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Raining feral cats and dogs? Implications for the conservation of medium-sized wild mammals in an urban protected area

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Abstract

Mammals are one of the most negatively affected groups by urbanization, nevertheless, urban reserves can help their conservation. The study of wildlife within the reserves is important for the persistence of these populations, but stressors factors as feral fauna might endanger the conservation of wildlife. Therefore, our objective was to analyze the patterns of temporal and spatial activity of wild and feral mammals within the San Angel Pedregal Ecological Reserve, UNAM, Mexico City, using trap cameras. We found five species of wild mammals and two feral ones. All mammals were primarily nocturnal, except for the Rock Squirrel which changes their behavior in comparison with individuals in natural habitats. All wildlife species showed a high temporal overlap of activity with feral fauna particularly, Rock Squirrel, Eastern Cottontail, and Gray Fox. The analysis of spatial co-occurrence showed that the probability of an encounter between species at a certain point of the reservation is random. Although, due to the reduced area of the reserve, species may overlap spatially. In general, our results indicate that feral fauna has a high overlap of activity with wildlife, however, the studied reserve protects wildlife populations. Therefore, to reduce this overlap, we recommend creating a dog and cat management program for urban protected areas and surrounding areas. Particularly in REPSA, we encourage to continue with the control program of feral species in the long term and change the management of waste within the UNAM.

Keywords Activity patterns · REPSA · Pedregal ecosystem · Urban reserves · Overlap · Mesopredators

Introduction

For the first time in history most of the human population resides within urban areas (Kark et al. 2007). This unusual environment presents wildlife with novel challenges, in particular, a loss of natural resources (e.g. habitat) and elevated anthropogenic disturbance levels (e.g. pedestrian and vehicular traffic, industrial noise) (Lowry et al. 2013). In urban areas, a small number of species can be adapted to human-dominated landscapes replacing a wider range of native species, this process is known as urban biotic homogenization (sensu Kark et al. 2007) and is driven by forces exclusive to metropolitan areas (Fischer et al. 2012). Overall, wild fauna populations are forced to move outside of cities or are eliminated after urbanization (Woodroffe 2000), adjust to urbanization through genetic changes, or adapt through phenotypic plasticity (Kark et al. 2007; Lowry et al. 2013). Given the extent of urbanization, a deeper understanding of the behavior of animals that persist in urban areas is essential to design and manage plans for them in urban environments.

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Disturbance-related variables in urban areas, such as pedestrian and vehicular traffic, can affect behavior of animals (Baker et al. 2007; Murray and St. Clair 2015; Ditmer et al. 2018). For terrestrial mammals, movement and activity associated with foraging behavior can be a high-risk activity in urban environments (e.g. by collision with vehicles) (Lowry et al. 2013). One way that urban mammals can deal with this disturbance is by altering their behavior, specifically, individuals become more active after human and vehicular traffic are reduced (Dowding et al. 2010; Patten and Burger 2018). Thus, the most important adaptations for the mammalian's persistence in urban areas are small body size, behavioral plasticity, and diet diversity (Santini et al. 2019). On another hand, dog and cat's dependence on human assistance vary along a continuum, ranging from "pets" which are being completely dependent in one extreme, to feral dogs and cats living in wild populations with no human care in the other (Coleman et al. 1997; Vanak and Gompper 2009). A high percentage of the world's total domestic dog and cat population are considered "wandering," that is, an intermediate stage of feral dogs and cats (i.e., owners breed them free, and they usually return home only for feeding) (sensu Hughes and Macdonald 2013). These animals supplement their diet through hunting, but even when they are well-fed, they can attack and harass wild animals (Campos et al. 2007; de Andrade Silva et al. 2018; Villatoro et al. 2019). In this sense, encounters between feral fauna with native wildlife might occur because they share common resources such as food, space and time (Mella-Méndez et al. 2019).

Urban green infrastructure has been suggested to provide multiple benefits to humans residents (Kendal et al. 2017; Andersson 2018). Its elements can include a variety of green spaces such as protected areas, parks, open spaces, playing fields, to name a few (Girma et al. 2019). Urban green infrastructure, as urban protected areas, provides a major opportunity for conservation of native biodiversity in the heavily urbanized landscapes (Watts and Larivière 2004), even when animal populations could be isolated (Watts and Larivière 2004). Currently, the effect of feral fauna on native wildlife is an issue that has gained importance in order to the preservation of mammals in protected areas (Zapata-Ríos and Branch 2016; Parsons et al. 2018; Villatoro et al. 2019; Zanin et al. 2019). A growing body of evidence has demonstrated that negative impacts on native wildlife include increased mortality, resources competition, and transmission of infectious agents (Suzan and Ceballos 2005; Loss et al. 2013). Although, that the impacts of feral fauna predation on native mammals remain unclear, it has been suggested that cats could prey on an important number of native mice, shrews, voles, squirrels, rabbits birds, and reptiles (Loss et al. 2013). Whereas knowledge about the global ecological impacts of feral dogs is less than about feral cats (Young et al. 2011; Zapata-Ríos and Branch 2016; Doherty et al. 2017). Notwithstanding is known feral dogs can significantly disrupt intact ecosystems, affecting negatively threatened and endangered wildlife species (Young et al. 2011). Feral dogs can be effective interference competitors (i.e. a species that can drive spatial exclusion, harassment, or mortality to other intraguild species), especially with medium-sized and small carnivores (Vanak and Gompper 2009). Thereby, within the urban protected areas, feral fauna, might play an important role as stressors on native wildlife mammal and affect their persistence (Parsons et al. 2016; Zapata-Ríos and Branch 2016). Therefore, it is imperative to assess the temporal and spatial activity overlaps between native mammals and feral fauna in an urban protected reserve to conduct better plans of feral fauna control programs and to establish viable populations of native wild mammals.

Our general aim was to assess the activity patterns of medium-sized mammals within an urban protected reserve in Mexico. More specifically, we were interested in the following questions: (a) Which are the species medium-size mammals inside an urban reserve?; (b) Which are the activity patterns of medium-sized mammals within an urban reserve?; (c) Does exist temporal or spatial overlapping in activity between feral fauna and wildlife mammals?; and (d) Which wildlife fauna species are more vulnerable to overlapping their activities with feral fauna? Based on empirical evidence, we speculated that most wildlife mammals would be more active after human activities (i.e. between midnight and early morning). On the other hand, we expected overlapping temporal and spatially (i.e. spatial aggregation) in activities between feral and wildlife mammals due to the extent reduced to the urban reserve. Finally, we expect that the feral cats would be overlap activities with herbivorous mammals, whereas feral dogs would be overlap activities with carnivorous mammals.

Materials and methods

Study area

The Pedregal of San Angel's Ecological Reserve (REPSA, for its acronym in Spanish) is an urban protected reserve which is located in the main campus of the National Autonomous University of Mexico (UNAM), in Mexico City (Rojo and Rodriguez 2002; Lot and Cano-Santana 2009; Lot et al. 2012). The REPSA has high biological and cultural value because it represents an important heritage for Mexico City (Hortelano-Moncada et al. 2009) and it is one of the few remnants of original vegetation within one of the most populated cities in the planet (Lot and Cano-Santana 2009; Lot et al. 2012).

The REPSA has an extension of 237.3 ha (core area of 171 ha and 13 buffer zones with 66 ha), this urban reserve is embedded in the southwest of Mexico City (Hortelano-

Moncada et al. 2009; Lot and Cano-Santana 2009; Nava-Escudero 2015) (Fig. 1). The soil is basaltic, a product of the eruption of Xitle volcano 2000 years ago (Siebe 2000; Lot and Cano-Santana 2009). The lava region of the volcano and adjacent cones is known as Pedregal (80 km^2). Its climate is temperate subhumid with rains in summer (June–November), with an average annual rainfall of 700 to 900 mm and a mean temperature of 14 to 15 °C (Hortelano-Moncada et al. 2009). Due to the variability of substrate and altitude (2200 to 2277 m.a.s.l.), the REPSA presents different plant associations, being classified as xerophilous scrub, with a dominance of an endemic shrub (*Pittocaulon praecox*) and herbs (Hortelano-Moncada et al. 2009; Lot and Cano-Santana 2009; Secretaria Ejecutiva del Pedregal de San Ángel 2018). The Pedregal's ecosystem is characterized by high biodiversity, endemism, and restricted distribution species (Lot and Cano-Santana 2009). However, the REPSA is extremely fragile due to urbanization which has caused the deterioration and fragmentation of its habitat, added to the introduction of feral species (i.e. feral cats and dogs) that compete and displace native species (Cruz-Reyes 2009; Lot et al. 2012). In the core areas of REPSA, humans and their pets have restricted and negligible access, but the feral fauna of city has unlimited entry.

Field work

We used camera traps to record terrestrial mammals; this method represents an effective monitoring tool (Nichols et al. 2011; Burton et al. 2015; Kolowski and Forrester 2017). Between August 2017 and June 2018, 11 camera traps were positioned in the study area with a distance mean of 72.13 m (± 23.74 SD). Camera traps fixed to tree trunks at a height ranging from 0.5 to 1 m, in the south – north-oriented position to avoid being activated by direct sunlight (Si et al. 2014; Swan et al. 2014; Coronel-Arellano et al. 2018). All cameras were programmed to operate continuously (24 h/day) at one-minute intervals, taking three continuous photographs (digital images), when activated. Three models of digital cameras were used: four Cuddeback® (Non-Typical Inc.,

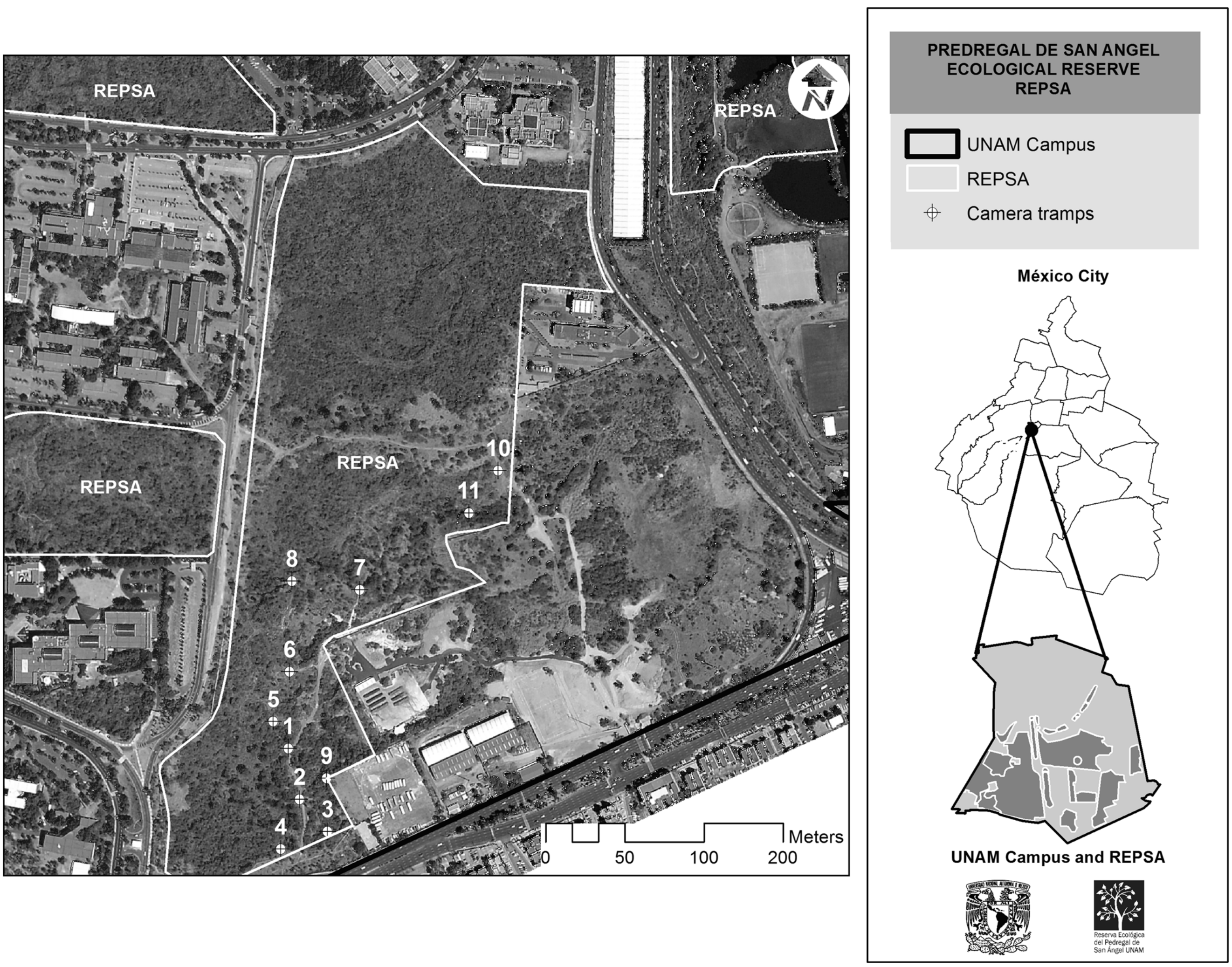

Fig. 1 Study area in Mexico City

Green Bay, WI, USA), four Bushnell® (Bushnell Outdoor Products, Kansas, USA), and three Scoutguard® (HCO Norcross, GA, USA). GPS geographic coordinates were recorded for each site in which a camera trap was placed.

Data analysis

We identified the species of mammals from the photographs using field guides (Reid 1997; Bowers et al. 2004). Sampling effort was calculated by multiplying the total number of cameras placed, by the number of days they were operating (1 d = 24 h) (Coronel-Arellano et al. 2016). Thus, we calculated a photographic capture rate (number of photographs of each species divided by the sampling effort in days), which we used as a measure of relative abundance (Porfirio et al. 2014; Coronel-Arellano et al. 2016).

We determined the sampling efficiency by comparing the percentage of observed species richness versus expected species derived from a richness estimator. We used Jackknife 1 because this estimator assumes there is no temporal variation in the capture probability for all species and it has been shown to provide better results in relation to other estimators of diversity in mammals (Tobler et al. 2008). The estimator Jackknife 1 was calculated using the EstimateS Version 9.1.0. software (Colwell 2013), through which a species accumulation curve was generated with 1000 iterations. For the construction of the curve, we used the maximum number of traps stations ($n = 11$) as sampling effort and extrapolated to double ($n = 22$), as an estimate of the number of species that would be recorded with an increased sampling effort. For sampling efficiency, we only analyzed wildlife with a mean weight of 0.5 kg or more. We did not include smaller species in this analysis because camera traps do not efficiently detect them (Tobler et al. 2008).

To avoid temporal autocorrelation, we considered independent records those separated at least by one hour. Next, activity was assigned into two categories: (1) diurnal, one hour after sunrise and one hour before sunset; and (2) nocturnal, one hour after sunset and one hour before sunrise (modified from Foster et al. 2013). The proportion of diurnal and nocturnal activity of mammal species was estimated using a kernel density estimator with the overlap package (Meredith and Ridout 2014) from R (R Develompment Core Team 2017).

We used the non-parametric kernel density estimation procedure described in Ridout and Linkie (2009) and Linkie and Ridout (2011) to compare the overlap of temporal activities between pairs of species. We first converted all times to radians and then we used kernel density estimation to generate a probability density distribution of each species' activity pattern (Ridout and Linkie 2009). Next, we calculated the overlap term Δ for small sample sizes ($n < 50$), a value ranging from 0 to 1, defined as the area under the curve formed by taking the smaller of two density functions at each point in time (Ridout and Linkie 2009). Subsequently, we obtained 95% confidence intervals for these estimates from 1000 bootstrap samples. Finally, we graphed the kernel density estimates of daily activity patterns of each wildlife mammal overlapped with daily activity patterns of feral dogs and cats, to assess the time of day when the feral fauna could interact with each wild species. We used 1000 simulations to generate the null distributions that the empirical overlap values were compared against, simulations were implemented by the freely available Time overlap software (available at: http://hydrodictyon.eeb.uconn.edu/people/willig/Research/activity%20pattern.html). This program uses the Rosario algorithm designed specifically for temporal data (Castro-Arellano et al. 2010). Rosario maintains the observed temporal autocorrelation, and thus creates biologically meaningful null spaces. Time overlap software implements these null model tests with both Pianka (1973) and Czekanowski (Feinsinger et al. 1981) indices to estimate overlap, we decided to report just the former because the results with either index were generally congruent (Castro-Arellano et al. 2010). Whether temporal overlap is greater than expected by chance means that activities are coincident or aggregated between species; the opposite suggests segregated activities. We used a one-tailed t-test to assess differences statistically and the *P* value was calculated as the proportion of randomizations. We calculated community temporal overlap twice, first among all species (both feral and wildlife mammals) and second considered only wildlife species.

Finally, we used the C-score as a measure of co-occurrence, to examine whether the species overlap in their spatial occurrence. We used software EcoSim Version 7.0 (Gotelli and Entsminger 2005) to compare the observed C-score to the average C-score generated from 5000 randomly constructed assemblages. We used a conservative null model, a fixed proportional model to generate randomly constructed assemblages. If this index is unusually large compared with a null distribution, there is less pairwise species co-occurrence (i.e. spatial segregation) than expected by chance. If the index is unusually small, there is more species co-occurrence (i.e. spatial aggregation) than expected by chance. *P*-values were calculated directly from comparing the observed C-score to the histogram of C-scores from the 5000 randomly constructed assemblages. We calculated community spatial overlap twice, first among all species (both feral and wildlife mammals) and second considered only wildlife species.

Results

We accumulated a total sampling effort of 1693 camera-days and a total of 6066 photos of mammals. We identified seven mammal species (five native wildlife species and two feral species). The species detected belonging to four orders, six families and seven genera. The order Carnivora representing the highest number of species (Table 1; Fig. 2).

The species with the greatest relative abundance were the Ringtail (*Bassariscus astutus*), Virginia Opossum (*Didelphis virginiana*), and Eastern Cottontail (*Sylvilagus floridanus*) (Fig. 3). In contrast, the species with the lowest relative abundance were Rock Squirrel (*Otospermephilus variegatus*), and feral dog (*Canis lupus familiaris*) (Fig. 3).

Comparing the observed species richness of wildlife mammals with a mean weight of 0.5 kg or more ($n = 5$) versus the estimated richness (Jackknife 1 = 5), we recorded 100% of expected species of medium-sized mammals in the study area, using this sampling method. Based on extrapolation of the sampling effort, we assume that we obtained a representative sample of wildlife mammals in the REPSA (Fig. 4). However, in our study compared with Hortelano-Moncada et al. (2009) five species were not registered in the REPSA (*Sciurus aureogaster, Notocitellus adocetus, Mephitis macroura, Spilogale angustifrons, Mustela frenata*).

All mammals, except for the Rock Squirrel (3.8% nocturnal activity), were primarily active at night (Table 1; Fig. 5). Ringtail and Virginia Opossum showed the highest overlap between pairs of species (Table 2). Feral species, both cats and dogs, showed the highest temporal overlap with Grey Fox, Eastern Cottontail, and Rock Squirrel (Table 2). The highest activity of Grey Fox overlapped with the periods of activity of cats (6:00 h) and with dogs (18:00 h) (Fig. 5). Whereas, the highest activity of Eastern Cottontail overlapped with cats at 9:00 h and with dogs at 11:00 h (Fig. 5). Finally, the activity period of Rock Squirrel overlapped with cats at 15:00 h (Fig. 5).

The other mesopredator species (i.e. Virginia Opossum and Ringtail) showed also high temporal overlap with feral dogs and cats (Table 2). Prey species (i.e. Rock Squirrel and Eastern Cottontail) showed high overlap with mesopredator species and feral cats (Table 2).

Rosario algorithm showed significant coincident nonrandom temporal activities, independent of the temporal resolution used. Pianka index comparing all species was 0.43, with a temporal overlap less than expected by chance indicating segregated activities ($t = 705.1$; $P < 0.001$), while comparing only wildlife species, Pianka index was 0.47 indicating segregated activities ($t = 29.88$; $P < 0.001$). Moreover, C-scores did not differ from chance, among all species ($P = 0.25$) or only wildlife species ($P = 0.22$).

Discussion

In this study, we evaluated the species richness, abundance, temporal and spatial activity overlap of feral and native mammals via camera trapping in an urban protected area in Mexico City, one of ten largest megacities of the world. Our results show that dominant species in relative abundance were *B. astutus*, *D. virginiana*, and *S. floridanus*; the other four species showed low abundance within the study area. Previous studies inside the REPSA point out similar results (Negrete and Soberón 1994; Castellanos-Morales et al. 2008; Granados-Pérez 2008; Ramos-Rendón 2010).

Thus, we consider that *B. astutus*, *D. virginiana*, and *S. floridanus* have viable and well-conserved populations in the study area, although a reduction in their abundance has been previously reported (Ramos-Rendón 2010). Therefore, it is important to carry on a long-term study to determine whether this decrease is part of the natural fluctuations caused by density-dependent mechanisms (Matthysen 2005; Reed and Slade 2008; van de Kerk et al. 2013) or the result of the presence of feral fauna. On another hand, green areas connectivity, garden size, and garden structure are important factors that provide a refuge that may act as resources for wild carnivores that inhabit cities (Bateman and Fleming 2012). Based on metapopulation theory (Hanski and Simberloff 1997), we speculate that populations of *B. astutus* and *D. virginiana* in the REPSA acting as source populations, that could be dispersed from REPSA towards parks and gardens. This idea is supported by the fact that individuals have been observed crossing streets, using parks, new reports from other parts of Mexico City (NoticierosTelevisa 2019), and dead by car collisions. Thus, our findings highlight the value of urban protected areas to conserve native fauna, where REPSA could be work as a model to replicate in other cities.

The sampling method used (camera traps) recorded all expected richness in the sampled area, thus, we have a representative sample of medium-sized mammals inhabiting in this

Table 1 Mammal species registered by camera trap in REPSA, Mexico City

Order	Family	Specie	Percentage of nighttime captures (%)
Didelphimorphia	Didelphidae	*Didelphis virginiana*	96.03
Lagomorpha	Leporidae	*Sylvilagus floridanus*	49.8
Rodentia	Sciuridae	*Otospermophilus variegatus*	3.8
Carnivora	Canidae	*Urocyon cinereoargenteus*	47.67
		Canis lupus familiaris	42.8
	Felidae	*Felis silvestris catus*	36.25
	Procyonidae	*Bassariscus astutus*	95.5

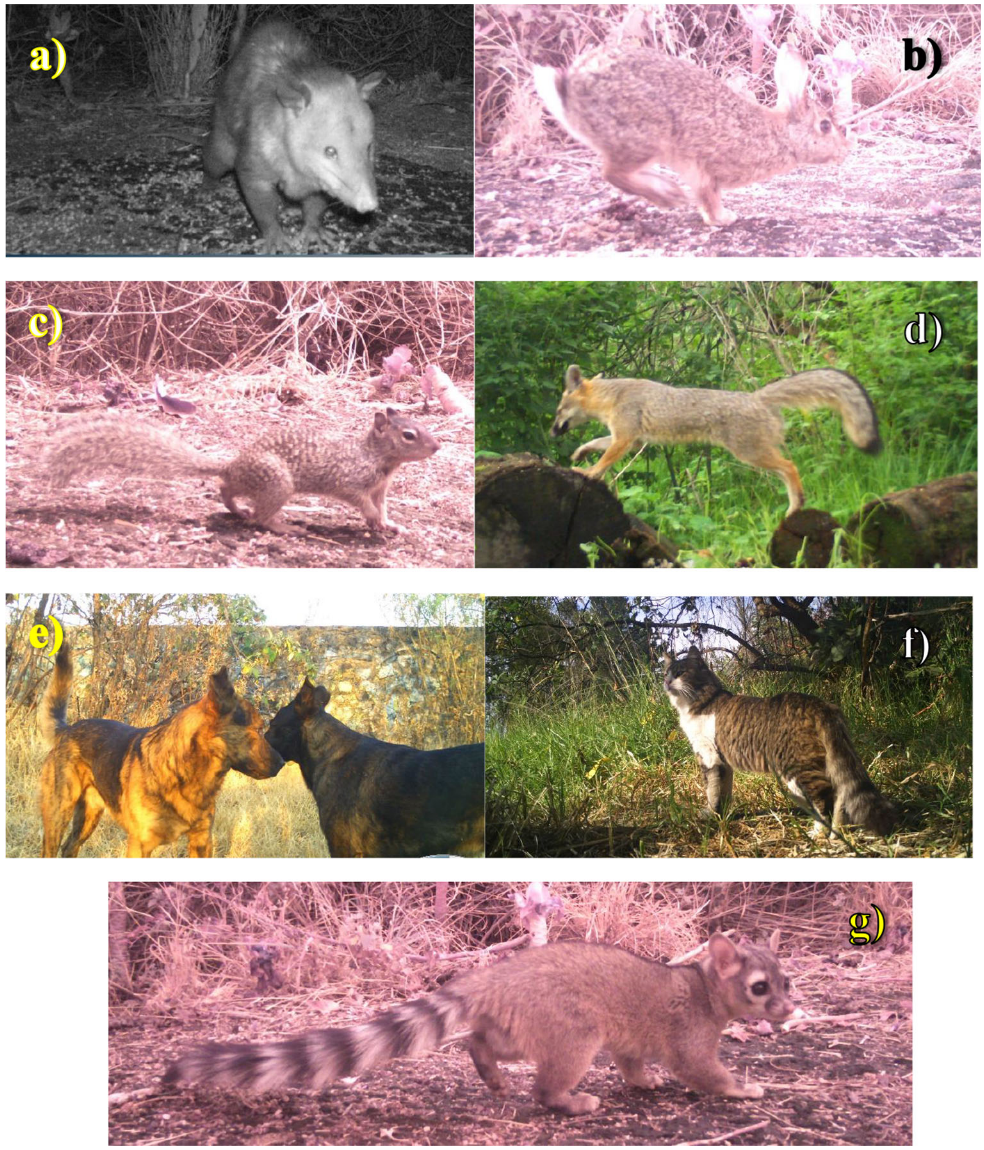

Fig. 2 Species detected with camera traps in The Pedregal of San Angel's Ecological Reserve. **a** *Didelphis virginiana*, **b** *Sylvilagus floridanus*, **c** *Otospermophilus variegatus*, **d** *Urocyon cinereoargenteus*, **e** *Canis lupus familiaris*, **f** *Felis silvestris catus*, **g** *Bassariscus astutus*

urban reserve. Nevertheless, other studies in the area have reported additional species, including *Mephitis macroura, Spilogale angustifrons, Mustela frenata, Sciurus aureogaster,* and *Notocitellus adocetus* (Hortelano-Moncada et al. 2009). Further studies in all core areas of the REPSA would be necessary, together with a greater sampling effort to discard the extirpation of these species in the REPSA.

Our results point out that most species have a pattern of nocturnal activity, except for the Rock Squirrel. The activity patterns of the wild species registered in the REPSA are similar to findings reported in different regions of Mexico and North America in natural habitats without urbanization (Farías et al. 2012; Harrison 2013; Wang et al. 2015), with the exception of Rock squirrels (Young 1979). However, caution must be taken with our conclusion because there is scarce data about activity patterns of species to compare with results recorded in our study; even when species recorded are considered common, thereby their study in different habitats should be promoted. Overall, our results indicate that mammal species co-occurrence in the REPSA tend to segregate their activities through time of the day, but spatially the co-occurrence is random. That is, mammals in the REPSA have activities at distinct hours during the day likely to avoid an encounter with other species, but, spatially they could overlap (Castellanos-Morales et al. 2009). Also, our study suggests that species temporal activity patterns might change in relation to different interspecific interactions to allow species coexistence within this mammal assemblage (*see* Gómez-Ortiz et al. 2019). Finally, it is important to point out that this is the first study to document the patterns of activity of different species and their overlapping among the mammal community in a small urban protected area. Furthermore, we argue that management programs of urban protected areas should explicitly

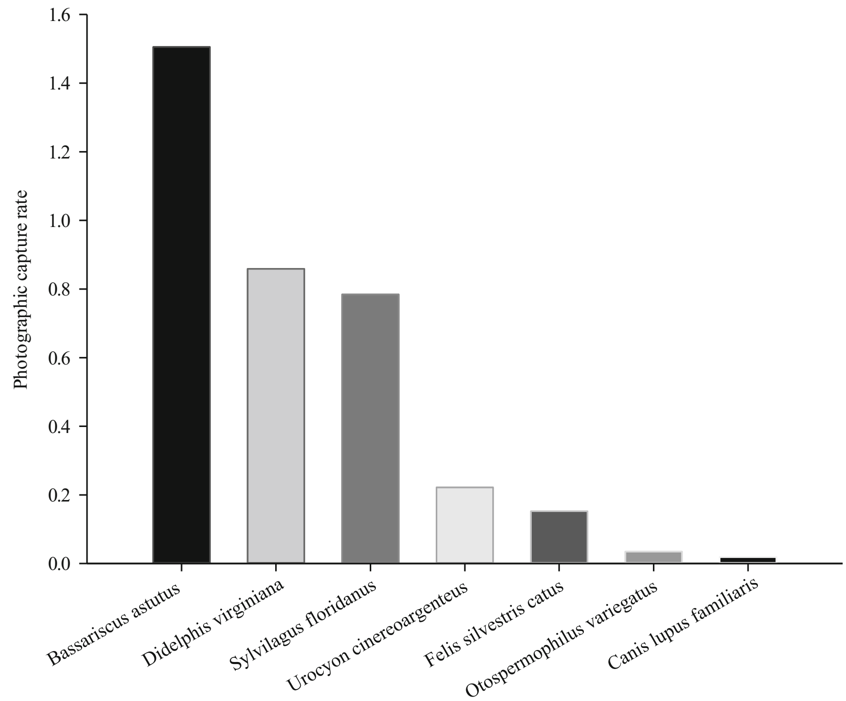

Fig. 3 Photographic capture rate of seven species of mammals recorded with camera traps in the Pedregal of San Angel's Ecological Reserve, Mexico City

include a plan for learning about the patterns of activity and how these are affected by environmental drivers and threats.

Rock squirrel was the only species that observed changes in its behavior compared with activity patterns reported in natural habitats (Young 1979), but it was not possible to distinguish the impact between urbanization and feral fauna on this aspect. Diurnal species may be particularly sensitive to urbanization due to a greater temporal overlap with humans and their domestic dogs (Nix et al. 2018). Thus, likely both urbanization and feral fauna, particularly feral cats, are interacting on the activity change of the Rock squirrel. Meanwhile, Gray fox was the largest carnivore native species with the highest overlap with feral fauna, similar results were found in urban parks by Mella-Méndez et al. (2019). Gray fox tends to adapt their activity patterns (Kapfer and Kirk 2012; Gómez-Ortiz et al. 2019) in order to avoid times and habitats where the risk of predation is high (Farías et al. 2012). Likewise, dogs make flexible use of resources into the landscape. These behaviors might reduce the encounter possibility between them, but not avoid them, so the risk of conflict is

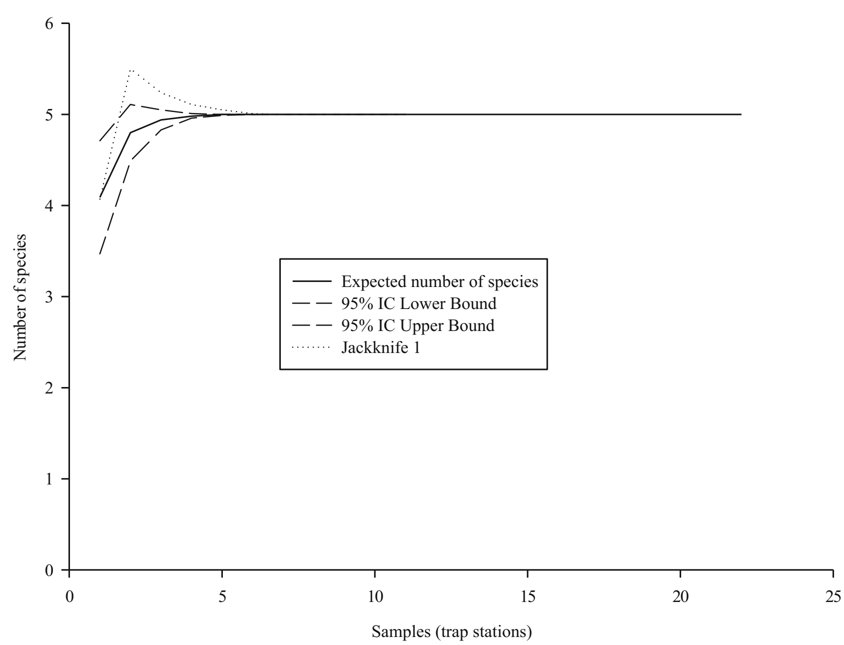

Fig. 4 Species accumulation curve of mammals (body size >500 g) documented with camera traps

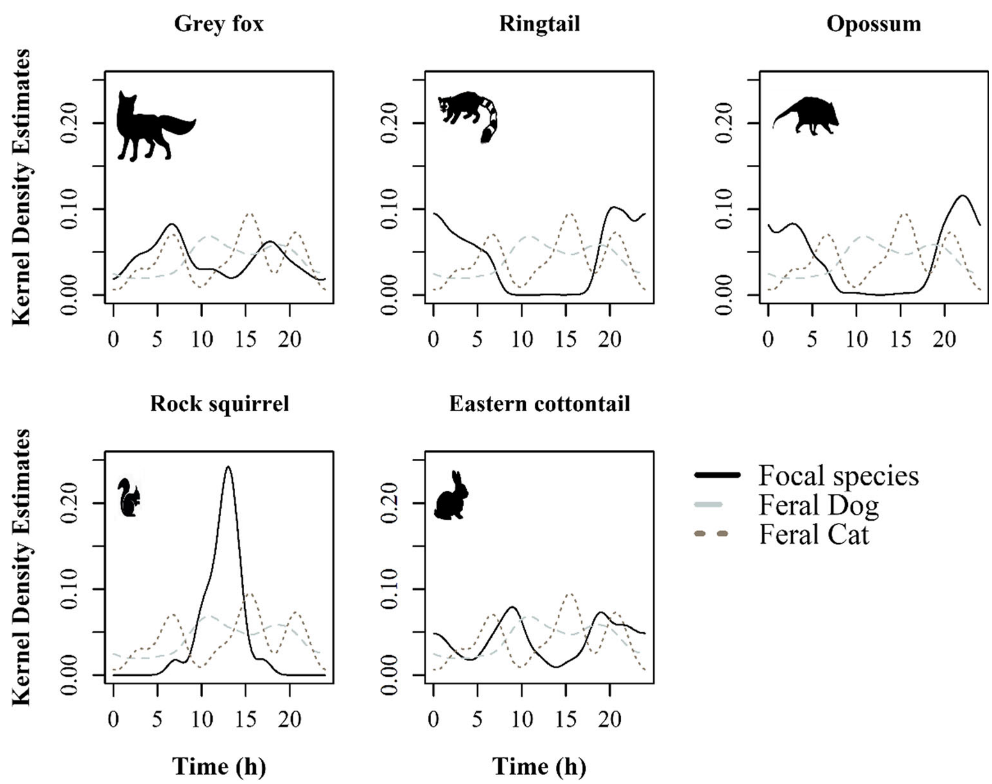

Fig. 5 Kernel density estimates of daily activity patterns of five wildlife mammals with two feral mammals in the Pedregal of San Angel's Ecological Reserve, Mexico City, Mexico

latent (Riley 2006). Because both Rock squirrel and Gray fox are important for the maintenance of ecosystem services (e.g. seed dispersers, particularly in arid zones, as REPSA) (Young 1979; Villalobos Escalante et al. 2014) and their behavior could be negatively affected by feral fauna, we suggest conservation programs for both species due to their importance in the Pedregal's ecosystem preservation.

We found that feral cats in REPSA have similar activity patterns that feral cats in other cities and rural habitats (Horn et al. 2011; Wang and Fisher 2012). While, feral dogs likely change their activity patterns in urban areas compared with rural or natural ones. Given that, in a rural-urban gradient feral dogs tend to be diurnal (Wang et al. 2015), whereas inside the cities they tend to be nocturnal (Fox et al. 1975; de Andrade Silva et al. 2018). The feral dogs (*Canis familiaris*) and cats (*Felis catus*) are categorized as the most abundant carnivores globally, and their impact on native species is often amplified because they are subsidized by humans (Villatoro et al. 2019).

Table 2 Overlap values (Δ) between the activity of species pairs of six wildlife species and two feral in REPSA, México city

Species	Virginia Opossum	Rock Squirrel	Eastern Cottontail	Grey Fox	Feral dog	Feral cat
Ringtail	**0.90** **(0.86–0.92)**	0.049 (0.02–0.09)	0.57 (0.5–0.6)	0.51 (0.4–0.56)	0.48 (0.2–0.7)	0.42 (0.3–0.48)
Virginia Opossum		0.057 (0.01–0.1)	0.56 (0.48–0.59)	0.49 (0.37–0.53)	0.47 (0.26–0.68)	0.68 (0.5–0.86)
Rock Squirrel			0.27 (0.11–0.36)	0.27 (0.08–0.34)	0.32 (0.04–0.49)	**0.47** **(0.31–0.6)**
Eastern Cottontail				0.71 (0.58–0.75)	**0.61** **(0.41–0.79)**	**0.74** **(0.64–0.82)**
Grey Fox					**0.72** **(0.56–0.95)**	**0.72** **(0.59–0.82)**
Feral dog						**0.68** **(0.5–0.86)**

Confidence intervals of 95% in parenthesis and in bold the highest observed values of overlap between pair of species

Nevertheless, the impacts of feral fauna, particularly dog on native mammals, still are not well understood (George and Crooks 2006). Previous studies suggest that feral cats have caused or contributed to bird, mammal, and reptile extinctions (May and Norton 1996; Loss et al. 2013; Taylor-Brown et al. 2019). Doherty et al. (2016) suggest that feral cat arguably the most damaging invasive species for animal biodiversity worldwide. We found that feral cats have high activity during the peaks of activity of herbivores (i.e. Rock Squirrel and Eastern cottontail). Thereby, although we did not record a predation event, feral cats could be working as important predators of native fauna in the REPSA, mainly, Rock Squirrel and Eastern Cottontail. This is according to others studies which found in feces and gut of feral cats, remains of these small mammals as *Neotoma mexicana* and *Reithrodontomys fulvescens* (Granados-Pérez 2008; Ramos-Rendón 2010). Whereas effects of dogs on wildlife may include the disruption of carnivore behavior via barking and scent-marking (e.g. urine and scat) until harassment or mortality (George and Crooks 2006; Vanak and Gompper 2009; Young et al. 2011; de Andrade Silva et al., 2018). In the REPSA, feral dogs would have a negative effect on wildlife mesopredators, particularly the Gray fox, mostly by competence for feeding resources (e.g. waste) (Silva-Rodríguez and Sieving 2012). A similar result was found in urban parks in Mexico (Mella-Méndez et al. 2019). Our results, combined with previous studies, suggest that key factors resulting in the success of mammals in cities are the omnivory (Riem et al. 2012), species' behavior (i.e. nocturnal activities) (Patten and Burger 2018), and body size (medium to small) (Gómez-Ortiz et al. 2019), through these traits they avoid humans and feral species.

Overall, our results indicate that feral fauna might be harmful to both predators and herbivores mammals inside urban reserves. Therefore, we suggest five actions to minimize the activity overlapping of feral and native fauna. First, we suggest an awareness program for the citizens in urban and rural areas, in order to avoid the abandonment of their pets. Likewise, due to the citizen's strong bond with dogs and cats (Villatoro et al. 2019), this program must highlight the harmfulness of feral dogs and cats on native fauna. Second, due to biodiversity plays a fundamental role in the prevention and control of diseases, reducing and dampen the direct transmission of infectious diseases, which are transferred to humans, domestic, and wild species (Suzan and Ceballos 2005; González-Martínez et al. 2016). In this way, the program must include domestic dog and cat vaccination and sterilization continuous activities (Zapata-Ríos and Branch 2016). Third, due to the importance of native fauna as providers of ecosystem services, the program must also highlight the importance of native fauna over feral fauna, via sharing information to citizens about the process of ecosystem services loss associated with the feral fauna presence that which can lead potential economic losses (Young et al. 2011; Loss et al. 2013; Parsons et al. 2016). Fourth, it is necessary to change the waste management inside and around cities in order to avoid the overlapping of native with feral fauna in the waste collectors (Silva-Rodríguez and Sieving 2012) and likely the attacks between them. Finally, increased understanding of factors that exacerbate domestic dog and cats impacts on wildlife is also required (e.g. urbanization and road construction that can facilitate dog access to primary habitats) (Doherty et al. 2017; Nix et al. 2018). Particularly, Mexico is a hot-spot of threatened species by feral dogs (Doherty et al. 2017). After this study, inside the REPSA was established a program of feral fauna control. In the future, this program could work as a good example of feral fauna control over time (Ramírez-Velázquez 2017) in order to the preservation of wildlife fauna.

Feral fauna has been suggested to be a significant problem for the native mammal community in several protected areas in America, Asia, Europe and Australia (Young et al. 2011; Wang and Fisher 2012; Loss et al. 2013; Doherty et al. 2016, 2017; Zapata-Ríos and Branch 2016; Mella-Méndez et al. 2019). Predation appears to be the most significant threat to wildlife in peri-urban reserves, particularly where undisturbed habitat is adjacent to new residential development (Mccarthy 2005). Therefore, it is urgent to implement protocols to study and control feral fauna in different types of protected areas around the world. This study analyses aspects of feral and wild-fauna and propose a general protocol related to protected areas near or within urban areas, but it would be necessary to implement a specific action for different cases (e.g. urban areas, natural, agricultural, etc.).

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