Using local ecological knowledge to access the distribution of the Endangered Caatinga howler monkey (*Alouatta ululata*)

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ABSTRACT

A lack of basic knowledge about the Endangered Caatinga howler monkey (*Alouatta ululata*) in Northeastern Brazil makes it difficult to design and implement effective conservation strategies. Traditional or Local Ecological Knowledge (LEK) has contributed to the development of conservation strategies for many species, including primates. Thus, we aimed to improve our understanding of the geographic range of Caatinga howler monkey, collect LEK on the species, and understand how people interact with these howlers to help future conservation efforts. We conducted semi-structured interviews with members of local communities in two regions within the currently known distribution range of the species. We constructed maps based on the information currently available in the literature and on the data obtained through our interviews. Through LEK, we identified new areas of occurrence for Caatinga howler monkeys, increasing the species' range in a Northeastern direction in the state of Ceará. Gross domestic product (GDP) and population size were inversely related to the amount of knowledge that the local human population showed about the Caatinga howler monkeys, indicating that local wealth influences in the amount of LEK. Despite a positive attitude towards Caatinga howler monkeys in both regions (i.e. howlers were not killed in retaliation for crop-feeding and locals found their vocalizations pleasant), we identified poaching and medicinal uses of the species. Our data demonstrated that the range of Caatinga howler monkeys was larger than previously recorded and also that local knowledge was crucial for triangulating the species location.

Keywords: Neotropical Primates; Ethnoprimatology; Occurrence areas; Local Community; Socioeconomic Profile; Conservation.

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INTRODUCTION

The Caatinga howler monkey (*Alouatta ululata*) is a poorly known species endemic to Northeastern Brazil (Ferreira et al. 2016; Oliveira et al. 2007; Oliveira and Kierulff 2008). As with many primate species, Caatinga howler monkey populations are in decline due to hunting pressure, fragmentation and habitat loss (Ferreira et al. 2016; Oliveira et al. 2007; Oliveira and Kierulff 2008). In fact, based on data from interviews conducted with the local human population, Pinto and Roberto (2011) suggested that the main threats for Caatinga howler monkeys in Northern Piauí are hunting pressure (51.8% of interviewees), followed by deforestation (25.9%) and forest fires (11.1%). Nevertheless, there is very limited information about the ecology, behavior, number of Caatinga howler monkey populations and their relation with local human communities (Oliveira and Kierulff 2008). This lack of information makes it difficult to design and implement effective plans for the conservation of the species. According to the Brazilian list of threatened fauna (Ferreira et al. 2016) and IUCN (Oliveira and Kierulff 2008), the Caatinga howler monkey is categorized as an Endangered species. Together with five other species, the Caatinga howler monkey now features in the second phase of the Brazilian Plan of Action for the Conservation of Primates in the Northeast (PANPriNE) of the country (Portaria nº 242, de 26 de março de 2018). Caatinga howler monkeys are characterized by their vocalizations. They are a folivore-frugivore species and have a diet composed of at least 23 plant species (Pinto and Roberto 2011). The species' home range varies between 13.85 ha and 35.62 ha (depending on the estimation method and type of vegetation) and groups

are small, ranging in size from 8-10 individuals (Pinto and Roberto 2011). The taxonomic status of the Caatinga howler monkey is still under debate, with some suggesting that it is a subspecies of red-handed-howler monkeys, *Alouatta belzebul* (see Gregorin 2006; Viana et al. 2015). Here we follow Gregorin (2006) and consider Caatinga howler monkeys as a separate species from red-handed-howler monkeys. Caatinga howler monkeys occur in one of the poorest regions of Brazil (Leal et al. 2005; Veiga et al. 2004), and they are distributed across three states: Maranhão (north), Piauí (north and north central) and Ceará (northwest) (Ferreira et al. 2016; Oliveira et al. 2007; Oliveira and Kierulff 2008).

The increase in human populations and rapid expansion of urban areas have led to widespread primate population declines, mostly due to habitat fragmentation and hunting pressure (Fuentes and Hockings 2010; Stafford et al. 2016; Torres Junior et al. 2016). To minimize the negative effects of interactions between human and non-human primates, it is essential to understand the core nature of such interactions (Fuentes 2006). Humans and non-human primates have interacted in many ways for a long time, with positive and negative implications for both parties, and these interactions vary historically and culturally (Ceballos-Mago and Chivers 2010; Dore et al. 2017; Fuentes 2006; Fuentes and Hockings 2010; Stafford et al. 2016). Understanding such interactions is an important tool for primate conservation due to the influence of human development on primate habitats (Fuentes and Hockings 2010). Thus, understanding the context and details of relationships between humans and other primates can help significantly in the attempt to find solutions for the conservation of primates (Estrada 2006; Fuentes et al.

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2016). Ethnoprimatology analyzes these relationships between humans and non-human primates (Dore et al. 2017; Fuentes and Hockings 2010; Hill and Webber 2010; Riley 2006; Stafford et al. 2016).

Investigations on Traditional or Local Ecological Knowledge (LEK) helps to further increase the understanding of the relationship between primates, non-human primates and their sometimes shared environment (Torres Junior et al. 2016). LEK basically describes local human communities' accumulated knowledge of their natural environment (Toledo 2002). It is based on their extensive contact with nature, and is passed on and modified across generations through cultural transmission (Gadgil et al. 1993; Silvano et al. 2008; Torres Junior et al. 2016). Studies of LEK have provided new and important information for science (Alves et al. 2016; Ceballos-Mago and Chivers 2010; Davis and Wagner 2003; Gilchrist et al. 2005; Silvano et al. 2008; Torres Junior et al. 2016), contributing to the development of management and conservation strategies in many fields (Gilchrist et al. 2005; Gray et al. 2017; Haenn et al. 2014; Olsson and Folke 2001; Pandey 2003; Riedlinger and Berkes 2001). For instance, Gray et al. (2017) used LEK from fishing communities to monitor the hunting of rare fish species. Gilchrist et al. (2005) found LEK to be a useful source of information to help with management and conservation strategies for three out of four marine birds. Nevertheless, they also suggest that the use of LEK should be applied together with scientific studies to reliably implement management decisions. LEK can help in obtaining new information on the presence or qualitative abundance of species (Alves et al. 2016; Anadón et al. 2009; Anadón et al. 2010; Moller et al. 2004; Starr et al. 2011; Vaughan et al. 2003). This

approach can provide high-quality and low-cost information (Anadón et al. 2010) to researchers about species' ranges. Data on the occurrence of poorly known species are essential to establish conservation planning at a regional scale (Rondinini et al. 2006) and habitat extent is one of the most important pieces of information when assessing the conservation status of species (Burgman and Fox 2003; Lunney et al. 1995). Several species on the IUCN red list have limited or no data at all on their distribution and thus, LEK could be used as a potential tool to obtain such information (Castellanos-Galindo et al. 2011). McPherson et al. (2016), for example, used local knowledge to obtain information on the distribution and habitat needs of *Tragelaphus spekii gratus*. Newton et al. (2008) used semi-structured interviews with hunters and museum reports to produce the first distribution maps for the pangolins *Manis pentadactyla* and *M. javanica* in Vietnam. Moreover, local knowledge has already been used as a tool for testing the validity of predictive models aiming to assess mammalian spatial distribution and to identify local species richness patterns (López-Arévalo et al. 2011).

LEK and cultural traditions are increasingly threatened by changes in land use, urbanization and modernization of public services such as education systems and globalization processes (Pilgrim et al. 2008; Gomez-Baggethun et al. 2013). The degradation of LEK can have negative implications for the status of the biodiversity (Tang and Gavin 2016), where low levels are decisive for the conservation of biodiversity, mainly in regions where hunting pressure is high (Petry and Smith 2004; Pilgrim et al. 2008). Gross Domestic Product (GDP), charcoal production and human population size can indicate community wealth and

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urbanization levels in rural and indigenous areas and may help to estimate patterns of LEK (Czech and Pister 2005; Cullen-Unsworth et al. 2007; Cullen et al. 2007; Pilgrim et al. 2008; Aswani et al. 2018). Studies have shown, for instance, that there is an inverse relationship between local marine ecological knowledge and wealth (Cullen et al. 2007). Furthermore, industrialized communities have less knowledge of species names and uses than nature resource-dependent communities (Pilgrim et al. 2008). Knowledge levels can differ between individuals of different ages and tend to be concentrated in a small group of people (Pilgrim et al. 2008; Aswani et al. 2018). This suggests that knowledge of species names, for instance, becomes concentrated in fewer people who have personal interests (e.g., environmental students) in wealthier industrialized communities. In contrast, knowledge of species names and uses in resource-dependent communities are likely to be shared among all community members engaged in the daily tasks that meet their family's needs (Pilgrim et al. 2008).

This study focused on two regions within the known distribution area of the Caatinga howler monkeys in the Caatinga Bioma in Northeastern Brazil to address the following questions: 1) Could LEK provide new reports of the presence of Caatinga monkeys in unknown areas? 2) Do social (i.e. population size), economic (i.e. GDP and Charcoal production) and landscape characteristics influence both LEK and the relation between local communities and the Caatinga howler monkeys? In this study, we intended to improve our understanding of the geographic range of the Caatinga howler monkey, obtain LEK of the species and understand how people interact with it to help future conservation efforts.

MATERIAL AND METHODS

Study area

We carried out the study in two regions with different geography, environments and cultures. Both sites are in the Caatinga biome and have a semi-arid climate (Alvares et al. 2013; Moro et al. 2016). We selected two specific regions (i.e. Ceará and Piauí regions detailed below) within the range of the currently known distribution area for Caatinga howler monkeys. Primate species inhabiting both areas are: *Alouatta ululata*, *Callithrix jacchus* (common marmoset) and *Sapajus libidinosus* (bearded capuchin) (Bicca-Marques et al. 2006; Oliveira and Kierulff 2008). The spoken language in both areas is Portuguese with little variation in local accent. The investigated regions were:

1) Ceará Region is in the Northwestern area of the state of Ceará, Brazil, and includes several towns in the municipalities of Santana do Acaraú and Ibiapaba Mountain (Figure 1). Much of Ceará region is in two protected areas: Serra da Ibiapaba Environmental Protection Area (1,628,424.61 ha) and Serra da Meruoca Environmental Protection Area (29,361.27 ha, Drummond et al. 2009; MMA 2016). The area is composed of humid forest enclaves, with high altitudes (750 – 900 m), steep slopes, high rainfall (the annual mean above 1,100 mm), low temperatures (24 - 26ºC) and good conditions for agriculture (Souza and Oliveira 2006; Tabarelli and Santos 2004). Livestock raising is an uncommon activity in the humid enclaves but local people raise animals in captivity (Souza and Oliveira 2006). Agriculture is the main activity in these regions, horticulture, coffee, rice and sugarcane plantations (Souza and Oliveira 2006). The steep nature of the area limits the sugarcane industry (Souza and

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Oliveira 2006). Tourism is an important activity in the area (e.g., hiking at Ibiapaba Mountain). The local community is mainly composed of cultivators and rural workers.

2) Piauí Region is in the North-central area of the state of Piauí, and includes several towns in the municipalities of Castelo do Piauí and Valença do Piauí (Figure 1). Piauí region has one protected area (Marvão Private Natural Heritage Reserve) with 5,096.86ha. In contrast to Ceará region, most of Piauí region is unprotected (Drummond et al. 2009; MMA 2016). The area has high annual mean temperatures (28-30ºC), low humidity (60-65%), high evapotranspiration (1400-1550 mm), high evaporation (2000-2500 mm), and low and irregular precipitation (annual mean 800-1000 mm) (Andrade Júnior et al. 2004; Gomes et al. 2005). The region has large areas of semideciduous trees and dry forest areas and some parts have typical Cerrado forest features (pers. obs.). Livestock farming is the main activity in the area, focused mainly on goats and cattle. Farmers ("vaqueiros") raise animals free-range in the Caatinga forest. Agriculture is also present in the region, but on a smaller scale when compared to livestock.
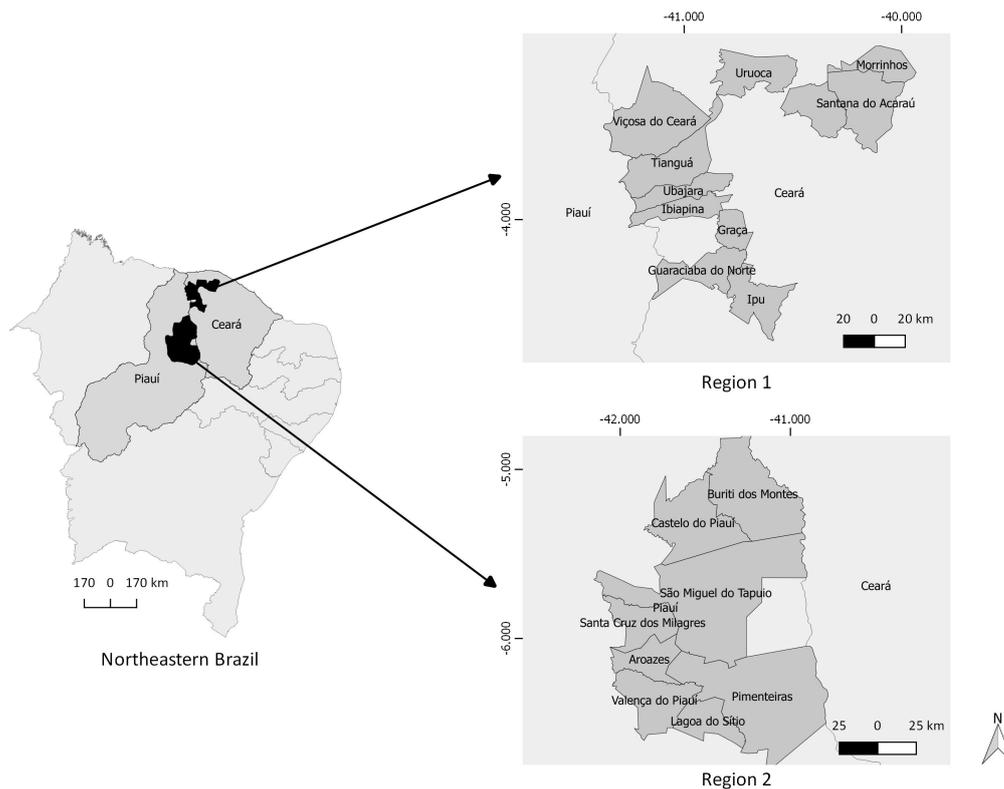

Figure 1. Areas surveyed for the presence of the species and LEK in Ceará and Piauí regions in the states of Ceará and Piauí, respectively, in North-eastern Brazil. We conducted interviews in all the named municipalities in August 2016 in Ceará region and in January 2017 in Piauí region.

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Survey Methods

First, we conducted two 10-day expeditions to perform semi-structured interviews (Huntington 2000). RRF conducted the interviews in Portuguese, often accompanied by a field assistant, in August 2016 in the Ceará Region and in January 2017 in Piauí Region. A third 10-day field expedition was conducted in May 2017 to confirm the presence of the species in the areas where new presence reports were obtained during the first two expeditions. For logistical reasons, we were limited to 10-day expeditions.

We conducted 50 interviews in the Ceará Region. Between the municipalities of Santana do Acaraú and Ibiapaba Moutain in the state of Ceará, we drove approximately 650 km, crossing 11 municipalities (Figure 1). In the Piauí region, we conducted 62 interviews. Between the municipalities of Castelo do Piauí and Valença do Piauí, in the state of Piauí, we drove approximately 700 km crossing eight municipalities (Figure 1).

Each interview lasted approximately 20 minutes however, when we met people who knew about the Caatinga howler monkeys, we spent an extra 10–20 min with them. In our interviews, we targeted local men and women who used the forest for some sort of activity (e.g., farmers, cultivators and hunters) and/or who lived close to areas with natural vegetation, and who were 18 years old or older. We approached interviewees on local roads near areas with natural vegetation where there was a potentially suitable habitat for the Caatinga howler monkeys, to avoid concentrating the interviews in a specific place. Thus, we pre-established a minimum number of 50 interviews per region due to the expected low number of people on the road in such

condition. Here we used the terms "local community" and "local people" as synonyms, when referring to the people living in small villages (i.e. clusters of houses) in the rural area of the visited counties. All interviewees were long-term residents (i.e. they had been living in the area since childhood or were born in the area).

We started interviews as an informal conversation with the interviewees, seeking to gain their trust first, then inquiring about their knowledge of local wildlife. We always asked for consent before beginning an interview. We explained that participation in our study was voluntary and that the interviewee could withdraw at any time if they wished to do so. We explained that all interviews were anonymous and they would not be at any risk in answering the questions. We also explained the benefits of the study for the conservation of animals in general and only proceeded with the interview if the person agreed and was comfortable with the situation. At the end of the interviews we always informed the interviewees that we were carrying out research in the region to specifically learn about the distribution of the Caatinga howler monkey. We avoided giving this information prior to the beginning of the interview so that we did not influence the responses of the interviewees. The present study agrees with the The Ethical Code Developed by British Sociological Association to conduct the interviews (https://www.britsoc.co.uk/media/24310/bsa_ statement_of_ethical_practice.pdf). The study was endorsed by the MSc Programme in Conservation Biology, Faculty of Sciences; Lisbon University, Portugal (Mestrado em Biologia da Conservação, Departamento de Biologia Animal, cE3c Centro de Ecologia, Evolução e Alterações Ambientais. Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal).

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We began interviews with some general questions about the mammals that can be found in the region, other than the Caatinga howler monkey, for example: collared peccaries (*Pecari tajacu*), pumas (*Puma concolor*), lowland pacas (*Cuniculus paca*)*,* capybaras (*Hydrochoerus hydrochaeris*) and deer (*Mazama* sp.). We aimed to determine how knowledgeable the interviewee was about the local fauna. After this initial approach, we asked questions about the common marmoset (*Callithrix jacchus*) and the bearded capuchin (*Sapajus libidinosus*) and finally about the Caatinga howler monkey. We asked the interviewees to describe the animal and its vocalization to confirm whether they were familiar with the species. We also asked the same questions using different wording to check whether the information provided by the respondents was consistent. Once the interviewee confirmed the presence of the Caatinga howler monkey in the region or showed that they knew of the species, we asked: (1) When was the last time you saw the Caatinga howler monkey? (2) How often do you hear the vocalization (e.g., always, seasonal or infrequent)? (3) How many animals did you see in the group? (4) Have Caatinga howler monkeys always existed in the region? (5) Have Caatinga howler monkey populations declined or increased? (6) Do people hunt the Caatinga howler monkey? (7) Do people eat Caatinga howler monkey here? (8) Where do Caatinga howler monkeys live? and (9) What do Caatinga howler monkeys eat? Some of the questions were aimed at elucidating the species biology (e.g., knowledge on vocalization and diet patterns) to help guiding future studies.

Mapping Caatinga howler monkey distribution

To compile and expand the distribution areas for Caatinga howler monkeys, we mapped the distribution of the species based on the information currently available in the literature (Bonvicino et al. 1989; Ferreira et al. 2016; Gregorin 2006; Gutiérrez and Marinho-Filho 2017; Oliveira et al. 2007; Oliveira and Kierulff 2008; Viana et al. 2015); and the new reports and records we obtained in the expeditions conducted in the present study. We used QGIS 2.8 software (QGIS Development Team 2016) to construct the maps.

Statistical Analysis

Data on Gross Domestic Product (GDP), human population size and charcoal production of the municipalities in both regions were obtained through the Brazilian Institute of Geography and Statistics. We used Mann-Whitney U tests to verify whether the two regions differed significantly in these aspects. Finally, we use descriptive statistics to provide the information obtained from the interviewees about their ecological knowledge and interaction with Caatinga howler monkeys.

RESULTS

Distribution of the Caatinga howler monkey

We obtained 17 reports of the presence of the Caatinga howler monkey in Ceará region. We obtained historical and current reports in Auiá (-3.449481°; -40.476306°), a set of enclaves which are new occurrence areas for Caatinga howler monkeys,

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increasing the species' range in a northeastern direction in Ceará State (Figure 2). We obtained 10 reports of the presence of the species in this area, and recorded the species vocalization during a further expedition in the same area in May 2017. This signifies an expansion of approximately 6,133 km^2 of the known species range (~3%). From our interviews, we also obtained seven reports on the eastern slope of Ibiapaba Mountain (Figure 2).

We obtained no reports of Caatinga howler monkeys in the enclaves to the east of Aiuá and saw no evidence of a suitable habitat for Caatinga howler monkeys in the area. However, it is possible that there are more undiscovered Caatinga howler monkey populations further south of Piauí, overlapping with the distribution of the black-and-gold howler monkey (*Alouatta caraya*). The western limit of the species' range is still uncertain due to overlapping with the distribution of the red-handed howler monkey (*Alouatta belzebul*).

We obtained 35 reports of the presence of the Caatinga howler monkey and one direct observation in Piauí region. We obtained reports of the presence of the species in all the municipalities we visited, except Buriti dos Montes (Figure 3). We observed a group of approximately eight individuals, including two infants in the Cágados area, and we heard three more groups vocalizing in the same area. We also identified four potential study sites in privately owned areas where Caatinga howler monkey groups could be monitored in the future (Figure 3).
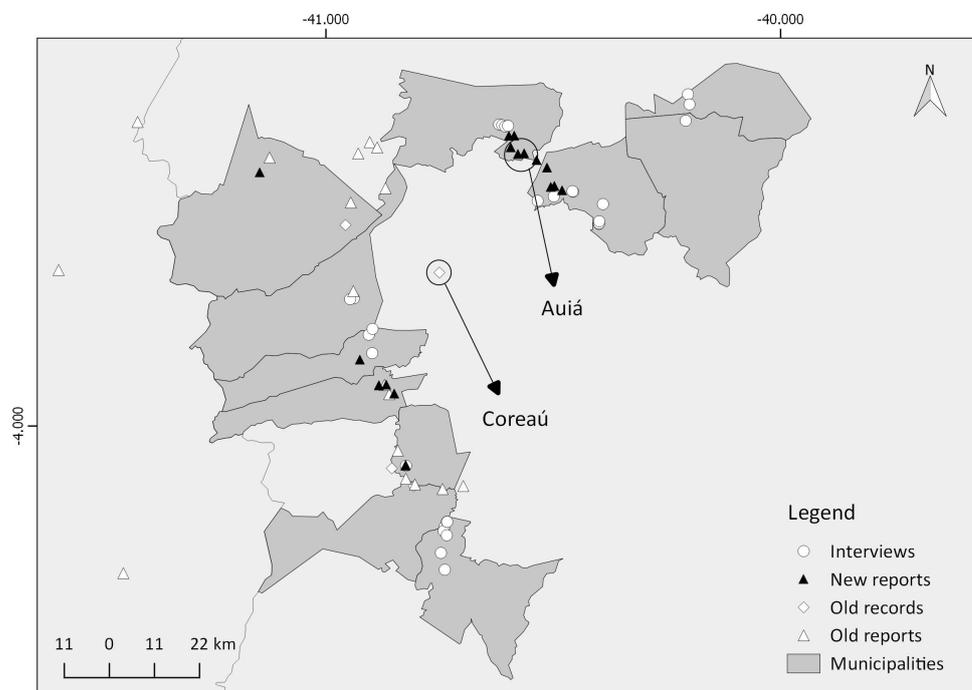

Figure 2. Localization of the municipalities surveyed in the Ceará region, state of Ceará, Northeastern Brazil, highlighting the new reports (LEK reports), previous records and previous reports of the Caatinga howler monkey presence in the region. The area was surveyed in August 2016.
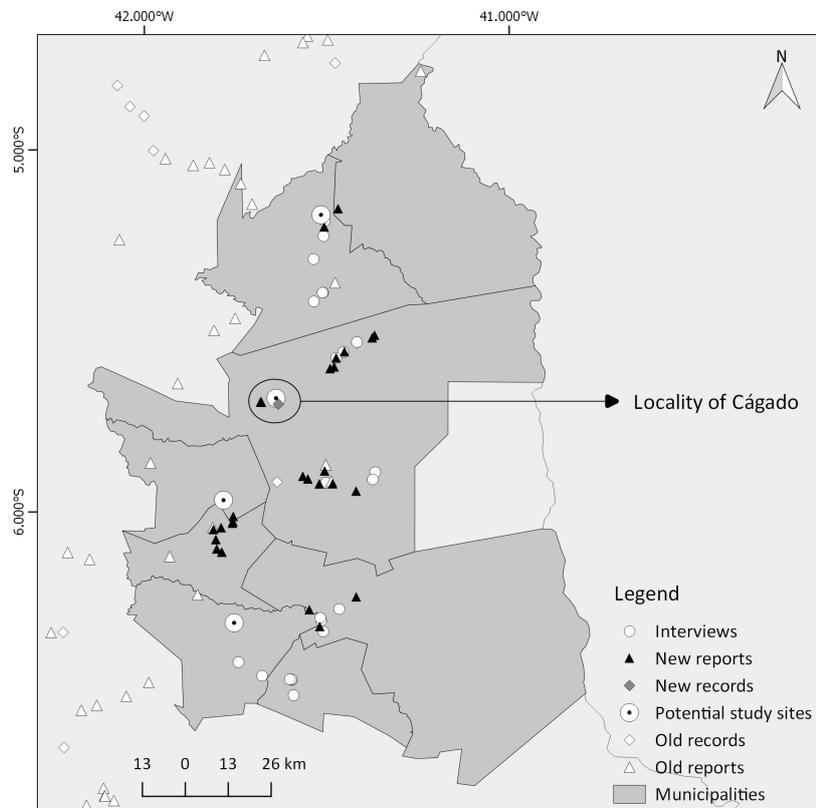
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Figure 3. Localization of the municipalities surveyed in the Piauí region, state of Piauí, Northeastern Brazil, highlighting the new reports (LEK reports), previous records and previous reports of the Caatinga howler monkey presence in the region. The area was surveyed in January 2017.

Profiles of the communities in the Ceará and Piauí region

The Ceará region had a larger resident population than the Piauí region (Mann-Whitney, U=2.849, N1= 11, N2= 8, p < 0.01). Even though The Ceará region had a greater total GDP (sum of the GDP of each municipality in 2014) (74,164) than the Piauí region (51,311), there was no significant difference between the GDP of Ceará and Piauí regions when we considered the municipalities separately (Mann-Whitney, U=1.073, N1= 11, N2= 8, p = 0.32). In both regions, the GDP increased every year between 2010 and 2014. Overall, charcoal production was five times higher in the Piauí region than in the Ceará region in 2014 (3,132 t and 480 t, respectively) and 2015 (2,773 t and 500 t, respectively), but we found no significant differences for the year 2014 (Mann-Whitney, U= 0.908, N1= 11, N2= 8, p = 0.36) or in 2015 (Mann-Whitney, U= 0.578, N1= 11, N2= 8, p = 0.56) when we considered the municipalities separately.

In the Ceará region, 4% of interviewees were female and 96% were male. In the Piauí region, 11% of interviewees were female and 89% were male. The larger number of males in both areas could be a reflection of the method carried out to approach the interviewees (i.e. we

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approached them on local roads near areas with natural vegetation where men can be more easily found than women in both areas). In these communities, women traditionally stay at home making food and organizing the house. Men stay away from home for much of the day, working in agriculture or with livestock.

Local Ecological knowledge of the Caatinga howler monkey

We observed differences in the level of LEK according to economic (i.e. charcoal production and GDP), social (human population size) and environmental (type of vegetation and topography) characteristics of the regions.

Based on our observations and interviews, in the Ceará region, Caatinga howler monkey groups were in humid enclave areas but they were mainly restricted to areas with steep slopes. In Piauí region, Caatinga howler monkey groups inhabited flat areas with arboreal Caatinga (a mix of carrasco vegetation and Cerrado) and in canyons (valleys that hold a water source, with tall green plants). Caatinga howler monkey populations usually inhabited locations far from urban areas.

In the Ceará region, nearly half of the interviewees knew about Caatinga howler monkeys (Table 1). These people were long term residents in the area and lived very close to Caatinga howler monkey groups. In the Aiuá area and Ibiapaba Mountain, interviewees reported that Caatinga howler monkeys live in the mountains of the region, feed mostly on leaves and fruits, howl early in the morning or late in the afternoon and more often during the rainy season (period of February to June). Local people also said that they believe that Caatinga howler monkey populations have declined and that

poaching still occurs in the region (Table 1). An 80-year-old man from the Uruoca municipality reported that major droughts in previous years (i.e., 1958) were important events for the local extinction of several medium and large sized mammal populations. He explained that the lack of water and food for the region's fauna, and hunting, were responsible for these extinctions. The local community, faced with the scarcity of natural resources during the drought, used the wild animals as a source of food more frequently.

In both regions, Caatinga howler monkeys are popularly known as Guariba or Capelão. However, the proportion of people who knew about Caatinga howler monkeys was much greater in the Piauí region than in the Ceará region (Table 1). Interviewees in the Piauí region reported that: Caatinga howler monkey populations live in canyon areas and in arboreal Caatinga areas far from urban areas, feed on leaves and fruits and also on some cultivated fruits such as mango (*Mangifera indica* L.), guava (*Psidium guajava* L.), cashew (*Anacardium occidentale* L.), custard apple (*Annona squamosa* L.); They also said that the monkeys howl in the early morning or late afternoon and more frequently during the pre-rainy season (November to January), when the cashew is fruiting or on the rainy season (February to June). Local people also said that Caatinga howler monkey populations have declined and that they believe that poaching still occurs in the region. Some interviewees in the Piauí region (18%) also reported that eating Caatinga howler monkeys would be like eating other humans, suggesting they did not appreciate performing such behavior (Table 1).

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We obtained reports of the use of Caatinga howler monkeys for medicinal purposes in two areas in São Miguel do Tapuio (i.e. Cágados and Palmeira) and in one area in Valença do Piauí (i.e. Retiro). In the Cágados area, where we recorded four

Table 1. Summary of Local Ecological Knowledge (LEK) of the Caatinga howler monkeys in Regions Ceará and Piauí in the states of Ceará and Piauí in Northeastern Brazil, during August 2016 and January 2017, respectively. *Responses are not mutually exclusive, which means they can overlap one another .

Question	Given responses	Percentages of interviewees that gave each response in:	
		Ceará region	**Piauí region**
Do you know of the Caatinga howler monkeys?	Yes	44%	92%
	No	56%	8%
Where do Caatinga howler monkeys live?	Mountains	100%	0%
	Canyon areas and in arboreal Caatinga	0%	91%
	I don't know	0%	9%
When do Caatinga howler monkeys vocalize? *	Early hours of the morning or late hours of the afternoon	53%	51%
	Rainy season (i.e. February to June)	53%	15%
	Pre-rainy season (period of November to January) and the fruiting of the cashew	0%	11%
	I don't know	47%	49%
What do Caatinga howler monkeys eat? *	Leaves and fruits	41%	48%
	Cultivated fruits	0%	34%
	I don't know	59%	52%
Did Caatinga howler monkeys population decline?	Yes	47%	25%
	No	0%	0%
	I don't know	53%	75%
Does poaching occur in the area?	Yes	47%	43%
	No	53%	57%
	I don't know	0%	0%

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groups of Caatinga howler monkeys, five locals reported that Caatinga howler monkeys are often found dead during the dry season, potentially due to lack of food and/or water. They also reported that during the wettest period of the year, Caatinga howler monkeys howl at night (about until eight o'clock). Three men that lived in Cágados reported that the howler monkey bosses of social groups (i.e. the alpha or dominant male) performed most of the reproductive and protection behavior. They also reported that these type of males usually played around the group vocalizing loudly and often defecated together at the same time.

The Caatinga howler monkey vocalizations were often mentioned by the interviewees, confirming the peculiar characteristic of *Alouatta* species (i.e. production of very loud howls that can be easily identified). In both regions, the interviewees reported that they usually do not see the animals, but often listen to their vocalizations. The locals reported that during the wettest period of the year, Caatinga howler monkeys are seen and heard more frequently. Moreover, they reported that during the driest period of the year, Caatinga howler monkeys howl more infrequently. Some people, in both regions, reported that Caatinga howler monkeys' vocalizations are similar to the noise produced by the old sugar cane mill moved by animal traction. All interviewees said that Caatinga howler monkeys live in small groups (between three and eight animals) or alone. Direct observations and recording of the vocalizations of the Caatinga howler monkeys would be important to confirm such information passed on by the local community and to further investigate the communication system of the species.

Relationship between local human communities and Caatinga howler monkeys

The relationship between the local community and the study species was found to be similar in both study regions, with no conflicts between them. In general, the local people treated Caatinga howler monkeys with relative indifference, keeping a neutral or positive relationship with the animals. Even when Caatinga howler monkeys feed on fruits that are consumed by the local people (e.g., mango, cashew and guava), they do not seem to have negative perceptions of the monkeys. Nevertheless, there were reports of poaching and medicinal use of the species in three areas (i.e. Cágados, Palmeira and Retiro as reported above). Their meat is not a frequent component of people's diets, but it is regarded as a delicacy, tasty and peculiar. 33% of the local people we interviewed reported that they enjoyed the vocalizations produced by Caatinga howler monkeys and 15% believed that such vocalizations could announce or attract the rains, which was good for agriculture. In contrast, interviewees reported that Caatinga capuchin monkeys, *Sapajus libidinosus*, are involved in negative interactions with the local communities (i.e. retaliation) in both study regions, because the capuchins forage crops and orchards (63.6% of the areas we visited in Ceará region and 87.5% in Piauí region; seven municipalities in each region).

DISCUSSION

Our study extends the known range of the Caatinga howler monkey and shows that local knowledge is useful in understanding the distribution of these primates. Based on the compilation of data currently available

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and data we collected, we found that the distribution area of Caatinga howler monkeys incorporates the Ibiapaba mountain micro-region, the Coreaú micro-region and the area of Aiuá (the eastern limit of the range) in the northwestern area of the state of Ceará (Bonvicino et al. 1989; Gregorin 2006; Guedes et al. 2000; Gutiérrez and Marinho-Filho 2017; Oliveira et al. 2007; Oliveira and Kierulff 2008; Viana et al. 2015). The east slopes of the Ibiapaba Mountain (an area that is very steep with natural vegetation) house a large proportion of the Caatinga howler monkeys population in Ceará (Oliveira et al. 2007). Moreover, Oliveira et al. (2007) detected Caatinga howler monkeys in Coreaú city in Ceará state through vocalizations. This was the easternmost distribution point for the species. However, despite few reports in Ceará region, we registered Caatinga howler monkeys around Auiá (approximately 34 km east of Coreaú city). It is difficult to know if there are more Caatinga howler monkey populations in the northeastern area of its range because, like other researchers (Oliveira et al. 2007), we did not observe the species. Nevertheless, our results show an expansion of 6,133 km^2 of the known species' range. Caatinga howler monkey populations may also exist to the south of their known range or in the state of Maranhão (west of the known range). More surveys are urgently needed to understand their full distribution. Analysis of LEK in our study suggests that local people should be engaged in conservation strategies to help better understand species' geographic ranges.

We showed evidence that human population size, GDP, charcoal production, level of LEK and regional environmental characteristics may somehow effect Caatinga howler monkey distribution. For

instance, the Ceará region had a larger human population than the Piauí region. This may have affected the distribution of the Caatinga howler monkeys in Ceará region, where only areas that are difficult to access (such as hilltops and areas with steep slopes) remain as suitable environments for Caatinga howler monkeys, potentially due to deforestation for agriculture and hunting pressure in other areas. Caatinga howler monkeys may not inhabit flatter areas in the Ceará region because of the type of vegetation available (Caatinga shrub vegetation IBGE 2004), tree cover loss and hunting pressure.

Both regions have experienced an increase in GDP over the last few years, but the Ceará region had a higher overall GDP than the Piauí region. GDP is an important factor to consider when preparing conservation strategies for Caatinga howler monkeys, because increasing GDP can be a strong driver for the expansion of urban areas, resulting in further habitat loss and a potential increase in hunting pressure. Surveys have shown a correlation between an increase in GDP and biodiversity loss (Czech 2008; Mcdonald et al. 2008; Seto et al. 2012) and a negative influence on Endangered species (Asafu-Adjaye 2003; Hoffman 2004). Additional studies are urgently needed to better understand factors influencing the Caatinga howler monkey distribution. Ethnographic data, for instance, would be critical in designing and implementing conservation measures as well as guiding research priorities (Burgman and Fox 2003; Gilchrist et al. 2005; Hill 2002; Rondinini et al. 2006) in the study areas.

The Piauí region produced more charcoal than the Ceará region. The municipality of São Miguel do Tapuio has a very large area, about 5207 km^2, and is one of the largest charcoal production areas in the region. We

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recorded at least 4 groups of Caatinga howler monkeys in this municipality. Although there are large areas of natural vegetation there, most of these areas may be threatened by charcoal production. Caatinga howler monkey populations in the Piauí region depend on land owners and the local community to keep their habitat intact, since there are no protected areas in this region (MMA 2017). This highlights the importance of including the local community in the preservation of this Endangered species. North-central Piauí is an important area for the conservation of Caatinga howler monkeys because there are many populations and suitable habitats outside protected areas (Freire Filho and Palmeirim 2018 in press"). The establishment of national parks or other types of protected areas in both study regions might be beneficial. However, the creation of protected areas does not necessarily ensure wildlife protection in Brazil (e.g., Diniz and Brito 2015; Lessa et al. 2016) and monitoring of the Caatinga howler monkey habitats and populations would also be needed. Local community leaders should be involved in the construction of any protected areas to ensure sustainability and reduce conflicts that could pose risks to the local wildlife. Before the establishment of such protected areas, it is important to thoroughly understand how the boundaries of the areas affect local communities and propose alternatives to mitigate any potential impacts.

We found that the characteristics of the study regions may influence the level of LEK about our study species as well as the relationships between humans and the howler monkeys. More people knew of Caatinga howler monkeys in the Piauí region than in the Ceará region. Also, people in the Piauí region gave more detailed information

about the species. Gilchrist et al. (2005) hypothesized that Local Ecological Knowledge should decline with increasing distance from both communities and travel routes, but this hypothesis has not been explicitly tested. In the Piauí region, Caatinga howler monkeys use canyons and areas with arboreal vegetation most frequently (Oliveira et al. 2007; Oliveira and Kierulff 2008). Canyons are very important areas in the driest period of the year for the primate species that inhabit the Serra da Capivara National Park in Piauí, since these are areas where water and food resources remain available (Moura 2007).

In the Piauí region we obtained reports of the death of Caatinga howler monkeys in the driest season of the year, potentially due to the lack of food and water resources characteristic of this season. This information coincides with what an 80-year-old man reported in the municipality of Uruoca in Ceará. He stated that a great drought in 1958 was responsible for the extinction of Caatinga howler monkeys in the region. This statement coincides with periods of great drought in Ceará state (Brabo Alves et al. 2004). Wild animals are an important protein source for several local communities, especially during the seasonal drought periods, when crops become scarce and domestic animals are decimated by starvation and thirst (da Silva Neto et al. 2017). Therefore, existing human pressures are likely to threaten species' persistence in the Caatinga (de Oliveira Araújo et al. 2012) and changes in climate could worsen the situation for the Caatinga's biodiversity (de Oliveira Araújo et al. 2012). However, climatic change essentially results from man's action on ecosystems that degrade very quickly but recover very slowly and lose biodiversity (da Silva 2004). In the Caatinga, a slight variation in temperature and

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precipitation (da Silva 2004) has an important role in the spatial patterns of its species richness (de Oliveira and Diniz-Filho 2011). Therefore, the climatic changes expected for future years, resulting from both human actions and natural phenomena in the biome, will be preponderant for the preservation of Caatinga howler monkeys.

In both Regions, people reported that Caatinga howler monkeys howl more frequently during the wettest period of the year. Some people said that they believed that Caatinga howler monkeys are responsible for bringing the rains and/or announcing that there will be rain in that particular year. Howl frequency is known to vary seasonally and according to the time of the day for some howler monkey species. For instance, researchers working on other howler monkey species have found that howling occurs most frequently in the early morning (Cunha and Jalles-Filho 2007; Sekulic 1982a,b; Whitehead 1989) as appears to be the case with Caatinga howler monkeys based on what the interviewees reported. Our direct observations and our interviewees also indicated that Caatinga howler monkeys howl frequently in the late hours of the afternoon. Colombian red howler monkeys (*A. seniculus*) howl throughout the day during the rainy season, but they howl much more frequently in the early morning during the dry season, due to high temperatures during the day (Sekulic 1982a). Information on howling times and seasons may help guide future surveys of the species, increasing the chances of locating the species and optimizing researchers' time and use of funding. This information would also be important in contributing to further understanding the ecology and behavior of Caatinga howler monkeys during the driest and wettest period of the year, to determine how the species

may react to future climate changes.

Many studies examine conflicted relationships between human and non-human primates (Hill 2000; Hill and Webber 2010). These conflicts are often caused by the expansion of agriculture (Madden 2004) and sometimes by difficulties in adapting to non-human primate species (Strum 1994). Poorly understood conflicts between humans and wildlife may represent one of the main problems for the creation of effective conservation and management strategies to promote the sustainability of human-wildlife interactions (Madden and McQuinn 2014; Setchell et al. 2017). The local communities included in our study generally maintained a harmonious relationship with Caatinga howler monkeys, although people reported poaching and medicinal uses of the Caatinga howler monkeys. The locals do not see Caatinga howler monkeys as a problem, possibly because Caatinga howler monkeys do not approach houses or feed on crops, unlike the Caatinga capuchin monkeys, who feed on crops and orchards near houses and are aggressive towards farmers (Freitas et al. 2008; Liebsch and Mikich 2015; Rocha et al. 2014). People see Caatinga capuchin monkeys as pests, and often kill or mob them (Rocha 2000; Rocha et al. 2014). These negative relationships reflect those between local residents and other capuchin species in other areas (Liebsch and Mikich 2015; Rocha 2000; Rocha et al. 2014). A better understanding of the motives behind local people's reactions to the presence of the capuchin monkeys will help conservationists to promote behavioral changes in the human population, and thus, create positive conservation outcomes. Establishing conflict-mitigation strategies that target problematic wildlife behaviors, such as crop-feeding, are particularly complicated and continuing research to

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understand these complex interactions may guide effective land-use plans (Hockings and Sousa 2013; Wittmer et al. 2006; Woodroffe et al. 2005).

Despite the overall peaceful relationship between Caatinga howler monkeys and the local human population, the report of the medicinal use of Caatinga howler monkeys in Piauí region is a critical interaction to highlight. This has also been reported elsewhere in the Northern region of Piauí State (Pinto and Roberto 2011). The medicinal use of several groups of animals is part of Brazilian culture (Alves and Santana 2008; Costa-Neto and Marques 2000; Ferreira et al. 2012; Silva 2008; Souto et al. 2011). *Alouatta belzebul* is used as medicine for whooping cough, sore throats and asthma (Alves et al. 2010). Their hyoid bone is filled with water and used as a cup (Alves et al. 2007). Nevertheless, hunting and trafficking of endangered animals such as Caatinga howler monkeys for any reason is prohibited by Brazilian law and the penalties for such crimes include spending six months to one year in jail and the payment of R$ 500 per specimen. The fine can rise to R$ 5000 if it is an Endangered species (Art. 29 da Lei Federal 9605/98 - Lei de Crimes Ambientais). However, the authorities' oversight of hunting and trafficking of endangered animals means that locals often engage in such activities. The knowledge of these penalties may have influenced the responses given by the locals in our interviews, with reports of hunting and illegal trafficking potentially being underestimated. Further research is needed to better understand exactly how the monkeys are used as medicine and for what purposes and the cultural significance of using Caatinga howler monkeys. We also need to understand in what circumstances locals would turn to an alternative treatment and whether a replacement treatment would be readily available and affordable. These are ethical issues to be considered.

GDP and/or the characteristics of each region influenced the relationship between primates and the local human communities in the study regions. These factors may also be responsible for the different distribution patterns of the Caatinga howler monkey in the two study regions. Conflict over land use is often associated with studies of human-nonhuman primate interactions (Fuentes 2006). However, Caatinga howler monkeys are part of a genus of Neotropical primates that tolerates a certain degree of anthropogenic disturbance (Bicca-Marques 2003; Crockett 1998; Horwich 1998). In some municipalities in the Piauí region, Caatinga howler monkey groups come within 10 m of local houses. Nevertheless, in these municipalities, we found no evidence in our interviews and direct observations that the animals were hunted. In contrast, anthropogenic disturbances in other areas in both study regions may stimulate or facilitate poaching, with Caatinga howler monkeys being an easy target because of their calm behavior and evident vocalization. Further studies are needed to elucidate the degree of anthropogenic pressure on Caatinga howler monkeys in both regions and to understand how they interact with human-made habitats.

We hope our study can be used to generate effective management and conservation strategies to help the preservation of this poorly known and highly threatened primate species. LEK has proven to be a useful, relatively inexpensive and less time consuming tool to obtain important data on Caatinga howler monkeys. Through LEK we obtained some basic information about the ecology of this poorly known species (e.g., diet, vocalization pattern,

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social behaviors, population fluctuation and seasonality). Nevertheless, additional studies are certainly still needed to elucidate the total geographic range, behavioral ecology patterns and natural history of the species. Such information would be better acquired by direct observations of the animals in systematic and long-term studies. Despite the harmonious relationship between locals and Caatinga howler monkeys, the use of environmental education as a tool for raising conservation awareness will be essential for the survival of this Endangered primate. Such education environmental approaches should focus on creating awareness to reduce hunting and deforestation of the Caatinga howler monkey habitat.

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