El Colegio de la Frontera Sur

Patrones de actividad y abundancia relativa de especies presa de *Panthera onca* y *Puma concolor* en un paisaje modificado en el centro de Belice

Tesis
presentada como requisito parcial para optar al grado de
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Por

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para obtener el grado de **Maestra en Ciencias en Recursos Naturales y Desarrollo Rural**

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Dedicatoria

A mis padres, mis primeros maestros y fuentes de inspiración y motivación.

"We learn more by looking for the answer to a question and not finding it than we do from learning the answer itself." - Lloyd Alexander

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Tabla de contenido

Resumen

Es importante comprender los efectos que las actividades antropogénicas tienen sobre las especies presa de grandes felinos, ya que ellas cumplen funciones vitales en el ecosistema y a menudo son una fuente de proteínas para las personas en las zonas rurales. En este estudio se evaluó el Índice de Abundancia Relativa (IAR) y los patrones de actividad de cinco especies presa de jaguar y puma (*Dasypus novemcinctus, Cuniculus paca, Odocoileus virginianus, Dasyprocta punctata* y *Pecari tajacu*) en un paisaje modificado en el centro de Belice; así como los factores que influyen en el comportamiento y el IAR de las especies presa. Se analizaron datos de 29 estaciones de cámaras trampa distribuidas en el valle del Río Belice. Se evaluó la influencia del hábitat y los factores antropogénicos sobre el IAR de las especies presa. Además, se analizaron las diferencias en los patrones de actividad de las especies de presas y estimamos la superposición con la actividad de depredadores, personas y perros domésticos. Los resultados sugieren que el venado cola blanca y el agutí son más abundantes que las otras tres especies en el área de estudio. El venado cola blanca evitó los asentamientos humanos, pero fue asociado con área agrícolas. Su comportamiento catemeral hizo que se traslape en actividad con los depredadores, pero también con los humanos y los perros domésticos. Hubo una gran superposición en la actividad entre el armadillo de nueve bandas y el jaguar; y las cinco especies presa mantuvieron cierto traslape con los perros domésticos, lo que sugiere posibles riesgos de depredación. Este estudio proporciona una comprensión de los factores que afectan la abundancia relativa de especies de presas y la interacción con los depredadores y las personas, pero destaca la necesidad de una evaluación más profunda de la interacción entre los perros domésticos y la fauna silvestre.

Palabras clave: Abundancia relativa, depredadores, paisaje antropogénico, perros domésticos, traslape de actividad.

Introducción

El crecimiento exponencial de la población humana ha resultado en el aumento de actividades antropogénicas como la deforestación, fragmentación del hábitat, agricultura y caza excesiva (Reyna-Hurtado et al. 2009; Hoffmann et al. 2010; Zeilhofer et al. 2014). Estas actividades han causado una disminución en las poblaciones de numerosas especies en los trópicos (Butchart et al. 2010). Los paisajes afectados por la actividad humana pueden mostrar diferencias en la abundancia de especies y los patrones de actividad en comparación con las áreas protegidas (Caro 2002). No obstante, hay casos en los que la actividad humana puede ser adecuada para algunas especies (e.g., especies de borde) debido a la heterogeneidad que promueve en el hábitat (Caro 2001; Ries et al. 2004; Ahumada et al. 2013). Analizar los efectos de estos factores antropogénicos en fauna silvestre, es esencial para entender la adaptabilidad y la persistencia de las especies en paisajes modificados, ya que este conocimiento puede ser una herramienta para la conservación de la biodiversidad en ecosistemas fragmentados o perturbados.

En los últimos años, las cámaras trampa se han convertido en una herramienta útil para mejorar la comprensión de la dinámica ecológica y poblacional de los animales silvestres (Nichols et al. 2011). Se han desarrollado diversos análisis estadísticos con información fotográfica de especies identificables (Karanth 1995; Royle y Nichols 2003; MacKenzie et al. 2006), pero hay mucho menos analices disponible para especies sin marcas notables (e.g., armadillos o venados), a pesar de que estas especies también son el objetivo común de estudios con cámaras trampa (Palmer et al. 2018). El análisis de las tasas de captura fotográfica se está convirtiendo en una alternativa prometedora para desarrollar índices de abundancia (Kelly 2008; Rovero y Marshall 2009). El índice de abundancia relativa (IAR) se puede representar por la frecuencia de captura, que se estima como el número de capturas de un animal por noches trampa (Carbone et al. 2001; O’Brien et al. 2003). Los IARs se calculan fácilmente, se entienden intuitivamente y se pueden usar para una amplia gama de esquemas de muestreo (O’Brien et al. 2003; Jenks et al. 2011). Además de la abundancia relativa, las cámaras trampa también han mejorado la capacidad de estudiar la actividad de las especies (van Schaik y Griffiths 1996). Los patrones de actividad son una característica central del comportamiento y corresponden con los ritmos biológicos de los individuos (Azevedo et al.2018). A menudo, estos patrones de actividad están influenciados por diferentes factores como adaptaciones fisiológicas, condiciones abióticas (Nielsen 1984; Scheibe et al. 1999) y el comportamiento de las especies (e.g., organización social o evasión de la competencia) (Gittleman y Harvey 1982).

Las cámaras trampa han permitido un monitoreo no invasivo a través de escalas espacio-temporales (O'Connor et al. 2017; Steenweg et al. 2017) en áreas protegidas y no protegidas. Los estudios que utilizan cámaras trampa para comprender la abundancia y los ritmos biológicos en paisajes modificados son escasos en las regiones neotropicales (Gómez et al. 2005; Paviolo et al. 2009; Kolowski y Alonso 2010; Foster et al. 2013; Azevedo et al. 2018) y con mayor frecuencia se han enfocado en los depredadores (Foster et al. 2010a; Zeller et al. 2011; Petracca et al. 2014; Boron et al. 2016; Azevedo et al. 2018). Por lo tanto, existe la necesidad de evaluar y comprender la dinámica de las especies presa en estos paisajes debido a su importancia cultural y ecológica.

Las presas abarcan una amplia gama de especies, incluidas aves, mamíferos, insectos e incluso plantas. Sin embargo, en la premisa de este estudio, las especies presa se refieren a mamíferos, en particular, ungulados, insectívoros y roedores. Las poblaciones silvestres de estas especies presa son importantes para el funcionamiento del ecosistema y frecuentemente son una fuente vital de proteínas para las personas en zonas rurales (Robinson y Bennett 2000). Por lo tanto, la sobreexplotación, y la subsecuente reducción de abundancias o extirpación de estas especies puede tener consecuencias negativas a largo plazo. Una disminución en sus poblaciones puede reducir la dispersión de las plantas, aumentar la competencia intraespecífica y reducir la diversidad general de especies de plantas (Licona et al. 2011). Además, esta reducción también puede afectar la reproducción y la mortalidad de los depredadores o alterar sus patrones de actividad (Fuller y Sievert 2001; Foster et al. 2010b; Harmsen et al. 2011).

Los procesos biológicos de las especies presa pueden ser alterados en paisajes modificados de manera directa (i.e., la extracción de presas) (Oksanen y Oksanen 2000) o indirecta (i.e., paisaje antropogénico adverso) (Ordiz et al. 2013). La caza afecta de manera directa a aproximadamente 34% de todas las especies de mamíferos amenazadas en los trópicos (Dirzo y Raven 2003). Resultando en una reducción de las poblaciones de mamíferos por la cacería. En América Central y del Sur los animales de caza más frecuentes son presas importantes para el jaguar (*Panthera onca*.) y puma (*Puma concolor*) (Novack et al. 2005; Foster et al. 2010a). En Belice, la paca (*Cuniculus paca*) y el venado cola blanca (*Odocoileus virginianus*) son dos de las principales fuentes de carnes de animales silvestres (Foster et al. 2016); en Perú, la paca y el armadillo de nueve bandas (*Dasypus novemcinctus*) (Bodmer y Lozano 2001); y en México se cazan, la paca, el pecarí de collar (*Pecari tajacu*), el armadillo de nueve bandas, el agutí (*Dasyprocta punctata*.) y el venado cola blanca también entre otras (Santos-Fita et al. 2012; Ramírez-Barajas y Calmé 2015). Además, otras actividades antropogénicas tienen un efecto discreto pero igualmente prevalente sobre la dinámica de la población, al causar cambios en la percepción de las especies sobre si un área es segura o peligrosa (Frid y Dill 2002).

No está claro si las especies presa pueden mantener su abundancia y ritmos biológicos en paisajes dominados por humanos tal como sucede en áreas protegidas donde son más "ecológicamente efectivas" (Ordiz et al. 2013). Hay especies que son selectivas en el uso de hábitat, como los pecaríes de labios blancos (*Tayassu pecari*), que prefieren los bosques continuos (Reyna-Hurtado y Tanner 2007) y son más vulnerables a la alteración del hábitat (Petracca et al.2014). Por el contrario, otras especies presa son más flexibles desde el punto de vista ecológico, como el venado cola blanca (Zeller et al. 2011; Petracca et al. 2014) que pueden mostrar cierta tolerancia a la presión de caza (Reyna-Hurtado y Tanner 2007), y su adaptabilidad también permite que esté altamente asociado con áreas agrícolas (Mandujano et al. 1991).

En Belice es limitada la información de especies de presa de jaguar y puma en paisajes perturbados. Se conoce que la población humana del país consume carne de animales silvestres, lo que representa al menos el 10% de la carne y el pescado que se consume a nivel nacional (Foster et al.2016). La mayoría de estas especies de caza también son especies presa de grandes felinos, lo que resulta en una competencia directa entre humanos y depredadores y, posteriormente, una reducción significativa en las poblaciones de presas. Por ejemplo, el armadillo de nueve bandas es una especie presa importante en la dieta del jaguar (50% de frecuencia, 50% de biomasa) y la paca para la dieta de puma (60% de frecuencia, 50% de biomasa) (Foster et al. 2010a) pero también son especies de caza preferidas por los cazadores (Reyna-Hurtado y Tanner 2007; Santos-Fita et al. 2012; Ramírez-Barajas y Calmé 2015; Foster et al. 2016). Se han realizado pocos estudios sobre especies presa en Belice, y estos incluyen: preferencia de hábitat y comportamiento de la paca (Gutiérrez et al. 2017, Harmsen et al. 2018); consumo de carne de animales silvestres (Foster et al. 2016); ecología espacial del pecarí de labios blancos (Hofman et al. 2016); y patrones de actividad del jaguar, puma y sus presas (Harmsen et al. 2011). Por otra parte, es necesario comprender los efectos de las actividades antropogénicas sobre estas especies presa en Belice, ya que se está experimentando un auge agrícola.

Para aumentar el conocimiento sobre las especies presa de grandes felinos y la influencia que sufren por actividades humanas, en el presente estudio se utilizaron datos de cámaras trampa para evaluar la diferencia en el índice de abundancia relativa (IAR) y los patrones de actividad de cinco especies presa: armadillo (*Dasypus novemcinctus)*, paca (*Cuniculus paca*), venado cola blanca (*Odocoileus virginianus*), agutí (*Dasyprocta punctata*) y el pecari de collar (*Pecari tajacu*), en un paisaje modificado en el centro de Belice. Además, se evaluaron los factores de hábitat y antropogénicos que influyen en el IAR de las especies objetivo. Finalmente, se evaluaron la superposición de los patrones de actividad de las cinco especies presa con los de sus principales depredadores (jaguar y puma), personas y perros domésticos. Se hipotetizo que debido a sus flexibilidad ecológica, el IAR del venado cola blanca y agutí será mayor que el armadillo de nueve bandas, la paca y el pecarí de collar (Mandujano et al. 1991) y que no habrá diferencia en los patrones de actividad con los previamente reportados para estas especies en áreas modificadas y áreas protegidas (Harmsen et al. 2011; Azevedo et al. 2018). Los resultados obtenidos proporcionarán información sobre el comportamiento y la abundancia relativa potencial de las especies presa en un paisaje modificado en el centro de Belice. Esta información es importante para el desarrollo de planes de gestión del área de estudio.

Activity patterns and relative abundance of mammalian prey species of jaguar and puma in a modified landscape in central Belize

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ABSTRACT

It is important to understand the effects that anthropogenic activities have on prey species, as they fulfill vital functions in the ecosystem and are often a source of protein for people in rural areas. In this study, the Relative Abundance Index (RAI) and activity patterns of five prey species of jaguar and puma (*Dasypus novemcinctus*, *Cuniculus paca*, *Odocoileus virginianus, Dasyprocta punctata*, and *Pecari tajacu*) were evaluated in a modified landscape in Belize; as well as factors influencing species behavior and RAI. Data from 29 camera trap stations distributed throughout the Belize River Valley were analyzed. The influence of habitat and anthropogenic factors on the RAI of these species was evaluated. Furthermore, we qualified activity patterns of the five species were categorized and their overlap with predators, people and domestic dogs was estimated. Results suggest that white-tailed deer and agouti were more abundant in our study area than the other three species. White-tailed deer avoided human settlements, but was associated to agricultural areas. Its cathemeral behavior caused high overlap in activity with predators but also with human and domestic dogs. There was high overlap in activity between nine-banded armadillo and jaguar. Additionally, the five species had some overlap in activity with domestic dogs which suggests a possible high mortality risk. This study provides an insight into factors affecting relative abundance of prey species and interaction with predators and people, but highlights the need tofurther understand the interaction between dogs and wildlife.

Es importante comprender los efectos que las actividades antropogénicas tienen sobre las especies presa de grandes felinos, ya que ellas cumplen funciones vitales en el ecosistema y a menudo son una fuente de proteínas para las personas en las zonas rurales. En este estudio, se evaluó el Índice de Abundancia Relativa (IAR) y los patrones de actividad de cinco especies presa de jaguar y puma (*Dasypus novemcinctus*, *Cuniculus paca*, *Odocoileus virginianus*, *Dasyprocta punctata* y *Pecari tajacu*) en un paisaje modificado en Belice; así como los factores que influyen en el comportamiento y el IAR de las especies presa. Se analizaron datos de 29 estaciones de cámaras trampa distribuidas en el Valle del Río Belice. Se evaluó la influencia del hábitat y los factores antropogénicos sobre el IAR de las especies presa. Además, se analizaron las diferencias en los patrones de actividad de las especies de presas y estimamos la superposición con la actividad de depredadores, personas y perros domésticos. Los resultados sugieren que el venado cola blanca y el agutí son más abundantes que las otras tres especies en el área de estudio. El venado cola blanca evitó los asentamientos humanos, pero fue asociado con área agrícolas. Su comportamiento catemeral hizo que se traslape en actividad con los depredadores, pero también con los humanos y los perros domésticos. Hubo una gran superposición en la actividad entre el armadillo de nueve bandas y el jaguar, y las cinco especies de presas mantuvieron cierto traslape con los perros domésticos, lo que sugiere posibles riesgos de depredación. Este estudio proporciona una comprensión de los factores que afectan la abundancia relativa de especies de presas y la interacción con los depredadores y las personas, pero destaca la necesidad de una evaluación más profunda de la interacción entre los perros domésticos y la fauna silvestre.

KEYWORDS

Relative abundance; anthropogenic landscape; coefficient of overlap; domestic dogs; predators

SPECIES ABUNDANCE AND ACTIVITY PATTERNS MAY DIFFER IN HUMAN MODIFIED LANDSCAPES WHEN COMPARED WITH PROTECTED AREAS (Caro 2002). This difference is due to the presence of anthropogenic activities, such as deforestation, habitat fragmentation, agriculture, roads, trails (Zeilhofer *et al.* 2014), and excessive hunting (Reyna-Hurtado *et al.* 2009, Hoffmann *et al.* 2010). These activities may have a positive or negative effect on the biological rhythms and relative abundance of species (Addessi 1994, Benedetti-Cecchi *et al.* 2001). For instance, species that are forest dwellers respond negatively to habitat loss, reducing their distribution and abundance; whereas, there are cases in which human activity may be suitable for some species (e.g. edge species) because of the habitat heterogeneity it promotes (Caro 2001, Ries *et al.* 2004, Ahumada *et al.* 2013). Understanding the effects of these anthropogenic factors is essential in comprehending species adaptability and persistence in human modified landscapes since it is a priority for biodiversity conservation.

Frequently, studies on species' biological rhythms and abundance are restricted by the lack of funds and the cryptic behavior of the species. However, in recent years camera traps have become an effective tool in understanding the dynamics and behavior of species (Caravaggi *et al.* 2017) through inferences based on observed patterns (Brown 1995, Marquet 2000, Hubbell 2001). This has permitted non-invasive and cost effective monitoring across considerable spatiotemporal spans (O'Connor *et al.* 2017, Steenweg *et al.* 2017) in both protected and non-protected areas. However, such studies using camera traps to understand species distribution, abundance, and biological rhythms in human-modified landscapes are limited and often focused on predators (Foster *et al.* 2010b, Boron *et al.* 2016, Azevedo *et al.* 2018). Hence, there is a great need to understand the dynamics of prey species in these landscapes because of their cultural and ecological importance.

Prey species encompass a wide array of birds, mammals, insects and even plants. Nevertheless, in the premise of this study, prey species refers to mammals, in particular, ungulates, insectivores and rodents. Wild populations of these prey species are important for the functioning of the ecosystem and are often a vital source of protein for people in rural areas (Robinson & Bennett 2000); overexploitation of these species may have long-term negative consequences. A decrease in their populations can reduce plant dispersal, increase conspecific competition and low overall diversity of plant species (Licona *et al.* 2011). This decline in prey populations can also affect the reproduction and mortality of their predators (Fuller & Sievert 2001, Harmsen *et al.* 2011). Prey species can also influence activity patterns of predators as seen for jaguar and puma (Harmsen *et al.* 2011, Foster *et al.* 2013, Azevedo *et al.* 2018). These important roles of these prey species highlights to need to understand their biological processes and how modified landscapes alter them directly (e.g. harvesting of prey populations; Oksanen & Oksanen 2000) or indirectly (e.g. an adverse anthropogenic landscape; Ordiz *et al.* 2013).

It is unclear whether these species can sustain their abundance and biological rhythms in human dominated landscape like in protected areas where they are more ‘ecologically effective’ (Ordiz *et al.* 2013). There are species that are selective in use of specific habitat like the white-lipped peccaries (*Tayassu pecari*) which prefer continuous forests (Reyna-Hurtado & Tanner 2007, Briceño-Méndez *et al.* 2016) and are more vulnerable to habitat disturbance (Petracca *et al.* 2014). On the contrary, other prey species are more ecologically flexible such as the white-tailed deer (*Odocoileus virginianus*) (Zeller *et al.* 2011, Petracca *et al.* 2014), which can display some tolerance to hunting pressure (Reyna-Hurtado & Tanner 2007), and its adaptability also allows it to be highly associated with agricultural areas (Mandujano *et al.* 1991).

In Belize, information of prey species of jaguar and puma in disturbed landscapes is limited. All the cultural groups within the country consume bushmeat, which represents at least 10% of the meat and fish consumed nationally (Foster *et al.* 2016). Most of these game species are also important prey for predators, resulting in a direct competition between human and predators, and subsequently, a significant reduction in prey populations. For example, the nine-banded armadillo (*Dasypus novemcinctus*) is an important prey species in the diet of jaguar (50% relative occurrence, 50% biomass) and the paca (*Cuniculus paca*) for the diet of puma (60% relative occurrence, 50% biomass) (Foster *et al.* 2010) but they are also favored game species among hunters (Reyna-Hurtado & Tanner 2007, Santos-Fita *et al.* 2012, Ramírez-Barajas & Calmé 2015, Foster *et al.* 2016). Few studies have been conducted on prey species within the country, and these include: habitat preference and the behavior of paca (Gutierrez *et al.* 2017, Harmsen *et al.* 2018); the consumption of bushmeat (Foster *et al.* 2016); the spatial ecology of white-lipped peccary (Hofman *et al.* 2016); and jaguar (*Panthera onca*), puma (*Puma concolor*) and prey activity patterns (Harmsen *et al.* 2011).

There is a need to understand the effects of anthropogenic activities on mammalian prey species in Belize, as the increase in development has augmented their exposure to these factors. With our study, we intend to give an insight of the behavior and abundance of these important species in a modified landscape. We evaluated the Relative Abundance Index (RAI) and activity patterns of five species (*Dasypus novemcinctus*, *Cuniculus paca*, *Odocoileus virginianus*, *Dasyprocta punctata*, and *Pecari tajacu*) that are prey of jaguars and pumas in a modified landscape in central Belize; also, we evaluated factors influencing the prey species behavior and RAI in a human-modified landscape. We focused on three main questions: (1) Is there a difference between the five prey species relative abundance index and temporal activity patterns?; (2) Is the relative abundance index influenced by habitat and anthropogenic factors?; and (3) How do prey species' activity patterns overlap with those of their main predators, people and domestic dogs? We hypothesized that due to their ecological flexibility, the RAI of white-tailed deer and agouti would be higher than nine-banded armadillo, paca and collared peccary (Mandujano *et al.* 1991, Reid 2009); and, that there would be no difference in activity patterns previously reported for these species (Harmsen *et al.* 2011, Azevedo *et al.* 2018). Specifically, we predicted: (1) that RAI of the five species would be associated with both habitat and anthropogenic factors; (2) there would be high activity overlap between the five prey species and their main predators; and (3) there would be low activity overlap between prey species, people and domestic dogs.

METHODS

STUDY AREA— The study area extends 329 km^2 from Rancho Dolores to Burrell Boom in the northwest and Bigfalls Farm in the east, all of which encompass the Belize River Valley (BRV) located in the Belize district (17 ° 30'-17 ° 35 'N, 88 ° 25'-88 ° 35 'W). The average annual precipitation of the region oscillate between 1435 and 1600 mm with an average temperature of 25.2 ° C, which varies between 21 and 31.5 ° C during the year. The BRV is a mosaic of secondary forest, small farms, large-scale agriculture, pastures, forest fragments and riverine habitat along the Belize River (Fig. 1). The continuous change in the landscape is due to agricultural practices and development of settlements (Lyon 1996). The human population of the

BVR is about 4,100 individuals, which is equivalent to 13 individuals / km^2 (Belize Statistical Institute, 2010). The BRV is an important area for the connection between the two largest forest blocks in Belize, the Conservation and Management Area of Rio Bravo and the Maya Mountain Massif, of which 20 percent is protected. Hunting is allowed during specific seasons within the study area (Belize Wildlife Protection Act, 2000, 2003). It is illegal to hunt without a license, and hunt outside the specified season and in protected areas. However, most people within the area do not apply for permits (Correa, unpublished data) and the government lacks the capacity to enforce these laws due to staff shortages (Foster *et al.* 2016).

FOCAL SPECIES—In this study we include five focal species, nine-banded armadillo (*Dasypus novemcinctus*), paca (*Cuniculus paca*), white-tailed deer (*Odocoileus virginianus*), agouti (*Dasyprocta punctata*) and collar peccary (*Pecari tajacu*). All are terrestrial mammals of which paca is considered habitat specialist (prefers the broadleaf forest; Emmons 2016) while the others are habitat generalists (Emmons 2013, Loughry & Abba 2014, Gallina & Lopez 2016, Gongora *et al.* 2016). The five species have been reported to be a part of the diet of jaguar and puma (Novack *et al.* 2005, Foster *et al.* 2010a).

CAMERA TRAPPING— A total of 29 camera stations was established along old logging roads, old trails, and, in farms and private forest patches. The cameras were spaced on average 2.56 km (+/- 0.95 km) from the nearest station. Each camera station consisted of one or two independent camera-traps (Bushnell Infrared, Bushnell®, Kansas, USA or Panthera camera trap V4, Panthera, New York, USA). Cameras were programmed to run continuously, 24 h/day, with a triggering time of five seconds. Data from the camera traps were collected for two years but only during the dry season of each year (March to July 2014-2015; n = 5,289 trap nights) due to the inaccessibility of the stations during the rainy season. Monthly checks were conducted to download data and maintain the cameras in case of malfunction.

HABITAT AND ANTHROPOGENIC FACTORS— We considered seven factors that may influence the relative abundance of target species which include habitat variables (distance to river, % of forest and agriculture) and anthropogenic variables (distance to settlements and roads, number of hunters and people presence). Using the ArcGIS software, six factors were extracted from recent geospatial data containing roads, rivers and habitat use (updated after Meerman, 2015) available on the Belize biodiversity and environmental resources data system (http: // www.biodiversity. bz /). A one-kilometer buffer was created for each sampling point to measure the proportion of forest and agriculture. The *nearby* function in the ArcGIS software was used to calculate the closest distance to rivers, roads and settlements for each sampling point. The hunters' information was obtained from a hunting project conducted within the study area (Urbina et al., unpubl.). The sampling points were superimposed on a hunting intensity map which displayed the number of hunters that reported using those grid cells. We used the number of hunters reported in the cell containing the sample point as our factor. Human presence was estimated using the formula of relative abundance index as described below. All the factors were normalized and Spearman rank correlations were used to test collinearity. Only factors with low collinearity were used ($\rho > 0.60$) (Table S1).

DATA ANALYSIS— We documented the date and time for each species detection. Images taken an hour apart were considered as independent events in order to reduce pseudo-replication (Lucherini *et al.* 2009). For camera stations containing two camera units, the record was classified as an event if the image of both cameras was captured at the same time and date. In the event of multiple individuals of social species, such as collared peccaries, people and domestic dogs, we considered it be a single record of the species (Azevedo *et al.* 2018). The records of both years were pooled, because there were low detections of the species.

Naïve occupancy was calculated as the proportion of camera stations in which at least one image of the target species was captured. We also calculated the relative abundance index (RAI) of the target species following the formula used by Jenks *et al.* (2011) and Arroyo-Arce *et al.* (2017): RAI = (C / MS) * 100 nights / traps, whereas: C is the number of photographic events; MS is the sampling effort (measured as the sum of trap nights of each camera) seasonal or total and 100 trap nights (standard unit). Linear regressions were performed to evaluate the influence of anthropogenic factors (distance to settlements, distance to roads, RAI of people and hunting intensity) and habitat factors (% of forest cover, % of agriculture and distance to river) have on the RAI of the prey species.

Activity patterns were developed based on the proportion of independent records during the day (from sunrise to sunset) and night (from sunset to sunrise) (van Schaik & Griffiths 1996). The time of the detections were converted to solar time to avoid incorrect definitions of species activity patterns. Solar time was defined based on the position of the sun, compensating for the local time zone as in Foster *et al.* (2013). Species were classified following Gómez *et al.* (2005) and Romero-Muñoz *et al.* (2010), as diurnal (<15% of records were at night), nocturnal (>85% of records were at night), mostly diurnal (15–35% of records were at night), mostly nocturnal (65–85% of the records were at night), crepuscular (50% of records were during the crepuscular period), and cathemeral (species that were active both day and night). The daily activity patterns of each prey species were estimated using the method developed by Ridout &

Linkie (2009) and also to measure overlap between prey species, predators (puma and jaguar) and anthropogenic factors (people and domestic dogs). A non-parametric kernel density estimation was first performed to evaluate the daily activity patterns of each prey species. The non-parametric kernel density assumes that photographic records are random samples from a continuous distribution instead of grouping them into discrete time categories (Foster *et al.* 2013). Then, the overlap coefficient ($\Delta 1$) was used to measure the level of overlap between two kernel density estimates, and overlap was presumed to be the area under both density curves (Azevedo *et al.* 2018). The coefficient of overlap ranged from 0 (no overlap) to 1 (complete overlap) (Ridout & Linkie 2009, Linkie & Ridout 2011). A bootstrap with 10,000 resamples was conducted to calculate the confidence interval of each overlap analysis (Meredith & Ridout 2016). All the analyses were performed in R 3.5.1 using the R-package 'overlap' (Meredith & Ridout 2016).

RESULTS

Agouti was present in 48 percent of the camera stations, followed by white-tailed deer with 45 percent. Both paca and collared peccary were present in 34 percent of the stations. Nine-banded armadillo occupied the least number of stations (31%). All species occupied mostly agricultural areas (crop and livestock), savannah areas and forest patches (Table 1). The prey species with the highest RAI was agouti, followed by white-tailed deer, whereas the lowest RAI was for collared peccary (Table 2). We detected no significant relationship between all prey species and habitat factors with the exception of collared peccary, which demonstrated a significantly positive relationship with distance to river ($F_{1, 26} = 4.81$, $p < 0.05$, $r^2 = 0.16$) (Table S2). The RAI of collared peccary increased with increasing distance to rivers (Fig. S1). Anthropogenic factors were not significant predictors for the RAI of nine-banded armadillo and paca ($p>0.5$) (Table S2). We found that distance to settlement was a significant predictor for the RAI of white tailed deer ($F_{1, 26} = 22.83$, $p < 0.05$, $r^2 = 0.47$), collared peccary ($F_{1, 26} = 4.37$, $p < 0.05$, $r^2 = 0.14$) and agouti ($F_{1, 26} = 5.90$, $p < 0.05$, $r^2 = 0.19$). Both, white tailed deer and collared peccary demonstrated a positive relationship with distance to settlement as their RAI increased with increasing distance; whereas agouti had a negative relationship as the RAI decreased with increasing distance to settlements (Fig. S1). Distance to road was also a significant predictor for the RAI of white tailed deer ($F_{1, 26} = 8.37$, $p < 0.05$, $r^2 = 0.20$) and similarly, the RAI of this species increased with increasing distance to roads (Fig. S1).

Overall, nine-banded armadillo and paca demonstrated a predominant nocturnal activity (90 % and 95 %, respectively). The agouti was mostly diurnal (66% diurnal and 26% crepuscular), and collared peccary was diurnal (89% of diurnal activity), whereas, white-tailed deer was the only prey species that demonstrated a more cathemeral activity (59% diurnal and 38% nocturnal) (Fig. 2). All five prey species exhibit overlap in locations with predators, people and domestic dogs (Table S3). Prey species displayed different overlap coefficient with predators. Nine-banded armadillo (Δ_1=0.77) and paca (Δ_1=0.85) had a high overlap with jaguar (Table 2). We also detected a high overlap between white tailed deer and puma (Δ_1=0.75) (Table 2). A Low overlap was detected between agouti and jaguar (Δ_1=0.33); and similarly, for paca and puma (Δ_1=0.47) (Table 2). Both, nine-banded armadillo and paca had a low overlap with people and domestic dogs (Table 2). Collared peccary had the highest overlap with people and dogs (Δ_1=0.89 and Δ_1=0.82 respectively), followed by the white-tailed deer (Δ_1=0.70 and Δ_1=0.76 respectively) (Table 2).

DISCUSSION

All prey species (nine-banded armadillo, paca, white-tailed deer, agouti and collared peccary) in our study are classified as least concern by the IUCN, because of their wide distribution range (Emmons 2016a , Emmons 2016b, Loughry & Abba 2014, Gallina & Lopez 2016, Gongora *et al.* 2016). However, due to increasing threats such as habitat loss and fragmentation there is an urgent need to know their abundance and to understand their behavior, especially in human modified landscapes. As a contribution to fill this gap, we found that white-tailed deer and agouti are more resilient to human activity, exhibiting the highest RAI throughout the landscape. Additionally, our data suggest a high interaction between white-tail deer, collared peccary and anthropogenic factors (people and domestic dogs).

We recognize that prey and predators might use the space differently, hence displaying difference in their detection patterns (Harmsen *et al.* 2011). Furthermore, RAI may have a potential bias because of nonlinear relationships between the index and true abundance across species, space and time (Foster & Harmsen 2012, Sollmann *et al.* 2013). However, when cameras are placed or samples taken randomly, positive linear relationships between RAI and independent density estimates have been identified through space, time and species for herbivores (Carbone *et al.* 2001, Rowcliffe *et al.* 2008, Rovero & Marshall 2009). Thus, we assume the RAI allowed conservative inferences about the ecology of unmarked animals like most of our target species.

Similarly to our hypothesis, the results indicate that agouti and white-tailed deer had the highest RAIs in the landscape. Our results suggest that agouti had the highest relative abundance in the area. This can be due to low hunting pressure as it is not a favored game species (Foster *et al.*

2016) nor a prey species within the diet of jaguar and puma in Belize (Foster *et al.* 2010a), as agouti is a buffer prey and only consumed when preferred prey are scarce (Novack *et al.* 2005). On the contrary, in rural areas in Yucatán Peninsula, Mexico, it is one of the main hunted game (Santos-Fita *et al.* 2012, Ramírez-Barajas & Calmé 2015) and consumed by jaguar and puma in Mexico (Ávila–Nájera *et al.* 2018) and Guatemala (Novack *et al.* 2005). Agoutis are also known to prefer gardens and plantations because these provide a food source (Emmons & Feer 1997, Reid 2009) which are prominent within the settlements in the study area.

High abundance of white-tailed deer is associated with temperate and tropical deciduous forests, and scrublands; yet, because of the adaptability of the species, it is also associated with agricultural areas (Mandujano *et al.* 1991). This association was also detected in our study as the majority of records of the deer were on camera stations in agricultural areas (Table 1) and demonstrating the second highest RAI of the study area. White-tailed deer is considered to have some tolerance to hunting pressure as reported by Reyna-Hurtado & Tanner (2007) in which the relative abundance was higher in hunted areas than in non-hunted, suggesting that this tolerance is due to the ecological flexibility and the association with farmlands of the species; hence, allowing the use of these modified habitats.

Even though collared peccary has been reported to have a high tolerance for human disturbance particularly with regards to human density and reduction of forest cover (Altrichter & Boaglio 2004), in our study it had the lowest RAI. Additionally, low RAI for nine-banded armadillo and paca were also reported in the study. These low abundances can be an indication of possible overexploitation of these species in the area as they are highly consumed during annual cultural festival such as the La Ruta Maya river challenge (Shanelly Carrillo [Belize

Forest Department] and Yahaira. L. Urbina [University of Belize] personal observations). However, in the case of the collared peccary, low RAI can be a result of the classification used for social species and not using the average group size detected. An increment in RAI (from 0.68 to 1.07) was identified when using the average group size of collared peccaries; but, we opted to make a conservative estimate, hence we used single records. We also concede that for nine-banded armadillo and paca, we may have failed to detect them because some of the locations were too open for these species to risk predation.

No significant relationship was detected between relative abundance (RAI) of nine-banded armadillo, paca and both habitat and anthropogenic variables. Other factors (e.g. hunting rates and microhabitat features) that were not considered could have more influence or weight in explaining relative abundance of these species in the study area. Even though, the RAI of collared peccary was associated with human settlements and rivers, and the RAI of agouti with human settlements, we recognized that we are unable to make strong inferences due to the low predicting power (< 20% of data is explained) of these variables. Therefore, suggesting that these factors were not the most appropriate in predicting RAI at the spatial scale of this study. We also acknowledge that we had few records, which may have contributed to the low predicting power of these statistical models. Lower records in modified landscapes have been reported in Mexico in which only the paca was detected (Figueroa de León *et al*. 2016), thus, implying that the landscape conditions of the study still permits the presence of generalist species, such as the collared peccary and agouti, in certain abundances, since these species can adapt to a certain level of anthropogenic pressure (Emmons & Feer 1997, Reid 2009, Petracca *et al.* 2014). Contrary to specialists species, white-lipped peccary and red brocket deer, which prefer continuous forest (Reyna-Hurtado & Tanner 2007, Briceño-Méndez *et al.* 2016) and this was observed in our study, as white-lipped peccary was not detected and red brocket deer had low detections during the survey. White-tailed deer was the only species in which we found that relative abundance increased with distance to settlements and roads. Ramos-Robles *et al.* (2013) also found that distance to settlement is positively related to white-tailed deer density. The avoidance of road systems is a result of hunting rates as roads provide greater access to wildlife population (Wilkie *et al.* 2000).

Beside abundance of these prey species it is also important to understand their behavior in such critical landscapes which are important for the connection of wildlife populations. We observed that the five target species maintained similar activity patterns previously reported in protected and non-protected areas (Gómez *et al.* 2005, Harmsen *et al.* 2011, Foster *et al.* 2013, Azevedo *et al.* 2018, Leuchtenberger *et al.* 2018). Activity patterns are usually influenced by species´ body size, Van Schaik & Griffiths (1996) stated that smaller mammals are nocturnal as an anti-predation strategy, whereas larger mammals exhibit a more cathemeral activity pattern because of energy requirements and associated feeding habitats. Both nine-banded armadillo and paca exhibited nocturnal behavior, but not with the agouti, which had more diurnal activity, with peaks between 6:00 to 8:00 and 16:00 to 18:00, similarly observed in Bolivia by Gómez *et al.* (2005). Paca and agouti are known to have similar diet requirements hence they avoid competition by temporal separation of their activity patterns in protected areas (Gómez *et al.* 2005) and in our study these rodents exhibited similar behavior in a modified landscape. Additionally, they showed spatial overlap as agouti was present in 67 percent of the locations in which paca was detected. The collared peccary had a diurnal activity as reported in the

Cockscomb wildlife sanctuary in Belize (Harmsen *et al.* 2011) and white-tailed deer, the largest in size, had a cathemeral activity. Hence, these results indicate that the anthropogenic pressure in central Belize has not yet modified the activity patterns of the target species or conspecific competition between paca and agouti.

Prey species are considered to have great influence on jaguar and puma activity patterns (Harmsen *et al.* 2011, Foster *et al.* 2013, Azevedo *et al.* 2018). There was high overlap between nine-banded armadillo, paca and jaguar, as previously reported by Foster *et al.* (2013). Nine-banded armadillo is the main prey for jaguar both in protected and non-protected areas making up 50 percent and 33 percent of its diet, respectively (Foster *et al.* 2010a). Contrary, to the low overlap between paca and puma, its main predator. This could be a result of the mostly diurnal activity demonstrated by the large cat in the central Belize landscape, which allows the puma, a generalist carnivore, to consume a wide assortment of prey including diurnal and nocturnal species (Murphy & Ruth, 2010). The cathemeral behavior of white-tailed deer caused it to have high overlap with predators but also with human and domestic dogs (Fig. 3). Although it is not the main prey for jaguar as it makes up 2 % of its diet (Ávila–Nájera *et al.* 2018). Contrary for puma, Novack *et al.* 2005 reports the deer is an important prey for the large cat. Cathemeral behavior exposes the white-tailed deer not only to predation but also to possible high hunting pressures. In general, humans and domestic dogs were most active during the day, hence leading to a higher temporal overlap with the diurnal prey species than those that are nocturnal, leaving these species exposed to more encounters with people and domestic dogs. There was some overlap with all the target species and both people and domestic dogs. The highest temporal overlaps between people and dogs were with white-tailed deer and collared peccary. Indicating a possible higher mortality risk (Azevedo *et al.* 2018) as these species also overlapped spatially with people and domestic dogs detections (Table S3). The effect of human presence on the target species is probably due mainly to hunting. Hunting occurs during day and night time in the area (Urbina *et al.* unpubl.). However, the overlap between prey species and domestic dogs deserves further comments as free-ranging dogs are becoming a problem for conservation (Gompper 2013). Dogs in natural areas are stimulated by the environment hence reacting similarly to their wild ancestors (Scott & Fuller 1974, Gompper 2013) developing greater hunting abilities and changing their social behavior by forming packs (Rubin & Beck 1982). Although, in our study dogs were mostly solitary, there were a few groups of 2-3 dogs roaming the landscape. We cannot make strong inferences about the impact that dogs have on the prey populations, as it is beyond the scope of our study, however it does highlight a potential high interaction between them.

Information about prey species in human modified landscape is essential for their conservation and management plans, since it address gaps in understanding behavior and populations outside protected areas. Our results demonstrated that white-tailed deer can tolerate certain level of human disturbance because even though it avoided human settlements, it was still associated with agricultural areas (Mandujano *et al.* 1991). Major emphasis should be place in understanding the cause of the low RAI of nine banded armadillo, paca, and collared peccary. Additionally, information obtained gave insights into how the target species can still sustain activity patterns in modified landscapes. Although camera-trap data in our study identified the possible high interaction between the prey species, people and dogs, further studies are needed to fully understand the impact domestic dogs may have on the wildlife populations; and to understand the relationship between abundance and hunting rates as animal mortality in modified landscapes is strongly associated with the spatial distribution of hunting efforts (Sirén et al. 2004).

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DATA AVAILABILITY STATEMENT

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TABLES

TABLE 1. Percentage of habitat types of camera station locations in which the five species were detected.

	# of camera present	Agriculture	Savannah	Forest
Dasypus novemcinctus	*9*	44	22	33
Cuniculus paca	*10*	50	10	40
Odocoileus virginianus	*13*	54	23	23
Dasyprocta punctata	*14*	29	14	57
Pecari tajacu	*10*	30	30	40
Average		**41**	**20**	**39**

TABLE 2. Summary of the number of independent records (*n*), Relative Abundance Index (RAI), Naïve occupancy (Naïve λ) and estimates of coefficients of overlapping (Δ_1) of the five prey species with predators (*Panthera onca* and *Puma concolor*), people and domestic dogs, and corresponding 95% confidence intervals (CI).

				Predators				Anthropogenic factors			
				Panthera onca		*Puma concolor*		People		Domestic Dog	
				n = 90		n= 20		n = 241		n = 142	
Species	*n*	RAI	Naïve λ	Δ_1	CI	Δ_1	CI	Δ_1	CI	Δ_1	CI
Dasypus novemcinctus	39	0.76	0.31	0.77	0.63-0.87	0.38	0.23-0.62	0.12	0.11-0.26	0.24	0.20-0.40
Cuniculus paca	41	0.80	0.34	0.85	0.69-0.92	0.47	0.30-0.71	0.21	0.18-0.39	0.33	0.28-0.52
Odocoileus virginianus	59	1.15	0.45	0.6	0.48-0.73	0.75	0.52-0.86	0.70	0.59-0.81	0.76	0.64-0.86
Dasyprocta punctata	108	2.10	0.48	0.33	0.29-0.47	0.53	0.36-0.69	0.51	0.46-0.64	0.55	0.36-0.69
Pecari tajacu	35	0.68	0.34	0.35	0.28-0.54	0.69	0.46-0.81	0.89	0.71-0.92	0.82	0.68-0.90

FIGURES LEGENDS

FIGURE 1. Map of study area and camera stations installed between 2014 and 2015 a human modified landscape in Belize River Valley.

FIGURE 2. Activity pattern of nine-banded armadillo (n = 39), paca (n = 41), white-tailed deer (n =59), agouti (n = 108) and collared peccary (n = 35), based on camera-trap surveys (from 2014 to 2015) in the Belize River Valley.

FIGURE 3. Density estimates of daily activity pattern of white-tailed deer, predators, people and domestic dogs in the Belize River Valley. The coefficient of overlap is represented by the shaded area.

FIGURES

Fig. 1

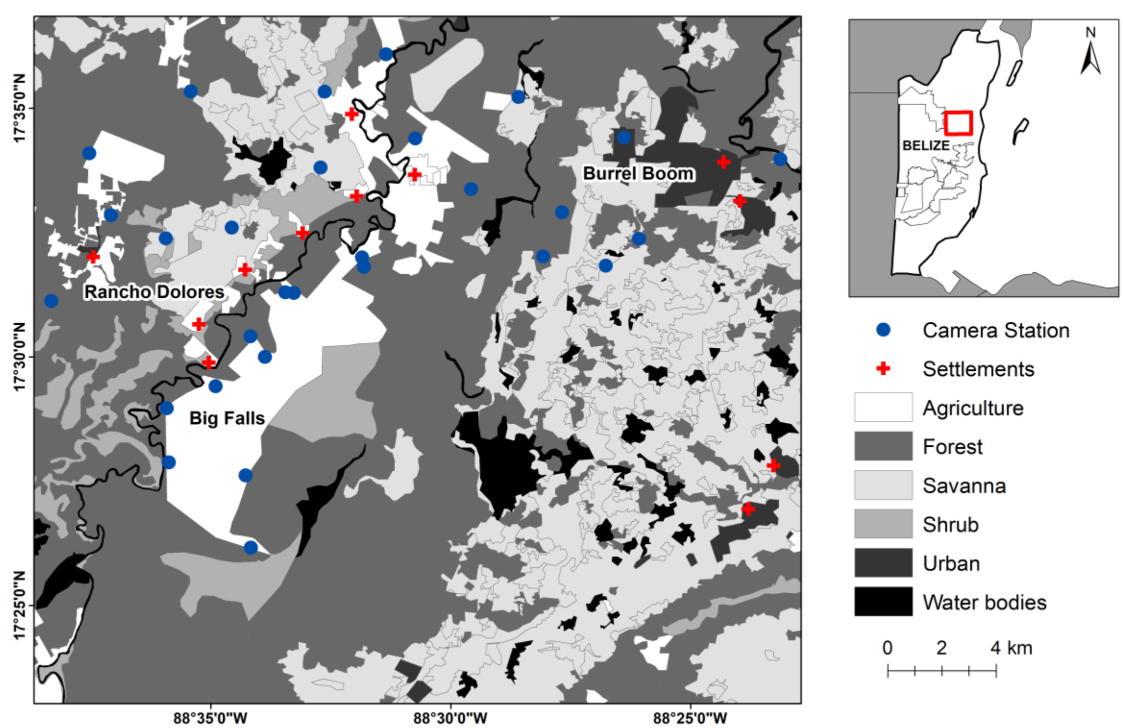


Fig.2

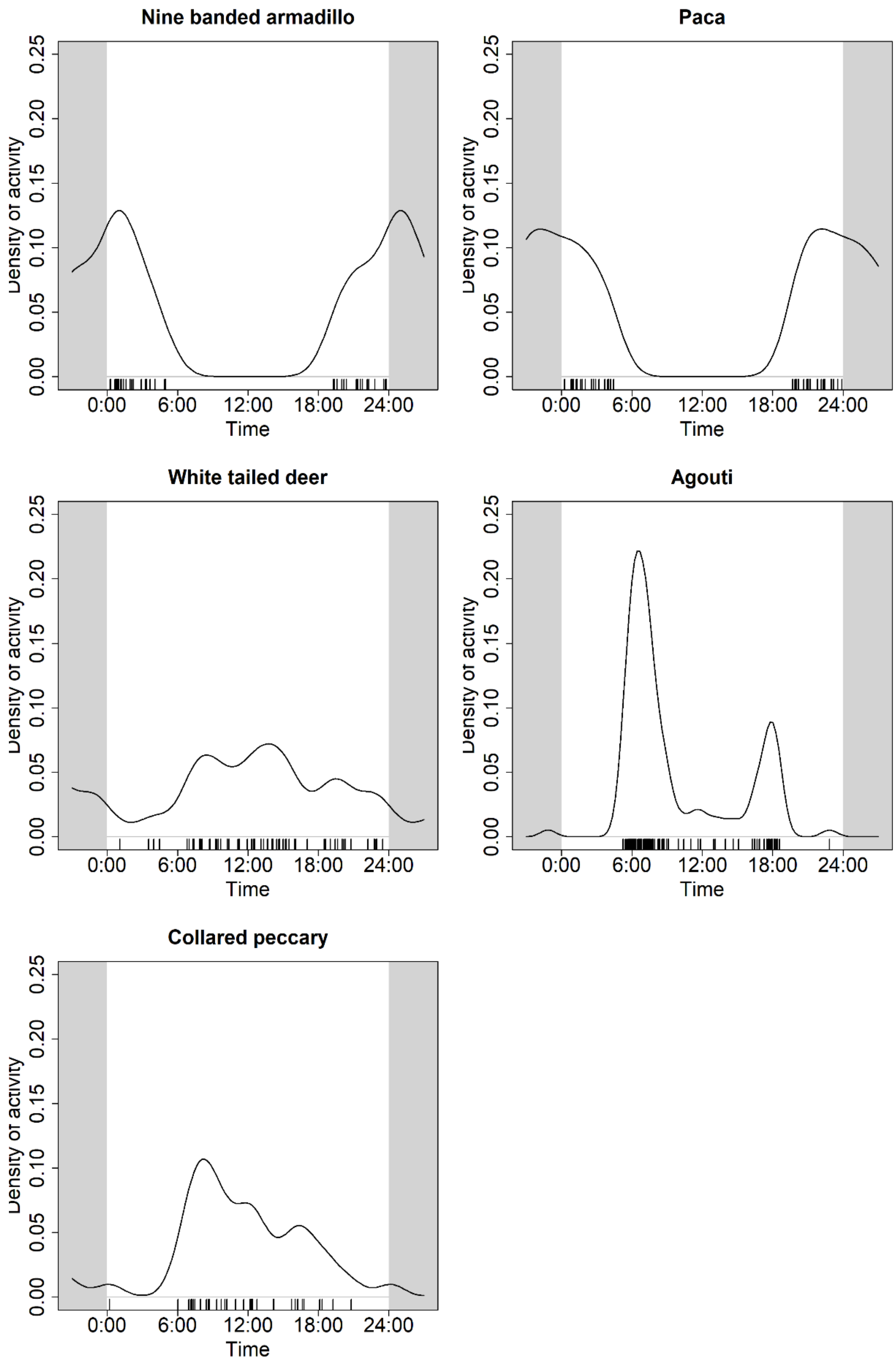
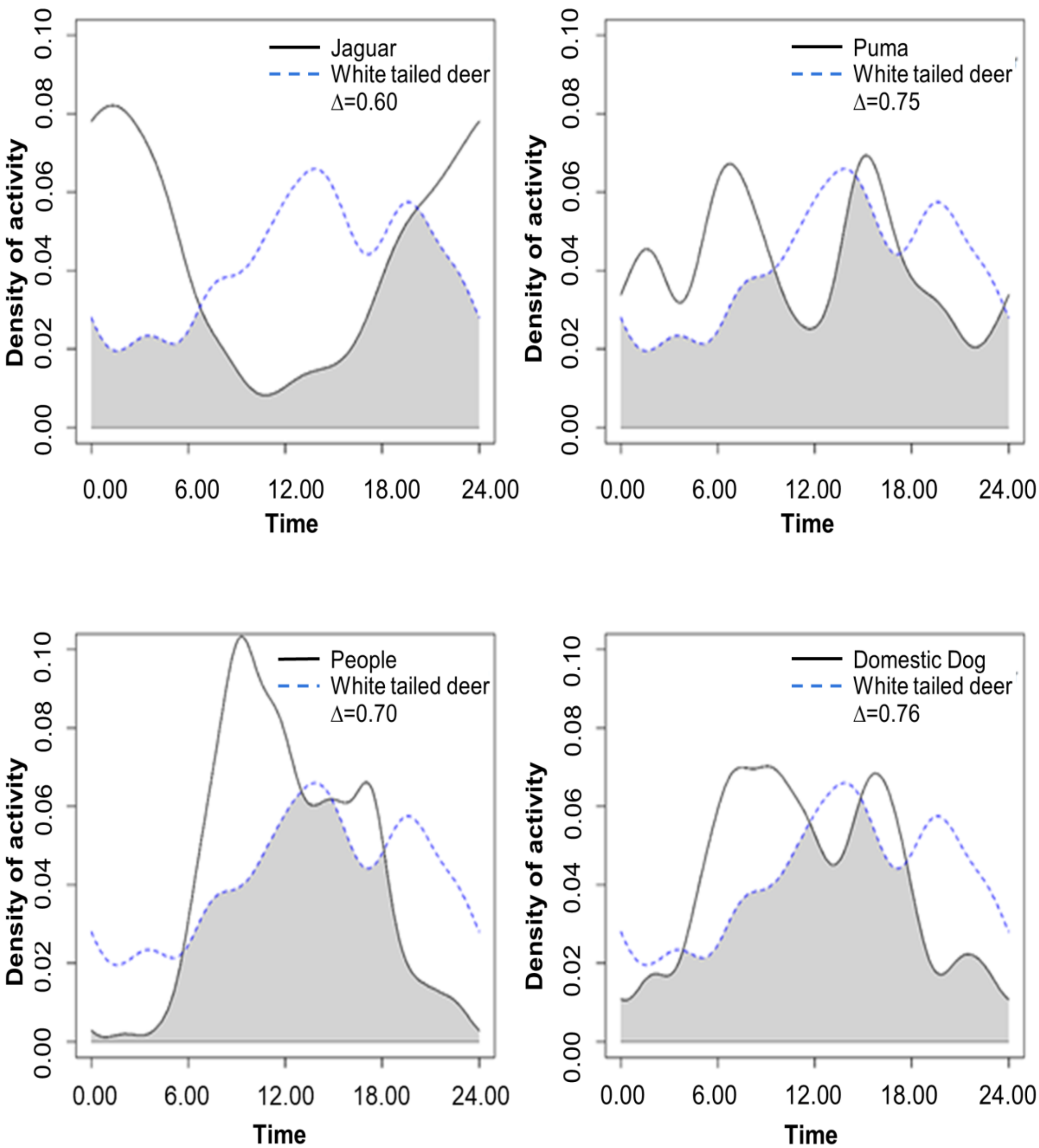

Nine banded armadillo
Paca
White tailed deer
Agouti
Collared peccary
Density of activity
0.00
0.05
0.10
0.15
0.20
0.25
0:00
6:00
12:00
18:00
24:00
Time

Fig. 3



Jaguar
White tailed deer
Δ=0.60
Puma
White tailed deer
Δ=0.75
People
White tailed deer
Δ=0.70
Domestic Dog
White tailed deer
Δ=0.76
Density of activity
0.00 0.02 0.04 0.06 0.08 0.10
Time
0.00 6.00 12.00 18.00 24.00

SUPPLEMENTARY INFORMATION

TABLE S1. Collinearity ratio between habitat and anthropogenic factors.

	Distance to settlement	# of hunters	Distance to road	RAI of people	Distance to river	Forest cover	% of agriculture
Distance to settlement	1	0.07	0.46	-0.05	0.28	-0.03	0.22
# of hunters	0.07	1	0.37	0.04	0.32	0.00	-0.02
Distance to road	0.46	0.37	1	-0.14	0.52	0.08	0.00
RAI of people	-0.05	0.04	-0.14	1	-0.09	0.02	0.30
Distance to river	0.28	0.32	0.52	-0.09	1	-0.12	-0.51
Forest cover	-0.03	0.00	0.08	0.02	-0.12	1	-0.10
% of agriculture	0.22	-0.02	0.00	0.30	-0.51	-0.10	1

TABLE S2. Summary of linear regressions between the Relative Abundance Index (RAI) of nine-banded armadillo (*Dasypus novemcinctus*), paca (*Cuniculus paca*), white-tailed deer (*Odocoileus virginianus*), agouti (*Dasyprocta punctata*), collared peccary (*Pecari tajacu*), and habitat and anthropogenic factors in Central Belize.

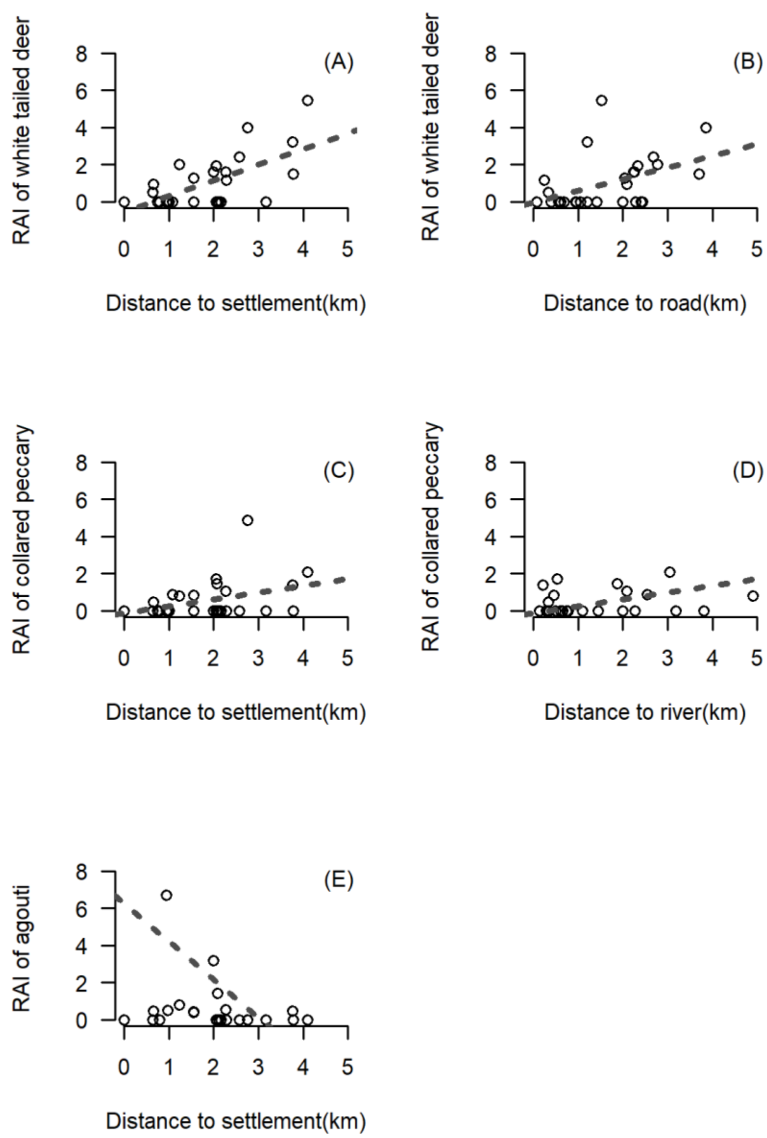
Independent variables	B	SE B	β	t	p
Nine banded armadillo					
Settlements	0.17	0.68	0.32	0.99	0.33
Roads	0.99	0.67	-0.14	-0.40	0.68
People presence	0.66	0.42	0.03	0.42	0.68
Hunters	-0.25	0.84	0.12	1.30	0.20
% of forest	0.23	0.68	1.24	0.90	0.37
River	0.42	0.49	0.18	0.97	0.33
% of agriculture	0.84	0.51	-0.34	-0.24	0.81
Paca					
Settlements	0.82	0.49	-0.06	-0.29	0.77
Roads	1.02	0.47	-0.20	-0.81	0.42
People presence	0.73	0.30	-0.010	-0.25	0.80
Hunters	0.68	0.62	0.002	0.03	0.98
% of forest	0.51	0.48	0.430	0.43	0.66
River	0.65	0.35	0.03	0.19	0.85
% of agriculture	0.70	0.36	-0.02	-0.02	0.98
White tailed deer					
Settlements	-0.52	0.41	0.83	4.26	**<0.05**
Roads	-0.01	0.46	0.62	2.52	<**0.05**

People presence	1.07	0.33	-0.02	-0.47	0.65
Hunters	1.11	0.67	-0.02	0.07	0.83
% of forest	1.19	0.52	-0.47	-0.44	0.65
River	0.65	0.37	0.18	1.27	0.21
% of agriculture	0.61	0.38	1.41	1.38	0.18
Agouti					
Settlements	6.24	1.75	-2.04	-2.43	**<0.05**
Roads	5.15	1.79	-1.6	-1.7	0.10
People presence	2.52	1.19	0.01	0.07	0.94
Hunters	6.44	2.30	-0.47	-1.83	0.08
% of forest	0.60	1.87	4.64	1.21	0.23
River	3.78	1.39	-0.59	-1.15	0.26
% of agriculture	3.16	1.42	-2.21	-0.06	0.57
Collared Peccary					
Settlements	-0.11	0.37	0.37	2.09	**<0.05**
Roads	0.04	0.37	0.32	1.63	0.12
People presence	0.68	0.24	-0.04	-0.93	0.36
Hunters	0.93	0.49	-0.05	-0.83	0.42
% of forest	0.85	0.39	-0.69	-0.87	0.39
River	0.15	0.26	0.22	2.19	**<0.05**
% of agriculture	0.71	0.29	-0.56	-0.72	0.47

TABLE S3. Proportion of overlap in camera station between prey species, predator, people and domestic dogs.

Species	# of camera present	*Panthera onca*	*Puma concolor*	People	Domestic Dog
Dasypus novemcinctus	9	0.44	0.22	0.89	0.78
Cuniculus paca	10	0.50	0.30	0.80	0.70
Odocoileus virginianus	13	0.77	0.62	0.77	0.38
Dasyprocta punctata	14	0.79	0.43	0.93	0.79
Pecari tajacu	10	0.80	0.50	0.90	0.60

FIGURE S1 Regression displaying a relationship between: (A) RAI of white tailed deer and distance to settlement; (B) RAI of white tailed deer and distance to road (km); (C) RAI of collared peccary and distance to settlement (km); (D) RAI of white tailed deer and distance to river (km); and (E) RAI of agouti and distance to settlement (km).



Conclusiones generales

En este estudio se analizó la abundancia relativa y el patrón de actividad de cinco especies de mamíferos (*Dasypus novemcinctus, Cuniculus paca, Odocoileus virginianus, Dasyprocta punctata* y *Pecari tajacu*) en un paisaje modificado en el centro de Belice. Es un paso importante para la conservación de estas cinco especies, ya que en los últimos años se han expuesto a más factores antropogénicos como la fragmentación y la alta cacería (Zeilhofer et al. 2014).

En particular, los resultados muestran que el agutí (IAR = 2.10) y el venado cola blanca (IAR = 1.15) son las especies con mayor presencia en el paisaje analizado en el centro de Belice, ya que exhibieron la mayor abundancia relativa y la mayor ocupación naive. Se corroboró que estas dos especies son más adaptables a los paisajes antrópicos. En el caso del venado cola blanca, hubo una asociación con las áreas agrícolas, la cual ya había sido reportada previamente para la especie en México. Las áreas agrícolas pueden ser áreas semi-óptimas si la caza está regulada, ya que proporcionan una fuente importante de alimento en paisajes modificados para algunas especies como venado cola blanca, agutí, paca y pecarí de collar. El alto IAR del agutí es explicado por la falta de depredación y la presión de caza en la zona de estudio, mientras que las especies presa favoritas para la caza (armadillo de nueve bandas, paca y pecarí de collar) tuvieron la menor abundancia relativa.

No pudimos hacer inferencias sobre los factores que influyen en la abundancia relativa del armadillo de nueve bandas y la paca. Ninguno de los factores de hábitat o antropogénicos considerados mostró un efecto sobre la abundancia relativa ni fueron buenos predictores para el IAR del pecarí de collar y agutí. Lo anterior sugiere que probablemente otros factores, como las características del microhábitat y disponibilidad de recursos, afectan la abundancia relativa de estas cuatro especies. El venado cola blanca fue la única especie que demostró un efecto por los asentamientos humanos y caminos, al parecer los evita por el alto riesgo de mortalidad que implican. Aunque no se encontró ninguna relación significativa entre la abundancia relativa de las especies objetivo y número de cazadores, es importante para la conservación de las especies, monitorear las actividades de caza dentro del área de estudio. Todavía hay una deficiencia en el conocimiento sobre el vínculo entre la abundancia de especies y las tasas de extracción por la caza. Por lo que se recomienda una investigación de seguimiento para entender esta relación, ya que la mortalidad de fauna en paisajes modificados está fuertemente asociada con la distribución espacial de los esfuerzos de caza (Sirén et al. 2004).

A pesar de que el área de estudio está experimentando un avance importante de la frontera agrícola, la matriz de hábitat todavía permite que todas las especies objetivo mantengan patrones de actividad similares a los reportados en áreas protegidas. Además, los depredadores mantuvieron una alta superposición de actividad temporal con sus presas principales.

Reconocemos que todas las especies presas están expuestas tanto a la presencia humana como a los perros domésticos, considerados una amenaza creciente para la vida silvestre. La superposición temporal y espacial de las presas con los seres humanos es una indicación de alto riesgo de mortalidad, como resultado de las actividades de caza. Se necesitan más estudios para comprender completamente el impacto que los perros domésticos pueden tener en sus poblaciones, y una vez más, enfatizamos la necesidad de vincular la abundancia relativa y las tasas de caza de las cinco especies presa.

Este estudio resalta la necesidad de crear de manera urgente, planes de manejo adecuados para el centro de Belice, debido a la importancia del hábitat, dado que hay proyecciones nacionales para desarrollar esta área. Recientemente, el gobierno de Belice aprobó la propuesta de proteger el área donde se realizó este trabajo, permitiendo una oportunidad única para incorporar datos ecológicos en planes de manejo. Por lo tanto, este estudio será complementario para que los administradores, conservadores y encargados de formular políticas ambientales, hagan planes de manejo efectivos para la supervivencia de estas especies.

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