ISSN 0065-1737 *Acta Zoológica Mexicana (n.s.), 29(3): 520-533 (2013)*

ACTIVITY PATTERNS OF JAGUAR, PUMA AND THEIR POTENTIAL PREY IN SAN LUIS POTOSI, MEXICO

ANUAR D. HERNÁNDEZ-SAINTMARTÍN,[1] OCTAVIO C. ROSAS-ROSAS,[1,3] JORGE PALACIO-NÚÑEZ,[1] LUIS A. TARANGO-ARÁMBULA,[1] Fernando CLEMENTE-SÁNCHEZ[1] & ALMIRA L. HOOGESTEIJN[2]

[1]Colegio de Postgraduados Campus San Luis Potosí, Iturbide #73, C.P.78622, Salinas de Hidalgo, San Luis Potosí, México.<anuarhernandez@gmail.com>, <octaviocrr@colpos.mx>, <jpalacio@colpos.mx>, <clemente@colpos.mx>, <ltarango@colpos.mx>
[2]Departamento de Ecología Humana, Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional, Unidad Mérida, Antigua carretera a Progreso Km 6, C.P. 97310, Mérida, Yucatán, México.<almirahoo@mda.cinvestav.mx>
[3]corresponsalauthor: <octaviocrr@colpos.mx>

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ABSTRACT. Jaguars (*Panthera onca*) and pumas (*Puma concolor*) are sympatric species in Mexico and have ecological similarities. The understanding of interespecific interactions between these species are important for effective conservation strategies. We studied activity patterns of jaguars, pumas and their potential prey species through camera-trapping photographs obtained by during four seasonsin the Abra-Tanchipa Biosphere Reserve , San Luis Potosí, Mexico. We described activity patterns of 12 terrestrial vertebrate species, the degree of overlap of jaguar and puma activity; and the prey – predator relationship. Both felids showed cathemeral activity and overlapping between their activities. Jaguar activity showed a significant correlation with eight prey species activity. Puma activity was no related with any prey species activity. Activity peaks of both felids suggest that temporal segregation is a strategy which minimizes interspecific encounters allowing the coexistence of several individuals in this small reserve.
Keywords: jaguar, puma, prey, activity patterns, camera-trapping.

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RESUMEN. El jaguar (*Panthera onca*) y el puma (*Puma concolor*) en México son especies simpátricas y presentan similitud ecológica. El entendimiento de las interacciones interespecíficas entre estas

Recibido: 10/07/2012; aceptado: 07/05/2013.

especies es importante para la elaboración de estrategias efectivas de conservación. Se estudiaron los patrones de actividad del jaguar, el puma y sus presas potenciales, a través del análisis de las fotografías obtenidas en cuatro temporadas de foto-trampeo en la Reserva de la Biosfera Sierra del Abra-Tanchipa (RBSAT), San Luis Potosí, México. Se describieron los patrones de actividad de 12 especies de fauna, el grado de sobreposición en la actividad del jaguar y el puma; y su relación con la actividad de sus presas. Ambos felinos presentaron actividad catemeral con traslape en sus patrones de actividad. La actividad del jaguar está relacionada significativamente con la actividad de ocho especies de presas; la actividad del puma no se relacionó con la actividad de ninguna presa. Los picos de actividad de ambos felinos sugieren que la separación temporal es una estrategia para minimizar los de encuentros interespecíficos que permite la coexistencia de varios individuos en reservas pequeñas.
Palabras clave: jaguar, puma, presas, patrones de actividad, foto-trampeo.

INTRODUCTION

Large carnivores are fundamental elements in all terrestrial ecosystems (Terborgh *et al.* 2001) and one of the most worldwide endangered groups of mammals (Ceballos *et al.* 2005; Weber & Rabinowitz 1996). Large felid populations have been reduced by habitat loss; prey depletion and hunting of individuals for traditional medicine and/or predator control (Inskip & Zimmerman 2009). One of the principal strategies for large felids conservation is the establishment of natural protected areas. Current land management aspects, tolerance and public policy have limited the creation of protected areas large enough to maintain viable population of these species (Parris *et al.* 2003). Under these circumstances, small sized protected areas become more important in large felids conservation (Núñez 2010). However, small protected areas are more susceptible to isolation and degradation processes; strategies for large felids conservation and management should be based in extensive ecological knowledge of the species. This knowledge has toinclude data related to abundance, population dynamics, intra and/or interspecific relationships (Beck *et al.* 2005).

The jaguar (*Panthera onca*) and the puma (*Puma concolor*) are the only species of large felids inhabiting the Americas (Currier 1983, Seymour 1989). Both are considered key and umbrella species (Miller & Rabinowitz 2002); under this paradigm, strategies for its long term conservation should benefit the entire ecosystem (Roberge & Angelstam 2004). In Mexico, the jaguar is listed as endangered and legally protected since 1987 (Diario Oficial de la Federación 2010), however, habitat loss and hunting of individuals in response to livestock predation are the likely causes for a significant reduction of its original distribution, and population numbers (Chávez *et al.* 2005). In contrast, the puma is subject to regulated harvest, but scarce information about their real population status and illegal predator control could represent a threat for their populations (Laundré & Hernández 2010).

Throughout their distribution both jaguars and pumas are sympatric (Haines 2006); in northern habitats both species are very similar in body size (Iriarte *et al.* 1990, Núñez *et al.* 2002), and they can consume the same prey species (Harmsen *et* *al.* 2011, Núñez *et al.* 2000, Taber & Novaro 1997). Despite this ecological similarity, it has been suggested that competition between jaguars and pumas is low because they evolved coexisting strategies (Haines 2006), including trophic segregation (e. g. Aranda & Sánchez-Cordero 1996), mutual avoidance by spatial separation (Taber & Novaro 1997, Scognamillo *et al.* 2003, Núñez *et al.* 2002, Emmons 1987) and different daily activity patterns (Romero-Muñoz 2010). Studies about interactions of these felids conducted in other countries, have reported activity of jaguars as primarily nocturnal (Di Bitteti *et al.* 2010, Emmons 1987, Gómez *et al.* 2005, Maffei *et al.* 2004, Núñez *et al.* 2002, Rabinowitz & Nothingham 1986). In contrast, pumas tend to be more active in crepuscular hours with an important activity along daytime (Di Bitteti *et al.* 2010, Estrada 2008, Núñez *et al.* 2002). The difference in activity patterns has been suggested as a strategy to avoid and / or minimize confrontations, and to maximize the probability of encounter with their preferred prey (Rabinowitz & Nottingham 1986, Harmsen *et al.* 2011).

In this study we analyze temporal activity of jaguars, pumas and their potential prey using data obtained by camera-trapping in the Abra-Tanchipa Biosphere Reserve (RBSAT) San Luis Potosi, Mexico. Previous studies conducted in the region, showed that jaguars and pumas can consume the same prey species and travel along the same trails (Rueda *et al.* in press, Hernández-Saint Martin *in revision*). We expect to find ecological segregation by differential activity patterns in these species. The objectives of this study were 1) to describe and compare activity patterns of jaguars and pumas, 2) to describe activity patterns of potential prey, and 3) to relate activity of both large felids with activity patterns of their potential prey species.

MATERIALS AND METHODS.

Study area. This study was conducted in the RBSAT, in northeastern San Luis Potosi, Mexico (22° 04’ 38’’-22° 23’ 56’’ N and 98° 53’ 07’’-99° 00’ 44’’ O). It is located about 30 km north of Ciudad Valles, the second largest city of the state (Fig. 1). RBSAT is the only federal protected area in the subtropical ecosystems of San Luis Potosi and covers approximately 220 km^2 of well-preserved tropical dry forest surrounded by fragmented areas (Arriaga *et al.* 2000, Rzedowski 2005). The predominant arboreal species are chaka (*Bursera simaruba*), ojite (*Brosium alicastrum*), limoncillo (*Esenbeckia berlianderi*), rajador (*Lysiloma divaricata*), volantín (*Wimmeria concolor*), ebano (*Ebano ebanopsis*), tenaza (*Pithecellobium pallens*), uña de gato (*Zanthoxylum fagara*), chicharrillo (*Harpalyce arborescens*), aguacatillo (*Persea palustris*), palma real (*Sabal mexicana*), and soyate (*Beaucarnea recurvata*) (Rzedowski 2005). The area has 161 vertebrate species including five of the six wild felids of Mexico: the jaguar, puma, ocelot (*Leopardus pardalis*), margay (*L. wiedii*) and jaguarundi (*Puma yagouaroundi*) (Martínez-Calderas *et al.* 2011, Villordo-Galván *et al.* 2010). The topography is rugged with numerous rock outcrops. The eleva-

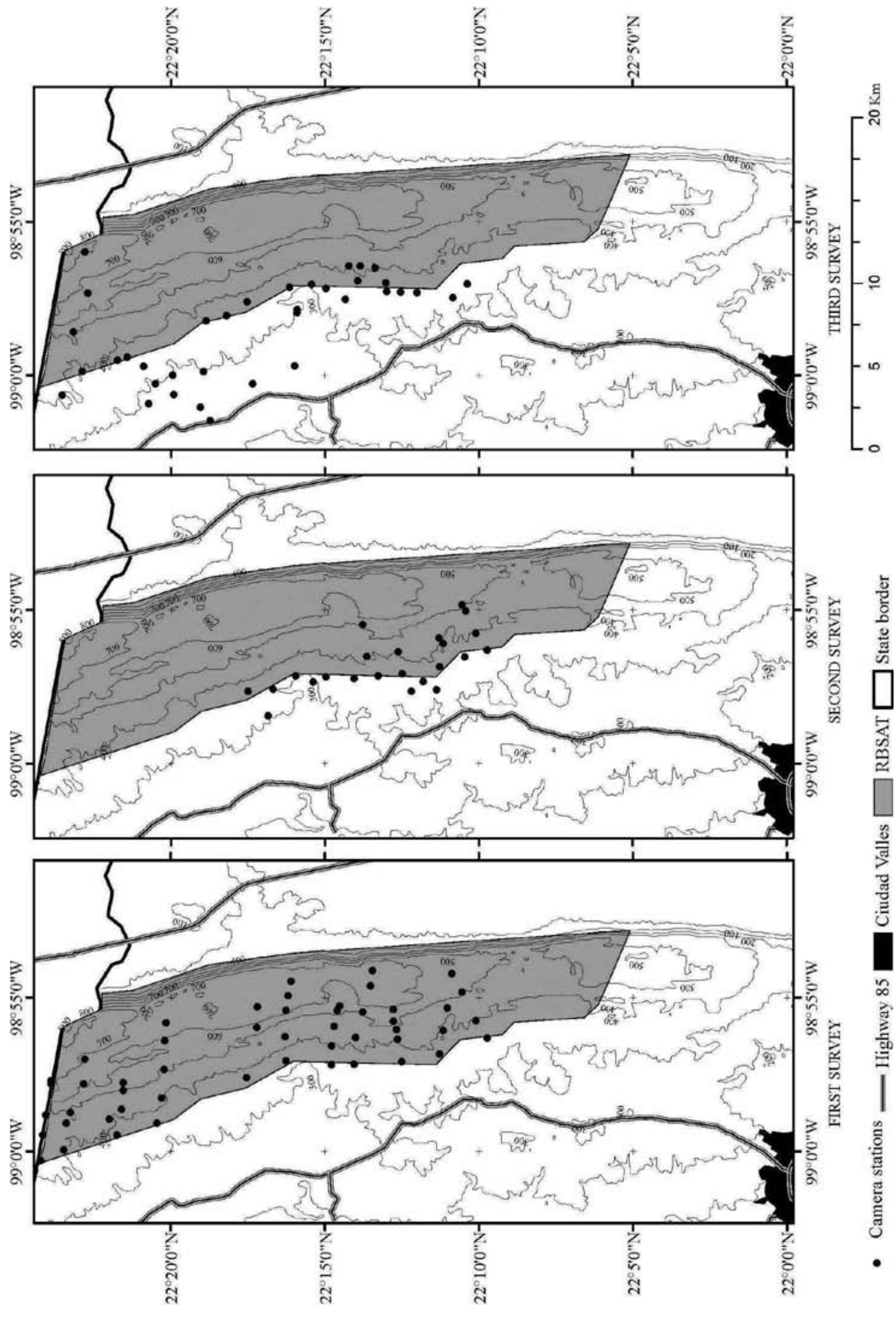

Figure 1. Camera trapping surveys in Sierra del Abra-Tanchipa Biosphere Reserve (RBSAT). Black dots represent camera stations.

tion range from 400 to 700 meters, and an average annual rainfall of 1100 mm with a marked seasonality: torrential rains may be present during July through October (wet season) and the dry season extends from November to May. The average annual temperature is 25.5°C but temperatures can range between 35°C and 50°C (Arriaga *et al.* 2000). The protected area has no perennial waterways, the only water source during the dry season are artificial livestock ponds located outside the reserve. There are few wildlife trails. The only road suitable for vehicles inside the protected area consist in an old mine dirt road to the North. Three firebreaks surround the borders of protected area; the longest runs 20 km along the West border, and two 3 km long are located in the North and South limits. All these trails are rarely used by people; consequently human disturbance in the core area is practically absent. RBSAT is one of the smallest Biosphere Reserves of Mexico (Vargas & Escobar 2000), surrounded by an ongoing change of land use, principally sugar cane (*Saccharum* spp.) plantations to the West and sorghum (*Sorghum* spp.) plantations and cattle ranching to the East (Chapa-Vargas & Monzalvo-Santos 2012). Nine human settlements surround the RBSAT with a total of 3860 habitants.

Data sampling. Data of activity patterns of jaguars and pumas and their prey were obtained through analysis of photographs collected by three camera-trapping surveys (Bridges & Noss 2011) from October 2010 to March 2012. We deployed camera stations inside the core and surrounding areas of RBSAT. Each camera station consisted of one (single stations) or two (double stations) camera traps fixed to trees at 40 cm overground; these were placed in sites with previous evidence of large felids or prey activity (game trails, fresh tracks, scrapes, scats). We programed all cameras to operate continually for 24 hrs with 3-5 minutes delay between photographs; date and hour were printed in each photographic event. We placed camera stations at a distance of two to three km. No attractants were used at camera stations. We checked camera stations every 20 days to verify proper functioning, check-ups included battery changes, photograph unloading and memory/film capacity.

Trapping efforts were different between the three surveys (Table 1). Different camera models were used. In the first survey we deployed 51 camera stations, 45 single and six double composed of the following brands and models: a) thirty three Capture Cuddeback® Digital; b) eight StealthCam® Digital; c) five Xtreme-5 Wildview® Digital; d) three Moultrie® DGS-200 Digital and e) eight DeerCam® DC200 35 mm. During the second survey we used 23 camera stations, 11 singles and 12 double, composed of the following brands and models: a) thirteen Xtreme-5 Wildview® Digital, b) nine StealthCam® Digital; c) five Moultrie® DGS-200-Digital; and d) eight DeerCam® DC200 35 mm. During the third survey we used 27 camera stations, eight single and 19 double composed of the following brands and models: a) nine StealthCam® Digital and b) thirty seven Xtreme-5 Wildview®.

Table 1. Camera trapping surveys in Sierra del Abra-Tanchipa Biosphere Reserve, Mexico.

Survey	Sampling effort (night traps)	Photographs	Independent events
October 16th – December 17th 2010	3264	516	276
April 16th – July 16th 2011	2161	697	287
November 15th 2011- March 11th	3238	937	487
Mean± SD	2887.7±629.4	716.7±211.2	350±118.8

Data analysis. Of all obtained photographs we select those that consisted of independent events. We define these independent events as: a) consecutive photographs of different individuals of the same species; b) each individual of one species in a group photograph; c) photographs of individuals of the same species with a separation of at least 30 minutes; d) consecutive photographs of individuals of different species; and e) photographs of individuals that can be individually identified (O'Brien *et al.* 2003). Following the suggestion of Maffei *et al* (2004) we analyzed activity patterns of all species with an average ≥11 independent events across surveys. Because trapping effort was significantly different between surveys (χ^2=274.41, d.f.=2, p> 0.05), we obtained the mean value of independent event´s percentage by hour of the different surveys. We assumed that these values correctly represent the activity patterns of species during the study period.

We calculated percentage of diurnal (from 06:01 to 18:00) and nocturnal (from 18:01 to 6:00) independent events of each species. Using this information, we classified species as 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 by night), and cathemeral (organisms active intermittently both day and night) (Romero-Muñoz *et al.* 2010). We plotted bar charts with percentages of independent events by hour (Romero-Muñoz *et al.* 2010).

Activity patterns data present a circular distribution (Zar 2010), consequently we compared activity patterns of jaguars and pumas in two ways; first we used the Pianka index O_{jk} to quantify activity patterns overlap between jaguars and pumas (Estrada *et al.* 2008, Krebs 1999). We also compared the activity patterns of both felids using the non-parametric Wheeler and Watson test (W); this test indicates if there is a significant statistic difference between two circular distributions, and it has been used to analyzed data from 24 hrs activity patterns (Romero-Muñoz *et al.* 2010). The statistic W can be compared with a χ^2 distribution with two degrees of freedom (Zar 2010).

We calculated Pearson correlations between the 24-hour activity patterns of jaguar and pumas and the activity patterns of each prey species to assess the level of association in activity. Prior to this analysis we transformed percentages with the

Arcsine-root transformation (Zar 2010). Descriptive analyses were conducted with Microsoft Excel (Microsoft Corporation 2006) and circular statistics analysis were made with Oriana 4.0 (www.kovcomp.com) and Stat Graphics Centurion XV (StatPoint Inc. 1982-2007); all at a significance level of $p= 0.05$.

RESULTS

We deployed 101 camera stations inside the core and surrounding areas of RBSAT in three surveys (Fig. 1). We obtained 2628 photographs of 25 species, 1194 photographs were identified as independent events (Table 2). Of the 25 species only 12 (including the jaguar and the puma) had an average of independent events≥11. The 10 prey species have been reported as components in the diet for jaguars or pumas by other authors in other regions of Mexico, Central and South America (Aranda & Sánchez-Cordero 1996; Foster *et al.* 2009, Garla *et al.* 2001; Novack *et al.* 2005; Núñez *et al.* 2000, Rosas-Rosas *et al.* 2003, Taber & Novaro 1997, Weckel *et al.* 2006). Domestic species (cattle, horses and dogs) were photographed only in the surrounding areas outside the polygon of RBSAT.

Jaguars were cathemeral; but activity was significantly higher in night hours (χ^2= 5.06, d.f.=1, $p<0.05$) with an activity peak between 18:00 and 00:00 hrs (Fig. 2). Similarly, pumas were also cathemeral; however percentages of diurnal and nocturnal activity were similar (χ^2=0.26, d.f.=1, $p>0.05$). Puma activity peaks where opposite to those of the jaguar; with activity peaks between 02:00 and 10:00 hr (Fig. 2). Jaguars and pumas showed a relative high overlap in their activity patterns (Pianka's index O_{jk} = 0.73), and we found no significant difference in the circular distributions for both felids (χ^2=0.75, df= 2, p□0.05).

Seven prey species can be considered diurnal and showed significantly more activity at day hours; these included great curassow (*Crax rubra*) (χ^2=77.79, d.f.=1, $p<0.05$); Plainchachalaca (*Ortalis vetula*) (χ^2=79.85, d.f.=1, $p<0.05$); collared peccary (*Pecari tajacu*) (χ^2=44.44, d.f.=1, $p<0.05$); white-nosed coati (*Nasua narica*) (χ^2=91.32, d.f.=1, $p<0.05$); white-tailed deer (*Odocoileus virginianus*) (χ^2=34.29, d.f.=1, $p<0.05$), cattle (*Bos* sp.) and horses (*Equus* sp.) (χ^2=77.79, d.f.=1, $p<0.05$). Ocelots (χ^2=35.43, d.f.=1, $p<0.05$); grey foxes (*Urocyon cinereoargenteus*) (χ^2=47.44, d.f.=1, $p<0.05$) and rabbits (*Sylvilagus* sp.) (χ^2=26.54, d.f.=1, $p<0.05$) were mostly nocturnal (Fig. 3).

The activity of jaguars was positively related with the activity of gray foxes, ocelots and rabbits (all $p<0.05$). In contrast, puma activity had no significant correlation to any prey species (Table 3).

DISCUSSION

Cathemeral activity of jaguar found in this research is rarely reported in other studies and only had been described for Amazonian rain forest habitats of Peru (Gómez *et al.*

Table 2. Independent events obtained by camera trapping in the Sierra del Abra-Tanchipa Biosphere Reserve, Mexico.

	Survey		
Species	1	2	3
Mammals			
Brocket deer *Mazama temama*	9	1	—
Cattle *Bos* sp.	—	85	86
Collared pecari *Pecari tajacu*	4	3	20
White-tailed deer *Odocoileus virginianus*	103	29	77
Coyote *Canis latrans*	—	1	1
Domestic Dog *Canis familiaris*	—	9	7
Gray fox *Urocyon cinereoargenteus*	5	15	11
Jaguar *Panthera onca*	19	22	34
Jaguarundi *Puma yagouaroundi*			2
Margay *Leopardus wiedii*	4	—	4
Ocelot *Leopardus pardalis*	9	18	28
Raccon *Procyon lotor*			7
Puma *Puma concolor*	25	31	22
White-nosed coati *Nasua narica*	58	62	12
Nine-banded armadillo *Dasypus novemcinctus*	1	—	1
Opossums *Didelphis* sp.	3	5	2
Horses *Equus* sp.	—	22	15
Spotted paca *Cuniculus paca*	5	2	11
Squirles *Sciurus* sp.	8	2	3
Rabbits *Silvilagus* sp.	3	24	124
Birds			
Crested Guan *Penelope purpurescens*	7	—	—
Great curassow *Crax rubra*	70	78	23
Plain Chachalaca *Ortalis vetula*	6	15	38
Thicket Tinamou *Crypturellus cinnamomeus*	4	6	2
Wild turkey *Meleagris gallopavo*	—	2	7

2005) and Bolivia (Emmons 1987). In contrast, cathemeral pattern with highly diurnal activity founded in pumas is reported in several studies (Chávez *et al.* 2005, Di Bitteti *et al.* 2010, Estrada 2008, Harmsen *et al.* 2009, Núñez *et al.* 2002). Cathemeral activity increments probability of encounter with a more diverse prey base (Scogna-

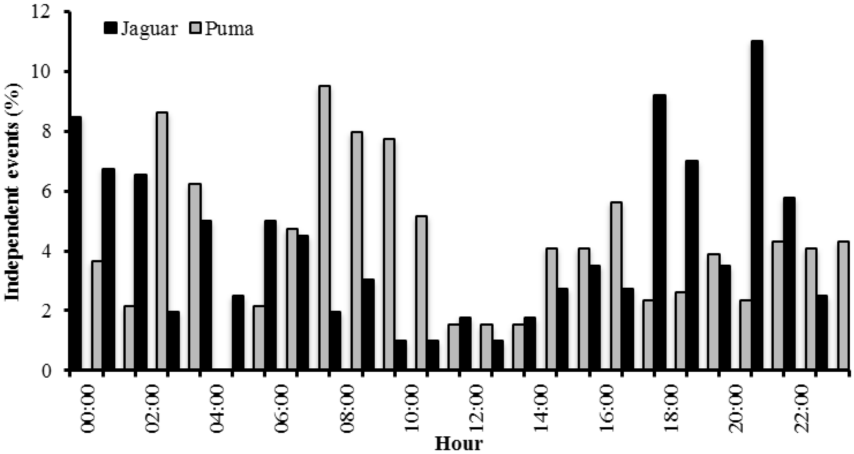

Figure 2. Activity patterns of jaguar and puma and their potential prey in Sierra del Abra–Tanchipa Biosphere Reserve.

millo *et al.* 2003), this could be specifically beneficial for a generalist predator like puma which consume a broader prey variety including diurnal and nocturnal prey (Oliveira 2002).

In RBSAT, jaguars and pumas showed important activity at day hours (34.09% and 53.59%, respectively); these findings are similar to results obtained in the Venezuelan llanos (Scognamillo *et al.* 2003) and some biomes of Brazil (Foster *et al.* 2013). Diurnal activity of large felids has been reported as an indicator of absence of human disturbance in the habitat (Paviolo *et al.* 2009). The rugged topography and lack of trails inside RBSAT generate minimal human presence inside protected area; this allows jaguars and pumas to be active during diurnal hours without risk of encounters with humans.Unsurprisingly, both felids showed less activity around noon, period whit the highest temperatures (Hernández-Saint Martín, Pers. Obs.) suggesting that jaguars and pumas tend to avoid movement during the hottest hours, this has also been reported in other sites of neotropics (Estrada 2008).

Temporal segregation among carnivore's species has been suggested as a strategy to reduce interference competition and the risk of intraguild predation (Fedriani *et al.* 2000), however this pattern is rarely reported for large predators species like jaguar and puma (Romero-Muñoz *et al.* 2010). In this study, activity of both large felids was no significantly different. However, jaguar showed peaks of activity that began around sunset decreasing about two hours after sunrise; this is in opposition to the highest activity of the puma that began around dawn, decreasingat 10:00 and staying relatively stable during the remaining hours of the day. This suggests that despite the overlap of activity patterns (Pianka Index O_{jk} =0.73), the activity of jaguars is at its

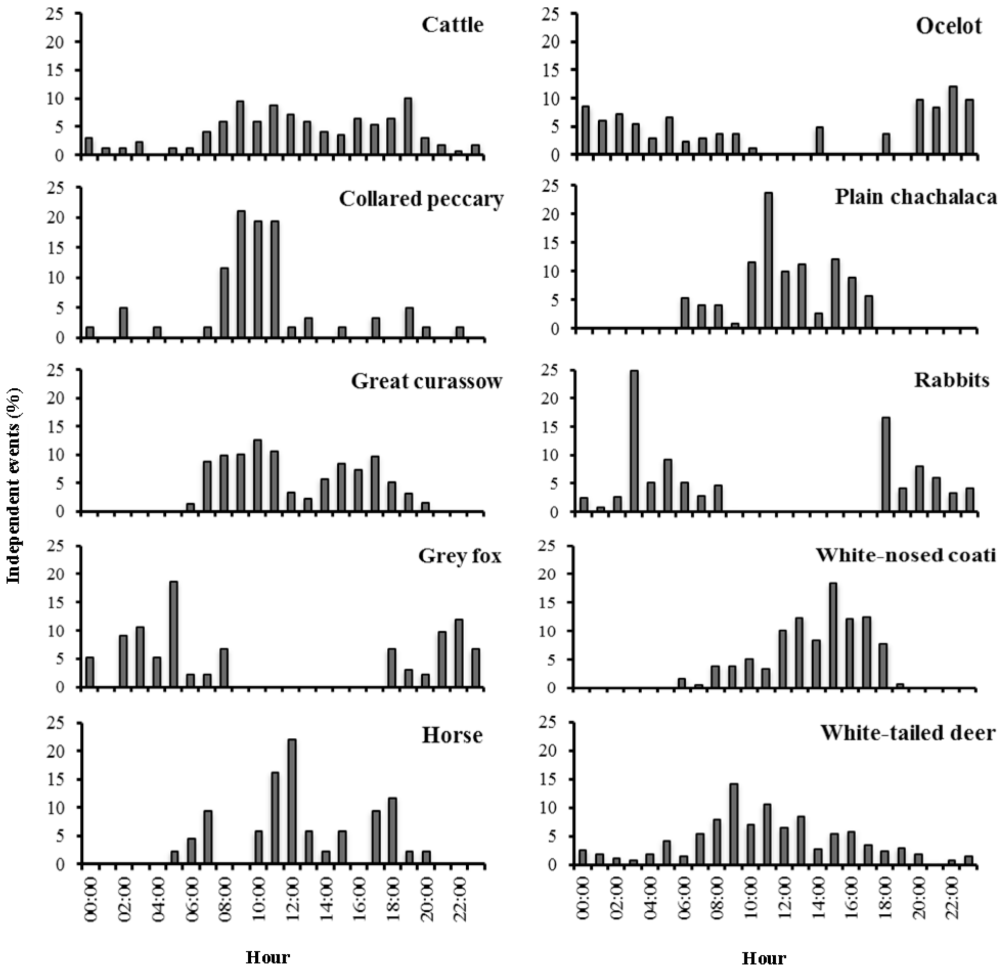

Figure 3. Activity patterns of prey species in Sierra del Abra–Tanchipa Biosphere Reserve.

peak when the activity of the puma´s decrease. Encounters between two species of large carnivores usually end with interspecific aggression and the maiming or killing of one of the aggressors. The severity of the attack seems to increase with the high densities of carnivores (Palomares & Caro 1999).

Individual identification using differential coat patterns and conspicuous features of the photographed jaguars and pumas (Kelly *et al.* 2008, Silver *et al.* 2005) showed that at least 13 different jaguars and six pumas were present in RBSAT during this study (Hernández-Saint Martín *in revision*). This abundance of large felids without evidence of interspecific aggression (e. g. scars or wounds produced by fighting) in

Table 3. Correlations between activity patterns of jaguar, pumas and prey species.

Potential prey species	Jaguar	Puma
Cattle	−0.34	0.24
Collared peccary	−0.39*	0.15
Great curassow	−0.48*	0.24
Grey fox	0.44*	0.11
Horse	−0.35	−0.26
Ocelot	0.43*	0.20
Plain chachalaca	−0.66*	−0.03
Rabbits	0.41*	0.07
White-nosed coati	−0.46*	−0.03
White-tailed deer	−0.61*	0.07

* Significant correlations $p < 0.05$

photographed animals, suggest temporal segregation is a mechanisms which allows coexistence of several individuals of both species in the small area of RBSAT.

Other studies across Latin-American countries have suggested that activity patterns of jaguars and pumas are determined by activity of their prey species (Foster *et al.* 2013, Emmons 1987, Núñez *et al.* 2000, Scognamillo *et al.* 2003, Harmsen *et al.* 2011). In RBSAT, jaguar's diet is mainly collared peccary, withe-tailed deer and white-nosed coati; and puma prey consists mainly on withe-tailed deer, rabbits and great curassow (Hernández-Saint Martín *in revision*); activity of jaguars was significantly related with activity of their principal prey species, but all these relationships were negative (Table 3). This suggests that jaguar hunts prey when they are not active and probably more vulnerable, like during the night hours. In contrast, activity of pumas was no significantly related with activity of any prey species. The RBSAT is one of the last protected refuges for wildlife, especially for large felids northeast of the Sierra Madre Oriental in San Luis Potosi. Despite its small size, it protects a large diversity of medium and great sized mammals.The results of this study suggest that temporal segregation allows coexistence of several individual of jaguars and pumas in small protected areas (Núñez 2010). This situation depends on the existence of large and diverse prey base that allows a flexible carnivore community in the area (Harmsen *et al.* 2009). However, the accelerated change in land use and tenure around the reserve could alter these patterns and may derivate in intra-guild aggressions and interference competence that could threat the long term survival of large felid in this area.

ACKNOWLEDGMENTS. We are grateful to J. Pimentel (Colegio de Postgraduados, Campus San Luis Potosí) and L. Chapa (Instituto Potosino de Investigación Científica y Tecnológica A.C.) for funding support to this study. A. Durán (CONANP-RBSAT) provided logistic support in fieldwork. L. Bender (Alaska Department of Fish and Game, U.S.), L. Chapa (Instituto Potosino de Investigación Científica y Tecnológica A.C.) and H. López (Universidad Autónoma de Nuevo León) provided camera traps. H. Guzman, M. Aguilar and L. Martínez assisted during the field work; their contribution was instrumental to the study.

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