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Abstract

The puma (*Puma concolor*) has the largest distribution of any mammal in the Americas, but has disappeared from large areas of its former range. Half of the puma's current distribution lies within Brazil where it is listed as Vulnerable. One major threat to the puma is human-induced mortality due to depredation on livestock. Searching clusters of positions from GPS-collared carnivores is a useful method to investigate kill-rate on wild prey as well as livestock depredation. The goal of this study was to investigate parameters that could make cluster searches of puma more effective in the Caatinga biome in Brazil, and to preliminarily assess the proportion of livestock among prey. A female puma was fitted with a satellite GPS-collar in a mountainous area in Bahia, Brazil. 40 clusters from 17 consecutive puma days were visited. Eight prey items were found in these clusters. Five were domestic animals and three were wild prey. Domestic animals predated on were sheep (*Ovis aries*) and goat (*Capra aegagrus*) while wild prey were rock cavy (*Kerodon rupestris*), nine-banded armadillo (*Dasypus novemcinctus*) and six-banded armadillo (*Euphractus sexcinctus*). Domestic animals accounted for 93 % of body mass in carcasses found during the study period. The puma stayed for longer periods at larger prey. The amount of time it spent at a cluster was the only near-significant variable indicating that a cluster contained a kill site. Using a GPS position interval of one position every third hour would have led to all clusters with kill sites being found. Streamlining the method of cluster searches could make it useful for both puma and jaguar (*Panthera onca*) in Caatinga in the future. The study indicates that pumas kill livestock in Caatinga and that further studies are necessary in order to find suitable interventions to reduce livestock depredation.

Introduction

Background

While many cat species have historically decreased greatly in numbers due to human persecution (Nowell & Jackson 1996), the puma still populates large areas of the Americas and is considered to be the most widespread mammal species in the Western Hemisphere (Sunquist & Sunquist 2002). It can be found from southern mainland Chile in the south to Canada in the north. Its historical distribution included every major habitat type on the continent up to the boreal forests of the north (Nowell & Jackson 1996). While still widespread, it has been extirpated from the eastern half of the United States and also from areas in South America (Nowell & Jackson 1996; Nielsen et al. 2015).

Large felids are threatened worldwide by conflicts with animal owners. The cats kill or threaten to kill livestock and other domestic animals, and are often killed as an effect of this (Guggisberg 1975; Rabinowitz 1986; Nowell & Jackson 1996; Mazzolli et al. 2001; McCarthy & Chapron 2003; Verdade & Campos 2004; Palmeira et al. 2008; Alves et al. 2009; Azevedo et al. 2013; Johansson et al. 2015). Mitigating this conflict is of great importance to cat and carnivore conservation (Nowell & Jackson 1996; Linnell et al. 1999).

Pumas in Brazil

Brazil is the largest country in South America with an area of 8,515,770 km² and 206 million people (Central Intelligence Agency 2017). Half of the puma's current distribution lies within Brazil (Mazzolli 2000) and it occurs in all biomes in the country (Azevedo et al. 2013). Brazil has an estimated puma population of between 34,900 and 328,800 individuals and is considered Vulnerable (VU; Azevedo et al. 2013). It is internationally listed as Least Concern (LC) with a decreasing population (Nielsen et al. 2015). Some current threats to pumas in Brazil include habitat fragmentation and degradation due to agriculture, mining and logging as well as illegal hunting and culling due to depredation on domestic animals (Azevedo et al. 2013).

The puma is protected from hunting throughout most of its range in the Americas, including Brazil (Nowell & Jackson 1996). Hunting of wildlife is prohibited in Brazil since 1967 (Verdade & Campos 2004) except for a few selected groups of indigenous people, for animals considered pests to agriculture and for selected species in the state of Rio Grande do Sul (Clayton 2011; Bruha 2014; C. B. Campos pers. comm.).

The puma is a generalist predator (Nowell & Jackson 1996) with a diet ranging from insects, birds, mice and large rodents (*Agouti paca*, *Dasyprocta punctate* & *Hydrochoerus hydrochaeris*) to porcupine (Hystricomorpha suborder), pronghorn (*Antilocapra americana*), donkey (*Equus africanus*), wapiti (*Cervus canadensis*), white-tailed deer (*Odocoileus virginianus),* brocket deer (*Mazama* sp.), bighorn sheep (*Ovis canadensis*) and moose (*Alces alces*) varyingly across the continent (Guggisberg 1975; Anderson & Lindzey 2003; Novack et al. 2005; Cassaigne et al. 2016), with small and medium sized prey being more common in the tropics (Nowell & Jackson 1996). Scavenging behavior is uncommon in the puma (F. Lindzey 1993, cited in Nowell & Jackson 1996; Cassaigne et al. 2016). Depredation on livestock such as sheep, goat and cattle is common (Mazzolli et al. 2001; Palmeira et al. 2008; Rosas-Rosas et al. 2008; Palmeira et al. 2015).

Puma ecology has been studied using GPS and VHF collars in several biomes in Brazil (Mazzolli 2000) but not in the Caatinga (C. B. Campos pers. comm.) – a biome in which the puma is widely distributed but considered Endangered (EN; Azevedo et al. 2013). Caatinga has only received very little scientific research in general compared to other biomes in the country (Leal et al. 2005; Santos et al. 2011).

Poaching of wildlife, including the puma's potential prey, is common in Caatinga. Poaching is done via shooting and trapping, the latter both for meat, other products and for live animals (Alves et al. 2009).

Wolff (2001) conducted a study of puma diet in a national park in Caatinga using scat analysis. The study showed a diet of armadillo (*Dasypus novemcinctus* & *Dasypus* sp.), southern tamandua (*Tamandua tetradactyla*), black-rumped agouti (*Dasyprocta prymnolopha*), collared peccary (*Pecari tajacu*), lizard (Lacertilia suborder), gray brocket (*Mazama gouazoubira*), snake (Serpentes subfamily), Peters' lava lizard (*Tropidurus hispidus*) and striped hog-nosed skunk (*Conepatus semistriatus*).

While scat analysis can be a useful method for investigating prey selection of carnivores, it does not provide information on kill rate, amount of prey consumed or any knowledge regarding where and how the prey was killed. Countries with warmer climates also cannot use the method of snow tracking in order to find prey (Haglund 1966; Odden et al. 2006).

Another way of investigating prey selection of large carnivores is by visiting cluster sites by GPS- or radio-collared individuals. This method involves finding locations where the carnivores have spent a certain amount of time, resulting in clusters of positions from the collars.

A cluster site could indicate that the animal has been feeding at the site and it is possible to search these sites for prey remains after the animal has left (Anderson & Lindzey 2003; Sand et al. 2005; Cavalcanti & Gese 2010; Rauset et al. 2012). Cluster visits are, however, expensive and time-consuming and GPS-collars have limited battery capacity and thus the number of positions possible to retrieve from the GPS collars needs to be optimized.

Therefore, I have conducted a study to: 1) investigate the interval of GPS positions needed to obtain a given level of accuracy in finding prey remains in clusters; 2) assess other parameters that may assist in defining clusters to be visited; and 3) preliminarily assess proportion of livestock among prey of puma in Caatinga.

Figure 1. The red point marks the location of the study area. Map source: CIA World Factbook 2018.

Methods

Study area

The study has been conducted in the Caatinga biome in the northern parts of Bahia state, Brazil. Caatinga is a seasonal dry tropical forest and one of six terrestrial biomes in Brazil. It encompasses 844,453 km² in north-eastern Brazil across the states of Piauí, Ceará, Rio Grande do Norte, Paraíba, Pernambuco, Alagoas, Sergipe, Bahia and parts of Minas Gerais (Instituto Brasileiro de Geografia e Estatística 2004).

Caatinga is characterized by high inter-annual variability in rainfall with periods of severe drought (C. B. Campos pers. comm.) and the vegetation is characterized by shrubs, low trees and thorny plants. The biome receives between 240 and 1,500 millimeters of rainfall annually (Leal et al. 2005). The area has two distinct seasons: a rainy season that ranges from January until May, normally for 2-4 months, and a dry season for the rest of the year (Santos et al. 2014; Pinheiro et al. 2016). Due to the arid nature of the Caatinga, it sometimes happens that there is no rainfall even in the rainy season (Santos et al. 2014).

Caatinga is one of the most populated semi-arid regions of the world. About 15 % (more than 25 million) of the Brazilian human population lives within Caatinga (Santos et al. 2004; Leal et al. 2005; Alves et al. 2009). The rural population is extremely poor (Leal et al. 2005; Alves et al. 2009). It is common for people on the countryside to keep livestock in the form of sheep, goats, cattle, pigs and poultry. The sheep, goats and cattle are normally free-ranging. Poultry and pigs are often kept inside of or near villages. Other common domestic animals are dogs (*Canis lupus familiaris*) and cats (*Felis catus*; C. B. Campos pers. comm.).

Leal et al. (2005) reports that 6.4 % of Caatinga is protected in the form of federal, state and private reserves, and less than 1 % of the biome is strictly protected in the form of national parks. 27.5 % of the biome has been transformed into pasture, agricultural land or other intensive forms of land use.

The area in which the study was conducted is a complex of mountains of around 8,000 km² in size and which has the largest continuum of Caatinga vegetation in the country (Morato 2010; C. B. Campos pers. comm.). The area is located south-west of Juazeiro and south and east of the Sobradinho Reservoir in the state of Bahia (Figure 1). The area is dry and only a few natural sources of water exist within the study area during the dry season. The area is sparsely populated. Several villages exist on the outskirts of the mountains but only a few settlements can be found inside the mountain range. There are several anti-predator pens inside villages in the study area[1] and part of these villages' sheep and goats are herded into these pens at night (C. B. Campos pers. comm.).

The area had for a long time been suggested to become a national park (Bragança 2017; Barros 2018; C. B. Campos pers. comm.) and in April 2018, after field work for this study had concluded, Boqueirão da Onça National Park, covering 3,476 km² (Presidência da República 2018a), and Boqueirão da Onça Environmental Protected Area, covering 5,057 km² (Presidência da República 2018b), were created.

Besides puma, the area also hosts a jaguar population. The jaguar is critically endangered in the biome (Morato et al. 2013) and the study area is considered a priority jaguar conservation area (Morato et al. 2014). Other carnivores known to exist in the study area include ocelot (*Leopardus pardalis*), jaguarundi (*Puma yagouaroundi*), oncilla (*Leopardus tigrinus*) tayra (*Eira barbara*), South American coati (*Nasua nasua*), striped hog-nosed skunk (*Conepatus semistriatus*), lesser grison (*Galictis cuja*), crab-eating raccoon (*Procyon cancrivorus*) and crab-eating fox (*Cerdocyon thous*; Campos et al. unpubl. data).

Potential wild prey for puma in the area includes nine-banded armadillo, six-banded armadillo, gray brocket (*Mazama gouazoubira*), collared peccary (*Pecari tajacu*), Brazilian guinea pig (*Cavia aperea*), giant anteater (*Myrmecophaga tridactyla*), lesser anteater (*Tamandua tetradactyla*), common marmoset monkey (*Callithrix jacchus*), black-and-gold howler monkey (*Alouatta caraya*), robust capuchin monkey (*Sapajus* sp.), large American opossums (*Didelphis* sp.), capybara (*Hydrochoerus hydrochaeris*), agouti (*Dasyprocta* sp.) and rock cavy (Campos et al. unpubl. data).

Collaring

Beginning in October 2016, a team from Programa Amigos da Onça[2] set up flexible snares with VHF-based trap transmitters in the study area, with the purpose of collaring puma and jaguar. The team used a method similar to that employed by Johansson (2017) on snow leopards (*Panthera uncia*). The VHF signals of the trap transmitters were monitored every hour at dusk, night and dawn, and physical visits were conducted at all snares in morning hours. A wildlife veterinarian was always at standby in the field camp should an animal trigger any of the traps.

After three capturing campaigns of between 21 and 43 days each, a female puma sprung a snare and was tran-

[1] The anti-predator pens were built by Programa Amigos da Onça as part of a project with the goal of reducing sheep and goat depredation and adjoining conflicts between humans, jaguars and pumas in the region. http://procarnivoros.org.br/index.php/projetos/programa-amigos-da-onca-grandes-predadores-e-sociobiodiversidade-na-caatinga/

[2] A study about jaguar and puma ecology is conducted by Programa Amigos da Onça in the Boqueirão da Onça region. http://procarnivoros.org.br/index.php/projetos/programa-amigos-da-onca-grandes-predadores-e-sociobiodiversidade-na-caatinga/

Table 1. Data from the eight kill sites found.

Prey species	Prey weight (kg)	Weight gone (%)	Puma kill	Time (h)	Returned	Entered cluster	Distance to kill (m)	Shade (%)
Domestic goat	40	81 %	Probable	15:00	1	Day	4.9	15
Domestic sheep	15	93 %	Probable	05:00	1	Night	4.9	40
Domestic goat	30	93 %	Probable	18:59	0	Day	16.3	50
Domestic sheep	10	95 %	Probable	18:30	1	Day	8.4	40
Rock cavy	1	100 %	Probable	05:29	0	Day	8	50
Nine-banded armadillo	4	88 %	Probable	07:29	0	Day	33.4	45
Six-banded armadillo	3	83 %	Definite	13:30	0	Day (dawn)	49.8	80
Domestic goat	8	88 %	Probable	10:00	0	Night	4.6	25

quilized and fitted with a Lotek G5C 375B GPS-collar on 28 March 2017. The puma weighed 30 kg at time of capture. Her age was estimated to be six years and she was not lactating (C. B. Campos pers. comm.).

The GPS-collar was programmed to take one position every hour during the study period, for a total of 24 positions per day, except for a trial period of 10 days in which it was set to an interval of one position every 30 minutes. The collar transmitted coordinates via satellite to a computer once per day. The GPS-collar had a 98 % GPS fix ratio (629 of 642 possible positions) during the study. No compensation was made for lost positions.

Cluster visits

Cluster sites were visited in order to search for remains of prey from the puma. A cluster is a gathering of GPS-positions in a small geographical area within a limited span of time, indicating that the puma might have been eating something at the site.

In this study, a cluster was defined as two consecutive GPS-positions within 100 meters of each other. This is narrower than the 200 meter per hour limit used by Sand et al. (2005) for gray wolf (*Canis lupus*) and the 100 meter per two hours used by Cavalcanti & Gese (2010) for jaguars, hypothesizing that pumas kill smaller prey and thus stay for shorter periods at clusters. A cluster center was defined by calculating an average value of all latitude and longitude positions within the cluster. All clusters were created using the one hour position interval. The trial period using a 30 minute position interval resulted in more GPS positions being inside of clusters than outside, effectively dissolving the definition of a cluster, and thus the extra positions taken with the 30 minute interval were removed from the dataset when creating the clusters.

Using this method of searching clusters, it was assumed as a working hypothesis that prey items larger than five kg would be more likely to be found within clusters. Prey items smaller than five kg could be eaten in less than an hour and the puma could move on without leaving a cluster of positions, leaving these kill sites undetected. Smaller prey items would also have a higher risk of being carried away by scavengers, and would be more difficult to detect in the field due to their smaller size. This working hypothesis is supported by Cassaigne et al. (2016) who found that cluster searches made smaller prey (<15 kg) underrepresented compared to scat analysis in puma diet, and also by Webb et al. (2008) who found that the smaller prey of gray wolf was often missed even with a 30 minute position interval for clusters. Apart from prey items, it was expected that many clusters would also be bed sites where the puma had rested (Cavalcanti & Gese 2010; Smith et al. 2014).

Field work was conducted between 30 April and 17 May 2017. Data was collected for 17 consecutive puma days, from the start of the cat entering the first cluster (21 April 2017) to the cat leaving the last cluster (8 May 2017). A total of 40 clusters were visited during the study.

Clusters were visited together with a local field guide, knowledgeable in local fauna and acquainted with the geography and trails in the area. Each cluster center was searched for carcasses in an inward to outward spiral up to a 50 meter radius from the cluster center. Carcasses were located both visually and by smell. Searching stopped once a carcass of matching age was found or when the entire area had been searched. If a carcass of matching age was found then the cluster was defined as a kill site. A GPS position was taken at the locations of carcasses found, making it possible to compare the distances between the pre-defined cluster centers and the locations of the carcasses.

Visibility varied in the clusters, with some areas being more open and easier to search, whereas others had dense undergrowth, leaving carcasses possibly hidden and more difficult to find. Due to overly dense and thorny vegetation, not all clusters could be searched according to the pre-defined 50 meter radius, so in some cases a smaller area was searched. In most of these cases, the cluster center was made up of a trail, with dense surrounding vegetation, making it unlikely, but still possible, that carcasses could have been missed.

Field notes were taken of species and age class of carcass (juvenile or adult), estimated date of death, estimated original weight of prey, proportion of prey weight gone by time of visit, percent shade within a radius of ten meters from the cluster center and other tracks found at the cluster. Prey found were considered to be definitely killed by puma if puma-sized bite marks were found on a carcass of similar age as when the puma entered the cluster. Prey were considered to be probably killed by puma if the carcass was of similar age as when the puma entered the cluster but bite marks could not be found. Carcasses that were considered older than when the puma was at the site were ignored. All clusters were also photographed in four directions from the cluster center.

An objective was set to wait for at least two days after the puma had left the cluster and until it was at a distance where there would be no risk that it could return to the site during the visit. Clusters were visited on average eight days after the puma had left the cluster (range 4-16 days).

Data analysis

ESRI ArcGIS 10.5 was used to create clusters based on the GPS-positions. It was also used to measure distance between cluster centers and 1) nearest inhabited house; 2) nearest road passable by car; and 3) nearest trail, road or open area potentially used as trail. The maps used for these purposes were those provided in the software's online library at the time of analysis (8 June 2017). Distances between pre-defined cluster centers and carcasses found were measured. The number of times the puma left and later returned to the clusters was also calculated with ArcGIS.

Home range size (Minimum Convex Polygon 100 % and Minimum Convex Polygon 95 %) was calculated with Centre for Northern Forest Ecosystem Research Home Range Extension for ESRI ArcView 3.2a. Data used for this analysis were the 629 positions recorded for the puma during the study (21 April to 8 May 2017), including the positions from the 30 minute position interval test period.

Other variables, such as number of hours the puma spent at a cluster and if it entered the cluster during hours of light (6:00-18:00) or dark (18:00-6:00) were calculated in Microsoft Excel 2010.

In order to calculate what position interval of the GPS collar that is needed to find carcasses, selective removal of position intervals was done. With this data, it is possible to calculate what position interval is required and thus optimize battery capacity of the GPS-collar as well as time use when selecting clusters to visit. Tests were done with intervals of 1 hour, 2 hours, 3 hours, 4 hours, 6 hours, 8 hours, 12 hours and 24 hours. Midnight (0:00) was always the first position time used, and positions were removed after this time. Thus, the test with a 2 hour interval kept positions from the times 0:00, 2:00, 4:00 and so on. The distance between two consecutive locations in each test was measured in ESRI ArcGIS 10.5 to make sure that they were still within 100 meters of each other. The number of remaining clusters and carcasses after each test was noted. Some clusters could have been split into two clusters, but these extra clusters were ignored and so clusters were only subtracted.

A logistic regression test was done with Statistical Discovery from SAS software JMP 14 in order to find out what variables indicated that a cluster was a kill site or not. The dependent binary variable examined was "kill site: yes/no" with other variables being hours spent at cluster, number of times the cat returned to the cluster, distance between cluster and nearest house, distance to nearest road, distance to nearest trail and if the puma arrived at the cluster at hours of light (6:00-18:00) or dark (18:00-6:00). The puma was considered to have left a cluster if one position was more than 100 meters away from the closest cluster position, and considered to have returned to a cluster if at least one new position was within 100 meters of any previous existing cluster position.

Results

Prey selection

Prey remains were found in 8 out of 40 clusters searched (Figure 2). Wild prey items found were rock cavy, six-banded armadillo and nine-banded armadillo. Domestic prey items found were domestic goat and domestic sheep. Wild prey totaled 8 kg in original biomass (range 1 to 4 kg per item) and domestic prey totaled 103 kg (range 8 to 40 kg per item). Wild prey accounted for 7 % of original biomass of carcasses and domestic prey 93 %. On average, 90 % of original prey weight was gone at time of visit (range 81 to 100 %). A large proportion of the weight lost was due to the carcasses drying in the sun as well as likely consumption by vultures and other scavengers, so not all weight lost could be expected to have been consumed by the puma (Table 1).

One prey item (a six-banded armadillo) was considered to be definitely killed by puma and the remaining seven prey items were considered to have been probably killed by puma. Most carcasses were severely degraded and dry, leaving no possibility of seeing claw marks or bite marks. They all, however, matched the date the puma was at the site as well as its foraging behavior.

The average time between kill sites was 32.9 hours (range 14.5 to 97). The puma spent on average 11.75 hours at kill sites (range 5 to 19 hours) compared to 5 hours at clusters that were non-kill sites (range 1 to 12 hours). The puma spent more time at larger prey items (Figure 3). The cat revisited three clusters once and all three of these were kill sites.

The puma entered six out of eight kill sites (three domestic and three wild prey) at bright hours (6:00 to 18:00) and the remaining two (both domestic prey) at dark hours (18:00 to 6:00). One of the eight kill sites was entered at dawn (precisely at 6:00), none at dusk (18:00).

The distance between the original cluster center and actual prey found was on average 16.3 meters (range 4.6 to 49.8 meters). Smaller prey items were generally found further from the cluster center (Table 1). One armadillo carcass of matching age was found 120 meters away from a cluster center and was thus excluded from the dataset.

Percent shade averaged 43 % at kill sites (range 15 to 80 %) and 45 % at non-kill sites (range 5 to 75 %; Table 1).

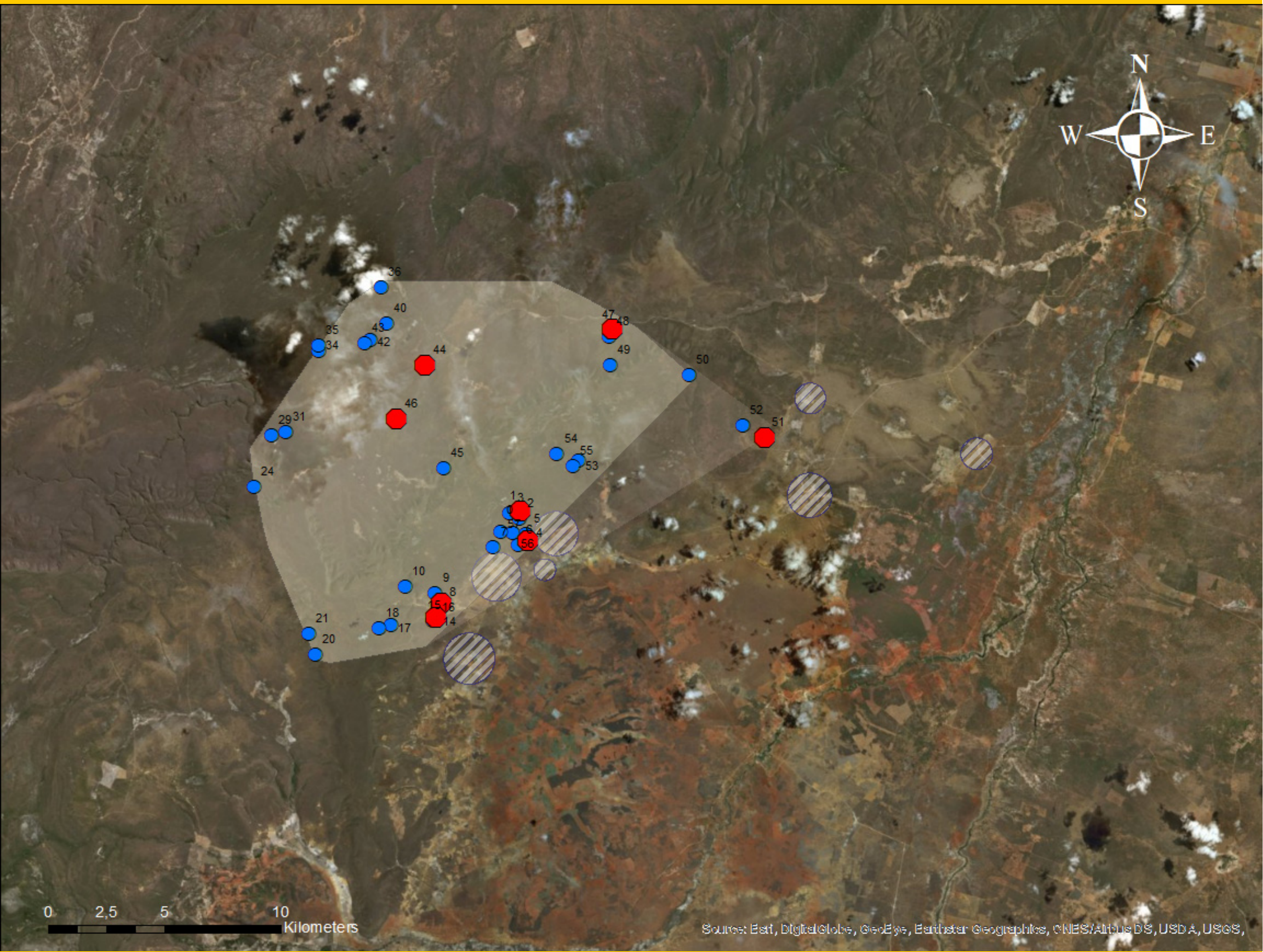
The area used by the puma during the study period (17 puma days) was 180 km² using MCP 100 % and 160 km² using MCP 95 % (Figure 2).

Position interval test

Decreasing the position interval from one position every hour (40 clusters) to one every second hour (29 clusters) and one every third hour (24 clusters) gave fewer clusters to visit, with the same amount of kill sites found. With a GPS position interval of four hours, seven out of eight prey would have been found. With a GPS position interval of 12 hours or more, no prey would have been found (Table 2).

The logistic regression analysis shows that the amount of time the puma spent at a cluster is the only factor with a near-significant value (p=0.066) indicating whether a cluster contains a kill site or not. The other variables, the cat returning to a cluster, distance to trail, distance to house, distance to road and whether the cluster was entered during time of light or dark, showed little significance (Table 3).

Figure 2. The map shows clusters visited (blue points) and carcasses found (red points). The colored polygon is the home range used during the 17 day study period, measured in MCP 95 % (dark gray) and 100 % (light gray). Round white-gray striped areas, mainly south and east, indicate villages and settlements within or near the home range.



Discussion

Cluster visits

The method of using cluster searches to find prey had not been tried on puma in Caatinga before this study. The study shows that the method could be functional in Caatinga, albeit with some caveats.

During the study, the puma moved in an area that, although mountainous, could be accessed by car and hike within a day. There are trails that are used by both the local people and domestic animals. The logistics of visiting clusters, however, did make it time-consuming and difficult. The daytime temperature was generally between 35-40 degrees Celsius and no water could be found within the area, meaning that all supplies, including camping equipment, food and water had to be carried throughout the treks. The longest trek was three continuous days in order to visit several nearby clusters at the same time.

If this puma would have had its home range 30 or more kilometers to the west, collecting data would have been considerably more difficult, with longer treks and larger backpacks. Since the area does not have cell phone reception, satellite phone would be the only way of accessing the internet in the field. Getting back to a village with internet access to download new coordinates is therefore a necessity. This adds to the complexity of using this method should the animal be far away from the nearest village.

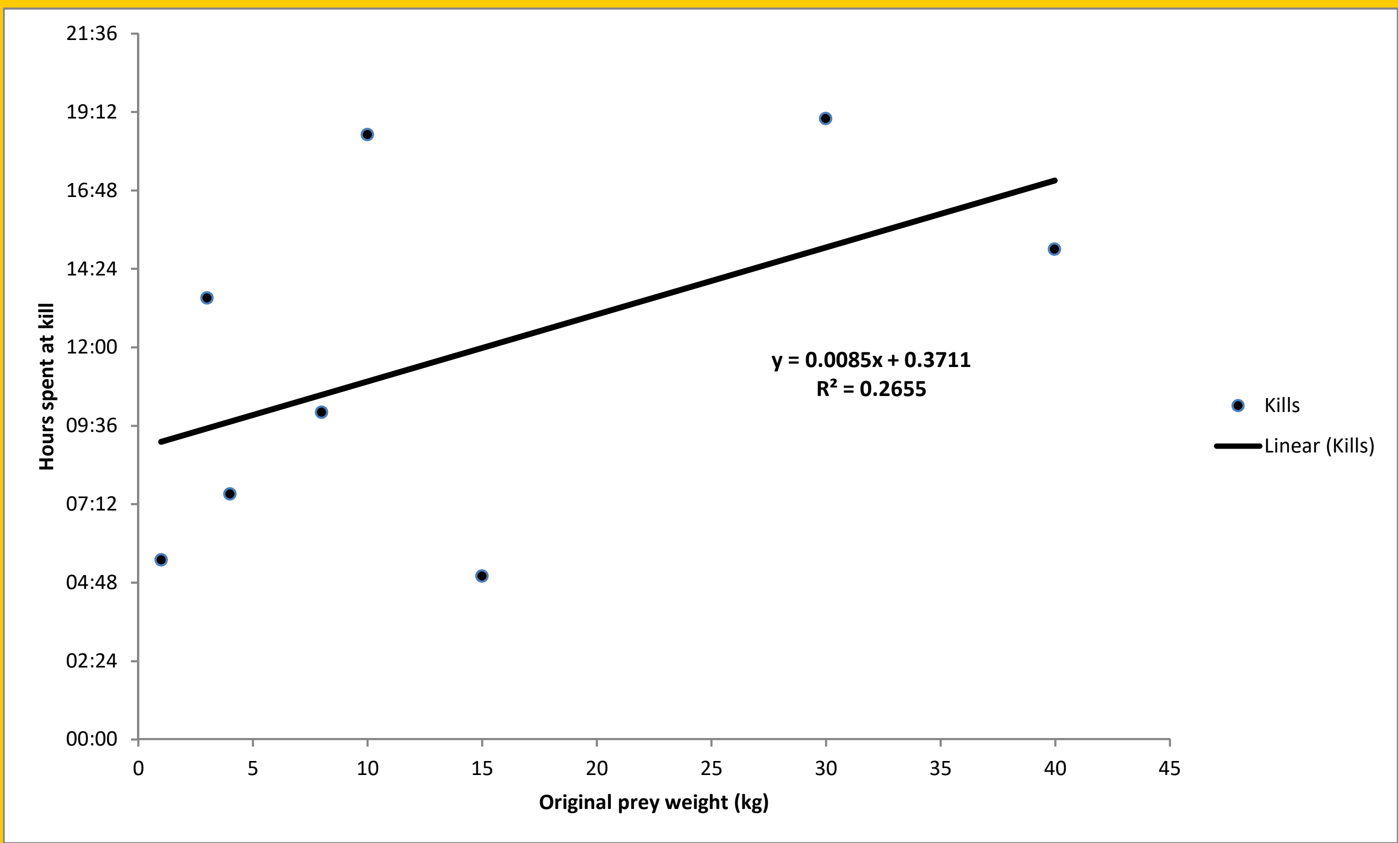
One way of having greater success in finding kill sites using cluster visits could be to use trained dogs as these could smell the remains (Odden et al. 2013). But the warm climate of Caatinga and the need to bring water and food for the dog would make trekking more difficult.

The data gathered in this study has given an important piece of knowledge into the puma's prey selection and behavior in this environment. Following the puma for 17 consecutive days resulted in eight kill sites found. Considering the density of the vegetation in some clusters, it is fully possible that some carcasses could have been left undetected. Smaller prey, especially, would have a lesser chance of being detected using this method. The risk of missing smaller prey also increases since they can be eaten on spot or be more easily carried away by scavengers. One thing that indicated that this happens is that the smaller prey items were generally found further from the cluster centers. Two out of three wild prey found were armadillos that left hard shells to be found. Other small wild prey might leave either nothing or only small tufts of hair, as in the case of the rock cavy found. This means that a study using this method would have a higher probability of detecting larger prey and the results would be biased toward this.

The results point to that visiting clusters using a GPS position interval of one position every third hour will include all kill sites, but as a precaution, an interval of two hours is recommended. This is comparable to the findings of Sand et al. (2005) on gray wolves in Scandinavia, noting that one position every hour was required to find the majority of large prey. Since the kill sites found were entered both during day and night, I recommend using an equal position interval during day and night.

The amount of time the puma spent at the clusters was the only factor showing near-significance of indicating kill sites, similar to what Webb et al. (2008) found for gray wolves in Canada, and Gese et al. (2016) for jaguars in Brazil. It is therefore advisable when selecting clusters to visit that focus should be on clusters where the carnivore has spent more time. A problem with this, however, is that the results could be further biased toward larger prey.

Figure 3. Correlation between original prey weight and hours spent at cluster, showing that the puma spent more time at larger prey items.



Livestock depredation

The results point toward that the puma in this study killed livestock. There were several villages within its home range, and free-ranging livestock was readily available, although parts of it were herded into anti-predator pens at night. Data from across Brazil have pointed to varying degrees of livestock depredation by puma. Sheep and goats appear to be the main domestic animals predated on, with reported losses up to 84 % for sheep and 78 % for goats in one study (Mazzolli et al. 2001), but also cattle, mainly calves, are predated on by puma. In one farm in central Brazil, 18.9 % of cattle mortality was due to puma and jaguar depredation, where pumas only predated on calves (Palmeira et al. 2008). Mazzolli et al. (2001) found, however, that it was more common for farmers to have cattle losses due to diseases, falls from cliffs and theft, rather than from depredation by carnivores. One study also found that livestock depredation was more common in jaguars than in pumas (Azevedo 2008). In the case of this study, the area has both jaguars and pumas and it is possible that farmers will not differentiate between livestock killed by puma and that killed by jaguar.

Table 2. Position interval test, showing how many clusters and carcasses would have been found with different position time intervals.

Position interval	Clusters	Total carcasses	Domestic	Wild
1 hour	40	8	5	3
2 hours	29	8	5	3
3 hours	24	8	5	3
4 hours	16	7	5	2
6 hours	10	5	4	1
8 hours	9	4	3	1
12 hours	0	0	0	0
24 hours	0	0	0	0

The questions of how common livestock depredation is in Caatinga and under what circumstances it happens cannot be answered in the short time span of this study. The depredation on livestock occurred at both day (60 %) and night (40 %). There are seven anti-predator pens in one village inside the puma's home range and several domestic animals that were predated upon during the study could be attributed to this village. C. B. Campos (pers. comm.) noted that depredation on sheep and goat was reduced from 23 % to 14 % in the year after construction of the anti-predator pens. Mazzolli et al. (2001) also found that farms in southern Brazil, where animals were corralled at night, had less depredation from puma.

In the time of this study, domestic animals provided the backbone of food for the puma. It is, however, important to stress that the data is from one individual in a specific area and a very limited time frame.

The puma in this study used an area of 180 km² during the 17 day study period. The full year home range is likely larger, and could thus encompass more villages and farms. For comparison on home range size, a meta-study with data from across the Americas showed that average puma home range size was 282 km² (Gonzalez-Borrajo et al. 2017).

Possible solutions and future

To further see prey selection, and especially livestock depredation, I recommend a continuation of cluster searches on puma in Caatinga. I also recommend the same method be employed on the jaguar to compare predation patterns. Seeing which species of carnivore that predates on which species of livestock and in which situations will help to improve protective measures. More individuals would have to be studied and for longer periods of time, preferably continuously throughout the year to see if there is variation in livestock depredation in different seasons, something that has been indicated in other studies (Palmeira et al. 2008). This study was conducted in the dry season where pumas and other wild prey have very limited access to water sources. It is possible that results would be very different in the rainy season, with animals likely dispersing over larger distances due to more available water sources and shade. The calving times of livestock will likely also influence results.

Building anti-predator pens for the herds of all villages will probably reduce depredation by both puma and jaguar, although this is a daunting task and selection should be done with regards to which villages that suffer the greatest losses. Constructing night pens could, in turn, reduce poaching of large carnivores. The female puma in this study was, for example, killed in February 2018 by a rancher that suspected livestock depredation.

A side effect of constructing more night pens might also be that since the food availability for carnivores, as in livestock, will be reduced, the carnivores might also decrease in numbers if food is a limiting factor. Thus, I also recommend investigating the availability of wild prey for both puma and jaguar in the area, to see if there is sufficient wild prey to sustain populations of the carnivores in the area. Seeing prey selection of wild prey would also give information as to what species to focus on when combating wildlife poaching.

Table 3. Logistic regression model with a single variable predicting the presence of a carcass at a cluster.

Variables	Regression Coefficient	Std Error	P-value
Hours at cluster	-0.72	0.39	0.066
Returned	11.08	3693	0.998
Distance to house	-0.00046	0.00046	0.313
Distance to trail	0.006	0.0057	0.295
Distance to road	-0.00033	0.00046	0.465
Dark or light	-0.57	0.99	0.567

This study has examined the method using cluster searches to study prey selection on puma in Caatinga, Brazil. A female puma was followed for 17 days resulting in eight prey found, of which domestic animals were more often encountered and which provided more food in terms of biomass for the puma. A GPS interval of one position every third hour throughout the day would have resulted in finding all prey. Clusters with prey were entered both at day and night indicating that collars should not only be programmed to retrieve positions during night. The amount of time spent at a cluster was the only near-significant indicator of a cluster being a kill site. The method of using cluster searches can be useful in Caatinga but will be biased toward finding larger prey. All in all, the method can be a useful tool for helping to understand the situation and for constructing conservation measures.

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