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PERSPECTIVE

Reducing conflict between the common vampire bat *Desmodus rotundus* and cattle ranching in Neotropical landscapes

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Keywords
cattle management, common vampire bat *Desmodus rotundus*, human-wildlife conflict, Neotropics, prevention and mitigation strategies, systematic review, zoonosis

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ABSTRACT

Increased cattle ranching in Neotropical landscapes has led to human–wildlife conflicts that complicate the relationship between agricultural production and biodiversity conservation. We review the literature related to conflicts between livestock production and the common vampire bat Desmodus rotundus, specifically, the factors that influence the incidence of problems caused by bites to cattle. We summarise the strategies proposed to reduce these problems and propose actions from the perspectives of cattle management, landscape ecology and the biology of the common vampire bat. The literature shows that free-range extensive management systems, where cattle graze in areas with forest cover, near riparian zones, caves, secondary vegetation (generally shrublands and immature trees), and vegetation fragments and edges, increase the implications and the severity of the conflict. As a result of different selection forces, the wing morphology and echolocation characteristics of the common vampire bat facilitate its movement under these landscape conditions, thus favouring a scenario of greater interaction with cattle. We propose the establishment of a 'buffer zone' to separate the cattle as far as possible (at least 1 km) from the elements of the landscape that are key for the movement patterns of common vampire bats in cattle ranching areas. The feeding events of this species are positively associated with host availability and landscape elements that provide habitat and connectivity, which shows that the cause of this conflict originates from the process of cattle production and the invasion of the habitat of the common vampire bat. Anti-rabies vaccination programmes in cattle and forest–cattle separation are the most important strategies to minimise conflict and prevent rabies outbreaks.

Palabras clave
Manejo de ganado, murciélago vampiro común *Desmodus rotundus*, conflicto humanos-vida silvestre, neotrópico, estrategias de prevención y mitigación, revisión sistemática, zoonosis

RESUMEN EN ESPAÑOL

El aumento de la ganadería en paisajes neotropicales ha llevado a conflictos entre humanos y vida silvestre, que complican la relación entre la producción agropecuaria y la conservación de la biodiversidad. Revisamos la literatura relacionada con los conflictos entre la producción ganadera y el murciélago vampiro común Desmodus rotundus, específicamente, los factores que influyen en la incidencia de los problemas causados por las mordeduras al ganado. Resumimos las estrategias propuestas para reducir estos problemas y proponemos acciones desde las perspectivas del manejo del ganado, la ecología del paisaje y la biología del murciélago vampiro común. La literatura muestra que los sistemas de manejo extensivo, donde el ganado pasta en áreas con cobertura forestal, cerca de zonas ribereñas, cuevas, vegetación secundaria, fragmentos y bordes de vegetación, aumentan las implicaciones y la severidad del conflicto. Como resultado de diferentes fuerzas de selección, la morfología alar y las características de ecolocalización del murciélago vampiro común facilitan su movimiento en estas condiciones del paisaje, favoreciendo así un escenario de mayor interacción con el ganado. Proponemos el establecimiento de una 'zona de amortiguamiento' para separar el ganado lo más lejos posible (al menos 1 km) de los elementos del paisaje que son clave para el patrón de movimiento del murciélago vampiro común en áreas ganaderas. Los eventos de alimentación de esta especie se asocian positivamente con la disponibilidad de hospederos y elementos del paisaje que brindan hábitat y conectividad, lo que demuestra que la causa de este conflicto se origina en el proceso de producción ganadera y la invasión del hábitat del murciélago vampiro común. Los programas de vacunación antirrábica en el ganado bovino y la separación entre el bosque y el ganado son las estrategias más importantes para minimizar los conflictos y prevenir los brotes de rabia.

INTRODUCTION

The worldwide expansion of cattle ranching has contributed to deforestation and land-use change, transforming large areas into grazing areas for beef and dairy cattle (Szott et al. 2000). For example, in Chiapas, Mexico, 43283 ha of forest was converted to pastureland each year between 2003 and 2008 (Covaleda et al. 2014). Cattle ranching has increased mainly in response to human diet changes and human population growth causing increased animal protein demands (Vitousek et al. 1997, Tello et al. 2020). In industrialised and emerging countries, consumption patterns have led to increased cattle production in Neotropical ecosystems (Foley et al. 2005). The expansion of cattle farming is one of the main causes of land-use change in the Neotropics, which significantly modifies the functioning of ecosystems and threatens biodiversity (Eastmond & García 2010, Alonso 2011, Olimpi & Philpott 2018).

One socioecological problem that results from the expansion of cattle farming, particularly beef cattle ranching, is the conflict between cattle ranchers and wildlife (Peterson et al. 2010, Nyhus 2016). Human–wildlife conflict occurs when the presence or behaviour of wild species results in threats or losses to human interests or needs (IUCN 2020, Gross et al. 2021) and is one of the most important challenges for biological conservation (Le Bel et al. 2010). In general, the factors that promote conflict arise directly from anthropic activities, especially when humans and wild species share space, food and other resources (Lamarque et al. 2009, Gross et al. 2021, Schell et al. 2021).

Most conflicts between ranchers and wildlife in the Neotropics are due to predation of livestock (Hoogesteijn & Hoogesteijn 2008, Rumiz et al. 2011, Peña-Mondragón et al. 2016), competition for forage (Bonino 2006), parasitism and disease transmission (Delpietro & Russo 2009, Novaes et al. 2010, Sánchez-Gómez et al. 2022). In this work, we chose a case of parasitism involving the common vampire bat *Desmodus rotundus* (hereafter vampire bat) and cattle to exemplify this conflict.

People stigmatise bats to a large degree because of an array of negative myths and folklore in western culture (Scavroni et al. 2008), despite their essential role in ecosystem processes (Williams-Guillén et al. 2008, Kunz et al. 2011, Trejo-Salazar et al. 2016, Díaz et al. 2018, Saldaña-Vázquez et al. 2019, Tremlett et al. 2020). In natural ecosystems, the vampire bat is rare and mainly feeds on the blood of large herbivorous mammals (Herrera et al. 1998), but in agricultural landscapes, it feeds preferentially on the blood of cattle (Voigt & Kelm 2006, Bobrowiec et al. 2015, Wray et al. 2016, Bohmann et al. 2018, Carter et al. 2021). This demonstrates the exceptional capacity of diet adaptation in the face of changes in environment and food sources caused by anthropic activities.

The feeding behaviour of the vampire bat (hematophagy) is rare among the more than 1400 species of bat recorded worldwide (Simmons & Cirranello 2022). Of these, only three species are hematophagous, and they are distributed exclusively in the American continent. In addition to *Desmodus rotundus*, there are *Diaemus youngii* and *Diphylla ecaudata* which are considered rare in nature, feed mainly on bird blood and do not cause significant damage to agricultural production. In nature, this type of feeding can have an ecological function in the control of wild populations. Unfortunately, economic interests in cattle production involve *Desmodus rotundus* in the transmission of the rabies virus to livestock, which inevitably results in the death of infected individuals. By feeding on beef cattle, the vampire bat bite may also cause weakening (due to bleeding), anaemia, secondary infections of wounds, reduction in milk production and skin damage (reducing market value) in bitten individuals. This conflict has propitiated nonselective actions to eradicate vampire bats, such as the use of fire, chemical fumigations and obstruction of shelters, negatively impacting nonhematophagous species (Burneo et al. 2015). However, governments actively discourage these non-specific actions (Goncalves et al. 2020a, b).

Cattle ranching in Neotropical landscapes with the presence of vampire bats creates a conflict between cattle production and the conservation of bat populations (Belotto 2001, Mayen 2003, Burneo et al. 2015), further threatening the benefits that humans obtain from bats. Aiming to help mitigate this conflict, we review and analyse published information on factors that facilitate attacks (bite incidence) and rabies transmission to cattle by the vampire bat in Latin America. With this systematic review, we complement ongoing strategies and propose actions to reduce the vampire bat–cattle ranching conflict, considering three main factors: 1) cattle management, 2) landscape composition and configuration and 3) the biology of the vampire bat.

METHODS

We conducted eight systematic searches (referred to as $B_1 - B_8$) of studies of vampire bat–cattle conflict, through five search engines and databases: ScienceDirect, Web of Science, Dimensions, Scielo and Google Scholar. We used the following keywords (in the title and abstract) in English and Spanish: B_1 'Cattle ranching' AND/OR 'Neotropical bats', B_2 'Cattle ranching' AND/OR 'Vampire bats', B_3 'Livestock attacks' OR 'Livestock mortality' AND 'Vampire bats' OR '*Desmodus rotundus*', B_4 'Human-wildlife conflict' AND 'Neotropical bats', B_5 'Ranchos ganaderos' AND/OR 'Murciélagos neotropicales', B_6 'Ranchos ganaderos' AND/OR 'Murciélago vampiro' OR '*Desmodus rotundus*', B_7 'Ataques al ganado' OR 'Mortalidad de ganado' AND 'Murciélago vampiro' OR '*Desmodus rotundus*', B_8 'Conflicto humano-vida silvestre' AND 'Murciélagos neotropicales'. Google Scholar and Dimensions provided the highest number of results; however, we only reviewed the first 30 pages because, after these pages, we observed a reduction in the specificity of the searches with the keywords.

We counted the number of articles related to the keywords in each search. According to the criteria of information in the title and abstract, we chose to review studies that evaluated any aspect related to the conflict between cattle production and the vampire bat, including: risk factors for vampire bats attacks on domestic/wild animals; assessment of the vampire bat–cattle conflict; strategies employed to manage the problem; and use of space by the vampire bat and its association with cattle management attributes and landscape structure. The documents we selected were systematised in a database to exclude duplicated records. Subsequently, we reviewed and analysed the full text of these articles to select the information that directly contributed to our objective.

RESULTS AND DISCUSSION

The searches yielded 4730 documents associated with the keywords, from which 128 were initially selected for review based on the information in the title and abstract (Table 1; Appendix S1). After reviewing the full texts, we selected 54 articles with information on factors associated with the vampire bat–cattle conflict (Appendix S1). The studies we selected took place in 16 countries and were published from 1971 to 2021; most of the information was from Mexico and Brazil (Fig. 1).

Cattle management and landscape context as factors associated with vampire bat feeding events in cattle

The composition and configuration of the landscape where cattle graze, combined with the characteristics of the cattle management system (e.g. degree of cattle confinement, forage production strategy, periodicity of individual replacement or breed composition), are likely to be the main factors determining the probability of vampire bat feeding events and, therefore, the risk of transmission of the rabies virus to cattle (Delpietro & Russo 1996, Novaes et al. 2010, Bárcenas-Reyes et al. 2015, de Andrade et al. 2016, Goncalves et al. 2017, Ávila-Flores et al. 2019, Bolívar-Cimé et al. 2019, Mendoza-Sáenz et al. 2021). The possibility of finding individual bats that test positive for bovine rabies is latent. Therefore, extensive deforestation and habitat fragmentation, as well as impacts associated with cattle ranching or human settlements, could be important scenarios to trigger positive cases of rabies (Schneider et al. 2009, Botto-Nuñez et al. 2020).

Cattle management systems determine the degree of interaction between vampire bats and livestock. Extensive management systems (those where cattle have a certain degree of autonomy over diet selection through grazing, water consumption and access to shelter; OIE 2021) located close to wooded areas in which cattle graze freely, increase the frequency of vampire bat feeding events on cattle, compared with management systems in open areas that lack arboreal vegetation (Arellano et al. 1971, Gomes et al. 2007, Novaes et al. 2010, Ávila-Flores et al. 2019, Lanzagorta-Valencia et al. 2019, Mendoza-Sáenz et al. 2021). This suggests that efforts to mitigate the impact of the vampire bat in cattle production should focus on areas with free-grazing systems located in the interface with forest fragments. On the other hand, in intensive or confined cattle management systems, encounters between vampire bats and cattle are primarily determined by ranch infrastructure, including the architecture of shelters and characteristics of the immediate area. For example, shelters with walls, roofs and lightning, which are also close to roads and towns with high human activity, exhibit a low incidence of vampire bat attacks (Moya et al. 2015, Lanzagorta-Valencia et al. 2019).

Food availability for vampire bats (e.g. cattle) plays a prominent role in this human–wildlife conflict. Increasing land used for cattle farming has benefited the vampire bat, because cattle provide highly abundant, easily accessible food within the bats' habitat (Delpietro et al. 1992, Brown 1994, Becker et al. 2018, Bolívar-Cimé et al. 2019, Sánchez-Gómez et al. 2022). In the last decades, the geographical expansion of ranching has made this conflict more noticeable, which shows that the ultimate cause of the problem is the process of cattle production and the invasion of the natural habitat of the vampire bat, derived from the economic interests of the ranchers.

The landscape where cattle production occurs plays an important role in the interaction between vampire bats and cattle. Vampire bats use riparian zones, forest fragments, acahuales (secondary vegetation, generally shrublands and immature trees), tree lines and forest edges to move around cattle-ranching landscapes. These landscape elements provide roosting sites and facilitate orientation, since the ability of vampire bats to detect small objects or calculate distances through echolocation is limited (Joermann 1984, Rodríguez-San Pedro & Allendes 2016). The presence of water courses (rivers, lakes and other types of aquatic environments) is important for the presence and abundance of vampire bats in cattle breeding areas (Mendoza-Sáenz et al. 2021). Bats probably use them as corridors for food searches, or simply because these areas provide suitable resting places (Lord 1988, Tadei et al. 1991, Ávila-Cabadilla et al. 2012) since they are little used for anthropic activities.

Table 1. Number of documents found for the review in the scientific literature search engines, from which 128 documents were selected (see Appendix S1). B_{1-8} refer to the eight systematic searches that we conducted with different search terms (see Methods for details)

Search engine	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	Total
ScienceDirect	73	48	181	96	0	0	2	0	400
Google Scholar	300	300	300	300	300	220	300	6	2026
Scielo	134	164	12	16	34	0	0	0	360
Dimensions	300	300	300	300	300	300	75	44	1919
Web Of Science	1	4	15	2	1	0	1	1	25

The availability of roosting sites and their proximity to grazing areas also influence the feeding prevalence of vampire bats on livestock (Moya et al. 2015, Mendoza-Sáenz et al. 2021). This may explain why vampire bats are more abundant in agricultural landscapes with forests and riparian areas (Ávila-Cabadilla et al. 2012). Although they use caves as their main roosting sites, trees also represent an important resource, particularly large trees with holes and cavities (Flores-Crespo 1978, Uieda 1996). However, artificial refuges (abandoned mines, tunnels, uninhabited houses and culverts; Greenhall et al. 1983, Flores-Crespo & Arellano-Sota 1991, Gomes & Uieda 2004) close to food sources have replaced natural refuges in some scenarios.

The vampire bat is abundant in fragmented landscapes with 30 to 60% forest cover, where small wooded patches are interspersed with open pastures (Estrada & Coates-Estrada 2002, García-García & Santos-Moreno 2014, Ávila-Gómez et al. 2015, Kraker-Castañeda et al. 2017, Bolívar-Cimé et al. 2019). By contrast, vampire bats may be rare or absent in landscapes with high cover of continuous forest, without livestock and with low availability of roosting sites (Saldaña-Vázquez et al. 2010, Kraker-Castañeda et al. 2017). The low abundance of vampire bats in natural areas should be even more accentuated if the local ecosystem is subject to defaunation due to hunting and other human activities.

Fig. 1. Map showing the study area and the number of selected publications by country which resulted from the systematic searches of the literature on the common vampire bat *Desmodus rotundus* and its association with attacks on domestic or wild animals, the characteristics of the landscape and cattle management. No research was conducted in Honduras, El Salvador, Colombia, Venezuela, Guyana, or Suriname, though these countries are within the geographic range of the vampire bat. The USA and the majority of Argentina and Chile fall outside the range.

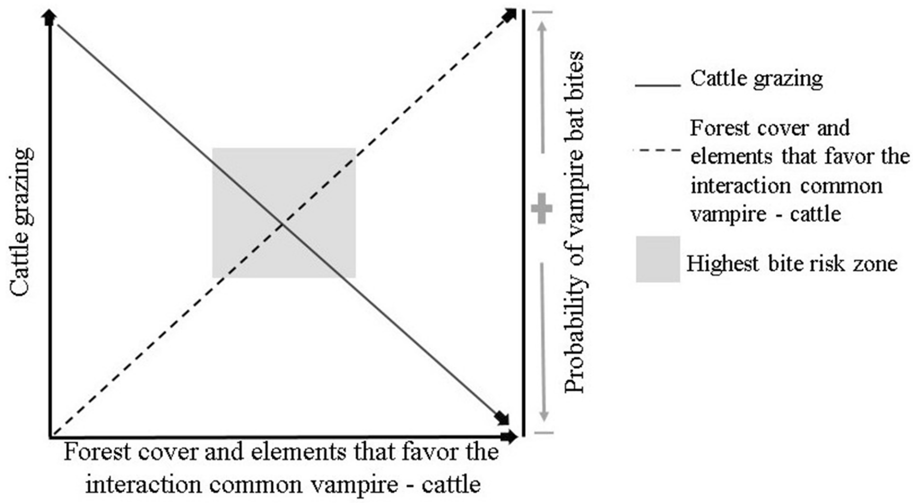

Fig. 2. Probability of common vampire bat *Desmodus rotundus* bites on cattle and risk of bovine rabies transmission.

The wing morphology and echolocation of vampire bats contribute towards our understanding of their preference for fragmented landscapes. Wing morphology in bats is associated with habitat use, flight and foraging performance due to different selection forces (Norberg & Rayner 1987). Vampire bats have broad, short wings and high wing loading (weight/wing area), imposing restrictions for flying in open areas and manoeuvring in highly cluttered areas. The wing morphology of vampire bats is adapted to semiopen habitats with low structural complexity, such as forest edges, unlike species with narrow and elongated wings that are adapted to flying fast and manoeuvring in open areas (e.g. species of the family Molossidae; Salgado-Mejía et al. 2021).

Vampire bats emit short, broadband, low-intensity echolocation pulses for spatial orientation (Schmidt & Schmidt 1977, Rodríguez-San Pedro & Allendes 2016). These types of echolocation pulse are best suited to detecting details of small objects and to distinguishing them from the proximate background. However, the weakness of such pulses is that they result in short detection ranges for objects (including hosts) via echolocation (Rodríguez-San Pedro & Allendes 2016). The latter characteristic probably conditions vampire bats to rely on linear elements of the landscape as landmarks for spatial orientation, which is key to understanding why this species avoids open fields (Ávila-Flores et al. 2019). Although vampire bats also use vision for spatial orientation, they are limited by their visual field and tend to move close to the ground in search of hosts, during commuting flights, and to reach their roosting sites (Eklof 2003, Rodríguez-San Pedro & Allendes 2016, Ávila-Flores et al. 2019).

Ecomorphology could support the idea that vampire bats prefer wooded areas to avoid moonlight and minimise predation risk (Mitchell & Burns 1973). However, it is necessary to improve our understanding of the daily foraging activity of the vampire bat and the nocturnal foraging activity of livestock, in order to understand the possible effect of lunar light on vampire bat foraging and the risk of cattle attacks. Alternatively, vampire bats could prefer flying in the darkness, protected by tree canopies, to maximise the effectiveness of echolocation at the expense of vision (a similar trade-off hypothesis is proposed for vampire bats by Wu et al. 2018). Therefore, a landscape with grazing areas located closer to these elements provides a higher encounter probability between vampire bats and cattle. In consequence, fragmented landscapes connected by linear features will favour the detection of hosts, which may result in a higher risk of rabies virus transmission (Gomes et al. 2007, Sampedro et al. 2008, Novaes et al. 2010, Mendoza-Sáenz et al. 2021).

The movement patterns of vampire bats suggest that, when foraging, their home range size is variable (Crespo et al. 1961, Wilkinson 1985, Flores-Crespo & Arellano-Sota 1991, Trajano 1996), with nightly movements of up to 15–20 km (Malaga-Alba 1954). Cattle are most vulnerable to vampire bats when they graze in wooded areas or close to linear landscape elements, and vampire bats are rarely captured in open fields (Medina et al. 2007, Ávila-Flores et al. 2019, Mendoza-Sáenz et al. 2021). Our observations support this idea, since they indicate the absence of bites in a herd confined in an open field. In the latter scenario, we found the closest wooded elements providing habitat and connectivity to vampire bats at 1 km from the herd, in a lagoon system composed of high forest cover, riparian zones and linear edge elements, where there are records of the vampire bat.

Reducing interactions between the vampire bat and cattle in Neotropical landscapes

Despite the strategies coordinated and implemented by federal agencies, vampire bats frequently feed on cattle in Neotropical landscapes. Methods used to mitigate this problem have not produced the expected impact. Many authors have questioned their long-term effectiveness in controlling vampire bat populations and the occurrence of bovine paralytic rabies outbreaks (Streicker et al. 2012, Correa-Scheffer et al. 2014, Osorio-Rodríguez & Saldaña-Vázquez 2019, Kraker et al. 2021). Currently, there are no sustainable solutions to address the problems derived from the interaction between the vampire bat and livestock, which, combined with the emergence of SARS-CoV-2, has generated a new context where human perception of bats has become more complicated. Future scenarios will require a sum of efforts and strategies to mitigate the problem.

We recognise that the conflict between the vampire bat and cattle ranchers relates to cattle production system and producers' economic interests. This juncture improves habitat suitability for vampire bats by providing abundant food sources and novel roosting sites with multiple flight pathways to reach them. Therefore, we recognise a strong influence of the landscape structure and the intrinsic characteristics of the vampire bat (e.g. wing morphology and echolocation), which influence its movement and foraging patterns. The susceptibility of cattle to rabies and all related factors (e.g. natural and induced immunity) are additional factors not addressed in this review. We are dealing with a multifactorial problem, as argued in the past.

It is important to reduce the cattle-ranching process as much as possible to mitigate the conflict with the vampire bat (e.g. by reducing cattle density per ranch or pasture plot). Also, we can identify elements of the surrounding landscape that favour the movement of vampire bats and establish cattle management systems that reduce the encounter rate between vampire bats and cattle. Under this scheme, our premise is that the greatest risk to cattle (probability of being attacked) is a function of their population size and mobility due to management, combined with the physiographic and ecological elements that favour interactions with vampire bats (Fig. 2).

To reduce the conflict, we propose a strategy of territorial reorganisation of cattle production units and pasture plots based on three elements: cattle management, landscape structure and the ecology of the vampire bat. In the spatial reconfiguration of production units, ranchers should avoid forested areas and place cattle herds as far away as possible from these areas. Cattle should be separated from potential roosting sites for the vampire bat, such as caves, steep rocky hills and abandoned human constructions, as well as continuous forests, forest fragments, riparian zones and other elements of the landscape that function as biological corridors, in order to restrict the movement of vampire bats towards cattle.

One key point for this proposal is to evaluate the distances that vampire bats can travel in open fields. Based on the available information, we recommend separating the cattle from the elements of the landscape that favour the movement of vampire bats by at least 1 km if possible, or at least restricting cattle movements at night to more than 200 m from linear landscape elements. The latter distance is because the attributes of the immediate landscape surrounding the site (in a radius of at least 200 m), where cattle rest at night, influence the probability of being bitten by vampire bats (Lanzagorta-Valencia et al. 2019).

The feasibility of implementing this proposal should be evaluated with the participation of ranchers, since it entails cultural considerations, family or community decisions and investment of time, effort and probably money. Separating cattle-grazing areas from forests by 1 km is a difficult task in the field because of the size of the area involved. Otherwise, the idea is to separate them as much as possible, depending on the producers' capacity and the production units' areas. Relocating cattle herds would imply a trade-off associated with the disablement of certain grazing areas, which the producers would have to change and give a new land use in exchange for avoiding interactions with vampire bats. These ranch areas would generate a 'buffer zone' that they can use to create systems multipurpose. The areas could be used for crops of human consumption, some trees, shrubs or forage crops to supplement the cattle diet (Murgueitio et al. 2011). Therefore, there should be a territorial restructuring at the ranch level to avoid having grazing areas adjacent to landscape elements that provide habitat to vampire bats and favour their interaction with cattle.

We now know that a triggering factor in the dependence of vampire bats on the landscape elements mentioned above is their sense of spatial orientation and movement patterns. The latter is key to consider in cattle production strategies that are highly affected by the presence of vampire bats. If the vampire bat's traits truly limit this species, the proposed spatial reconfiguration of cattle herds away from elements that provide habitat would drastically reduce their interaction with cattle.

This proposal is specific to cattle systems highly affected by vampire bats and many producers. Producers with a high density of cattle, who are dedicated exclusively to this sector or invest more considerable economic resources, tend to manage larger grazing areas (when management is extensive). They can establish a territorial reorganisation at the ranch level, considering the characteristics of the landscape to establish cattle production that reduces the conflict with the vampire bat. Similarly, small producers can coordinate with small property owners through rancher associations. There should be a strategy to diversify agricultural activities. Agricultural or forage crop areas are advantageous as a barrier to separate grazing areas from other landscape elements that provide habitat to vampire bats to reduce the risk of interactions with cattle.

The Neotropical region comprises a wide diversity of scenarios with particular social, environmental, and spatial contexts that form distinctive ecosystems. Therefore, there will be scenarios where the implementation of this proposal must be carefully analysed, where it is probably not applicable, or has to be a complementary strategy. For example, in South American countries, specifically in the Amazon region, it is common for humans to be a secondary source of food for the vampire bat (Schneider et al. 2009). The latter situation has caused a change in the epidemiological profile of rabies in Brazil, which places the vampire bat as the main agent responsible for rabies virus transmission to the human population (Horta et al. 2022). Given this scenario, the mobility of livestock that acts as the first option for a food source could cause vampire bats already established in that area to seek humans as an alternative source of food and increase the number of attacks on humans (López et al. 1992, da Costa et al. 1993, Goncalves et al. 2002). Therefore, we must point out that, although the proposal may be applicable in many areas of the Neotropical region, it is limited to scenarios where the problem of vampire bat attacks is restricted only to livestock.

CONCLUSIONS

The conflict between vampire bats and cattle production is related to the form of production. The severity of the conflict depends strongly on the system of cattle production, the structure of the surrounding landscape and the biology of the vampire bat as a multifactorial problem. The most non-invasive strategy to reduce interactions between vampire bats and cattle is establishing a buffer zone. With a buffer zone, cattle herds are kept away (at least 1 km, or as far as possible) from the landscape elements that are key to the movement patterns of vampire bats. As a minimum, cattle movements at night should be restricted to areas more than 200 m from linear landscape elements. The proposed buffer zone can have advantages in containing multipurpose systems. It can provide crops for human consumption or forage to supplement the cattle diet. This proposal can complement pre-established strategies for the mitigation of the problem, once it has been validated with the participation of the producers. It is important to mention that this type of proposal would be enriched by debate with and participation of expert researchers in the study of the natural history of the vampire bat and with specialists in cattle management, which we trust will happen in the future to improve the proposal.

Recommendations for cattle systems

We recommend reassessing the strategy of extensive cattle production and detain the ranching process in forestry areas, since cattle availability is positively associated with the feeding prevalence of the vampire bat. We recommend implementing territorial restructuring in cattle ranches so that grazing areas are separated by a buffer zone from areas with forest cover. The highest risk associated with the vampire bat is a function of higher levels of host availability and elements that provide habitat to vampire bats, thus favouring interactions with cattle. We suggest conducting studies on the movement patterns of vampire bats in open fields, which would reinforce the proposal and help to improve the management of anthropised landscapes and the coexistence between cattle production and bat populations. Rabies vaccination programmes should represent the first preventive strategy for the transmission of bovine rabies, which is central to this problem. Establishing and reinforcing communication links between producers and institutions responsible for monitoring animal health and zoonosis risks is necessary. We recommend establishing an epidemiological surveillance system in wild populations and reinforcing institutional programmes, scientific research, personnel training and the development of human resources to monitor and attend to human and animal health.

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DATA AVAILABILITY STATEMENT

Data base of the literature revised and selected in our study are freely available online in the supplementary material of the paper.

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article at the publisher's website.

Appendix S1. Specialised literature on the vampire bat that is reviewed and cited in the manuscript.