Received: 9 August 2018 | Revised: 28 November 2018 | Accepted: 8 January 2019
DOI: 10.1111/btp.12628

ORIGINAL ARTICLE

WILEY bioTROPICA ASSOCIATION FOR TROPICAL BIOLOGY AND CONSERVATION

Human activities influence the occupancy probability of mammalian carnivores in the Brazilian Caatinga

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Funding information
Neotropical Grassland Conservancy; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior; Rufford Foundation, Grant/Award Number: project 18442-1

Abstract

The Caatinga is a semi-arid domain, characterized by reduced humidity and high rates of anthropogenic impact. In addition to the low availability of water, carnivorous mammals are still exposed to a number of threats related to landscape modifications. We used data from camera traps and occupancy models to investigate the habitat use by carnivores in an area of Caatinga in northeastern Brazil. We found a negative correlation between the distance from wind farms and the occupancy probability of the jaguar, and a positive correlation with the occupancy probability of the jaguarundi. Puma and jaguarundi occupied primarily sites near watercourses, whereas the occupancy of the crab-eating fox was correlated positively with the presence of poachers. The ocelot was detected more frequently at sites distant from human settlements, whereas the jaguar was detected more often in areas far from wind farms. We found a negative correlation between the distance of water and the detection of the ocelot. The detection of the crab-eating fox was influenced positively by the detection of cattle. In addition to the negative influence of some anthropic activities, our results indicate that water is a very important resource for species, and the few permanent sources of this resource available in the area must be preserved. The replication of our research in other systems, worldwide, that are experiencing similar pressures, should permit a systematic evaluation of the management and conservation strategies needed to rebuild or maintain populations, restore ecosystems, and support conservation policies in human-altered landscapes.

Abstract in Portuguese is available with online material.

KEYWORDS
biodiversity, habitat use, human activities, semi-arid environment, wind farm

1 | INTRODUCTION

Habitat fragmentation, the overexploitation of natural resources, and the introduction of exotics species are inter-related impacts associated with the human occupation of natural landscapes and comprise the main threats to the planet's biodiversity (Hoffmann et al., 2011). In this context, mammals of the order Carnivora are considered to be of the highest priority for conservation actions, due to their position at the top of trophic webs (Estes et al., 2011) and their vulnerability to the conversion of natural habitats into more inhospitable environments (Purvis, Gittleman, Cowlishaw, & Mace, 2000). Global evaluations of the conservation status of carnivores have revealed a preoccupying scenario and the urgent need for effective conservation measures (Di Minin et al., 2016; Ripple et al., 2014). Almost half of the carnivores found in Brazil are threatened as a result of the synergic impacts of habitat degradation, the depletion of prey populations, and illegal hunting (Beisiegel, 2017). In the Caatinga domain, for example, five of the six wild felids are classified in some threat category (MMA 2014). The Caatinga is the largest seasonal dry forest in South America (Beuchle et al., 2015) and is one of the world's most densely populated semi-arid ecosystems, with a total population of approximately 27 million inhabitants. The Caatinga is also the most ruralized region in Brazil, accounting for 32% of the country's ranches (Brasil 2017).

The Caatinga has already lost 63.3% of its original vegetation cover, due primarily to cattle ranching, deforestation, and the harvesting of firewood, and the establishment of human settlements, roads, and other infrastructure, such as wind farms (Silva & Barbosa, 2017). Poaching has also had a long history in the Brazilian Caatinga, and poaching pressure is still intense, threatening the persistence of many wild species, which have become locally extinct in many parts of the region (Alves et al., 2016). Poaching with dogs is extremely popular in the region, and the dogs used in this activity are typically under little control (Neto, Santos, Sousa, Fernandes-Ferreira, & Lucena, 2012). These rural free-ranging dogs, which are owned or associated peripherally with human habitations but not confined, are in constant contact with wildlife, especially when these habitations border wildlife reserves or other natural areas (Campos, Esteves, Ferraz, Crawshaw, & Verdade, 2007; Vanak & Gompper, 2009). In natural areas, dogs cause a range of deleterious impacts on the local biodiversity, such as limiting the spatial distribution of wild carnivores (Massara et al., 2018). The ongoing expansion of human activities throughout the Caatinga has seen the progressive replacement of natural ecosystems by anthropogenic environments (Silva & Barbosa, 2017).

Changes in the landscape caused by human activities may alter the distribution of animal species and provoke shifts in their behavior, given that the most sensitive animals will tend to avoid areas modified by human activities (Schuette, Wagner, Wagner, & Creel, 2013). The establishment of wind farms in the Caatinga has raised profound concerns in the region's researchers. While wind power is an important alternative to fossil fuels, it does have impacts on the environment (Costa, Paula, Petrucci-Fonseca, & Álvares, 2017). Given the structure of the turbines, that is, high towers with moving blades, most research into the impacts of these structures on wildlife have focused on birds (Drewitt & Langston, 2006) and bats (Arnett, 2005), although they are known to affect other species (Helldin et al., 2012). The expansion of wind power operations has been identified as one of the principal threats to the existence of the largest American felids, the puma (*Puma concolor*) and the jaguar (*Panthera onca*) (Beisiegel, 2017).

In addition to all these impacts, the carnivores of the Caatinga have to adapt to the region's intense scarcity of water. The Caatinga becomes increasingly more arid toward its central portion, where long periods of intense drought often occur (Prado, 2003). Given the loss of its natural vegetation cover and ongoing climate change (Schulz, Koch, Cierjacks, & Kleinschmit, 2017), permanent sources of water are becoming increasingly scarce in the Caatinga. This is likely to have profound impacts on its fauna, given that the availability of water is a primary factor determining the distribution of species in hot and arid environments, on a number of different scales (Hawkins et al., 2003; Thrash, Theron, & Bothma, 1995).

Given all these considerations, understanding how anthropogenic impacts and the availability of water influence the habitat use by carnivores will be fundamental to the planning of land use and the development of effective conservation strategies. In the present study, we investigated the occupancy probability of carnivores in relation to the distance from human infrastructure, including human settlements and wind farms, and watercourses within a priority area for the conservation of the biodiversity of the Caatinga, the Boqueirão da Onça (MMA 2016). While the carnivores of the study community face adverse conditions, some mid-sized species, such as the crab-eating fox (*Cerdocyon thous*) and the hog-nosed skunk (*Conepatus semistriatus*), present ecological attributes, such as plasticity in habitat use and generalist diets, that confer them with a relative tolerance of human activities (Dias, 2017; Dias & Bocchiglieri, 2016). Based on previous studies, we expected that these generalist mesocarnivores would prefer areas of greater anthropogenic impact due to the availability of feeding resources and refuge from their predators and main competitors (Schuette et al., 2013). On the other hand, we expected a positive correlation between the distance from human settlements and wind farms and the occupancy probability of the felids, which are more sensitive to anthropogenic impacts (De Angelo, Paviolo, & Di Bitetti, 2011). In addition to the infrastructure itself, we expected the occupancy of all carnivores to be influenced negatively by the presence of poachers and dogs, given the potential risk they represent. However, we did expect the occupancy probability of the jaguar and puma to be related positively with the occurrence of cattle, given that these animals are potential prey for the felids. As there are no known ecological interactions between cattle and the other wild carnivores, we did not expect the occurrence of these domestic animals to influence the occupancy of the other species monitored in the present study. As water is a scarce and limiting resource in the Caatinga, we also expected a negative correlation between the occupancy probability of the carnivore species and the distance to permanent watercourses.

We also expected the probability of carnivore detection to be influenced by infrastructure (human settlements and wind farms) and the availability of water in a similar manner to the occupancy probability. Furthermore, we expected that the detection of domestic dogs and poachers would have a negative influence on the detection probability of the wild carnivores, given that these species would avoid areas in which dogs and poachers are detected, at least temporarily. Given the increasing number of reports of the predation of cattle within the study area, we expected jaguar and puma (but not other carnivores) to be detected at higher rates in areas in which cattle is more abundant. Finally, we predicted a positive relationship between the number of days of sampling and the detection probability of the species.

2 | METHODS

2.1 | Study area

The present study was conducted in a region known as Boqueirão da Onça, located in the north of the state of Bahia (Figure 1). This region covers a total area of approximately 9,000 km² and is considered to be of "extremely high" importance for the conservation of biodiversity by the Brazilian Environment Ministry, due to the diversity of threatened and rare species, speleological patrimony, representativeness of ecosystems and vegetation cover (MMA 2016).

At Boqueirão da Onça, as in other parts of the Caatinga, the rains tend to be brief and unpredictable, with the short rainy season generally lasting from October to December. Over the past 10 years, mean annual precipitation was 563.6 mm, and the temperature was 27°C, according to data from the Brazilian National Institute of Meteorology (INMET 2018). The arboreal-shrubby caatinga and the arboreal caatinga are the predominant vegetation types in this ecoregion (Velloso, Sampaio, & Pareyn, 2002), although a mosaic of phytophysiognomies can be found within the area, including rock fields, plateau forests, and stands of palms, known as "veredas" (Roos, Souza, Campos, Paula, & Morato, 2012). Tracts of denser vegetation, with some emergent trees, can be found on escarpments and in deep valleys. As in most of this semi-arid region, there are few permanent streams, and the rare sources of water are derived from springs that flow throughout the year. Within the Boqueirão da Onça, we defined the study area as the zone influenced by the São Pedro and Delfina wind farms, located in the municipalities of Sento Sé and Campo Formoso, respectively.

2.2 | Data collection

We established a 20-km × 30-km (600-km²) grid based on a satellite image, which was subdivided into 150 plots of 4-km². We selected 60 plots randomly to establish the sampling sites and installed a camera trap in each plot to record carnivores, with a mean distance of 2 km (range: 1.5–3.28-km) between adjacent traps. We used Acorn LTL-5210 (n = 4) and Bushnell (n = 56) cameras traps. The traps were set to operate for 24 hours and installed primarily on trails and unpaved roads, which are known to be access routes used by carnivores (Karanth, 1995). We did not use baits to attract animals.

The study period encompassed the seven months of the dry season, from January to July 2017, and resulted in a total sampling effort of 8,678 trap-days. To calculate sampling effort, we excluded the traps that were stolen (n = 2) and the days on which the cameras were nonoperational. In the latter case, the day on which the last record was obtained was considered to be the last day on which the camera was operational for the calculation of sampling effort. We analyzed the records of seven carnivore species: crab-eating fox—*Cerdocyon thous*; ocelot—*Leopardus pardalis*; northern tiger cat—*Leopardus tigrinus*; jaguar—*Panthera onca*; puma—*Puma concolor*; jaguarundi—*Herpailurus yagouaroundi*, and hog-nosed skunk—*Conepatus semistriatus*.

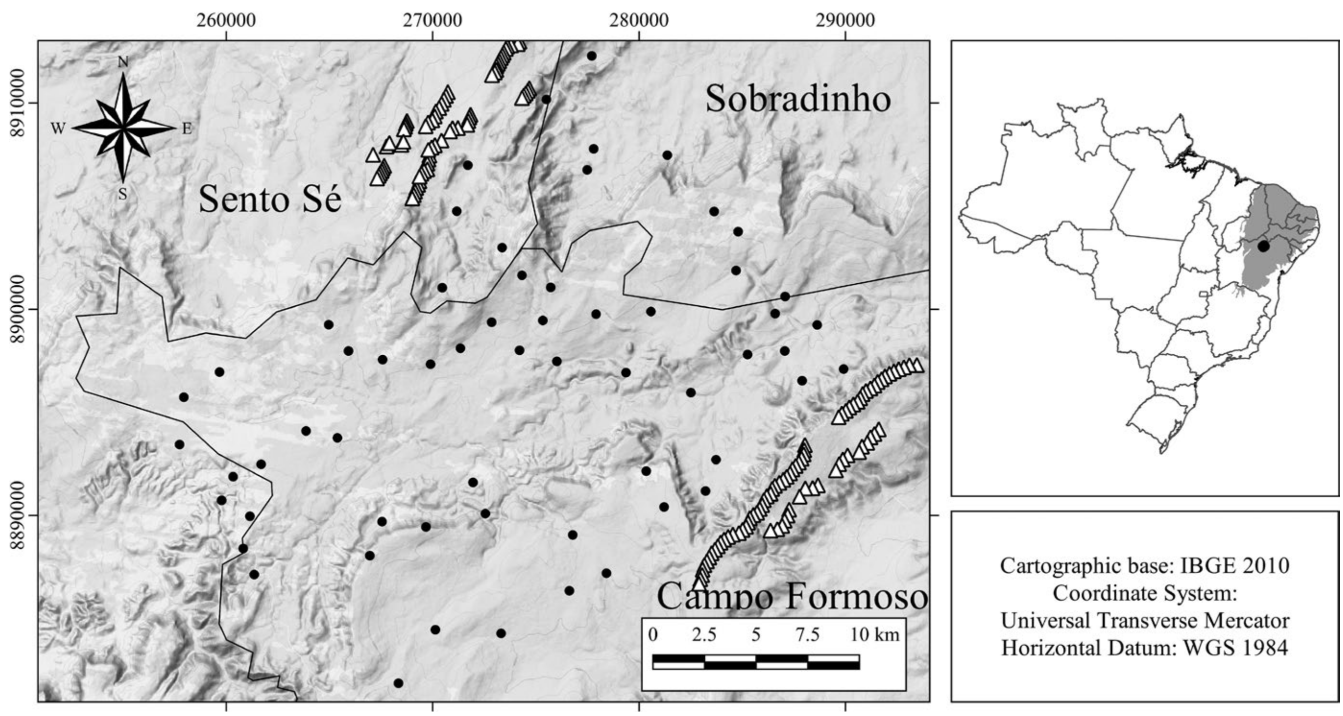

FIGURE 1 Distribution of the camera traps (black dots) in the Boqueirão da Onça, Bahia, Brazil. The black lines represent the limits of the three municipalities Sento Sé, Sobradinho, and Campo Formoso. The white triangles represent the wind turbines. The insert (top right) shows the study site (black dot) within the Caatinga domain (gray shading) in northeastern Brazil

2.3 | Modeling occupancy and detection probabilities

The occupancy probability (Ψ) of a species is defined as the probability that site *i* is occupied by the species, while the detection probability (*p*) is defined as the probability of detecting the species at site *i* and during time *t*, given that the species occurs in the area. These parameters can be modeled as a function of the covariates (MacKenzie et al., 2002). In the present study, we interpreted the detection probability as a proxy of frequency (or intensity) of use (e.g., Cassano, Barlow, & Pardini, 2014; Massara et al., 2018).

To investigate the influence of human activity on the occupancy probability of the carnivores, we measured three covariates at each sampling site, that were, the distance from each site to the nearest (a) cattle ranch, (b) human settlement, and (c) wind farm. As water is a limiting resource in the Caatinga, we also measured the distance from each site to the nearest permanent source of water (e.g., spring). We also investigated the direct influence of domestic dogs, cattle, and poachers on the occupancy probability of the carnivores, estimating separately the conditional occupancy probability ($\Psi_{conditional}$; MacKenzie et al., 2006) of dogs, cattle, and poachers at each site using the "single-season" occupancy model in the PRESENCE program (Hines, 2006). The conditional occupancy probability is defined as the probability that the species is present at a site, given it was not detected. When a species is detected at the site, its $\Psi_{conditional} = 1$ (MacKenzie et al., 2006). These conditional occupancy probabilities were used as a site covariate in our analysis. We measured the distance covariates in QGis. 2.14 (http://www.qgis.org/en/site/) and used them as the site covariates in our analyses (Table 1).

TABLE 1 Covariates used to model the probabilities of occupancy (Ψ) and detection (*p*) of carnivores at Boqueirão da Onça, Bahia, northeastern Brazil. The mean (range) of values is given for each covariate. The values for the detection of dogs, cattle, and poachers are the mean proportion of periods (20 in total) of the detection of these species among the different sites

Covariates	Mean and range (minimum-maximum)
Distance from settlements (m)	9,656.7 (700–16,300)
Distance from wind farms (m)	8,729.9 (950–19,739)
Distance from watercourses (m)	5,074.4 (220–15,590)
$\Psi_{conditional}$ of Dog	0.38 (0–1.00)
$\Psi_{conditional}$ of Cattle[a]	0.25 (0–1.00)
$\Psi_{conditional}$ of Poacher[a]	0.22 (0–1.00)
Dog detection	0.04 (0–0.08)
Cattle detection	0.09 (0.02–0.17)
Poacher detection	0.03 (0–0.07)
Days of camera operation	144.6 (30–200)

[a]$\Psi_{conditional}$ is the probability that a site is occupied by the target species, given its specific detection history.

We also used covariates related to the distance of each site from the nearest cattle ranch, human settlement, wind farm, and watercourse to model the detection probability (*p*) of the carnivores. To investigate the influence of the presence of domestic dogs, cattle, and poachers on the detection probability of the wild carnivores, we constructed three "sampling covariates." Each of these covariates is related to the detection (1) or not (0) of dogs, cattle, and poachers at each site during each sampling period. Finally, we considered the number of days on which each camera was operational at each site during each sampling period to evaluate for the influence of this covariate on the carnivore's detection.

We prepared a correlation matrix prior to running the analyses to determine whether pairs of predictor covariates were highly correlated, that is, $r \geq 0.7$ (Goad, Pejchar, Reed, & Knight, 2014). As the distance from cattle ranches was highly correlated with that from both settlements and wind farms (0.72 and 0.73, respectively), we excluded ranches from the subsequent analyses.

2.4 | Data analysis

We used a "single-season" occupancy model (MacKenzie et al., 2002), run in the Mark program (White & Burnham, 1999) to determine the influence of the covariates on the probabilities of occupancy and detection of the carnivores. The 200 days of sampling were grouped in 20 periods (occasions) of 10 days to characterize the history of detection of each species at each sampling site. Given the small number of detections of the jaguar, the data on this species were organized in 10 periods (occasions) of 20 days. As our primary objective was the identification of the predictor covariates that have the greatest effect or influence on the probabilities of occupancy and detection of the carnivores, we adopted a model selection strategy based on all the possible combinations contemplated by our a priori hypotheses. Specifically, we constructed 1094 models (see Table S1) based on all the possible additive combinations of the covariates that may have influenced the probabilities of occupancy (Ψ) and detection (*p*) of each carnivore. This approach resulted in a set of balanced models (Doherty, White, & Burnham, 2012), which allowed us to calculate the accumulative AICc (w_+) weights of each covariate (Burnham & Anderson, 2002) and evaluate which were the most likely ($w_+ \geq 0.50$) to have influenced the occupancy and detection probabilities of the carnivores.

We evaluated for a possible lack of independence (overdispersion) among sites using the goodness-of-fit test developed specifically for the analysis of "single-season" occupancy (MacKenzie & Bailey, 2004) analyzed in the PRESENCE program (Hines, 2006). When overdispersion was found, the models were adjusted by the Quasi AICc (QAICc).

3 | RESULTS

The goodness-of-fit test indicated significant overdispersion only for the northern tiger cat ($\hat{c} = 2.00$; $p = 0.01$). The distance from wind farms was correlated negatively with the occupancy probability of the jaguar ($w_+ = 0.68$; Table 2) and positively with that of the

TABLE 2 Cumulative AICc weights for the covariates used to model the occupancy probabilities (Ψ) and detection (p) of mammalian carnivores at Boqueirão da Onça, Bahia, northeastern Brazil. The estimates of the effects of the covariates (β parameters) are given for the most parsimonious model that included each covariate. The Ψ values were modeled as a function of the distance from water, settlements, and wind farms, with the $\Psi_{conditional}$ for domestic dogs (Dog_{cond}), cattle ($Cattle_{cond}$), and poacher ($Poacher_{cond}$). The p values were modeled as a function of the distance from water, settlements, and wind farms, and the detection of dogs, cattle, and hunters, and the number of days on which the cameras were operational. The mean values of occupancy ($\hat{\psi}$ and detection ($\hat{p}$) of the species were obtained from the most parsimonious models, which included the covariates with the highest cumulative weight ($w_+ \geq 0.50$)

Covariates	Cumulative AICc Weights	β parameters			Real parameters		
		Estimate	Lower 95% IC	Upper 95% IC	Estimate	Lower 95% IC	Upper 95% IC
Crab-eating fox occupancy (Ψ)							
$Poacher_{cond}$	0.94	9.11	−2.99	21.22	–	–	–
Distance from settlements	0.36	-4.8×10^{-4}	-8.2×10^{-4}	-1.4×10^{-4}	–	–	–
Dog_{cond}	0.33	2.10	0.15	4.04	–	–	–
Distance from watercourses	0.18	3.4×10^{-4}	7.0×10^{-5}	6.2×10^{-4}	–	–	–
$Cattle_{cond}$	0.04	0.72	−0.86	2.31	–	–	–
Distance from wind farms	0.03	-3.4×10^{-5}	-1.8×10^{-4}	1.2×10^{-4}	–	–	–
$\hat{\psi}$	–	–	–	–	0.65	0.49	0.80
Crab-eating fox detection (p)							
Camera operation	1.00	0.32	0.20	0.44	–	–	–
Cattle detection	0.58	0.80	0.29	1.31	–	–	–
Distance from watercourses	0.29	7.0×10^{-5}	1.5×10^{-5}	1.3×10^{-4}	–	–	–
Distance from settlements	0.05	3.6×10^{-5}	-1.8×10^{-5}	9.0×10^{-5}	–	–	–
Distance from wind farms	0.05	-6.5×10^{-5}	-1.2×10^{-4}	-4.7×10^{-6}	–	–	–
Poacher detection	0.03	0.22	−0.55	0.99	–	–	–
Dog detection	0.02	−0.01	−0.78	0.77	–	–	–
$\hat{p}$	–	–	–	–	0.18	0.14	0.23
Ocelot occupancy (Ψ)							
Distance from wind farms	0.12	-1.58×10^{-4}	-3.83×10^{-4}	6.8×10^{-5}	–	–	–
Distance from watercourses	0.10	-1.5×10^{-4}	-3.5×10^{-4}	4.8×10^{-5}	–	–	–
$Cattle_{cond}$	0.08	1.17	−1.16	3.50	–	–	–
$Poacher_{cond}$	0.07	1.17	−1.18	3.52	–	–	–
Dog_{cond}	0.06	−0.81	−2.41	0.79	–	–	–
Distance from settlements	0.05	7.6×10^{-5}	-1.8×10^{-4}	3.3×10^{-4}	–	–	–
$\hat{\psi}$	–	–	–	–	0.68	0.50	0.82
Ocelot detection (p)							
Camera operation	1.00	0.31	0.16	0.45	–	–	–
Distance from watercourses	0.99	-2.33×10^{-4}	-3.26×10^{-4}	-1.40×10^{-4}	–	–	–
Distance from settlements	0.99	2.35×10^{-4}	1.44×10^{-4}	3.26×10^{-4}	–	–	–
Poacher detection	0.22	1.6	−0.03	2.35	–	–	–

(Continues)

TABLE 2 (Continued)

Covariates	Cumulative AICc Weights	β parameters			Real parameters		
		Estimate	Lower 95% IC	Upper 95% IC	Estimate	Lower 95% IC	Upper 95% IC
Distance from wind farms	0.08	-6.3×10^{-5}	-1.7×10^{-4}	4.2×10^{-5}	–	–	–
Cattle detection	0.05	0.24	−0.39	0.87	–	–	–
Dog detection	0.04	0.22	−0.96	1.41	–	–	–
$\hat{p}$	–	–	–	–	0.13	0.08	0.17
Northern tiger cat occupancy (Ψ)							
Dog_{cond}	0.21	1.11	−1.88	4.10	–	–	–
$Cattle_{cond}$	0.21	−0.89	−3.01	1.22	–	–	–
Distance from watercourses	0.16	4.8×10^{-6}	-2.8×10^{-4}	2.9×10^{-4}	–	–	–
Distance from wind farm	0.16	2.8×10^{-5}	-2.1×10^{-4}	2.6×10^{-4}	–	–	–
Distance from settlements	0.16	3.1×10^{-5}	-2.7×10^{-4}	3.3×10^{-4}	–	–	–
$Poacher_{cond}$	0.15	0.66	−2.16	3.48	–	–	–
$\hat{\psi}$	–	–	–	–	0.64	0.38	0.84
Northern tiger cat detection (*p*)[a]							
Camera operation	0.99	0.42	0.01	0.83	–	–	–
Distance from settlements	0.29	-8.6×10^{-5}	-2.2×10^{-4}	4.4×10^{-5}	–	–	–
Poacher detection	0.22	0.77	−0.69	2.24	–	–	–
Cattle detection	0.22	0.60	−0.55	1.75	–	–	–
Distance from wind farms	0.20	-4.4×10^{-5}	-1.4×10^{-4}	5.3×10^{-5}	–	–	–
Distance from watercourses	0.16	-4.3×10^{-5}	-1.9×10^{-4}	1.1×10^{-4}	–	–	–
Dog detection	0.14	0.31	−1.26	1.87	–	–	–
$\hat{p}$	–	–	–	–	0.08	0.04	0.11
Jaguar occupancy (Ψ)							
Distance from wind farms	0.68	-1.01×10^{-3}	-2.6×10^{-3}	5.7×10^{-4}	–	–	–
Distance from watercourses	0.18	1.3×10^{-4}	7.4×10^{-4}	4.8×10^{-4}	–	–	–
Dog_{cond}	0.17	1.18	−2.80	5.16	–	–	–
$Cattle_{cond}$	0.16	1.45	−2.61	5.52	–	–	–
$Poacher_{cond}$	0.15	0.57	−3.13	4.27	–	–	–
Distance from settlements	0.14	2.4×10^{-4}	-5.3×10^{-4}	0.001	–	–	–
$\hat{\psi}$	–	–	–	–	0.56	0.30	0.83
Jaguar detection (*p*)							
Distance from wind farm	0.71	7.8×10^{-4}	2.4×10^{-4}	1.3×10^{-3}	–	–	–
Cattle detection	0.47	−18.40	−15,053.1	15,016.3	–	–	–
Dog detection	0.30	−19.65	6.2×10^{-7}	−19.65	–	–	–
Distance from settlements	0.16	-1.5×10^{-4}	-5.7×10^{-4}	2.7×10^{-4}	–	–	–
Poacher detection	0.16	0.96	−1.48	3.40	–	–	–

(Continues)

TABLE 2 (Continued)

Covariates	Cumulative AICc Weights	β parameters			Real parameters		
		Estimate	Lower 95% IC	Upper 95% IC	Estimate	Lower 95% IC	Upper 95% IC
Camera operation	0.13	0.04	−0.11	0.20	–	–	–
Distance from watercourses	0.13	6.1×10^{-5}	-2.5×10^{-4}	3.8×10^{-4}	–	–	–
$\hat{p}$	–	–	–	–	0.10	−0.01	0.22
Puma occupancy (Ψ)							
Distance from watercourses	0.60	-7.4×10^{-4}	-1.7×10^{-3}	2.5×10^{-4}	–	–	–
$Cattle_{cond}$	0.36	2.08	−0.14	4.29	–	–	–
Distance from wind farms	0.23	-4.4×10^{-4}	-1.1×10^{-3}	2.7×10^{-4}	–	–	–
Distance from settlements	0.09	4.4×10^{-5}	-2.8×10^{-4}	3.7×10^{-4}	–	–	–
$Poacher_{cond}$	0.07	−0.76	−4.50	2.97	–	–	–
Dog_{cond}	0.07	−0.43	−3.16	2.29	–	–	–
$\hat{\psi}$	–	–	–	–	0.23	0.05	0.42
Puma detection (p)							
Camera operation	0.88	0.89	−1.74	3.53	–	–	–
Cattle detection	0.43	1.10	−0.05	2.26	–	–	–
Distance from wind farms	0.37	-5.7×10^{-4}	-9.5×10^{-4}	-2.0×10^{-4}	–	–	–
Distance from settlements	0.34	5.4×10^{-4}	1.6×10^{-4}	9.2×10^{-4}	–	–	–
Distance from watercourses	0.11	1.9×10^{-4}	-2.2×10^{-4}	6.1×10^{-4}	–	–	–
Poacher detection	0.10	1.42	−0.94	3.78	–	–	–
Dog detection	0.08	0.91	−1.38	3.19	–	–	–
$\hat{p}$	–	–	–	–	0.06	0.02	0.10
Jaguarundi occupancy (Ψ)							
Distance from wind farms	0.84	4.3×10^{-4}	-3.3×10^{-5}	8.9×10^{-4}	–	–	–
Distance from watercourses	0.53	-1.3×10^{-3}	-2.4×10^{-3}	-1.8×10^{-4}	–	–	–
Distance from settlements	0.35	8.2×10^{-4}	4.3×10^{-5}	1.6×10^{-3}	–	–	–
$Cattle_{cond}$	0.11	1.82	−1.86	5.51	–	–	–
$Poacher_{cond}$	0.07	−1.08	−5.06	2.90	–	–	–
Dog_{cond}	0.05	−0.01	−3.33	3.31	–	–	–
$\hat{\psi}$	–	–	–	–	0.54	0.29	0.79
Jaguarundi detection (p)							
Camera operation	0.86	0.23	0.01	0.44	–	–	–
Distance from wind farms	0.29	-1.5×10^{-4}	-2.9×10^{-4}	-4.8×10^{-6}	–	–	–
Distance from watercourses	0.29	-1.6×10^{-4}	-3.0×10^{-4}	-2.6×10^{-5}	–	–	–
Poacher detection	0.20	−19.94	-1.6×10^{4}	1.5×10^{4}	–	–	–
Distance from settlements	0.08	-7.5×10^{-5}	-2.3×10^{-4}	8.4×10^{-5}	–	–	–

(Continues)

TABLE 2 (Continued)

Covariates	Cumulative AICc Weights	β parameters			Real parameters		
		Estimate	Lower 95% IC	Upper 95% IC	Estimate	Lower 95% IC	Upper 95% IC
Cattle detection	0.06	−0.56	−2.01	0.88	–	–	–
Dog detection	0.05	−0.08	−2.13	1.97	–	–	–
$\hat{p}$	–	–	–	–	0.04	0.03	0.06
Striped hog-nosed skunk occupancy (*Ψ*)							
Dog_{cond}	0.41	−15.18	−36.4	6.04	–	–	–
Distance from settlements	0.31	-1.0×10^{-3}	-2.5×10^{-3}	5.5×10^{-4}	–	–	–
$Cattle_{cond}$	0.22	−3.99	−21.43	13.43	–	–	–
$Poacher_{cond}$	0.16	−9.31	−23.43	4.81	–	–	–
Distance from watercourses	0.15	4.6×10^{-4}	-5.6×10^{-4}	1.5×10^{-3}	–	–	–
Distance from wind farms	0.14	1.6×10^{-4}	-5.5×10^{-4}	8.7×10^{-4}	–	–	–
$\hat{\psi}$	–	–	–	–	0.47	0.19	0.76
Striped hog-nosed skunk detection (*p*)							
Camera operation	0.96	0.50	−0.27	1.28	–	–	–
Poacher detection	0.33	−19.99	−20.00	−19.99	–	–	–
Distance from settlements	0.32	-9.8×10^{-4}	-2.5×10^{-3}	5.5×10^{-4}	–	–	–
Distance from watercourses	0.14	-5.9×10^{-5}	-2.2×10^{-4}	1.1×10^{-4}	–	–	–
Dog detection	0.13	1.49	−0.75	3.73	–	–	–
Cattle detection	0.13	−0.19	−1.68	1.29	–	–	–
Distance from Wind farms	0.12	-1.1×10^{-5}	-1.2×10^{-4}	9.9×10^{-5}	–	–	–
$\hat{p}$	–	–	–	–	0.04	0.01	0.06

[a]Result of the adjusted model for QAICc.

jaguarundi (w_+ = 0.84; Table 2). The distance from permanent watercourses was correlated negatively with the occupancy probability of two species, the puma (w_+ = 0.60; Table 2) and the jaguarundi (w_+ = 0.53; Table 2). By contrast, the occupancy probability of the crab-eating fox was correlated positively with the presence of poachers (w_+ = 0.94; Table S1). Neither the distance from settlements nor the presence of dogs or cattle had any influence on the occupancy probability of any of the wild carnivores (w_+ < 0.50; Table 2).

The number of days on which the cameras were operational had a positive influence on the probability of detection of all species (w_+ > 0.50; Table 2), except for the jaguar (w_+ = 0.13; Table 2). The distance from settlements correlated positively with the probability of detection of the ocelot (w_+ = 0.99; Table 2). The distance from wind farms correlated positively with the detection of the jaguar (w_+ = 0.71; Table 2). The distance from permanent sources of water correlated negatively with the detection probability of the ocelot (w_+ = 0.99; Table 2). The detection probability of the crab-eating fox was correlated positively with the presence of cattle (w_+ = 0.58; Table 2). However, the detection of dogs and poachers not influenced the detection probability of the wild carnivores (w_+ < 0.50; Table 2). Except for the number of days of operation of the cameras, no covariate influenced the occupancy and detection of striped hog-nosed skunk.

4 | DISCUSSION

As expected, the different carnivore species responded in distinct ways to the anthropogenic impacts evaluated in the present study. The distance from wind farms was the human variable that most influenced the occupancy probability of two felids, the jaguar and the jaguarundi. In contrast with our expectations, however, the jaguar presented a higher occupancy probability at sites closer to wind farms. Previous research in the Caatinga has indicated a positive relationship between the probability of occurrence of the jaguar and highland areas (Astete et al., 2016; Morato, Ferraz, Paula, & Campos, 2014), which correspond with the location of wind farms. As they are more remote, these areas tend to be less affected by habitat loss, which would favor the occurrence of the jaguar, which is highly dependent on areas of natural vegetation (De Angelo et al., 2011). These areas of better-preserved habitat may also harbor populations of the prey species most frequently targeted by the jaguar in the study area, and this demands further investigation, given that the presence of top predators tends to be correlated positively with the presence of their prey (Karanth, Nichols, Kumar, Link, & Hines, 2004). Alternatively, the higher occupancy probability of the jaguar in these areas may be associated with thermoregulation. The presence of deep valleys and ravines on the slopes of the upland areas offer a refuge from the extreme temperatures of the Caatinga (Astete et al., 2016). Given this, we believe that the synergic effects of these two factors (availability of prey and thermoregulation) may account for the pattern of occupancy of the jaguar observed within the study area.

By contrast, the jaguarundi occupancy presented a positive relationship with the distance from the wind farms, which may be related to the use of less dense habitats, given that this feline is an adaptable generalist able to occupy more open areas, and even habitats that have suffered anthropogenic impacts (Oliveira et al., 2010). One potential alternative, however, is that this pattern of occupancy in the jaguarundi represents a behavioral response to the presence of the jaguar. As jaguars may prey on the jaguarundi, the larger carnivores of this trophic guild may influence the behavior and distribution of the smaller species (Oliveira & Pereira, 2014). In particular, smaller felids may avoid larger ones by occupying habitats of lower quality (Di Bitetti, De Angelo, Di Blanco, & Paviolo, 2010), although their contrasting patterns of activity—while jaguarundi is typically diurnal, the jaguar is primarily nocturnal (Di Bitetti et al., 2010)—may minimize the possibility of direct contact. The exact nature of the interaction between these two species will only be elucidated with more detailed data on their patterns of spatial and temporal niche partitioning.

The probabilities of occupancy of the jaguarundi and the puma also increased with the proximity of watercourses. This association with sources of water has been noted in previous studies of both jaguarundi (Giordano, 2016) and puma (Astete et al., 2016). In semi-arid environments like the Caatinga, the availability of water is without doubt one of the primary factors limiting biological diversity (Oliveira & Diniz-Filho, 2010). Given this, one important management strategy practiced in some protected areas of this region is the installation of artificial watering troughs in an attempt to guarantee the survival of the resident species, especially during prolonged droughts (Astete et al., 2016; Dias, Guedes, Silva, & Sena, 2017). The findings of some studies indicate that the preference of carnivores for sites in the vicinity of water sources is related to the presence of denser vegetation in these areas, which provides shelter and the opportunity to encounter prey species dependent on water (Schuette et al., 2013). The correlation between the occupancy of jaguarundis and pumas, and water sources in Boqueirão da Onça may also be related to the fact that the present study was conducted during the dry season. In this case, we expected to find differences in the occupancy of these species during the rainy season, when water accumulates in intermittent streams and the temporary pools that form within rock formations (lajedos).

Contrary to our predictions, the presence of poachers only had a marked effect on the occupancy of the crab-eating fox, and in this case, with a positive association. This indicates that this fox is relatively tolerant of the presence of humans, which is consistent with its adaptability to a wide range of environmental conditions (Dias & Bocchiglieri, 2016). The crab-eating fox is a generalist carnivore in many aspects of its ecology, including its activity patterns, habitat use, and diet, which suggests that its association with sites occupied by poachers may be related to the availability of resources such as animal carcasses and discarded food leftovers. However, this positive association of the crab-eating fox with sites occupied by poachers may pose a threat to this canid, increasing its encounter probability with both humans and domestic dogs. The crab-eating fox is among the carnivores most impacted in the Caatinga because it both preys on livestock and feeds on crops (Alves et al., 2016). Although the principal reason for hunting this canid is this direct conflict with humans, its body parts (fat, fur, and tail) are used in traditional medicine (Alves, 2009). Domestic dogs can interact with crab-eating fox at multiple levels, which may result in competition, mortality (Lemos, Azevedo, Costa, & May Junior, 2011), and pathogen spillover (Jorge, Rocha, May Junior, & Morato, 2010).

Both biological and technical factors determine the probability of some species will be detected at a given study site. Our study has shown that the proximity of human settlements affected the intensity (or frequency) of habitat use by the ocelot, with its detection probability being influenced negatively by this covariate. Despite being relatively well adapted to different types of habitat, including farmland (Oliveira et al., 2010), the sum of the evidence indicates that the ocelot is associated strongly with native habitats (Massara, Paschoal, Doherty, Hirsch, & Chiarello, 2015; Massara et al., 2018). This pattern of habitat use is thought to be related to the cryptic behavior of this feline and its preference for forest-dwelling prey (Lyra-Jorge, Ribeiro, Ciocheti, Tambosi, & Pivello, 2010). In addition to these factors, we believe that its reduced frequency in the areas adjacent to human settlements is related to conflicts with shepherds and goatherders. Local residents in the study area, including poachers, reported that this feline is persecuted as a retaliation for the predation of lambs and goat kids, which are one of the principal sources of income in the local human settlements. This would account for the evasive behavior of the ocelot, which tended to avoid areas occupied by humans.

The distance from wind farms also had a strong influence on the detection of the jaguar. While the majority of the sites occupied by this species were in the vicinity of these installations, they were visited only very infrequently during the study period. In other words, while these areas encompass better-preserved native vegetation with potential jaguar prey, the areas directly adjacent to the wind farms are exposed to noise from the turbines, intense traffic of heavy vehicles and humans, and an excess of artificial light (Costa et al., 2017). These areas are also affected by an increase in poaching pressure due to the availability of access roads (Helldin et al., 2012), and the occurrence of microtremors and noise caused by the use of explosives for the preparation of the foundations of the turbines. The synergic effects of these impacts may contribute to a less frequent use of these areas by the jaguar. Similar patterns of habitat use have been reported in other big cat species, indicating that a fear of humans is widespread in this group and induces shifts in behavior patterns and habitat use (Smith et al. 2015). In Africa, for example, lions (*Panthera leo*) adopt alternative behavioral strategies in areas with a high risk of human contact, such as more rapid movements (Oriol-Cotterill, Macdonald, Valeix, Ekwanga, & Frank, 2015). In North America, pumas will spend less time feeding on their prey in areas occupied by humans, resulting in an increase in predation rates to compensate for the loss of energy intake (Smith et al. 2015). In this context, while areas in the vicinity of wind farms may represent important source of resources for the jaguar, it may use these sites relatively infrequently to avoid contact with humans.

Our observations indicate a strong influence of the presence of water on the probability of detection of the ocelot. A similar pattern has been observed in other regions, where the association with riparian habitats may be related to the greater availability of prey in these environments (Goulart et al., 2009). In the case of our study area, we believe that the higher frequency of use of sites near sources of water by the ocelot were associated with the availability of the water itself, given that this resource is available at a small number of sites during the dry season. There is no evidence of physiological adaptations in small-bodied mammals (e.g., rodents and marsupials) in the Caatinga, related to the scarcity of water, although many species may adapt to this condition behaviorally (Carmignotto & Astúa, 2017). As there are no data on larger-bodied mammals, we believe that carnivores, such as the ocelot, may visit water sources more frequently during the dry season, shifting their behavior during the rainy season, when water becomes more abundant. Further research will be necessary to better understand potential seasonal fluctuations in habitat occupancy and detection by carnivores, and their physiological adaptations.

The crab-eating fox was the only carnivore whose detection was influenced by the occurrence of cattle. Previous studies have shown that this canid is a generalist and is tolerant of anthropogenic impacts (Dias & Bocchiglieri, 2016). The compaction of the soil and the elimination of undergrowth by grazing cattle reduce the availability of refuges for many organisms, which may favor some opportunistic predators by increasing the detectability of their prey, and as a consequence, their capture rates (Preston, 1990). Research in semi-arid environments in Australia indicates an association between lizards and area grazed by cattle (Read & Cunningham, 2010). In addition to the effects of grazing, areas occupied by cattle are characterized by widespread deposits of fecal matter, which attract a diversity of coprophagous organisms, including coleopterans (Aidar et al., 2000). The crab-eating fox is known to be omnivorous predator, and in the Caatinga, lizards and beetles may represent an important component of its diet (Dias & Bocchiglieri, 2016; Olmos, 1993). In this case, the foxes may visit areas occupied by cattle relatively frequently due to the abundance of easily captured prey items.

Camera traps are an extremely valuable research tool for the collection of systematic data on carnivore communities and activity patterns (Dias, Campos, & Rodrigues, 2018; Massara, Paschoal, Bailey, Doherty, & Chiarello, 2016). However, the use of camera traps also has certain limitations, including malfunction and the potential for theft. This reinforces the need to maximize the number of sampling days to ensure reliable records. Unreliable data will obviously have a negative effect on the reliability of the modeling and its potential for the generation of realistic estimates of occupancy probabilities. This is emphasized by the fact that the operational trap-days was the most important covariate of the detection probability of the carnivores monitored in the present study.

In a region exposed to a wide range of anthropogenic impacts, such as Boqueirão da Onça, the availability of water may also have a profound influence on the occurrence of many other species. However, the inconclusive findings on the northern tiger cat reinforce the need for further ecological research and the investigation of the factors that may threaten the persistence of this endangered species. Habitat use by striped hog-nosed skunk does not appear to be affected by the anthropogenic factors evaluated in this study. In fact, this small carnivore is generalist in the habitat use and can occupy from preserved environments (Dias, 2017) to degraded, including human settlements (Dias, Ribeiro, Bocchiglieri, & Pereira, 2014). To our knowledge, this is the first study in the Neotropical region to evaluate the influence of wind farms on habitat use by medium- and large-bodied mammals, and we hope that our findings will provide an incentive for further research in other regions of the world, where these facilities have been installed or are under construction. Understanding the impacts of wind farms on larger mammals will provide important insights for wildlife managers and the companies operating in this sector and contribute to the development of strategies for the effective mitigation of the negative impacts of these installations. The negative response of endangered species, such as the jaguarundi and the jaguar, raises concerns for the conservation of the species over the short to medium term. Despite this, areas affected by wind farms also appear to be important to the jaguar, which emphasizes the need for the implementation of conservation measures directed at this species. The collection of data using telemetry may provide more systematic insights into the intensity of use of these areas by this carnivore. This may have important implications for the conservation of the jaguar in Boqueirão da Onça, given that a number of new wind farms are planned for the region.

Landscapes occupied by human populations are expanding continually, with a concomitant reduction in the availability of areas capable of supporting a diverse predator community (Wang, Allen, & Wilmers, 2015). Recent estimates indicate that the natural vegetation of the Caatinga decreases year on year, and currently, 63.3% of its total area has been modified by anthropogenic impacts (Silva & Barbosa, 2017). Boqueirão da Onça is one of only a few locations with extensive areas of continuous caatinga vegetation, which harbor one of the regions last surviving jaguar populations, and further reinforces its classification as a priority area for the conservation of biodiversity (MMA 2016). The potential for the protection of areas such as Boqueirão da Onça is becoming increasingly difficult in the Caatinga, given the advanced stage of degradation of its natural habitats (Silva & Barbosa, 2017). Given this, we emphasize the urgent need for intervention by government agencies in our study area, to protect its extremely diverse biota. Our findings also indicate that anthropogenic impacts on the carnivore community should not be overlooked, and that their potential effects must be evaluated separately for each species. Given the rapid modification of the landscape in which Boqueirão da Onça is inserted, effective measures are required from environmental agencies in order to guarantee that the development of the region is not prioritized to the detriment of the conservation of its biodiversity.

Our findings indicate that both human activities and the availability of water have some influence on the habitats use by carnivores in semi-arid environments. The replication of our research in other systems vulnerable to similar pressures will permit the systematic evaluation of the compatibility of the conservation of local biodiversity with the expansion of human development and infrastructure. As different carnivore species have distinct ecological roles, they may also be more or less sensitive to anthropogenic disturbances (Lyra-Jorge et al., 2010). In this context, we have shown that some carnivores do not respond as intensively as others to the availability of water or anthropogenic impacts, and this emphasizes the importance of community-level research, to identify the most sensitive species and determine appropriate measures for the conservation and management of landscapes and their wildlife. While some landscapes impacted by human activities may be able to support carnivore communities (Lyra-Jorge et al., 2010), increasing development may threaten many species (Wang et al., 2015). This highlights the need for the creation of protected areas, which can mitigate anthropogenic pressures (Andam, Ferraro, Pfaff, Sanchez-Azofeifa, & Robalino, 2008), contribute to the conservation of key groups, such as carnivores (Nagy-Reis, Nichols, Chiarello, Ribeiro, & Setz, 2017), and protect springs and other important resources for the local wildlife.

ACKNOWLEDGMENTS

We are grateful to the Neotropical Grassland Conservancy for providing Memorial Grants and the Rufford Foundation for providing small grants (project 18442-1). We also thank the CAPES provided grants to DMD and RLM. We are also grateful to Professor Adriano Paglia of the UFMG and the Pró-Carnívoros for logistic support. Special thanks go to Dr. Ronaldo Morato of the Cenap/ICMBio for the support during the conception of the project. The anonymous reviewers kindly reviewed and helped to improve the manuscript.

DATA AVAILABILITY

Data available from the Dryad Digital Repository: https://doi.org/10.5061/dryad.2864hc8 (Dias, Massara, Campos, & Guimarães Rodrigues, 2019).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Dias DM, Massara RL, de Campos CB, Henrique Guimarães Rodrigues F. Human activities influence the occupancy probability of mammalian carnivores in the Brazilian Caatinga. *Biotropica*. 2019;51:253–265. https://doi.org/10.1111/btp.12628