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RESEARCH

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Density, abundance, and activity of the chilla or grey fox (*Lycalopex griseus*) in Isla Grande de Tierra del Fuego, Chile

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Abstract

Background The chilla or grey fox (*Lycalopex griseus*) is a native species from continental Chile and neighboring areas of Argentina. It was introduced to Isla Grande de Tierra del Fuego in 1951 and began to increase its abundance, to the chagrin of local sheep ranchers. Since 1998, its hunting has been authorized. Here we update information on the density, abundance, and activity of this fox in the Chilean sector of Tierra del Fuego Island, to evaluate its population trend since the last census conducted by the Servicio Agrícola y Ganadero (SAG) in 2007.

Methods and results We carried out two fox censuses on a 941-km transect on public roads, divided into eight routes, from October to November (spring) of 2021 and 2022, following the same design used by SAG for the fox assessments carried out from 1999 to 2007. We report a reduction of > 50% in the density and abundance of chilla foxes with respect to the 2007 estimate, which could be attributed to the interference by free-ranging dogs (*Canis lupus familiaris*), through restricting the use of space by the fox, while transmitting diseases and parasites, and to human hunting pressure and vehicle collisions.

Discussion The chilla fox decline highlights the need for an in-depth study to determine the ecological and socio-economic impact of this exotic species on the ecosystems of Tierra del Fuego Island and the desirability of its management, if needed.

Keywords Diseases, Dog interference, Hunting, Parasites, Population census, Road survey, Road kills

Background

The chilla or grey fox (*Lycalopex griseus*) is a canid distributed all along Chile [1, 2]. It is capable of inhabiting contrasting environments ranging from the hot and dry Atacama Desert to the cold and rainy forests of the Magallanes Region, often in coastal sectors, showing a preference for open areas of shrubland and steppe [1, 2]. Despite this broad habitat use, the probability of occurrence of its populations tends to decrease in sectors close to urban and suburban areas, and/or in the presence of dogs (*Canis lupus familiaris*) [3, 4]. Its conservation category according to the IUCN is Least Concern (LC) since 2008 [1, 2].

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The chilla fox diet varies according to differences in the environmental availability of its prey. Throughout Chile it consumes rodents, birds, lizards, insects, and fruits --components that are present in its diet throughout the year--, with exotic rabbits being preyed on less frequently [1, 2], and with scavenging habits in some localities of Chile [5]. It is considered a meso-predator able to survive in areas with intermediate degrees of anthropization, such as suburban areas [6]. Regarding its diel activity, data obtained in Torres del Paine National Park (Magallanes Region, Chile) showed that this fox is active both during the day and night and that its mean density reaches 3.3 individuals/km^2 in open habitats but decreases to 1.3/km^2 when extrapolating to the whole Park [1]. In Chilean Tierra del Fuego Island, where it is exotic, a maximum density of 2.36 individuals/km^2 has been estimated [7] but no information exists on its diel activity.

Fourteen individuals of chilla fox were introduced to the Onaisín sector of Chilean Tierra del Fuego in 1951 [8, 9], with the aim of biologically controlling an outbreak of European rabbits (*Oryctolagus cuniculus*), introduced several years earlier to the island [8, 10], and whose abundance was estimated at 30 million rabbits at the date of the introduction of the chilla fox [8, 10]. Such biological control was ineffective, and it is now known that the decline in rabbit abundance was due to the effects of the introduction of the Myxoma virus, leading to their near eradication from Tierra del Fuego Island [8, 10]. Since its introduction to date, the population of chilla fox increased considerably [7, 9]. An excerpt from Exempt Resolution No. 1233 of the Servicio Agrícola y Ganadero (SAG, Chile) [11] stated that such fox numbers had boomed, according to population censuses carried out by SAG since 1992. In parallel with that increase, a decline in the abundance of native avifauna on the island had been observed --especially that of the Ruddy-headed Goose (*Chloephaga rubidiceps*)--, together with an increase in predation on domestic sheep (*Ovis aries*) [7, 11]. Thus, SAG's Resolution No. 1981 of 1998 [11] authorized hunting of chilla fox with a quota of 10 specimens per hunter per day from May 1 to July 31 of every year (winter season).

Few studies have been conducted on the effects of the chilla fox invasion to Tierra del Fuego Island, and even less on the effects on local biodiversity or its socio-ecological implications [1, 2]. The conflicts of interest and factors that affect hunting pressure on this fox militate against its comprehensive management, if needed. Such practice should be based on the results of population analyses, considering the different economic and social sectors involved [12]. The last time SAG conducted a census of the chilla fox on the island was in 2007 [7], and basic population information is still missing. Therefore, the purpose of this research was to estimate the density, abundance, and diel activity of *Lycalopex griseus* on the Chilean side of Tierra del Fuego Island.

Methods

Study area

Tierra del Fuego Island is shared by Chile and Argentina, with 29,484 km^2 corresponding to Chilean territory, called Province of Tierra del Fuego in the Region of Magallanes and Antártica Chilena, whose capital is Porvenir city. According to Köppen's climate classification, its climate is subpolar oceanic, with short, cool summers and long, cold winters, as well as strong winds and fog most of the year [13]. The northern and central parts of the island are rather flat steppes dominated by the bunchgrass *Festuca gracillima* and the dwarf shrub *Chiliotrichum difussum*, while the southern parts are more rugged forests of Coihue-Canelo *(Nothofagus betuloides-Drymis winteri)*, Coihue-Lenga *(N. betuloides-N. pumilio*), Lenga (*N. pumilio-Maytenus disticha*), or Ñirre (*N. antarctica-Chiliotrichum difussum*) [13].

Field work

The sampling area corresponded to the Tierra del Fuego Province, Magallanes and Antártica Chilena Region. Due to the extension of the territory, the sampling area was limited to 16,017 km^2 (54% of the total). To the north and west the limit was the Strait of Magellan, to the east the border with Argentina, and to the south the Almirantazgo Sound. Linear transects were carried out using public roads, which were divided into eight routes. The work was carried out from October to November (spring) of both 2021 and 2022 (Fig. 1), following the same design used by SAG for the population assessments carried out between 1999 and 2007, standardizing the method used, the season of the year, and the observation schedules [7].

The routes were traveled in a 4×4 vehicle, at a constant speed of 20 km/h from 19:00 h (before twilight) to 00:00 h, divided into five hourly ranges (Range 1 = 19:00 to 20:00, range 2 = 20:00 to 21:00, range 3 = 21:00 to 22:00, range 4 = 22:00 to 23:00, and range 5 = 23:00 to 00:00.), until completion of a given route. To count foxes, one observer was disposed on each side of the vehicle, equipped with a 1200 w LED spotlight (with a range of > 100 m, brand OSMAO, origin: China) and a record sheet. Upon the sighting of foxes, the number of individuals and the perpendicular distance to the vehicle were recorded. Fifty m was considered as the maximum observation distance for each observer (i.e., the transects where 100 m wide). A laser distance meter was used to measure the perpendicular distance of each individual observed. The records were taken by the same two observers, and

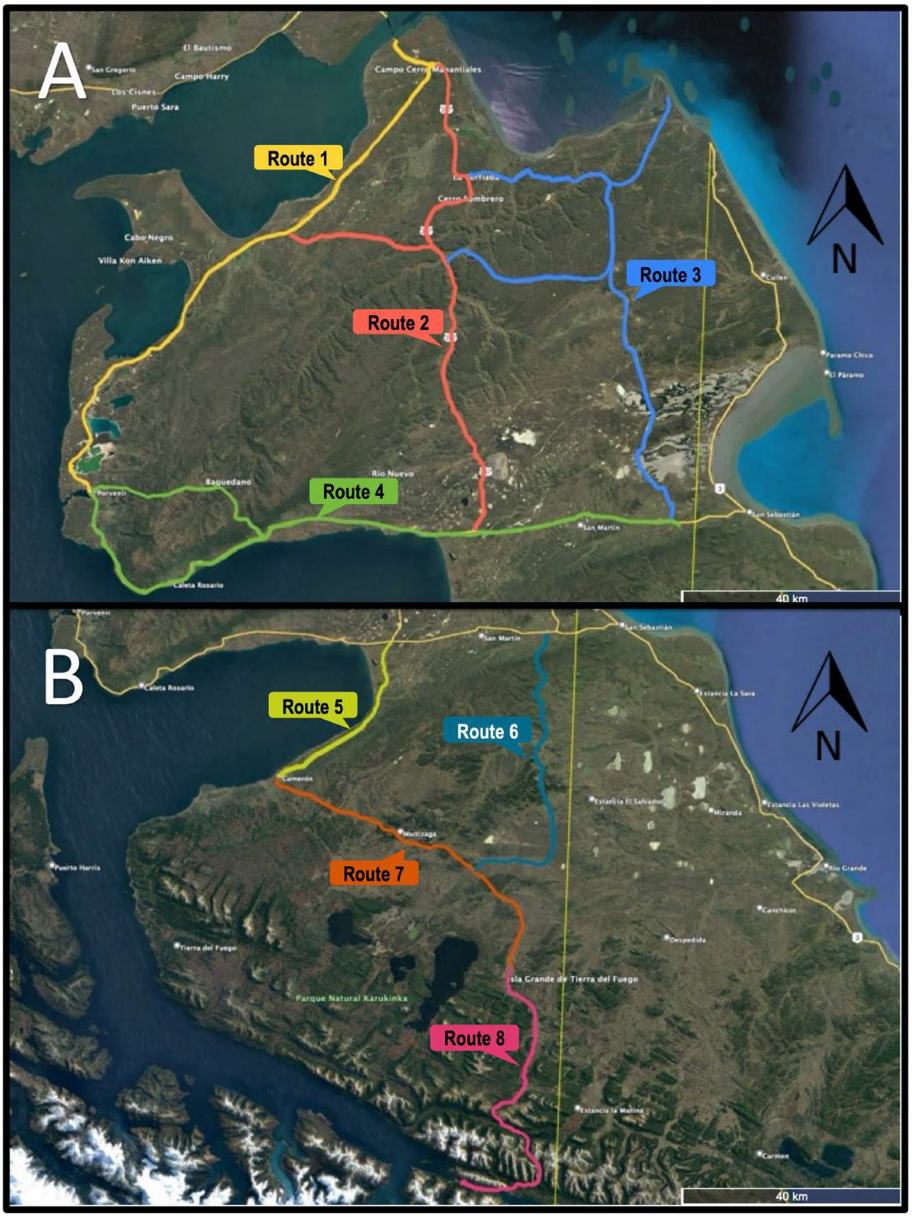

Fig. 1 Satellite image of north, central (**A**) and southern (**B**) Tierra del Fuego Island, showing the eight northerly sampling routes. Notice the straight yellow line demarcating the border with Argentina

the estimates of the perpendicular distance of the sightings were standardized.

Population parameters

The DISTANCE program [14] was used to calculate population density and abundance based on the use of line transects. For this purpose, the lowest value of the Akaike's function, the lowest coefficient of variation, and the lowest number of parameters (length of the transect, observation distance, number of observations, and area covered) were used. The maximum observation range used was 50 m per side of the transect, so that all observations were at a high probability of detection, providing strong reliability. The observations at greater distance, beyond 50 m, were with lower values of detection probability (below 0.7) and were thus excluded from the present work. The DISTANCE output is a set of estimates: density, upper and lower confidence limits, and coefficient of variation (%). Distance models have four assumptions, which must be met to have reliable

density and abundance estimates: (a) Animals are distributed independently of line transects (randomly). (b) All animals on or near the transect are always detected. (c) Measurements are accurate. (d) Animals are detected at their initial location [15]. The calculation of Berryman's R-function, which relates the growth rate and the size of a population at a specific time, was included [16].

The probability of detection was high for all the distance ranges at which chilla fox individuals were observed. All distance ranges had a value greater than 0.7 probability of detection, so the reliability of the data was high. The effective bandwidth is the distance at which the area above the curve (number of animals not detected within the effective bandwidth), equals the area below the curve (number of animals detected beyond the effective bandwidth) [17]. In this case, all distance ranges were included in the effective bandwidth (Fig. 2).

Diel activity

This was measured considering the records of the hours at which chilla foxes were observed. Observations were recorded from 19:00 to 00:00 h, separated into the five hourly ranges described above. The ranges of hours of greatest diel activity were compared with the ranges of least activity, expressing the results as a percentage.

Results

A total of 941 km was sampled twice (2021 and 2022) along the eight routes travelled. Considering that each transect was 100 m wide, we estimated a sampled area of 94.1 km^2 over which 138 individuals of chilla fox were recorded in 2021 and 77 in 2022 (Table 1).

For an effective sampling area of 16,017 km^2 in Chilean Tierra del Fuego Island, we estimated a density of 1.55 chilla foxes per km^2, which translates into a total

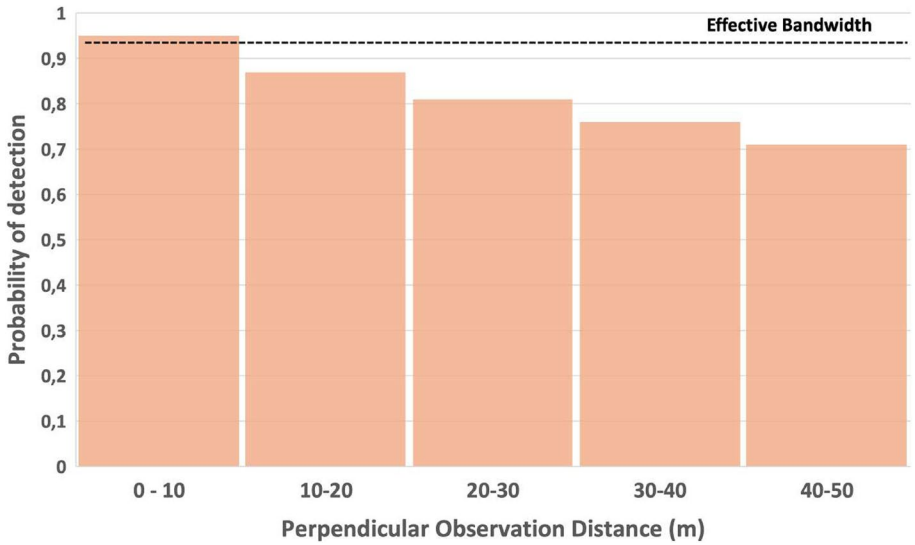

Fig. 2 Probability of detection of *Lycalopex griseus* individuals in relation to the perpendicular distance of observation

Table 1 Length of each route sampled, area surveyed per route, and number of *Lycalopex griseus* observed during the 2021 and 2022 population surveys on the Chilean side of Tierra del Fuego Island

Route N°	Length (km)	Area (km^2)	N° Individuals 2021	N° Individuals 2022
1	130	13.0	24	12
2	134	13.4	18	13
3	172	17.2	27	12
4	183	18.3	19	9
5	48	4.8	11	16
6	87	8.7	15	5
7	86	8.6	16	10
8	101	10.1	8	0
Total	941 km	94.1 km^2	138 individuals	77 individuals

population of 21,630 foxes for the year 2021 (Table 2). This result is 34.3% below the population density and with 37.9% fewer individuals in comparison to the population census last carried out in 2007 by SAG. Similarly, for 2022, we estimated a chilla fox density of 0.9/km^2 with an abundance of 13,298 individuals, which corresponded to a further population decrease of 58.1% and 61.5%, respectively, as compared to our 2021 census (Table 2).

The chilla fox population studied in Tierra del Fuego Island had mainly crepuscular activity, with a peak between 22:00 and 23:00 h (Fig. 3). It is worth mentioning that during the date of sampling, sunset occurred at 21:58 h, unlike the rest of the Chilean territory, where sunset is 1 h earlier (because of the different time zones involved). Therefore, we considered the range 21:00 to 23:00 h as crepuscular. A total of 64.5% of the recorded activity of chilla foxes was concentrated during that twilight period. It is important to note that the coefficients of variation (CV) were below 20%, which ensures the precision of the estimates.

The censuses carried out by SAG from 1999 to 2007 covered only the northern and central areas of Chilean Tierra del Fuego Island, excluding its southern part [7], thus they correspond only to our routes 1 through 4 (Fig. 1). Therefore, to compare our 2021 and 2022 results to the SAG's earlier ones, we recalculated our census data by excluding routes 5 through 8 (Fig. 1). It is then possible to observe that from 1999 to 2005 there was a trend towards negative fox growth rates, followed by a sudden increase in 2006 and 2007, an again by a marked decrease from 2021 to 2022. Overall, the density and abundance of chilla fox on the Chilean side of the island has generally decreased during the last 22 years (1999–2022) (Table 3).

Discussion

Coinciding with the previous work of SAG [7], our transects with the highest density and abundance of chilla fox were those near Onaisín, the same sector where 14 foxes were released in 1951 [8]. This suggests that the area has remained a site of fox settlement and a source of propagules for the rest of the island [9]. The transects examined showed different fox densities, but there was a tendency for the highest figures to be found along the routes in the northern and central sectors of the island, especially routes 1 (connecting Primera Angostura to Porvenir city) and 4 (Porvenir to Onaisín, including the

Table 2 Population estimates (density and abundance) of *Lycalopex griseus* obtained during the 2021 and 2022 surveys on the Chilean side of Tierra del Fuego Island from the eight sampling routes stretching 941 km. *Density* individuals/km^2, *Lcl* lower confidence limit, *Ucl* upper confidence limit, *CV* coefficient of variation as percentage, *Abundance* total fox population in the sampling area (94.1 km^2)

Year	Density	Lcl	Ucl	CV%	Abundance	Lcl	Ucl
2021	1.55	0.69	2.17	12	21,630	14,770	36,117
2022	0.90	0.67	1.78	17	13,298	7,877	21,378

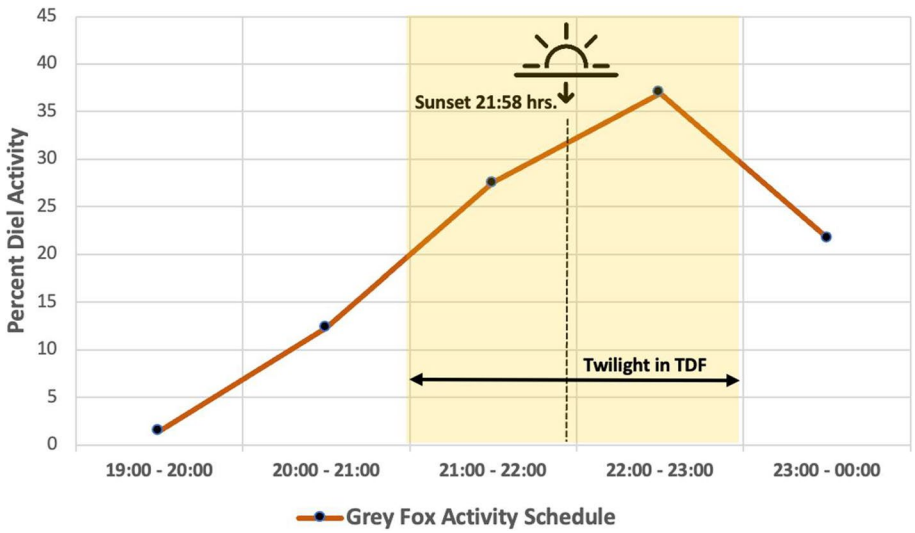

Fig. 3 Percentage of diel activity of *Lycalopex griseus* observed during our 2021 and 2022 surveys (combined) on the Chilean side of Tierra del Fuego Island

Table 3 Consolidated population censuses of *Lycalopex griseus* observed during 1999–2022 surveys (SAG and ours combined) along routes 1 through 4 (Fig. 1) on the Chilean side of Tierra del Fuego Island. In the last column we added Berryman's R function, which relates the growth rate and the size of a population at any given time

Year	Density (ind/km^2)	Abundance (N° ind)	R function
1999	1.44	21,281	0
2000	1.75	25,872	0.195
2002	1.24	18,343	-0.344
2003	0.86	12,688	-0.369
2004	0.79	11,671	-0.084
2005	0.53	7,879	-0.393
2006	2.25	33,185	1.438
2007	2.36	34,863	0.049
2021	1.01	13,188	-0.972
2022	0.67	6,894	-0.649

gold route through Cordón Baquedano) (Fig. 1). On the contrary, towards the south of the island --especially along route 7 that connects Cameron town with Pampa Guanaco and route 8 that goes from Pampa Guanaco to Caleta María cove (i.e., entering Karukinka Natural Park)--, are the routes with the lowest fox figures. These results could be explained by the preference of the chilla fox for open areas of scrub and steppe, which predominate in the northern and central sectors of the island and not in the south, where the landscape gradually transforms into dense forests of *Nothofagus* spp. [9, 14].

A salient aspect to consider is the decrease in both density and abundance of chilla foxes by more than 50% between the population census conducted by SAG in 2007 and our results in 2021–2022. Several hypotheses may be entertained to explain this decrease. The first is related to the presence of free-living dogs (wrongly called feral dogs and the result of irresponsible ownership), which have apparently increased over the last 20 years on the island. Although there are no dog population census data, through a registry of carnivore attacks on livestock, by 2001 ranchers attributed to free-living dogs the main mortality factor [12], displacing chilla foxes to second place. In southern Chile it has been shown that chilla foxes have lower occurrence in areas where dogs are present; for instance, near urban and suburban areas [3]. There, free-living dogs apparently chase off and/or kill foxes, generating a constant harassment. Competition for resources between both species has not been demonstrated, but dogs seem to restrict habitat use by foxes [3, 4]. In addition, there is the transmission of parasites and diseases from free-living dogs to foxes. Such is the case of the transmission of Distemper, Echinococcosis, Parvovirus, Scabies, and other ectoparasites and endoparasites [18], which could be affecting fox survivorship [19–21].

Another factor that could be explaining the decline in chilla fox density and abundance may be hunting pressure and constant vehicular collisions. Since 1998 the hunting of chilla fox has been authorized by SAG, because it is an exotic animal on the island [11]. This authorization was putatively for the purpose of exporting fox skins, and it specified that the only hunting method permitted was by 0.22 caliber rifle, and that no traps or snares may be used, nor any other method prohibited by the regulations of Chile's Hunting Law [11]. This SAG Resolution was originally based on the claims that the chilla fox population had experienced a marked increase on the island. But considering our study, this diagnosis is no longer valid because a significant population decrease has been detected. Secondly, another ground for the SAG Resolution was that the chilla fox population had caused marked mortality on sheep, a situation that was serious during the lambing season [11]. But considering SAG's own technical reports, the main cause of sheep mortality has been attacks by free-living dogs [12]; new reports and updated studies are urgently needed. Thirdly, the same SAG Resolution raised the issue that the chilla fox increase had resulted in a decrease of the native avifauna. But there is no such evidence in technical reports or scientific literature. Only speculatively, it has been suggested that the historical decline of the Ruddy-headed Goose (*Chloephaga rubidiceps*) could be attributed to predation by foxes [22]. Finally, in relation to vehicular collisions, in the last 15 years there has been an increase in the paved roads connecting different points of the island, a situation that has exposed chilla foxes (and other species) to becoming more frequent road kills, especially on the international roads connecting the Chilean and Argentinian sides of the island. But up to now, this phenomenon has yet to be quantified.

In conclusion, the chilla or grey fox (*Lycalopex griseus*) population on the Chilean side Tierra del Fuego Island has considerably diminished since 2007. It is therefore necessary to study the ecological effects of this species on the island's food webs and ecosystems [9] and to conduct a socioeconomic valuation of its impact [23]. This would help to re-evaluate the criteria set in 1998 that authorized the hunting of this fox species [11].

Abbreviation

SAG Servicio Agrícola Ganadero [Agriculture and Livestock Service], Chile

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Author contributions
Conceptualization (CZ, NS, JR, FMJ); data curation (JO, IV, BB) funding acquisition (FMJ); investigation (CZ, JO, IV, BB); writing (CZ, FMJ) – original draft; writing – review and editing (CZ, BB, NS, JR, FMJ).

Declarations

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Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no conflict of interest.

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