Sarcoptic mange; an emerging threat to Chilean wild mammals?

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Abstract

Sarcoptic mange has been anecdotally reported in Chilean wildlife during the last decade. Although this disease can have devastating outcomes for biodiversity, there is no comprehensive assessment of this potential threat in Chile. Because the current capacity to monitor sarcoptic mange and other wildlife diseases is limited in this country, we used abnormal alopecia to define a probable case and combined several sources of information to identify, to the extent available data allows, the location and temporal trends of wild mammals with probable sarcoptic mange

across Chile. We surveyed park rangers, examined rehabilitation center databases, and collated citizen and media reports. The information gathered suggests that observations of alopecic wild mammals, mainly foxes (*Lycalopex* sp.*)*, the spatial extent of this problem, and the number of species fulfilling our case definition have increased over the last 15 years. Moreover, alopecic mammals are currently located broadly in Chile. We also confirmed the utility of alopecia to define a probable sarcoptic mange case in the most commonly affected group*, Lycalopex* foxes. Our findings are highly concerning from a conservation perspective. We thus emphasize the need for an urgent surveillance and management plan for sarcoptic mange and other diseases that may be threatening Chilean biodiversity.

Introduction

Human-mediated global environmental change and movement of pathogens and domestic hosts have driven the emergence of disease in wildlife across the globe (Daszak, Cunningham, and Hyatt 2000; Tompkins et al. 2015). Evidence supporting that emerging diseases can lead to population declines and extinctions of wild species, and to subsequent changes at the community and ecosystem levels has accumulated in the last decades (O'Hanlon et al. 2018; Harvell et al. 2019; Schultz, Cloutier, and Côté 2016). Indeed, emerging disease events have become a concern for the conservation of marine and terrestrial biodiversity globally (Daszak, Cunningham, and Hyatt 2000; Tompkins et al. 2015; O'Hanlon et al. 2018; Harvell et al. 2019; Schultz, Cloutier, and Côté 2016; Harvell et al. 1999).

Although disease emergence in wild species of South America is underrepresented in the scientific literature (Tompkins et al. 2015), this continent is not exempt from the global trend. For example, a cetacean morbillivirus has recently been associated with mass mortality in Guiana dolphins (*Sotalia guianensis*) in Brazil (Groch et al. 2018) and *Corynebacterium*

pseudotuberculosis is currently affecting the endangered huemul deer (*Hippocamelus bisulcus*) in Chile (Morales et al. 2017).

Further, the globally emerging sarcoptic mange (Astorga et al. 2018), caused by the burrowing mite *Sarcoptes scabiei*, has been anecdotally reported in wild mammals of Chile (Verdugo et al. 2016; Alvarado, Skewes, and Brevis 2004), including within protected areas (C. Cunazza and Diaz 2014; López Jiménez 2018). Worryingly, this skin disease can have catastrophic effects on wild populations as seen in other places around the world (Martin et al. 2017). It is therefore of concern that Chilean stakeholders increasingly perceive alopecic native mammals, a classic presentation of *S. scabiei* infestation, as more common and more broadly spread across the country. However, with no formal national system in place to monitor wildlife health in Chile and no centralized repository of information on disease in Chilean wildlife, tracking sarcoptic mange (or other diseases) over relevant temporal and spatial scales becomes a very difficult task. Moreover, efforts to generate such data country-wide have not been made. These deficiencies and patchy data inherently limit the capability to confirm perceptions and effectively inform policy. If sarcoptic mange is a growing problem in Chile, then public and private action to prevent biodiversity impacts is warranted.

Here, we aimed to describe the trend of sarcoptic mange in Chilean wildlife over the last 15 years within protected areas as well as the location of cases in non-protected landscapes at the country level. To fulfill these objectives, we relied on abnormal alopecia, the highly visible main characteristic of sarcoptic mange, to establish a definition of a probable case. With this case definition, we tracked probable infested mammals over time and space in protected areas of Chile. Moreover, we combined multiple independent sources of information to also identify alopecic wild mammals outside protected areas and summarize their locations in this country. Finally, we assessed the validity of alopecia to define a case of sarcoptic mange by testing individuals with abnormal hair loss admitted to rehabilitation centers and quantify the likelihood of occurrence of

S. scabiei in these probable cases. We discuss the implications of our findings for mammal conservation and the need for a National Wildlife Health Surveillance program in Chile.

Material and methods

Procedures involving human participants were limited to surveys and conducted in accordance with the ethical standards of the University of California, Davis, Institution Review Board (Protocol # 1320102-1).

a) Description of abnormal alopecia trend in protected areas over the last 15 years

Through an anonymous survey (S1) we collected information on wild mammals observed with abnormal hair loss (from here on alopecia) within Chilean public protected areas over the past 15 years. Selected protected areas included National Parks, National Reserves, and National Monuments with permanent park-ranger presence. The web-based survey was sent through the Chilean National Forest Service (known as "CONAF" from the Spanish "Corporación Nacional Forestal") to the head-ranger of each protected area. Specifically, the survey inquired about live and dead wild mammals sighted or found with alopecia (yes-no) between 15-10 (2004-2008), 10-5 years ago (2009-2013), and within the last 5 years (2014-2018) in the protected area. We also requested the number of individuals per species sighted with this condition per time period within the categories: 1-5, 5-20 and more than 20 individuals. The survey included pictures of Chilean wild mammals with abnormal, sarcoptic mange-like hair loss to avoid reports of animals undergoing seasonal molt (S1). Prior to deployment, the survey was improved with voluntary feedback from 2 rangers. The survey was available for response over the last 2 months of 2018. If the surveyed head-rangers had not been in that position for the 15-year period, we requested

them to submit the historical information of the corresponding protected area, based on internal records.

b) Location of probable and confirmed sarcoptic mange cases across the country

To construct a summary of the recent location of probable (abnormal alopecia) and clinically diagnosed *S. scabiei* cases in Chilean wild mammals, we used the information provided by the head-ranger of the protected areas surveyed (the last 5 years); citizen reports; digital news outlets and wildlife rehabilitation centers. We built a web-based platform that allowed citizens to anonymously report alopecic wild mammals across the country (www.salud-silvestre.uchile.cl). We communicated the existence of this website and its purpose to appropriate stakeholders, and we created a social media webpage ("Salud Silvestre Chile") to create awareness of this project. Reports required details on the species sighted, the date and place (District and Province) of the sighting, and at least one picture of the affected animal. This picture allowed confirmation of the species and actual alopecia by the authors. Reports not including at least one picture, or with pictures not showing clear alopecia, or with alopecia not resembling abnormal hair loss (e.g., seasonal molting) were disregarded. We included reports received between January 2017 through August 2019.

We searched the internet for cases of sarcoptic mange in wildlife reported in digital news outlets by using combinations of the keywords "zorro" (fox), "guanaco" (guanaco), "vicuña" (vicuna) "enfermedad" (disease), "sarna" (mange), and "Chile". We chose these species because members of the genus *Lycalopex* (foxes) and South American camelids (guanaco and vicuna; *Lama guanicoe* and *Vicugna vicugna*, respectively) were the most common wild species with alopecia according to the other information sources. In this data subset we included only those cases that were not observed or found in protected areas to avoid duplication with the survey.

Finally, we used a previously compiled dataset from five wildlife rehabilitation centers in Chile that covered the period 2011-2015 (Romero et al. 2019) and requested new information from these centers and an additional one to include newer data. Specifically, we solicited records from mammals admitted since 2016 fulfilling the case definition of abnormal alopecia. For each case, we asked for the geographic origin, species affected, and the date of capture or admittance. We also solicited relevant clinical information, such as the presence, extent, and severity of skin/hair lesions, body condition, and the presence of ectoparasites (e.g., fleas and ticks) at the initial clinical examination.

c) Validity of alopecia to define a case of sarcoptic mange

To assess the validity of abnormal alopecia for sarcoptic mange case definition we requested skin scrapes from animals with abnormal alopecia admitted to the rehabilitation centers mentioned above. Samples retrieved were assessed for the presence of mites. *S. scabiei* was confirmed microscopically in mite-positive samples following standard guidelines (Fain 1968). Further, one mite was selected from each positive animal for DNA extraction and genetic confirmation. Genomic DNA was extracted using a NucleoSpin Tissue kit (Macherel-Nagel) following the manufacturer's instructions. We conducted PCR to amplify the ITS-2 gene (450 bp (base pairs) fragment) using primers RIB-18 and RIB-3 and conditions described in (Zahler et al. 1999) and the 16S rRNA gene (360 bp fragment) using primers 16SD1 and 16SD2 and conditions described in (Walton et al. 2004). The PCR products were electrophoresed in 1.5% agarose gel stained with Sypro Red Protein Gel Stain. PCR fragments were sequenced in both directions at Catholic University Sequencing Unit (Santiago, Chile), inspected and aligned using software Geneious 11.0.5 (Kearse et al. 2012). Sequences were compared to those available in GenBank (National Center for Biotechnology Information, National Institutes of Health, Bethesda, Maryland, USA) using the Basic Local Alignment Search Tool to confirm the species.

Once we had a definitive diagnosis of sarcoptic mange in the tested wild mammals that fulfilled our case definition, we assessed the likelihood of *S. scabiei* infestation in these individuals under different levels of "true prevalence" of this mite. For this purpose, we assumed a binomial distribution parameterized by n, the number of animals fulfilling our case definition that were admitted to the rehabilitation centers and PCR-tested for sarcoptic mange, and $\hat{p}$, the potential prevalence (in proportion) of *S. scabiei* infestation in wild mammals with abnormal alopecia.

The datasets are available at https://figshare.com/s/7c99a6f010278f8325e9.

Results

a) Description of abnormal alopecia trend in protected areas over the last 15 years

We received responses from 53 of the 86 PAs with a permanent ranger (61.2%). We excluded Juan Fernandez Archipelago National Park because it is not in continental Chile. Therefore, we report the results from 52 protected areas. Examples of alopecic wild mammals observed by the rangers are shown in S3. A total of 13 protected areas (25.80%) across all zones in Chile reported the presence of wild mammals, dead or alive, with alopecia at least once during the last 15 years (for a visualization of the zones see S2 Fig). Specifically, 3, 2, 4, and 4 protected areas reported at least one observation in the North, North-Central, Central, and Austral Zones. Four of the 48 protected areas existing during 2004-2008 (between 15 – 10 years ago) were positive (8.33%). Three of these areas are located in Central Chile while the remaining one is located in the Austral zone. Six of the 51 protected areas existing during 2009-2013 (between 10 – 5 years ago) were positive (11.76%). These protected areas were located in the North (n=2), North-Central (n=1), and Central zones (n=3). Four of these protected areas were new positives (0.078 incidence proportion). Finally, during the last five years, alopecic wild mammals, dead or alive, were

observed in 11 of the 52 protected areas existing during 2014-2018 (21.15%) ranging from the North to the Austral zones of the country, except in the South Zone. Six of them were new positives with respect to the previous period (0.115 incidence proportion). If we only consider the 48 protected areas that were at risk for the entire 15 year timeframe, then percentages of affected protected areas were: 8.33% (n=4), 12.5%, (n=6) and 20.83% (n=10), whilst the incidence proportion for the last 2 periods was 0.083 and 0.104, respectively. The location of protected areas with reports of alopecic wild mammals, dead or alive, per time period are shown in Fig 1A. To facilitate visualization, this figure highlights the Provinces containing protected areas with alopecic mammals, but we acknowledge that these individuals were not necessarily present across the entire provincial territories.

A summary of all the wild species reported with abnormal alopecia per period of time is shown in Table 1. The most frequently reported native mammal species were foxes (*Lycalopex sp.*) and South American camelids (guanaco; *Lama guanicoe* and vicuna; *Vicugna vicugna*). Alopecic Chilla foxes (*L. griseous*) *and* Andean foxes (*L. culpaeus*) were observed in 9 protected areas across zones except in the South (4 and 7 protected areas per species, respectively) while *L. guanicoe* and *V. vicugna* were reported in 5 protected areas in the North, North-Central and Austral zones (3 and 4 total protected areas per species, respectively). Provinces containing protected areas with reports for these taxa per time period are shown in Fig. 1B-C. The reports of these two groups (foxes, South American camelids) across the 15 years period follows the general pattern: the number of protected areas with abnormally alopecic individuals increased over time (Fig 1A). The abundance categories reported were 1-5 affected animals in most cases, though 5–20 affected South American camelids were reported twice during the two most recent time periods (10–5 and last 5 years; Table 1).

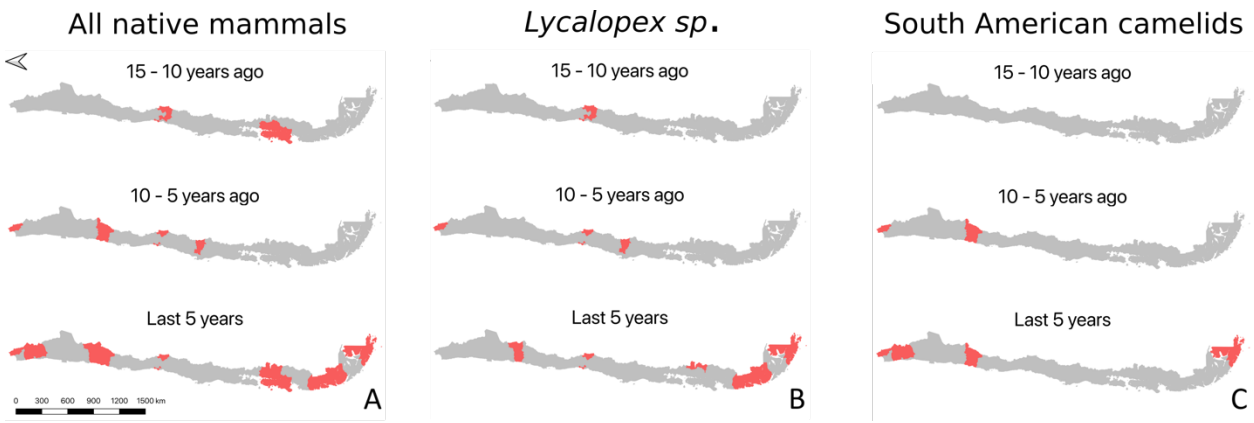

Fig 1A-C. Location of alopecic native mammals, *Lycalopex* foxes, and South American camelids respectively, within protected areas during three time periods. The red polygons show the Provinces containing protected areas with records of alopecic wild mammals over time. We present the information at this scale to facilitate visualization.

b) Location of probable and confirmed sarcoptic mange cases across the country

We received 14 valid web-based citizen reports of alopecic wild mammals during a 32-month period. These animals were sighted between January 2013 and August 2019 from North-Central to Austral Chile, covering 12 Provinces. *Lycalopex sp*. were the group most commonly reported (Table 2). These individuals showed hair loss and hyperkeratosis, some of them were emaciated, and one had a rectal prolapse. In most cases, the appearance of these foxes resembled typical *S. scabiei* infestation. Furthermore, the cururo (*Spalacopus cyanus*) and pudu (*Pudu puda*) also presented evident hair loss. The photographs are available at https://figshare.com/s/e5853b619495bd0a7cdf. Three reports were disregarded because pictures were absent or abnormal alopecia was arguable.

Table 1. Number of protected areas in which wild mammals were reported with abnormal alopecia per period of time and the abundance of affected individuals per species and time.

Species (common name)	Live or dead	Number of protected areas with alopecic mammals*.		
		15 – 10 years ago (number of cases)	10 – 5 years ago (number of cases)	During the last 5 years (number of cases)
Conepatus chinga (Molina'shog-nosed skunk)	Live			1 (1 – 5)
Hippocamelus bisulcus (Huemul deer)	Live			1 (1 – 5)
Lama guanicoe (Guanaco)	Live		2 (1 – 5)	2 (1 – 5 and 5 – 20)
Vicugna vicugna (Vicuna)	Live		2 (1 – 5 and 5 – 20)	3 (1 – 5)
	Dead		2 (1 – 5)	3 (1 – 5)
Lycalopex culpaeus (Andean fox)	Live	2 (1 – 5)	1 (1 – 5)	5 (1 – 5)
	Dead	2 (1 – 5)	3 (1 – 5)	1 (1 – 5)
Lycalopex griseus (Chilla fox)	Live	1(1 – 5)		2 (1 – 5)
	Dead			1 (1 – 5)
Pudu puda (Pudu)	Live	1 (1 – 5)		1 (1 – 5)
Thylamys elegans (Yaca)	Dead	1 (1 – 5)		

*Includes protected areas created between 2004 and 2018.

Table 2. Mammal species with alopecia reported by citizens and the number of reports per species.

Species (common name)	Number of reports
Lycalopex culpaeus (Andean fox)	9
Lycalopex griseus (chilla fox)	3
Pudu puda (pudu)	1
Spalacopus cyanus (cururo)	1

We retrieved reports from digital news outlets on four *L. griseus* and three *L. culpaeus* that were either found with alopecia or clinically diagnosed with sarcoptic mange. These animals were observed in five Provinces of the Central zone and one of the South zone between 2012-2017, but three of them were clustered in 2016. The report from the South zone corresponds to a previously reported case of sarcoptic mange in *L. griseus* (Verdugo et al. 2016). The URLs for each case are provided in S4. We did not included outputs that were associated with CONAF news that provided information of *Lycalopex* foxes with abnormal alopecia in two protected areas of Central Chile. No reports on affected South American camelids were found in this information source. Further, we extracted reports from previously collected data (Romero et al. 2019) on five *L. culpaeus,* four *L. griseus*, and a single lesser grison (*Galictis cuja*) with alopecia admitted to three different rehabilitation centers between 2013 and 2015. Of these, four *L. culpaeus*, one *L. griseus*, and the single *G. cuja* were clinically diagnosed with *S. scabiei*. The Province of origin of these last nine animals was unknown but they all came from the Central zone. Finally, we gathered information from 12 additional *L. culpaeus* admitted to three rehabilitation centers between April 2016 and February 2019 that fulfilled our case definition. These animals presented

hyperkeratosis, pyoderma and emaciation and were all clinically diagnosed with sarcoptic mange. They were found in five Provinces from Central Chile and included two individuals observed in a protected area which was positive for alopecic mammals in the survey to park rangers. Fleas, ticks, and lesions caused by snare traps were additional findings reported in these cases.

Across data sources, *Lycalopex* was the most common group found with alopecia. Based on the dates of observation and their location (excluding cases with unknown origin), these animals were all unique cases. The location of alopecic *Lycalopex* individuals (Provinces) that we were able to trace combining all data sources and that have been observed since 2012 is shown in Fig 2. As previously, we acknowledge that these individuals were not necessarily present across the entire provincial territory, but we chose this scale to facilitate visualization. Finally, South American camelids were the second most common group reported with alopecia. All camelid cases were reported by park rangers.

c) Validity of alopecia to define a case of sarcoptic mange

Three rehabilitation centers provided skin samples from nine *L. culpaeus* that fulfilled our case definition (see above). Mites morphologically consistent with *S. scabiei* were isolated from all of them (S5 Fig). Direct sequencing in both directions of the internal transcribed spacer-2 amplicon from the first case produced a 404-base pair consensus product with 99.3% homology to *S. scabiei* (GenBank accession number A980753). Also, direct sequencing in both directions of the 16S rRNA amplicon of 331 base pair rendered a 99.7% homology with *S. scabiei* (GenBank accession number MF083740). Conventional PCR and sequencing performed on individual mites removed from the skin confirmed *S. scabiei* for three (for ITS-2) and four (16S) of the nine *L. culpaeus* cases.

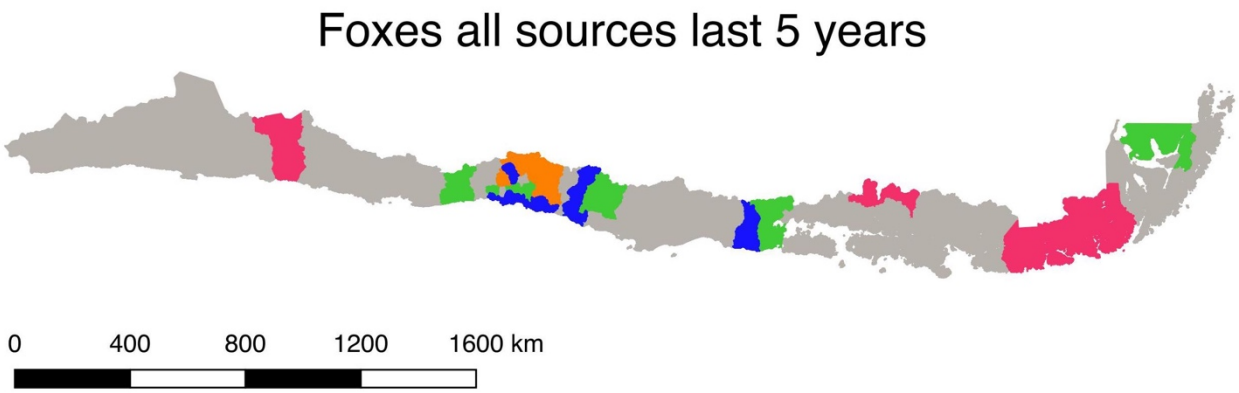

Fig 2. Location of alopecic *Lycalopex* foxes within and beyond protected areas since 2012. The red, green, blue, and orange colors show the Provinces that contain records of alopecic *Lycalopex* foxes according to park rangers, web-based reports by citizens, cases from news outlets, and foxes admitted to rehabilitation centers, respectively. This map also includes a previously reported case (Verdugo et al. 2016) but does not include nine *Lycalopex* sp. admitted to rehabilitation centers according to Romero et al. (2019) whose Province of origin is unknown. We present the information at this scale to facilitate visualization.

Given that all cases admitted to rehabilitation centers were *Lycalopex* foxes, we were only able to assess the validity of alopecia as a proxy for *S. scabiei* infestation in this group. A binomial outcome of nine *S. scabiei* infested foxes (successes) out of nine with alopecia (n=9) has a probability to occur ≥ 0.5 if at least 0.923 ($\hat{p}$) of the general population of alopecic foxes are, indeed, infested with this mite (Fig 3). The distance between the geographic origin of these nine foxes and their dates of admission suggests the independence of six foxes while the remaining three could be clustered. If this is correct and we consider this cluster as a single fox (for a total

of 7 theoretical successes), then our conclusions of a very high likelihood of *S. scabiei* infestation in alopecic foxes remain valid.

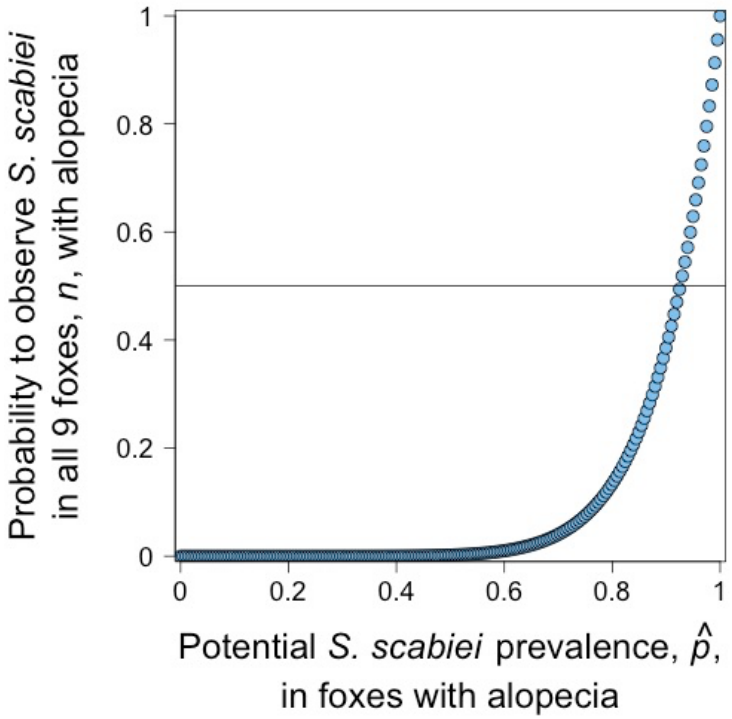

Fig 3. The probability of observing nine alopecic foxes (*n*) all of them infested with *Sarcoptes scabiei* under different potential sarcoptic mange prevalence, *p̂*. The horizontal line shows the 0.5 probability for this outcome.

Discussion

Herein we collated data from several sources to assess, to the extent that current information allows, the trend of alopecic wild mammals in Chilean protected areas over the past 15 years and to summarize the current location of affected animals within and beyond protected areas. We observed a potential increment in the number of protected areas in Chile in which wild mammals

with abnormal alopecia have been sighted during the last 15 years, and a broad presence of cases across most of the Chilean territory in recent times. Data also support an increasing number of species observed with abnormal alopecia and a potential increment of cases within specific taxa. This suggested trend follows the current global emergence of sarcoptic mange in wildlife (Niedringhaus et al. 2019; Astorga et al. 2018).

Lycalopex foxes were the group most commonly reported with abnormal alopecia and were present across all data sources and time periods. The information from the Chilean National Park Service (CONAF) suggests that the geographical location of protected areas presenting these individuals has increased over time. In the last 10 years these animals were observed in protected areas located beyond Chile's Central zone where they were thought to be restricted (C. Cunazza and Diaz 2014). The incorporation of other sources of information, including citizen reports, allowed us to centralize dozens of cases that were located broadly across the country. Further, we confirmed *S. scabiei* in alopecic *L. culpaeus* from Central Chile, consistent with previous reports in a *L. griseus* from the southern part of the country and in other non-Chilean *Lycalopex* species (Verdugo et al. 2016; Deem et al. 2002), and we showed that abnormal alopecia is a good indicator of sarcoptic mange in *L. culpaeus*.

CONAF data support that alopecic South American camelids (vicuna and guanaco) are currently found in a larger geographic extension compared to 15 years ago. *S. scabiei*-infested South American camelids have been previously reported in protected areas of the North Zone (López Jiménez 2018) and the North Central zone (Bonacic et al. 2014) in agreement with our survey results. Alopecia was first mentioned in the northern part of the North Central zone in 2002 (Zárate and Valencia 2010) but CONAF data presented here suggest a potential spread of the disease towards the southern area. Consistently, sarcoptic mange in this taxon has been increasingly described in recent times in Peru, Bolivia, and Argentina (Castillo 2018). In the Austral zone, specifically in Tierra del Fuego Island, sarcoptic mange in guanacos has been recognized previously (Alvarado, Skewes, and Brevis 2004).

Although our results tend to support an expanding trend of alopecic wild mammals (more species with individuals fulfilling our case definition that were observed in a larger number of protected areas) and *S. scabiei* is likely a parsimonious explanation for several of the cases observed, our survey is not without limitations. It is possible that self-selection bias occurred in the rangers that responded to the survey and that those rangers in protected areas with alopecic mammals were more likely to participate. Nevertheless, if this were true, the proportion of affected protected areas would be biased upwards but the suggested temporal and spatial trends would remain. We also relied on historical records to avoid recall bias of alopecic mammal sightings by park rangers; however, the "surveillance" efforts and storage of this information could be better now than 20 years ago. We were informed by CONAF that differences in surveillance efforts and data recording were highly unlikely for the last two periods when a potential increment in positive protected areas was observed.

Moreover, we advertised the web-platform to report alopecic wild mammals by several means and its value is justified in the recovery of alopecic cases that would otherwise not have been recorded. However, reporting may have been constrained by the visibility of alopecic animals or degree of public awareness. This first experience suggests that web-based citizen reporting seems to be more useful for wild species present in easily accessed human-modified landscapes such as *Lycalopex* foxes versus South American camelids. This could explain the reports mostly belonging to the former group but none of the latter.

Finally, we cannot claim that all alopecic mammals were infested with *S. scabiei*. Indeed, the reported huemul in the Austral Zone is probably an individual affected by *C. pseudotuberculosis* (Morales et al. 2017). We assessed the ability of alopecia to establish a probable sarcoptic mange case by formally testing alopecic wild mammals for *S. scabiei*. However, we only had access to foxes with abnormal alopecia that were admitted to wildlife rehabilitation centers and not free-ranging individuals. It is possible that *S. scabiei*-infested foxes are more likely to be captured and admitted into rehabilitation centers compared to other

conditions leading to abnormal alopecia. If so, then our results may not apply to the general "abnormally alopecic fox" population. Further, we did not have access to alopecic South American camelid samples to assess the ability of this sign to establish the probability of *S. scabiei* infestation. This is relevant because its use as a proxy to define a sarcoptic mange case in wildlife can be misleading (Valldeperes et al. 2019). However, park rangers are most likely capable of distinguishing normal molting from abnormal alopecia and the external appearance of confirmed South American sarcoptic mange cases from a recent outbreak in Argentina resemble the observations reported by CONAF, providing more support to *S. scabiei* infestation in these animals (S3; Ferreyra, 2019).

The data limitations mentioned above result from the fact that Chile, as is the case in all South American nations, does not have a National Wildlife Health Surveillance program (Pinto et al. 2008). The lack of such a program hinders the collection of representative data on disease and etiologies in native mammal populations; our understanding of the epidemic or endemic nature of diseases, seasonal trends, and eventual populations impacts; and, most importantly, the response and management of health-related and potentially conservation-threatening issues. These threats include pathogens that have recently been detected in Chilean wildlife involving endemic endangered species. For example, caseous lymphadenopathy, echinococcosis, and a parapoxvirus-associated foot disease in the endangered huemul deer (Morales et al. 2017; Hernández et al. 2019; Vila et al. 2019); and Chytridiomycosis in the endangered Darwin's frog (*Rhinoderma* spp.; Soto-Azat et al. 2013). Moreover, several other pathogens have been sporadically detected in Chilean wildlife within protected areas (C. Cunazza and Diaz 2014; López Jiménez 2018) the status, trend, and relevance of which remain unknown.

Considering that several reports we collated correspond to confirmed and probable sarcoptic mange, its etiology, the mite *S. scabiei*, is a multi-host pathogen (Bornstein, Mörner, and Samuel 2001), whose transmission may behave in a frequency-dependent manner (Devenish-Nelson et al. 2014), and infested hosts present a long infectious period. These traits

have been associated with easier disease spread and disease-mediated extinction (Cross et al. 2005; De Castro and Bolker 2005). Indeed, this mite is continuously reported in new species (Gonzalez-Astudillo et al. 2018), it can devastate populations of wild species (Martin et al. 2017) and it is currently considered a global emerging threat for wildlife conservation (Astorga et al. 2018). Further, *S. scabiei* may interact with other conservation threats or it could generate fragmented populations susceptible to stochastic events.

Lycalopex is a Neotropic endemic genus that belongs to a taxonomic family with worldwide records of *S.scabiei*-driven extirpations or near extirpations of common and endangered species (Lindström and Others 1991; Soulsbury et al. 2007; Uraguchi, Ueno, and Iijima 2014; Henriksen et al. 1993; León-Vizcaíno et al. 1999; Pence and Ueckermann 2002). In Chile, *L. culpaeus* and *L. griseus* fulfill the description of the first group, while the endemic and endangered Darwin´s fox (*Lycalopex fulvipes*) and the endemic and vulnerable Fuegian culpeo (*L. c. lycoides*), certainly belong to the second category (Silva-Rodríguez et al. 2016; Ministerio del Medio Ambiente 2011). These two endangered foxes would be highly at risk from any lethal disease outbreak. Of concern, mite-associated morbidity has recently been reported in these two foxes (Briceño et al. 2020).

In the case of South American camelids, sarcoptic mange is considered a main threat for this group in Chile (Bonacic et al. 2014; Zárate and Valencia 2010; Vargas, Bonacic, and Moraga 2016). An ongoing sarcoptic mange outbreak has nearly caused the local extinction of vicuna and guanaco in San Guillermo National Park in Argentina (Ferreyra, 2019), revealing the potential consequences of *S. scabiei* in these species. In addition to this infectious threat, the guanaco could become extinct in three of the five countries where it is currently present, projections for the conservation of South American camelids in the Chilean North Central zone are not optimistic, and Chilean coastal populations have rapidly declined (Bonacic et al. 2014; Zárate and Valencia 2010; Vargas, Bonacic, and Moraga 2016; González and Acebes 2016).

Despite being previously recognized in Chile and representing a potential threat for Chilean wildlife, data on *S. scabiei* in *Lycalopex sp.* and South American camelids are remarkably

precarious and this is the first attempt to describe the spatio-temporal status of this disease nationwide. Our findings, the potential consequences of this disease, and the absence of robust *S. scabiei* data further reinforce the need of a National Wildlife Health Surveillance program.

Furthermore, it is anticipated that disease emergence will occur more often in wild species globally as a result of human-mediated movement of pathogens, parasites, and domestic hosts, and concurrent changes in the environment including habitat destruction and the climate emergency (Daszak, Cunningham, and Hyatt 2000; Tompkins et al. 2015). These drivers are occurring in Chile. For example, 30% of native temperate forest was lost during the last three decades (Zamorano-Elgueta et al. 2015) and 69% of mammals were already threatened by habitat destruction in Central Chile twenty years ago (Simonetti 1999). Consequently, new disease events in Chilean native species should be expected in the upcoming years.

Based on our previous arguments we encourage the urgent convening of an intersectoral working group of private stakeholders, academia, and public agencies with the goal of establishing a National Wildlife Health Surveillance program in Chile. Existing uncertainties with respect to sarcoptic mange levels and trends and the potential threat posed by this disease justify its prompt launch and provides an opportunity for capacity-building and trouble-shooting during start-up. Such a program should fulfill the attributes, purposes, and roles recently proposed by experts (Stephen et al. 2018) and should engage domestic animal and human health sectors as well as conservation and biodiversity constituents through a One Health approach. Government-led wildlife health programs have had remarkable positive influences on the conservation of species as well as on public health (Brand 2013; Kuiken et al. 2005; Reif 2011). Although there is an incipient valuable pilot effort lead by the Chilean National Park Service to monitor diseases, it only covers some protected areas and several components need to be expanded or substantially improved to generate a functional country-level Wildlife Health Program (P. Cunazza, Díaz, and Vera 2015; Aizman, Díaz, and López 2016).

Nations failing to properly prepare to confront pathogen threats in wildlife may expect to experience catastrophic outcomes for conservation as described worldwide (De Castro and Bolker, 2005). Moreover, governments should strive towards fulfilling their responsibilities to meet societal needs and obligations in their role as keepers of a public good.

Conclusions

Alopecic wild mammals seem to have become more common in Chile and observed in an increasing area of the country during the last 15 years. Sarcoptic mange is a likely cause at least in the genus most commonly reported with alopecia, *Lycalopex,* and in South American camelids. Based on these findings and the catastrophic consequences this disease has had worldwide, we encourage the establishment of a National Wildlife Health Surveillance program in Chile. Such program is also justified by the recent detection of pathogens causing morbidity and mortality in native species, including the iconic Huemul deer, classified as endangered in the IUCN's Red List.

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References

Aizman F, Díaz M, and López G. 2016. Proyecto piloto para la instalación en una región del país de un sistema de manejo de salud/enfermedad en fauna vertebrada residente del SNASPE regional. Corporación Nacional Forestal.

Alvarado L, Skewes O, Brevis C. 2004. Estudio de sarna clínica en guanaco (*Lama guanicoe*) silvestre, en el sector centro-sur de Isla Tierra del Fuego, Chile. DVM Thesis, Facultad de Medicina Veterinaria, Universidad de Concepción, Chillán, Chile.

Astorga F, Carver S, Almberg ES, Sousa GR, Wingfield K, Niedringhaus KD, Peach Van Wick, et al. International meeting on sarcoptic mange in wildlife, June 2018, Blacksburg, Virginia, USA. Parasit Vectors. 2018. 11, 449.

Bonacic C, Bonacic D, Muñoz A, Riveros JL, Vargas S. 2014. Estrategia Multisectorial para la Conservación de Camélidos Silvestres Sudamericanos de la Región de Atacama. Laboratorio Fauna Australis, Facultad de Agronomía e Ingeniería Forestal, Pontificia Universidad Católica de Chile.

Bornstein S, Mörner T, Samuel WM. *Sarcoptes scabiei* and sarcoptic mange. 2001. In: Samuel WM, Pybus MJ, Kocan AA (editors) Parasitic Diseases of Wild Mammals, Ames, IA: Iowa State University Press. 2001; pp 107–119.

Brand CJ. 2013. Wildlife mortality investigation and disease research: Contributions of the USGS National Wildlife Health Center to endangered species management and recovery. EcoHealth. 10, 446–454.

Briceño C, González-Acuña D, Jiménez JE, Bornscheuer ML, Funk SM, Knapp LA. 2020. Ear mites, *Otodectes cynotis*, on wild foxes (*Pseudalopex spp*) in Chile. J Wildl Dis. 56, 105-112.

Castillo H. 2018. Implicancias sanitarias en el manejo sostenible de camélidos sudamericanos silvestres. Sarna y otras enfermedades producidas por parásitos. Grupo especialista camélidos sudamericanos News 7.

Cross PC, Lloyd-Smith JO, Johnson PLF, Getz WM. 2005. Duelling timescales of host movement and disease recovery determine invasion of disease in structured populations. Ecol Lett. 8, 587–595.

Cruces Larraín CA. 2013. Descripción de perros con sarna sarcóptica atendidos en el Centro de Salud Veterinaria El Roble. Universidad de Chile.

Cunazza P, Díaz M, Vera C. 2015. Criterios y lineamientos para el manejo de la amenaza “enfermedad” en fauna vertebrada residente en el SNASPE. Corporación Nacional Forestal.

Cunazza C, Diaz M. 2014. Catastro nacional descriptivo sobre enfermedades de la fauna vertebrada presente en las áreas silvestres protegidas del Estado y definición de recomendaciones generales para su manejo. Corporación Nacional Forestal.

Daszak P, Cunningham AA, Hyatt AD. 2000. Emerging infectious diseases of wildlife--threats to

biodiversity and human health. Science. 287, 443–449.

De Castro F, Bolker B. 2005. Mechanisms of disease-induced extinction. Ecol Lett. 8, 117–126.

Deem SL, Noss AJ, Cuéllar RL, Villarroel R, Linn MJ, Forrester DJ. 2002. Sarcoptic mange in free-ranging pampas foxes in the Gran Chaco, Bolivia. J Wildl Dis. 38, 625–628.

Devenish-Nelson ES, Richards SA, Harris S, Soulsbury C, Stephens PA. 2014. Demonstrating frequency-dependent transmission of sarcoptic mange in red foxes. Biol Lett. 10: 20140524.

Fain A. 1968. Étude de la variabilité de *Sarcoptes scabiei* avec une révision des Sarcoptidae. Acta Zoologica et Pathologica Antverpiensia. 1968, 1–196.

Ferreyra H. 2019 Caracterización de un brote se sarna en camélidos silvestres del Parque Nacional San Guillermo, San Juan. MSc. Thesis. Universidad Nacional de Córdoba.

Gonzalez-Astudillo V, Leon-Alvarado OD, Ossa-Lopez PA, Rivera-Paez FA, Ramírez-Chaves HE. 2018. Sarcoptic mange in wild quichua porcupines (*Coendou quichua* Thomas, 1899) in Colombia. Int J Parasitol Parasites Wildl. 7, 95–98.

González BA, Acebes P. 2016. Reevaluación del guanaco para la Lista Roja de la UICN: situación actual y recomendaciones a futuro. Grupo especialista camélidos sudamericanos News. 6, 15–20.

Groch KR, Santos-Neto EB, Díaz-Delgado J, Ikeda JMP, Carvalho RR, Oliveira RB, Emi B. Guari, et al. Guiana dolphin unusual mortality event and link to cetacean morbillivirus, Brazil. 2018.

Emerg Infect Dis. 24, 1349–1354.

Harvell CD, Kim K, Burkholder JM, Colwell RR, Epstein PR, Grimes DJ, Hofman, EE, et al. 1999. Emerging marine diseases--climate links and anthropogenic factors. Science. 285, 1505–1510.

Harvell CD, Montecino-Latorre D, Caldwell JM, Burt JM, Bosley K, Keller A, et al. 2019. Disease epidemic and a marine heat wave are associated with the continental-scale collapse of a pivotal predator (*Pycnopodia helianthoides*). Science Advances. 5: eaau7042.

Henriksen P, Dietz HH, Henriksen SA, Gjelstrup P. 1993. Sarcoptic mange in red fox in Denmark. Dansk Veterin. 76: 12–13.

Hernández F, Verdugo C, Cárdenas F, Sandoval R, Morales N, Olmedo P, Bahamonde A, et al. 2019. *Echinococcus granulosus* in the Endangered Patagonian Huemul (*Hippocamelus bisulcus*). J Wildl Dis. 55, 694-698.

Kearse M, Moir R, Wilson A, Stones-Havas S, Cheung M, Sturrock S, Buxton, S, et al. 2012. Geneious Basic: an integrated and extendable desktop software platform for the organization and analysis of sequence data. Bioinformatics. 28, 1647–1649.

Kuiken T, Leighton FA, Fouchier RAM, LeDuc JW, Peiris JSM, Schudel A, et al. 2005. Public health. Pathogen surveillance in animals. Science. 309, 1680–1681.

León-Vizcaíno L, Ruíz de Ybáñez MR, Cubero MJ, Ortíz JM, Espinosa J, Pérez L, Simon MA, and Alfonso, F. 1999. Sarcoptic mange in Spanish ibex from Spain. J Wildl Dis. 35, 647–659.

Lindström ER. 1991. Pattern and spread and effects of sarcoptic mange among red fox

populations in Sweden. In: Global Trends in Wildlife Management. Bobek B, Perzanowski K, and Reglin WL (editors), Proceedings of the Eighteenth International Union of Game Biologists, Krakow, Poland. 1, 591–595.

López Jiménez GB. Catastro y registro de la distribución de patógenos identificados en mamíferos nativos amenazados de Chile, asociándolos al Sistema Nacional de Areas Silvestres Protegidas del Estado. Universidad de Chile. 2018. Available: http://repositorio.uchile.cl/handle/2250/159249.

Martin AM, Burridge CP, Ingram J, Fraser TA, Carver S. 2017. Invasive pathogen drives host population collapse: effects of a travelling wave of sarcoptic mange on bare-nosed wombats. J Appl Ecol. 00, 1–11.

Ministerio del Medio Ambiente. 2011. Aprueba y oficializa la clasificación de especies según su estado de conservación, quinto proceso. Decreto Número 33.

Morales N, Aldridge D, Bahamonde A, Cerda J, Araya C, Muñoz R, et al. 2017. *Corynebacterium pseudotuberculosis* Infection in Patagonian huemul (*Hippocamelus bisulcus*). J Wildl Dis. doi:10.7589/2016-09-213.

Niedringhaus KD, Brown JD, Sweeley KM, Yabsley, MJ. 2019. A review of sarcoptic mange in North American wildlife. Int J Parasitol Parasites Wildl. 9, 285-297.

O'Hanlon SJ, Rieux A, Farrer RA, Rosa GM, Waldman B, Bataille A, 2018, et al. Recent Asian origin of chytrid fungi causing global amphibian declines. Science. 360, 621–627.

Pence DB, Ueckermann E. 2002. Sarcoptic manage in wildlife. Rev Sci Tech. 21, 385–398.

Pereira Olivares DL. 2017. Estudio descriptivo retrospectivo de casos de perros con enfermedades dermatológicas parasitarias en el Hospital Clínico Veterinario de la Universidad de Chile, período 2001-2013. Universidad de Chile.

Pinto J, Bonacic C, Hamilton-West C, Romero J, Lubroth J. 2008. Climate change and animal diseases in South America. Rev Sci Tech. 27, 599–613.

Reif JS. Animal sentinels for environmental and public health. 2011. Public Health Rep. 126, 50–57.

Romero F, Espinoza A , Sallaberry-Pincheira N, Napolitano C. 2019. A five-year retrospective study on patterns of casuistry and insights on the current status of Wildlife Rescue and Rehabilitation Centers in Chile. Rev. Chil. Hist. Nat. 92, 1-6.

Schultz JA, Cloutier RN, Côté IM. 2016. Evidence for a trophic cascade on rocky reefs following sea star mass mortality in British Columbia. 2016. PeerJ. 4: e1980.

Silva-Rodríguez EA, Farías AA, Moreira-Arce D, Cabello J, Hidalgo-Hermoso E, Lucherini M, et al. *Lycalopex fulvipes*. The IUCN Red List of Threatened Species.

Simonetti JA. 1999. Diversity and conservation of terrestrial vertebrates in. Revista Chilena de Historia Natural. 72, 493–450.

Soto-Azat C, Valenzuela-Sánchez A, Clarke BT, Busse K, Ortiz JC, Barrientos C, et al. 2013. Is chytridiomycosis driving Darwin's frogs to extinction? PLoS One. 8, e79862.

Soulsbury CD, Iossa G, Baker PJ, Cole NC, Funk SM, Harris S. 2007. The impact of sarcoptic mange *Sarcoptes scabiei* on the British fox *Vulpes vulpes* population. Mamm Rev. 37, 278–296.

Stephen C, Sleeman J, Nguyen N, Zimmer P, Duff JP, Gavier-Widén D, et al. 2018. Proposed attributes of national wildlife health programmes. Revue Scientifique et Technique-Office International des Epizooties. 37, 925-936.

Tompkins DM, Carver S, Jones ME, Krkošek M, Skerratt LF. 2015. Emerging infectious diseases of wildlife: a critical perspective. Trends Parasitol. 31, 149–159.

Uraguchi K, Ueno M, Iijima H. 2014. Demographic analyses of a fox population suffering from sarcoptic mange. J Wildl Manage. 8, 1356-1371.

Valldeperes M, Granados JE, Pérez JM, Castro I, Ráez-Bravo A, Fandos P, et al. 2019. How sensitive and specific is the visual diagnosis of sarcoptic mange in free-ranging Iberian ibexes? Parasites Vectors. 12, 405.

Vargas S, Bonacic C, Moraga C. 2016. Recopilación preliminar de registros de amenazas actuales a las poblaciones de camélidos silvestres en la zona Centro-Norte de Chile. GECS News. 6, 22–27.

Verdugo C, Espinoza A, Moroni M, Valderrama R, Hernandez C. 2016. Sarcoptic mange in a South American gray fox (Chilla Fox; *Lycalopex griseus*), Chile. J Wildl Dis. 52, 738–741.

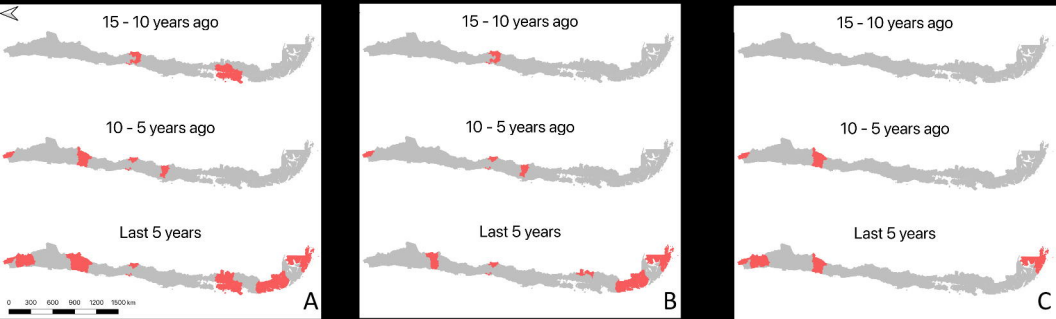
Vila AR, Briceño C, McAloose D, Seimon TA, Armién AG, Mauldin EA, et al. 2019. Putative parapoxvirus-associated foot disease in the endangered huemul deer (*Hippocamelus bisulcus*) in Bernardo O'Higgins National Park, Chile. PlosOne. 14, e0213667.

Walton SF, Dougall A, Pizzutto S, Holt D, Taplin D, Arlian LG, et al. 2004. Genetic epidemiology of *Sarcoptes scabiei* (Acari: Sarcoptidae) in northern Australia. Int J Parasitol. 34, 839–849.

Zahler M, Essig A, Gothe R, Rinder H. 1999. Molecular analyses suggest monospecificity of the genus *Sarcoptes* (Acari: Sarcoptidae). Int J Parasitol. 29, 759–766.

Zamorano-Elgueta C, Rey Benayas JM, Cayuela L, Hantson S, Armenteras D. 2015. Native forest replacement by exotic plantations in southern Chile (1985–2011) and partial compensation by natural regeneration. For Ecol Manage. 345, 10–20.

Zárate R, Valencia JC. Enfermedades del guanaco en vida silvestre. 2010. Plan Nacional de Conservacion del Guanaco Lama guanicoe, Müller, 1776 en Chile 2010 - 2015 Macrozona Norte y Centro. Corporacion Nacional Forestal. pp. 21–22.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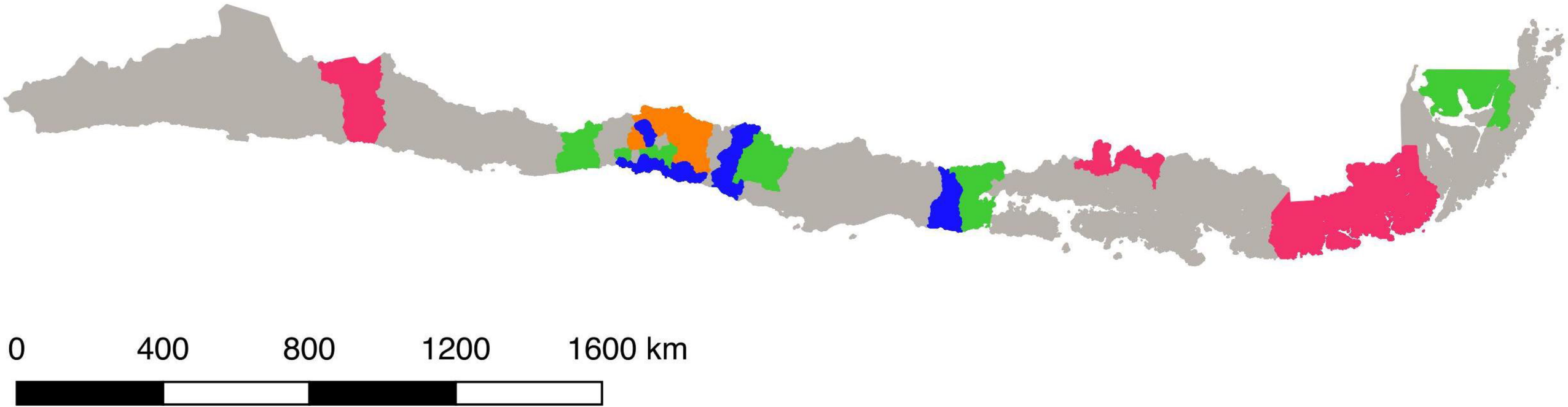

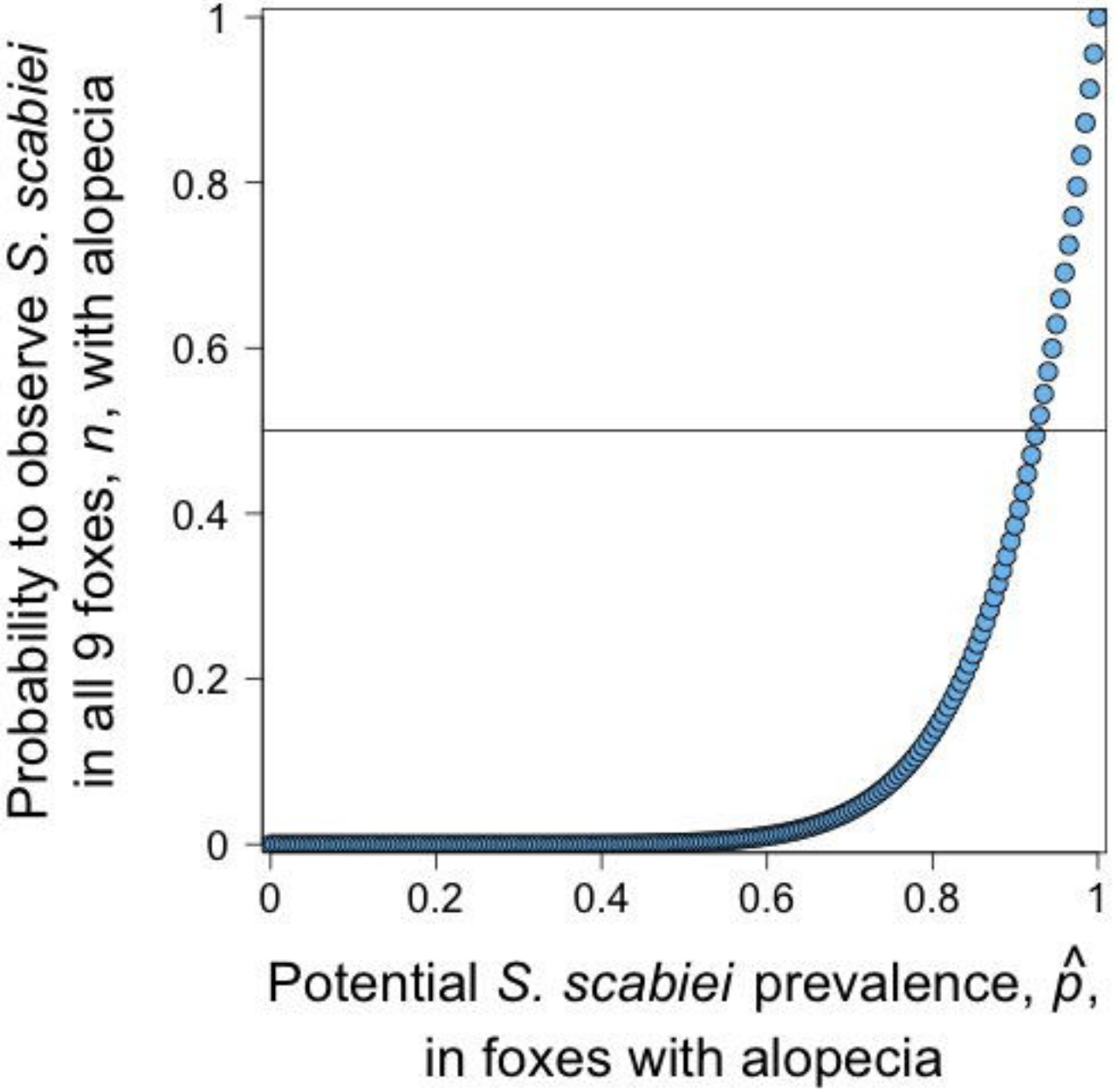
Probability to observe S. scabiei in all 9 foxes, n, with alopecia
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1
Potential S. scabiei prevalence, p̂, in foxes with alopecia