The impacts of domestic dogs (*Canis familiaris*) on wildlife in two Brazilian hotspots and implications for conservation

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Guedes, J. J. M., Assis, C. L., Feio, R. N., Quintela, F. M., 2021. The impacts of domestic dogs (*Canis familiaris*) on wildlife in two Brazilian hotspots and implications for conservation. *Animal Biodiversity and Conservation*, 44.1: 45–58, Doi: https://doi.org/10.32800/abc.2021.44.0045

Abstract

*The impacts of domestic dogs (*Canis familiaris*) on wildlife in two Brazilian hotspots and implications for conservation.* Exotic species are major threats to biodiversity worldwide. Domestic dogs (*Canis familiaris*) are among the most common invasive predators in the world, interacting with wildlife in many ways. We present ecological data based on camera traps and occasional observations of free–roaming domestic dogs from localities within the Brazilian Atlantic forest and Cerrado hotspots. *Canis familiaris* was the second most abundant mammal species, and the most abundant carnivore. Dogs chased, killed, and/or competed with at least 26 native species. They consumed none of the killed animals, which together with the predominant records of solitary individuals acting during the daytime indicates they are mainly free–roaming dogs relying on humans for food and shelter. The high numbers of dogs and the wide range of prey suggest wildlife could be greatly impacted by domestic dogs, especially in areas that are highly threatened by anthropogenic activities, such as biodiversity hotspots. We highlight possible measures (such as the eradication or removal of dogs from natural areas) that could help to reduce the environmental damage caused by domestic dogs in the region.

Key words: Conservation biology, Biological invasion, Exotic species, Atlantic forest, Cerrado

Resumen

*Efectos de los perros domésticos (*Canis familiaris*) en la vida silvestre en dos puntos críticos del Brasil e implicaciones para la conservación.* Las especies exóticas son una de las principales amenazas para la biodiversidad en todo el mundo. Los perros domésticos (*Canis familiaris*) se encuentran entre los depredadores invasores más comunes del mundo, ya que interactúan con la vida silvestre de muchas maneras. Presentamos datos ecológicos obtenidos mediante cámaras de trampeo y observaciones ocasionales de perros domésticos criados en libertad de localidades situadas dentro de los puntos críticos del bosque atlántico y el Cerrado brasileños. *Canis familiaris* fue la segunda especie de mamífero más abundante y el carnívoro más abundante. Los perros interactuaron con al menos 26 especies nativas persiguiéndolas, matándolas o compitiendo con ellas. No consumieron ninguno de los animales muertos, lo que, junto con los registros predominantes de individuos solitarios en actividad diurna, indica que se trata principalmente de perros criados en libertad que dependen de los humanos para alimentarse y refugiarse. La elevada abundancia de perros y la gran variedad de presas sugieren que la vida silvestre podría verse muy afectada por los perros domésticos, especialmente en zonas muy amenazadas por actividades humanas, como los puntos críticos de biodiversidad. Destacamos algunas medidas (por ejemplo, la erradicación o eliminación de perros de áreas naturales) que representan una posibilidad de reducir los daños ambientales causados por perros domésticos en la región.

Palabras clave: Biología de la conservación, Invasión biológica, Especies exóticas, Bosque atlántico, Cerrado

Received: 19 V 20; Conditional acceptance: 21 VII 20; Final acceptance: 22 IX 20

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ORCID ID: 0000-0003-0485-3994

ISSN: 1578–665 X
eISSN: 2014–928 X

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Introduction

The Earth's biota has been severely impacted by anthropogenic activities, leading to population declines and species loss at a global scale (Barnosky et al., 2011; Dirzo et al., 2014). Among the many causes threatening wildlife, the introduction and dispersal of exotic species is a major threat, being of great concern to many conservationists (Gurevitch and Padilla, 2004; Macdonald et al., 2007). In general, the negative impact of exotic species does not only affect native species but can also affect whole communities and ecosystem structures (Sakai et al., 2001).

Although there are thousands of exotic species worldwide, invasive mammalian predators are likely those that cause most damage to biodiversity (Bellard et al., 2016; Doherty et al., 2016, 2017). For instance, invasive predators are directly related to the extinction of more than a hundred vertebrate taxa (Doherty et al., 2016). Among invasive predators, dogs (*C. familiaris*) and cats (*Felis catus*) are surely the most common, the most numerous and the most widespread (Butler et al., 2004; Ferreira et al., 2011). Currently, the global domestic dog population is about 700 million to 1 billion individuals (Hughes and Macdonald, 2013; Gompper, 2014). Dogs have been living in close proximity with humans since their domestication around 15,000–30,000 years ago (Savolainen et al., 2002; Gompper, 2014). When they escape, when they are abandoned, or when they are allowed by their owners to roam, they may become 'free–roaming' animals, relying on human communities for food and shelter, or become feral dogs, living in the wild without any contact with humans at all (Boitani and Ciucci, 1995; Young et al., 2011; Hughes and Macdonald, 2013).

Free–roaming and feral dogs can pose problems of many types. They can harm wildlife and natural environments, and endanger human welfare through the transmission of contagious diseases (Schloegel and Daszak, 2005). They may become predators and compete with other species for resources such as food and shelter (Young et al., 2011), and they may even hybridize with other canids (Vilà and Wayne, 1999). Furthermore, the costs involved in controlling free–roaming dog populations, in livestock kills, and in medical treatments for dog bites cannot be overlooked (Pimentel et al., 2000; Bergman et al., 2009). Domestic dogs have contributed to the global extinction of at least 11 vertebrate species, and free–ranging dogs have had some impact on a further 188 species worldwide (Doherty et al., 2017). Species with limited defense capability, such as the Galapagos marine iguanas (*Amblyrhynchus cristatus*) or the New Zealand kiwi (genus *Apteryx*), have undergone population declines due to predation by a relatively small number of domestic dogs (Kruuk and Snell, 1981; Taborsky, 1988). In Tanzania, eastern Africa, an outbreak of rabies and canine distemper caused the death and apparent local extinction of African wild dogs (*Lycaon pictus*), and the mortality of 30 % of lions (*Panthera leo*) in Serengeti National Park (Cleaveland et al., 2007). In Brazil, domestic dogs might have contributed to the population decline of the bush dog (*Speothos venaticus*) at Brasília National Park. In the same area, the maned wolf (*Chrysocyon brachyurus*) was recorded more frequently in sites without the presence of dogs (Lacerda et al., 2009; Lessa et al., 2016).

The total population of free–roaming domestic dogs in Brazil is about 25 million individuals (Campos et al., 2007). Free–roaming and feral dogs are commonly recorded in both protected and unprotected areas of high conservation relevance in the country (Galetti and Sazima, 2006; Lessa et al., 2016; Allemand et al., 2019). Their presence in natural areas can be particularly damaging if areas are embedded in hotspots for biodiversity conservation –areas with high species richness and endemism, but highly threatened by human activities (Myers et al., 2000)– such as the Atlantic forest and Cerrado ecoregions in Brazil. At least 35 species have already been reported as prey of domestic dogs in these ecoregions across seven Brazilian states (e.g., Galetti and Sazima, 2006; Campos et al., 2007; Lacerda et al., 2009; Lessa et al., 2016). Even highly fragmented and unprotected areas in these hotspots may harbor significant components of native fauna, possessing endemic, endangered, and even undescribed species (Lion et al., 2016; Barbosa et al., 2017; Avigliano et al., 2019). The damage caused by free–roaming dogs on wildlife are still little understood and even neglected, especially in South America countries (Lessa et al., 2016). Therefore, more studies are necessary to improve our current understanding of the real consequences of such interactions (Galetti and Sazima, 2006; Young et al., 2011; Hughes and Macdonald, 2013). Here we present novel records of the interaction between domestic dogs and wildlife together with data on the occurrence and abundance of both domestic dogs and native species in natural environments from the Atlantic forest and Cerrado hotspots in southeastern Brazil. We also discuss potential ecological consequences of such interactions on wildlife and associated ecosystems, and provide some guidelines for decision makers to mitigate those problems in the region.

Material and methods

The study area was composed of 10 municipalities in the state of Minas Gerais, southeastern Brazil (fig. 1). These localities comprise unprotected forest fragments located in subtropical moist broadleaf forests and subtropical savanna ecoregions (Dinerstein et al., 2017) (hereafter Atlantic forest and Cerrado, respectively), and also an ecotone (transition) area between these two ecoregions (table 1). The Atlantic forest is currently reduced to about 12 % of its original cover. Most forest fragments are small (< 50 ha) and located near populated areas (Ribeiro et al., 2011). The Cerrado has also gone through a severe deforestation process over the last decades, with its original area now reduced to about 22 % (IBGE, 2019). Overall, the matrices (surroundings) of the forest fragments in the study area are composed mainly of pasture and crop plantations. Although these forest

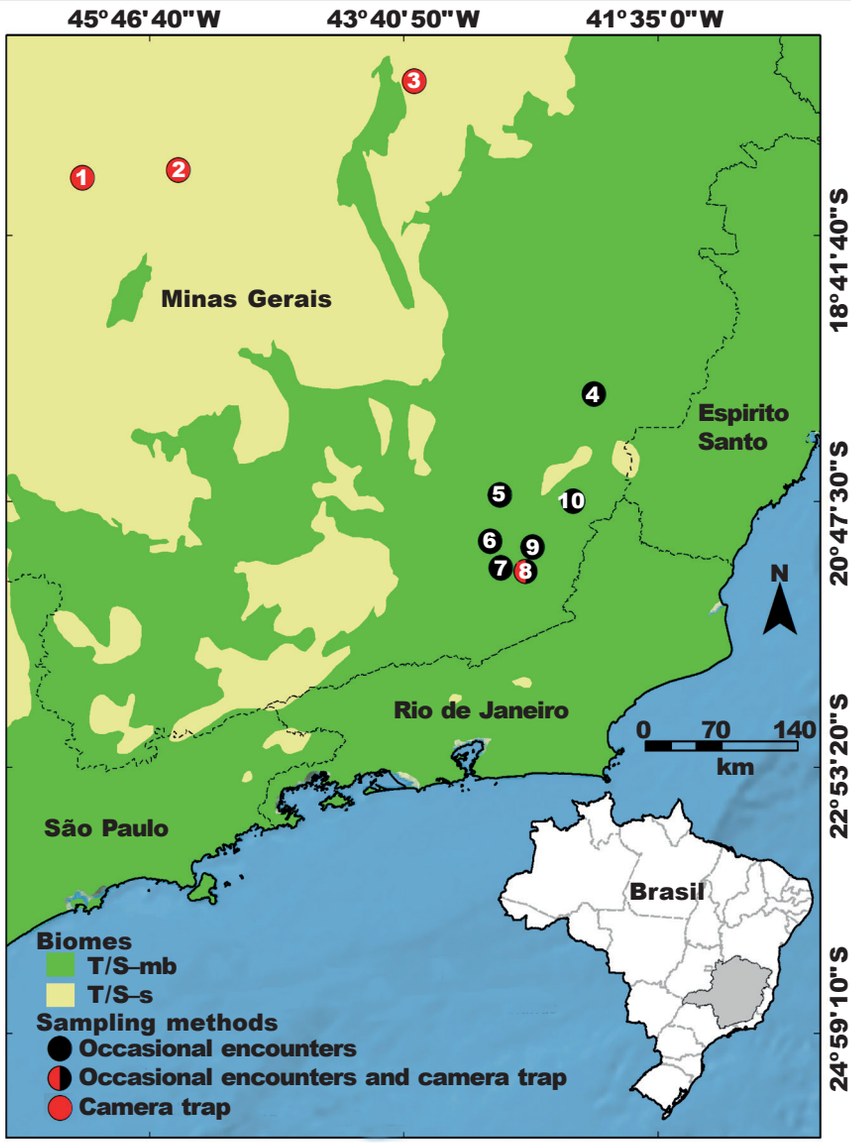

Fig. 1. Municipalities where the study was conducted in the state of Minas Gerais: 1, Presidente Olegário; 2, São Gonçalo do Abaeté; 3, Olhos D'água; 4, Santa Bárbara do Leste; 5, Viçosa; 6, Ubá; 7, Astolfo Dutra; 8, Cataguases; 9, Miraí; 10, São Francisco do Glória. The inset map shows the Brazilian federative units, highlighting the state of Minas Gerais in grey. Biomes: T/S–mb, tropical and subtropical moist broadleaf forests; T/S–s, tropical and subtropical grasslands, savannas and shrublands.

Fig. 1. Municipios del estado de Minas Gerais donde se realizó el estudio: 1, Presidente Olegário; 2, São Gonçalo do Abaeté; 3, Olhos D'água; 4, Santa Bárbara do Leste; 5, Viçosa; 6, Ubá; 7, Astolfo Dutra; 8, Cataguases; 9, Miraí; 10, São Francisco do Glória. En el mapa ampliado se observan las unidades federativas brasileñas y se destaca el estado de Minas Gerais en gris. Biomas: T/S–mb, bosques húmedos tropicales y subtropicales; T/S–s, pastizales, sabanas y matorrales tropicales y subtropicales.

remnants are small and severely threatened by human activities, they are still relevant to the conservation of biodiversity because they harbor many endemic and endangered species (Faria et al., 2009; Moraes et al., 2015; Guedes et al., 2017; Laurindo et al., 2019).

To investigate the ecological interactions between dogs and wild animals, we first classified these interactions into: (i) predation, (ii) chasing, and (iii) competition. We considered interactions as predation when dogs injured or killed other animals; chasing when other species were disturbed by dogs, but without physical engagement between them; and competition (i.e., for space and food) when dogs co–occurred (found in the same site) with native

carnivores (Hughes and Macdonald, 2013; Lessa et al., 2016). Interactions were recorded through opportunistic encounters (OE) and camera trap (CT) data. Opportunistic encounters were obtained from seven municipalities during 2008 and 2020 (table 1) by two researchers during fieldwork to assess environmental impact, and represent sporadic, occasional, anecdotal records. When domestic dogs were observed interacting with wild animals, observers remained in place until the end of the interaction. Despite the long period involved in assessing the environmental impact in both ecoregions, we only obtained occasional records were obtained in areas of the Atlantic forest biome. Data of CTs obtained from 2014 to 2016 was also used to analyze ecological interactions between domestic dogs and native species and to estimate abundance for mammal species in the study area. These data were obtained from 23 sampling sites distributed across four municipalities (table 1). We used the number of records as a proxy for abundance, but it is worth mentioning that this does not correspond exactly to the number of individuals because sometimes one photograph can include more than one individual. Camera traps were installed on tree trunks at heights of 40–50 cm above the forest floor, all in areas of native vegetation; in other words, CTs were not installed in areas of eucalyptus (exotic) plantations. The distance between cameras (considering the closest one) at each site ranged from 0.7 to 14.8 km. We used meat, fruits, and maize as bait, aiming to increase detection and to provide better estimates of abundance for the recorded species. We acknowledge that these baits may not cover the diet of all mammals occurring in the study area and could therefore bias our abundance estimates, but because most species are naturally rare (Preston, 1948), random detection would likely be too low without using baits. In all sampling sites, camera traps remained active for at least 67 days, had infrared sensors to detect movement and temperature variation, and were programmed to shoot at 10–second intervals between shots. The sampling effort in each study site was calculated as: 24h/trapping * nº of camera traps * nº of sampling period in days (see table 1).

Whenever possible, dogs were identified through aspects of pelage color, sex, size and any other characteristics that could be useful for individual distinction (fig. 2). For abundance estimates, individuals from the same species were counted only for a given sampling site when records were obtained over periods of more than 24 hours. We chose this conservative approach to avoid counting the same specimen of a given species more than once when it wanders around the same CT multiple times in the same day, which could inflate abundance estimates. We used a non–parametric Kruskal–Wallis rank sum test to investigate whether there were differences in mean mammal abundance between ecoregions. Using Pearson's χ^2–test we also tested if the number of records of domestic dogs, carnivores, and other mammals was dependent of the ecoregion. Analysis was performed using the statistical software R version 3.3.3 (R Core Team, 2017). The period of activity of domestic dogs was obtained through time stamps of camera shots, and was classified into diurnal (active from 6 to 18 h) or nocturnal (active from 18 to 6 h), which roughly represent day/night time in southeastern Brazil during most of the year. Information on ecological aspects and geographic distribution of native mammal species follows Paglia et al. (2012). The status of conservation of native mammal species at national and global levels follows ICMBio (2018) and IUCN (2020), respectively.

Results

In seven municipalities we recorded a total of 79 individuals belonging to 25 native species that were killed or chased or were potentially competing for resources with domestic dogs in the study area (one bird, two lizards, and 22 mammals; table 2). Of 13 species killed by domestic dogs, three (*Tropidurus torquatus*, *Cerdocyon thous* and *Nectomys squamipes*) are recorded as being preyed upon by dogs for the first time. Species directly interacting with dogs varied greatly in body size, including small–sized animals such as the eastern collared spiny lizard *Tropidurus torquatus* (Teixeira and Giovanelli, 1999) and large mammals such as the capybara *Hydrochoerus hydrochaeris* (Paglia et al., 2012). The dogs consumed none of the animals they killed, and the attacks persisted until the prey stopped moving.

The total sampling effort of CTs was 65,520 hours (mean = 16,380 hours/city). Overall, we obtained 649 records of 31 mammal species (27 natives and four exotics) across four municipalities (fig. 3). More than half of these records were from the Atlantic forest (51.3%), which also had higher average mammal abundance (mean = 19.6 ± 40, range: 1–162, n = 17). The Cerrado accounted for 40.2% of the total abundance (mean = 10.9 ± 12.8, range: 1–45, n = 24), followed by the ecotone area with 8.4% (mean = 5.5 ± 4.5, range: 5–13, n = 10). Although the differences in mean mammal abundance were not statistically significant among ecoregions (Kruskal–Wallis $\chi^2 = 0.501$, $df = 2$, $p = 0.778$), the number of records of domestic dogs, carnivores, and other mammals was highly dependent on the biome in which they occurred (χ^2–test = 43.715, $df = 4$, $p < 0.001$). Considering all records, the black–eared opossum *Didelphis aurita* (24.96%) was the most common species, followed by domestic dogs (14.18%) and the tapeti *Sylvilagus brasiliensis* (7.7%).

The number of records of domestic dogs varied among ecoregions, where most dogs were recorded in the Atlantic forest (n = 55; 59.7%), followed by the Cerrado (n = 24; 26%) and the transition area (n = 13; 14.3%). Among species of the order Carnivora, *Canis familiaris* was the most common, followed by the South American coati *Nasua nasua* (3,24%), the maned wolf *Chrysocyon brachyurus* (3.08%), the crab–eating fox *Cerdocyon thous* (2.62%), the tayra *Eira barbara* (2%), the striped hog–nosed skunk *Conepatus amazonicus* (0.92%), the ocelot *Leopardus pardalis* (0.62%), the cougar *P. concolor* (0.62%), *Felis catus* (0.46%), the crab–eating raccoon

Table 1. Detailed information about the methods used in each municipality in the state of Minas Gerais, southeastern Brazil: N, number of sites/city; T, total sampling effort. Biome: AF, Atlantic forest; Ce, Cerrado; Ec, ecotone. Sampling methods (SM): OE, occasional encounter; CT, camera–trap; * occasional encounters in Cataguases in 2010–2011, 2013–2015, and 2017–2018.

*Tabla 1. Información detallada sobre la metodología utilizada en cada municipio del estado de Minas Gerais, en el sureste del Brasil: N, número de sitios/ciudad; T, esfuerzo de muestreo total. Bioma: AF, bosque Atlántico; Ce, Cerrado; Ec, ecotono. Métodos de muestreo (SM): OE, observación ocasional; CT, cámara de trampeo; * observaciones ocasionales en Cataguases ocurridos en los años de 2010–2011, 2013–2015 y 2017–2018.*

Municipality	Coordinates	SM	Period	N	T	Biome
Astolfo Dutra	21º 18' 29" S 42º 51' 41" W	OE	2009	–	–	AF
Miraí	21º 09' 03" S 42º 37' 06" W	OE	2008–2009	–	–	AF
Santa Bárbara do Leste	19º 58' 32" S 42º 08' 45" W	OE	2015	–	–	AF
São Francisco do Glória	20º 47' 31" S 42º 16' 58" W	OE	2020	–	–	AF
Ubá	21º 07' 15" S 42º 56' 11" W	OE	2013	–	–	AF
Viçosa	20º 45' 17" S 42º 52' 42" W	OE	2015–2016	–	–	AF
Cataguases *	21º 22' 31" S 42º 41' 08" W	CT, OE	VI 2015 to VIII 2016	2	20,160 h	AF
Olhos D'água	17º 23' 45" S 43º 34' 11" W	CT	III 2014 to V 2014	5	10,800 h	Ec
Presidente Olegário	18º 24' 56" S 46º 25' 05" W	CT	VII 2016 to X 2016	8	23,040 h	Ce
São Gonçalo do Abaeté	18º 20' 29" S 45º 49' 57" W	CT	IV 2016 to V 2016	8	11,520 h	Ce

Procyon cancrivorus (0.46 %), the jaguarundi *Puma yagouaroundi* (0.15 %), and the southern tiger cat *Leopardus guttulus* (0.15 %).

Most domestic dogs were recorded in diurnal activity (n = 74; 80.4 %) but some individuals were also found at night (n = 18; 19.6%). On most occasions, domestic dogs were solitary (n = 66; 71.7 %), but we also recorded groups of two to four individuals (n = 26; 28.3 %). Although we did not measure any specimen, body sizes (estimated based on photographs) varied from small to large, but most individuals were medium–sized.

The great majority of native mammals occur both in the Atlantic forest and Cerrado biomes, except for *Didelphis aurita* and the black capuchin *Sapajus nigritus*, which are considered endemic to the Atlantic forest (Paglia et al., 2012). Although the black capuchin *Sapajus nigritus* is considered endemic to this ecoregion, we also observed this species in a Cerrado area. Half the species recorded have terrestrial habits, and only a few are scansorial ('climber') (16.6 %), semifossorial (can live above– and below–ground) (13.3 %), arboreal (13.3 %) or semiaquatic (can live partly on land and partly in water) (6.6 %). More than two thirds of mammals recorded in the study area are nocturnal, with only 20 % being diurnal, and 13.3 % being active both day and night. Regarding their conservation status, three species are considered vulnerable (the giant Anteater *Myrmecophaga tridactyla*, the giant armadillo *Priodontes maximus* and the oncilla *Leopardus guttulus*) and two are considered near threatened (*Chrysocyon brachyurus* and *Sapajus nigritus*) at a global level (IUCN, 2020). Nationally, six species are considered vulnerable (*C. brachyurus*, *L. guttulus*, *Puma concolor*, *P. yagouaroundi*, *M. tridactyla*, and *P. maximus*) (table 3).

Table 2. Recorded species competing, chased, and/or killed by domestic dogs in seven municipalities in the state of Minas Gerais, Brazil: N, number of specimens. Impact type (IT): Ch, chasing; P, predation; C, competition. Municipality of record: AST, Astolfo Dutra; CAT, Cataguases; MIR, Miraí; ODA, Olhos D'água; SBL, Santa Bárbara do Leste; SFG, São Francisco do Glória; SGA, São Gonçalo do Abaeté; PRE, Presidente Olegário; UBA, Ubá; VIC, Viçosa.

Tabla 2. Especies registradas compitiendo, perseguidas o matadas por perros domésticos en siete municipios del estado de Minas Gerais, en Brasil: N, número de especímenes. Tipo de impacto (IT): Ch, persecución; P, depredación; C, competencia. Municipios de registro: AST, Astolfo Dutra; CAT, Cataguases; MIR, Miraí; ODA, Olhos D'água; SBL, Santa Bárbara do Leste; SFG, São Francisco do Glória; SGA, São Gonçalo do Abaeté; PRE, Presidente Olegário; UBA, Ubá; VIC, Viçosa.

Species	N	Common name	Municipality of record	IT
Mammalia				
Callithrix penicillata	1	Black–pencilled marmoset	CAT	Ch
Cerdocyon thous	15	Crab–eating fox	UBA, PRE, ODA, SGA, CAT	P, C
Chrysocyon brachyurus	9	Maned wolf	CAT, PRE, SGA, ODA	C
Conepatus amazonicus	2	Striped hog–nosed skunk	SGA	C
Cuniculus paca	1	Spotted paca	CAT, VIC	P
Dasypus novemcinctus	1	Nine–banded armadillo	CAT, MIR	Ch, P
Didelphis aurita	3	Brazilian common opossum	CAT	P
Eira barbara	1	Tayra	CAT, PRE	P
Hydrochoerus hydrochaeris	1	Capybara	VIC	Ch
Kannabateomys amblyonyx	1	Atlantic bamboo rat	CAT	Ch
Leopardus guttulus	1	Southern tiger cat	SGA	C
Leopardus pardalis	4	Ocelot	CAT	C
Mazama gouazoubira	1	Red brocket	SBL	P
Nasua nasua	20	South American coati	CAT, PRE, SGA	P, C
Nectomys squamipes	1	South American water rat	CAT	P
Philander frenatus	1	Southeastern four–eyed opossum	SFG	P
Procyon cancrivorus	3	Crab–eating raccoon	CAT, SFG	P, C
Puma concolor	4	Cougar	CAT, SGA	C
Puma yagouaroundi	2	Jaguarundi	MIR, CAT	Ch, C
Sphiggurus villosus	2	Orange–spined hairy dwarf porcupine	CAT, VIC	Ch
Sylvilagus brasiliensis	1	Tepeti; forest rabbit	AST	P
Tamandua tetradactyla	1	Southern tamandua	CAT	Ch
Aves				
Crypturellus tataupa	1	Tataupa tinamou	CAT	Ch
Squamata				
Salvator merianae	1	Black–and–white tegu	CAT	P
Tropidurus torquatus	1	Eastern collared spiny lizard	CAT	P

Discussion

In the present study, we found 13 species that were killed by domestic dogs, adding three novel records (*Tropidurus torquatus*, *Cerdocyon thous* and *Nectomys squamipes*) to the growing list of native species killed by canines in the Atlantic forest and Cerrado ecoregions (Galetti and Sazima, 2006;

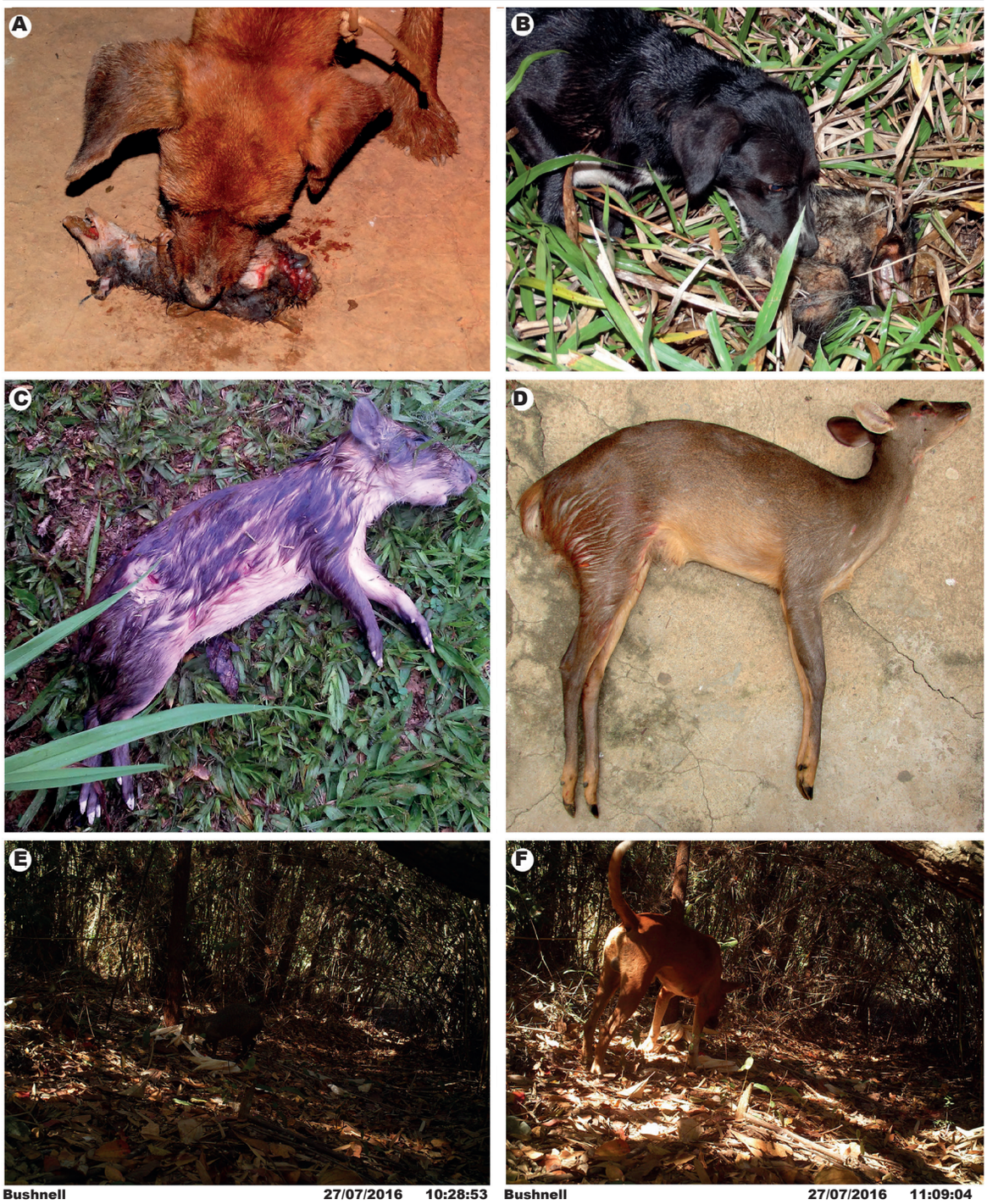

Fig. 2. Records obtained from occasional encounters (A–D) and camera traps (E–F): A–D, *Philander frenatus* (A), *Didelphis aurita* (B), *Cuniculus paca* (C), and *Mazama gouazoubira* (D), all killed by domestic dogs in the municipalities of São Francisco do Glória, Cataguases, Viçosa, and Santa Bárbara do Leste, respectively; E–F, *Dasyprocta azarae* and a domestic dog recorded in the same locality, and near the same time, in the municipality of Presidente Olegário.

Fig. 2. Registros obtenidos de observaciones ocasionales (A–D) y con cámaras de trampeo (E–F): A–D, Philander frenatus *(A),* Didelphis aurita *(B),* Cuniculus paca *(C) y* Mazama gouazoubira *(D), todos matados por perros domésticos en São Francisco do Glória, Cataguases, Viçosa y Santa Bárbara do Leste respectivamente; E–F,* Dasyprocta azarae *y un perro doméstico encontrados en la misma localidad y casi al mismo tiempo en Presidente Olegário.*

Campos et al., 2007; Oliveira et al., 2008; Lacerda et al., 2009; Lessa et al., 2016; Pereira et al., 2019). The diversity of animals killed, varying greatly in body size, indicates that free–roaming dogs are generalists regarding the prey they hunt and feed on (Galetti and Sazima, 2006; Campos et al., 2007; Pereira et al., 2019). Many other species, despite not being killed, were either chased or potentially competed with domestic dogs, which can also have negative effects on wildlife (Hughes and Macdonald, 2013; Doherty et al., 2017). Since the studied sites are embedded within two biodiversity hotspots (Myers et al., 2000), the native fauna in the state of Minas Gerais could be highly impacted by the additional pressure exerted by domestic dogs. It seems, too, that many species that are negatively affected by domestic dogs are also highly threatened by other impacts, such as habitat loss and illegal hunting (Lessa et al., 2016).

We highlight that terrestrial mammals (regardless of size) are more vulnerable to dog attacks than arboreal and aquatic mammal species, for example, as encounter rates are probably higher and chances of escape are lower. Similar results were found in other studies conducted in Brazil (Galetti and Sazima, 2006; Campos et al., 2007; Rangel et al., 2013; Pereira et al., 2019), and even in global assessments, terrestrial mammals are the group most impacted by interactions with domestic dogs (Hughes and Macdonald, 2013; Doherty et al., 2017). The fact that the dogs did not consume the animals they attacked suggests they are free–roaming –rather than feral dogs (Hughes and Macdonald, 2013)– in close relationship with human settlements where they may obtain food and shelter. This pattern of killing but not feeding upon their prey has been reported in other studies (Galetti and Sazima, 2006; Oliveira et al., 2008; Rangel et al., 2013; Pereira et al., 2019) where dogs may chase, capture, and eventually kill other species apparently for fun (Gompper, 2014). This could be explained by the close evolutionary relationship between dogs and wolves, and the 'predation instinct' preserved in dogs (Bradshaw, 2006). One aspect of concern related to this predatory behavior is that most remaining native vegetation in Brazil is currently highly fragmented, and small sized in the case of the Atlantic forest (Ribeiro et al., 2009). Combined with the proximity of these fragments to urban and rural areas, this environment creates a favorable scenario for invasion and dispersion of free–roaming dogs (Manor and Saltz, 2004; Torres and Prado, 2010; Paschoal et al., 2016; Allemand et al., 2019). We acknowledge, however, that human interference (presence during occasional encounters) could lead dogs to abandon their prey after killing it, thus biasing this result. Furthermore, dogs certainly feed upon many other specimens (especially small ones) that we could only know of through, for example, analysis of fecal samples (Campos et al., 2007; Nogales et al., 2013). Nonetheless, this only emphasizes that the predation events we observed might represent merely a small fraction of the real magnitude of the impact of dogs on wildlife, which in effect has been shown to be hugely underestimated (Doherty et al., 2017).

In our study, *Canis familiaris* was the second most abundant species out of 31 mammal taxa recorded by camera traps, and the most abundant carnivore. Other studies have presented similar findings, where domestic dogs frequently stand out among the most abundant species in many natural areas in Brazil, affecting native species in several ways (Curi et al., 2006; Srbek–Araujo and Chiarello, 2008; Lacerda et al., 2009; Frigeri et al., 2014; Paschoal et al., 2016). In addition to the direct impact caused by injuries and death to other predators, such as the crab–eating fox (*Cerdocyon thous*) and the jaguarundi (*Puma yagouaroundi*), domestic dogs could also be indirectly affecting other carnivores through transmission of infectious diseases, for example (Young et al., 2011), or competition for space and food (Hughes and Macdonald, 2013; Lessa et al., 2016). The latter can be further aggravated when free–roaming dog abundances are high, since they can exert excessive predation pressure upon prey, considerably reducing their population size and their ability to recover, thus shrinking the availability of food for other predators (Young et al., 2011). Although it was not statically significant, the average and overall dog abundance in the Atlantic forest was high when compared to that in the ecotone and Cerrado areas. Variation in dog densities across regions are well known and depend mainly on human population densities (Gompper, 2014), which seems the main driver of the observed pattern since the Atlantic forest accounts for more than 40 % of the Brazilian population with more than 100 million people (da Fonseca, 1985; Morellato and Haddad, 2000).

Another interesting aspect is that most records showed dogs in diurnal activities mostly solitary. This is different from what is usually observed with feral dogs, which aggregate in groups of up to six individuals and are primarily active in nocturnal and crepuscular periods (Boitani and Ciucci, 1995). Coupled with other findings presented here (see above), this finding suggests that dogs observed in our sampled localities were likely free–roaming animals that retreat to nearby human habitations for shelter or food. The presence of free–roaming dogs rather than feral dogs is not surprising since more than 75 % of the world dog population are likely free–roaming individuals (Hughes and Macdonald, 2013). It is worth mentioning that most native mammals recorded in the study areas are nocturnal (see table 3), which could somewhat limit the negative impact of free–roaming dogs due to a mismatch of activity time. Moreover, as most dogs likely rely directly on humans to survive –at least partially– this consideration could provide an opportunity for the implementation of effective management actions to control the impact of dogs on wildlife.

The conservation status of most native mammals recorded herein in co–occurrence with domestic dogs is of least concern, and the majority of these species have wide geographic distribution (occurring in more than one biome; table 3). However, seven of these are included in threat categories at a national or global level. Considering that our study was conducted outside protected areas and the recorded native taxa also suffer from other impacts, such as habitat loss and

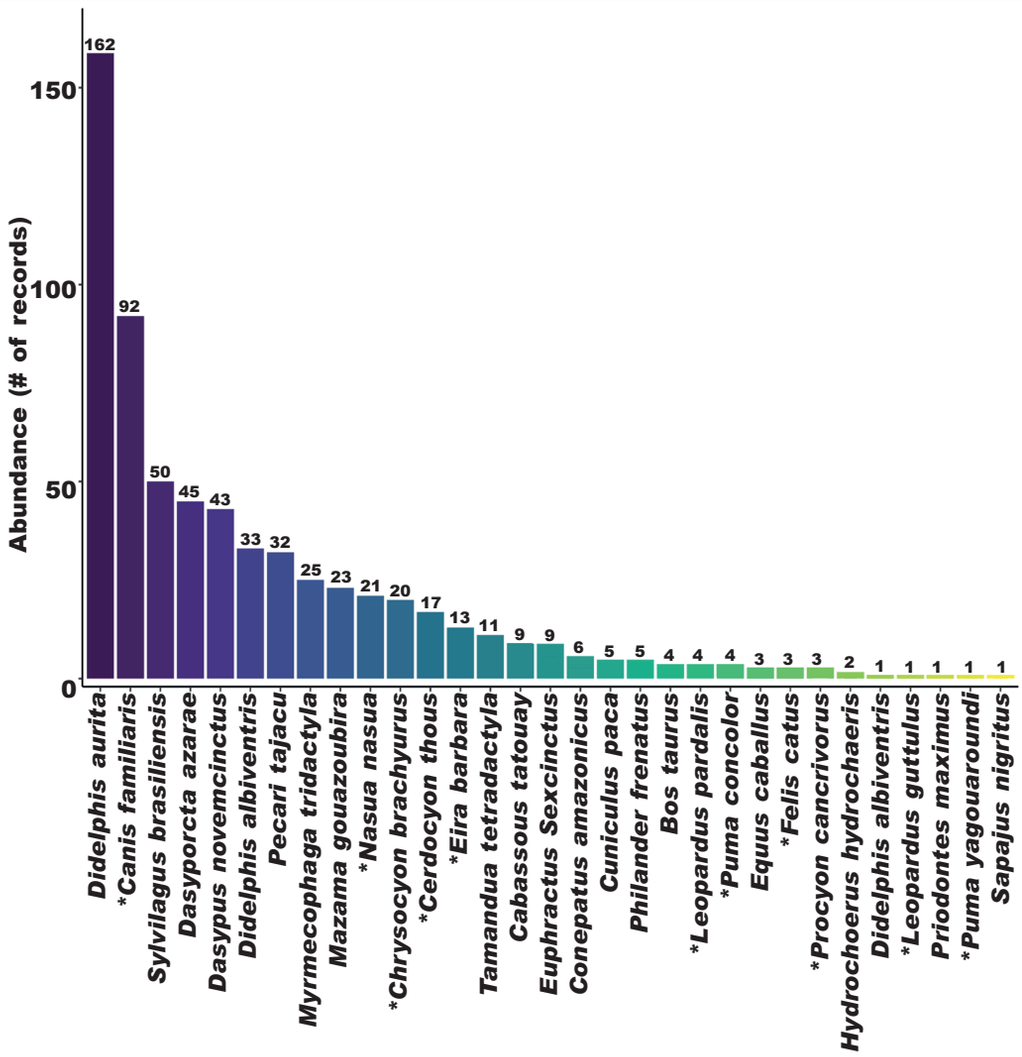

Fig. 3. Total number of records of mammals obtained from 2014 to 2016 by camera trapping in four municipalities of the state of Minas Gerais, southeastern Brazil (see table 1). Species are ordered in decreasing number of records; * species from the order Carnivora.

*Fig. 3. Número total de registros de mamíferos obtenidos de 2014 a 2016 mediante cámaras de trampeo en cuatro municipios del estado de Minas Gerais, en el sureste del Brasil (véase la tabla 1). Las especies se ordenan por número decreciente de registros; * especies del orden Carnivora.*

fragmentation (Chiarello, 1999), hunting (Cullen et al., 2001), and road kill (Cáceres et al., 2010), our results underline another concerning issue for the biological conservation in these areas. Although the magnitude of the impact of domestic dogs is still unclear (Doherty et al., 2017), it is evident that this invasive predator can add to the impact and risk of local extinctions of native species, particularly of other carnivores (Doherty et al., 2016, 2017; Lessa et al., 2016).

Even with the growing recognition and concern of the impact caused by domestic dogs on native species, management of the problem is a challenge for professionals working in wildlife conservation. The society, animal protection and welfare organizations, and authorities or decision makers do not generally take the impact of this invasive predator on wildlife into account, and may be reluctant to take action to control dog populations, particularly due to their close association with humans (Dalla Villa et al., 2010; Hughes and Macdonald, 2013). For example, in the municipalities where predation events were recorded in this study, animal welfare organizations and the local people commonly organize campaigns to feed free–ranging dogs but are reluctant to manage dog populations such as their removal from streets, vaccinations, and long–term castration programs. These contrasting 'behaviors' could, eventually, have a negative effect on animal welfare. These organizations

Table 3. Distributional, ecological and conservation data of native mammals recorded through occasional encounters and camera trapping in the studied sites: Biomes: AF, Atlantic forest; AmF, Amazon forest; Ca, Caatinga; Ce, Cerrado; Pp, Pampa; Pt, Pantanal. Habitat: Ar, arboreal; Te, terrestrial; Sf, Semifossorial; Sc, Scansorial; Saq, Semiaquatic. Activity period: D, diurnal; N, nocturnal. Conservation status (CS): DD, data deficient; LC, least concern; NT, near threatened; VU, vulnerable.

Tabla 3. Datos ecológicos, de distribución y de conservación de mamíferos nativos registrados en observaciones ocasionales y con las cámaras de trampeo en los sitios estudiados. Biomas: AF, bosque atlántico; AmF, bosque amazónico; Ca, Caatinga; Ce, Cerrado; Pp, Pampa; Pt, pantanal. Hábitat: Ar, arbóreo; Te, terrestre; Sf, semifosorial; Sc, escansorial; Saq, semiacuático. Periodo de actividad: D, diurno; N, nocturno. Estado de conservación (CS): DD, datos insuficientes; LC, preocupación menor; NT, casi amenazado; VU, vulnerable.

				CS	
Species	Biome	Habitat	Activity	IUCN	Brazil
Cabassous tatouay	AF, Ce, Pp	Sf	N	LC	LC
Callithrix penicillata	AF, Ce, Ca	Ar	D	LC	LC
Cerdocyon thous	AF, Ce, Ca, Pt, Pp	Te	N	LC	LC
Chrysocyon brachyurus	Ce, Pt, Pp	Te	N, D	NT	VU
Coendou spinosus	AF, Ce	Ar	N	LC	LC
Conepatus amazonicus	Ce, Ca	Te	N	LC	LC
Cuniculus paca	AmF, AF, Ce, Ca, Pt, Pp	Te	N	LC	LC
Dasyprocta azarae	AF, Ce, Pt, Pp	Te	D	DD	LC
Dasypus novemcinctus	AmF, AF, Ce, Ca, Pt, Pp	Sf	N	LC	LC
Didelphis albiventris	Ce, Ca, Pt, Pp	Sc	N	LC	LC
Didelphis aurita	AF	Sc	N	LC	LC
Eira barbara	AmF, AF, Ce, Ca, Pt	Te	D	LC	LC
Euphractus sexcinctus	AmF, AF, Ce, Ca, Pt, Pp	Sf	D	LC	LC
Hydrochoerus hydrochaeris	AmF, AF, Ce, Ca, Pt, Pp	Saq	N/D	LC	LC
Kannabateomys amblyonyx	AF, Ce	Ar	N	LC	LC
Leopardus pardalis	AmF, AF, Ce, Ca, Pt, Pp	Te	N	LC	LC
Leopardus guttulus	AF, Ce	Te	N	VU	VU
Mazama gouazoubira	AF, Ce, Pt, Pp	Te	N, D	DD	LC
Myrmecophaga tridactyla	AmF, AF, Ce, Ca, Pt, Pp	Te	N	VU	VU
Nasua nasua	AmF, AF, Ce, Ca, Pt, Pp	Te	D	LC	LC
Nectomys squamipes	AF, Ce	Saq	N	LC	LC
Pecari tajacu	AmF, AF, Ce, Ca, Pt, Pp	Te	N, D	LC	LC
Philander frenatus	AF, Ce	Sc	N	LC	LC
Priodontes maximus	AmF, AF, Ce, Pt	Sf	N	VU	VU
Procyon cancrivorus	AmF, AF, Ce, Ca, Pt, Pp	Sc	N	LC	LC
Puma concolor	AmF, AF, Ce, Ca, Pt, Pp	Te	N	LC	VU
Puma yagouaroundi	AmF, AF, Ce, Ca, Pt, Pp	Te	N	LC	VU
Sapajus nigritus	AF	Ar	D	NT	NT
Sylvilagus brasiliensis	AmF, AF, Ce, Ca, Pt, Pp	Te	N	LC	LC
Tamandua tetradactyla	AmF, AF, Ce, Ca, Pt, Pp	Sc	N	LC	LC

do not usually consider that by only providing food, and without any other control measures, they may be increasing dog abundance, potentiating negative impacts over wildlife (Newsome et al., 2015). Several studies conducted in different countries have provided subsidies, management methods and/or guidelines to decision makers for the mitigation of problems caused by domestic dogs (Butler et al., 2004; Campos et al.,

2007; Hughes and Macdonald, 2013; Lessa et al., 2016; Doherty et al., 2017). Based on the Brazilian 'reality' (of a developing country and its limitations), we highlight some of the measures we believe would be most feasible to implement: (1) introduce regular removal of domestic dogs in natural areas, mainly from small forest fragments; (2) establish programs of environmental education informing local people –especially dog owners– about the direct and indirect impacts of free–ranging dogs on wildlife and ecosystems; (3) introduce the mandatory use of dog collars containing contact information with the owner (especially around priority areas for conservation), coupled with legal prohibition of abandonment; (4) carry out population control through euthanasia and/or castration of abandoned individuals in urban and rural areas; and (5) create and maintain long–term vaccination programs of domestic dogs, and when necessary, of native species.

In conclusion, in this study we have shown some of the impacts domestic dogs have on wildlife in unprotected areas in two Brazilian biodiversity hotspots. Due to a long history of human exploitation, these areas are currently small, highly fragmented, and mostly under no legal protection. Their native fauna are under constant threat from activities such as illegal logging, hunting –especially medium to large–sized mammals, and fires. The additional impact of domestic dogs can thus have severe consequences on wildlife, contributing, for example, to local extinctions. Although the growing literature has highlighted these negative impacts, management of this invasive predator can be complex, especially due to the dog's close historical relationship with humans –often referred to as "man's best friend". Interdisciplinary approaches combining both ecological and social views will be essential to overcome these problems, allowing us to safeguard wildlife from this particular threat.

Acknowledgements

We thank Dendrus Projetos Ambientais e Florestais and VertAmbiental Consultoria, Projetos e Serviços for financial support; and José Lelis Pontes and Anderson de Almeida for providing information about dog predation. J. J. M. G. and C. L. A. thank the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for their scholarship. We are also grateful to Montserrat Ferrer and three anonymous reviewers for their valuable comments on previous version of this manuscript.

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