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Community-based monitoring of wild felid hunting in Central Amazonia

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Abstract

Hunting is a critical issue in wild felid conservation, contributing to the decline of these species worldwide. Here, we present 18 years of a community-based monitoring program, quantifying and characterizing wild felid hunting in two sustainable development reserves in Central Amazonia. We investigated how felid hunting was affected by the flood pulse and whether local human population size, habitat type, and total hunting events influenced felid hunting. We recorded 71 adult felids being killed, most of them in opportunistic events (88.7%), usually during hunting expeditions aimed at other game species. Four felid species were recorded in the hunts (*Panthera onca*, *Leopardus pardalis*, *Puma concolor*, and *Leopardus wiedii*) with jaguars accounting for almost half of all hunting events ($N = 35$). We found that more felid hunting events occurred during the flooded season, in more populated communities, and in *várzea* habitats. Most felids were hunted opportunistically, demonstrating the complexity of human-felid interactions. Stories of attacks on humans are widespread in the study area, which may strengthen an instinctive fear of felids, driving their persecution. The increase of hunting events during the flooded season seems to be related to a higher probability of encounters between humans and wild felids. High waters make fishing difficult, therefore, locals hunt more, entering deep into the forest through flooded habitats. Since jaguars have an arboreal lifestyle during the flooded season in *várzea* forests, they are easily spotted by locals and have less of a chance to escape since they are slower and more exposed when swimming, which increases the probability of being killed. It is generally acknowledged that involving local stakeholders in conservation projects is essential for their success. In our case, collaboration among researchers and community members was fundamental to access hunting information. We show that community-based monitoring empowers the local communities and facilitates data collection on sensitive topics.

Introduction

Hunting is a critical issue in the conservation of wild felids and is responsible for the decline of wild felid populations inside and outside protected areas, especially when associated with other large-scale impacts, such as habitat loss and fragmentation (Ripple *et al.*, 2014; Benítez-López *et al.*, 2019; Loveridge *et al.*, 2020). In Brazil, two conservation initiatives have been important in the mitigation of wild felid hunting – the Brazilian Fauna Protection Law of 1967 (Federal Law 5197/67) and the inclusion of these species in CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) – Appendix 1 (CITES, 1973). These actions made hunting and trade of felids illegal in Brazil and internationally and reduced commercial hunting of felids (Antunes *et al.*, 2016). Recent studies, however, have shown an increase in Chinese-driven trade of wild felids in Central and South America (Morcatty *et al.*, 2020) and hunting continues to threaten felid populations in Brazil (Macdonald & Loveridge, 2010; Paula, Desbiez, & Cavalcanti, 2011; Ramalho, 2012).

Wild felids are also killed in retaliation to livestock depredation (Jędrzejewski *et al.*, 2017; Zarco-González *et al.*, 2018), and because of social, cultural, and psychological motivations (Dickman, Marchini, & Manfredo, 2013). A variety of factors have been shown to predict the intention to kill wild felids, such as social group identity and religion (Marchini & Macdonald, 2012; Dickman *et al.*, 2014), as well as perceived threat to human safety and fear (Knox *et al.*, 2019).

Amazonia is the most important biome for the long-term conservation of Neotropical felids due to its large area, connectivity, preservation status, low human density, and proportion of land inside protected areas (de la Torre *et al.*, 2018). These attributes help maintain wild felid populations but do not impede hunting, especially in floodplain *várzea* habitats and surrounding *terra firme* forests, which concentrate a large portion of Amazonian peoples (Barthem *et al.*, 2004; Ramalho, 2012). Quantitative and qualitative information on hunting rates of wild felid species that occur in Amazonia are scarce (see Carvalho Jr. & Pezzuti, 2010; Carvalho Jr. & Morato, 2013; Carvalho Jr., 2019). Monitoring hunting activity in the Amazon, especially for charismatic species under legal protection such as wild felids, is either logistically complex and/or time-consuming, while important information may be withheld in fear of sanctions (St. John, Mai, & Pei, 2015). This lack of information not only hampers conservation strategies but limits extrapolations of hunting impact on these species to hunting occurrence. To evaluate the present-day impact of hunting on wild felid populations in Amazonia it is fundamental to characterize hunting events (why, when, and where it happens), and estimate and monitor hunting rates.

In this study, we present data from 18 years of a community-based monitoring program to quantify and characterize the hunting of wild felids by local communities in Mamirauá and Amanã Sustainable Development Reserves, Central Amazonia. We also test the hypothesis that the hunting of wild felids in the region is seasonal and intensifies with the rising of the water level of the Amazon River basin, which fluctuates over 10 m every year. Furthermore, we test whether local human population, habitat type, and total hunting events influence felid hunting.

Materials and methods

Study areas

Mamirauá Sustainable Development Reserve (MSDR) is located at the confluence of the Japurá and Amazon Rivers, but is entirely encompassed within the Amazon River basin (03°08′S, 64°45′W and 02°36′S, 67°13′W) (Fig. 1). It was created in 1990, covers an area of 11,240 km^2, and is the largest protected area exclusively protecting the *várzea* ecosystem in the world. This study was conducted in the Southeastern portion of the reserve, which covers an area of 2,600 km^2, and has a population of 5,605 people (2.16 people/km^2) distributed in nine geopolitical sectors and 73 communities. Residents of MSDR are descendants of indigenous populations and immigrants from Northeastern Brazil who came to the region during the late 19th and early 20th centuries to work on rubber extraction (IDSM, 2014).

Amanã Sustainable Development Reserve (ASDR) is located in the interfluve between the black waters of the Negro River basin and the white alluvial waters of the Japurá River basin (01°35′S, 62°44′W and 03°16′S, 65°23′W) (Fig. 1). It was created in 1998 and covers a mosaic of three main ecosystems – *igapó*, *várzea*, and *terra firme* – covering an area of 23,500 km^2. It includes a population of 5,458 people distributed over 133 communities. This study was conducted in two of the largest geopolitical sectors of ASDR, the Amanã Lake sector, which covers an area of 2,484 km^2, and has a population of 738 people (0.30 people/km^2), distributed in 22 communities, and the Paraná do Amanã sector, which covers an area of 2,600 km^2 and has a population of 831 people (0.32 people/km^2), distributed in 20 communities. The population in ASDR is of similar descent as MSDR's, and presently the predominant sources of income of both populations are small-scale agriculture, fishing, extraction of wood and non-timber forest products, and may include commercial or subsistence hunting. (Moura *et al.*, 2016; Peralta & Lima, 2019).

Várzea forests are seasonally flooded by nutrient-rich whitewater of the Amazon River and its tributaries (Prance, 1979). *Igapó* and *terra firme* forests are on an alluvial *paleo-várzea* substrate from the tertiary and quaternary formation (Junk *et al.*, 2011). Since this substrate originated from ancient Andean sediments, these areas have intermediate fertility. The *igapó* forest is also seasonally flooded but by nutrient-poor blackwater and occurs in narrow strips along Amanã Lake (Irion *et al.*, 2010). The higher portions of unflooded lands are characterized as *terra firme* forests.

The distribution of wild felids and other medium and large-sized animals in Amazonia is highly influenced by the flood-pulse (Alvarenga *et al.*, 2018). Five felid species (*Panthera onca*, *Puma concolor*, *Leopardus pardalis*, *Herpailurus yagouaroundi*, and *Leopardus wiedii*) have been recorded in ASDR and four in MSDR (*P. onca*, *P. concolor*, *L. pardalis*, and *L. wiedii*). However, only two species (*P. onca* and *L. wiedii*) have resident populations in MSDR, both of them adapted to a semi-arboreal lifestyle to survive in the canopies during the flood season (Alvarenga *et al.*, 2018; Ramalho *et al.*, 2021).

Community-based monitoring of felid hunting

Data on the hunting of wild felids was obtained through a community-based wildlife use monitoring program carried out for 18 years (2002–2019) in the study areas (Fauna Use Monitoring System, hereafter SMUF). The SMUF was conceived and designed in partnership with local people of both reserves and since its implementation has monitored 10 communities, five in MSDR and five in ASDR (Table 1; Fig. 1).

Hunting data were collected by local residents of the monitored communities (hereafter monitors), who were hired and trained to record daily data on hunting events voluntarily reported by other villagers onto a standardized form. Through this form, we collected the date, location, and

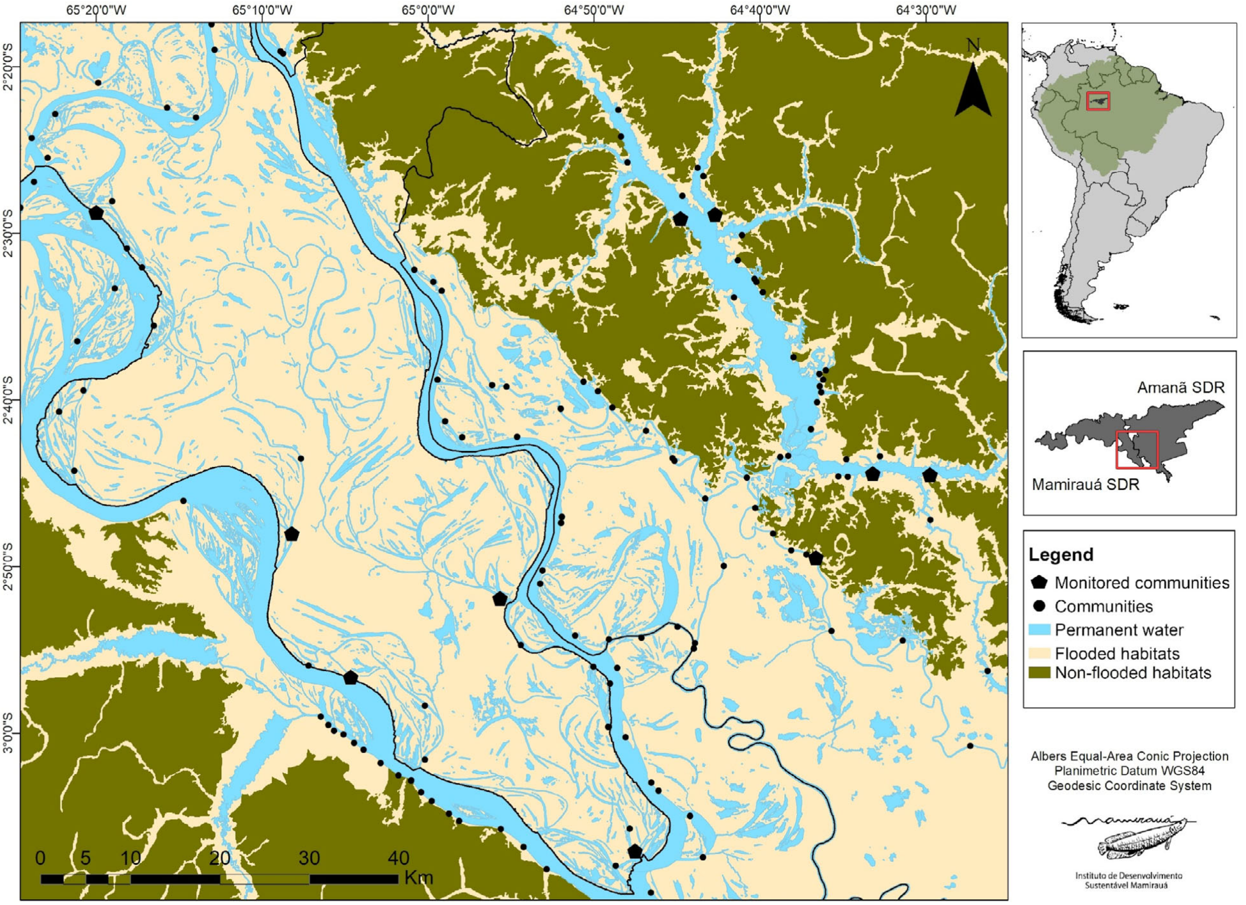

Figure 1 Location of monitored communities in Amanã and Mamirauá Sustainable Development Reserves, Amazonas state, Brazil.

Table 1 Communities where the Fauna Use Monitoring System (SMUF) was implemented in Amanã and Mamirauá Sustainable Development Reserves, Amazonas state, Brazil. "Current population" refers to a 2018 census in Amanã and a 2019 census in Mamirauá

Communities	Reserve	Environment	Monitoring period	Sampling effort (months)	Current population
São Francisco do Aiucá	Mamirauá	Várzea	2002–2010; 2013–2015	77	140
Barroso	Mamirauá	Várzea	2002–2012	61	79
Boca do Mamirauá	Mamirauá	Várzea	2002–2011	69	100
São Raimundo do Jarauá	Mamirauá	Várzea	2002–2007; 2014–2015	58	159
Sítio Fortaleza	Mamirauá	Várzea	2003–2004; 2007–2011	39	65
Belo Monte	Amanã	Terra Firme	2007–2013	47	84
Boa Esperança	Amanã	Terra Firme	2002–2016	161	300
Bom Jesus do Baré	Amanã	Terra Firme	2002–2019	172	80
Nova Jerusalém	Amanã	Terra Firme + Várzea	2002–2019	157	266
São José do Urini	Amanã	Terra Firme	2002–2008	59	105

ecosystem type where the hunt took place, the species killed, its sex, age, and reproductive status (e.g. pregnant), as well as the type of hunt or activity of the hunter at the moment of the kill, the type of weapon used, if the meat was consumed or sold, the number of hunters involved, and the period of the day when the event took place.

We defined hunting motivation into two categories: intentional, when the hunter went out with the intention of hunting the specific species of felid that was killed; and opportunistic, whenever the hunter was performing other activities, including hunting of other game species that were not the felid species killed.

Data analysis

The flood-pulse was considered to identify four distinct seasons: dry season (September–November), rising season (November–May), flood season (May–July), and receding season (July–September) (Ramalho *et al*., 2009). To test the effect of water level on the number of wild felids killed, we used the mean water level for each month as the predictor variable and tested its influence on felid hunting events with a linear regression analysis. We opted to combine hunting of all species of felids into one response variable (felid hunting events) because locals tend to perceive all wild felids as a threat to themselves and/or to their livestock, which leads them to behave similarly when encountering a felid, regardless of the species.

To determine which factors influence the number of felids killed, we used GAMLSS (generalized additive model for location, scale, and shape; Stasinopoulos & Rigby, 2007). GAMLSS is a semiparametric analysis capable of fitting linear and nonlinear trends, and to address time and spatial non-independence. In addition, GAMLSS analysis is a flexible statistical framework capable of handling a wide range of distributions beyond the exponential family (Stasinopoulos *et al*., 2017). To avoid bias, the response variable was standardized by the sampling effort, therefore, we divided the number of felids killed per year in each community by the number of monitored months in the same year. Since the habitat where the communities are located influences how people live and interact with the environment, we considered 'habitat' as a predictor variable along with 'human population' of each community in monitored years, and 'total hunting events' of each community per year. To classify the habitat of the communities, we considered the area where communities are located and the area where each hunting record occurred, resulting in three categories, *terra firme*, *terra firme* + *várzea*, and *várzea* (Table 1). Human population of each community in monitored years was estimated through the coefficients of linear regressions based on three censuses held by Mamirauá Institute in 2002, 2006, and 2011 in both reserves. The total hunting events was the sum of all hunting events minus felid hunts per community per year. As the total hunting events variable is also influenced by the sampling effort, we standardized it following the same approach described for the response variable. Finally, to avoid pseudoreplication we used 'year' and 'community' as random variables.

Previous to the GAMLSS we tested for auto-correlation in predictor variables using Pearson correlation, but no correlation was found ($r > 0.6$). To find the best-fitted family, we selected a range of family distributions according to the distribution of the response variable. Afterward, based on the Generalized Akaike Information Criterion (GAIC) and on the adjusted residuals we selected the Zero Adjusted Inverse Gaussian family. To find the best performance between under- and over-fitted models, we developed variable selection for remaining variables through the GAIC and the adjusted residuals. In the Generalized AIC, we defined the best-ranked model as the model with the smallest AIC (Burnham & Anderson, 2004). The final model retained 'human population' and 'habitat' as predictor variables, and 'community' as a random variable. GAMLSS analysis was calculated with the package *gamlss* (Rigby & Stasinopoulos, 2005) and the graphics constructed with packages *ggplot2* (Wickham, 2016) and *tibble* (Müller & Wickham, 2021), all in R software (R Core Team, 2021).

Results

From 2002 to 2019, 10 communities (five within the *várzea* forests, four within *terra firme* forests, and one community comprising both ecosystems) were monitored resulting in a total effort of 900 month*communities. The human population of monitored communities ranged from 65 to 300 individuals. During this period, we recorded the hunting of 71 adult felids belonging to four species. Of these hunting events, 24 (33.8%) were reported in *várzea* forests and 37 (52.1%) in *terra firme* forests, while 10 (14.1%) were recorded in an area with both *várzea* + *terra firme* forests. The jaguar (*Panthera onca*) was the most frequently hunted species with 35 (49.3%) records, of which 23 (65.7%) occurred in *várzea* forests. The only other species of felid hunted in *várzea* forests was the ocelot (*Leopardus pardalis*) with a single record (Table 2). In *terra firme* forests, the ocelot was the most frequently hunted species with 14 events recorded, while the jaguar was hunted on 9 occasions. Eleven pumas (*Puma concolor*) and two margays (*Leopardus wiedii*) were hunted in *terra firme* forests, while two margays and three jaguars were hunted in an area within *terra firme* + *várzea* forests. Six individuals of *Leopardus* genus that were not precisely identified by hunters were killed in ASDR, one in the *terra firme* forests and five in the area containing both *terra firme* + *várzea* forests (Table 2). Males of puma (sex ratio = 1:0.83; $N = 11$), ocelot (1:0.71; $N = 12$), margay (1:0.33, $N = 4$), and *Leopardus* spp. (1:0.20; $N = 6$) were killed more frequently than females, while female jaguars were killed slightly more frequently than males (1:1.08; $N = 27$).

From the 71 felid hunting events, we obtained information on the method used to kill the specimens in 61 events. The most common method of hunting was with a shotgun ($N = 58$; 95.08%), and dogs were used in association with shotguns in only seven events (11.47%). On three occasions, no firearms were used when hunting jaguars. These animals were killed with either a machete, an ax, or with the association of a harpoon and a machete while the animal was crossing a bay in Amanã Lake.

Most felids were killed in opportunistic events ($N = 55$; 88.7%), usually during hunting expeditions aimed at other game species ($N = 27$), such as spotlight hunting of the nocturnal spotted paca (*Cuniculus paca*; $N = 9$). Other opportunistic events occurred during fishing trips ($N = 11$), agricultural labor ($N = 3$), or when the felid was crossing a water body ($N = 1$). Seven hunting events were described as intentional by the hunters. In two of these events, the hunter killed jaguars in retaliation to livestock predation, and in the

Table 2 Number of felids killed in each habitat type (*Terra Firme*, *Várzea*, and TF + V = *Terra Firme* + *Várzea*) and season in Amanã and Mamirauá Sustainable Development Reserves, Amazonas state, Brazil

	Habitat			Season			
Felid species	Terra Firme	Várzea	TF + V	Dry	Rising	Flood	Receding
Panthera onca	9	23	3	4	10	14	7
Puma concolor	11	0	0	2	3	4	2
Leopardus pardalis	14	1	0	3	9	2	1
Leopardus wiedii	2	0	2	0	1	3	0
Leopardus spp.	1	0	5	0	0	4	2
Total	37	24	10	9	23	27	12

other five, no reason was reported. In other nine felid hunting events, hunters did not declare their motivation to hunt.

Felids were hunted throughout the year, but we found a positive relationship between the number of animals hunted per month and mean monthly water level ($\beta = 0.42$; $P < 0.05$; $R^2 = 0.34$; Fig. 2). Most species had a peak in hunting events during the flood season, while the ocelot was the only species that was mostly hunted during the rising of the water level (Table 2).

During variable selection, 'total hunting events' was excluded from the final model, indicating it could be adding noise instead of additional significant information. From the remaining variables, human population size had a positive effect on the number of felids hunted, indicating an increase in the number of hunts in more populated communities ($\beta = 0.004$; $P < 0.01$; Fig. 3(a) and Table 3). The habitat where communities are located also influenced the number of felids hunted with *várzea* having significantly more hunting activity than the others (βvárzea = 0.767; $P < 0.001$; Fig. 3(b) and Table 3).

Discussion

The number of jaguars hunted during this study may be high considering the life-history traits of the species hunted (Carvalho Jr. & Desbiez, 2013), while this result varied for the other species. Nevertheless, hunting of wild felids seems to be widespread in Brazilian Amazonia. For instance, in seven villages of the Kaxinawá indigenous territory, one jaguar and two pumas were killed during 1 year, all of which were declared as killed for self-defense (Constantino *et al.*, 2008). In Tapajós-Arapiuns Extractive Reserve, a similar category of protected area as the ones in this study, 32 jaguars and 22 pumas were reported as killed in approximately one decade in surveyed communities (Carvalho Jr. & Pezzuti, 2010). In another extractive reserve in the Brazilian Amazon, a fifth of

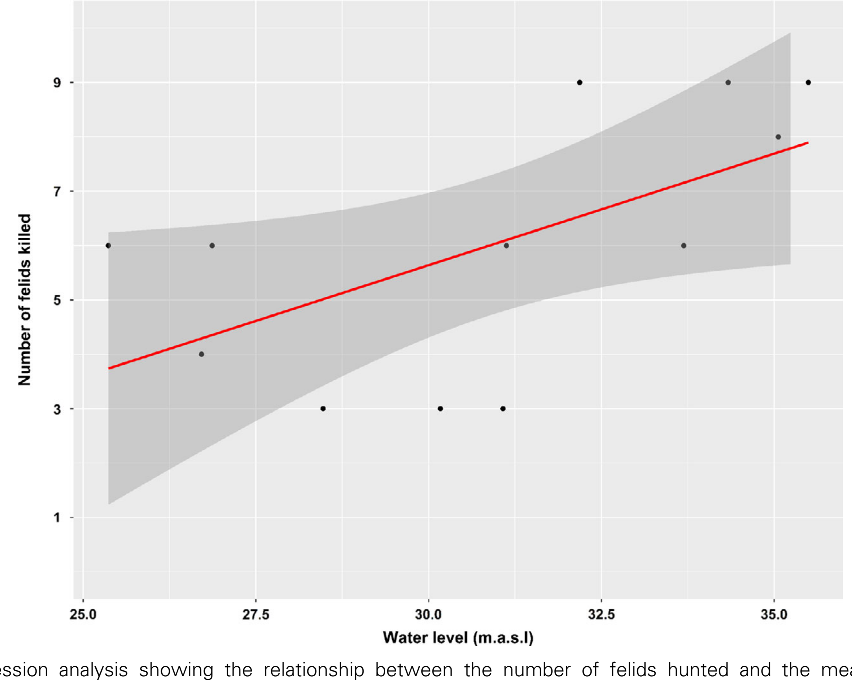

Figure 2 Linear regression analysis showing the relationship between the number of felids hunted and the mean monthly water level ($\beta = 0.41$; $P < 0.05$; $R^2 = 0.36$) in Amanã and Mamirauá Sustainable Development Reserves, Amazonas state, Brasil.

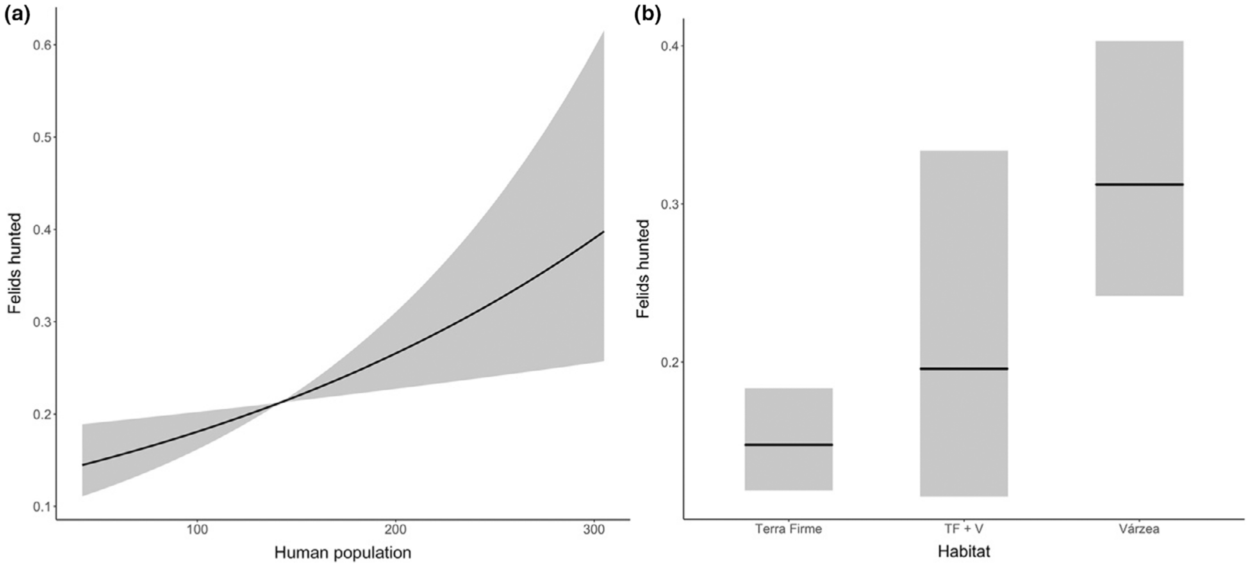

Figure 3 Relationship between felid hunting and human population size (a) and habitat (b) at Amanã and Mamirauá Sustainable Development Reserves, Amazonas state, Brazil (shaded area, 95% CI). Original values are plotted on a log-transformed y-axis.

Table 3 Details of the best-fit models using generalized additive models for location, scale, and shape (GAMLSS) for felid hunting at Amanã and Mamirauá Sustainable Development Reserves, Amazonas state, Brazil (Zero Adjusted Inverse Gaussian family)

Predictor variables	Estimate	Std. Error	*t* value	*P*
Intercept (terra firme)	−2.466	0.217	−11.358	<0.001
Terra firme + várzea	0.279	0.306	0.912	0.364
Várzea	0.767	0.224	3.426	<0.001
Human population	0.004	0.001	3.051	<0.01

surveyed households were involved in at least one jaguar hunt in the past 5 years (Carvalho Jr., 2019). In rural settlements bordering a national park in the Southwestern Amazon, one ocelot, three jaguars, and four pumas were hunted over a year, reportedly due to depredation on domestic animals (Lima, Napiwoski, & Oliveira, 2020), while one jaguar, two pumas, and two ocelots were reported as being hunted for the same reason in rural settlements around another national park in the Northern Amazon (Melo *et al*., 2015). Past studies have shown that even relatively low hunting levels may cause a decrease in population growth rate, turning it more susceptible to other potential threats (Carvalho Jr. & Desbiez, 2013). In that matter, the increasing levels of anthropogenic pressures in the Amazon, such as deforestation, wildfires and illegal mining, raises an alert as these threats combined with hunting activity might prove to be a risk for felids (e.g. Menezes *et al*., 2021).

Jaguars were hunted at least 35 times during this study, accounting for almost half of all events recorded (49.3%). The only previous study for this region has estimated that approximately 70 jaguars are hunted per year (Ramalho, 2012). At first glance, these numbers are somewhat worrisome since jaguars have relatively low reproduction rates, small population sizes and require large portions of pristine habitats to thrive, making them especially sensitive to persecution (Sunquist & Sunquist, 1989). However, both reserves are located in a massive continuous conservation zone of more than 6,000,000 ha - the Central Amazon Ecological Corridor. This protected block of forest is sparsely populated with all settlements limited to the main watercourses (IDSM, 2014), therefore it is reasonable to expect that the large interfluvial areas act as a nursery for the species, maintaining metapopulation dynamics and population stability through time, if extraction rates do not rise. Estimates of jaguar density in MSDR seem to corroborate this hypothesis, presenting no population decrease over 6 years of study - 17.8 $\pm$ 8.0 ind/100 km^2 (mean $\pm$ SD; Ramalho, 2012).

The felids killed in this region are commonly consumed by local communities (Ramalho, 2012). In our study, though, we recorded only one case in which the hunter said that he likes to consume puma and jaguar meat. He also commented on his preference for puma meat, which, according to him, was tastier than jaguar. Some villagers commented that puma meat taste is similar to red brocket deer meat (*Mazama americana*), a species ranked among the preferred game animals by Amanã Lake's villagers (Valsecchi & Amaral, 2009).

The fact that most felids were hunted opportunistically (88.7% of hunting events) demonstrates the complexity of human-felid interactions in the region. Another study in the same area found that most felid hunting events were opportunistic (57.7% of hunting events; Ramalho, 2012). Although livestock depredation has been pointed out as the main motive influencing intentional killing of felids in the same region (Michalski *et al*., 2006; Ramalho, 2012), in this study only two hunting events were reported as retaliation for livestock depredation, demonstrating that there are other underlying factors influencing felid hunting. Hunters in the region have previously declared that they hunt felids whenever they have the opportunity, especially jaguars (Valsecchi & Amaral, 2009; Lopes *et al*., 2012). In the Bolivian Amazon, 65.5% of respondents mentioned fear when asked why they had killed a jaguar (Knox *et al*., 2019). Fear, as well as personal and social motivations, have been shown to be important factors influencing jaguar killing behavior in the Brazilian Amazon (Marchini & Macdonald, 2012). The perception of felids as a threat to people may be reinforced by stories of attacks on humans, driving negative attitudes and increased acceptance of felid persecution (Carvalho Jr., 2019; Knox *et al*., 2019). Stories of attacks on humans are widespread in the study area, despite actual attacks being rare, which might be strengthening an instinctive fear for wild felids, driving their persecution.

We confirmed our hypothesis that hunting is associated with water level and it seems that hunters from our study areas concentrate felid hunting during high water peaks. During this period, fish availability decreases, and hunting is prioritized by rural peoples in the Amazon, spending more time and effort on this activity to achieve daily protein needs (Endo, Peres, & Haugaasen, 2016; Tregidgo *et al*., 2020). In addition, since water channels are the main way for hunters to reach their hunting grounds, high water levels provide easier access to source areas of game species. High water levels also shrink habitats available for felids in flooded *várzea* forests, when jaguars, for instance, are commonly spotted in trees by local people (Ramalho *et al*., 2021), where they have less of a chance to escape since they are slower and more exposed when swimming. Therefore, the combination of higher hunting frequency, more access to hunting areas, and higher sighting of felids during the wet season in the Amazon likely increases the probability of wild felid species being killed.

Similarly, rising and flood seasons are precisely when the spotted paca hunting intensifies, as well as fishing within flooded forests and in the river's margin (Valsecchi, El Bizri, & Figueira, 2014). This hunt occurs at the beginning of the night, by foraging the margins of small streams in a canoe, with a flashlight and a shotgun. This is likely to increase the probability of encountering felids because hunters' spotlighting activity may overlap with felid nocturnal activity, and in the canoes, hunters make practically no noise.

Despite the fact that we recorded more felids killed in *terra firme*, after considering the sampling effort our results indicate the opposite - felids are hunted more often in flooded *várzea* forests than in *terra firme*. This may be explained by the significantly higher density of jaguars in *várzea* forests compared to *terra firme* (Ramalho, 2012; Tobler *et al*., 2013; Alvarenga *et al*., 2018) and the fact that almost half of all recorded felids hunted were jaguars. The higher density of jaguars increases the probability of encounters with humans, and ultimately, the probability of being hunted. Additionally, jaguars' arboreal habits in flooded *várzea* environments makes them more vulnerable to being hunted (Ramalho *et al*., 2021) compared to non-flooded *terra firme* forests. Our results also indicate felids are hunted more frequently where the human population is larger. Felid persecution is widespread (Inskip & Zimmermann, 2009), and our results show that these species are killed opportunistically in our study area. This is illustrated by the variety of occasions in which felids were killed, such as when local villagers were fishing, farming or simply when a felid was seen swimming across a water body. Therefore, an increase in human activity prompted by a larger human population is expected to have a direct effect on felid hunting.

It has been increasingly acknowledged that involving local stakeholders in conservation projects is essential (Berkes, 2004; Brondizio & Le Tourneau, 2016). In our case, the collaboration among researchers, community members, and hunters was fundamental to the functioning of SMUF given that access to hunting data is contingent upon hunters' willingness to share information. Community-based monitoring empowers the local communities' involvement in conservation and increases the reliability of data collection on sensitive topics (Brooks, Waylen, & Mulder, 2012; Campos-Silva *et al*., 2018). This approach also sheds light on small felid hunting, which is rarely declared in interviews and, sometimes, may "become bigger animals" in the reports. Trustworthy relationships between researchers and community members were key for this collaboration to occur. Finally, this collaboration also brought practical implications, for SMUF results have influenced the formulation of management strategies for game species present in the Management Plans of Mamirauá and Amanã Reserves.

The results in this study increase our knowledge about felid hunting in the Amazon, contributing for developing conservation strategies aimed at promoting human-carnivore coexistence. Felid killing was shown to be mostly opportunistic, prevalent in *várzea* forests during the flood season and in communities with larger populations. Characterizing this threat allows environmental awareness and social marketing campaigns to be tailored for increased effect. For instance, targeted interventions regarding felid conservation in communities which have a large population and are located in *várzea* forests, especially during the flood season could have a more significant impact. However, it should be noted that our results reflect the characteristics of our study area, a well-preserved protected area of considerable size with a large jaguar population, and this should be taken into account before generalizing our findings.

Since our study stems from a community-based project with significant local participation, efforts to reduce felid killing may be more readily embraced by local communities, increasing social acceptability towards conservation goals (König *et al*., 2020; Volski *et al*., 2021). Finally, our results show that human population size is a driver of felid persecution. Considering the general tendency of human population growth and reduction of natural habitats in the Amazon, community-based strategies aimed at promoting human-wildlife coexistence will become increasingly important for maintaining viable felid populations as well as securing local communities' livelihoods.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

References

Alvarenga, G.C., Ramalho, E.E., Baccaro, F.B., da Rocha, D.G., Ferreira-Ferreira, J. & Bobrowiec, P.E.D. (2018). Spatial patterns of medium and large size mammal assemblages in várzea and terra firme forests, Central Amazonia, Brazil. *PLoS One* **13**, e0198120.

Antunes, A.P., Fewster, R.M., Venticinque, E.M., Peres, C.A., Levi, T., Rohe, F. & Shepard, G.H. (2016). Empty forest or empty rivers? A century of commercial hunting in Amazonia. *Sci. Adv.* **2**, e1600936.

Barthem, R.B., Charvet-Almeida, P., Montag, L.F.A. & Lanna, A.E. (2004). *Amazon Basin, GIWA Regional assessment 40b*. Kalmar: University of Kalmar.

Benítez-López, A., Santini, L., Schipper, A.M., Busana, M. & Huijbregts, M.A.J. (2019). Intact but empty forests? Patterns of hunting-induced mammal defaunation in the tropics. *PLoS Biol.* **17**, e3000247.

Berkes, F. (2004). Rethinking community-based conservation. *Conserv. Biol.* **18**, 621–630.

Brondizio, E.S. & Le Tourneau, F.M. (2016). Environmental governance for all. *Science* **352**, 1272–1273.

Brooks, J.S., Waylen, K.A. & Mulder, M.B. (2012). How national context, project design, and local community characteristics influence success in community-based conservation projects. *Proc. Natl. Acad. Sci. USA* **109**, 21265–21270.

Burnham, K.P. & Anderson, D.R. (2004). Multimodel inference: understanding AIC and BIC in model selection. *Social Methods Res.* **33**, 261–304.

Campos-Silva, J.V., Hawes, J.E., Andrade, P.C.M. & Peres, C.A. (2018). Unintended multispecies co-benefits of an Amazonian community-based conservation programme. *Nat. Sustain.* **1**, 650–656.

Carvalho, E.A.R., Jr. (2019). Jaguar hunting in Amazonian extractive reserves: acceptance and prevalence. *Environ. Conserv.* **46**, 334–339.

Carvalho, E.A.R., Jr. & Desbiez, A.L.J. (2013). Modeling the impact of hunting on the viability of a jaguar population in Amazonia, Brazil. *Lat. Am. J. Conserv.* **3**, 8–14.

Carvalho, E.A.R., Jr. & Pezzuti, J.C.B. (2010). Hunting of jaguars and pumas in the Tapajós–Arapiuns extractive reserve, Brazilian Amazonia. *Oryx* **44**, 610–612.

Carvalho, E.A.R., Jr. & Morato, R.G. (2013). Factors affecting big cat hunting in Brazilian protected areas. *Trop. Conserv. Sci.* **6**, 303–310.

Constantino, P.d.A.L., Fortini, L.B., Kaxinawa, F.R.S., Kaxinawa, A.M., Kaxinawa, E.S., Kaxinawa, A.P., Kaxinawa, L.S., Kaxinawa, J.M. & Kaxinawa, J.P. (2008). Indigenous collaborative research for wildlife management in Amazonia: the case of the Kaxinawá, acre, Brazil. *Biol. Conserv.* **141**, 2718–2729.

Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora (1973) [Text of the Convention]. http://www.cites.org/eng/disc/text.shtml.

de la Torre, J.A., González-Maya, J.F., Zarza, H., Ceballos, G. & Medellín, R.A. (2018). The jaguar's spots are darker than they appear: assessing the global conservation status of the jaguar Panthera onca. *Oryx* **52**, 300–315.

Dickman, A., Marchini, S. & Manfredo, M. (2013). The human dimension in addressing conflict with large carnivores. In *Key topics in conservation biology 2*: 110–126. Macdonald, D.W. & Willis, K.J. (Eds.), Chichester: John Wiley & Sons.

Dickman, A.J., Hazzah, L., Carbone, C. & Durant, S.M. (2014). Carnivores, culture and 'contagious conflict': multiple factors influence perceived problems with carnivores in Tanzania's Ruaha landscape. *Biol. Conserv.* **178**, 19–27.

Endo, W., Peres, C.A. & Haugaasen, T. (2016). Flood pulse dynamics affects exploitation of both aquatic and terrestrial prey by Amazonian floodplain settlements. *Biol. Conserv.* **201**, 129–136.

Inskip, C. & Zimmermann, A. (2009). Human-felid conflict: a review of patterns and priorities worldwide. *Oryx* **43**, 18–34.

Irion, G., de Mello, J.A.S.N., Morais, J., Piedade, M.T.F., Junk, W.J. & Garming, L. (2010). Development of the Amazon valley during the middle to late Quaternary: sedimentological and climatological observations. In *Amazonian Floodplain Forests - Ecophysiology, Biodiversity and Sustainable Management*: 27–42. Junk, W.J., Piedade, M.T.F., Wittmann, F., Schöngart, J. & Parolin, P. (Eds.), Heidelberg: Springer-Verlag.

IDSM (Instituto de Desenvolvimento Sustentável Mamirauá). (2014). *Plano de Gestão: Reserva de Desenvolvimento Sustentável Mamirauá - RDSM*, 3rd edn. Tefé: IDSM.

Jędrzejewski, W., Carreño, R., Sánchez-Mercado, A., Schmidt, K., Abarca, M., Robinson, H.S., Boede, E.O., Hoogesteijn, R., Viloria, Á.L., Cerda, H., Velásquez, G. & Zambrano-Martínez, S. (2017). Human-jaguar conflicts and the relative importance of retaliatory killing and hunting for jaguar (*Panthera onca*) populations in Venezuela. *Biol. Conserv.* **209**, 524–532.

Junk, W.J., Piedade, M.T.F., Schöngart, J., Cohn-Haft, M., Adeney, J.M. & Wittmann, F. (2011). A classification of major naturally-occurring amazonian lowland wetlands. *Wetlands* **31**, 623–640.

König, H.J., Kiffner, C., Kramer-Schadt, S., Fürst, C., Keuling, O. & Ford, A.T. (2020). Human-wildlife coexistence in a changing world. *Conserv. Biol.* **34**, 786–794.

Knox, J., Negrões, N., Marchini, S., Barboza, K., Guanacoma, G., Balhau, P., Tobler, M.W. & Glikman, J.A. (2019). Jaguar persecution without "cowflict": insights from protected territories in the Bolivian Amazon. *Front. Ecol. Evol.* **7**, 494.

Lima, N.S., Napiwoski, S.J. & Oliveira, M.A. (2020). Human-wildlife conflict in the southwestern Amazon: poaching and its motivations. *Nat. Conserv. Res.* **5**, 109–114.

Lopes, G.P., Valsecchi, J., Vieira, T.M., Amaral, P.V. & Costa, E.W.M. (2012). Hunting and hunters in lowland communities in the region of the middle Solimões, Amazonas, Brazil. *Uakari* **8**, 7–18.

Loveridge, A.J., Sousa, L.L., Seymour-Smith, J., Hunt, J., Coals, P., O'Donnell, H., Lindsey, P.A., Mandisodza-Chikerema, R. & Macdonald, D.W. (2020). Evaluating the spatial intensity and demographic impacts of wire-snare bush-meat poaching on large carnivores. *Biol. Conserv.* **244**, 108504.

Macdonald, D. & Loveridge, A. (2010). *The biology and conservation of wild felids*. New York: Oxford University Press.

Marchini, S. & Macdonald, D.W. (2012). Predicting ranchers' intention to kill jaguars: case studies in Amazonia and Pantanal. *Biol. Conserv.* **147**, 213–221.

Melo, E.R.A., Gadelha, J.R., Silva, M.N.D., Júnior, A.P.S. & Pontes, A.R.M. (2015). Diversity, abundance and the impact of hunting on large mammals in two contrasting forest sites in northern amazon. *Wildlife Biol.* **21**, 234–245.

Menezes, J.F.S., Tortato, F.R., Oliveira-Santos, L.G.R., Roque, F.O. & Morato, R.G. (2021). Deforestation, fires, and lack of governance are displacing thousands of jaguars in Brazilian Amazon. *Conserv. Sci. Pract.* **3**, e477.

Michalski, F., Boulhosa, R.L.P., Faria, A. & Peres, C.A. (2006). Human-wildlife conflicts in a fragmented Amazonian forest landscape: determinants of large felid depredation on livestock. *Anim. Conserv.* **9**, 179–188.

Morcatty, T.Q., Bausch Macedo, J.C., Nekaris, K.A.-I., Ni, Q., Durigan, C.C., Svensson, M.S. & Nijman, V. (2020). Illegal trade in wild cats and its link to Chinese-led development in central and South America. *Conserv. Biol.* **34**, 1525–1535.

Moura, E.A.F., Nascimento, A.C.S., Corrêa, D.S.S., Alencar, E.F. & Sousa, I.S. (2016). *Sociodemografia da Reserva de Desenvolvimento Sustentável Mamirauá*. Tefé: IDSM.2001–2011.

Müller, K. & Wickham, H. (2021). tibble: Simple Data Frames. R package version 3.1.5. https://CRAN.R-project.org/package=tibble.

Paula, R.C., Desbiez, A. & Cavalcanti, S.M. (2011). *Plano de ação nacional para a conservação da onça-pintada*. Brasília: Instituto Chico Mendes de Conservação da Biodiversidade, ICMBio.

Peralta, N. & Lima, D. (2019). Economia familiar. In *Sociobiodiversidade da Reserva de Desenvolvimento Sustentável Amanã (1998–2018): 20 anos de pesquisa*: 214–225. Nascimento, A.C.S. et al. (Eds.), Tefé: IDSM.

Prance, G.T. (1979). Notes on the vegetation of Amazonia III. The terminology of amazonian forest types subject to inundation. *Brittonia* **31**, 26.

R Core Team. (2021). *R: a language and environment for statistical computing*. Vienna, Austria: R Found. Stat. Comput.

Ramalho, E.E. (2012). *Jaguar (Panthera onca) population dynamics, feeding ecology, human induced mortality, and conservation in the Várzea Floodplain Forests of Amazonia*. PhD thesis. Gainesville: University of Florida.

Ramalho, E.E., Macedo, J., Vieira, T.M., Valsecchi, J., Calvimontes, J., Marmontel, M. & Queiroz, H.L. (2009). Ciclo hidrológico nos ambientes de Várzea da Reserva de Desenvolvimento Sustentável Mamirauá - Médio Rio Solimões, Período de 1990 a 2008. *Uakari* **5**, 61–87.

Ramalho, E.E., Main, M.B., Alvarenga, G.C. & Oliveira-Santos, L.G.R. (2021). Walking on water: the unexpected evolution of arboreal lifestyle in a large top predator in the Amazon flooded forests. *Ecol.* **102**, e03286.

Rigby, R.A. & Stasinopoulos, D.M. (2005). Generalized additive models for location, scale and shape, (with discussion). *Appl. Stat.* **54**, 507–554.

Ripple, W.J., Estes, J.A., Beschta, R.L., Wilmers, C.C., Ritchie, E.G., Hebblewhite, M., Berger, J., Elmhagen, B., Letnic, M., Nelson, M.P., Schmitz, O.J., Smith, D.W., Wallach, A.D. & Wirsing, A.J. (2014). Status and ecological effects of the world's largest carnivores. *Science* **343**, 1241484.

Stasinopoulos, D.M. & Rigby, R.A. (2007). Generalized additive models for location, scale and shape (GAMLSS) in R. *J. Stat. Softw.* **23**, 1–46.

Stasinopoulos, D.M., Rigby, R.A., Heller, G.Z., Voudouris, V. & Bastiani, F.D. (2017). *Flexible regression and smoothing: Using GAMLSS in R*. London: Chapman and Hall/CRC.

St. John, F.A.V., Mai, C.-H. & Pei, K.J.-C. (2015). Evaluating deterrents of illegal behaviour in conservation: carnivore killing in rural Taiwan. *Biol. Conserv.* **189**, 86–94.

Sunquist, M.E. & Sunquist, F.C. (1989). Ecological constraints on predation by large felids. In *Carnivore behavior, ecology, and evolution*: 283–301. Gittleman, J.L. (Ed.), New York: Cornell University Press.

Tobler, M.W., Carrillo-Percastegui, S.E., Zúñiga Hartley, A. & Powell, G.V.N. (2013). High jaguar densities and large population sizes in the core habitat of the southwestern Amazon. *Biol. Conserv.* **159**, 375–381.

Tregidgo, D., Barlow, J., Pompeu, P.S. & Parry, L. (2020). Tough fishing and severe seasonal food insecurity in Amazonian flooded forests. *People Nat.* **2**, 468–482.

Valsecchi, J. & Amaral, P.V. (2009). Perfil da caça e dos caçadores na Reserva de Desenvolvimento Sustentável Amanã, Amazonas – Brasil. *Uakari* **5**, 33–48.

Valsecchi, J., El Bizri, H.R. & Figueira, J.E.C. (2014). Subsistence hunting of *Cuniculus paca* in the middle of the Solimões River, Amazonas, Brazil. *Braz. J. Biol.* **74**, 560–568.

Volski, L., McInturff, A., Gaynor, K.M., Yovovich, V. & Brashares, J.S. (2021). Social effectiveness and human-wildlife conflict: linking the ecological effectiveness and social acceptability of livestock protection tools. *Front. Conserv. Sci.* **2**, 682210.

Wickham, H. (2016). *ggplot2: elegant graphics for data analysis*, 2nd edn. New York: Springer-Verlag.

Zarco-González, M.M., Monroy-Vilchis, O., Sima, D., López, A. & García-Martínez, A. (2018). Why some management practices determine the risk of livestock predation by felids in the Selva Maya, Mexico? Conservation strategies. *Perspec. Ecol. Conserv.* **16**, 146–150.