Oncifelis geoffroyi*) to prey decline in Argentina. *Journal of Mammalogy* 87, 1132–1139.
- Pereira, J.A., Fracassi, N.G., Rago, V., Ferreyra, H., Marull, C.A., McAloose, D., Uhart, M.M., 2010. Causes of mortality in a Geoffroy's cat population – A long-term survey using diverse recording methods. *European Journal of Wildlife Research* 56, 939–942.
- Pia, M., López, M., Novaro, A., 2003. Effects of livestock on the feeding ecology of endemic culpeo foxes (*Pseudalopex culpaeus smithersi*) in Central Argentina. *Revista Chilena de Historia Natural* 76, 313–321.
- Rajaratnam, R., Sunquist, M., Rajaratnam, L., Ambu, L., 2007. Diet and habitat selection of the leopard cat (*Prionailurus bengalensis borneoensis*) in an agricultural landscape in Sabah, Malaysian Borneo. *Journal of Tropical Ecology* 23, 209–217.
- Reynolds, J.C., Aebischer, N.J., 1991. Comparison and quantification of carnivore diet by faecal analysis: a critique, with recommendations, based on a study of the Fox *Vulpes vulpes*. *Mammal Review* 21, 97–122.
- Reynolds, R.T., Scott, J.M., Nussbaum, R.A., 1980. A variable circular-plot method for estimating bird numbers. *Condor* 82, 309–313.
- Sandell, M., 1989. The mating tactics and spacing patterns of solitary carnivores. In: Gittleman, J.L. (Ed.), *Carnivore Behavior, Ecology, and Evolution*. Cornell Univ. Press, Ithaca, New York, pp. 164–182.
- Sere, C., Steinfeld, H., Groenewold, J., 1995. *World livestock production systems – current status, issues and trends*. FAO Animal Production and Health Paper, XX.
- Sokal, R.R., Rohlf, F.J., 1995. *Biometry*. WH Freeman & Co, New York.
- Sousa, K.S., Bager, A., 2008. Feeding habits of Geoffroy's cat (*Leopardus geoffroyi*) in Southern Brazil. *Mammalian Biology* 73, 303–308.
- Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C., 2006. *Livestock's long shadow – Environmental issues and options*. The Livestock, Environment and Development (LEAD) Initiative & FAO, Rome, Italy.
- White, G.C., Garrott, R.A., 1990. *Analysis of Wildlife Radiotracking Data*. Academic Press Inc., New York.
- White, P.J., Ralls, K., 1993. Reproduction and spacing patterns of kit foxes relative to changing prey availability. *Journal of Wildlife Management* 57, 861–867.
- Wilson, D.E., Mittermeier, R.A., 2009. *Handbook of the Mammals of the World. 1. Carnivora*. Lynx Editions, Spain.
- Zar, J.H., 1996. *Biostatistical Analysis*. Prentice-Hall, New Jersey.