Ecological Processes

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Camera traps reveal the natural corridors used by mammalian species in eastern Mexico

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Abstract

Background: Habitat loss and fragmentation in the Sierra Madre Oriental (SMO) ecological corridor have negative impacts on the movement and distribution of mammalian species that are of great ecological and evolutionary importance. Part of the SMO ecological corridor that is located in the state of Hidalgo is less studied despite being a potential dispersal route for mammals. The objectives of this study were to evaluate the presence and activity of terrestrial mammals in the riparian and non-riparian zones of SMO.

Results: Camera traps detected 15 mammalian species (i.e., 14 native and 1 domestic) in the non-riparian zone, and 12 mammalian species in the riparian zone (i.e., 10 wild and 2 domestic). The riparian corridor was mainly used by opportunistic medium-sized carnivores, while large carnivores and their potential prey were more frequent in the non-riparian zone.

Conclusions: Our findings suggest terrestrial mammals avoid the use of natural corridors due to the presence of domestic dogs, cattle and humans and look for new dispersal routes to move through their habitat and find the resources they need to survive. Even though some species can use disturbed corridors to move and find resources, they will change their activity patterns to avoid contact with humans and potential threats like dogs. It is, therefore, crucial to identify not one, but several corridors that must be preserved to improve the connectivity of terrestrial mammals in disturbed landscapes.

Keywords: Activity, Jaguar, Cattle, Detectability, Dog, Herbivore, Disturbance, Prey, Relative abundance

Background

Movement is essential for organism persistence as it is related to ecological and evolutionary processes (Nathan 2008). Studies have shown that movements are necessary to search for resources and mates, and to avoid predators or competitors, all of which are associated with survival and breeding (Fahrig 2007). However, the ability of species to move through their habitats is influenced by various human-induced activities such as agriculture (Hilty et al. 2006; Scanes 2018), invariably affecting species richness and diversity in any given area (Jackson and Fahrig 2013). It is therefore necessary to conserve or restore degrading habitats to improve connectivity via corridors across protected and unprotected areas (Hilty et al. 2006). The connectivity of habitat patches encourages the exchange of individuals across populations, which also increases genetic diversity (Rosenberg et al. 1997). Several landscape elements, such as forests, hedgerows, fences, roadside vegetation, riparian vegetation, and canyons are considered biological corridors (Bennett 1998; Hilty et al. 2006), though the riparian zones, canyons, and other natural formations stand out because they originate from natural processes (Bennett 1998).

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For terrestrial mammals, riparian zones allow them to move through fragmented landscapes such as farmlands (Hilty and Merenlender 2004; Paolino et al. 2018), and to search for resources in different seasons of the year (Phoebus et al. 2017). Riparian zones are also vital for species sensitive to habitat disturbance because they provide higher habitat quality and more space to move within disturbed areas (Zimbres et al. 2017, 2018).

In Mexico, the Sierra Madre Oriental (SMO) Ecological Corridor was designated to enhance habitat connectivity and biological diversity (Del Río-García et al. 2020; Rodríguez-Soto et al. 2011, 2013; Dueñas-López et al. 2015). However, routes used by different mammalian species are relatively unknown and require additional attention (Hilty et al. 2006) to formulate robust conservation actions (Ripple et al. 2014).

Therefore, the objective of the current study was to determine the presence and activity of terrestrial mammals in the riparian and non-riparian corridors within the study area. We hypothesize that mammals sensitive to disturbance will use the riparian zone to locate resources.

Methods

Study area

The SMO is a physiographic region (Morrone et al. 2017) with mountain ranges separated by valleys with average elevations from 1500 to 1700 m asl (Fig. 1). It extends from the northern border of Tamaulipas to the southern end of Puebla (Solana López 2008). This region has undergone extensive land-use changes due to the expansion of agricultural land and infrastructural development, causing habitat loss and fragmentation for many wildlife species (Sahagún-Sánchez et al. 2011). Like the rest of the SMO, the Sierra de Hidalgo is a region disturbed by changes in land use that have transformed natural vegetation into farmlands (Lorenzo Guillermo et al. 2019). Despite this disturbance, the state of Hidalgo is rich in mammalian species (Aguilar-López et al. 2015; Morales García et al. 2015, 2016; Sánchez Rojas et al. 2016).

The study was carried out in an area that connects two Natural Protected Areas (NPAs), including the Sierra Gorda Biosphere Reserve, and Los Mármoles National Park, located in the municipalities of Pacula and Jacala de Ledezma, Hidalgo. These connecting areas are privately

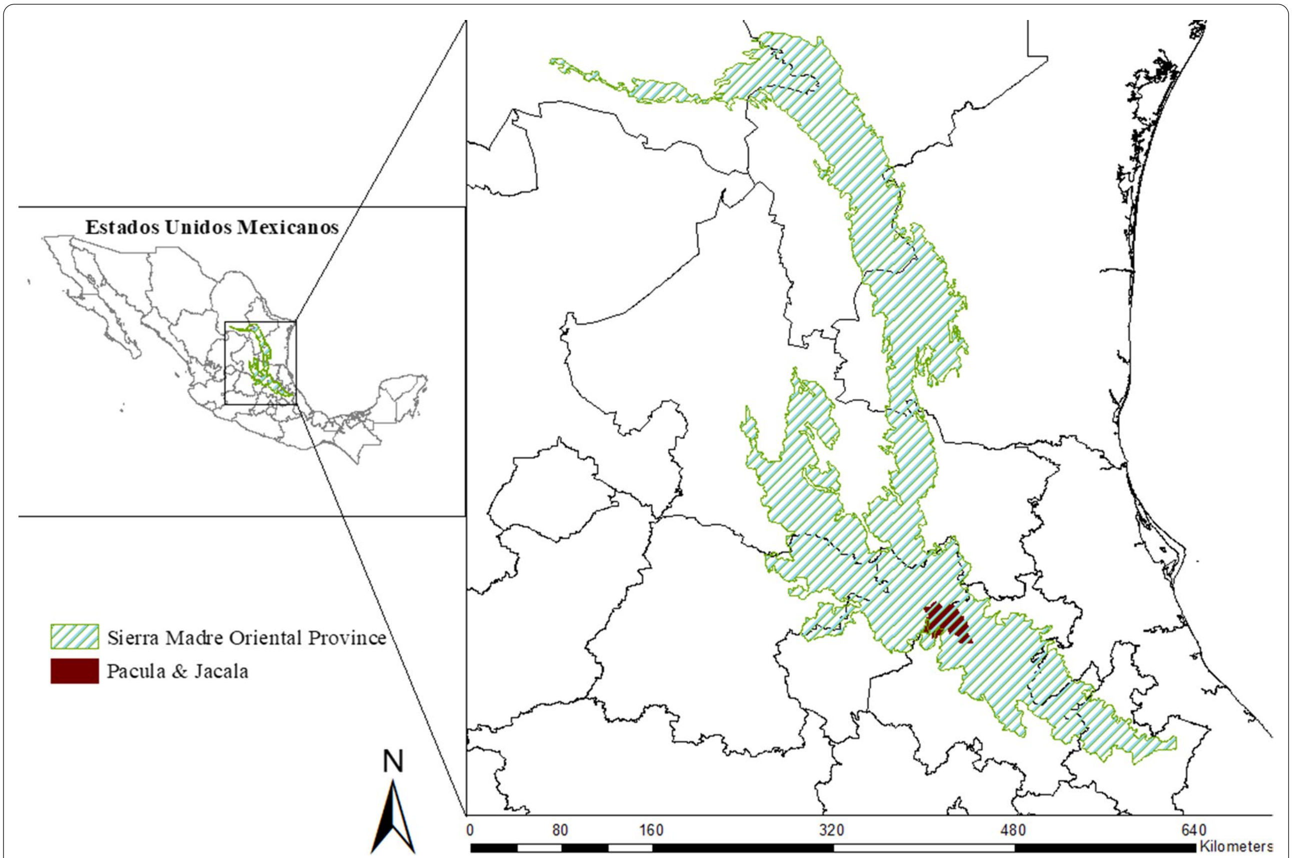

Fig. 1 Sierra Madre Oriental physiographic region, obtained from the shapefiles of Morrone et al. (2017)

owned by communal land owners, to which we were granted access.

Secondary vegetation is dominant, but is interspersed with crop and livestock farming (INEGI 2009a, b; Chokkalingam and De Jong 2001; Lorenzo Guillermo et al. 2019) and ranges from 400 to 2500 m asl. The climate is subhumid with annual temperatures ranging from 14 to 24 °C, and annual precipitation ranging from 500 to 1100 mm (INEGI 2009a, b). The land uses and vegetation types in Pacula and Jacala, respectively, consist of pine–oak forests (58% and 63%), submontane scrub (16% and 17%), cropland (16.8% and 17.4%), urban areas (0.2% and 0.6%). Pacula also contains lowland deciduous forest (7%) and grassland pasture (2%) (INEGI 2009a, b).

Camera-trapping

We conducted terrestrial mammal surveys at two sites, including one that had perennial streams (riparian zone) and one that had non-perennial streams (non-riparian zone). We sampled during the dry season from January to April 2019, a time when non-perennial streams were completely dry, unlike the riparian zones (Fig. 2).

We used infrared sensor cameras (Bushnell Trophy Cam HD®, Cuddeback digital E3®, and Stealth Cam STC-Q8X®) for sampling. We set eight single-camera stations at wildlife crossings adjacent to permanent water bodies in the riparian zone, and eight single-camera stations at wildlife trails or ravines in the non-riparian zone (Bender et al. 2017). We placed the camera-traps with a distance of 1.5 to 2.5 km between them, 50 cm from the ground, oriented north–south, and programmed to take three photographs every 30 s for 24 h (Cove et al. 2013; Hernández-SaintMartín et al. 2015). We checked the cameras every 15–20 days to change the batteries and memory cards (Bender et al. 2017) to ensure an operating time of 70 days. At the end of the sampling period, we compiled the photographs registered in the camera-traps using the program Wild ID® to identify the mammalian

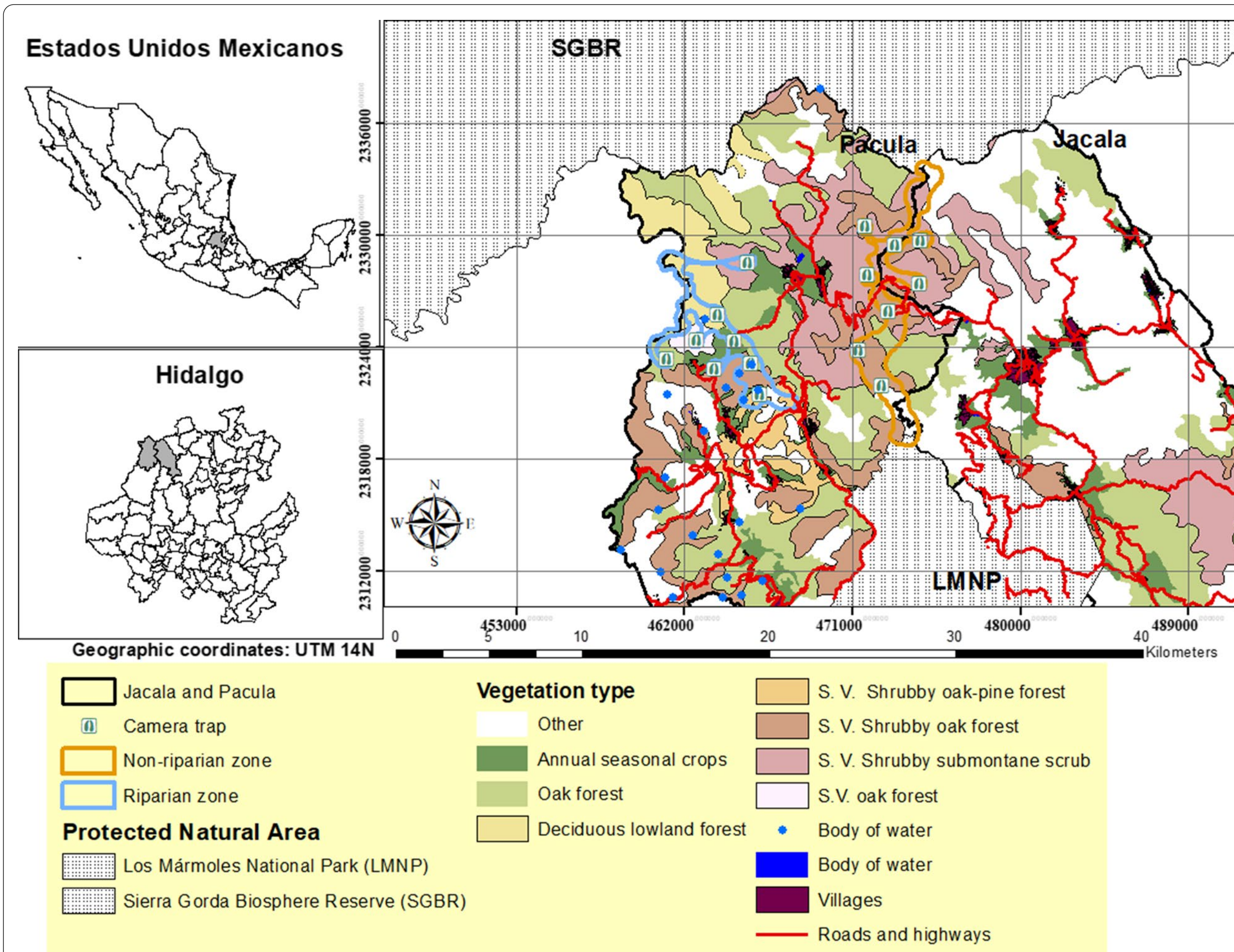

Fig. 2 Locations of camera traps in the municipalities of Pacula and Jacala, Hidalgo

species and create an occurrence database (Hilty and Merenlender 2004) for subsequent analyses.

Relative abundance index of terrestrial mammals

Based on the mammal photographic records, we estimated the relative abundance indices (RAIs) for each species in each of the zones. First, we determined the number of independent events following the methodology of O'Brien et al. (2003), where an independent event is a set of photographs of individuals of the same or different species taken more than 1 h apart. Where we recorded several individuals of the same species, their total number was estimated (Cruz-jácome et al. 2015). Subsequently, we calculated the RAI as the number of independent events per species divided by the total number of trap days and multiplied by 100 (O'Brien et al. 2003). With this formula, we estimated the mean and standard deviation of the RAI for each species in both sampling sites using the RAI statistical package in the R® Statistical Software (Mandujano 2019).

In this study, the RAI was not considered an estimate of abundance of mammals since this index can be affected by other factors, such as camera placement, home ranges or species movement (Sollmann et al. 2013), as the RAI assumes constant detections (O'Brien 2011). We therefore considered the RAI as an activity index, where the activity of species increases when there are more individuals or because they use the sites where they are recorded more frequently (Sollmann 2018).

Activity patterns of terrestrial mammals

From the independent events obtained for each mammal in the riparian and non-riparian zone, we analyzed the activity patterns of the species that had at least 11 independent events (Hernández-SaintMartín et al. 2013) to estimate accurate coefficients of overlap for the species (López-Tello 2019). Following the method of Romero-Muñoz et al. (2010), we obtained the percentage of diurnal and nocturnal activities to determine their categories based on established ranges: diurnal (< 15% of observations at night), nocturnal (> 85% of observations at night), mostly diurnal (15–35% of observations at night), mostly nocturnal (65–85% of observations at night), or cathemeral (organisms active intermittently day and night).

We then determined the overlap coefficient (Dhat) using 0 (different activity) and 1 (same activity). The estimates of overlap and activity patterns were obtained through the overlap package in the statistical software R® (López-Tello 2019).

Results

We recorded a total of 14 species of wild mammals and one domestic mammal in the non-riparian zone during a 420-day sampling period with eight camera traps. In the riparian zone, we detected 10 species of wild and two domestic mammals with a sampling effort of 351 days using seven camera traps (Table 1; Fig. 3). We recorded some noteworthy mammals, jaguar (*Panthera onca*), tayra (*Eira barbara*), and margay (*Leopardus wiedii*) which are listed as endangered species in Mexico (SEMARNAT 2010) and white-tailed deer (*Odocoileus virgninanus*) and collared peccary (*Pecari tajacu*), which are prey for jaguar and puma (*Puma concolor*).

Likewise, we also observed greater use of the riparian zone by domestic animals and humans compared to the non-riparian zone. On the other hand, herbivores such as white-tailed deer and collared peccary used the non-riparian zone more frequently (Table 1).

In the riparian zone the gray fox (*Urocyon cinereoargenteus*) was the most common carnivore (Fig. 4), while the least encountered was the raccoon (*Procyon lotor*), for herbivores, cattle (*Bos taurus*) were the most abundant, and the least commonly recorded was the collared peccary.

In the non-riparian zone, the gray fox was again the most common carnivore, while the puma was the least common. On the other hand, the collared peccary was the most common herbivore, followed by the white-tailed deer (Fig. 5).

Of the registered mammals, the activity pattern was only estimated for the species with more than 11 independent events, following the recommendations of López-Tello (2019): the gray fox, ringtail (*Bassariscus astutus*), collared peccary, and white-tailed deer. We observed an overlap in the activity pattern of both carnivores (Dhat = 0.87), with the gray fox being mostly nocturnal and the ringtail completely nocturnal (Fig. 6).

In the case of herbivores, we did not observe an overlap (Dhat = 0.35), although both species are mostly diurnal, having activity peaks at different times of the day (Fig. 7).

Discussion

Our research results suggest that some terrestrial mammals might avoid natural corridors where human activities are present. We hypothesize that mammals sensitive to disturbance will use the riparian zone to locate resources, and our results reject this hypothesis since we only recorded eurytopic mammals in the riparian zone, such as gray fox, ringtail, raccoon, and Virginia opossum (*Didelphis virginiana*). All of these are species capable of exploiting numerous resources

Table 1 Independent events and relative abundance index of terrestrial mammals in riparian and non-riparian zones

Common name	Scientific name	Riparian corridor		Non-riparian corridor	
		Independent events	RAI	Independent events	RAI
American hog-nosed skunk	*Conepatus leuconotus*	1	0.35 ± 0.92	4	0.72 ± 1.08
Collared peccary	*Pecari tajacu*	1	0.2 ± 0.54	60	12.14 ± 31.56
Cougar	*Puma concolor*	–	–	1	0.18 ± 0.51
Cattle	*Bos taurus*	25	7.14 ± 18.9	20	3.57 ± 6.06
dog	*Canis lupus familiaris*	9	2.98 ± 4.48	–	–
Gray fox	*Urocyon cinereoargenteus*	84	27.23 ± 42.64	32	11.43 ± 20.3
Hooded skunk	*Mephitis macroura*	8	2.6 ± 4.79	4	0.72 ± 1.32
Jaguar	*Panthera onca*	–	–	7	1.25 ± 3
Margay	*Leopardus wiedii*	–	–	1	0.42 ± 1.18
Mexican gray squirrel	*Sciurus aureogaster*	3	0.61 ± 1.13	1	0.18 ± 0.51
Mouse	*Rodent* sp.	3	0.82 ± 2.16	5	0.89 ± 2.52
Virginia opossum	*Didelphis virginiana*	12	3.87 ± 7.35	–	–
Racoon	*Procyon lotor*	1	0.32 ± 0.84	2	0.42 ± 1.18
Ringtail	*Bassariscus astutus*	35	7.24 ± 9.55	9	1.61 ± 3.54
Tayra	*Eira barbara*	–	–	1	0.36 ± 1.01
Western spotted skunk	*Spilogale gracilis*	–	–	1	0.36 ± 1.01
White-tailed deer	*Odocoileus virginianus*	4	0.84 ± 1.09	22	11.01 ± 23.53

The number of camera days for the riparian corridor was 351 and 420 days for non-riparian corridor. Table also shows the number of independent events per species and RAI (mean relative abundance index with standard error)

to survive in disturbed areas (Castellanos-Morales et al. 2009; Rodriguez et al. 2021). Moreover, we recorded the hooded skunk (*Mephitis macroura*), which can tolerate and survive in disturbed areas (Farías-González and Hernández Mendoza 2021). On the other hand, in the non-riparian zone we recorded the margay and tayra, which are known to be sensitive to habitat loss (Presley 2000; Martínez-Calderas et al. 2016).

Likewise, we observed a greater abundance of white-tailed deer and collared peccary in the non-riparian zone, despite being species that are tolerant to habitat fragmentation and moderate hunting (Chávez Hernández et al. 2011). The jaguar and puma were also recorded, probably following their main prey (Hernández-SaintMartín et al. 2015; Booker 2016), avoiding the riparian zone that is highly disturbed (Mora 2017) possibly due to human-induced activities (Lorenzo-Guillermo et al. 2019) that might limit the extent of available habitats and resources.

It should be noted that the absence of some mammals in the riparian zone does not imply that they do not use this corridor, which could have been influenced by factors such as the number of trap nights, sampling design, equipment flaws, among others (Shannon et al. 2014; Si et al. 2014; O'Connor et al. 2017). In addition, some mammalian species might have been missed in the riparian zone, so it's important to estimate detection probabilities to identify factors that might influence species detection (MacKenzie et al. 2006).

The records of eurytopic species in an area with a greater presence of human activities is similar to the results found in other studies, where the ringtail, gray fox, Virginia opossum and raccoon are opportunistic species that inhabit urban areas where they can take advantage of resources found in disturbed areas (Castellanos-Morales et al. 2009; Rodriguez et al. 2021). On the other hand, according to other studies, the hooded skunk lives mainly in riparian zones (Hwang and Larivière 2001; Cervantes et al. 2002), which coincides with our results, since we recorded this species only in riparian zones.

The presence of human-related activities (dogs and cattle) in the riparian zones is likely a principal reason we observed more frequent use of the non-riparian area by mammals in our study (Cao et al. 2016; Yen et al. 2019).

In Yen et al. (2019), the presence and abundance of native mammals increased as they moved away from urban areas in Taipei-Keelung metropolis, particularly in those sections with abundant and freely roaming domestic dogs. Similarly, in an NPA in the Ecuadorian Andes, the presence of dogs negatively affected the occupancy of small-large sized carnivorous mammals, such as the puma (Zapata-Ríos and Branch 2018), skunks (Zapata-Ríos and Branch 2016), deer and other mammals (Guedes et al. 2021). These findings

Fig. 3 Records of terrestrial mammals in riparian and non-riparian corridors. **a** Tayra, **b** margay, **c** jaguar, **d** cougar, **e** collared peccary, **f** white-tailed deer, **g** Ringtail, **h** gray fox, **i** American hog-nosed skunk, **j** hooded skunk, **k** Western spotted skunk, **l** racoon, **m** Mexican gray squirrel, **n** mouse, **o** Virginia opossum, **p** cattle, **q** dog

Fig. 3 continued

Fig. 3 continued

correspond with our work, where species such as the puma and the western spotted skunk were only recorded in the non-riparian zone and other species such as the American hog-nosed skunk (*Conepatus leuconotus*), white-tailed deer and the collared peccary were more frequent.

Cattle can negatively affect wildlife in riparian areas through intense competition for food resources, and soil compaction (Kaweck et al. 2018). This trend has been observed across different species of ungulates that are either sensitive or tolerant to the presence of cattle (Chaikina and Ruckstuhl 2006). Cao et al. (2016) even reported that as the intensity of grazing by cattle increased, the richness and diversity of small mammals decreased. These studies corroborate our findings and suggest that the presence of domestic species would deter wild mammals in the riparian compared to the non-riparian zones.

The abundance of white-tailed deer and collared peccary can be affected by the presence of people and the

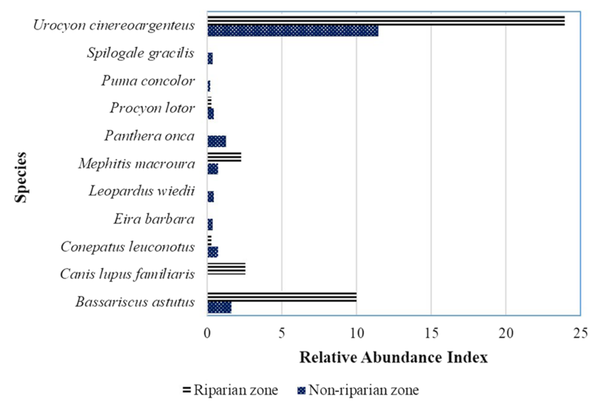

Fig. 4 Relative abundance index of mammalian carnivores in riparian and non-riparian zones

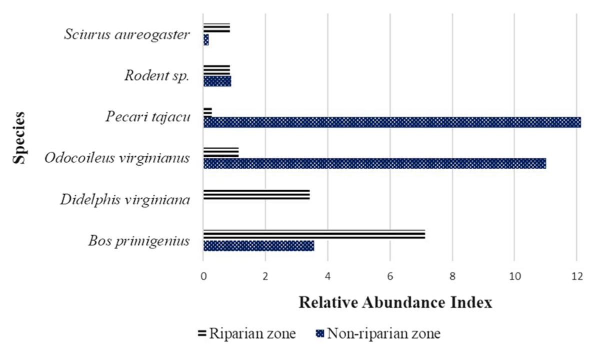

Fig. 5 Relative abundance index of herbivores, omnivorous and granivores mammals in riparian and non-riparian zones

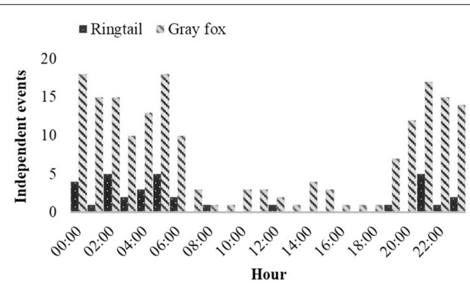

Fig. 6 Activity patterns of mammalian carnivores in riparian and non-riparian zones

resulting increase in hunting pressure. Chávez Hernández et al. (2011) found that these species are hunted intensely in the state of Chiapas, where both species had a low relative abundance. It is possible that both ungulates avoid riparian zones to reduce both competition with cattle and encounters with hunters. Similarly, the

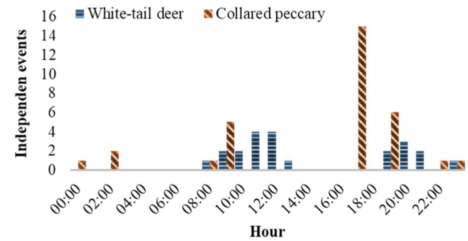

Fig. 7 Activity patterns of large herbivores in riparian and non-riparian zones

jaguar and puma might be avoiding riparian areas to avoid being hunted. In our study area, we found 2 skulls of jaguars that had been shot and we heard several testimonies about the hunting of pumas due to depredation of livestock. This coincides with studies in other regions of the country where there is a negative perception towards large cats (Rosas-Rosas et al. 2003, 2008; Gómez-Ortiz and Monroy-Vilchis 2013; Rojas-Martínez and Soriano 2018). On the other hand, the observation of jaguars and puma in non-riparian zones could be correlated with prey availability, thus influencing their travel routes. Other studies positively correlated the presence of puma and jaguar with potential prey like white-tailed deer, collared peccary, and white-nosed coati (*Nasua narica*) in the NPA of the Abra Tanchipa Biosphere Reserve in San Luis Potosí (Hernández-Saint-Martín et al. 2013, 2015). Similarly, Booker (2016) made similar observations in Calakmul Biosphere Reserve an NPA where that the presence of jaguar was a positively related to the presence of its potential prey.

In the case of skunks recorded in the non-riparian zone, we observed a greater abundance of the American hog-nosed skunk, followed by the hooded skunk, with the least frequent being the western spotted skunk. This suggests temporary segregation to avoid competition as was found in Farías-González and Hernández Mendoza (2021).

We conducted our research during the dry season where the availability of water and other resources is limited in one of the corridors. However, most mammal species have home ranges that probably allow them to move between the two sites to search for resources, since the distance between the two sites is about 5–6 km, with the non-riparian zone being only about 3 km away from water bodies. Some studies document the following home ranges: the jaguar (4–20 km/day; Silva-Caballero 2019), puma (1–3 km/day; Vega-Flores and Farías-González 2021), white-tailed deer (2 km/day; Contreras-Moreno et al. 2021), collared peccary (2 to 11 km^2; Reyna-Hurtado et al. 2017) and medium-sized mammals such as the margay can move up to 6 km a day (Hodge 2014).

For both sites, the gray fox was the most common mammal, followed by the ringtail in the non-riparian zone. Both species had nocturnal activity patterns. Although these species, as well as other mammals in our study, are capable of using resources in disturbed areas (Castellanos-Morales et al. 2009), they might be moving at night to avoid predation in riparian areas by domestic dogs (Guedes et al. 2021). We did observe a dog hunting a ringtail on our study area. Shamoon et al. (2018) noted that some species of mammals restricted their activity patterns to night time in an agricultural field to avoid contact with humans. In our study, we observed where humans attacked a gray fox, which would fit this hypothesis. On the other hand, large mammals such as collared peccaries and white-tailed deer not only avoid contact with humans, but also avoid predators (Shamoon et al. 2018). Hernández-SaintMartín et al. (2013) observed diurnal activity patterns for collared peccaries and white-tailed deer, while their main predators had cathemeral activities in the northeast of the SMO. In our work, both the collared peccary and the white-tailed deer had diurnal activity, which suggests that they might be avoiding an overlap of activities with their predators. Although we were unable to estimate the activity of the jaguar and puma due to low sample sizes, both carnivores were recorded only at night, which might cause their prey to move only during the day to avoid predation.

Conclusions

Terrestrial mammals would avoid the use of natural corridors with the presence of domestic dogs, cattle, and humans, and look for new dispersal routes to move through their habitat and find the resources they need to survive. Even though some species like gray fox, ringtail and other species can use disturbed corridors to travel and find resources, they might change their activity patterns to avoid contact with humans and potential threats like dogs. It is therefore crucial to provide more than one corridor to enhance connectivity for terrestrial mammals on disturbed landscapes.

Abbreviations

NPA: Natural Protected Area; RAI: Relative abundance index; SMO: Sierra Madre Oriental; °C: Celsius degree; m: Meter; asl: Above sea level.

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Author contributions

JOHR participated in the study design, placed the camera-traps stations, collected the images, he created the datasets and applied the statistical analysis and wrote the interpretation of the results and was a major contributor in writing the manuscript. OCRR participated in the study design, he chose the study site and helped in the statistical analysis and interpretation of the results and was a major contributor in writing the manuscript. JLAC participated in the study design and helped in the interpretation of the results. LLM participated in the study design and in the analysis of autocorrelation. LATA participated in the study design and in the interpretation of the results. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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