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Ecology

Contributions on the diet of free-ranging dogs *(Canis lupus familiaris)* in the Nevado de Toluca Flora and Fauna Protection Area, Estado de México, Mexico

Contribuciones a la dieta de perros de vida libre (Canis lupus familiaris) *en el Área de Protección de Flora y Fauna Nevado de Toluca, Estado de México, México*

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Abstract

Dogs (*Canis lupus familiaris*) are an invasive alien species that can negatively impact natural ecosystems due to the potential of predation, competition, or disease transmission. Nonetheless, few studies assess the ecological impacts of these species on protected areas. Our objective was to determine the diet of free-ranging dogs, through scat analysis within the Nevado de Toluca Flora and Fauna Protection Area, Estado de México, Mexico. A total of 130 scat samples from dogs were collected with the help of a bloodhound. Prey items identified in the scats were classified into 6 food categories: wild mammals, birds, insects, livestock, vegetative matter and human-derived food. Wild mammals were the most frequent category (FO = 62.3%; RO = 40.3%). We present the first evidence of 8 rodents, 1 shrew, and 2 skunk species as part of the diet of free-ranging dogs. Some identified preys are species endemic to Mexico with special protection status according to Mexican law. We recommend following the global-level policies aimed at reducing the population of dogs in Protected Areas.

Keywords: Free-ranging dogs; Diet; Natural protected area; Predators; Mexico

Resumen

Los perros (*Canis lupus familiaris*) son una especie exótica invasora que puede impactar negativamente a los ecosistemas naturales debido al potencial de depredación, competencia o transmisión de enfermedades. No obstante,

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existen pocos estudios que evalúan los impactos ecológicos de esta especie en áreas protegidas. El objetivo de la presente investigación fue determinar la dieta de perros de vida libre a través de análisis de materia fecal, dentro del Área de Protección de Flora y Fauna Nevado de Toluca en el Estado de México. Se colectaron 130 muestras de perros de vida libre las cuales fueron colectadas con la ayuda de un sabueso entrenado. Los ítems alimenticios se clasificaron en 6 categorías: mamíferos silvestres, aves, insectos, ganado, materia vegetal y desechos derivados de humanos. La categoría de mamíferos silvestres fue la más frecuente (FO = 62.3%; RO = 40.3%). Se presenta la primera evidencia de 8 especies de roedores, 1 especie de musaraña y 2 especies de zorrillos como parte de la dieta de los perros de vida libre. Algunas de las presas identificadas son especies endémicas de México con algún estatus de protección de acuerdo con la NOM-059-SEMARNAT-2010. Recomendamos seguir las políticas globales destinadas a reducir la población de perros en áreas protegidas.

Palabras clave: Perros de vida libre; Dieta, Área natural protegida; Depredadores; México

Introduction

Protected areas (PA) are often used as the main strategy to protect biodiversity from humans or human-related activities (Margules & Pressey, 2000). The effectiveness of each PA for conserving and maintaining biodiversity may vary, mainly due the local biological features of the land, and the way such areas are managed (Juárez-Ramírez et al., 2016). In Mexico, PA are managed mainly by the Mexican National Commission for Protected Areas (Comisión Nacional de Áreas Naturales Protegidas-Conanp), which currently manages 182 PA that represent 11% of Mexico's territory and 22% of its marine surface (Conanp, 2019).

Invasive alien species in PA can seriously damage native species and ecosystems on a global scale in a similar way as habitat loss and degradation (IUCN, 2000). Monitor and control invasive alien species in such a topographically complex landscape is challenging, and is especially true in a country without enough resources allocated to biological conservation (Lira, 2004). One invasive alien species of concern is the dog (*Canis lupus familiaris*).

Recently, the Mexican government classified dogs as an invasive alien species that can have strong negative effects on local wildlife and called for control of dogs in vulnerable sites for biodiversity like PA and other key biodiversity areas (e.g. important bird areas, alliance for zero extinction sites; DOF, 2016a). The national strategy on invasive species in Mexico called for local consultations to establish site-specific needs and management strategies to prevent, control, and eradicate invasive species around the country (Conabio, 2010).

Unlike other invasive alien species, dogs are often associated with human presence, and in some cases, particularly dependent on humans (Boitani et al., 2017; Morters et al., 2014; Silva-Rodríguez & Sieving, 2012).When domestic dogs are defined by their human dependence and main range type, they can be classified as free-ranging or free-roaming dogs, in which mobility is not restricted and does not depend entirely on humans (Jensen, 2007; OIE, 2019). In the long term, when they reproduce and recruit their populations in the wild without any human interference (e.g. human-derived materials), they are considered truly feral (Jensen, 2007; Reponen et al., 2014; Vanak & Gompper, 2009a).

Undoubtedly, dogs play an important role in rural communities, where they are used to facilitate hunting, protect property, and reduce human-wildlife conflicts by protecting livestock from people or predators (Khan, 2009). However, when neglected, irresponsible dog ownership may lead to the transition from companion-help dogs to free-ranging dogs, resulting in numerous ecological impacts in natural ecosystems (for a review, see Young et al., 2011) and socioeconomic impacts on livestock rearing (Home et al., 2017; Montecino-Latorre & San Martín, 2019). Free-ranging dogs now function as predators, prey, competitors, and reservoirs or transmitters of diseases, and could hybridize with native species (Doherty et al., 2016; Ritchie et al., 2014; Vanak & Gompper, 2009a).

The amount of available resources for such a generalist and opportunistic species and its close relationship with humans have resulted in a worldwide population estimated from 700 million (Hughes & Macdonald, 2013) to one billion domestic (including free-ranging) dogs (Gompper, 2014). Free-ranging dogs are opportunistic-generalist predators, that not only behave as scavengers or depend on human-related food but also can hunt wild animals, consuming almost any available prey (e.g., insects, reptiles, birds, mammals, and other predators; Gompper, 2014), with medium-sized wild mammals being one of the most affected (Glen & Dickman, 2008; Hughes & Macdonald, 2013; Lessa et al., 2016; Mella-Méndez et al., 2019). Domestic dogs have contributed to 11 vertebrate extinctions and are a potential threat to 188 endangered species worldwide, 29 of which are distributed throughout Central America, the Caribbean, and Mexico (Doherty et al., 2017).

Predation of native, endemic, and even critically endangered wildlife by free-ranging dogs has been documented at the global level (Butler & du Toit, 2002; Campos et al., 2007; Iverson, 1978; Kruuk & Snell, 1981; Silva-Rodríguez et al., 2010; Young et al., 2011). Although the direct killing of wildlife is the most obvious impact, dogs also harass or chase native species, which can result in altered patterns of wildlife activity (Lenth et al., 2008).

The presence of free-ranging dogs in the Nevado de Toluca Flora and Fauna Protection Area had been previously documented, particularly in the Cacalomacan Ecological Park (CEP) (Sánchez-Jasso et al., 2013). The CEP is an important area for the conservation of biodiversity and the free-ranging dogs may pose a risk for local wildlife and park visitors. Eighty-five vertebrate species occur in the park along with free-ranging dogs. However, no additional data regarding the presence, biology, and ecology of free-ranging dogs in the area are available.

Here, we estimated the diet of free-ranging dogs (*Canis lupus familiaris*) in Cacalomacan Ecological Park, as a step towards understanding the potential impacts on local wildlife species.

Materials and methods

The study was carried out in the Cacalomacan Ecological Park (CEP), located within a fragmented area of the Nevado de Toluca Flora and Fauna Protection Area (hereafter Nevado de Toluca) (19°12'37" N, 99°44'42" W; 19°12'31" N, 99°43'51" W; 19°11'31" N; 99°44'22" W, 19°11'47" N; 99°45'09" W), at an elevational gradient ranging from 2,800 to 3,247 m asl (Sánchez-Jasso et al., 2013). The Nevado de Toluca is regarded as a priority terrestrial region by the Mexican government owing to its great biodiversity, endemism, water catchment, and high biological and landscape value (DOF, 2016b). It was established as a National Park in 1936, but was later re-categorized to a Flora and Fauna Protection Area (Sánchez-Jasso & Cebrián-Abellán, 2015). According to the IUCN Management Protected Areas, the Nevado de Toluca is a category VI area, allowing the sustainable use of natural resources in which the aim is to conserve biodiversity, particularly at ecosystem and landscape scales, but not to strictly protect them from human interference (IUCN, 2020).

The Nevado de Toluca, like other PA in Mexico, encompasses many communities within its 53,589 hectares (Héritier & Leberton, 2017), including 10 municipalities, 16 rural communities and more than 5,000 inhabitants (INEGI, 2010). Together with a surrounding 1 km influence area, results in 41 communities interconnected by roads (DOF, 2016b; INEGI, 2011; Fig. 1).

The 244 ha rural community-owned park (CEP) is an isolated woodland, forested with Mexican white cedar

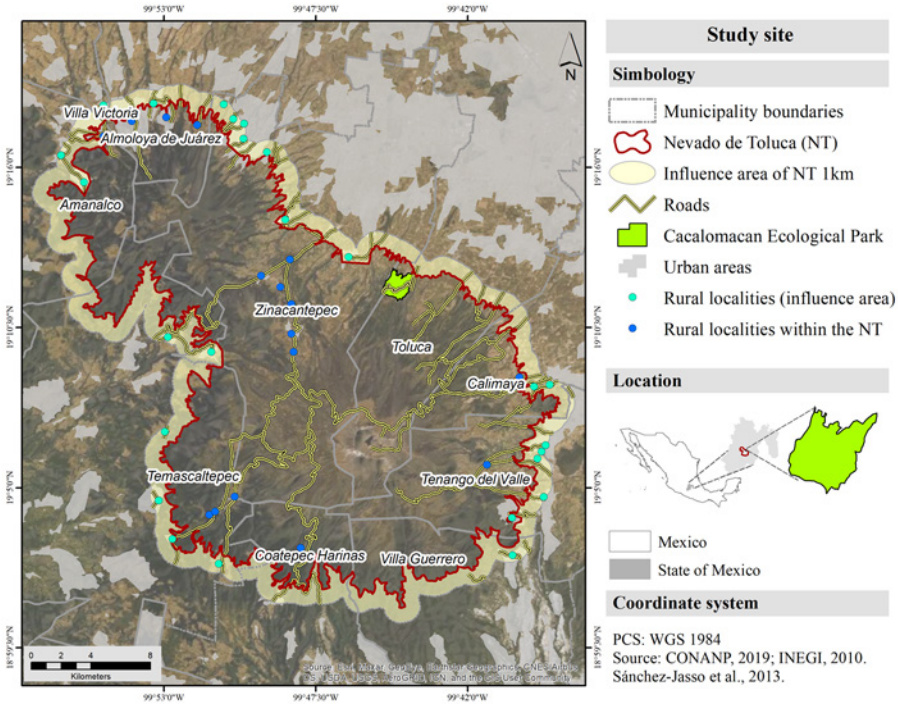

Figure 1. Location of Cacalomacan Ecological Park within the Nevado de Toluca in the State of México, Mexico. Datum WGC 84, Zone 14.

(*Cupressus lindeyi*) and Mexican weeping pine (*Pinus patula*), creeks with native vegetation of Mexican sacred fir (*Abies religiosa*) and Mexican alder (*Alnus jorullensis*), surrounded by urban and farming lands about 10 km from the urban border (Sánchez-Jasso et al., 2013) (Fig. 1).

During our study, from June 2013 to January 2014, at least 3 groups of 6 to 12 dogs as well as solitary individuals were seen in the area. The dogs ranged from the size of a small Toy Poodle breed to a big German Shepherd breed. We estimated the diet of free-ranging dogs by scat analysis (Reynolds & Aebischer, 1991). Scats were collected twice per month with the help of a bloodhound trained to only locate dog scats in different habitat. The starting time was always 3 hours after sunrise, with a one-hour warmup period for the hound (Long et al., 2007). We randomized start locations by selecting starting compass bearings from trails throughout the CEP so that no area was intentionally sampled first (Wasser et al., 2004). Only scats with no signs of deterioration (mostly intact, without washing out) were collected (n = 130) (Sélem-Salas et al., 2011). All samples were labeled for laboratory analysis. Scats were sun-dried and washed in a sieve (1 mm), using cold water to separate all the elements such as hairs, bones, feathers and other prey components from other organic and human-origin material (Ramakrishnan et al., 1999) for further specific analyses. Prior to the analyses, 2 experts on local vertebrates were trained in identifying scat contents by practicing with reference material and reference scats (Mattioli et al., 2006; Sanchez-Jasso et al., 2013). They thoroughly dissected and examined the scats at the same time, using a local reference collection as well as with the help of specific taxonomists, thus reducing the individual observer bias (Spaulding et al., 2000).

Hair in scats was examined visually to identify the color pattern, and microscopically to examine its medullary pattern using a modification of the technique described by Arita and Aranda (1988), which consisted of rinsing the hair in soapy water for 48 hours, placing it into xylol for 24 hours, and then mounting it on a microscope slide, using Canada balsam. Morphological observations, photomicrographs and measurements were performed using a Nikon binocular microscope (Eclipse 80i ®) coupled to a Nikon DS-Ri2® digital camera with the help of NIS-Elements BR® microscope imaging software.

All remains were analyzed and identified to the lowest taxon possible with reference guides and input from specialists on local wildlife. To identify hair, teeth, mandibles and bone fragments of mammals we consulted Hall and Kelson (1959) and Monroy-Vilchis and Rodríguez (1999). Bone remains were deposited and are available in the Repository (http://www.ibirds.org) of the Institute for Biodiversity Research, Development & Sustainability (iBIRDS), Toluca, Mexico (accession number Mammals-01/2015). Photographs of hair were deposited in the same collection. From birds, only large feathers and bones were used for identification (Peterson & Chalif, 1989; Scott & McFarland, 2010). From insects, only the remains of beetles were found and later identified (Delgado, 2008). Residue of vegetative matter such as seeds and grass were also recorded and separated for identification.(Rzedowski et al., 2005; Sánchez, 1974). Human-derived food (HDF) was identified by the presence of plastic bags or food wrappers, which were common wastes found in the park (Vanak & Gompper, 2009b).

All the prey items identified in the scats by their taxonomic characteristics were classified into 6 food categories: wild mammals, birds, insects, livestock, vegetative matter, and human derived food (HDF). We estimated the frequency of occurrence (FO) defined as: $FO = (fi*100)/N$. Where fi is the number of occurrences of each prey and N is the total number of samples, and relative frequency of occurrence (RO), defined as: $RO = (fi*100)/T$. Where fi is the number of occurrences of each prey and T is a total occurrence of all prey types in all samples, T is obtained by adding the fi (Helder & de Andrade, 1997).

Results

We identified 201 food items in 130 dog scats. The scats contained members of 5 classes, 13 orders, 16 families, 21 genera and 22 species (Table 1). The most frequent food categories in the diet of free-ranging dogs were wild mammals (FO = 62.3%; RO = 40.3%), followed by vegetative matter (FO = 51.5%; RO = 33.3%), HDF (FO = 21.5%; RO = 13.9%), livestock (FO = 13.8%; RO = 9%), birds (FO = 3.8%; RO = 2.5%) and insects (FO = 1.5%; RO = 1%) (Table 2).

The wild mammals' category was represented by 11 families, 18 genera and 19 species (Table 1). The Mephitidae family had the most frequently found items in the scats (FO = 19.2%; RO = 12.4%), followed by the Cricetidae family (FO = 17.7%; RO = 11.4%), and the Leporidae family (FO = 11.5%; RO = 7.5%). The Canidae and Soricidae families had the least number of items found in the scats (FO = 0.8%; RO = 0.5%) (Table 2).

In the vegetative matter category, *Prunus serotina* was the item most frequently consumed (FO = 28.5%; RO = 18.4%). For livestock, *Bos taurus* was the item most frequently consumed (FO =3.8%; RO = 2.5%). Bird and insect categories had the lowest frequency in the diet of free-ranging dogs (Table 2).

Table 1

Species found in free-ranging dog scat.

Kingdom	Class	Order	Family	Genus	Species	Endemism	NOM-059 Status
Animal	Mammalia	8	11	18	19	8	4
	Aves	1	1	1	1	0	0
	Insecta	1	1	1	1	0	0
Plantae	Magnoliopsida	2	2	1	1	0	0
	Liliopsida	1	1	0	0	0	0
Total		13	16	21	22	8	4

Table 2

Frequency of occurrence (FO) and relative frequency of occurrence (RO) of free-ranging dogs diet in Cacalomacan Ecological Park. *fi* = Number of occurrence of each prey, *FO* = frequency of occurrence (*fi*(100)/130); *RO* = relative frequency of occurrence (*fi*(100)/201); N.I. + = not identified.

Categories	Family	Scientific name	Common name	*fi*	Frequency of occurrence (%)	
					FO	RO
Wild mammals	Didelphidae	*Didelphis marsupialis*	Virginia opossum	2	1.5	1.0
	Dasypodidae	*Dasypus novemcinctus*	Nine-banded armadillo	2	1.5	1.0
	Leporidae	*Sylvilagus floridanus*	Eastern cottontail	3	2.3	1.4
		Sylvilagus cunicularius	Mexican cottontail	2	1.5	1.0
		Sylvilagus spp.		10	7.7	5.0
	Cricetidae	*Peromyscus* spp.		9	6.9	4.5
		Reithrodontomys chrysopsis	Volcano harvest mouse	1	0.8	0.5
		Neotoma mexicana	Mexican woodrat	4	3.1	2.0
		Neotomodon alstoni	Mexican volcano mouse	1	0.8	0.5
		Microtus mexicanus	Mexican vole	2	1.5	1.0
		N.I. small rodent+		6	4.6	3.0
	Sciuridae	*Spermophilus* sp.	N.I. Ground squirrel	1	0.8	0.5
		Sciurus oculatus	Peter`s squirrel	2	1.5	1.0
		Glaucomys volans	Mexican flying squirrel	2	1.5	1.0
	Felidae	*Lynx rufus*	Bobcat	3	2.3	1.5
	Canidae	*Urocyon cinereoargenteus*	Grey fox	1	0.8	0.5
	Mephitidae	*Mephitis macroura*	Hooded skunk	13	10	6.5
		Conepatus leuconotus	American hog/nosed skunk	12	9.2	6.0
	Procyonidae	*Bassariscus astutus*	Ringtail	2	1.5	1.0
	Soricidae	*Cryptotis alticola*	Central Mexican broad-clawed shrew	1	0.8	0.5
	Vespertilionidae	N.I.+		2	1.5	1.0
	Total			81	62.3	40.3

Table 2. Continued

Categories	Family	Scientific name	Common name	*fi*	Frequency of occurrence (%)	
					FO	RO
Birds	Cuculidae	*Geococcyx velox*	Lesser roadrunner	2	1.5	1.0
		N.I.+		3	2.3	1.5
	Total			5	3.8	2.5
Insects	Scarabaeidae	*Orizabus isodonoides*	Beetle	2	1.5	1.0
	Total			2	1.5	1.0
Livestock	Bovidae	*Bos Taurus*	Cow	5	3.8	2.5
		Ovis aries	Sheep	1	0.8	0.5
	Suidae	*Sus scrofa*	Pig	2	1.5	1.0
		N.I.+		10	7.7	5.0
	Total			18	13.8	9.0
Vegetable matter	Rosaceae	*Prunus serotine*	Wild black cherry	37	28.5	18.4
	Poaceae	Crops		19	14.6	9.5
	Solanaceae	Crops		11	8.5	5.5
	Total			67	51.5	33
Human derived food (HDF)	Total			28	21.5	13.9

Discussion

We found wildlife species in the diet of free-ranging dogs from the CEP including locally endemic species and species not previously known to be consumed by free-ranging dogs. Wild mammals, including skunks, rodents, and rabbits were the most frequent prey in the diet of free-ranging dogs. Eight rodent species, 1 shrew, and 2 skunk species we identified have not been previously reported as part of the diet of free-ranging dogs. Of these, the volcano harvest mouse, Mexican volcano mouse, Peter's squirrel, and Central Mexican broad-clawed shrew are endemic species to Central Mexico, and the latter, together with the Mexican flying squirrel have special protection status under Mexican law (Ceballos & Oliva, 2005; Semarnat, 2010).

Like reports in Brazil and Mexico, where dogs consume medium sized mammals including other carnivores (Campos et al., 2007; Mella-Méndez et al., 2019), we found gray fox and bobcat in the scats of free-ranging dogs. Whether these species were killed or scavenged by dogs is unknown. Skunks are considered to be medium sized mammals and thus, could be a threatened prey of free-ranging dogs (Gallina et al., 2008; Mella-Méndez et al., 2019).We present the first evidence of the consumption of hooded skunk (*Mephitis macroura*), and eastern hog-nosed skunk (*Conepatus leuconotus*) by free-ranging dogs, which also were the most frequent species found. Free-ranging dogs in CEP may be assuming the role of wild canids, acting as both predators and competitors with other mammals (Vanak & Gompper, 2009a, 2010).

As free-ranging dogs are opportunistic and rabbits (*Sylvilagus*) are normally abundant in a wide variety of habitats including open grass pine in the Trans-Mexican Volcanic Belt (Fa et al., 1992), the consumption of rabbits was expected. Our findings are consistent with the results of other studies in which rabbits, although not necessarily the most frequently consumed item, are common in the free-ranging dog diet (García-Aguilar, 2012; Green & Gipson, 1994; Lessa et al., 2016).

Within the 19 species of wild mammals found in the scat of free-ranging dogs, 7 were previously reported in the CEP. In comparison with previous studies that reported 11 species of wild mammals in the CEP, we have added 12 different records of mammals in this area (Sánchez-Jasso et al., 2013; Table 3). These findings may simply be related to methods and sampling effort on former surveys, and therefore the species were present but had not been previously reported. The difference in the number of mammals in our study could also suggest that some species

are not necessarily present in the CEP but are found in scats due to the extensive home-range of free-ranging dogs around the Nevado de Toluca, which may pose a further risk for local wildlife.

Vegetative matter was the second category most frequently appearing in the diet of free-ranging dogs. Within the vegetative matter, wild black cherry was the most frequent item found in all scats. This frequency might be related to the type of habitat in the study site, as the main vegetation reported is a temperate coniferous-pinus forest which in the Trans-Mexican Volcanic Belt is associated with species of fruit trees (*Prunus* spp.) and croplands (Rzedowski, 1978).

Dogs that live close to human settlements are highly dependent on HDF, and unlike feral dogs, free-ranging dogs are more opportunistic and supplement their diet with HDF (Vanak & Gompper, 2009b). The CEP is located about 10 km from the urban border and it is surrounded by urban and cropland areas. Also, during the study, we saw some free-ranging dogs feeding in waste containers around the park, explaining its presence in the free-ranging dog's diet. Scavenging rather than predation was probably the main reason why livestock remains were found in the diet, as the presence of a clandestine dump adjacent to CEP that received livestock remains (*Bos taurus*, *Ovis aries* and *Sus scrofa*) in an open pit was found during the study.

Table 3

Comparative records of wild mammals in Cacalomacan Ecological Park from Sanchez-Jasso et al 2013 and this study. ✸ New records, ☑ Sánchez-Jasso et al. (2013), • Mexican endemic.

Family	Species	This study	Sánchez-Jasso et al. (2013)	NOM-059 Status
Didelphidae	*Didelphis virginiana*	☑	☑	
Dasypodidae	*Dasypus novemcinctus*	☑	☑	
Leporidae	*Sylvilagus floridanus*	☑	☑	
	Sylvilagus cunicularius•	☑	☑	
Cricetidae	*Peromyscus* spp.	✸		
	Reithrodontomys chrysopsis•	✸		
	Neotoma mexicana•	✸		
	Neotomodon alstoni•	☑	☑	
	Microtus mexicanus•	✸		
Sciuridae	*Spermophilus* sp.	✸		
	Sciurus oculatus•	✸		Special protection
	Sciurus aureogaster		☑	
	Glaucomys volans	✸		Threatened
Geomyidae	*Cratogeomys planiceps*		☑	
	Cratogeomys fumosus•		☑	Threatened
Felidae	*Lynx rufus*	✸		
Canidae	*Urocyon cinereoargenteus*	✸		
	Canis latrans		☑	
Mephitidae	*Mephitis macroura*	☑	☑	
	Conepatus leuconotus	✸		
Mustelidae	*Mustela frenata*		☑	
Procyonidae	*Bassariscus astutus*	☑	☑	
Soricidae	*Cryptotis alticola*•	✸		Special protection
Vespertilionidae	N.I.	✸		

Remains of birds and insects were visible in the scats in low frequency. In the bird category, we found remains from the Lesser Roadrunner, a species previously reported in the study site (Sánchez-Jasso et al., 2013). In the insect category we found remains from *Orizabus isodonoides*, a specialized rhizophagus-stenophagus beetle that feeds exclusively on grass roots (Morón et al., 2010). The Order Coleoptera was previously reported as part of the diet of free-ranging dogs (Vanak & Gomper, 2009b).

The diet of free-ranging dogs depends on various factors such as habitat, climate, availability of resources, and proximity to human settlements (Gompper, 2014). The Nevado de Toluca has not only human settlements, but networks of trails and roads (Fig. 1) that facilitate the dispersal of the free-ranging dogs into forested areas (Sepúlveda et al., 2015). The home-range of free-ranging dogs in rural/forest areas has been documented to be from 444 to 2,850 ha (Nesbitt, 1975; Scott & Causey, 1973). Studies support the theory of resource dispersion as the key to the home-range size of an animal. This theory establishes that the minimum territory size of an animal is determined by the distribution of the patches of prey (Macdonald, 1991). The theory of resource dispersion could explain the need for the dogs to have a large home-range, even though they live in a resource-rich environment (Meek, 1999).

Free-ranging dogs have been highlighted as a potential threat to wildlife particularly in protected areas (Paschoal et al., 2016; Zapata-Ríos & Branch, 2016). In Mexico, within the Islas del Pacífico, Península de Baja California PA (previously Valle de los Cirios PA) and particularly on Cedros Island, the consumption of the California Sea Lion (*Zalophus californianus*), the Northern elephant seal (*Mirounga angustirostris*) (Gallo-Reynoso & García-Aguilar, 2008), the riparian brush rabbit (*S. bachmani*), Cedros Island mule deer (*Odocoileus hemionus cerrosensis*) and San Diego pocket mouse (*Chaetodipus anthonyi*) by feral dogs has been documented (García-Aguilar, 2012). More recently, the predation of 9 banded armadillos (*Dasypus novemcinctus*) and common opossums (*Didelphis marsupialis*) by free-ranging dogs in urban and peri-urban PA of a city in Veracruz was also recorded (Mella-Méndez et al., 2019). The Nevado de Toluca hosts endangered-endemic species like the Peter's squirrel (*S. oculatus*), Central Mexican broad-clawed shrew (*Cryptotis alticola*), and the Mexican flying squirrel (*Glaucomys* v. g.) that in this study were part of the diet of the free-ranging dogs (Table 3).

The incorporation of dogs into the list of invasive alien species for Mexico will facilitate actions according to current Mexican laws and regulations for the prevention, control and eradication of invasive alien species inside protected areas (DOF, 2016a). While the Nevado de Toluca management plan has determined a series of activities against invasive species, no specific actions have been established for dogs (DOF, 2016b; Conanp, 2016).

In order to effectively design, prioritize and implement conservation plans and actions to minimize the impact of dogs on wildlife, and to propose economically and operationally efficient dog control programs, it is necessary to understand how and where dogs pose a threat (Doherty et al., 2017).

Particularly for free-ranging dogs, basic strategies of eradication and extirpation from the wild may not be enough. This is because unlike other invasive alien species, the problem is not only to remove them from the PA, but to determine how to change the human behaviors that causes the problem (Villatoro et al., 2019). We recommend following global-level policies aimed at dramatically reducing the size of the population of free-ranging dogs in the urban-wild interface through: "proper management of solid waste, sterilization, castration programs, and responsible ownership of dogs, along with efforts that combine and involve scientific research and society outreach, and decide on the actions to control and eradicate this species" (IUCN, 2000; Young et al., 2011). With these strategies, as well as local community engagement and further research to identify specific risk sites in the entire Nevado de Toluca, not only will the welfare of dogs as pets be secured, but wildlife populations that live within and outside protected areas will be safeguarded.

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References

Arita, H. T., & Aranda, M. (1988). *Manual para el estudio e identificación de los pelos de los mamíferos silvestres*. México D.F.: Cuadernos de Divulgación del Instituto Nacional de Investigaciones sobre Recursos Bióticos.

Boitani, L., Francisci, F., Ciucci, P., & Andreoli, G. (2017). The ecology and behavior of feral dogs: a case study from central Italy. In J. Serpell (Ed.), *The domestic dog: its evolution, behavior and interactions with people* (pp. 342–368). Cambridge: Cambridge University Press. http://dx.doi.org/10.1017/9781139161800.017

Butler, J. R. A., & du Toit, J. T. (2002). Diet of free-ranging domestic dogs (*Canis familiaris*) in rural Zimbabwe: implications for wild scavengers on the periphery of wildlife reserves. *Animal Conservation*, *5*, 29–37. https://doi.org/10.1017/S136794300200104X

Campos, C. B., Esteves, C. F., Ferraz, K. M. P. M. B., Crawshaw, Jr. P. G., & Verdade, L. M. (2007). Diet of free-ranging cats and dogs in a suburban and rural environment, south-eastern Brazil. *Journal of Zoology*, *273*, 14–20. https://doi.org/10.1111/j.1469-7998.2007.00291.x

Ceballos, G., & Oliva, G. (2005). *Los mamíferos silvestres de México*. México D.F.: Fondo de Cultura Económica México/ Comisión Nacional para el Conocimiento y Uso de la Biodiversidad.

Conabio (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad). (2010). *Estrategia nacional de especies invasoras de México*. Prevención, Control y Erradicación. Accessed 22 March 2020: https://www.biodiversidad.gob.mx/especies/Invasoras/estrategia

Conanp (Comisión Nacional de Áreas Naturales Protegidas). (2016). *Programa de manejo del Área Natural Protegida con la categoría de Área de Protección de Flora y Fauna Nevado de Toluca- versión extensa*. Accessed 16 July 2020: https://simec.conanp.gob.mx/pdf_libro_pm/104_libro_pm.pdf

Conanp (Comisión Nacional de Áreas Naturales Protegidas). (2019). *Mapa actualizado de Áreas Naturales Protegidas*. Accessed 08 March 2020: http://sig.conanp.gob.mx/website/pagsig/anp/nal/mapasprevios/mapa_actualizado_anps_PREVIO.htm

Delgado, L. (2008). A new species of *Orizabus* (Coleoptera: Scarabaeidae) from Mexico, new records, and a revised key to the species. *Annals of the Entomological Society of America*, *101*, 53–57. https://doi.org/10.1603/0013-8746(2008)101[53:ANSOOC]2.0.CO;2

DOF (Diario Oficial de la Federación). (2016a). *Acuerdo por el que se determina la Lista de las Especies Exóticas Invasoras para México*. Accessed 10 March 2020. http://www.dof.gob.mx/nota_detalle.php?codigo=5464456&fecha=07/12/2016

DOF (Diario Oficial de la Federación). (2016b). *Resumen del programa de manejo del Área Natural Protegida con la categoría de Área de Protección de Flora y Fauna Nevado de Toluca*. Accessed 16 July 2020: https://simec.conanp.gob.mx/pdf_pcym/104_DOF.pdf

Doherty, T. S., Dickman, C. R. Glen, A. S., Newsome, T. M., Nimmo, D. G., Ritchie, E. G. et al. (2017). The global impacts of domestic dogs on threatened vertebrates. *Biological Conservation*, *210*, 56–59. https://doi.org/10.1016/j.biocon.2017.04.007

Doherty, T. S., Glen, A. S. Nimmo, D. G. Ritchie, E. G., & Dickman, C. R. (2016). Invasive predators and global biodiversity loss. *Proceedings of the National Academy of Sciences of the United States of America*, *113*, 11261–11265. https://doi.org/10.1073/pnas.1602480113

Fa, J. E., Romero, F. J., & López-Paniagua, J. (1992). Habitat use by parapatric rabbits in a Mexican high-altitude grassland system. *Journal of Applied Ecology*, *29*, 357-370.

Gallina, S., González-Romero, A., & Manson, R. (2008). Mamíferos pequeños y medianos. In R. Manson, V. Hernández Ortiz, S. Gallina, & K. Mehltreter (Eds.), *Agroecosistemas cafetaleros de Veracruz: biodiversidad, manejo y conservación* (pp. 161–180). México D.F.: Instituto de Ecología, A.C.

Gallo-Reynoso, J. P., & García-Aguilar, M. C. (2008). Análisis preliminar de la presencia de perros ferales en la isla de Cedros y su efecto sobre las colonias de pinnípedos. *Revista Mexicana de Mastozoología*, *12*, 130–140. http://dx.doi.org/10.22201/ie.20074484e.2008.12.1.49

García-Aguilar, M. C. (2012). Monitoreo de la población de perros ferales en la Isla de Cedros, Baja California, y las amenazas a la mastofauna nativa. *Acta Zoológica Mexicana*, *28*, 37–48.

Glen, A. S., & Dickman, C. R. (2008). Niche overlap between marsupial and eutherian carnivores: does competition threaten the endangered spotted-tailed quoll? *Journal of Applied Ecology*, *45*, 700–707. https://doi.org/10.1111/j.1365-2664.2007.01449.x

Gompper, M. E. (2014). *Free-ranging dogs and wildlife conservation*. Oxford: Oxford University Press.

Green, J. S., & Gipson, P. S. (1994). *Feral dogs. The handbook: prevention and control of wildlife damage*. Lincoln: University of Nebraska.

Hall, E. R., & Kelson, K. R. (1959). *The mammals of North America*. New York: The Ronald Press Company.

Helder, J., & de Andrade, K. (1997). Food and feeding habits of neotropical river otter *Lontra longicaudis* (Carnivora Mustelidae). *Mammalogy*, *61*, 193–203. https://doi.org/10.1515/mamm.1997.61.2.193

Héritier, S., & Leberton, C. (2017). From Revolutionary to contested park. Mobilization and conflicts in the recategorization process of the Nevado de Toluca National Park (Mexico). *Journal of Urban Research*, *16*, 3279. https://doi.org/10.4000/articulo.3279

Home, C., Pal, R., Sharma, R. K., Suryawanshi, K. R., Bhatnagar, Y. V., & Vanak, A. T. (2017). Commensal in conflict: Livestock depredation patterns by free-ranging domestic dogs in the upper Spiti landscape. *Ambio*, *46*, 655–666. https://doi.org/10.1007/s13280-016-0858-6

Hughes, J., & Macdonald, D. W. (2013). A review of the interactions between free-roaming domestic dogs and

wildlife. *Biological Conservation*, *157*, 341–351. https://doi.org/10.1016/j.biocon.2012.07.005

INEGI (Instituto Nacional de Estadística y Geografía). (2010). *Localidades de la República Mexicana*. México D.F.: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. Accessed 10 March 2020: file:///D:/GIS/Mexico/Nevado/datasets/loc2010gw/loc2010gw.html

INEGI (Instituto Nacional de Estadística y Geografía). (2011). *Conjunto de datos vectoriales de carreteras y vialidades urbanas*. Accessed 10 July 2020: http://internet.contenidos.inegi.org.mx/contenidos/Productos/prod_serv/contenidos/espanol/bvinegi/productos/geografia/carr_vial/Mexico/702825292102_s.zip

IUCN (International Union for Conservation of Nature). (2000). *IUCN Guidelines for the prevention of biodiversity loss caused by alien invasive species*. Accessed 10 July 2020: https://portals.iucn.org/library/efiles/documents/Rep-2000-052.pdf

IUCN (International Union for Conservation of Nature). (2020). IUCN Protected Area Categories System. Accessed 16 July 2020: https://www.iucn.org/theme/protected-areas/about/protected-areas-categories/category-vi-protected-area-sustainable-use-natural-resources

Iverson, J. B. (1978). The impact of feral cats and dogs on populations of the West Indian rock iguana, *Cyclura carinata*. *Biological Conservation*, *14*, 63–73. https://doi.org/10.1016/0006-3207(78)90006-X

Jensen, P. (2007). *The behavioral biology of dogs*. London: Cromwell Press.

Juárez-Ramírez, M. C., Aguilar-López, J. L., & Pineda, E. (2016). Protected natural areas and the conservation of amphibians in a highly transformed mountainous region in Mexico. *Herpetological Conservation and Biology*, *11*, 19–28.

Khan, M. M. H. (2009). Can domestic dogs save humans from tigers *Panthera tigris*? *Oryx*, *43*, 44–47. https://doi.org/10.1017/S0030605308002068

Kruuk, H., & Snell, H. (1981). Prey selection by feral dogs from a population of marine iguanas (*Amblyrhynchus cristatus*). *Journal of Applied Ecology*, 18, 197-204.

Lenth, B. E., Knight, R. L., & Brennan, M. E. (2008). The effects of dogs on wildlife communities. *Natural Areas Journal*, *28*, 218–227. https://doi.org/10.3375/0885-8608(2008)28[218:TEODOW]2.0.CO;2

Lessa, I., Guimarães, T. C. S., Bergallo, H. G., Cunha, A., & Vieira, E. (2016). Domestic dogs in protected areas: a threat to Brazilian mammals? *Natureza & Conservação*, *14*, 46–56. https://doi.org/10.1016/j.ncon.2016.05.001

Lira, M. S. (2004). Strategic communication and visual identity in the National Commission for Natural Protected Areas (Conanp), Mexico. In D. Hamú, E. Auchincloss, & W. Goldstein (Eds.), *Communicating Protected Areas* (pp. 87–91). IUCN Commission on Education and Communication. Accessed 10 July 2020: https://portals.iucn.org/library/sites/library/files/documents/2004-057.pdf

Long, R. A., Donovan, T. M., Mackay, P., Zielinski, W. J., & Buzas, J. S. (2007). Effectiveness of scat detection dogs for detecting forest carnivores. *Journal of Wildlife Management*, *71*, 2007–2017. https://doi.org/10.2193/2006-230

MacDonald, D. W. (1991). Resource dispersion and the social organisation of the red fox *Vulpes vulpes*. In J. A. Chapman, & D. Pursley (Eds), *Proceedings of the Worldwide Furbearers Conference* (pp. 918–949). Baltimore: University of Maryland Press.

Margules, C. R., & Pressey, R. L. (2000). Systematic conservation planning. *Nature*, *405*, 243–253. https://doi.org/10.1038/35012251

Mattioli, L., Capitani, C., Avanzinelli, E., Bertelli, I., Gazzola, A., & Apollonio, M. (2006). Predation by wolves (*Canis lupus*) on roe deer (*Capreolus capreolus*) in north-eastern Apennine, Italy. *Journal of Zoology*, *264*, 249–258. https://doi.org/10.1017/S095283690400576X

Meek, P. D. (1999). The movement, roaming behaviour and home range of free-roaming domestic dogs, *Canis lupus familiaris*, in coastal New South Wales. *Wildlife Research*, *26*, 847–855. https://doi:10.1071/wr97101

Mella-Méndez, I., Flores-Peredo, R., Bolívar-Cimé, B., & Vázquez-Domínguez, G. (2019). Effect of free-ranging dogs and cats on medium-sized wild mammal assemblages in urban protected areas of a Mexican city. *Wildlife Research*, *46*, 669–678. https://doi.org/10.1071/WR19074

Monroy-Vilchis, O., & Rodríguez, R. R. (1999). *Identificación de mamíferos de la Sierra de Nanchititla a través de pelo*. Toluca: Universidad Autónoma del Estado de México.

Montecino-Latorre, D., & San Martín, W. (2019). Evidence supporting that human-subsidized free-ranging dogs are the main cause of losses in small-scale farms in Chile. *Ambio*, *48*, 240–250. https://doi.org/10.1007/s13280-018-1066-3

Morón, M. A., Rodríguez-del Bosque, L. A., Aragón, A., & Ramírez-Salinas, C. (2010). Biología y hábitos de coleópteros escarabaeoideos. In L. A. Rodríguez-del Bosque & A. Morón (Eds.), *Plagas del suelo* (pp. 65–82). México D.F.: INIFAP/ Colegio de Posgraduados, Universidad Autónoma de Chapingo/ Mundi-Prensa.

Morters, M. K., Mckinley, T. J., Restif, O., Conlan, A. J. K., Cleaveland, S., Hampson, K. et al. (2014). The demography of free-roaming dog populations and applications to disease and population control. *Journal of Applied Ecology*, *51*, 1096–1106. https://doi.org/10.1111/1365-2664.12279

Nesbitt, W. H. (1975). Ecology of a feral dog pack on a wildlife refuge. In M. W. Fox (Ed.), *The wild canids: their systematics, behavioural ecology and evolution* (pp. 391–395). New York: Van Nostrand Reinhold.

OIE (World Organization for Animal Health). (2019). Terrestrial animal health code. Stray dog population control. Accessed 08 May 2019: http://www.oie.int/en/international-standard-setting/terrestrial-code/access-online/?htmfile=chapitre_aw_stray_dog.htm

Paschoal, A. M. O., Massara, R. L., Bailey, L. L., Kendall, W. L., Doherty, P. F., Hirsch, A. et al. (2016). Use of Atlantic Forest protected areas by free ranging dogs: estimating abundance and persistence of use. *Ecosphere*, *7*, 10 e01480. https://doi.org/10.1002/ecs2.1480

Peterson, R., & Chalif, E. L. (1989). *Aves de México: guía de campo*. México D.F.: Editorial Diana.

Ramakrishnan, U., Coss, R. G., & Pelkey, N. W. (1999). Tiger decline caused by the reduction of large ungulate prey: evidence from a study of leopard diets in southern India. *Biological Conservation*, *89*, 113–120. https://doi.org/10.1016/S0006-3207(98)00159-1

Reponen, S. E., Brown, S. K., Barnett, B. D., & Sacks, B. N. (2014). Genetic and morphometric evidence on a Galápagos Island exposes founder effects and diversification in the first–known (truly) feral western dog population. *Molecular Ecol*ogy, *23*, 269–283. https://doi.org/10.1111/mec.12595

Reynolds, J. C., & Aebischer, N. J. (1991). Comparison and quantification of carnivore diet by faecal analysis: a critique, with recommendations, based on a study of the fox *Vulpes vulpes*. *Mammal Review*, *21*, 97–122. https://doi.org/10.1111/j.1365-2907.1991.tb00113.x

Ritchie, E. G., Dickman, C. R., Letnic, M., Vanak, A. T., & Gommper, M. (2014). Dogs as predators and trophic regulators. In M. E. Gompper (Ed.), *Free-ranging dogs and wildlife conservation* (55–68). Oxford: Oxford University Press.

Rzedowski, J. (1978). *Vegetación de México*. México D.F.: Editorial Limusa.

Rzedowski, G. C., Rzedowski, J., Espinosa-Garduño, J., Acosta-Castellanos, S., Aguilar-Rodríguez, S., Aguilar-Santelices, R. et al. (2005). *Flora fanerogámica del Valle de México, 2a. Ed*. México D.F.: Instituto de Ecología, A.C./ Comisión Nacional para el Conocimiento y Uso de la Biodiversidad.

Sánchez, S. O. (1974). *La flora del Valle de México*. México D.F.: Editorial Herrero Hermanos.

Sánchez-Jasso, J. M., Aguilar-Miguel, X., Medina-Castro, J. P., & Sierra-Domínguez, G. (2013). Riqueza específica de vertebrados en un bosque reforestado del Parque Nacional Nevado de Toluca, México. *Revista Mexicana de Biodiversidad*, *84*, 360–373. https://doi.org/10.7550/rmb.29473

Sánchez-Jasso, J. M., & Cebrián-Abellán, F. (2015). Turismo de naturaleza en áreas protegidas de México. Una propuesta de conservación, aprovechamiento y desarrollo local en el Nevado de Toluca. *Cuadernos de Turismo*, *36*, 339–365. https://doi.org/10.6018/turismo.36.231041

Scott, M. D., & Causey, K. (1973). Ecology of feral dogs in Alabama. *Journal of Wildlife Management*, *37*, 253265.

Scott, S. D., & McFarland, C. (2010). Bird feathers: a guide to North American species. Mechanicsburg: Stackpole Books.

Sélem-Salas, C., MacSwiney, M., & Hernández-Betancourt, S. (2011). Aves y mamíferos. In Z. F. Bautista (Ed.), *Técnicas de muestreo para manejadores de recursos naturales* (pp. 351–388). México D.F.: Universidad Nacional Autónoma de México.

Semarnat (2010). Norma Oficial Mexicana NOM-059-SEMARNAT, *Protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo*. Diario Oficial de la Federación. Accessed 10 March 2020: https://www.dof.gob.mx/normasOficiales/4254/semarnat/semarnat.htm

Sepúlveda, M., Pelican, K., Cross, P., Eguren, A., & Singer, R. (2015). Fine-Scale movements or rural free-ranging dogs in conservation areas in the temperate rainforest of the coastal range of southern Chile. *Mammalian Biology*, *80*, 290–297. https://doi.org//10.1016/j.mambio.2015.03.001

Silva-Rodríguez, E. A., & Sieving, K. (2012). Domestic dogs shape the landscape-scale distribution of a threatened forest ungulate. *Biological Conservation*, *150*, 103–110. https://doi.org/10.1016/j.biocon.2012.03.008

Silva-Rodríguez, E. A., Verdugo, C., Aleuy, O. A., Sanderson, J. G., Ortega-Solís, G. R., Osorio-Zúñiga, F. et al. (2010). Evaluating mortality sources for the vulnerable pudu *Pudu puda* in Chile: implications for the conservation of a threatened deer. *Oryx*, *44*, 97–103. https://doi.org/10.1017/S0030605309990445

Spaulding, R., Krausman, P. R., & Ballard, W. B. (2000). Observer bias and analysis of gray wolf diets from scats. *Wildlife Society Bulletin*, *28*, 947–950.

Vanak, A. T., & Gompper, M. E. (2009a). Dogs *Canis familiaris* as carnivores: their role and function in intraguild competition. *Mammal Review*, *39*, 265–283. https://doi.org/10.1111/j.1365-2907.2009.00148.x

Vanak, A. T., & Gompper, M. E. (2009b). Dietary niche separation between sympatric free-ranging domestic dogs and Indian Foxes in central India. *Journal of Mammalogy*, *90*, 1058–1065. https://doi.org/10.1644/09-MAMM-A-107.1

Vanak, A.T., & Gompper, M. E. (2010). Interference competition at the landscape level: the effect of free-ranging dogs on a native mesocarnivore. *Journal of Applied Ecology*, *47*, 1225–1232. https://doi.org/10.1111/j.1365-2664.2010.01870.x

Villatoro, F. J., Naughton-Treves, L., Sepúlveda, M. A., Stowhas, P., Mardones, F. O., & Silva-Rodríguez, E. A. (2019). When free-ranging dogs threaten wildlife: public attitudes toward management strategies in southern Chile. *Journal of Environmental Management*, *229*, 67–75. https://doi.org/10.1016/j.jenvman.2018.06.035

Wasser, S. K., Davenport, B., Ramage, E. R., Hunt, K. E., Parker, M., Clarke, C. et al. (2004). Scat detection dogs in wildlife research and management: application to grizzly and black bears in the Yellowhead Ecosystem, Alberta, Canada. *Canadian Journal of Zoology*, *82*, 475–492. https://doi.org/10.1139/z04-020

Young, J. K., Olson, K. A., Reading, R. P., Amgalanbaatar, S., & Berger, J. (2011). Is wildlife going to the dogs? Impacts of feral and free-roaming dogs on wildlife populations. *BioScience*, *61*, 125–132. https://doi.org/10.1525/bio.2011.61.2.7

Zapata-Ríos, G., & Branch, L. C. (2016). Altered activity patterns and reduced abundance of native mammals in sites with feral dogs in the high Andes. *Biological Conservation*, *193*, 9–16. https://doi.org/10.1016/j.biocon.2015.10.016