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Habitat use and feeding behavior of domestic free-ranging goats in a seasonal tropical dry forest

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ABSTRACT

Traditional pastoralism based on free-ranging goats is indispensable for the rural economy of millions of people in the Brazilian Caatinga drylands. The use of landscape as rangelands for domestic herbivores benefits humans, but understanding its impacts on vegetation is crucial to sustainable strategies. Here we assessed how free-ranging domestic goats use mixed working landscapes in the largest dry forest of the Americas. We evaluated habitat use via GPS tracking and analysis of feeding preferences. Goats preferentially used open areas near human settlements and their impact on plant community may be negligible because they feed mostly on plants widely available in modified environments. Although free-ranging, the area of use was nearly constant (95.44 ha), but the size of herds varied (2–100 animals). Our study suggests that domestic goats can be considered dwellers of human-modified landscapes, foraging close to villages, on open (i.e., degraded) areas where abundant plant species thrive. Therefore, the extensive goat pastoralism in the Caatinga may have little impact on natural vegetation and could be sustainably managed under traditional management practices.

1. Introduction

Pastures are the most widespread anthropogenic category of land use on Earth, accounting for 22–26% of all converted lands (Phelps and Kaplan, 2017). In many arid and semiarid regions of the world, the land is not necessarily directly converted into anthropogenic pastures but, instead, used as rangelands, sometimes for millennia (Ellis et al., 2010). Free-ranging domestic herbivores are known to have a crucial role in the dynamics and function of rangeland ecosystems, from biological diversity to primary productivity (Forbes et al., 2019). However, the introduction of exotic herbivores can result in drastic ecological cascades with consequences across trophic levels and ecosystem functions, sometimes leading to ecosystem degradation (Rutherford et al., 2014). How exotic herbivores affect natural ecosystems depends on many factors, such as use intensity, the capacity of vegetation to cope with herbivory pressure, and climatic conditions (Bello et al., 2007). The consequences to those ecosystems can vary from positive (e.g., increased diversity and productivity) to negative (e.g., desertification), or even neutral (Charles et al., 2017). Yet, because domestic herbivores can select preferred habitats (Fritz et al., 1996), their influence on rangeland's ecosystems can be unevenly distributed in space and time (Speed et al., 2019).

Understanding how domestic herbivores use the space in rangelands is particularly useful to estimate both the drivers and extent of herbivore impacts on the natural ecosystems they feed upon (Georgiadis et al., 2007). Habitat use by native herbivores is naturally influenced by resource availability (biomass) and predator avoidance (Brown, 1999). Free-ranging domestic herbivores depend on humans to a certain degree for either food supplementation, protection from natural predators or water, factors that help to keep herds under control (Illius and O'Connor, 1999). Therefore, it is reasonable to expect that herd management may affect the home range of domestic free-ranging herbivores, and that those animals would concentrate their activities in selected portions of the landscapes (Araújo-Filho, 2013). For example, edible fast-growing plants usually thrive in agricultural landscapes and abandoned crops (Araújo-Filho, 2013; Lebrija-Trejos et al., 2010), helping domestic herbivores to stay close to human settlements. Small-scale shifting agriculture is also embedded within rangelands and creates a patchy distribution of areas undergoing natural regeneration (Murphy and Lugo, 1986) where edible plants and seedlings for herbivores are generally more abundant. Herds of free-ranging herbivores may, therefore, use the landscape following the spatial distribution of

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preferred habitats where food availability is high and predation risk is low.

Like many tropical dry forests around the world, the Brazilian Caatinga has been used for centuries as a source of resources for human subsistence (Silva and Barbosa, 2017). Currently, the Caatinga harbors around 26 million people, mostly poor and heavily dependent on natural resources, with a combination of fuelwood harvesting, small subsistence agriculture, and free-ranging domestic herbivores. And like in many dry forests around the world, goats (*Capra hircus*) are the most widespread and common domestic herbivores in the Caatinga, used as an important source of protein and income (Melo, 2017). Currently, 96% of the goatherds in Brazil – ca. 9 million animals – are in the Caatinga domains (IBGE, 2006), mostly raised extensively and free-ranging (Costa et al., 2008). Although reasonable to expect, the impact of free-ranging goats in the Caatinga is still poorly known and based on few studies focused on experimental exclusion studies of goats on vegetation (e.g., Menezes et al., 2020) or mixed evidence of grazing/browsing by cattle and goats evaluated together (Schulz et al., 2019). There is a large knowledge gap on how goats move through and select habitat within the Caatinga rangelands. Basic information on goats' home ranges and habitat preferences – which are essential for the sustainable herd management– are still missing.

Evidence in the literature points out that domestic goats prefer open areas with low vegetation cover (Baraza and Valiente-Banuet, 2008; Shrader et al., 2008). However, goats are mainly browsers (Rutter, 2002), and leaves of trees and shrubs, mostly found in forested areas, represent a large percentage of the diet of goats in the Caatinga (Araújo-Filho, 2013). Therefore, the balance between preference for low-density vegetated areas (a behavior probably evolved to avoid predation) and the higher availability of forage in more dense vegetation may drive habitat selection of goats in the Caatinga.

Here, we addressed the habitat selection by goats in a typical Caatinga working landscape where small-scale agriculture and free-ranging goats co-exist within a protected area. Specifically, we assessed: 1) Goats' home range size; 2) If the use of space by goats was a function of the vegetation density and distance to human settlements, and; 3) If goats had preference for specific plant species. As human commensals, we hypothesized that domestic free-ranging goats would be more likely to choose open areas and low-density vegetation closer to human settlements than high-density mature forest. We also hypothesized that goats preferred areas once impacted by human activities, such as abandoned crops and early successional vegetation. Based on our hypothesis, goats should a) represent an additional pressure over forest regeneration of the Caatinga rather than a degradation force of the mature high-density vegetation, and b) if they cause an impact on the diversity of plants, the abundances of the most consumed species must be influenced by the variation in the foraging pressure.

2. Material and methods

2.1. Study site

This study is part of the Catimbau Long Term Ecological Research Project (LTER Catimbau), started in 2012 in the Catimbau National Park (hereafter CNP), a 62,300 ha IUCN category II protected area, in Buíque, northeastern Brazil (Fig. 1; SNE, 2002). The semi-arid climate is predominant, with 650–1100 mm annual rainfall concentrated between March and July. Vegetation varies from shrubby to arboreal, with thorny species and an herbaceous component formed by grasses and dicotyledons, predominantly annual and abundant during rainy seasons (SNE, 2002).

Created in 2002, the CNP faces a conflicting administrative situation: currently with no management plan and contrary to the federal legislation for strictly protected areas, hundreds of families still live inside the Park and depend on the use of natural resources. During the study period, most of the poor population received federal financial assistance (enough for food and cooking gas, for example), but the dependence on natural resources for extra income remained high (Melo et al., 2017). The creation of the park, although still poorly implemented, at least slowed down the vegetation degradation by slash and burn activities. However, the free-ranging herd of goats remains one of the few alternatives to the use of natural resources within the CNP. In Northeastern Brazil, goat herding is carried out extensively or semi-extensively: animals released early in the morning range freely along the vegetation shared between landowners, and return at dusk after one or several days, receiving food and water in the dry season.

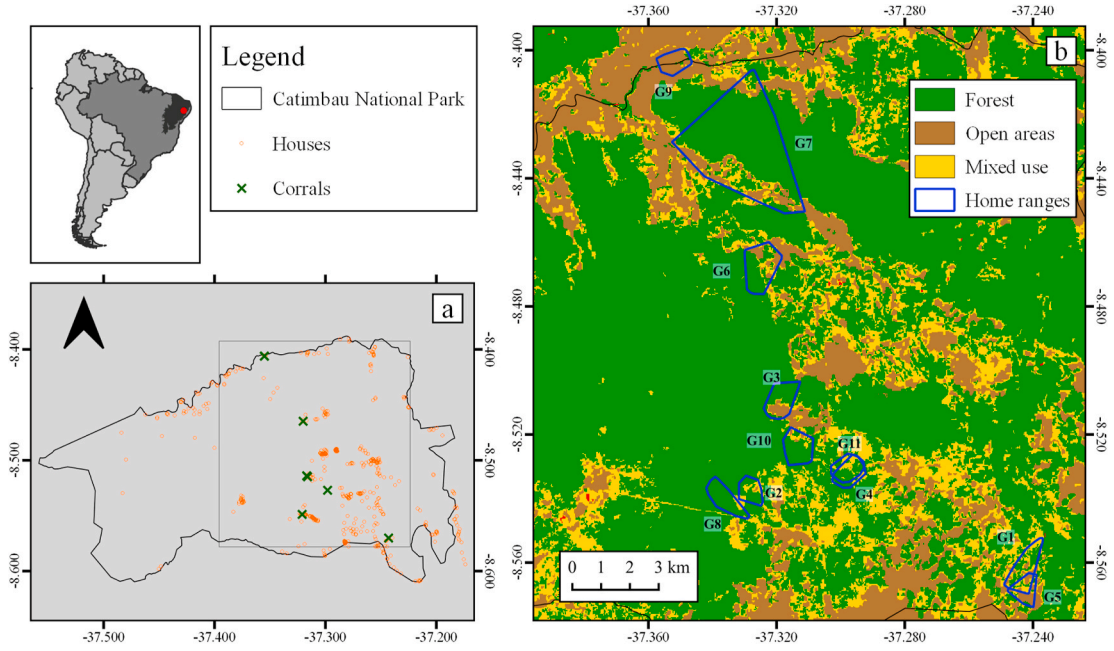

Fig. 1. Catimbau National Park (a), in Northeastern Brazil, with a detailed view of the landscape in the study area (b). Orange open dots represent records of 11 goats tracked by GPS, green crosses mark the goat's corrals, and minimum convex polygons for each animal are delimited in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

2.2. Landscape data

The land cover in CNP was classified based on the Mapbiomas Project v3.1 (Mapbiomas, 2018), using 30 m resolution Landsat images. We used classification maps from two consecutive years (2013 and 2014). Savanna formation, pastures, grasslands, and a mosaic of agriculture and pasture were, respectively, the most common land cover classes, covering more than 85% of the region, both in 2013 and 2014. Based on our familiarity with the area, we adopted simpler nomenclatures, more consistent with a real description of the region: *Forest,* instead of savanna formation; *Open areas*, instead of pasture; and *Mixed-use*, instead of the mosaic of agriculture and pasture. The percentage of land cover where animals were monitored did not differ between the two selected years: 69% covered by savanna/forest formation, 14% of pastures, and 17% for the mosaic of agriculture and pasture (Fig. 2).

Local households were recorded *in situ* using a GPS device (Garmin 64S) and households not visited were mapped via Google Earth in 2014. Eighty-one households were visited and surveyed for the number of goats raised. This information was then used to estimate the average number of goats per household within the study area. We then created a raster file with cells containing a distance cost value to the nearest house. To calculate a distance cost, we pondered the Euclidean distance by the terrain slope, considering the difficulties the terrain imposes on the goat mobility.

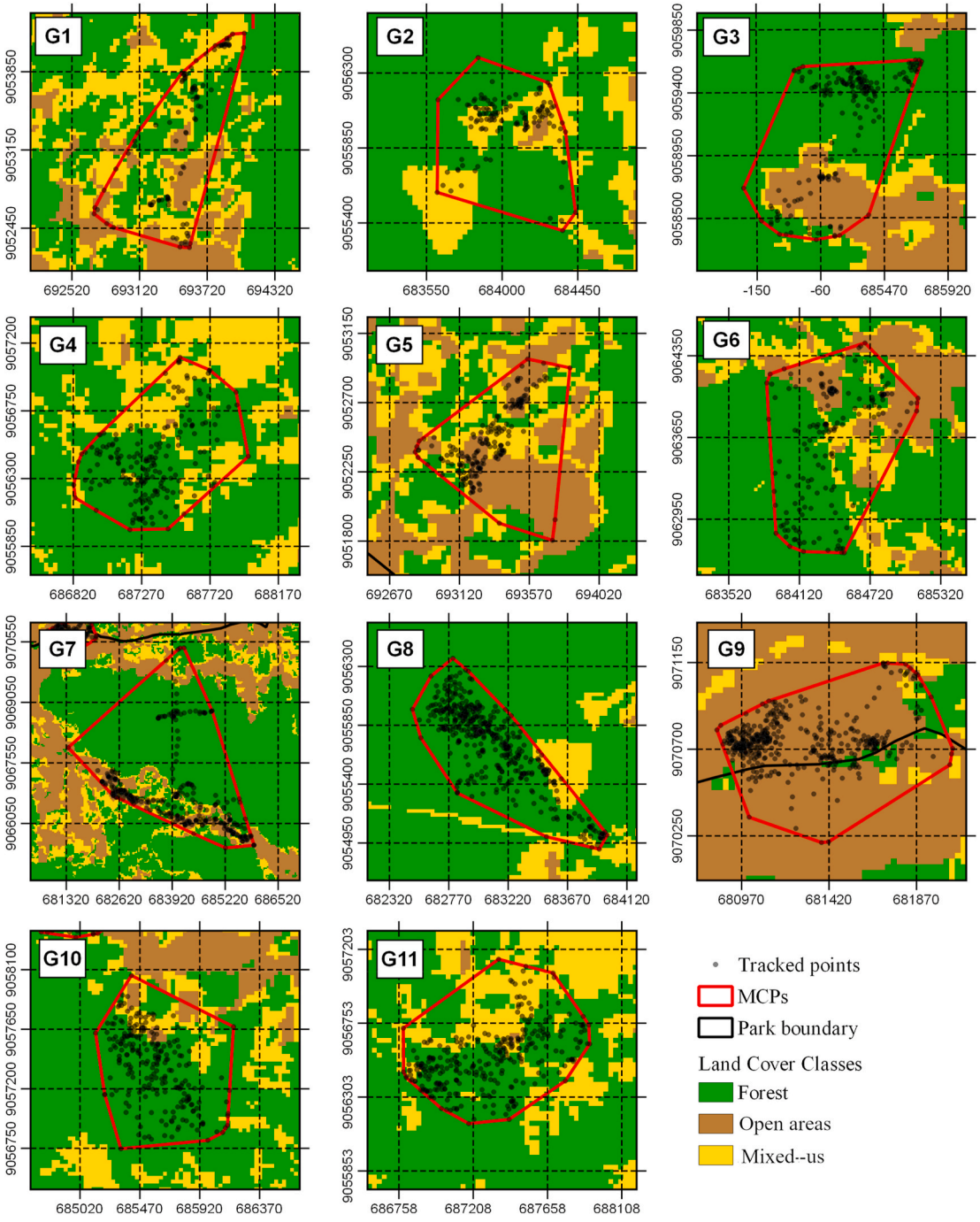

Fig. 2. Home ranges estimated by the minimum convex polygon of 11 domestic goats tracked by GPS in the Catimbau National Park, Northeastern Brazil.

2.3. Tracking animals and home ranges

The research was carried out from November 2013 to October 2014, with herds of seven different breeders. We tracked only females due to their herd leadership position. Eleven domestic goats were tracked using a GPS *data logger* (Catnip Technologies Ltd.) attached to collars with fiberglass clamps, and set to record position, time, and elevation every 15 min. Collars and data were retrieved by the research staff or removed by the goats' owners. Data recording ranged from three to 17 days (Table 1) and recorded points stored as tables and.gpx files using the @trip PC V5 software.

Considering goats tend to be diurnal animals (Rutter, 2002), and because we were interested in observing only their foraging activity and areas used, we only considered records taken between 04h30 and 17h30, an adequate time window for domestic free-ranging goat foraging (Rutter, 2002). To reduce the chance to record data from animals feeding on corrals, we excluded every point inside a buffer of 100 m radius from the center of the goat owner's farm.

2.4. Animal diet and impacts on vegetation

To assess diet during foraging activities, 34 goats were observed from distance in the field (Skarpe et al., 2007), one at a time on different days, and plant species consumed identified. We recorded how many times they bitted the same plant. Time spent observing the animals varied (191.26 min ±29.92). Although 28 of the observed animals were females and 6 males, the fact that goats forage in groups made us decide to aggregate the data and analyze them at the herd level. Therefore, we calculated the number of bites per minute for each plant species to measure plant species consumption rate and the plant species preference rank.

The relative plant abundance in the studied area was calculated based on a plant species list and abundance ranking for 15 of the LTER permanent plots at CNP (Rito et al., 2017). We then used a Pearson correlation test to analyze if the consumption rate of each species was correlated to their relative abundances in the landscape, so we could test if goats had a generalist feeding behavior. We were only able to run this analysis for 19 species recorded in the permanent plots. To assess the relationship between the plant abundance and the anthropogenic disturbance, we selected the top 5 abundant plant species consumed by the goats and analyzed the correlation between relative plant abundance and two previously calculated human pressure indexes (at the plot level) on their relative abundance. This way, we could check if goat's foraging activities were affecting the plant community. Therefore, we used chronic anthropogenic disturbance (CAD) indexes developed by Arnan et al. (2018). This study measured 12 metrics in loco and by remote sensing tools (e.g., cattle dung presence and distance of the measured spot to the nearest farm, respectively), aiming to synthesize the main CAD factors in the Caatinga's landscape. Apart from the individual influence of each of these factors on the ecosystem, the factors were grouped and analyzed to generate three different disturbance indexes: people pressure index, wood extraction index and livestock pressure index (LPI). Thus, the LPI was chosen as a measure of goat impact on the landscape, since it includes measures of herbivory and trampling of cattle and goats, goats' trail length (they forage along a net of relatively well-established trails), goat and cattle dung, and the number of goats and cattle owned by the neighboring farmers. Additionally, aiming to summarize all this information, the authors calculated the Global Multi-metric CAD index (hereafter, referred to as CAD index), which considers the three different indexes. Since it also includes goat impact measures, we also evaluated how these measures may affect plant community (for more details about the indexes, see Arnan et al., 2018).

2.5. Statistical analyses

We estimated home range via the Minimum Convex Polygon (MCP) using 95% of the available points (Calenge, 2011). Since animals can occasionally perform long journeys to outlying areas outside their living area, a common procedure to avoid home range overestimation is to remove a percentage (i.e., 5%) of the farthest points from the centroid of the cloud of points (Calenge, 2011). There was no correlation between the MCP and the number of collected points per animal (Pearson score = 0.115, $n = 11$, $p > 0.05$), thus eliminating the possibility that recording time could increase home range estimation. Therefore, we considered that the animal tracking effort was able to capture the real use of the area. We have done this analysis with the *move* package in R (Fieberg et al., 2018).

We used the Resource Selection Function (RSF) approach to evaluate if the use of resources by goats in the landscape was conditioned by the type of habitat and the presence of human settlements. The RSF is a function that gives probabilities of use for resource units of different types (Manly et al., 2002) and a given habitat is preferred when it is more widely used than expected at random. The analysis requires the definition of used habitats (i.e., goat registration points) and available habitats. We estimated the available habitat based on random points ($n = 100 \times$ the number of points used as habitats used) generated within each estimated MCP. We assumed that the detected MCP was a good proxy of the area that goats had available for use. For each of the points, we extracted (1) the cost distance to the nearest residence (Euclidean distance pondered by the slope of the terrain, where a hillier terrain

Table 1
Summary of tracking data from 11 domestic goats in the Catimbau National Park, Northeastern Brazil. Home ranges (in hectares) were calculated based on the minimum convex polygon (MCP) of all recorded points. The distance (in meters) from the corral to the nearest house was based on the Euclidean distance. SD = Standard deviation.

Goat id	Sex	Tracking period	Season	Number of tracking days	Selected recorded points	Home Range (ha)	Maximum distance to the corral (m)	Mean distance to the nearest house (m)	Proportion of Forest cover at the MCP	Proportion of Open areas at the MCP	Proportion of Mixed-use cover at the MCP
G1	F	Nov 2013	Dry	3	103	122.25	2093.08	886	0.47	0.22	0.3
G2	F	Nov 2013	Dry	5	124	62.89	1999.4	1098	0.71	0	0.29
G3	F	Apr 2014	Dry	6	189	107.55	1263.24	592	0.67	0.26	0.07
G4	F	Apr 2014	Wet	8	193	83.11	1065.64	1293	0.7	0	0.3
G5	F	May 2015	Wet	7	201	70.57	852.35	331	0.19	0.49	0.33
G6	F	Jun 2014	Wet	7	183	161.81	1513.56	593	0.63	0.22	0.16
G7	F	Jun 2014	Wet	8	318	1147.89	7150.84	1269	0.76	0.15	0.1
G8	F	Sep 2014	Dry	14	496	92.46	2636.49	1619	0.92	0	0.08
G9	F	Oct 2014	Dry	17	468	73.90	1009.16	314	0.07	0.9	0.03
G10	F	Oct 2014	Dry	8	238	101.83	1532.59	620	0.81	0.05	0.14
G11	F	Oct 2014	Dry	10	314	78.02	892.13	1317	0.65	0	0.35
Total				93	2827						
Mean				8.45	257	191.12	2000.77	903	0.60	0.21	0.19
SD				3.98	129.50	318.57	1798	442	0.26	0.27	0.11

implies a higher cost to the animal to move), and (2) land cover class. We then used logistic regression to test the selection of resources by the animals and a generalized linear mixed model (binomial family function with a logit link) with a 'template model builder' (glmmTMB) in the *glmmTMB* package v. 1.0.2.1 in R (Brooks et al., 2017). All RSF analyses were performed following Fieberg et al. (2018). Finally, to test whether goats could influence local vegetation we used Pearson's correlations among the abundance of the five most consumed plant species in the permanent vegetation plots and the value of both the CAD index and the LPI for those plots.

3. Results

3.1. Habitat use by free-ranging goats

In 55% of the 81 households, interviewees declared to raise goats extensively (i.e., free-ranging). The number of goats per household varied from 2 to 100 (mean = 22 animals/household). Based on this value, we estimated that the study area harbor ca. 1 goat/25 ha, or 0.04 goat/ha.

We tracked 11 goats belonging to different herds from 3 to 17 days, resulting in 2827 tracking points (Table 1). The maximum linear distance goats moved from their corral was 1994.26 m ± 1719.53 m and the mean distance of the recorded points to the nearest house was 903.0 m ± 442.0 m. Home-ranges varied from 70.57 ha to 1147.89 ha, and the average home range for 10 out of 11 tracked goats was rather constant: 96 ± 29 ha (Table 1). One goat was considered an outlier, with a home range 12 times larger than the average and was treated separately (Table 1).

Goats were raised in very different landscapes, from areas with >70% of forest cover to areas with <10% (Figs. 2 and 3). However, the resource selection model suggested that goats did not use home range areas randomly (z-value$_{\text{open areas}}$ = 5.86, p < 0.001) but presented an overall preference for open areas used more frequently than expected by pure availability (Fig. 4). As expected, goats used forested areas in a smaller frequency than expected by pure availability (z-value$_{\text{forest}}$ = −2.36, p = 0.018) (Fig. 4). Contrary to our expectations, cost distance had a small but significant effect on habitat selection (z-value$_{\text{cost distance}}$ = −2.36, p < 0.001), indicating that goats prefer to forage far from their corral.

3.2. Dietary preferences

Goats were observed for 6503 min and 53 plant species were consumed: 20 were trees, 17 shrubs, and 16 herbaceous (Table A1). Woody plants were the most consumed item (81% of the bites), nearly evenly divided between trees (40%) and shrubs (41%), while herbs accounted for only 19% of the plants consumed. Goats seemed to consume woody plants according to their availability in the landscape since the number of bites per minute was correlated with the plant abundance (Pearson's estimate = 0.518, df = 17, p-value = 0.023; Table 2). However, among the consumed species, the abundance of the 5 most abundant plants was not correlated with the CAD index (*p*-values for all pairwise correlations > 0.05; Fig. A1), suggesting that these species are widely abundant and independent of the human-caused disturbances, including goat's herbivory pressure. The same was true when we considered livestock pressure, based on the LPI data: plant abundance was not the result of goat herbivory pressure (Fig. A1).

4. Discussion

In our study, in an innovative way, we combined animal movement and dietary preference, offering a broad picture of habitat use and feeding behavior of goats, an economically and culturally important exotic herbivore in the Caatinga drylands of Brazil. We found that free-ranging goats are associated with human-modified landscapes – such as open areas – rather than dense vegetation, using the first more frequently that based on pure availability. Goats' home-range was nearly constant (ca. 100 ha) and relatively close to households. Also, dietary preferences pointed to a generalist feeding behavior: the most consumed plant species were correlated with the regional relative abundance of these species at the landscape scale. However, neither LPI

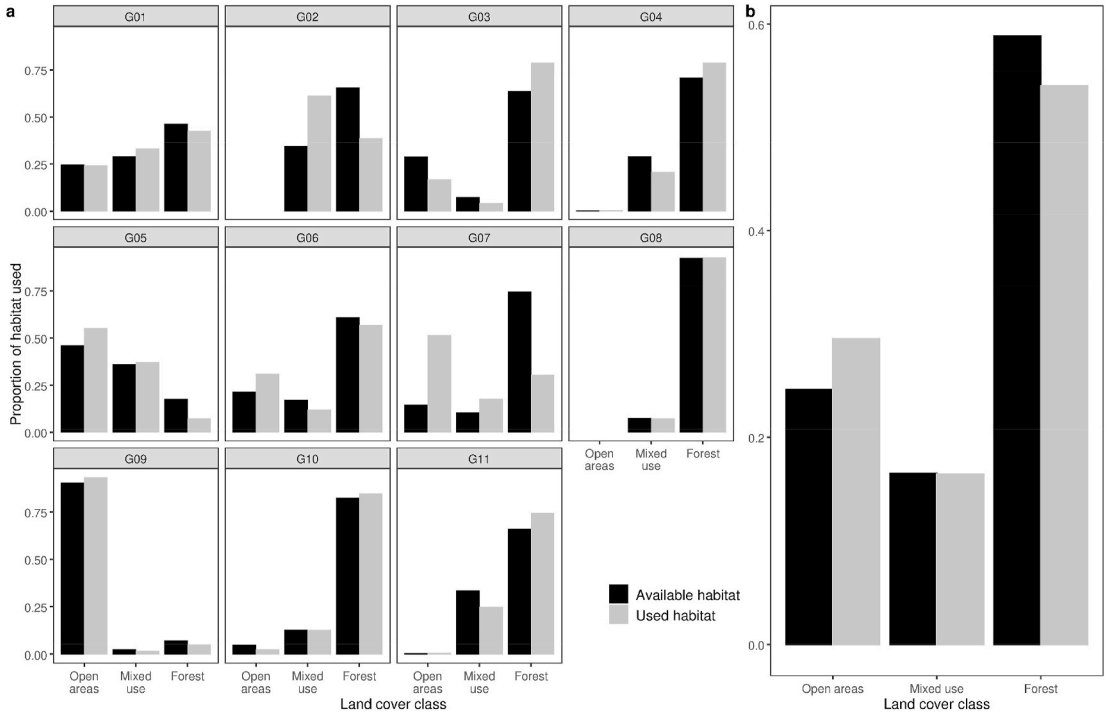

Fig. 3. Proportion of habitat available (black bars) and used (gray bars) for 11 goats tracked by GPS in the Catimbau National Park, Northeastern Brazil. Data is presented by each goat separately (a), and for all goats pooled (b).

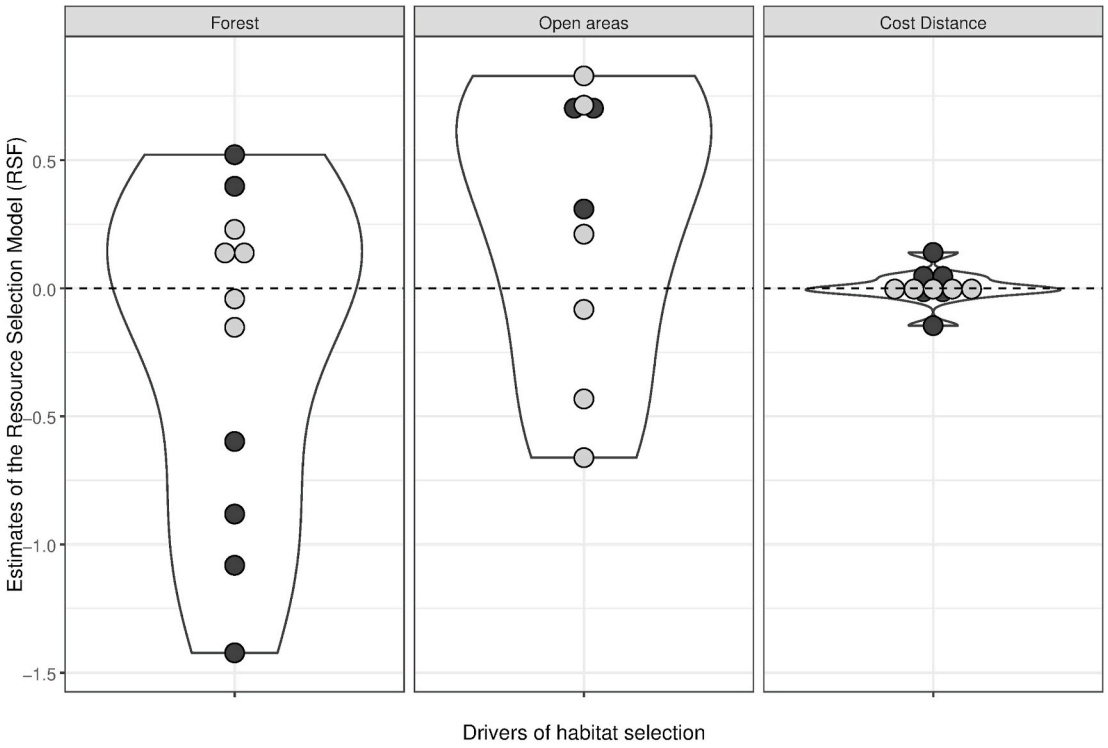

Fig. 4. Estimate values of the Resource Selection Function (RSF) analysis for each animal, representing the effect of the proposed drivers on the habitat selection of domestic goats in the Caatinga dry forest. Black dots refer to animals whose habitat selection was significantly responsive ($p < 0.05$) while gray dots are non-significant relationships. Consider that we choose to show here the RSF results for each animal, in an attempt to expose our data distribution, even though the general pattern found that we discuss on considers all animals together, with one estimate value for each predictor variable.

Table 2
Rate of consumption of woody plants by goats and the abundance of each species in the study area in the Catimbau National Park, in Northeastern Brazil.

Species	Family	Bites/min	Relative abundance
Bauhinia acuruana	Fabaceae	0.145	0.016
Cenostigma microphyllum	Fabaceae	4.149	0.079
Cereus jamacaru	Cactaceae	0.841	0.001
Commiphora leptophloeos	Burseraceae	2.445	0.007
Croton nepetifolius	Euphorbiaceae	3.140	0.061
Guapira graciliflora	Nyctaginaceae	0.009	0.006
Lantana camara	Verbenaceae	0.622	0.004
Libidibia ferrea	Fabaceae	0.015	0.001
Lippia gracilis	Verbenaceae	3.017	0.014
Manihot pseudoglaziovii	Euohorbiaceae	0.420	0.002
Neocalyptrocalyx longifolium	Capparaceae	0.020	0.020
Pilosocereus pachycladus	Cactaceae	2.200	0.006
Piptadenia stipulacea	Fabaceae	11.818	0.032
Pityrocarpa moniliformis	Fabaceae	2.497	0.110
Senegalia bahiensis	Fabaceae	3.521	0.037
Senegalia piauhiensis	Fabaceae	0.090	0.026
Senna rizzinii	Fabaceae	0.191	0.004
Syagrus coronata	Arecaceae	0.449	0.003
Ziziphus joazeiro	Rhamnaceae	0.195	0.005

nor CAD index affected plant species abundance. Therefore, there was not enough evidence to support the notion that domestic free-ranging goats are causing severe impacts on the Caatinga vegetation, at least not under lower densities as commonly practiced by rural households across the Caatinga. On the other hand, goats' small home ranges and preference for open areas (i.e., abandoned/regenerating areas), as those typically found around human settlements practicing shifting cultivation, suggests that goats may have an impact on the secondary succession of the Caatinga. Altogether, our results suggests that free-ranging goats can be raised in typical working landscapes of the Caatinga where a mix of forest and open/regenerating areas offer abundant plant species for foraging with low to moderate impact to vegetation.

We found low goat densities in the Catimbau National Park (CNP), a key aspect for impact assessments in rangelands (Schulz et al., 2016). The density we observed (0.04 goat/ha) is far below the values found in other semiarid regions, especially in areas with a clear detection of the effect of goats on the vegetation. In the Canary Islands, for example, the recorded density was two to eight times higher than that for CNP (Arevalo et al., 2011; Gangoso et al., 2006). A controlled study in the Chaparral, in the USA, assessed the effect of goat densities from 1.4 to 4.2 animals/ha, and all treatments had a significant effect on vegetation structure (Severson and Debano, 1991). In less populated areas of the world, such as in Western Australia, feral goats can present home ranges reaching 58,770 ha for males and 19.020 ha for females (King, 1992). The goats in Caatinga are no feral but domesticated and despite their adaptation to this dry environment, their traditional raising make them rely on water and food supplementation (mainly protein and in the dry season), which must limit their home range (Kronberg and Malechek 1997). Surely, this may vary according to cultural practices (Butt, 2010).

Although we detected an overall preference for open areas and avoidance of forested areas, there was a large variability among animals, which may reflect a strong variation in the habitat type (forests, mixed-use, and open areas) and availability within their home-ranges. Such diversity of habitats is common in the Caatinga, resulting of both natural vegetation heterogeneity, different land uses, terrain slope, and soil characteristics (Velloso et al., 2002). On the one hand, this highlights how generalist the domestic goats are, being able to adapt not only to harsh climatic conditions but also to very heterogeneous environments (Rutter, 2002), including higher digestive efficiency with low-quality forage (Ventura-Cordero et al., 2019). On the other hand, the fact that we found a clear habitat selection, even under such varying landscape structure (i.e., percentage of each habitat type) denotes that habitat selection is a strong force shaping goat's home-range (Kronberg and Malechek 1997; Lowrey et al., 2017). Our results are similar to those of

Baraza and Valiente-Banuet (2008), in the south-central Mexico semi-arid zone, which detected a preference of goats for treeless-exposed soil at the expense of areas with shrubs and trees. Therefore, free-ranging goats seem to behave as herbivores with some level of habitat selection and may suggest that their domestication process selected goats whose home ranges are limited (Kaiser et al., 2015), facilitating the management of those animals. However, different patterns of habitat preference may occur in areas under higher livestock densities (Cornelissen and Vulink, 2015).

Although animals foraged in small areas, not far from their corral (average of 2.7 km, but 1.48 km excluding the largest home range), our model detected a positive effect of distance in the probability of goat's presence. This was an unexpected result since goats are known to explore farther areas due to their selection of different foraging sources (Rutter, 2002). In semiarid savannas in Botswana, free-ranging goats used areas between 2 and 10 km far from villages (Skarpe et al., 2007). Supplementary feeding and water offered by breeders may decrease the risk of vegetation degradation as goats rely less on the natural vegetation (Illius and O'Connor, 1999). This strategy may help to keep goats using a reduced home range in the Caatinga, thus concentrating their activity near human-disturbed sites (Baraza and Valiente-Bunuet, 2008). Our results also highlight that goats behave as generalist herbivores, feeding on more available plants in the landscape. Some studies based on non-forest ecosystems found that goat grazing reduced taxonomic, functional, and phylogenetic diversity, resulting in vegetation homogenization (e.g Menezes et al., 2020; Salgado-Luarte et al., 2019). In our study site, a small but negative effect on the biomass and diversity of herbaceous communities was found using an exclusion experiment (Menezes et al., 2020). Therefore, some uncertainty remains on the potential impact of domestic free-ranging goats on dry forest vegetation. Such impact is controversial and very context-dependent, and influenced by the type of vegetation (Menezes et al., 2020) and density of animals (Severson and Debano 1991), with records in the literature of both positive (e.g., Mancilla-Leytón et al., 2013) and negative (Chidumayo and Gumbo, 2010; Schulz et al., 2016) impacts.

The Caatinga ecosystem has evolved with the presence of mega-herbivores (De Vivo and Carmignotto, 2004), and this is evidenced by the diverse defense structures local plants have, like thorns. However, mega-herbivores went extinct in the Caatinga (Alves et al., 2016; De Vivo and Carmignotto, 2004), and the current populations of large native herbivores are in decline due to hunting (Alves et al., 2016). The large-bodied fauna can play key functions in different ecosystems (Forbes et al., 2019). In a more recent period - on a scale of centuries - the pressure of herbivory in the Caatinga is predominantly from domestic animals, which makes the understanding of their true impact on ecosystems quite intriguing. Like for other herbivores, landscapes with a certain level of grazing pressure can improve the ecosystem's functionality, since they can act as nutrient spreaders and seed dispersers via fecal pellets (van der Waal et al., 2011). They also reduce the competing of mono-dominant plant species and hence promote plant biodiversity (Tahmasebi Kohyani et al., 2008). Finally, plant diversity promoted by moderate levels of herbivory can enhance carbon fixation (Forbes et al., 2019) and prevent severe ecosystems changes due to recurrent fires (Mancilla-Leytón et al., 2013). Understanding the impact of herbivores on the functioning of dry forest ecosystems is necessary when assessing sustainability issues on those areas (Forbes et al., 2019).

5. Implications

Ninety-five percent of the goat herd of Brazil is in the Caatinga and the discussion of such associated impacts is not straightforward and must consider different managing strategies local/traditional breeders adopt (Costa et al., 2002). Goats are part of a local socio-ecological context of poverty and dependence on natural resources, and this must not be ignored (Melo, 2017). Rangelands plays crucial services to humans as they provide forage for domestic herbivores (Nori, 2007). Maintaining the productivity and biological diversity of rangelands is a key-step in land management and conservation, and must be done by integrating social and environmental policies (Illius and O'Connor, 1999). Goats are adapted to the semiarid rangelands of the Caatinga and are part of the regional culture (Melo, 2017). More research addressing the role of domestic goats in degrading the Caatinga ecosystem is still needed to better understand this complex process. Research topics should address, for example, 1) spatially explicit analyses of goat foraging in landscapes with different socio-ecological contexts; 2) long-term studies (Garnick et al., 2018), including exclusion experiments and 3) Market and supply chain of goat meat within the Caatinga domains. Our study suggests that mapping habitat use and preferences by goats is an important step to better assess and understand how these herbivores use the landscape, providing tools to evaluate potential disturbance as well as to design management strategies to attend both biodiversity conservation and the sustainable use of the Caatinga rangelands. Considering both conservation and the people's well-being would lead to win-win management practices and, hence, to a more sustainable socio-ecological ecosystem.

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CRediT authorship contribution statement

Davi Jamelli: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Visualization. **Enrico Bernard:** Conceptualization, Methodology, Resources, Writing – review & editing. **Felipe P.L. Melo:** Conceptualization, Methodology, Resources, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaridenv.2021.104532.

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