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Landscape use and food habits of the chilla fox (*Lycalopex griseus,* Gray) and domestic dog (*Canis lupus familiaris*) in a peri-urban environment of south-central Chile

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Abstract

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Cities intensely modify natural environments and impose pressures on biodiversity. In this sense, carnivorous mammals are one of the groups most affected due to their food and space requirements. The feeding and spatial behavior of the chilla fox (*Lycalopex griseus*, G., 1837) and dogs were studied in the vicinity of a peri-urban protected area in south-central Chile. The diet of both canids was compared seasonally, for which feces were collected along trails in three habitats: native forest, exotic plantations and scrublands. Dog feces were collected at the same site to establish whether they were avoided by foxes. Chilla fox has been highlighted for consuming a high proportion of hares followed by rodents of the Muridae family, both being exotic mammals in Chile, whereas dogs showed a predominant consumption of anthropogenic food. Significant differences were observed for chilla fox in dietary diversity, mainly in summer and fall. No spatial segregation was observed with the domestic dog, which was evidenced in a high overlap in the use of all habitats. This scenario, together with continuous human presence, are elements that must be considered in the medium-term to evaluate the effects of anthropogenic pressures on native carnivores in the study area.

Keywords

biomass, canids, exotic prey, habitat, spatial overlap

Introduction

Carnivorous mammals are a group of relevance in ecosystem processes, which is evidenced mainly in the control of herbivorous species and the dispersal of plant species (Hairston et al., 1960; Rosalino et al., 2010). However, their populations are in continuous decline due to anthropogenic pressure on their natural habitats (Luck 2007), which affects their spatial requirements (Crooks, 2002). The process of habitat loss has intensified with urbanization in recent years (Zhao et al., 2006), with negative consequences for local biodiversity. Furthermore, the association of urbanized environments are associated with an increase of the probability of conflicts with local fauna (Schell et al., 2021), which limits their occurrence on their sites (Schuette et al., 2013). In addition, the presence of domestic dogs (*Canis lupus familiaris*) around these settlements may restrict the spatial distribution of carnivores, due to their close association with humans (Boitani et al., 2017). There are records that dogs exhibit generalist feeding habits in many ecosystems (Butler and Du Toit, 2002; Campos et al., 2007; Krauze-Gryz and Gryz, 2014), as well as the use of space (Torres and Prado, 2010; Krauze-Gryz and Gryz, 2014). In this way, dogs exert an interference effect on the home range on native fauna (Vanak and Gomper,

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2002; Vanak et al., 2014), affecting resource use according to their ecological requirements.

Although there is backgrounds information regarding the adaptation of carnivores to urban environments (Gese and Bekoff, 2004), this process is restricted to species whose spatial flexibility allows their establishment and success (Bateman and Fleming, 2012). This may be determined by the feasibility to subsidize carnivores with food of anthropo genic origin (Fedriani et al., 2001). However, this availability of resources could negatively affect their healthy conditions (Murray et al., 2015). Spatial dynamics of carnivores are associated to availability of local-scale resources (Walton et al., 2017), which suggests an inverse association between home range of these species and the productivity of a locality. Thus, when there is low food availability, individuals are forced to make greater movements in search of food (Šálek et al., 2015). In parallel, seasonality plays an important role in carnivores' spatial dynamics, since it modulates the occurrence of their prey over time (Borror et al., 1989; Hansson and Hentonnen, 1988). Therefore, in temperate forests, seasonal changes in prey consumption are to be expected in response to fluctuations in their availability. In this sense, peri-urban environments can be considered as habitats with low prey diversity (Fernández and Simonetti, 2013; Klimant et al., 2017), which limits the energetic requirements of carnivores (Gittleman and Harvey, 1982; Carbone and Gittleman, 2002). Thus, when considering this context, it is expected that seasonality will generate a change in carnivores in relation to the spectrum of prey consumed.

In south-central Chile, carnivores are partially associated with the native forest (Murúa, 1996), a habitat that has undergone a deep change in a significant proportion by forestry plantations and agroecosystems (Echeverría et al., 2008). One of these species is the chilla fox (*Lycalopex griseus*), a canid widely distributed throughout Chile (Del Solar and Rau, 2004). This fox, in addition to presenting great dietary flexibility (Martínez et al., 1993; Jaksic, 1997; Zúñiga et al., 2008; Muñoz-Pedreros et al., 2018), is found in many habitats throughout this country (Iriarte and jaksic, 2012). This canid has also generalist habits in the use of space (Guerrero et al., 2006; Zúñiga et al., 2009). However, there is an information gap about the space use of this species in urbanized environments (Silva-Rodríguez et al., 2020), as well as its seasonal variations.

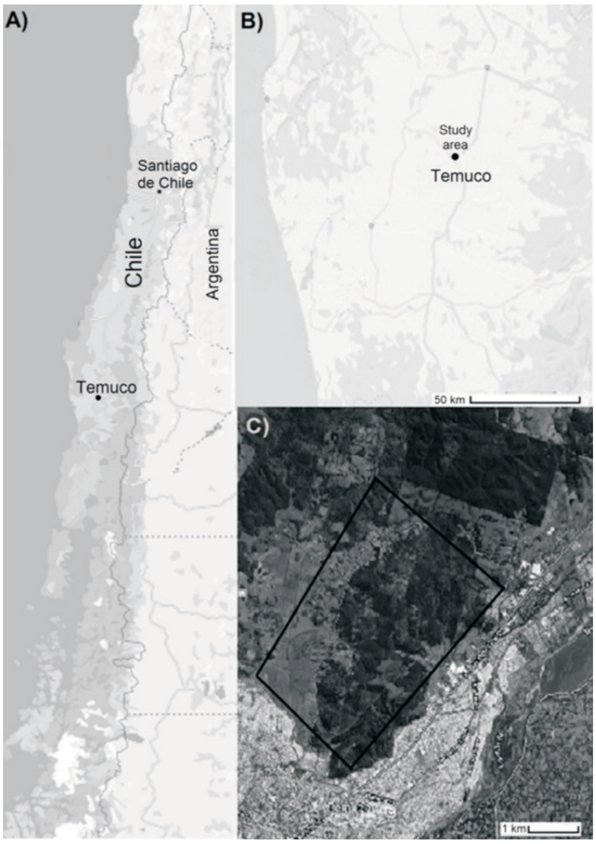

Fig. 1. Study area. A) General plane; B) Regional scale; C) Local scale. Lines indicate the area where the sampling was carried out. Source: Google Earth.

The objective of this study is to compare the seasonal diet and use of space between chilla fox and domestic dogs in a peri-urban environment of south-central Chile. Through the collection of feces, the diet of this canid and its spatial distribution through the available habitats was assessed. This was compared with recordings of domestic dog, an exotic carnivore widely distributed in this site. The seasonal differentiation of its trophic diversity is tested, as well its variation in the use of space in habitats through the seasons of the year. In addition, the hypothesis about spatial segregation between the chilla fox and domestic dog was tested, which would be reflected both in the type of food consume, as well in habitat use.

Materials and methods

Study area

Cerro Ñielol Natural Monument (38º43'S-72º35'W) is a 88 ha protected area in south-central Chile, which is adjacent to the city of Temuco (Fig. 1). It has an average altitude of 200 m asl, being a part of the Huimpil-Ñielol mountain range, with a perhumid Mediterranean-type climate (Di Castri and Hajek, 1976). The landscape is characterized by a deciduous forest, mainly represented by the roble-laurel-lingue formation (*Nothofago-Perseetum*; Oberdorfer, 1960). Three habitat types dominate the area: native forest; forest plantations of *Pinus radiata*; and scrubland, all included for the current data collection.

Sample collection and laboratory analysis

From December 2019 until December 2020, the trails of the protected area and its surroundings were traveled biweekly in search of feces from chilla foxes (the only fox observed in the study area) and dogs. This period included the following seasons: summer (December–March), fall (March–June), winter (June–August), and spring (September–December). A line of trails with a length of 4 km was considered, covering an area of 200 hectares. Chilla fox feces were recognized by morphological criteria (Chame et al., 2003; Muñoz-Pedreros, 2010), which allowed to establish a differentiation with respect to the puma (*Puma concolor)*, the other locally detected carnivore, and domestic dog, whose feces' size and color are clearly distinguishable (these latter are larger and darker). Another criterion used was the permanent sighting of the species in the study area (Zúñiga et al., 2008). Samples were placed in paper bags, labeled and stored for later analysis.

In the laboratory, feces of both carnivores were dried at 60 °C and then manually separated to obtain the remains of indigestible prey, such as mammalian hair and bones, as well as bird feathers and bones and arthropod elytra. These remains were identified based on keys (Day, 1966; Chehebar and Martin, 1989; Pearson, 1995), counting them according to their observed proportion with respected to the total obtained (Rau, 2009).

Analysis with ecological indexes and statistical tests

The observed diet of both species was quantified using a trophic diversity index (β; Levins 1968), which consists in: $\beta = 1/\Sigma(p_i)^2$, where p_i is the occurrence of the prey i in the diet of the species. This index allows determining the use of resources based on the total of items recorded. Standard deviation of this index was estimated using the Jackknife method (Jaksic and Medel, 1987). In parallel, standardized niche width was calculated (Bsta; Colwell and Futuyma, 1971), which consists in Bsta = (Bobs-Bmin)/(Bmax-Bmin), where Bobs is the observed niche breadth, Bmin is the minimum possible niche breadth (1), and Bmax is the maximum possible niche breadth. This index facilitates the contrast between seasons due to differences in food items through these periods. To compare prey diversity across seasons, Hutchenson procedure was used (Hutcheson, 1970), which is analogous to a T-test. To avoid the incidence of type-I errors as a consequence of multiple comparisons, Bonferroni correction was performed (Holm, 1979). The proportion in the consumption of each item was compared across seasons to determine if there were variations among these periods, for which the arithmetic mean of the frequencies obtained for each case was considered as the expected value (Zúñiga et al., 2021).

The biomass calculation of the prey consumed by chilla fox was carried out through geometric mean (Jaksic and Braker, 1983), an indicator that was estimated for the four sampling seasons. In parallel, the trophic isocline method was used (Kruuk and De Koch, 1980, adapted by Rau, 2009), which allows determining the importance of each prey in the trophic spectrum of the predator. This analysis was performed for the total of prey obtained in the whole sampling period. Estimation of prey biomass was based on the weight measurements reported by Amaya et al. (1979), Muñoz-Pedreros and Yáñez (2009), and Norambuena and Riquelme (2014).

Collected feces were also used to evaluate habitat use, which was carried out by comparing frequencies of recordings in each of the habitats sampled. The proportion of habitats was obtained through the GIS treatment of digital images using ArcView 3.2 software and its Spatial Analyst 2.0 extension. Thus, the sampled area corresponded to 53% scrubland, 19% plantations, and 28% native forest. To determine if the frequency of recordings observed in the habitats differed from that which would be expected by chance, a chi-square (χ^2) goodness-of-fit test was used (Sokal and Rohlf, 1995). In cases where comparisons were significant, Bonferroni confidence intervals were estimated (Byers et al., 1984), to determine the type of habitat selection exerted by these canids (negative, neutral or positive). Seasonal variations in habitat use were determined by Kruskal-Wallis analyses tests (Sokal and Rohlf, 1995),

Feces of both canids (chilla fox and domestic dog) were counted alongside 100 m sections (n = 40) of the trails traveled. The associations between the recordings of species were established through Pearson's correlations (Sokal and Rohlf, 1995; Neale and Sacks, 2001), which assumes the correlation coefficient would allow determining the type of spatial

Table 1. Dietary composition of chilla fox in the study area, through the sampled seasons. Numbers in rows indicates the observed abundance of prey consumed and their percentage

Prey	Summer	Fall	Winter	Spring
Mammals				
Rodents, Cricetidae				
Abrothrix longipilis	1 (2.63)	3 (15)	6 (17.64)	2 (7.14)
Abrothrix olivaceus	1 (2.63)	–	–	–
Oligoryzomys longicaudatus	–	–	2 (5.88)	–
Rodents, Muridae				
Rattus norvegicus	–		7 (20.58)	2 (7.14)
Rattus rattus	4 (13.33)	–	12 (35.29)	7 (25)
Rodents, Echymidae				
Myocastor coypus	1 (2.63)	–	–	1 (3.57)
Lagomorpha				
Lepus europaeus	3 (10)	7 (35)	4(11.76)	1 (3.57)
Birds				
Unidentified birds	5 (13.15)	6 (30)	2 (5.88)	2 (7.14)
Reptiles				
Liolaemus sp.	–	1 (5)	–	–
Arthropoda				
Unidentified insects	14 (36.84)	–	–	11 (39.28)
Vegetables				
Vegetal tissues	4 (10.52)	3 (15)	1 (2.94)	2 (7.14)
Seeds	5 (13.15)	–	–	–
Garbage	1	–	1	–
Total scats	10	11	16	11
Dietary breadth (β)	4.97 + 3.22	3.84 + 1.39	4.55 + 2.02	4.17 + 2.64
Standardized niche (Bsta)	0.49	0.71	0.59	0.45

association of both species based on the frequency of their respective recordings. Data were normalized through logarithm of recordings (X + 1; Neale and Sacks, 2001).

Frequencies of recordings of both species were compared at the habitat level, where the overlap was estimated using the Pianka's index (Pianka, 1973), and the significance of the comparisons was obtained by the procedure already indicated by Hutcheson (Hutcheson, 1970).

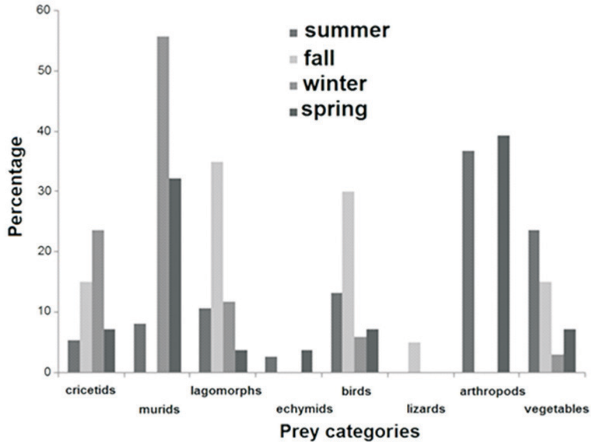

Fig. 2. Frequency of prey consumption by *Lycalopex griseus* in the study area through the sampled seasons.

Results

A total of 140 feces (48 from chilla fox and 92 from dogs) were collected, with small variations in diet composition between seasons (Table 1). However, there were not significant differences in both canids in these periods (Kruskal-Wallis test, H = 0.628, p = 0.882; 6.432, p = 0.075; for chilla fox and domestic dog, respectively; d.f. in all cases: 3). In dietary terms, the trophic spectrum of chilla fox was composed by seven prey categories (cricetids, murids, lagomorphs, echymids, birds, reptiles and arthropods), highlighting the consumption of the first two seasons, followed by lagomorphs (hares), birds and arthropods (Fig. 2). Additionally, garbage fragments were found in two ocassions (plastic waste), which were not incorporated into dietary analyses because these do not constitute part of a food resource.

The highest prey diversity (β) of chilla fox was observed in summer, followed by winter. Significant differences were observed when summer was compared with fall (T = 3.98, p = 0.0003), fall with winter (T = 3.19, p = 0.0027), and summer with spring (T = 6.06, p < 0.0001). In terms of frequency of consumption of each prey type, significant differences were observed throughout these periods in all cases (Chi-square test, p < 0.0001), except for European hare, *Lepus europaeus* (p = 0.0591). On the other hand, dog diet had a high proportion of food from anthropogenic sources, such as commercial dog food (>90%), with a minimal proportion of rodents (Muridae), which allowed to establish a clear dietary differentiation with respect to chilla fox, without having to carry out subsequent analyses.

In relation to the representation of biomass, the geometric means obtained were 17.92, 255.72, 131.94 and 18.88 grams for summer, fall, winter and spring, respectively. In terms of importance, it was observed that lagomorphs occupied the upper intermediate isocline (between 20% and 50%; Fig. 3), while murids occupied the isocline that is between 1% and 5%. Cricetids, birds and arthropods were placed in the lowest isocline, less than 1%. Reptiles, due to their low representation both in terms of frequency and biomass, were not included in the analysis. Due to the characteristics of dog food (see previous paragraph), it was impossible to quantify the biomass to perform the same analysis.

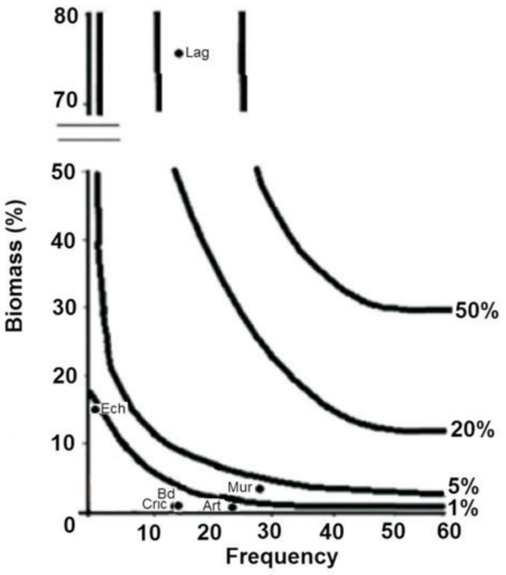

Fig. 3. Trophic isoclines for prey consumed by *Lycalopex griseus* in the study area. Art, Arthropods; Bd, Birds; Cric, Cricetids; Ech, Echymids; Lag, Lagomorphs; Mur, Murids.

Regarding to spatial habits, a seasonal variation in the proportion of use was observed for each species, with a predominance of scrublands and native forest (Fig. 4). Significant differences were observed for chilla fox in winter (χ^2 = 11.10, p = 0.0039, d.f.: 2) and dogs in spring (χ^2 = 116.93, p < 0.0001). In both cases, nevertheless, selectivity was not observed for any type of habitat, according to Bonferroni confidence intervals (Table 2). In addition, no changes were observed in the frequencies of use across seasons in scrublands (H = 3.41, p = 0.2124), plantations (H = 2.46, p = 0.4022), and forest (H = 3.21, p = 0.2835). In relation to overlap in the habitat use by chilla foxes and dogs, highest and significant values were obtained in summer and spring (S = 0.95; T =

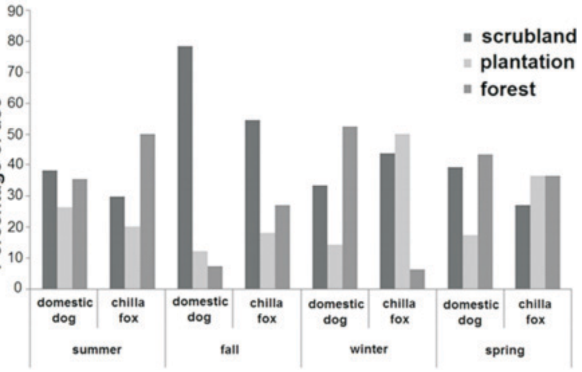

Fig. 4. Proportion of habitat use by chilla fox and domestic dog in the study area through sampled seasons.

Table 2. Frecuency of habitat use of chilla fox and domestic dog according to Bonferroni's confidence intervals. These comparisons were performed in the seasons (winter for chilla fox, spring for domestic dog) where a different pattern of chance was observed, according to goodness-of-fit tests.

Species	Habitat	Intervals of confidence	p-value
Chilla fox	Scrubland	0.141–0.734 (=)	0.520
	Plantation	0.201–0.799 (=)	0.190
	Forest	0–0.207 (=)	0.280
Domestic dog	Scrubland	0.148–0.635 (=)	0.520
	Plantation	0–0.363 (=)	0.190
	Forest	0.187–0.682 (=)	0.200

6.36, $p < 0.0001$; S = 0.92, T = 3.71, p = 0.001, respectively). No significant differences were observed in the rest of seasons (S = 0.92; T = 1.42, p = 0.1685, S = 0.58, T = 1.19, p = 0.2423 for fall and winter, respectively). Moreover, no associations were found in the frequency of recordings in the trails through the seasons (r = –0.083, p = 0.731; r = –0.208, p = 0.378, for summer, fall, winter and spring, respectively).

Discussion

The trophic diversity observed of the chilla fox differs from that reported in forests at the same latitude (Martínez et al., 1993; Zúñiga et al., 2008), which suggests a change in the local composition of prey in the study area. Previous reports indicate that the diet of this canid is based on small mammals, mainly native rodents, in habitats of high vegetation cover (Simonetti, 1989). However, this habitat type was not well represented in our study area. The low cover of arboreal vegetation in the vicinity of the protected area, could result in the absence of native rodents and a predominance of lagomorphs (hares), a fact that has been reported in Mediterranean environments of Central Chile (Fernández and Simonetti, 2013). The high proportion of lagomorphs (hares) in the trophic spectrum of the chilla fox is also noteworthy, considering its condition as an exotic and invasive species in the study area (Jaksic et al., 2002), which suggests a modification of their trophic preferences. On the other hand, the consumption of garbage is similar to that reported in peri-urban environments in the Northern Hemisphere (Jankowiak et al., 2016), which suggests a progressive incorporation of anthropogenic food in the trophic spectrum of this canid.

The differences observed in the dietary diversity of chilla fox among sampled seasons would be explained mainly by the reproductive characteristics of the prey, which would modulate its abundance throughout these periods (Hanski et al., 2001). In the case of fall and winter, a high frequency of consumption of native rodents was observed, which is consistent with that reported in forests of southern Chile, where the abundance of these mammals reaches its peak (González and Murúa, 1983). In contrast, there are reports that murids have irregular reproductive periods throughout the year (King et al., 1996), which is consistent with the highest capture rate observed in winter and spring by foxes. In the case of hares, there are reports in the Northern hemisphere of a marked seasonality in their reproductive patterns, which occurs mainly in winter (Banfield, 1974). This fact is consistent with the results obtained in the study area where, together with fall, the highest relative frequencies of consumption were observed. On the other hand, the seasonal pattern in the consumption of echymids (*Myocastor coypus*) must be observed with caution, due to the similarities on size between this rodent and chilla fox (Muñoz-Pedreros and Yáñez, 2009). Indeed, scavenging is likely due to bigger carnivores in the study area, and predation of *M. coypus* by chilla fox is still to be confirmed. This fact is due to the presence of puma in the study area, which has showed reports of consumption of *M. coypus* (Zúñiga and Muñoz-Pedreros, 2014). In consideration of this, it is important to quantify the population changes of prey used by the chilla fox in the study area across seasons, which would allow determining the degree of selectivity that this canid exerts on them according to the temporal variations (Jaksic, 1989).

Regarding the effect of prey biomass on the trophic spectrum of chilla fox, it was observed that hares were located in the upper position of the isoclines. This shows the importance that this item occupied in dietary terms. This finding is consistent with what was observed in agroecosystems (Zúñiga et al., 2018; Zúñiga et al., 2021), which suggests that this prey is acquiring more relevance as the environment is transforming (Simonetti, 1986). The incorporation of murids in the intermediate position of the isoclines is consistent with the aforementioned study of agroecosystems, which indicating that this group also presents importance in the diet of chilla fox, with a decrease of native prey (Novaro et al., 2000). On the other hand, the geometric mean values of prey in general terms are lower than those reported in agroecosystems (Zúñiga et al., 2021), which suggests a low availability of prey in peri-urban habitats, with limitations to obtain their energetic requirements (Silva et al., 2005).

The absence of an association between the abundance of dog and fox feces of dogs was surprising, due to the documented negative impact of dogs on the use of space by chilla fox (Silva-Rodrígeuz et al., 2010a). Considering the great flexibility in habitat use that dogs can perform through the landscape (Meek, 1999; Paschoal et al., 2018), this finding should be taken with caution. This can be explained by two reasons. First that the use of feces alone would not account for the interaction of chilla foxes with domestic dogs. In this way, its use combined with other types of signs, such as tracks, could reinforce the use of space by species in the study area (Barea-Azcón et al., 2007). On the other hand, it is proposed that a similarity in the use of habitat by both species would be compensated by a reduction in the overlap of their activity patterns, a situation that has been observed with urban parks in the Northern Hemisphere (Mella-Méndez et al., 2019). This mechanism would limit the likelihood of interference among species, which however must be tested to determine if it is applicable in the study area. A critical issue in this study is related with the low number of feces, which were lower than those observed in forested environments, despite their sampling efforts being similar (Zúñiga et al., 2008). This means that the effect the urban mosaic would affect the availability of preys, and therefore their spatial patterns. In a similar way, recordings of chilla foxes in agroecosystems were low in all seasons sampled (Zúñiga et al., 2021), which was explained by the homogenization of resources present in this environment (Benton et al., 2003).

The seasonal variations in the habitat use by foxes (Gołdyn et al., 2003; Zúñiga et al., 2009), could be explained by the temporary fluctuations in the availability of prey (Randa et al., 2009; Walton et al., 2017). In this way, the use of scrubland by chilla fox could be associated with the greater abundance of European hares. Hares are mainly found in this habitat, with a lesser occurrence in plantations, and in a minimal proportion in native forest (A.H. Zúñiga, personal observation). As such, under a scenario of reduction of prey availability (mainly in spring and summer), would imply the need for a great effort of displacement for obtain food, with the subsequent increase in interaction with humans (Silva-Rodíguez et al., 2010b).

An additional aspect that would partially explain the spatial pattern of chilla foxes in the study area is related to the frequent presence of humans, mainly due to recreational and sports activities. This fact was reported as one of the most important factors that affects the occurrence of carnivores, with evasive behaviors in spatio-temporal terms (Moreira et al., 2015; Baker and Liberg, 2018). Additionally, human visitors often bring their dogs to the study area, which would cause an additional effect on the avoidance effects on chilla foxes. Despite the fact that the COVID-19 pandemic has restricted human mobility, with likely positive effects on wildlife (Silva-Rodíguez et al., 2020), disturbance by people had been continuous in the study area, regardless of movement regulations. This fact would result in a pressure on wildlife of different degree compared to the period prior to the pandemic, which only be appreciable according to changes observed through long-term records.

In conclusion, a predominance of exotic prey was observed in general terms in the trophic spectrum of the chilla fox, which could be associated with seasonal variations of the population size of the preys. Although avoidance behavior of this wild canid in relation to the domestic dog was not observed, the continuous presence of the latter indicates that the observed pattern should be reinforced with complementary records. Systematic monitoring is necessary to indicate changes in the fox population as response to anthropic pressures (human and dog presence) over time.

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