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A camera-trap assessment of the native and invasive mammals present in protected areas of Magallanes, Chilean Patagonia

Evaluación con cámaras trampa de mamíferos nativos e invasores presentes en áreas protegidas de Magallanes, Patagonia chilena

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ABSTRACT

The Chilean Patagonia is characterized by extensive protected areas that encompass most of the region. Mammals are often among the priorities for these protected areas either as conservation targets (e.g., threatened species) or as threats (e.g., invasive species). Camera traps offer a cost-effective alternative to monitor these species, however baseline studies are scarce in the region. Therefore, our objective was to provide an assessment of camera-trapping detection rates for mammals that are present in protected areas of Magallanes, Chilean Patagonia. Between 2015 and 2022 we installed 278 camera traps (9,936 trap-days), distributed in seven protected areas. For each protected area, we calculated the detection rates and proportion of camera traps that detected each species. We recorded 18 mammalian species, including ten native, four domestic, and four invasive species. The culpeo fox (*Lycalopex culpaeus*) was the most frequently detected species, followed by invasive European hare (*Lepus europaeus*) and puma (*Puma concolor*). Endangered species like the huemul (*Hippocamelus bisulcus*) and southern river otter (*Lontra provocax*) were detected infrequently, whereas beaver (*Castor canadensis*) and American mink (*Neogale vison*) were only recorded in cameras that targeted them. From our data we suggest that generalist monitoring designs are likely to be effective for relatively common species like the culpeo fox. However, when species of interest are associated with specific features of the landscape (e.g., otters and water), other designs are needed. Based on our findings, we provide recommendations for the design of camera-trapping monitoring plans in protected areas.

Keywords: domestic animals, exotic species, protected area management, threatened species, wildlife monitoring.

RESUMEN

La Patagonia Chilena se caracteriza por una extensa red de áreas protegidas que cubren la mayoría de la región. Los mamíferos suelen ser prioridades para dichas áreas, ya sea como objetos de conservación (e.g., especies amenazadas) o amenazas (e.g., especies invasoras). Las cámaras trampa ofrecen una alternativa costo-eficiente de monitoreo, pero, en esta zona, los estudios de línea base son escasos. Nuestro objetivo fue proveer una evaluación de las tasas de detección en cámaras trampa de mamíferos en áreas protegidas de Magallanes, Patagonia Chilena. Entre 2015 y 2022 instalamos 278 cámaras trampas (9.936 días-trampa), en siete áreas protegidas. Para cada área protegida calculamos tasas de detección y proporción de cámaras trampas que detectaron cada especie. Registramos 18 especies de mamíferos, incluyendo diez especies nativas, cuatro domésticas y cuatro invasoras. El zorro culpeo (*Lycalopex culpaeus*) fue la especie detectada más frecuentemente, seguida por la liebre europea (*Lepus europaeus*) y el puma (*Puma concolor*). Especies amenazadas como el huemul (*Hippocamelus bisulcus*) y huillín (*Lontra provocax*) fueron detectadas infrecuentemente, mientras que el castor (*Castor canadensis*) y visón (*Neogale vison*) sólo fueron registrados en cámaras dirigidas a estos. A partir de nuestros datos sugerimos que diseños de monitoreo generalistas serán efectivos para especies relativamente comunes como el zorro culpeo. Sin embargo, cuando las especies de interés se asocian a atributos específicos del paisaje (e.g., huillín y agua), se requieren otros diseños. En base a nuestros hallazgos, proveemos recomendaciones para el diseño de planes de monitoreo con cámaras trampa en áreas protegidas.

Palabras clave: animales domésticos, especies amenazadas, especies exóticas, gestión de áreas protegidas, monitoreo de vida silvestre.

INTRODUCTION

Protected areas are one of the most important strategies for biodiversity conservation and ecosystem protection, as acknowledged by the Convention on Biological Diversity (Pimm *et al.* 2018; United Nations Biodiversity Conference 2022). These areas provide critical habitats for thousands of plant and animal species, many of them being endangered or threatened (Le Saout *et al.* 2013; Pimm *et al.* 2018). They also offer benefits to humans, including opportunities for recreation, education, and scientific research (Stolton *et al.* 2015; Naidoo *et al.* 2019). Current global targets aim at preserving 30 % of terrestrial and marine ecosystems within protected area systems (United Nations Biodiversity Conference 2022). Although this is a major challenge, some regions of the planet far exceed this goal. One of these regions is the Chilean Patagonia (south of 41° S), which currently has more than 54 % of its land under official protection (Martínez-Harms *et al.* 2021).

The Chilean Patagonia is characterized by a wide diversity of ecosystems, including evergreen and deciduous forests, peat bogs, steppes, ice fields, and coastal ecosystems associated with channels and fjords (Armesto *et al.* 2021). Human density in Patagonia is low and concentrated in a few urban centers (http://resultados.censo2017.cl/). Then, most of Chilean Patagonia are areas of low human impact (Jacobson *et al.* 2019), representing some of the last wilderness areas of the world (Mittermeier *et al.* 2003, Brooks *et al.* 2006). Despite this, there are significant knowledge and management gaps that limit the design and implementation of conservation strategies and actions (Martínez-Harms *et al.* 2021). Indeed, up-to-date management plans are lacking for Patagonia, a situation that also affects many other protected areas in Chile (Petit *et al.* 2018). In response to this, there has been a major effort to advance planning processes across several protected areas of Patagonia (CONAF 2022). However, those efforts remain a major challenge due to considerable knowledge gaps that limit the planning process (Martínez-Harms *et al.* 2021).

Mammals – particularly carnivores and ungulates – are frequently prioritized as conservation targets in Patagonia.

Mammals in the region include threatened species such as the endangered huemul (*Hippocamelus bisulcus*, Riquelme *et al.* 2018; Black-Decima *et al.* 2016) and southern river otter (*Lontra provocax*, Sepúlveda *et al.* 2021), as well as species that play key ecological roles such as the puma (*Puma concolor*, e.g., Elbroch & Wittmer, 2012) and guanaco (*Lama guanicoe*, González *et al.* 2022). Mesocarnivores, which have crucial functions in regulating prey populations and maintaining ecosystem health (Roemer *et al.* 2009), are also frequently prioritized as conservation targets. Patagonian mesocarnivores include foxes (i.e., *Lycalopex culpaeus*, *L. griseus*), small felids (*Leopardus geoffroyi*, *L. colocolo*), skunks (*Conepatus chinga*, for taxonomic discussions see Schiaffini *et al.* 2013; D'Elia *et al.* 2020), and small mustelids (*Galictis cuja*, *Lyncodon patagonicus*) (Johnson *et al.* 1990; Radic-Schilling *et al.* 2021).

Mammals are not solely seen as conservation priorities in the Patagonia region. Invasive mammalian species are among the main threats faced by Patagonian ecosystems (Anderson *et al.* 2006; Valenzuela *et al.* 2014; Schüttler *et al.* 2019). For example, the American mink (*Neogale vison*) has invaded extensive areas of Patagonia, becoming a threat to birds and small mammals (e.g., Schüttler *et al.* 2009; Fasola & Roesler 2018). The American beaver (*Castor canadensis*) was originally introduced to Tierra del Fuego, but since then it has colonized most of the island, spread out to the neighboring archipelagos, and even reached the mainland (Graells *et al.* 2015; Huertas-Herrera *et al.* 2020). Lagomorphs – including the European hare (*Lepus europaeus*) and rabbits (*Oryctolagus cuniculus*) – have also invaded most Patagonian ecosystems, becoming the main prey item for the native carnivore guild (Jaksic *et al.* 2002; Correa-Cuadros *et al.* 2023).

Mammals that threaten Patagonian ecosystems are not limited to wild invasive species, but also to domestic animals. For example, domestic dogs and cats prey on native species, particularly birds and mammals (Corti *et al.* 2010; Schüttler *et al.* 2018), and represent a disease risk for wild carnivores (Pedersen *et al.* 2007). Livestock is also a conservation concern (Schüttler *et al.* 2019), affecting the Patagonian forests (Mazzini *et al.* 2018; Vásquez 2002) and transmitting diseases to wild ungulates (e.g., Corti *et al.* 2013, 2020, 2022).

The inclusion of mammals – either as conservation targets or threats – in conservation planning requires baseline information that is often not available in Patagonia. For native mammals, information confirming their presence in different areas is relevant to define fine-grain conservation targets. In the case of invasive species, knowing their scope (proportion of the protected area or conservation target affected; Foundations of Success 2009) is fundamental to carrying out threat analysis. Moreover, species to be prioritized, either as conservation targets or threats, require monitoring programs to assess the effectiveness of management strategies (Block *et al.* 2001; Groves & Game 2016). The adequate design of these monitoring plans will also require baseline information (Block *et al.* 2001).

In the case of large and medium-sized mammals, camera traps have become a useful tool to collect data on species richness, population densities, occupancy, habitat use, and activity patterns of many species (Rovero *et al.* 2013, Kays *et al.* 2020, Chen *et al.* 2022). However, the design of monitoring plans for mammals requires preliminary data to determine the feasibility of monitoring a given indicator (e.g., occupancy, relative abundance index, etc.), as well as to adjust sample sizes (Rovero *et al.* 2013, Kays *et al.* 2020). This information is often scarce for many species in the Chilean Patagonia. In this context, the objective of our study was to provide an assessment of camera trapping detection rates for mammals present in protected areas of the Magallanes district, Chilean Patagonia. For this purpose, we conducted camera trapping in seven protected areas that have very different threats, logistical constraints, and information needs.

METHODS

Study area

The study was conducted in the Magallanes district of Chile. The region is characterized by a wide array of ecosystems that include steppes, evergreen and deciduous forests, peat bogs, glaciers, and coastal environments (Armesto *et al.* 2021). Human density is low (1.3 ind/km^2, 166,533 inhabitants) and nearly three quarters of the population is concentrated in Punta Arenas, the largest city of the region (BCN 2023). The Humboldt current determines cold and humid conditions in the Pacific coast (Butorovic 2019), with an average annual temperature of 7-8 °C, and an annual accumulated precipitation > 4,000 mm (Carrasco *et al.* 1998). The Andes mountain range forms a barrier that stops wet air masses coming from the Pacific Ocean (Endlicher & Santana 1988). Therefore, moist air masses precipitate on the western slope of the Andes while on the eastern edge precipitation drops abruptly (Butorovic 2019) with an annual average of 328 mm, mostly falling as snow in the winter months (Pisano 1985). This low precipitation favors the formation of a dry and cold steppe ecosystem dominated by graminoids of the genus *Festuca*, *Stipa*, and *Poa* (Radic-Schilling *et al.* 2021) and an average temperature of 4.7° C ranging 0-9.2° C (Pisano 1985).

We sampled seven protected areas that range from 189 to c. 1.5 million ha between 2015 and 2023 (Fig. 1, Table

1). The surveyed sites included three types of protected areas: National Parks (Torres del Paine, Alberto de Agostini, Yendegaia, and Cabo de Hornos), National Reserves (Laguna Parrillar and Magallanes), and Natural Monuments (Cueva del Milodón). Four of those protected areas are located on the mainland, two on the island of Tierra del Fuego, and one within the Cabo de Hornos archipelago. A synthesis of the characteristics of the surveyed protected areas is shown in Table 1. Additionally, we report important observations recorded in a Protected National Asset (Appendix 1).

Sampling design

The baselines reported here were conducted under very different logistical constraints and purposes including monitoring pilots, rapid baselines, research at broader scales, and capacity building. Therefore, we synthesize the original purpose of the sampling and the sampling characteristics for each protected area from south to north. Part of the data reported for Cabo de Hornos, Yendegaia, and Alberto de Agostini National Parks have been used in previous studies (Crego *et al.* 2015; Schüttler *et al.* 2019).

Cabo de Hornos National Park:

In the Cabo de Hornos National Park, we set camera traps on Hornos and Wollaston Islands during June and July 2015. Sampling focused on invasive mammalian carnivores (American mink, cats, and dogs), therefore, the cameras were baited with a perforated tuna can. We could only visit each island for a limited amount of time (~4 hours), thus we installed only two camera traps (Bushnell Trophy Cam, Bushnell Outdoor Products, Overland Park, KS) per visit around each navy post. We installed two camera traps in scrubland habitat in Hornos island which operated for 97 trap-days, and two cameras in coastal grassland, and forest habitat, respectively, in Wollaston Island for a total of 110 trap-days.

Yendegaia National Park:

We sampled the southern area of Yendegaia National Park during April 2017. Due to the extreme logistical difficulties associated with the area, sampling was designed to install and remove cameras allowing an operation time of 3-6 days per camera. To maximize effort, we set 34 camera traps (Bushnell Trophy Cam) along two trails, on lower elevations. Within trails,

Table 1. Synthesis of the main features of the protected areas sampled, ordered from south to north. / Síntesis de las principales características de las áreas protegidas muestreadas, ordenadas de sur a norte.

Protected area	Area (ha)	Main ecosystems*	Sampling season	Number of cameras	Trap-days
Cabo de Hornos National Park	63,093	Low altitude scrub, peat bogs	06/2015 – 07/2015	4	207
Yendegaia National Park	150,587	Evergreen forest, high altitude grasslands, low altitude scrub, peat bogs, glaciers, rivers, lagoons, lakes	04/2017 – 04/2017	38	187
Alberto de Agostini National Park	1,460,000	Evergreen forest, high altitude grasslands, low altitude scrub, peat bogs, glaciers, rivers, lagoons, lakes	01/2015 – 01/2015	44	93
			07/2015 – 09/2015	2	95
Laguna Parrillar National Reserve	18,414	Deciduous forest, evergreen forest, scrub, lagoons, peat bogs	12/2020-05/2021	59	3,828
Magallanes National Reserve	20,878	Deciduous forest, evergreen forest, deciduous scrub, peat bogs	04/2021 – 12/2021	15	1,691
Cueva del Milodón Natural Monument	189	Forests and scrub, steppe and grasslands	04/2021 – 05/2021	15	577
Torres del Paine National Park	227,298	Deciduous forest, evergreen forest, steppe and grasslands, high altitude grasslands, deciduous scrub, glaciers, rivers, lagoons, lakes	09/2021-12/2021	41	1,502
			10/2022-01/2023	60	1,756

*Source: https://simbio.mma.gob.cl/

cameras were spaced by at least 400 m. Considering the short time frame and that the main targets were carnivores, we used two commercial lures (Wiley Red #500, S. Stanley Hawbaker and Sons' Lures, Fort Louden, PA; Milligan Steppenwolf II, Chama, NM) imbibed in a sponge protected by trunks, sticks or stones. Additionally, we installed four cameras to confirm the presence of the following target species in sites where we detected signs. One of them was set in a site where we found scats that presumably corresponded to American mink, two were installed at latrines that appeared to belong to southern river otter, and the latter in a beaver trail next to the Yendegaia river (the three latter cameras were not lured). Cameras were removed after a maximum of six days. Considering the 38 camera traps, the sampling effort was 187 trap-days.

Alberto de Agostini National Park:
Alberto de Agostini National Park was sampled in January 2015 during a one-week expedition. Sampling effort was concentrated in three areas, two of them inside the National Park (Holanda and Pia Glaciers) and one of them at a short distance from the border of the park (Caleta Olla). The original purpose of the sampling was to determine if the area had been invaded by American mink (Crego *et al.* 2015). Forty-four camera traps were installed spaced 200 m between them. Given the logistics of the area, the specific location of the cameras was determined in the field, based on the accessibility to sites. The cameras were lured with canned fish and remained in the field for a short timespan (3 nights and 2 days per camera). The total sampling effort was 93 trap-days. In addition to the January campaign, in July 2015 two cameras were set for two months (95 trap-days) in forest and grassland habitat next to the Timbales Navy post. The cameras aimed to detect carnivores, thus a perforated tuna can was used as bait.

Laguna Parrillar National Reserve:
The sampling design in Laguna Parrillar National Reserve followed the design used by CONAF at a national level. For this purpose, a grid with square cells of 500 x 500 m was overlaid onto the reserve. Cells that were considered inaccessible were excluded. From the remaining cells, a random sample of 70 cells was selected. Cameras were installed in 60 of those cells (the remaining 10 were excluded), minimum sample size recommended for occupancy studies (Rovero *et al.* 2013; Kays *et al.* 2020). Thirty camera traps were initially installed in December 2020, and later relocated to the remaining locations in March 2021. Cameras were installed at heights ranging from 15 to 80 cm above the ground. The cumulative trapping effort was 3,828, involving 59 cameras (one camera did not work correctly).

Magallanes National Reserve:
The Magallanes National Reserve was sampled as part of a training course on the use of camera-traps held in April 2021. Fifteen camera installation sites were randomly selected within a grid of approximately 315 ha composed of 300 x 300 m cells, located in the eastern side of the reserve. Camera traps (Bushnell Trophy Cam E3 Essential) were installed as close as possible to the center of each cell, at 35-70 cm height from the ground and worked for an average of 114 days before they were removed, making a total effort of 1,691 trap-days.

Cueva del Milodón Natural Monument:
The Natural Monument Cueva del Milodón was sampled as part of a training course on the use of camera-traps held in April 2021. To select sampling points, a grid with 300 x 300 m cells was placed throughout the entire area. Of the total cells, 15 were systematically selected to cover a greater number of sites within the area. We set the camera traps (Bushnell Trophy Cam E3 Essential) as close as possible to the center of each selected cell. Cameras were set on trees, shrubs, or rocks depending on the availability of each site. The cameras were installed at 30-50 cm from the ground and operated on average for 38 days before being removed, yielding a total effort of 577 trap-days.

Torres del Paine National Park:
Torres del Paine National Park was sampled between September and December 2021, and again between October 2022 and early January 2023. Sampling was conducted as part of the pilot season (2021) and first year (2022) for the camera-trap monitoring program of the protected area. For this purpose, the park was subdivided in a grid of 1 x 1 km. Cells that were not accessible or that slightly overlapped the boundaries of the park were discarded. From the remaining, a total of 64 were selected for sampling using a stratified random sampling, allocating eight cells to each of the eight administrative areas of the park. Four of them were discarded, and for the pilot season camera traps were installed in 41 out of the remaining cells which amounted for a total effort of 1,502 trap days. For the second year, six cells that were not accessible were replaced. At each cell, the leading park ranger choose the specific site for the installation of the camera during the fieldtrip, aiming to place it as close to the center of the cell in an area with a clear view. Cameras were mounted on a stake 30-60 cm from the ground without the use of lures. Cameras remained in the field for at least 29 days (60 cameras, 1,756).

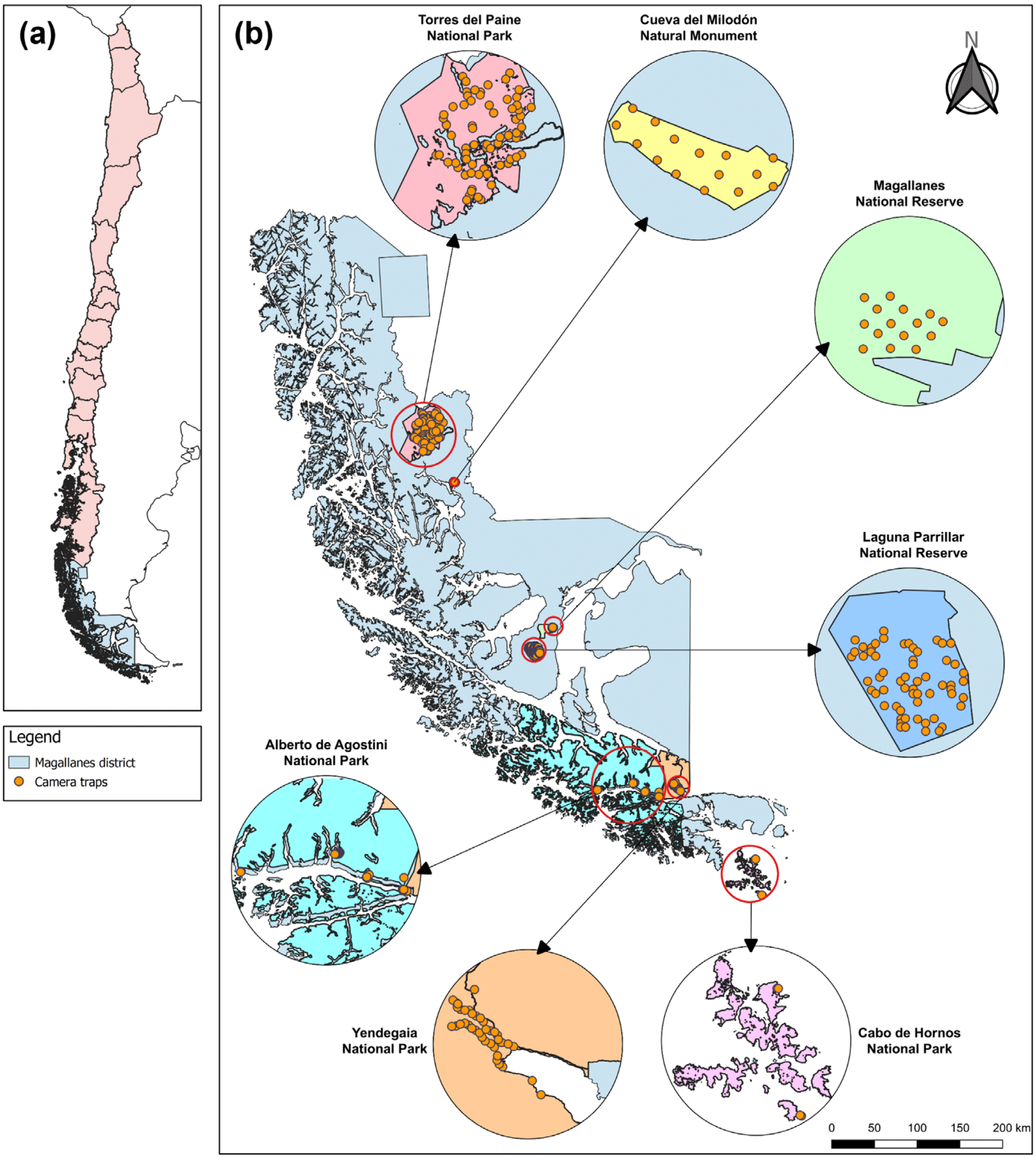

Figure 1. (a) Inset showing the Magallanes district, Chile. (b) Sampled protected areas, along with the location of the installed camera-traps. An enlargement of each protected area is shown for better visualization. The polygons of the protected areas were obtained through the SIMBIO platform of the Ministry of Environment of Chile (https://simbio.mma.gob.cl/). / (a) Mapa que muestra la región de Magallanes, Chile. (b) Áreas protegidas muestreadas, junto con la ubicación de las cámaras trampa instaladas. Se muestra un acercamiento de cada área protegida para una mejor visualización. Los polígonos de las áreas protegidas se obtuvieron a través de la plataforma SIMBIO del Ministerio del Medio Ambiente de Chile (https://simbio.mma.gob.cl/).

Data analysis

Camera trap data was manually classified using, in most cases, the procedures developed by Sanderson & Harris (2013). Data from Torres del Paine National Park was processed using MegaDetector (Beery *et al.* 2019) for the first collation and then manually classified using Timelapse 2.3.0.5. (Greenberg *et al.* 2019). Based on the data collected, we calculated two basic indicators for each protected area. First, we estimated the camera-trapping rate (number of independent pictures per 100 trap-days, as in Rovero & Marshall 2009; Silva-Rodríguez *et al.* 2018) for each protected area. We considered pictures obtained in a given camera-trap as independent when obtained with at least 60-min separation (Rovero & Marshall 2009). Camera-trapping rates (detection rates from here on) were estimated using the full datasets (i.e., data was not truncated). Then, we estimated the proportion of cameras that recorded any given species per protected area. For this purpose, we used two truncation criteria. For surveys that lasted at least a month per camera, we truncated the data after the cameras completed 30 days. This applied to most protected areas. In the case of Yendegaia and Alberto de Agostini National Parks, we kept the whole datasets because sampling was conducted in a very short time. Although these time frames are well below ideal scenarios (see Kays *et al.* 2020), the high level of remoteness of these areas suggests that other monitoring schemes may not be feasible.

RESULTS

We recorded 18 mammalian species, including ten native, four invasive, and four domestic species, plus unidentified rodents in the seven protected areas (Table 2). We detected three threatened species: huemul (Endangered), southern river otter (Endangered), and Fueguian culpeo fox (Vulnerable). The huemul was detected in Torres del Paine National Park and Laguna Parrillar National Reserve (Fig. 2a). In both areas, detection rates were low (Table 2). The endangered southern river otter was detected in Alberto de Agostini (Fig. 2b) and Yendegaia National Parks (Table 2), in cameras located at a short distance from the coastal border. Finally, the Fueguian culpeo fox (Fig. 2c) was detected in both protected areas located in Tierra del Fuego (Table 2). In Yendegaia National Park, the detection rate of this fox was high (29.4 pictures per 100, Table 2), and it was recorded in most of the cameras (63.2 %, Table 3).

Moreover, culpeo fox (including the Fueguian subspecies mentioned above) was recorded in 5 out of the 7 protected areas. When present, these canids were detected in a relatively high proportion of the cameras installed in the protected area (in most cases >20 %, Table 3). The presence of pumas was recorded in all protected areas located on the mainland (Table 2) but were detected in a higher proportion of sites in Torres del Paine National Park (29.3 % and 26.7 % of the cameras in 2021 and 2022, respectively, Table 3).

Other carnivores such as Patagonian skunks, Geoffroy's cats (Fig. 2d), lesser grison (Fig. 2e), and chilla foxes, were infrequently recorded (Table 2). However, both Geoffroy's cat and chilla fox were detected in 33.3 % of the cameras set in Cueva del Milodón Natural Monument. Guanaco (29.3 % and 21.7 % of the cameras in 2021 and 2022, respectively) and coypu (2.4 % of the cameras in 2021) were only detected in Torres del Paine National Park (Table 3).

Invasive hares were present in all protected areas surveyed in the mainland. The proportion of cameras that detected this lagomorph ranged from 25.4 % to 93.3 % (Table 3). Rabbits were detected in three protected areas, Cueva del Milodón Nature Monument, Magallanes National Reserve, and Yendegaia National Park. American mink and beaver were only recorded in cameras directed toward these species in Tierra del Fuego (Yendegaia for both species and Alberto de Agostini for mink). Horses had very high detection rates in Yendegaia National Park (28.8 pictures per 100 trap-days, Table 2) and were also detected in Torres del Paine National Park. Cattle was detected in Laguna Parrillar National Reserve and in Torres del Paine National Park. In the later park, cattle were recorded in 13.3-24.4 % of cameras, and in one of the cameras they co-occurred with huemul. Domestic dogs were detected in three protected areas. Dog records were infrequent and always associated with people in Torres del Paine National Park and Laguna Parrillar National Reserve. However, dogs were the most frequently detected carnivore in Magallanes National Reserve (1.8 pictures per 100 trap-days, Table 2). Domestic cats were detected in Magallanes National Reserve and in Cabo de Hornos National Park (Table 2). In the latter park, cats were the only carnivore recorded, and belonged to a resident family.

Table 2. Detection rates (number of independent pictures per 100 trap-days) of selected species of mammals in seven protected areas of Magallanes: Cabo de Hornos National Park (CHNP), Yendegaia National Park (YENP), Alberto de Agostini National Park (summer, AANP-1; and winter, AANP-2), Laguna Parrillar National Reserve (LPNR), Magallanes National Reserve (MANR), Cueva del Milodón Nature Monument (CMNM), and Torres del Paine National Park (TPNP-21 and TPNP22). We show the conservation status (Status) for native species (EN, Endangered; VU, Vulnerable; LC, Least Concern) following the official classification of Chile (MMA 2023). For this table, domestic and wild invasive species are grouped together as invasive (IN). / Tasas de detección (número de fotos independientes por cada 100 trampas-día) de especies seleccionadas de mamíferos en siete áreas protegidas de Magallanes: Parque Nacional Cabo de Hornos (CHNP), Parque Nacional Yendegaia (YENP), Parque Nacional Alberto de Agostini (verano, AAPN-1; e invierno, AAPN-2), Reserva Nacional Laguna Parrillar (LPRN), Reserva Nacional Magallanes (MARN), Monumento Natural Cueva del Milodón (CMNM) y Parque Nacional Torres del Paine (TPNP-1 y TPNP-2). Se presentan los estados de conservación (Estado) para las especies nativas (EN, En Peligro; VU, Vulnerable; LC, Preocupación menor), siguiendo la clasificación oficial de Chile (MMA 2023). Para esta tabla, las especies domésticas e invasoras son agrupadas como invasoras (IN).

Order	Family	Species	Common name	Status	CHNP	YENP	AANP-1	AANP-2	LPNR	MANR	CMNM	TPNP-1	TPNP-2
Carnivora	*Canidae*	*Canis familiaris*	Domestic dog	IN	-	-	-	-	0.05	1.77	-	0.07	-
		Lycalopex culpaeus	Culpeo fox	LC/VU*	-	29.38	4.30	6.32	1.10	1.01	-	0.53	1.08
		Lycalopex griseus	Chilla fox	LC	-	-	-	-	-	-	4.51	0.20	0.11
		Lycalopex sp.	Unidentified fox	-	-	-	-	-	0.31	0.24	2.25	0.47	0.63
	Felidae	*Felis catus*	Domestic cat	IN	2.42	-	-	-	-	0.06	-	-	-
		Leopardus geoffroyi	Geoffroy's cat	LC	-	-	-	-	-	-	1.21	0.20	0.28
		Puma concolor	Puma	LC	-	-	-	-	0.16	0.06	0.69	1.33	1.82
	Mephitidae	*Conepatus chinga*	Patagonian skunk	LC	-	-	-	-	-	-	-	0.53	0.06
	Mustelidae	*Galictis cuja*	Lesser grison	LC	-	-	-	-	-	0.24	-	-	-
		Lontra provocax	Southern river otter	EN	-	1.07	1.08	10.53	-	-	-	-	-
		Neogale vison	American mink	IN	-	2.67	47.31	-	-	-	-	-	-
Cetartiodactyla	*Bovidae*	*Bos taurus*	Cattle	IN	-	-	-	-	2.01	-	-	12.58	5.92
	Camelidae	*Lama guanicoe*	Guanaco	LC	-	-	-	-	-	-	-	5.33	5.58
	Cervidae	*Hippocamelus bisulcus*	Huemul	EN	-	-	-	-	0.03	-	-	-	0.23
Lagomorpha	*Leporidae*	*Lepus europaeus*	Hare	IN	-	-	-	-	2.40	13.37	23.22	7.19	3.59
		Oryctolagus cuniculus	Rabbit	IN	-	10.15	-	-	-	11.95	9.18	-	-
			Unidentified	IN	-	-	-	-	0.26	7.92	12.13	1.80	-
Perissodactyla	*Equidae*	*Equus caballus*	Horse	IN	-	28.85	-	-	0.03	0.95	-	2.93	2.73
Rodentia	*Castoridae*	*Castor canadensis*	American beaver	IN	-	4.27	3.23	-	-	-	-	-	-
	Myocastoridae	*Myocastor coipus*	Coypu	LC	-	-	-	-	-	-	-	0.07	-
			Small rodent	-	28.01	1.07	2.15	54.74	2.69	4.32	-	0.20	-
Sampling information		Sampling start year			2015	2017	2015	2015	2020	2021	2021	2021	2022
		Number of cameras			4	38	44	2	59	15	15	41	60
		Effort (trap days)			207	187	93	95	3,828	1,691	577	1,502	1,756

*LC for mainland, VU for Tierra del Fuego

Table 3. Proportion of cameras (%) that detected selected species of mammals in seven protected areas of Magallanes: Cabo de Hornos National Park (CHNP), Yendegaia National Park (YENP), Alberto de Agostini National Park (summer, AANP-1; and winter, AANP-2), Laguna Parrillar National Reserve (LPNR), Magallanes National Reserve (MANR), Cueva del Milodón Nature Monument (CMNM), and Torres del Paine National Park (TPNP-1 and TPNP-2). We show the conservation status (Status) for native species (EN, Endangered; VU, Vulnerable; LC, Least Concern) following the official classification of Chile (MMA 2023). For this table, domestic and wild invasive species are grouped together as invasive (IN). The reported effort for the proportion of cameras that detected each species is lower than the detection rates because the data was truncated after day 30. / Proporción de cámaras (%) que detectaron especies seleccionadas de mamíferos en siete áreas protegidas de Magallanes: Parque Nacional Cabo de Hornos (CHNP), Parque Nacional Yendegaia (YENP), Parque Nacional Alberto de Agostini (verano, AANP-1; e invierno, AANP-2), Reserva Nacional Laguna Parrillar (LPNR), Reserva Nacional Magallanes (MANR), Monumento Natural Cueva del Milodón (CMNM) y Parque Nacional Torres del Paine (TPNP-1 y TPNP-2). Se presentan los estados de conservación (Estado) para las especies nativas (EN, En Peligro; VU, Vulnerable; LC, Preocupación menor), siguiendo la clasificación oficial de Chile (MMA 2023). Para esta tabla, las especies domésticas e invasoras son agrupadas como invasoras (IN). El esfuerzo reportado para la proporción de cámaras que detectaron cada especie es menor que las tasas de detección debido a que los datos fueron truncados después del día 30.

Order	Family	Species	Common name	Status	CHNP	YENP	AANP-1	AANP-2	LPNR	MANR	CMNM	TPNP-1	TPNP-2
Carnivora	*Canidae*	*Canis familiaris*	Domestic dog	IN	-	-	-	-	1.7 %	26.7 %	-	2.4 %	-
		Lycalopex culpaeus	Culpeo fox	LC/VU*	-	63.2 %	9.1 %	50.0 %	27.1 %	20.0 %	-	12.2 %	21.7 %
		Lycalopex griseus	Chilla fox	LC	-	-	-	-	-	-	33.3 %	4.9 %	1.7 %
		Lycalopex sp.	Unidentified fox	-	-	-	-	-	8.5 %	13.3 %	20.0 %	9.8 %	10.0 %
	Felidae	*Felis catus*	Domestic cat	IN	25.0 %	-	-	-	-	6.7 %	-	-	-
		Leopardus geoffroyi	Geoffroy's cat	LC	-	-	-	-	-	-	33.3 %	7.3 %	5.0 %
		Puma concolor	Puma	LC	-	-	-	-	3.4 %	-	13.3 %	29.3 %	26.7 %
	Mephitidae	*Conepatus chinga*	Patagonian skunk	LC	-	-	-	-	-	-	-	7.3 %	1.7 %
	Mustelidae	*Galictis cuja*	Lesser grison	LC	-	-	-	-	-	13.3 %	-	-	-
		Lontra provocax	Southern river otter	EN	-	2.6 %	2.3 %	50.0 %	-	-	-	-	-
		Neogale vison	American mink	IN	-	5.3 %	25.0 %	-	-	-	-	-	-
Cetartiodactyla	*Bovidae*	*Bos taurus*	Cattle	IN	-	-	-	-	3.4 %	-	-	24.4 %	13.3 %
	Camelidae	*Lama guanicoe*	Guanaco	LC	-	-	-	-	-	-	-	29.3 %	21.7 %
	Cervidae	*Hippocamelus bisulcus*	Huemul	EN	-	-	-	-	1.7 %	-	-	-	5.0 %
Lagomorpha	*Leporidae*	*Lepus europaeus*	European hare	IN	-	-	-	-	25.4 %	93.3 %	86.7 %	26.8 %	31.7 %
		Oryctolagus cuniculus	Rabbit	IN	-	13.2 %	-	-	-	40.0 %	26.7 %	-	-
			Unidentified	IN	-	-	-	-	5.1 %	80.0 %	80.0 %	7.3 %	-
Perissodactyla	*Equidae*	*Equus caballus*	Horse	IN	-	39.5 %		-	1.7 %		-	17.1 %	6.7 %
Rodentia	*Castoridae*	*Castor canadensis*	American beaver	IN	-	2.6 %	2.3 %	-	-	-	-	-	-
	Myocastoridae	*Myocastor coipus*	Coypu	LC	-	-	-	-	-	-	-	2.4 %	-
			Small rodent		50.0 %	5.3 %	4.5 %	100 %	18.6 %	26.7 %	-	4.9 %	-
Sampling information	Sampling start year				2015	2017	2015	2015	2020	2021	2021	2021	2022
	Number of cameras				4	38	44	2	59	15	15	41	60
	Effort (trap days)				120	187	93	58	1,731	450	450	1,164	1,744

*LC for mainland, VU for Tierra del Fuego

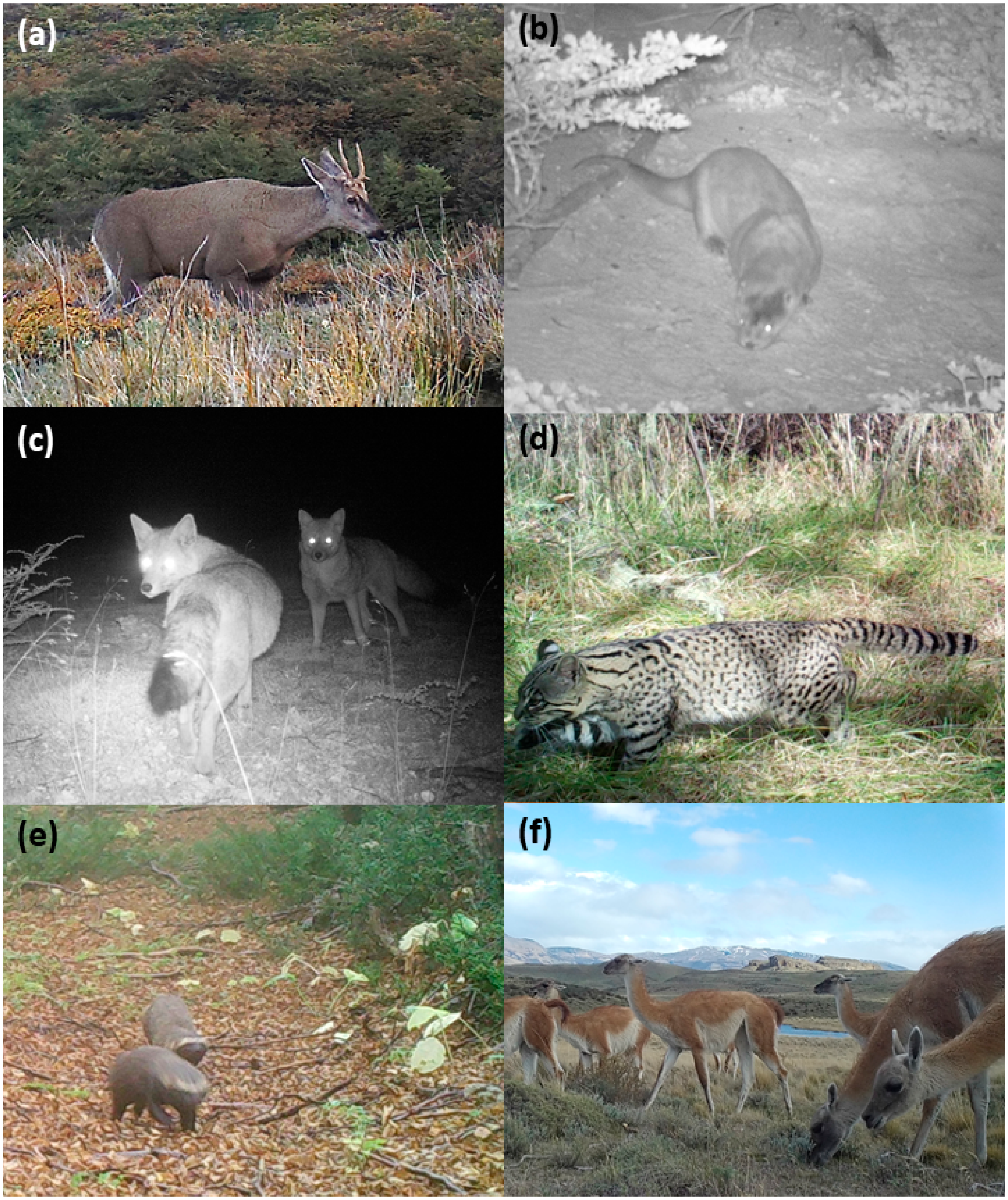

Figure 2. Native mammal records obtained through camera trapping in protected areas of Magallanes, Chilean Patagonia. (a) Huemul deer (*Hippocamelus bisulcus*) detected in Laguna Parrillar National Reserve. (b) Southern river otter (*Lontra provocax*) photographed in the vicinity of the Alemania glacier, Alberto de Agostini National Park. (c) Fueguian culpeo foxes (*Lycalopex culpaeus lycoides*) recorded in the Yendegaia National Park. (d) Geoffroy's cat (*Leopardus geoffroyi*) in Cueva del Milodón Natural Monument. (e) Lesser grisons (*Galictis cuja*) in Magallanes National Reserve. (f) Guanacos (*Lama guanicoe*) recorded in Torres del Paine National Park. / Registros de mamíferos nativos obtenidos mediante cámaras trampa en áreas protegidas de Magallanes, Patagonia chilena. (a) Huemul (*Hippocamelus bisulcus*) detectado en la Reserva Nacional Laguna Parrillar. (b) Huillín (*Lontra provocax*) fotografiado cerca del glaciar Alemania, en el Parque Nacional Alberto de Agostini. (c) Zorros culpeos fueguinos (*Lycalopex culpaeus lycoides*) registrados en el Parque Nacional Yendegaia. (d) Gato de Geoffroy (*Leopardus geoffroyi*) en el Monumento Natural Cueva del Milodón. (e) Quiques (*Galictis cuja*) en la Reserva Nacional Magallanes. (f) Guanacos (*Lama guanicoe*) registrados en el Parque Nacional Torres del Paine.

DISCUSSION

The key role of protected areas for biodiversity conservation is well-known, but monitoring their wild communities is not an easy task, especially in remote and inaccessible areas. Across Magallanes district, camera-traps were effective at detecting most of the medium and large-sized native mammals known to be present (see Johnson *et al.* 1990). However, armadillos (order Cingulata) were not recorded even though both the large-hairy armadillo (*Chaetophractus villosus*) and pichi (*Zaedyus pichiy*) are present in, or close to, some of the protected areas sampled (e.g., Texera 1973; Sierpe *et al.* 2013; Pasutti 2017). The Patagonian weasel (*Lyncodon patagonicus*) and pampas cat (*Leopardus colocolo*) were not detected either, which is not surprising considering the scarcity of records for both species in the region (e.g., Prevosti *et al.* 2009; Utrovicic *et al.* 2020). We suspect that the lack of detections of these four species could be due to a combination of rarity, underrepresentation of steppes in our study areas and, in the case of armadillos, low detectability due to the semifossorial behavior of both species (Superina *et al.* 2014).

Carnivores were common in most of our study areas. Some species, such as culpeo foxes, were consistently recorded across most protected areas (Table 2). Culpeo foxes had its highest detection rates in Tierra del Fuego. However, higher detection rates do not necessarily mean higher abundance (e.g., Sollman *et al.* 2013), especially considering that we used lures on the island, likely increasing detection rates. In any case, the high proportion of cameras with culpeo records in Yendegaia National Park, suggests a high occupancy. Therefore, our findings – albeit preliminary – appear to represent good news, given the vulnerable status of the Fueguian culpeo fox (MMA 2023). Pumas were detected in all the protected areas located in mainland and also in Cabo Froward National Asset (area not included in the dataset, but see Appendix 1, note that this is the southernmost record for the species). The detection rates of pumas were higher in Cueva del Milodón Natural Monument and especially in Torres del Paine National Park. The latter park is an area well known to have very high puma densities (Franklin *et al.* 1999; Elbroch *et al.* 2023), suggesting that the higher detection rates may be explained by higher abundance.

We suspect that the lower detection rates of smaller carnivores such as southern river otter, lesser grison, Patagonian skunk, and also the invasive American mink, could be explained by detectability issues, linked to the selection of sites and, possibly, camera setting. These issues are more discernible in the case of otters and minks, where the few cameras aimed at these species (location and/or bait) in Alberto de Agostini and Yendegaia National Parks were able to record them. These findings suggest that general monitoring designs are more adequate for species that have relatively high detection rates. However, generalist sampling designs may not be adequate for species with a restricted distribution within the protected area. In these cases, the cameras may record these species but will not yield detection rates high enough to allow their monitoring in the long term. In these cases, the sampling design of the monitoring plan should target the species of interest (e.g., close to the water and associated with latrines in the case of otters or minks, see Sepúlveda *et al.* 2014).

In our study, the endangered huemul was recorded in two protected areas: Torres del Paine National Park, where the species was known to be present (e.g., Garay *et al.* 2016), and Laguna Parrillar National Reserve. The individual recorded in Laguna Parrillar National Reserve likely corresponds to a male that was captured in a house in Río Seco, Punta Arenas (https://www.youtube.com/watch?v=Ty21dafq830), and released into the reserve five days before the picture was captured. We suspect that the individual detected in our cameras is the same huemul that was released as both lacked a bifurcation in its right antler (see Fig. 2a). The confirmed presence of huemul in Punta Arenas, Cabo Froward National Asset (Appendix 1), Kawésqar National Park (Moreira-Arce *et al.* 2021), Magallanes National Reserve (CONAF 2023), Bernardo O'Higgins (Pack *et al.* 2022) and Torres del Paine National Parks (this study, Garay *et al.* 2016) highlights the importance of Magellanic protected areas for the conservation of this endangered deer. At the same time, its discontinuous distribution (Riquelme *et al.* 2018), coupled with a low proportion of cameras with records (≤5 %, Table 3) where the species is present, suggests that the monitoring efforts for this deer in Magallanes require sampling designs that target preferred habitats and probably a species-focused regional-level monitoring program. On the other hand, although guanacos are very common in Magallanes (e.g., Lancaster *et al.* 2022), they were only detected through cameras in Torres del Paine National Park (Fig. 2f). These results are likely due to the underrepresentation of steppes in the protected areas sampled, and in some cases by the sampling protocols used (i.e., short operation time). The latter explanation applies to Yendegaia National Park, where solitary guanacos were observed – but not recorded in cameras – during field work (Silva-Rodríguez E., pers. obs). The lack of detections is likely linked to the very short time the cameras were active there.

We detected invasive species in all protected areas surveyed. Lagomorphs were frequent in most protected areas, with the exceptions of Cabo de Hornos National Park – where they are absent (Schüttler *et al.* 2019) – and Alberto de Agostini National Park, where they were not detected. Lagomorphs represent important prey items for the carnivore guild in Patagonia (Iriarte *et al.* 1991; Novaro *et al.* 2000; Guerisoli *et al.* 2021), however their potential indirect effects – such as apparent competition – are not well understood and could generate strong ecological impacts (e.g., Barbar & Lambertucci 2019). Although mink and beaver were only detected in protected areas from Tierra del Fuego (Yendegaia and Alberto de Agostini National Parks), their presence in mainland is already well-known (e.g., Jaksic *et al.* 2002; Graells *et al.* 2015). Similarly, camera traps failed to record muskrats (*Ondatra zibethicus*), even though this invasive rodent is known to be present in some of the areas surveyed (Crego *et al.* 2015; Schüttler *et al.* 2019). The lack of detections in protected areas where one or more of these species are known to be present (e.g., Laguna Parrillar National Reserve) can be explained by the fact that sampling did not target the habitats preferred by these species (e.g., freshwater ecosystems; Schüttler *et al.* 2010; Crego *et al.* 2016).

Domestic animals were present in most protected areas. Feral horses were detected in almost half of the cameras installed in the Yendegaia National Park, despite the short time they were deployed. Horses and cattle were also frequently recorded in Torres del Paine National Park. In the case of this park, there are animals that are owned (demonstrated by the fact that some of them were marked), as well as apparently feral horses (in the Laguna Azul area). The presence of livestock in protected areas is a threat to the conservation of natural ecosystems as they impact vegetation (Mazzini *et al.* 2018; Ballari *et al.* 2020) and spill pathogens over to wildlife (Salgado *et al.* 2009; Corti *et al.* 2013; Morales *et al.* 2017; Salgado *et al.* 2017).

Domestic dogs were infrequently detected, and detections corresponded to dogs accompanying people. The only exception was Magallanes National Reserve where dogs were recorded in a higher proportion of camera traps than any native carnivore. The difference between this and the other protected areas included in our study is likely explained by the fact that dogs are strongly associated with people and human settlements (Silva-Rodríguez *et al.* 2023), and the Magallanes National Reserve is located close to Punta Arenas, the largest city in the region. Although dogs are not allowed to enter protected areas in Chile, they roam into the area often with people, as reported in other areas (Schüttler & Jiménez 2022). The high detection rate of dogs in a protected area is a problem both for native prey (e.g., Corti *et al.* 2010) and carnivores (e.g., Vanak & Gompper 2009). Even though cats were rarely detected, its presence on islands also represents a concern (see Schüttler *et al.* 2019). Unlike other invasive species, domestic animals are often associated with humans. Notwithstanding their management is challenging, and prone to conflict with different stakeholders (e.g., Silva-Rodríguez *et al.* 2019), over the medium and long-term it may have higher odds of success than the control of wild invasive species.

Based on our findings, as well as on our previous experience (e.g., Silva-Rodríguez *et al.* 2018; Schüttler *et al.* 2019), we provide the following suggestions for the design of monitoring plans in the Chilean Patagonia:

(1) The design currently used by protected areas in Chile (e.g., Torres del Paine National Park) is logistically feasible in parks that are both accessible and implemented (e.g., enough park rangers and facilities). These conditions apply to three of the protected areas included in our study in Magallanes: Torres del Paine National Park, Cueva del Milodón Natural Monument, and Magallanes National Reserve, but could also be implemented in other protected areas, such as Pali-Aike National Park. The combination of detection rates and the proportion of cameras with detections suggests that analytical approaches, such as occupancy modeling (Mackenzie *et al.* 2002), are feasible for a few of the sampled species (e.g., culpeo in Laguna Parrillar National Reserve, see Ulloa 2022; pumas in Torres del Paine National Park, among others). Species that are detected infrequently (such as the huemul, otter and mink) will require monitoring designs specifically tailored to these species.

(2) Many protected areas face complex scenarios due to the lack of personnel, funding and/or infrastructure (e.g., Yendegaia National Park and Laguna Parrillar National Reserve). In these areas it is not feasible to sustain annual monitoring, and other alternatives should be explored. For example, monitoring could be conducted with a lower frequency (e.g., every five years). Alternatively, monitoring could be focused on specific conservation targets or threats. This was the case in Laguna Parrillar National Reserve where the monitoring shifted from a generalist monitoring (reported here for 2021) to one focused on invasive species (mink, muskrat, and beaver).

(3) In the case of protected areas that are extremely large (e.g., Alberto de Agostini National Park) and/or remote (Cabo de Hornos National Park), camera-trap monitoring is not feasible using the current design. Furthermore, these remote protected areas are often severely underfunded. For these areas, the convenience of camera-trapping needs to be evaluated and contrasted to other alternatives, such as environmental DNA (see Thomsen & Willerslev 2015). If, after thoughtful analysis, camera-trapping was still needed, then other sampling designs need to be considered. For example, monitoring could be conducted in clusters and with a lower frequency (e.g., once every five years). Likewise, the location

of clusters should consider accessibility to secure viability of the program, biological relevance of the selected areas, and the feasibility of obtaining logistic support through alliances (e.g., the Chilean Navy) to access those sites. We suggest that a reasonable approach would be to consider the regional protected areas as a subsystem, rather than treating them as isolated units. Such an approach could be useful to establish monitoring programs for species that, whilst present in many protected areas, appear to have patchy distributions within these areas (e.g., huemul).

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Appendix 1
Records from Cabo Froward Protected National Asset

Cabo Froward Protected National Asset (9,286 ha) is located in the southernmost point of the South American continent in the Brunswick Peninsula (53°41' S, 71°08' W). Cabo Froward has different type of environments, such as estuarine zones of several rivers, large surfaces covered by southern beech forest with Magellan's beech (*Nothofagus betuloides*) at coastal zones, and lenga (*N. pumilio*) near the tree line at mountain zones. There also are extensive peat bogs at middle altitude and large ecotone areas between the coast and the mountain environments. With the aim of detecting huemul, 17 camera-traps were installed in the San Nicolas River valley between December 2019 and November 2022. Considering that several cameras had performance issues, we do not report the full dataset. Nonetheless, we found relevant to report two records that, to our knowledge, are the southernmost observations of puma and huemul (Figure S1).

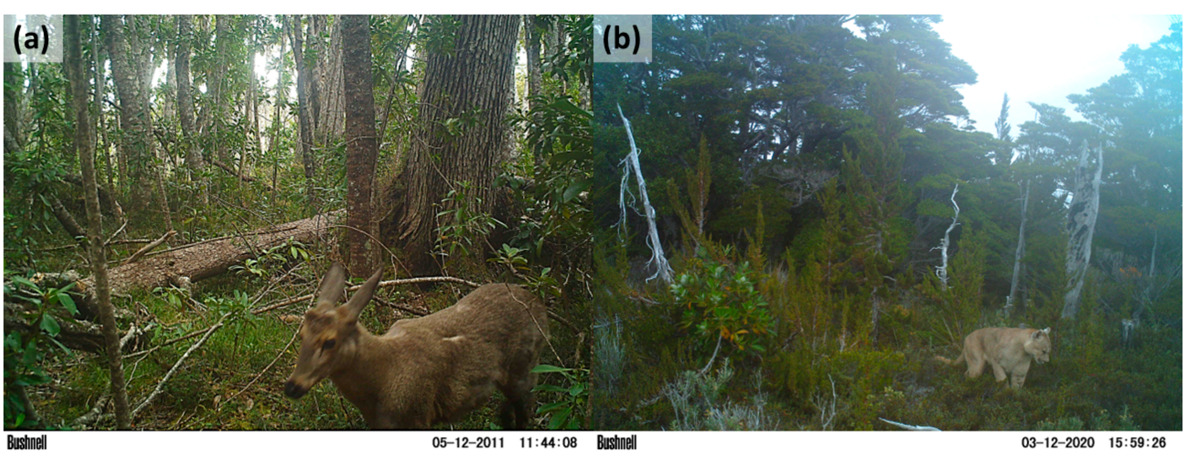

Figure S1. (a) Male huemul and (b) puma recorded in Cabo Froward National Asset. The huemul was detected on December 23rd, 2021 (the date shown on the picture is incorrect as the camera was configured erroneously). / (a) Huemul macho y (b) puma registrados en el Bien Nacional Protegido Cabo Froward. El huemul fue detectado el 23 de diciembre de 2021 (la fecha mostrada en la imagen es incorrecta, ya que la cámara tuvo un error de configuración).