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Modeling the risk of livestock depredation by jaguar along the Transamazon highway, Brazil

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Abstract

The jaguar is an endangered species in Brazil and one of the major threats is the hunting, sometimes as a result of livestock depredation. Understanding the ecological and anthropogenic factors that favor the predation of livestock by jaguar can help to reduce the number of attacks and thus, decrease cases of hunting in retaliation. We used field data on livestock depredation and environmental and anthropogenic variables to model the risk of depredation by jaguar along the Transamazon highway, a frontier region where ranching has been the main driver of deforestation. We used five algorithms and a final ensemble model in order to obtain a map of depredation risk, as well as to identify the variables related with it. The variables most related with depredation risk were distance to deforestation (negatively related) and cattle density (positively related). The major factors driving livestock depredation are related to anthropogenic disturbance, this means that the spatial distribution of risk is not a stable feature, but is likely to change dynamically following shifts in the deforestation frontier and in the livestock herd. Based on our results, it is reasonable to expect an increase in depredation of livestock in this area. The use of ecological niche modeling to identify potential hotspots of depredation of livestock is a recent innovation that holds potential to guide the allocation of conservation and management efforts over large areas at relatively low costs.

Zusammenfassung

Der Jaguar ist eine gefährdete Art in Brasilien, und eine der wichtigsten Bedrohungen ist die direkte Bejagung, die zum Teil eine Folge von Viehrissen ist. Die ökologischen und anthropogenen Faktoren zu verstehen, die Viehverluste durch den Jaguar begünstigen, kann helfen, die Zahl der Angriffe zu reduzieren und damit die Fälle von vergeltender Bejagung. Wir nutzten Daten zu Viehrissen, Umweltvariablen und anthropogenen Faktoren, um das Risiko von Rissen durch den Jaguar entlang der Transamazônica zu modellieren, eine Grenzregion, in der die Weidewirtschaft der treibende Faktor der Abholzung ist. Wir benutzten fünf Algorithmen und ein abschließendes Gesamtmodell, um eine Karte des Rissrisikos zu berechnen und die damit verbundenen Variablen zu identifizieren. Die am stärksten mit dem Rissrisiko verknüpften Variablen waren Entfernung zu

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Kahlschlägen (negativ) und Rinderdichte (positiv). Die Hauptfaktoren, die die Viehverluste bestimmen, sind mit menschlichen Eingriffen verbunden. Das bedeutet, dass die räumliche Verteilung des Risikos nicht stabil ist, sondern sich wahrscheinlich in der Folge von Änderungen der Abholzungsfront und des Viehbesatzes dynamisch ändern wird. Basierend auf unseren Ergebnissen sollte man in diesem Gebiet einen Anstieg der Viehverluste erwarten. Die ökologische Modellierung mit dem Ziel, potentielle Brennpunkte der Viehrisse zu identifizieren, ist eine aktuelle Innovation, die das Potential hat, bei relativ geringen Kosten eine Orientierungshilfe für die Verteilung von Naturschutz- und Managementbemühungen über große Gebiete zu geben.

Keywords: Conservation; Deforestation; Ecological niche modeling; Felids; Human–jaguar conflict

Introduction

The current extinction crisis has been severe for wild felids and about 50% of the 36 species are currently threatened (Macdonald & Loveridge 2010). Causes of felid declines are mostly anthropogenic and include habitat loss, prey depletion, and hunting (Inskip & Zimmermann 2009; Karanth & Chellam 2009; Macdonald & Loveridge 2010). Generally, the main reason for persecution is conflict resulting from depredation of livestock (Inskip & Zimmermann 2009), a problem that occurs throughout the world, but which tends to be particularly severe in frontier regions, where cattle farming comes into close contact with carnivore habitat (Michalski, Boulhosa, Faria, & Peres 2006). This is the case in much of the Amazonian deforestation frontier (Michalski et al. 2006; Marchini & Macdonald 2012). Ranching has been the main driver of deforestation in the region and currently occupies more land than any other agricultural activity (Fearnside 2005; Bowman et al. 2012). Conflicts related to livestock depredation by jaguar (*Panthera onca*) and puma (*Puma concolor*) are common throughout the region and have been reported from various sites (Michalski et al. 2006; Marchini & Macdonald 2012; Oliveira, Ramalho, & Paula 2012; Palmeira & Trinca 2012). To prevent losses, ranchers usually resort to retaliatory killing, compromising the conservation of these large felids (Marchini & Macdonald 2012; Palmeira & Trinca 2012). This situation is likely to worsen in the near future, since the Amazonian herd is growing at impressive rates (Bowman et al. 2012). Efforts to mitigate conflict in such a large area will necessarily require the allocation of scarce resources (MacDonald-Madden, Baxter, & Possingham 2008).

The spatial depredation risk is not evenly distributed (Jackson, Ahlborn, Gurung, & Ale 1996), habitat, landscape and anthropogenic factors can influence the odds of conflict, by determining the existence of depredation hotspots (Kissling, Fernández, & Paruelo 2009; Zarco-González, Monroy-Vilchis, & Alaníz 2013). Examples of spatial factors related to depredation risk include availability of wild habitat, percent of vegetation cover, slope, distance to settlements, and spatial distribution of livestock (Michalski et al. 2006; Kaartinnen, Luoto, & Kojola 2009; Kissling et al. 2009). Generally, the closer is the site to favored carnivore habitat, the higher is the risk of depredation (Inskip & Zimmermann 2009). The spatial identification of depredation hotspots can help to plan the allocation of conflict-solving efforts, such as adapting livestock husbandry, zoning, education and law enforcement (Kissling et al. 2009; Zarco-González, Monroy-Vilchis, Rodríguez-Soto, & Urios 2012; Zarco-González et al. 2013). One promising alternative to achieve this goal is the use of ecological niche models (Franklin 2009). These tools were originally designed to evaluate habitat suitability and species distribution, but they can also be used in other contexts and have been successfully applied in the spatial modeling of the risk of livestock predation (Zarco-González et al. 2012; Zarco-González et al. 2013).

In this study, we used field data on livestock depredation, and thematic layers representing environmental and anthropogenic factors, to model the risk of livestock depredation by jaguar along the Transamazon highway. We used five different modeling algorithms and a final ensemble model in order to obtain a map of depredation risk in the study area, as well as to identify the variables related with it. Finally, we explored the main patterns and applications of our results.

Materials and methods

Study area

The study was conducted along a 900 km section of the Transamazon highway (BR-230) between the Tapajós and Tocantins Rivers in Pará, Brazil (Fig. 1). This frontier region was settled after the construction of the Transamazon highway in the 1970s (Smith 1982). Colonization followed a grid blueprint that resulted in the typical fishbone pattern of deforestation (Smith 1982; Godar, Tizado, & Pokorny 2012). Most of the settled land is in the hands of smallholders, owning properties up to 200 ha, though larger ranches may reach 5000 ha or more (Bonaudo, Pendu, Faure, & Quanz 2005; Campos & Nesptad 2006; Godar et al. 2012). Extensive cattle ranching are the main driver of deforestation in the area (Godar et al. 2012). Despite extensive forest loss, most of the region is still covered by undisturbed rainforest, and the area has a well recognized potential for conservation (Bonaudo et al. 2005; Schwartzman, Alencar, Zarin, & Souza 2010;

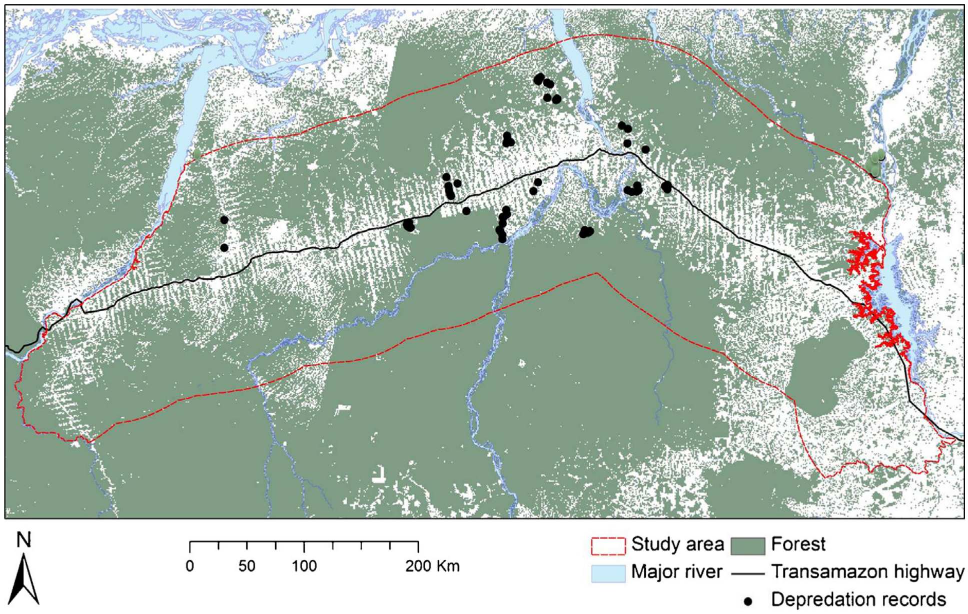

Fig. 1. Map of the study area, showing forest cover, the Transamazon highway, and depredation records used for modeling.

Godar et al. 2012). For the purposes of modeling, we defined our area of interest as the polygon limited by the Tapajós and Jamanxim Rivers to the west, Tocantins and Itacaiúnas Rivers to the east, and by a 100 km buffer north and south of the Transamazon highway. We used this distance from the road because most deforestation is restricted to a 100 km wide zone along both sides of the highway (Smith 1982; Alves 2002; Godar et al. 2012). The resulting polygon encompassed 13 million ha, 70% of which is rainforest.

Data collection

Fieldwork was conducted in March and June 2012. Our main objective was to obtain high-quality depredation records for ecological modeling, trying at the same time to cover most environmental gradients found in the study area. To do this, we adopted a snowball sampling strategy, combining data from informal interviews and key informants in a chain referral, to identify properties that experienced recent predation events. In total, we traveled more than 3000 km of roads, interviewing livestock owners and visiting depredation sites, to record date of attack, identity of prey and predator (based on evidence associated with carcasses) and geographical coordinates of each record. Depredation events were included in the analysis only if there was evidence of tracks, bites to the throat or neck, or dragging of the carcass described in the interviews or examined in the field (Zarco-González et al. 2013).

Data analysis

We used environmental layers to characterize attack sites: elevation (masl) and slope (degrees) (http://www.dpi.inpe.br/Ambdata/), distance to forests and to deforested areas (kilometers, http://www.obt.inpe.br/prodes/index.php), distance to roads (kilometers, http://siscom.ibama.gov.br/mapas/Novo_Flex/), distance to settlements (kilometers, http://downloads.ibge.gov.br/downloads_geociencias.htm) and cattle density (number of animals/kilometer, http://www.sidra.ibge.gov.br). Layers were processed in raster format with a resolution of 1 km^2, excluding all pixels with no data or representing water bodies. To reduce spatial correlation between depredation records, we filtered data and retained only one datum per pixel. Records were then divided into calibration and validation datasets, holding 75 and 25% of data respectively (Guisan & Zimmermann 2000; Araújo, Pearson, Thuiller, & Erhard 2005).

We generated spatial models of depredation risk in the software Open Modeller version 1.1.0 (http://www.openmodeller.sf.net) from the algorithms Environmental Distance (Hirzel & Arlettaz 2003), GARP with best subsets (Genetic Algorithm for Rule-set Production, Stockwell & Peters 1999) and Support vector machines (Cristianini & Scholkopf 2002). We ran Ecological Niche Factor Analysis (ENFA) in the software BioMapper 4 (Hirzel et al. 2004) to evaluate how characteristics of attack sites related to global conditions in the study area, and Maximum Entropy in the software Maxent (Maximum Entropy Species Distribution Modeling v3.3.3e, Phillips, Anderson, & Schapire 2006) to evaluate the relationship between predictor variables and depredation risk.

The evaluation of each model was done by considering the area under the curve (AUC) of the receiver operating characteristics (ROC) plot (Hanley & McNeil 1982). For each model, we ran two evaluations, one based on the calibration dataset (internal evaluation) and the other on the validation dataset (external evaluation).

Previous studies comparing the performance of different algorithms have found that model performance depends not only on the selected algorithm, but also on the dataset under use, thus making it impossible to identify a single algorithm as being the best in all cases (Elith et al. 2006; Hernandez et al. 2008). To overcome this problem, some authors have suggested the use of multiple algorithms, in order to identify areas of consistent prediction and to obtain reliable estimations (Anderson, Lew, & Peterson 2003; Araújo, Thuiller, & Pearson 2006; Hartley, Harris, & Lester 2006). According to this, we generated an ensemble model including all models with AUC values >0.7 in the external evaluation (Manel, Williams, & Ormerod 2001). We generated the ensemble model using the weighted average (Marmion, Hjort, Thuiller, & Luoto 2009). The precision of the ensemble model was evaluated by the AUC. In order to obtain an easily interpretable map of livestock depredation risk, we divided the predicted values into quartiles, in such a way that, in the final model, low risk is under the first quartile, high risk is above the third quartile, and medium risk is in the interquartile range.

Results

We obtained 84 depredation records, which after data filtering resulted in 64 records. The best-performing algorithms were Environmental Distance and Maxent, but outputs of all five algorithms were relatively similar, and all models were suitable for inclusion in the final ensemble model, based on the AUC value criteria (Table 1).

According to ENFA, characteristics of jaguar attack sites are different from the mean environmental conditions found in the study area (global marginality value = 0.797). Furthermore, the range of conditions where depredation occurs is quite restricted relative to global characteristics (specialization = 10.83 and tolerance = 0.092). According to Maxent, the most important variables affecting depredation risk were distance to deforestation (negatively related) and cattle density (positively related, Table 2). The Maxent

Table 1. AUC values by each algorithm in internal and external evaluation.

Algorithm	AUC	
	Internal evaluation	External evaluation
Environmental distance	0.995	0.912
GARP with best subsets	0.867	0.854
Support vector machines	0.851	0.838
ENFA	0.717	0.790
Maxent	0.847	0.908

Table 2. Variable contribution to livestock depredation risk model, according to Maxent.

Variable	Percentage contribution
Distance to deforestation	63.2
Cattle density	21
Distance to roads	5
Elevation	4.9
Slope	3.2
Distance to forest	1.9
Distance to settlements	0.7

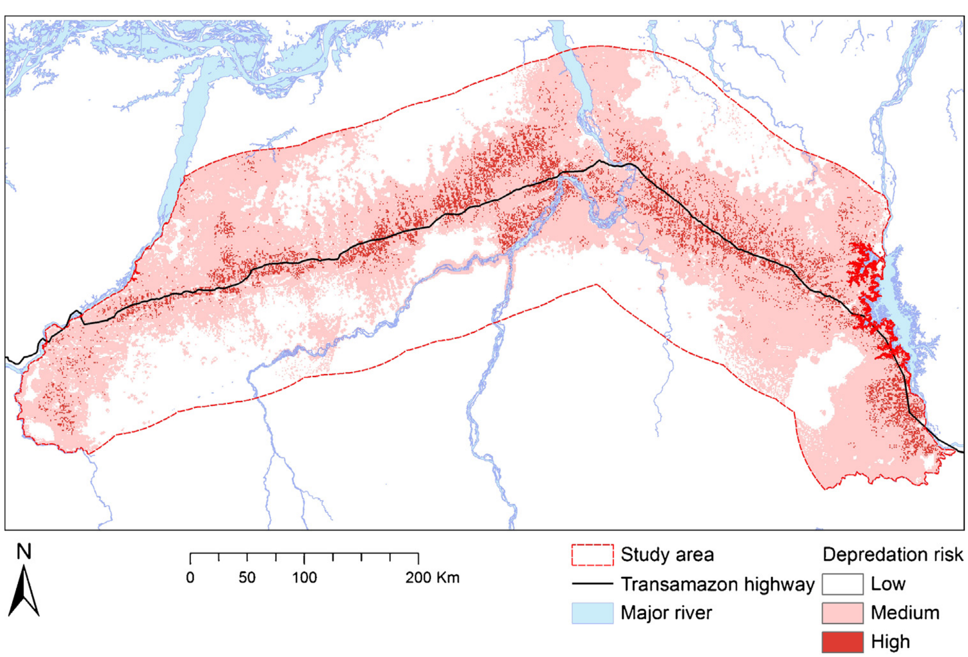

Fig. 2. Ensemble model of the risk of livestock depredation by jaguar in the study area.

response curve shows that depredation risk is high in deforested areas and at the forest-deforestation edge.

The final ensemble model has an AUC value of 0.879 (Fig. 2). Areas of high depredation risk (with probabilities higher than 66%) covered 5.8% of the study area, while medium and low risk areas covered 54.7 and 39.4% of the study area, respectively. Areas of risk were scattered throughout the study area, and there were no clearly identifiable depredation hotspots at the regional level (Fig. 2).

Discussion

Understanding the ecological and anthropogenic factors that favor the predation of livestock by jaguar can help reduce the number of attacks and thus, decrease cases of hunting in retaliation. Ecological niche modeling is a useful technique that has been recently applied to identify potential factors affecting high-risk zones (Zarco-González et al. 2012, 2013), covering large areas at relatively low cost. This study required 30 days of fieldwork and cost of US$ 7575 (including air tickets, stipends and fuel) to cover an area of 13 million ha. This cost could be further reduced by running a single expedition instead of two, or by employing local researchers to conduct fieldwork, since air tickets represented 50% of the total costs. As a comparison, conventional approaches using telemetry systems and/or intensive monitoring required 2 years or more to cover much smaller areas (15,000–20,000 ha), probably at higher costs (Azevedo & Murray 2007; Palmeira, Crawshaw, Haddad, Ferraz, & Verdade 2008). The fact that our main results are consistent with those of more intensive studies conducted over much smaller areas (Michalski et al. 2006; Azevedo & Murray 2007) is a good indicator of the potential of the technique.

In general, predictions generated by the different algorithms were consistent with one another. High risk sites are scattered throughout the study area and there are few clearly identifiable regional hotspots. High risk sites cover less than 6% of the area and occur in a relatively restricted range of environmental conditions, which are considerably different from the average conditions found in the study area. The major factors driving livestock predation are related to anthropogenic disturbance. This probably occurs because, on the one hand, human settlement followed a blueprint that paid little or no attention to natural landscape features (Smith 1982; Godar et al. 2012). Moreover, forest cover, elevation and slope are relatively homogeneous throughout the study area, so there are no strong environmental gradients. The predominance of anthropogenic factors and the scattered distribution of risk sites make this situation somewhat different to what has been typically reported in previous studies, where natural features, such as altitude, slope and distance to water, predominate (Azevedo & Murray 2007; Zarco-González et al. 2012; Zarco-González et al. 2013). On the other hand, the importance of deforestation and cattle density in the risk of livestock predation is consistent with previous findings (Michalski et al. 2006; Azevedo & Murray 2007).

The Maxent response curve shows that depredation risk was higher inside deforested areas and in forest areas close to deforestation, which actually represent pixels in the forest-deforestation border. This result is consistent with previous studies that have also reported higher risk of predation at sites located near forest edges (Michalski et al. 2006; Azevedo & Murray 2007; Palmeira et al. 2008). This agrees with the expectation that depredation risk will be higher in areas situated near suitable predator habitat (Inskip & Zimmermann 2009), and is consistent with the notion that jaguar avoid crossing large patches of open habitat (Michalski et al. 2006). The allocation of high risk to some forest sites is likely an artifact of the large pixel size used in this study. For example, Azevedo and Murray (2007) suggested that jaguar attacks are typically limited to a distance of 200 m from the forest edge. Depredation sites located so close to forests could easily fall inside forest pixels, even when located in deforested areas. Such misclassification can be minimized by using better resolution layers, though this may incur higher study costs for image acquisition.

Cattle density had a positive effect on depredation risk. Other studies have also reported a positive effect of livestock density or herd size to depredation. Zarco-González et al. (2013) found that the percentage of free-grazing livestock was positively related to depredation risk by jaguar in Mexico, and Michalski et al. (2006) reported a positive effect of herd size on the number of cattle killed by jaguar at ranches in another Amazonian site. This probably occurs because increased cattle densities lead to increased conspicuousness and higher encounter rates with carnivores, resulting in less time spent foraging and higher profitability for these opportunistic predators (Polisar et al. 2003). Furthermore, higher encounter rates also mean that individual jaguar that is not used to cattle may become accustomed and eventually inclined to kill opportunistically (Azevedo & Murray 2007). If cattle density has such an effect on depredation risk, then reducing stocking rates could help to avoid predation. However, this is unlikely to be a viable alternative. Recent studies have recommended ranching intensification in Amazonia, to increase land productivity, prevent pasture degradation, and to reduce the need for more deforestation (Muchagata & Brown 2003; Bowman et al. 2012). The potential benefits of increasing stocking rates are likely to outweigh the costs of eventual depredation events. This is particularly true considering that the economic impact of livestock depredation by carnivores is markedly low (Michalski et al. 2006; Azevedo & Murray 2007; Palmeira et al. 2008).

Since anthropogenic variables were more important in determining depredation risk, this means that the spatial distribution of risk is not a stable feature, but is likely to change dynamically following shifts in the deforestation frontier and in the livestock herd. Deforestation rates in Brazilian Amazonia have been decreasing in the last years, and approximately half of the area is currently protected as conservation units or indigenous lands (Nepstad et al. 2006; Malingreau, Eva, & Miranda 2011). However, this situation is unlikely to remain stable (Malingreau et al. 2011). There are projections of substantial increases in deforestation for the study area, ranging from 800 to 5000 km^2 in the next 20 years, as consequence of migratory movements resulting from the building of Belo Monte Dam in the Xingu River (Barreto et al. 2011). Furthermore, cattle ranching is spreading in the region and there is evidence that ranching in Amazonia requires the continuous expansion of pastures (Muchagata & Brown 2003; Godar et al. 2012). Based on these prospects and in our results, it is reasonable to expect a concurrent increase in livestock predation in this area.

Besides the fact that areas of high risk covered a relatively small portion of the study area, the impact of jaguar depredation on livestock in affected properties seems to be typically low, though we lack quantitative data on this issue. Nevertheless, the perception of local people is that jaguar impact is high and many interviewees admitted to retaliatory killing. Since removing livestock from deforested areas and reducing cattle densities are not viable alternatives, some other option must be sought to reduce livestock predation in the region. Previous authors have recommended more efficient land uses as alternatives to reduce deforestation, stabilize the frontier and to achieve "productive conservation" in the region (Nepstad, Stickler, & Almeida 2005; Campos & Nesptad 2006; Godar et al. 2012). The suggested measures typically involve regional zoning (Nepstad et al. 2005; Godar et al. 2012) and the implementation of a mosaic of land uses, including livestock, cash crops, and logging, embedded in a matrix of forests (Lima et al. 2006). To this, we add the recommendation that such zoning should also consider the potential for predation of livestock, for example by allocating pastures far from forest edges or raising only adult animals in these areas, since calves are more vulnerable to depredation (Azevedo & Murray 2007). Another alternative is to buffer pastures from forests by cash crops or other land uses. It is also important to note that protected areas in the study area are concentrated south of the Transamazon highway. To avoid the regional spread of deforestation and concurrent conflict, it would be advisable to identify areas north of the road holding potential to receive formal protection status. Otherwise, law enforcement could be used as an alternative to avoid deforestation.

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