Ecosistemas y Recursos Agropecuarios

Landscape and cattle management attributes associated with the incidence of *Desmodus rotundus* attacks on cattle

Características del paisaje y de manejo ganadero asociadas a la incidencia de ataques al ganado bovino por *Desmodus rotundus*

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ABSTRACT. Bovine paralytic rabies, transmitted by *Desmodus rotundus*, causes economic losses for Latin American livestock producers. Although the total number of reported cases has decreased markedly due to vaccination campaigns, economic losses can be significant for smallholders. Identifying risk factors for vampire bat attacks on cattle could help guide preventive control efforts in specific areas. The objective of this study was to analyze the relationship between the incidence of *D. rotundus* attacks on cattle and various landscape features and cattle management practices in northeastern Puebla, Mexico. We visited 61 properties with cattle between May and October 2011, in which we quantified the incidence of attacks on cattle and described landscape and cattle management attributes. The following features were described within a 200-m radius around the nightly resting site of cattle: topography, percent forest cover, and number of forest fragments, rivers and streams, tree lines, buildings, roads and highways. With these variables, we built models that were assumed to describe the levels of human interference, prey availability, and movement facilitation for bats. The human interference model (number of buildings plus number of roads) best explained the incidence of attacks on cattle. According to our results, the cattle with the highest vulnerability to attacks by vampire bats are those resting at night in less confined sites, far away from human activity. Results of this study suggest that rabies vaccination campaigns on cattle should focus on fragmented areas with few livestock management practices.
Key words: Fragmentation, cattle ranching, vampire bat, Puebla, rabies.

RESUMEN. La rabia paralítica bovina, transmitida por *Desmodus rotundus*, provoca pérdidas económicas al sector ganadero latinoamericano. Aunque el número total de casos notificados ha disminuido notablemente debido a las campañas de vacunación, las pérdidas económicas pueden ser significativas para pequeños propietarios. Identificar factores de riesgo podría ayudar a orien-tar esfuerzos de control preventivo en zonas específicas. El objetivo de este trabajo fue analizar la relación entre la incidencia de mordeduras por *D. rotundus* y diversos atributos pisajísticos y de manejo ganadero en el noreste de Puebla, México. Se visitaron 61 propiedades con ganado entre mayo y octubre de 2011; en cada sitio se cuantificó la incidencia de ataques al ganado y se describieron las características del paisaje y del manejo ganadero. En un radio de 200 m alrededor del sitio de descanso nocturno del ganado, se registró: topografía, cobertura vegetal y número de fragmentos vegetales, ríos y arroyos, líneas de árboles, construcciones humanas, carreteras y autopistas. Con estas variables, se construyeron modelos que describieron: facilitación de movimiento, niveles de interferencia humana y disponibilidad de presas para los murciélagos. El modelo de interferencia humana (número de construcciones más número de caminos) fue el que mejor explicó la incidencia de ataques. Los resultados sugieren que el ganado más vulnerable a los ataques de vampiros es el que descansa por la noche en sitios menos confinados y lejos de la actividad humana. Se propone que las campañas de vacunación contra la rabia bovina se concentren en áreas fragmentadas con escasas prácticas de manejo.
Palabras clave: Fragmentación, ganadería, murciélago vampiro, Puebla, rabia.

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INTRODUCTION

Bovine paralytic rabies represents one of the main problems for cattle ranching in the tropical regions of the Americas (Lee *et al*. 2012). The disease, caused by a virus of the genus *Lyssavirus* (family Rhabdoviridae), has a long incubation period culminating in an acute and lethal course (Fisher *et al*. 2018). Bovine paralytic rabies is usually transmitted by an infected animal biting a susceptible one, as the virus is present in the saliva of sick animals. To date, the only known vector of this virus to livestock is the common vampire bat (*Desmodus rotundus*), which feeds opportunistically on the blood of various mammalian species (Johnson *et al*. 2014).

Cases of bovine rabies are geographically limited to the distribution area of *D. rotundus*, which ranges from Tamaulipas, Nuevo León, Sonora and Chihuahua in Mexico, to central Chile, northern Argentina and southern Brazil (Zarza *et al*. 2017). In the last 50 years, the total number of reported cases in Latin America has decreased by several orders of magnitude, largely as a result of intense preventive vaccination campaigns (Arellano-Sota 1988). However, bovine rabies continues to be a problem that generates significant economic losses for the livestock sector. For example, between 1993 and 2002, 31 187 cases of bovine rabies were reported in Latin America (Belotto *et al*. 2005). In Mexico, in recent years, rabies outbreaks have spread to regions where they had previously not occurred (Bárcenas-Reyes *et al*. 2015). It is difficult to establish the precise amount of losses caused by bovine rabies, as cases usually occur in livestock areas where access to veterinary services is insufficient, there is little or no notification by producers, in many cases due to lack of knowledge of the disease or difficulty in communicating with the corresponding authorities, and diagnostic laboratories are limited (Acha and Málaga-Alba 1988). In this context, some authors have proposed that for every reported case of rabies, there could be 10 that go unreported (Fornes *et al*. 1974). Considering the underreporting, annual mortality in the whole region could be close to 50 000 head of cattle (Acha and Szyfres 2003).

Identifying risk zones is very useful in guiding preventive vaccination efforts in areas where livestock are most vulnerable to attacks by *D. rotundus*. The few studies conducted on this subject suggest that the incidence of attacks on livestock seems to be related to landscape attributes, especially those that describe the distribution of forested areas. For example, in the state of Sao Paulo, Brazil, riparian zones are reported to be landscape elements that facilitate attacks on livestock, because they favor the presence of suitable roosts for *D. rotundus* (Taddei *et al*. 1991). However, a study conducted in four municipalities in the same Brazilian state found that rivers are not associated with the risk of *D. rotundus* attacks on cattle (Gomes *et al*. 2007). In another study conducted in the state of Sao Paulo, it was found that pastures with the highest number of reported attacks on cattle tended to be surrounded by forest and sugarcane crops (Gomes *et al*. 2010). Recently, it was reported that some feral pigs were attacked by *D. rotundus* in an oil palm fragment surrounded by pastures, but not in other locations (Hernández-Pérez *et al*. 2019). In contrast, a study conducted in the Bolivian Prepuna reported that the incidence of attacks on stabled goats was more associated with the characteristics of the stockyards than with the characteristics of the vegetation (Moya *et al*. 2015). This suggests that livestock management strategies may affect the likelihood of a domestic animal being attacked. For example, it has been reported that cows that disperse inside pastures during the night are less attacked than those that are kept together (Delpietro and Russo 1996), while stabled animals (pigs) tend to be more attacked than those (cows) that move freely near villages (Bobrowiec *et al*. 2015).

This paper is founded on the assumption that the attributes analyzed (vegetation cover, topography, river distribution, prey abundance, prey accessibility and distribution of anthropogenic activities) facilitate or limit encounters between *D. rotundus* and its potential prey at a specific point in the landscape. The region studied, located within the distribution range of *D. rotundus*, is one of the most important livestock areas in the state. Therefore, the objective was to analyze the relationship between various landscape

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and livestock management attributes described *in situ* with the incidence of cattle attacks by *D. rotundus* in ranches in the northeast of the state of Puebla, Mexico. The results of the study provide elements that can help delineate livestock management strategies that reduce the likelihood of the rabies virus being transmitted to cattle. These types of preventive actions are crucial considering that population control of the vector has not proven to be an efficient measure for bovine rabies control (Streicker *et al.* 2012).

MATERIALS AND METHODS

Study area

The study was conducted in the northeast of the state of Puebla, a region with a long cattle ranching tradition and great potential for low-cost meat and milk production within the state, due to the high availability of good-quality inputs and forage. The study area is located within the Tuxpan-Nautla hydrological region, which includes part of the Sierra Madre Oriental and the Gulf Coastal Plain. In this region, the predominant climate is warm humid with year-round rainfall or abundant summer rainfall, and semi-warm humid with year-round rainfall; the average annual temperature ranges from 22 to 30 °C. The original vegetation includes portions of tropical evergreen forest, pine-oak forest, cloud forest and chaparral. Currently, agricultural zones are combined with fragments of natural vegetation dominated by subperennial tropical forest and cloud forest with varying degrees of disturbance (INEGI 2016).

Sampling design

We selected a sample of 61 locations (villages, ranches, rural settlements, hamlets and houses; Figure 1) with the presence of livestock, mainly cattle, that at the time of being visited had a minimum of 10 head. The locations were selected based on the facilities granted by the owners, covering most of the highways and roads in the northeast of the state, and trying to cover as much geographical area as possible. In each location, a 200-m radius circle (12.6 ha) was established as the sampling unit, taking as its center the area where the focal livestock was concentrated during the night before the inspection (see next section). The precise nightly resting site was identified with the help of farm staff. The sampling unit's perimeter was identified with the help of a GPS, and each unit had to be separated by at least 1 km from the nearest unit to maximize data independence. The scale was selected to obtain a representative description of each property, assuming that each sampling unit includes the most relevant landscape features that facilitate or limit access to prey for vampires. Each location was visited only once between the months of May and October 2011, allowing us to maximize the number of properties visited within a short timeframe. In each sampling unit, the cattle were inspected to estimate the incidence of attacks by the vampire bat and data were collected on landscape and livestock management attributes.

Cattle inspection

The cattle were checked only once in each location to identify the individuals that had been attacked by *D. rotundus*. The inspection was carried out in the mornings to take advantage of each ranch's own activities such as milking, vaccination and tick dip. When possible, cows were placed in the handling chute with one person on each side to check both flanks for bites. The entire body was checked, paying greater attention to the base of the ears, neck, udders, tail and legs, which are usually the parts of the body most attacked by *D. rotundus*. For the purposes of this study, only recent bat bites were recorded, that is, the cow had to be attacked the night before the day of the inspection. The criterion to identify recent bites was to observe a line of fresh or semi-dry blood just below the wound, since the cow may have had bites prior to that night. At least 10 cows of any race, sex and age were reviewed, always by the same observer. Based on these data, the incidence of attacks per sampling unit was estimated and defined as the percentage of individuals that were attacked at night relative to the total number of individuals checked.

Description of sampling units

The landscape and cattle management characteristics described for each sampling unit were

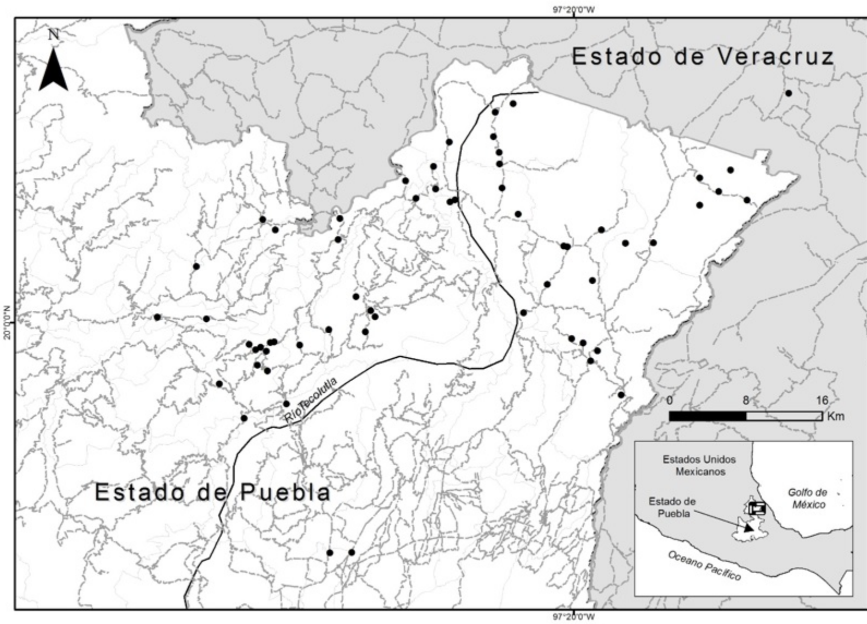

Figure 1. Distribution of 61 locations (sampling units) in the northeastern region of the state of Puebla, Mexico.

selected considering ecological aspects of *D. rotundus*, including attributes that might favor or limit its presence. The landscape attributes described in the field were (the categories are mentioned in parentheses in ascending order of valuation): dominant topography (flat, semi-undulating, undulating), number of rivers, number of streams, number of small fragments of tree vegetation (each made up of 10 trees and covering < 50% of the sampling unit), number of large fragments of tree vegetation (each covering $\geq$ 50% of the sampling unit), percent forest cover, number of tree lines (live fences), number of roads and highways, and number of enclosed buildings (including houses, warehouses and stables). Livestock management attributes considered were: type of location (ranch, house, village), type of management (stabling, semi-stabling, controlled grazing, free grazing), type of confinement (village, stable, corral, pasture, large undelimited areas), number of head of cattle within a 200-m radius, size of herd examined and number of head of other livestock species within a 500-m radius (in this case, the scale was extended to have a greater record of individuals).

Data analysis

Simple correlation analyses were performed to identify variables that might be related to the incidence of attacks. Additionally, we performed correlation analyses between all explanatory variables to identify redundant variables ($r \geq 0.8$), eliminating those that showed the lowest correlation value with the response variable. Generalized linear models (GLMs) with negative binomial error were used to explore the relationship between the incidence of attacks (%) and different combinations of the explanatory variables. To do this, landscape and cattle management variables were grouped into three models based on ecological considerations: 1) movement facilitation model: number of large vegetation fragments, number of small vegetation fragments, number of rivers and streams, number of tree lines, type of topography and percent vegetation; 2) human interference model: number of buildings and number of roads; and 3) prey availability model (which, according to our hypothesis, is dependent on cattle management): type of management, size of herd examined, number of head of cattle in 200 m and number of head of other livestock in 500 m. The

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overall performance of each model was assessed by the proportion of deviance that is explained by the variables considered (Pseudo-R^2). The Akaike Information Criterion (AIC) was used to identify the model that explains with the greatest parsimony the differences in incidence of attacks between ranches.

RESULTS

The average incidence of *D. rotundus* bites on cattle was 7.8%. In other words, almost eight out of every 100 cows in the northeastern region of the state of Puebla were bitten every night by hematophagous bats between May and October 2011. However, the spatial distribution of the bites was not homogeneous. While 26 properties (42.6% of the total) did not report any bites during the evaluated period, three ranches recorded an incidence of bitten cows of between 30 and 40%.

Univariate correlation analyses showed that, taken independently, the evaluated variables were little related to the incidence of attacks. Only the number of roads within a 200-m radius showed a significant (negative) relationship with the incidence of attacks ($r = -0.290$, $P = 0.024$; Figure 2), suggesting that the sites most traveled by vehicles and humans were avoided by *D. rotundus*.

Pseudo-R^2 values indicate that the constructed models (GLMs) explained a low proportion of the total variation in the data (Table 1). Among them, the model that best explained the incidence of cattle attacks was that of human interference, which consisted of the number of roads and the number of buildings. Within this model, the variable most related to the incidence of attacks was the number of roads within a 200-m radius (Table 2). The value of the β coefficient suggests that the greater the number of roads around the cows' resting site, the lower the incidence of attacks, and although its effect was statistically less significant, the number of constructions also had a negative relationship with the incidence of attacks (Figures 2 and 3). Although the relationships were not significant, it can be observed that the sites with the greatest presence of anthropogenic elements (roads and buildings) exhibited a low incidence of attacks on cattle.

The inclusion of the most significant variables of each model improved the performance of the combined model, although the deviance explained remained at very low levels (Table 1). In the combined model, the number of individuals of other livestock species within a 500-m radius emerged as an important variable (Table 2). According to the value of the β coefficient, it can be inferred that a greater local abundance of production animals (other than cows) is related to a lower incidence of attacks on cattle (Figure 4).

DISCUSSION

In this study, some factors related to the incidence of attacks on cattle by the common vampire bat (*D. rotundus*) were identified. Results suggest that the attributes of the immediate landscape surrounding the sites where cattle rest at night (200 m around) influence the probability of individuals being attacked by *D. rotundus*. The trends detected, although statistically insignificant, are compatible with existing knowledge of different ecological aspects of the common vampire bat.

The model that included variables related to human interference was the one that best explained the incidence of bat attacks on cattle in the northeastern region of Puebla. According to this model, *D. rotundus* avoids attacking cows resting in sites with intense human activity, that is, sites surrounded by multiple roads and buildings. These results agree with other studies where it has been found that individuals of this species tend to move away from areas with intense human activity. Although *D. rotundus* has been recorded in large urban centers in Brazil, its presence appears to be associated with large forested or peripheral areas of cities (Dantas-Torres *et al.* 2005, Esbérard *et al.* 2014), suggesting that evasion of areas with intense human activity occurs at small scales, such as those analyzed in this paper.

It is likely that the distancing of *D. rotundus* from areas with intense human activity is largely due to the presence of artificial lighting, as would be expected in species that naturally avoid high levels of luminosity.

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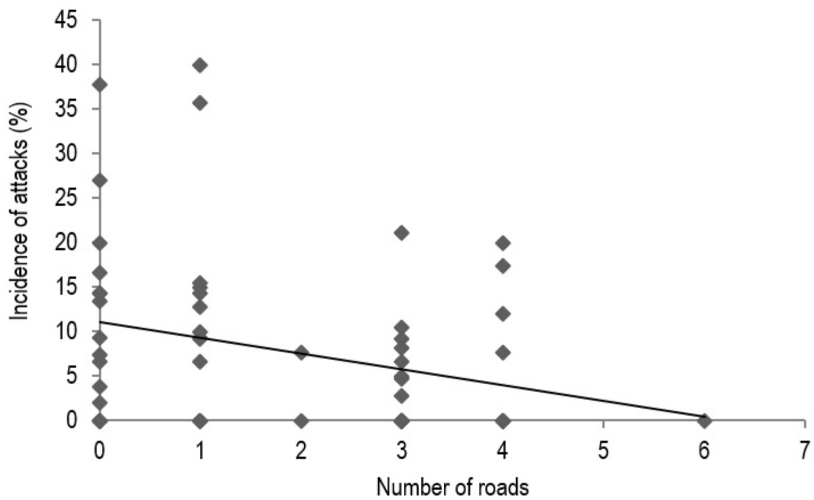

Figure 2. Relationship between the incidence of attacks on cattle and the number of roads in 61 sampling units in northeastern Puebla. Pearson's correlation coefficient showed that this relationship was significant (r = -0.290, P = 0.024).

Table 1. Statistical performance of three models that predict the incidence of cattle attacks by *D. rotundus* in 61 sampling units in the northeast of the state of Puebla. Residual deviance, Akaike Information Criterion (AIC) and Pseudo-R^2 are reported. The variables considered were: number of large vegetation fragments (LVF), number of small vegetation fragments (SVF), number of rivers and streams (RS), number of tree lines (TL), type of topography (TT), percent vegetation (%V), number of buildings (B), number of roads (Ro), type of management (TM), size of herd examined (SH), number of head of cattle in 200 m (H200m) and number of head of other livestock in 500 m (OTL500m).

Model	Model Variables	K	Deviance	Pseudo-R^2	AIC
Movement facilitation	TT+SVF+LVF+RS+%V+TL	7	55.5	0.033	363.9
Human interference	B+R	3	54.7	0.047	355.1
Prey availability	TM+H200m+OTL500m+SH	5	55.5	0.032	360.0
Combined	TT+ Ro+OTL500m	4	53.0	0.076	363.9

Table 2. Variables included in the two models that explained the highest proportion of deviance of incidence of attacks (human interference model and combined model) in 61 sampling units in northeastern Puebla. The value of the β coefficient, its confidence limits, and its significance are reported.

Variables	β Coef.	Confidence interval		Chi-squared	Significance
		Lower limit	Upper limit		
Human interference model					
Number of roads	-0.248	-0.564	0.068	2.371	0.124
Number of buildings	-0.026	-0.129	0.076	0.253	0.615
Combined model					
Type of topography	-0.041	-0.181	0.100	0.324	0.569
Number of roads	-0.321	-0.942	0.300	1.025	0.311
Other type of livestock <500 m	-0.300	-0.637	0.037	3.050	0.081

The information accumulated by multiple studies indicates that *D. rotundus* has a marked lunar phobia, that is, it tends to reduce its activity during nights or at times at night with high levels of moonlight (Saldaña-Vázquez and Munguía-Rosas 2013). In agreement with this pattern, it has been observed that *D. rotundus* does not leave its roost to forage until there is complete darkness (Wimsatt 1969). Flores-Crespo *et al.* (1972) suggested that the habit of foraging during the darkest hours of the night is probably because *D. rotundus* perceives light as a factor that increases the risk of predation.

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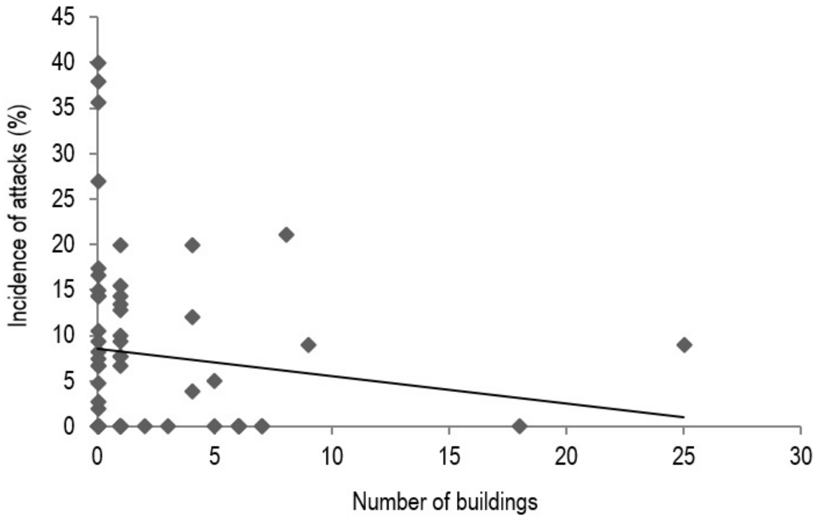

Figure 3. Relationship between the incidence of attacks on cattle and the number of buildings in 61 sampling units in northeastern Puebla. According to Pearson's correlation coefficient, this relationship was not significant (r = -0.133, P = 0.305). .

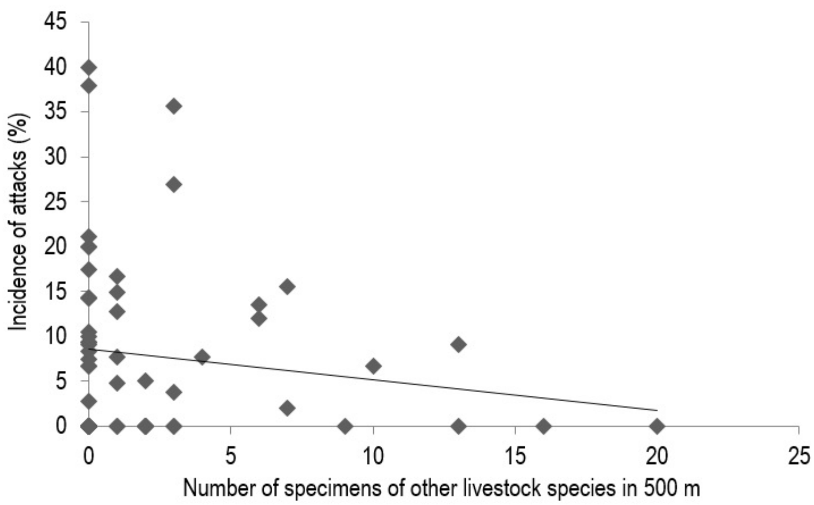

Figure 4. Relationship between the incidence of attacks on cattle and the number of specimens of other livestock species in 61 sampling units in northeastern Puebla. According to Pearson's correlation coefficient, this relationship was not significant (r = -0.148, P = 0.257).

The model associated with movement facilitation was constructed from landscape-level variables that could affect the movement of the vampire bat in the study area. In the northeastern part of the state of Puebla, the landscape is made up of multiple forest or secondary vegetation fragments surrounded by a matrix of grasslands for cattle ranching. These fragments, which are often associated with karst mountain areas of the Sierra Madre Oriental, could offer shelter and protection to hematophagous bats (Medina *et al*. 2007). In addition, the high availability of forest edges and live fences could be used by *D. rotundus* as flight routes as reported in insectivorous species (Brandt *et al*. 2007). For *D. rotundus*, which emits weak vocalizations with a wide range of frequencies, linear landscape elements (forest edges, live fences and streams) could act as reference points for spatial orientation. However, the movement facilitation model was not significant, which could be due to the fact that, in many locations, large and small vegetation fragments could not be included because they were outside the established scale (200-m radius). On the other hand, the null relationship between the incidence of attacks and the presence of rivers and streams may be due to most localities being away from bodies of water.

The model describing prey availability was established considering each property's cattle management practices, the presence of other livestock species in the area, and the size of the focal herd. Results of this model, although with little statistical power, seem to contrast with the findings of Delpietro and Russo (1996), who report that the vampire bat tends to more frequently attack cattle that are enclosed or tied up. The present study found a higher incidence of attacks in locations where the type of management is controlled grazing (pastures subject to rotation) or free grazing (large or free pastures in the mountains); although the results were not statistically significant, the 10 properties with the highest incidence of attacks (> 15%) had this type of management. On the other hand, four of the six locations where cattle were kept in stables or in the yards of houses did not record bites. It is likely that the structure of the stables or corrals, which usually have walls and roofs, represents an obstacle to the detection of prey by vampires, and these structures tend to be in places where there is anthropogenic movement and lighting. For example, Moya *et al*. (2015) report that the presence of complete roofs in corrals significantly reduces the incidence of attacks on stabled cattle. On the other hand, although larger groups were expected to be the most attacked by vampire bats as they are more easily detected, no relationship was found between the size of the group and the incidence of attacks. These results are similar to those reported by Moya *et al*. (2015), who found that the proximity of vampire bat roosts is a more important predictor of attacks on goats than the number of potential prey available.

According to one of the models generated in this work (combined model), the frequency of attacks on cattle is lower when other types of livestock (pigs, goats, horses or sheep) are present in the area. This result, although not statistically significant, suggests that other domestic species may represent alternative sources of food for the vampire bat, as has been reported in other regions of the continent (Mialhe 2014, Bobrowiec *et al*. 2015), reducing the pressure of attack on cattle. The testimonies of cowboys and ranchers seem to support this hypothesis, since according to them other livestock species are similarly attacked by the vampire bat when they are within reach.

The low statistical power observed in this work suggests that *D. rotundus* attacks on cattle may largely depend on variables that were not considered, such as the phase of the lunar cycle, the local abundance of the vampire bat, prevailing weather conditions (heavy rains or winds) or proximity to roosts (Moya *et al*. 2015). The inclusion of a single scale of analysis may have been a limiting factor for our study, by concealing the effect of factors operating at a wider landscape scale. However, the consistently low incidence of attacks at sites with a high presence of anthropogenic elements suggests that cattle vaccination efforts should be more intense in sites further away from villages, ranches and hamlets.

CONCLUSIONS

Although the models generated were not very robust, there was a lower incidence of *D. rotundus* attacks on cattle at nightly resting sites with greater human activity, particularly those surrounded by multiple roads (asphalt or dirt roads) and buildings. The presence of other livestock species (other than cattle) in the area surrounding the cows' resting site was negatively related to the incidence of attacks by vampire bats. The study of interactions between wildlife and human activity is often complex due to the large number of variables involved. However, the results of this work provide information to make decisions that favor coexistence between the vampire bat and cattle production.

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