Discover Animals

RESEARCH Open Access

Integrating scientometric analysis and zoo population data to identify knowledge and conservation gaps in three Neotropical canids

Leandro Ferreira Costa[1], Gabriela Ramos[2], Gustavo Nunes de Almeida[3], Luiza Figueiredo Passos[4], Cristiano Schetini de Azevedo[1*] and Maria Rita Silvério Pires[1]

*Correspondence:
Cristiano Schetini de Azevedo
cristiano.azevedo@ufop.edu.br
[1]Departamento de Biodiversidade, Evolução e Meio Ambiente, Instituto de Ciências Exatas e Biológicas, Universidade Federal de Ouro Preto, Campus Morro do Cruzeiro, s/n, Bauxita, Ouro Preto, Minas Gerais 35402-136, Brazil
[2]Programa de Pós-graduação em Ecologia de Biomas Tropicais, Instituto de Ciências Exatas e Biológicas, Universidade Federal de Ouro Preto (UFOP), Campus Morro do Cruzeiro, s/n, Bauxita, Ouro Preto, Minas Gerais 35402-136, Brazil
[3]Programa de Pós-graduação em Ciência Animal, Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista Júlio Mesquita Filho, Campus Jaboticabal, Via de Acesso Prof. Paulo Donato Castellane, s/n, Jaboticabal, São Paulo 14884-900, Brazil
[4]School of Biological and Environmental Sciences, Liverpool John Moores University, James Parsons Building, L3 3AF, Liverpool, UK

Abstract

This study provides an overview of the scientific literature and zoo distribution data for three threatened canid species in Brazil: the short-eared dog (*Atelocynus microtis*), the hoary fox (*Lycalopex vetulus*), and the bush dog (*Speothos venaticus*), for which the extent of knowledge on biology, ecology, and ex-situ management remains unclear, highlighting the need for systematic evaluation. A scientometric analysis of articles published between 1975 and 2023 was combined with an assessment of Zoological Information Management System (ZIMS) data on ex-situ populations. A total of 433 articles were identified, of which 168 were selected. Because some studies included more than one species, species-specific counts were not mutually exclusive and comprised 16 articles on the short-eared dog (*Atelocynus microtis*), 47 on the hoary fox (*Lycalopex vetulus*), and 105 on the bush dog (*Speothos venaticus*). Scientific production began in 1981 and increased steadily over time, with the bush dog being the most studied species and the short-eared dog the least. The short-eared dog was not represented in the ZIMS database. Most studies were conducted in-situ (116; 61.38%), followed by ex-situ (60; 31.74%), with only two combining both approaches (1.06%). Research spanned 13 areas, with parasitology (31; 18.45%) and conservation (28; 16.67%) being the most represented. Despite advances, including reproductive and behavioural studies in captivity, knowledge remains uneven across aspects of biology, ecology, and behaviour, particularly in integrating ex-situ and in-situ information. These limitations may hinder the refinement of management and conservation strategies. This study highlights the need for targeted research that combines field-based studies and strategically designed ex-situ investigations to strengthen conservation planning.

Keywords Conservation, Ex-situ, In-situ, Canidae, ZIMS

© The Author(s) 2026. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

1 Introduction

The family Canidae (Mammalia, Carnivora) comprises 36 living species, including domestic dogs, wolves, jackals, coyotes, and foxes, of which five are classified as Endangered or Critically Endangered in the global IUCN Red List, which provides worldwide conservation status assessments [1]. In Brazil, six canid species occur, occupying a wide range of habitats, including the Cerrado, Amazon, Pampas, and transitional and fragmented landscapes [1–6]. Four of these species, the maned wolf (*Chrysocyon brachyurus*), the short-eared dog (*Atelocynus microtis*), the bush dog (*Speothos venaticus*), and the hoary fox (*Lycalopex vetulus*), are classified as Vulnerable (VU) at the national level [7]. Across these species, major threats include habitat loss due to agricultural expansion, urbanisation and road development, as well as the spread of diseases associated with domestic animals [7–10].

Despite shared conservation challenges, scientific knowledge is unevenly distributed among Brazilian canids. A substantial body of research is available for the maned wolf, including comprehensive reviews across multiple areas of knowledge [11–13], whereas the remaining species have received comparatively less attention [1, 2, 14]. Within this context, the present study focuses on the short-eared dog, the hoary fox, and the bush dog, species of conservation concern for which available information remains limited. By synthesising existing knowledge on these three species, this study aims to advance understanding of their biology, ecology, and management, supporting improvements in ex-situ conservation practices and guiding future in-situ and ex-situ research to address current knowledge gaps.

Analysing the progress of scientific production on species of conservation concern can provide a quantitative overview that helps guide conservation efforts [15–17]. This can be achieved through scientometric approaches, which encompass bibliometric and network-based analyses of scientific literature, including co-authorship patterns and research topic mapping [18, 19]. These methods rely on databases and indexing platforms such as Scopus, Web of Science, or Google Scholar, and allow the identification of research trends, collaborations among research groups, and knowledge gaps within a given field [18, 19]. In this context, scientometric studies are valuable for guiding research priorities by revealing how scientific output is distributed across different topics and identifying underexplored areas. Accordingly, efforts to synthesise information on the conservation status, distribution, and threats to canid species span multiple disciplines, including taxonomy, morphology, evolution, population ecology, behaviour, diseases, and parasitology.

As populations decline, ex-situ conservation can become an important component of strategies to prevent species extinction. Zoos contribute to conservation in multiple ways, including maintaining assurance populations, supporting coordinated breeding programs, and acting as genetic reservoirs for threatened species [20–22]. In addition, they play important roles in education, public awareness, and the implementation of conservation initiatives, thereby supporting both in-situ and ex-situ efforts. Animals born and maintained under human care may also contribute to reintroduction or reinforcement programs, increasing or restoring wild populations through carefully planned translocations [23, 24]. To support these objectives, zoos participating in coordinated management programs develop studbooks that enable genetic and demographic management of ex-situ populations, ensuring their long-term sustainability [25, 26]. Another

key component of ex-situ conservation is the systematic collection and management of biological and husbandry data [27–29]. This information is centralised in the Zoological Information Management System (ZIMS), operated by Species360 [30], which compiles records ranging from basic life-history traits to detailed veterinary and management data across institutions worldwide [24, 31]. In this sense, ZIMS functions as a global repository of information that supports evidence-based management of ex-situ populations [20, 29, 32]. When integrated with scientometric analyses of scientific literature, ZIMS data provide complementary perspectives on knowledge production and population management. While scientometric approaches identify research trends, gaps, and collaboration patterns in published studies, ZIMS provides structured empirical data from ex-situ populations. Together, these two sources allow for a more comprehensive assessment of existing knowledge and highlight areas where further research and management actions are needed. In this study, we focus on canid species occurring in Brazil due to their national conservation relevance. However, both the scientometric and ZIMS datasets were analysed globally, reflecting the worldwide distribution of scientific knowledge and ex-situ populations.

Considering that the short-eared dog, the hoary fox, and the bush dog are canid species occurring in Brazil that are of conservation concern, this study aims to provide an integrated assessment of their scientific knowledge and ex-situ population status by addressing: (1) temporal trends in scientific publications; (2) differences in research effort among species; (3) distribution of knowledge across thematic areas and species; (4) presence and representation of these species in zoological institutions registered in ZIMS; (5) temporal variation in ex-situ population size and composition; and (6) identification of major knowledge gaps in the available literature. In addition, the study provides a descriptive assessment of ex-situ population structure, including changes in population size, sex ratio, and demographic trends over time.

We hypothesise that scientific production is unevenly distributed among canid species occurring in Brazil, with a higher research effort concentrated on the bush dog, while the short-eared dog is expected to be the least studied species. We further predict a general increase in scientific publications over time, with no abrupt shifts in publication trends. We also expect ex-situ populations to differ markedly among species, with some showing demographic stability or growth over time, whereas others are poorly represented or absent from zoological records. In addition, we predict that larger ex-situ populations will tend to be associated with higher numbers of recorded births and more consistent demographic structures.

2 Materials and methods

2.1 Studied Brazilian canid species

The target species for this study were the short-eared dog, the hoary fox, and the bush dog. The short-eared dog is a solitary, diurnal species, endemic to the Amazon biome (inhabiting forests, inland wetlands and savannahs), occurring from Ecuador to Brazil and probably extending into Peru and Colombia [2, 33], with few records over the last 30 years [34, 35]. In terms of feeding habits, the species is classified as a mesocarnivore, with a diet that includes fruit [2, 36]. The reasons given for the population decline are diseases transmitted by domestic dogs and habitat loss, which justify classifying the

species as Vulnerable according to the IUCN [2, 33] and the Brazilian Red List of Threatened Species [7].

The hoary fox is a small canid with a nocturnal habit and an omnivorous diet, which includes fruit, termites, other arthropods, small mammals, birds, and reptiles [37]. It is the only species among canids that is endemic to Brazil and endemic to the Cerrado biome (savannah-like vegetation) [38], although an expansion of its occurrence area was recently published [39]. The species is classified as Least Concern (LC) worldwide [1] and as Vulnerable on the Brazilian Red List of Threatened Species [7].

The bush dog is a diurnal canid, widely distributed from Panama in Central America to north-eastern Argentina and Paraguay, including Colombia, Venezuela, the Guianas, Brazil, eastern Bolivia, and Peru [40]. In Brazil, they occur in the Amazon, Pantanal, Atlantic Forest, Cerrado, and Caatinga biomes, preferably in preserved humid or riparian forests [41, 42]. They are social animals, and cooperative hunting has been reported [43, 44]. The species' conservation status at the international level is considered Near Threatened [1]. However, the bush dog is classified as Vulnerable, according to the Brazilian Red List of Threatened Species [7].

2.2 Scientometric data and statistical analyses

The academic articles on the three canid species were surveyed on 5 July 2023, across three electronic bibliographic databases: Web of Science (WOS), Scopus, and PubMed. WOS is considered the most comprehensive multidisciplinary database available [45, 46]. Scopus is also a widely used database that brings together scientific articles, conference abstracts, and books from both regional and global sources and ensures their relevance and quality through rigorous selection and evaluation by its board and independent peers [47, 48]. PubMed, which is almost entirely dedicated to biomedical research, also includes articles from zoology, as it includes the PMC (PubMed Central) article library, which indexes journals such as Frontiers in Zoology, Current Zoology, and ZooKeys [49].

Articles published between January 1975 and July 2023 were searched. This period was chosen for data comparison because it coincides with the ZIMS database's existence. For the research design, the selection of articles was based on the recommendations for systematic review of the PRISMA (Principal Reporting Items for Systematic Reviews and Meta-analyses) Statement [50]. The keywords employed for the article search are listed in Table 1. The asterisk (*) and the term 'AND' were utilised as Boolean operators to encompass all possible variations of the keywords. The term 'Brazil' was included to prioritise studies relevant to the Brazilian context, given the study's national focus. However, the search was not intended to exclude studies conducted outside Brazil, and articles were screened to retain those relevant to the focal species, regardless of the country of data collection, including studies conducted in multi-country contexts or general mammal surveys. Studies were included in the analysis if they were

Table 1 Search strings and keywords used to retrieve bibliographic records for the scientometric analysis of three Neotropical canids, supporting the assessment of knowledge patterns and conservation gaps

Canid*	Canid* AND Brazil
Scientific name	Scientific name AND Brazil
Common name	Common name AND Brazil

peer-reviewed articles focusing on the three focal canid species occurring in Brazil. Excluded materials comprised book chapters, abstracts, and conference proceedings. Studies were included in the analysis if they were peer-reviewed articles focusing on the three focal canid species occurring in Brazil and of conservation concern. We restricted the search to English-language articles to ensure consistency across databases. Excluded materials comprised book chapters, abstracts, conference proceedings, and other non-indexed publications. This approach ensured a standardised and reproducible dataset of indexed scientific literature.

The literature search generated 433 articles across the selected databases, with the largest contribution from Scopus, followed by Web of Science and PubMed. After removing duplicates and screening for relevance to the focal species, 168 articles met the inclusion criteria and were retained for the final analysis [Short-eared dog (16 publications); Hoary fox (47); Bush dog (105)] (Fig. 1).

All retrieved papers were exported to an Excel spreadsheet and subsequently imported into Rayyan, a free application for managing systematic reviews [51]. For each article, the following information was extracted and organised into thematic categories:

(i) Bibliographic information: year and country where the study was conducted (i.e., the geographic location of data collection, used for spatial analyses and mapping), authors, title, journal name, and database source.

(ii) Institutional information: country of the first author's institutional affiliation and type of institution responsible for the study (e.g., university, research institute, zoo). Authorship analyses were based exclusively on the first author's affiliation.

(iii) Study characteristics: type of study (experimental or review), focal species, and study context, classified as in-situ (field-based studies within the species' natural range) or ex-situ (studies conducted outside the natural range, typically under captive or controlled conditions). Additionally, studies were categorised as conducted in protected areas (i.e., legally designated conservation units, such as national parks or reserves) or in unprotected areas (i.e., natural areas without formal legal protection), based on information provided by the authors.

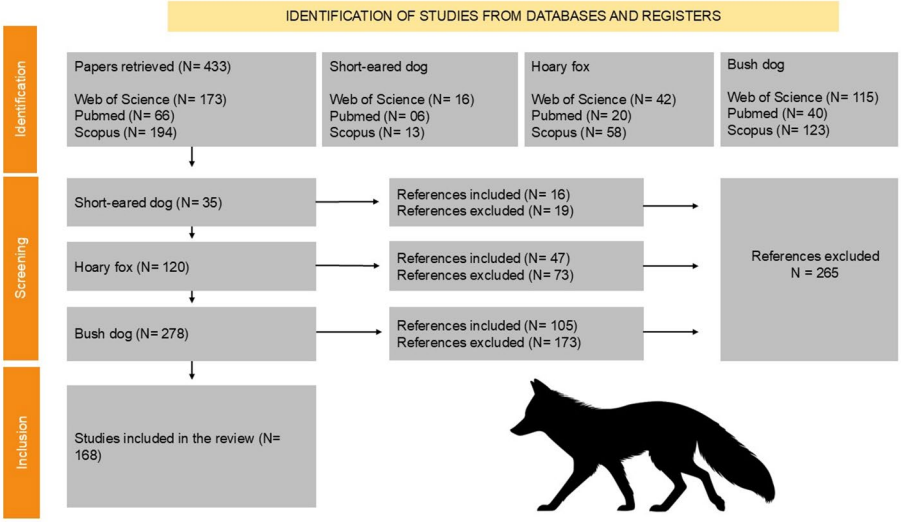

Fig. 1 Prisma Protocol applied to the scientometric analyses of the three Brazilian wild canid species threatened with extinction

(iv) Geographic classification: each study was classified as occurring in tropical or temperate regions based on the geographic location of the country where the study was conducted, following its position within the tropical or temperate zones of the globe.

(v) Research area: studies were classified into the following categories: anatomy/physiology (e.g., anatomical descriptions, physiological processes, neurosciences), behavior (e.g., parental care, reproductive behaviour, foraging, activity patterns), conservation (e.g., conservation status assessments), distribution (e.g., records outside known ranges or habitats), ecology (e.g., population ecology, diet, species interactions), parasitology (endo- and ectoparasites), pathology (diseases caused by pathogens or tumors), as well as ethnozoology, evolution, phylogeny, genetics, paleontology, and reproduction.

2.3 ZIMS database and statistical analysis

Data on the studied canid species kept in zoos were obtained from the Zoological Information Management System (ZIMS) database, operated by Species 360. Records from 1975 to 2024 were selected from ZIMS. The variables retrieved were the number and location of institutions that housed the species (city, state, and country; in accordance with the ZIMS data-use agreement, the identities of individual institutions cannot be disclosed, and therefore only geographic information is reported), the number of individuals per canid species, the sex ratio, and the numbers of births and deaths. This information enabled assessment of how many institutions keep the species of interest in their groups, their geographic locations, and whether they are successful or unsuccessful in reproduction.

2.4 Statistical analysis

The data extracted from the scientometric analysis were summarised using descriptive statistics and presented as absolute and relative frequencies where appropriate. For each variable, all occurrences reported in the selected publications were recorded. Consequently, a single article could contribute multiple records (e.g., more than one species, country, study site, institution, or research area). Therefore, the totals reported for some categories are not mutually exclusive and may exceed the number of unique articles included in the review. A piecewise regression was performed to assess the breakpoint in the number of publications over the years, i.e., the point at which there is a sudden increase in publications on endangered canids.

Generalised Linear Mixed Models (GLMMs) were applied to investigate whether the number of publications differed among areas of study (anatomy/physiology, behaviour, conservation, distribution, ecology, parasitology, pathology, ethnozoology, evolution, phylogeny, genetics, palaeontology, and reproduction) and between species. The model included the number of publications as the dependent variable, with species and area of study as fixed effects. Year was included as a random effect to account for repeated measures over time. The model was fitted using a Poisson distribution. Model selection was performed by comparing the full model with reduced models using likelihood ratio tests. The significance level was set at $p \leq 0.05$. The analyses were carried out using the R 4.4.2 software [52]. The *glmer* function from the *lme4* package was used to build the models

[53], while the graphs and map showing the locations where the studies on canids were conducted were built using the *ggplot2* package [54].

3 Results

The scientometric analysis revealed distinct temporal patterns of publication among the three canid species (Fig. 2). For the bush dog, the earliest records date back to 1981, with a gradual increase in publications over time and a more pronounced growth after the 2000s, including several peaks in the last decade, particularly between 2018 and 2023. In contrast, studies on the hoary fox began later, with the first publications appearing in 1997, followed by a moderate but consistent increase, especially after 2010, with noticeable growth in recent years. For the short-eared dog, the number of publications remained comparatively low throughout the period, with sporadic records beginning in 2008 and a slight increase after 2015, though no clear pattern of sustained growth. Overall, while all three species show an upward trend in scientific attention over time, the bush dog exhibits the most continuous and pronounced increase, whereas the hoary fox and the short-eared dog show more recent, less consistent publication trajectories (Fig. 2). Among the three species studied, the most significant number of published studies was on the bush dog, with a total of 109 articles (57.67%), followed by the hoary fox with 63 articles (33.34%), and the short-eared dog, with 17 articles (8.99%) (Fig. 2).

Analysing the evolution of scientific production across the three species over time, there was an upward trend for both the combined species and each species individually. This increase is more evident for the bush dog and hoary fox than for the short-eared dog. There was no abrupt increase or breakpoint in the publications over the period analysed (Fig. 3).

Brazil accounted for the most publications, followed by the United States and Argentina, while all other countries contributed relatively few studies (Table 2). Most studies were conducted in tropical regions and in protected areas. Brazil also had the highest number of first authors, followed by the United States and Argentina.

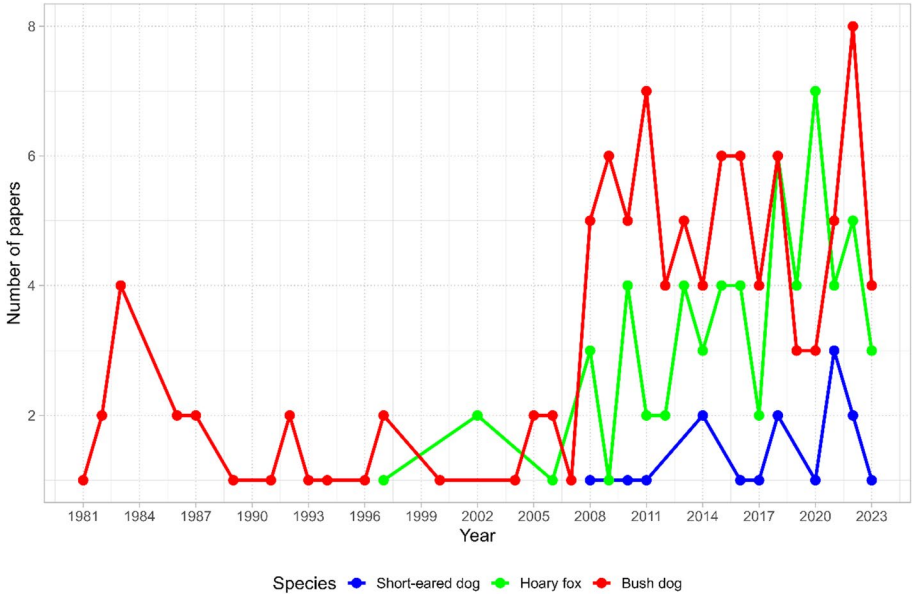

Fig. 2 Temporal evolution of the number of articles published on the three species of canids vulnerable to extinction between 1981 and 2023. Short-eared dog, hoary fox, and bush dog

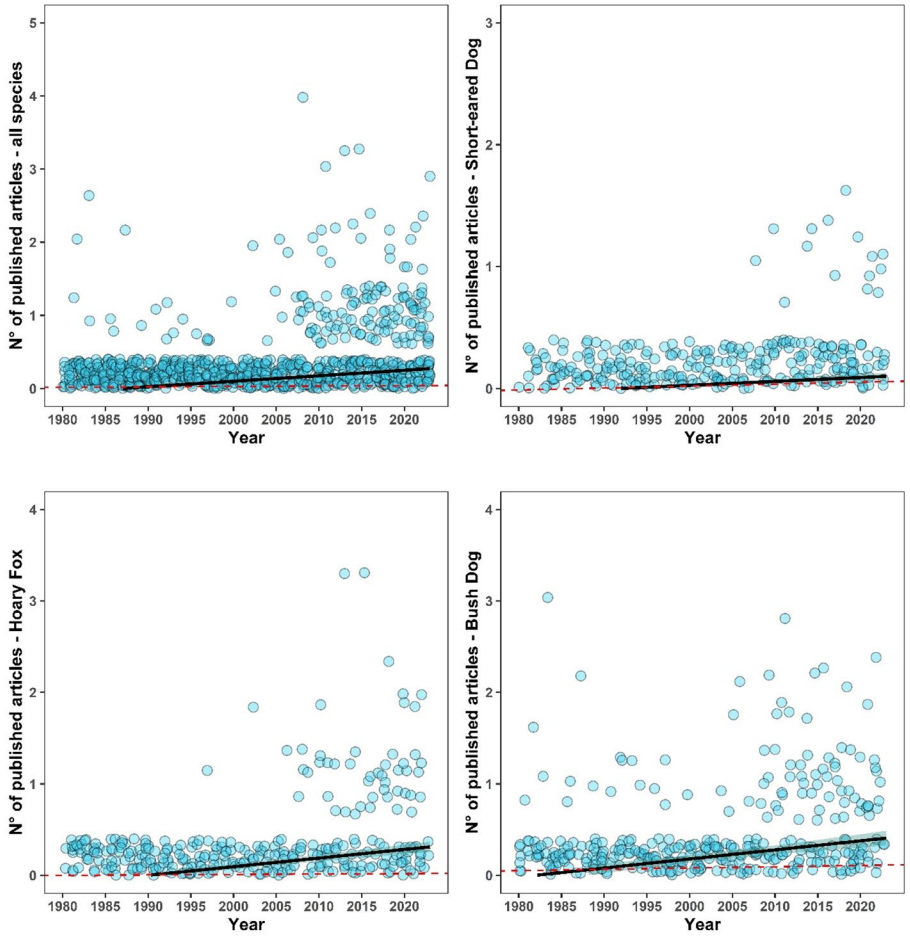

Fig. 3 Regression analysis of the number of publications over time for the three canid species studied, including the total number of articles published across all species, as well as publications on the short-eared dog (*Atelocynus microtis*), hoary fox (*Lycalopex vetulus*), and bush dog (*Speothos venaticus*)

Universities were the most common institutional affiliation among first authors, followed by research institutes and zoological institutions (Table 2). Most publications were experimental studies rather than review articles, and most research was carried out in-situ, with fewer studies conducted ex-situ or in both contexts. Sample sizes were generally small, with many studies focusing on a limited number of individuals.

For the three target species, studies were distributed across 13 areas of knowledge, with parasitology and conservation representing the most studied fields, while palaeontology and ethnozoology were the least represented (Fig. 4a; Table 3). The number of publications varied significantly across research areas, with parasitology and conservation showing higher values than the reference category (anatomy/physiology). Scientific production was unevenly distributed among species, with most studies focusing on the bush dog, whereas the short-eared dog was consistently underrepresented across all areas (Fig. 4b).

The study area and species significantly affected the number of publications per year, with the short-eared dog being the least-studied species, followed by the hoary fox and the bush dog (Table 3).

The information obtained from the ZIMS database revealed that no records of short-eared dogs under ex-situ conditions were found. For the hoary fox, ex-situ records are

Table 2 Summary of the main characteristics of the studies included in the scientometric analysis, showing sample sizes (n) and corresponding percentages (%) for each category

Variable	Category	*n*	%
Country	Brazil	172	65.1
	United States	19	7.2
	Argentina	19	7.2
	Other countries	< 10 each	–
Study area	Protected areas	148	56.1
	Unprotected areas	116	43.9
Region	Tropical	214	81.1
	Temperate	50	18.9
Institution	University	117	69.6
	Research institute	24	14.3
	Zoo	17	10.1
	Private	2	1.2
Study type	Experimental	150	89.3
	Review	18	10.7
Context	In-situ	116	61.4
	Ex-situ	60	31.7
	Both	2	1.1

Because individual publications could contribute multiple records (e.g., multiple countries, study sites, institutions, or species), category totals may exceed the total number of selected articles

sparse and limited to a small number of individuals since 2004, with no evidence of population growth in captivity (Fig. 5). The number of individuals remained consistently low, typically limited to one or two zoological institutions, and no births were recorded throughout the study period. Mortality events were sporadic, and the sex ratio of the hoary fox in ex-situ populations was initially male-biased but progressively shifted as male numbers declined, with females predominating in the most recent records. Overall, these results indicate that the hoary fox is rarely maintained ex-situ and lacks a self-sustaining captive population.

In contrast, the bush dog showed a well-established and expanding ex-situ population (Fig. 5). Records from 2004 to 2024 indicate a substantial increase in both the number of individuals and the number of participating institutions, with marked population growth over time. Reproductive events were consistently recorded throughout the study period, contributing to population expansion, although mortality was also observed. The sex ratio remained relatively balanced, with a slight male predominance. Overall, these results demonstrate that the bush dog has a stable and growing ex-situ population.

Additionally, the analysis of the bush dog age pyramid showed a shape in which the bottom is wider than the centre or top, with more male and female individuals at the bottom of the pyramid (Fig. 6).

4 Discussion

Overall, our findings support the study hypotheses and reveal pronounced differences in both research effort and ex-situ representation among the three canid species. Consistent with our predictions regarding publication trends and research effort, scientific production was unevenly distributed among species, with the bush dog receiving substantially greater research attention than the hoary fox and especially the short-eared dog, while publication output increased gradually over time for all species. Likewise, our predictions regarding ex-situ populations were supported, as we found marked

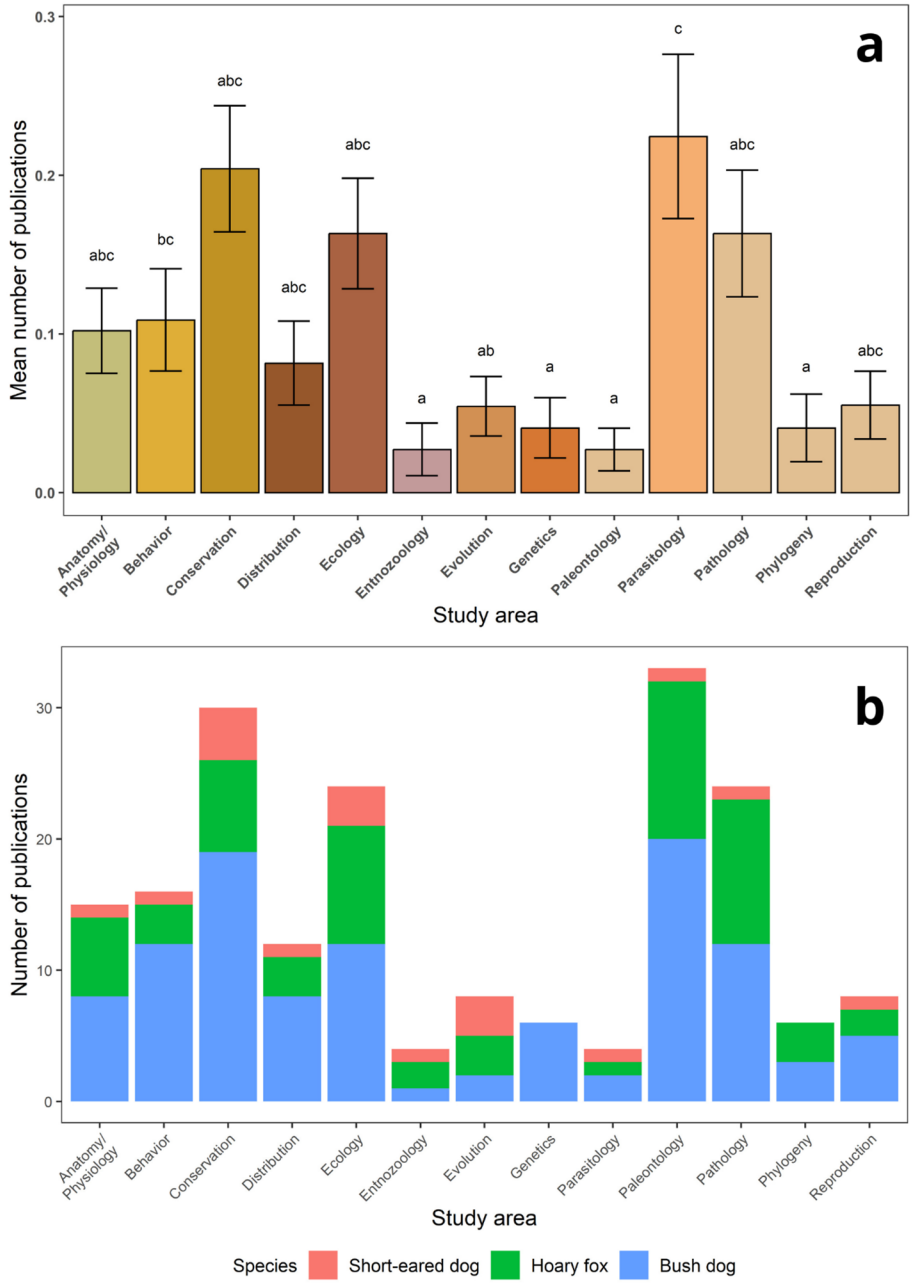

Fig. 4 **a** Areas of study covered by the articles included in the scientometric analysis of the three Brazilian canid species between 1975 and 2023, expressed as mean ± standard deviation of the number of studies per research area. Different lowercase letters (a, b, c) indicate statistically significant differences among research areas. **b** Distribution of studies across research areas, showing the total number of articles for each species: short-eared dog in orange, hoary fox in yellow, and bush dog in blue

differences among species, ranging from the relatively large, demographically active bush dog population to the low representation of the hoary fox and the complete absence of the short-eared dog in ZIMS records. Furthermore, the distribution of studies across thematic areas revealed important knowledge gaps, indicating that several aspects of the biology, ecology, and conservation of these species remain poorly understood. Together, these findings suggest that current knowledge and conservation opportunities are strongly influenced by species-specific ecological characteristics, research feasibility,

Table 3 Results of the Generalised Linear Mixed Model (GLMM) evaluating the effects of study area and species on the number of publications per year

Areas of knowledge	Estimate	Error	Z value	*p*
(Intercept)	-4.31	0.43	-10.13	< 0.001***
Behavior	0.08	0.37	0.22	0.826
Conservation	0.68	0.33	2.08	0.038*
Distribution	-0.22	0.40	-0.56	0.574
Ecology	0.49	0.34	1.43	0.154
Ethnozoology	-1.32	0.57	-2.32	0.021*
Evolution	-0.63	0.45	-1.42	0.157
Genetics	-0.91	0.49	-1.85	0.064
Paleontology	-1.33	0.57	-2.33	0.020*
Parasite	0.78	0.32	2.40	0.017*
Pathology	0.47	0.34	1.37	0.171
Phylogeny	-0.93	0.49	-1.89	0.058
Reproduction	-0.56	0.45	-1.25	0.213
Hoary fox	1.23	0.27	4.54	< 0.001***
Bush dog	1.82	0.26	7.06	< 0.001***

The model includes all species, with the short-eared dog as the reference species and anatomy/physiology as the reference study area. The year was included as a random effect

Significant effects are indicated as * $p < 0.05$ and *** $p < 0.001$

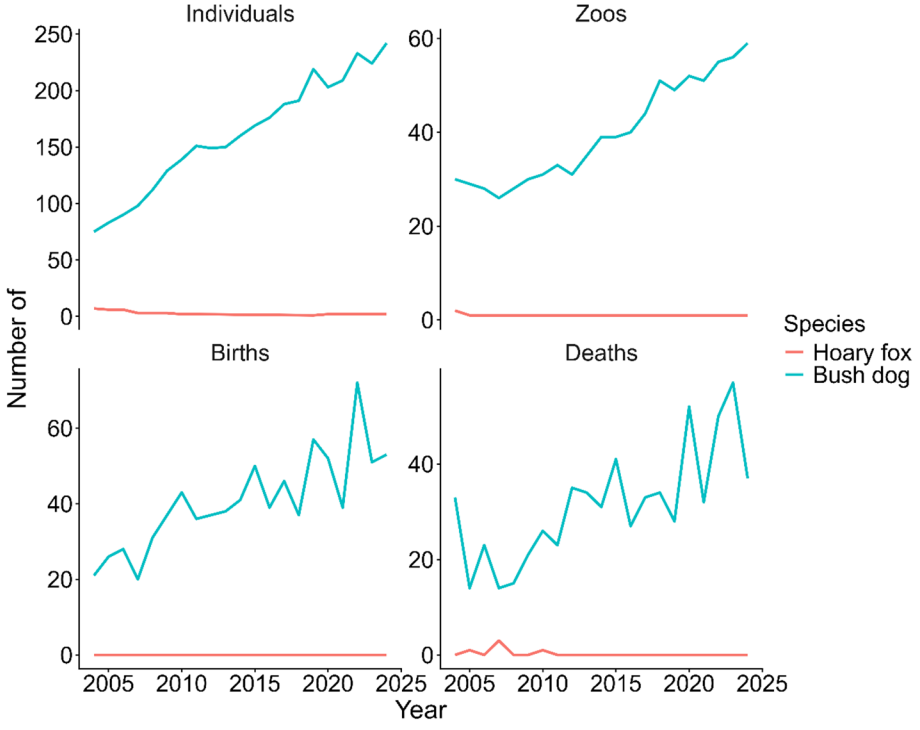

Fig. 5 Records on the relationship between the number of individuals, zoos, births and deaths for the hoary fox and the bush dog from 2004 to 2024

and the availability of ex-situ populations, highlighting priorities for future research and management efforts.

With respect to our hypotheses concerning temporal publication trends, differences in research effort among species, and the identification of knowledge gaps, the results demonstrate that information remains limited for all three canids despite a gradual increase in scientific production over time. Scientific production in this dataset begins

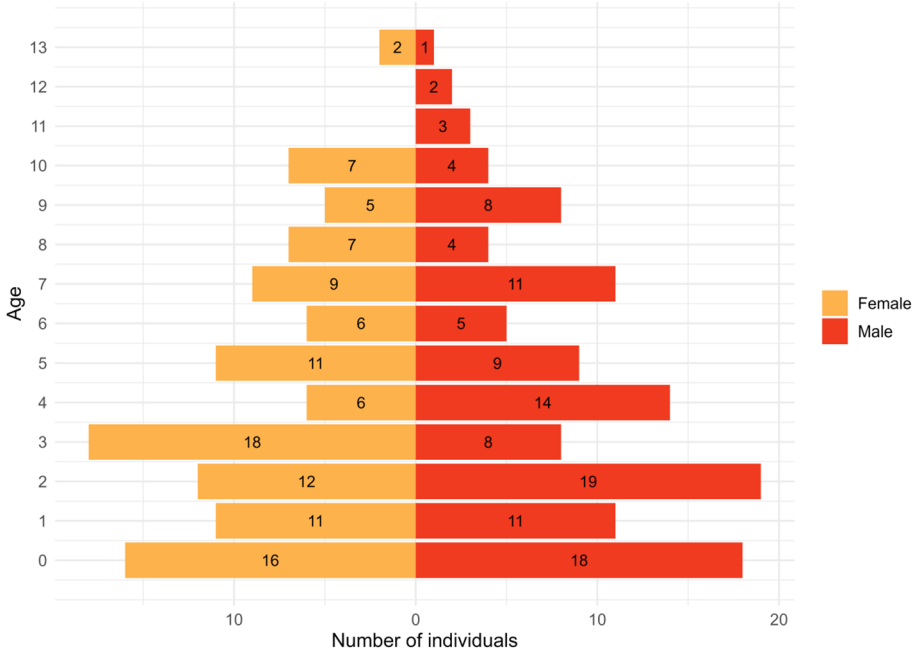

Fig. 6 Age pyramid of the threatened Brazilian canid, the bush dog, kept in zoos worldwide. Age in years

in the early 1980s for the bush dog and in 2010 for the short-eared dog, reflecting the temporal coverage of publications retrieved from Web of Science, Scopus, and PubMed under our search criteria (up to July 2023). It is important to note that this approach may not capture the full historical depth of knowledge, as it excludes non-indexed sources and does not incorporate taxonomic synonyms (e.g., *Pseudalopex vetulus*), which may still occur in the literature and affect retrieval completeness.

The observed differences in publication output are likely influenced not only by conservation priorities but also by species-specific differences in detectability and research feasibility. For example, the short-eared dog is rarely recorded in the wild, whereas bush dogs are notoriously difficult to detect due to their low densities, cryptic behaviour, and extensive movement [3]. Such characteristics can substantially limit opportunities for data collection and may contribute to the observed disparities in research effort among species.

Among the three species, the short-eared dog represents the most evident knowledge gap. As the only canid endemic to remarkably pristine areas of the Amazon forest, it is one of the world's least-studied wild canid species [14]. The species is rarely reported in fauna inventories, where its occurrence is often recorded as occasional, hypothetical, or confirmed [55]. The results of this study corroborate this pattern, as the short-eared dog had the fewest studies and was not represented in the ZIMS database. Consequently, additional ecological, behavioural, and conservation-oriented studies are urgently needed to support evidence-based conservation strategies for the species.

Unlike the three species evaluated here, some Neotropical canids, such as the maned wolf, have been the focus of sustained research efforts for several decades, including studies predating our indexed dataset [56, 57]. This contrast illustrates how differences in detectability, geographic distribution, conservation attention, and logistical feasibility can shape the accumulation of scientific knowledge.

Despite the late start in indexed research for all three species, scientific output has continued to increase over time. This trend is largely driven by publications on the bush dog, while the short-eared dog and hoary fox remain comparatively underrepresented. The observed imbalance highlights persistent knowledge gaps for these two species, which should be addressed through targeted research efforts and funding incentives, although it may also partially reflect differences in conservation status and research prioritisation among species.

Beyond differences in research effort among species, our results also revealed clear geographic patterns in scientific production. Brazil accounted for most published studies, and Brazilian researchers led most academic output. This pattern is not surprising, given that all three species occur in Brazil and that the hoary fox is endemic to the country [37]. Although "Brazil" was included as a keyword in the search strategy, the search was not restricted to studies conducted exclusively within the country. Nevertheless, its inclusion may have increased the likelihood of retrieving studies associated with Brazil. Therefore, the observed predominance of Brazilian publications likely reflects both a genuine concentration of research effort and, to some extent, a methodological effect of the search criteria.

The results also support Hypothesis 3 by demonstrating that scientific knowledge is unevenly distributed across research contexts and study systems. Most studies have been conducted in natural and protected areas, whereas ex-situ studies constitute a smaller but still important component of the available literature. Zoos have contributed particularly to research on the bush dog and, to a lesser extent, the hoary fox, corroborating previous findings [37, 57, 58]. However, differences in publication patterns between in-situ and ex-situ studies should be interpreted with caution, as they are strongly influenced by species-specific ecological traits and research feasibility. Bush dogs, for example, are widely recognised as difficult to study in the wild due to their low detectability, elusive behaviour, and large home ranges, which limit the effectiveness of conventional field methods [3]. As a result, captive studies have played an important role in advancing knowledge on aspects such as behaviour, vocalisation, and reproductive physiology [43, 58, 59]. Nevertheless, ex-situ approaches inherently constrain the study of ecological processes that depend on natural movement, dispersal, and interactions with the environment.

In contrast, the hoary fox is more readily detectable in open habitats and is not currently considered a threatened species, which may reduce the need for ex-situ management and help explain the limited number of captive studies. For this species, research has primarily focused on ecological aspects in natural and human-modified landscapes, including diet and interactions with anthropogenic environments [35, 37]. For instance, studies in pasture areas indicate that the hoary fox feeds on termites and may benefit from these environments, although they also expose individuals to risks such as attacks by domestic dogs and disease transmission [60].

More broadly, habitat loss driven by deforestation, roads, and mineral exploitation continues to affect all three species [61, 62], reinforcing the importance of studies conducted in both protected and unprotected areas. Rather than a simple absence of studies, the observed gaps reflect differences in research feasibility and conservation priorities among species. Future research should therefore be strategically directed to address species-specific knowledge gaps, particularly regarding responses to anthropogenic

pressures in unprotected landscapes and ecological processes that cannot be adequately captured in captive settings.

Within the thematic distribution of research effort identified under Hypothesis 3, parasitology emerged as one of the most prominent areas of study among the evaluated canids. However, differences between in-situ and ex-situ studies should be carefully interpreted. Captive settings facilitate repeated sampling, clinical monitoring, and the application of diagnostic methods that are often difficult to implement in the wild, which partly explains the concentration of parasitological studies, particularly those on leishmaniasis, using material from wild canids maintained in zoos [63, 64]. Nevertheless, ex-situ populations are maintained under controlled, often biosecure conditions, which limit their ability to reflect natural transmission dynamics, host–parasite interactions, and broader zoonotic processes. In contrast, studies conducted in natural habitats are essential for understanding parasite diversity, transmission pathways, and the ecological drivers of infection. This is particularly relevant for vector-borne diseases such as leishmaniasis, which can affect both wild and captive animals but whose dynamics are strongly influenced by environmental conditions, vector distribution, and interactions with domestic animals [65, 66]. Wild canids may act as reservoirs of pathogens of public health importance [65–68], reinforcing the need for field-based disease ecology studies. Rather than indicating an optimal study system, the observed pattern reflects complementary strengths and limitations of each research context. Current gaps are not only related to the number of studies, but also to their scope: there is still limited information on parasite diversity beyond a few well-studied diseases, as well as on infection dynamics, host competence, and the effects of anthropogenic pressures in natural populations. Addressing these gaps will require integrated approaches combining field studies, epidemiological surveillance, and, where appropriate, targeted investigations in captive settings.

Finally, consistent with Hypotheses 4 and 5, ex-situ populations differed markedly among species in representation, population size, and demographic structure, with important implications for both conservation and research opportunities. Zoos have played an important role in the conservation of endangered species, but their contributions vary markedly across the canids studied. According to ZIMS data, only the bush dog is well represented in captive populations, with a relatively stable demographic structure, whereas the hoary fox is poorly represented, and the short-eared dog is absent from registered institutions. These differences limit the potential of ex-situ populations to support research and conservation actions for some species [69]. In particular, the absence of short-eared dogs and the low number of hoary foxes in captivity limit opportunities for studies of behaviour, reproduction, and health under controlled conditions, as well as for the development of conservation breeding programs. Rather than indicating a general limitation of zoos, this pattern reflects species-specific challenges related to capture, husbandry, and conservation prioritisation. Consequently, the role of ex-situ conservation for these species remains uneven and should be evaluated in light of both biological constraints and management feasibility.

5 Conclusions

This study revealed substantial differences in both scientific knowledge and ex-situ representation among the three Neotropical canids evaluated. Consistent with our hypotheses, research effort was unevenly distributed among species, with the bush dog receiving considerably more attention than the hoary fox and especially the short-eared dog. Although scientific production has increased over time, important knowledge gaps remain, particularly regarding the ecology, behaviour, and conservation of the least-studied species.

Marked differences were also observed in ex-situ populations. While bush dogs were relatively well represented in ZIMS records and exhibited active demographic dynamics, hoary foxes were poorly represented, and short-eared dogs were absent from registered institutions. These patterns influence opportunities for research, management, and conservation planning and reinforce the complementary roles of in-situ and ex-situ approaches.

Overall, our findings highlight the need for continued investment in field-based research, particularly for species that remain difficult to detect and study in natural environments, while recognising the value of *ex situ* populations in addressing specific biological and conservation questions. An integrated approach that combines both research contexts will be essential to strengthening evidence-based conservation strategies for Neotropical canids.

Acknowledgements
The authors would like to thank the staff of Belo Horizonte Zoo, Humberto Espírito Santo de Mello, and Erica Fernandes Cipreste, and also to CAPES for Leandro Costa's scholarship.

Declaration of generative AI and AI-assisted technologies in the writing process
Statement: During the preparation of this work, the author(s) used DeepL, Grammarly, and ChatGPT to translate and improve the language of the paper. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

Author contributions
Leandro Ferreira Costa: Conceptualisation, Methodology, Data collection, Visualisation, Data Analysis, Writing – original draft, reviewing, and editing. Gabriela Ramos: Conceptualisation, Methodology, Visualisation, Data Analysis, Writing – original draft, reviewing, and editing. Gustavo Nunes de Almeida: Data Analysis, Writing – original draft, reviewing, and editing. Luiza Figueiredo Passos: Conceptualisation, Methodology, Visualisation, Data collection, Data Analysis, Writing – original draft, reviewing, and editing. Cristiano Schetini de Azevedo: Supervision, Conceptualisation, Methodology, Data Analysis, Writing – original draft, reviewing, and editing. Maria Rita Silvério Pires: Supervision, Conceptualisation, Methodology, Data collection, Visualisation, Data Analysis, Writing – original draft, reviewing, and editing.

Funding
This research did not receive a specific grant from public, commercial, or not-for-profit funding agencies.

Data availability
all data is available at: Costa, Leandro; Ramos, Gabriela; Almeida, Gustavo; Passos, Luiza; Azevedo, Cristiano; Pires, Maria Rita (2024), "Linking scientometrics to zoo collections: how these tools can help Brazilian canids avoid extinction", Mendeley Data, V1, doi: 10.17632/yb2zr6mscy.1.

Code availability
Not applicable.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 5 March 2026 / Accepted: 24 June 2026
Published online: 27 June 2026

References

1. IUCN. The IUCN red list of threatened species, Version 2025-2. 2026. https://www.iucnredlist.org. Acessed 13 May 2026.
2. Leite-Pitman MRP, Williamns RSR. The short-eared dog (*Atelocynus microtis*: Sclater 1883). In: Sillero-Zubiri C, Hoffmann M, MacDonald DW, editors. Canids: Foxes, Wolves, Jackals and Dogs Status Survey and Conservation Action Plan. Gland: IUCN; 2004. pp. 26–31.
3. Sillero-Zubiri C. Family Canidae (Dogs). In: Wilson DE, Mittermeier RA, editors. Handbook of the Mammals of the World. Barcelona: Lynx Editions; 2009. pp. 352–446.
4. Lucherini M, Pessino M, Farias AA. Pampas fox *Pseudalopex gymnocercus* (Fischer, 1814). In: Sillero-Zubiri C, Hoffmann M, MacDonald DW, editors. Canids: Foxes, Wolves, Jackals and Dogs Status Survey and Conservation Action Plan. Gland: IUCN; 2004. pp. 63–8.
5. Vieira EM, Port D. Niche overlap and resource partitioning between two sympatric fox species in southern Brazil. J Zool. 2007;272:57–63. https://doi.org/10.1111/j.1469-7998.2006.00237.x.
6. Di Bitetti MS, Di Blanco YE, Pereira JA, Paviolo A, Pírez IJ. Time Partitioning Favors the Coexistence of Sympatric Crab-Eating Foxes (*Cerdocyon thous*) and Pampas Foxes (*Lycalopex gymnocercus*). J Mammal. 2009;90:479–90. https://doi.org/10.1644/08-MAMM-A-113.1.
7. Ministério do Meio Ambiente. PORTARIA MMA Nº 148, de 7 de junho de 2022. Brasília; 2022.
8. Branco AFVC, Lima PVPSL, de Medeiros Filho ES, Costa BMG, Pereira TP. Avaliação da perda da biodiversidade na Mata Atlântica. Ciência Florestal. 2021;31:1885–909. https://doi.org/10.5902/1980509853310.
9. Wilson MC, Chen X-Y, Corlett RT, Didham RK, Ding P, Holt RD, et al. Habitat fragmentation and biodiversity conservation: key findings and future challenges. Landsc Ecol. 2016;31:219–27. https://doi.org/10.1007/s10980-015-0312-3.
10. Laurance WF, Lovejoy TE, Vasconcelos HL, Bruna EM, Didham RK, Stouffer PC, et al. Ecosystem Decay of Amazonian Forest Fragments: a 22-Year Investigation. Conserv Biol. 2002;16:605–18. https://doi.org/10.1046/j.1523-1739.2002.01025.x.
11. Querido LC, de Guimaraes A, Rosa AF, Sayer C, Passamani EJ. Understanding distribution and survey gaps of Mammals from the Atlantic Forest and Cerrado Biomes. Biota Neotrop. 2024. https://doi.org/10.1590/1676-0611-BN-2023-1569.
12. Reis SC dos, Dias JHP, de e Sousa LO, Chiarello AG, de Sá ME, Ramos IP. Germination of fruits eaten by the maned wolf *Chrysocyon brachyurus* (Illiger, 1815) (Carnivora, Canidae). Biota Neotrop. 2023;23:e20221413. https://doi.org/10.1590/1676-0611-bn-2022-1413.
13. Silva-Diogo O, Goebel LGA, de Sousa MR, Gusmão AC, da Costa TM, de Jesus AS, et al. Expansão da área de ocorrência do lobo-guará, *Chrysocyon brachyurus* (Carnivora, Canidae) no bioma amazônico. Oecol Aust. 2020;24:928–37. https://doi.org/10.4257/oeco.2020.2404.15.
14. Leite-Pitman MRP, Beisiegel BM. Avaliação do risco de extinção do cachorro-do-mato-de-orelhas-curtas *Atelocynus microtis* (Sclater, 1883) no Brasil. Biodiversidade Brasileira. 2013;3:133–7.
15. Chomitz KM. Transferable Development Rights and Forest Protection: An Exploratory Analysis. Int Reg Sci Rev. 2004;27:348–73. https://doi.org/10.1177/0160017604266030.
16. Pizzi F, Caroli AM, Landini M, Galluccio N, Mezzelani A, Milanesi L. Conservation of endangered animals: From biotechnologies to digital preservation. Nat Sci (Irvine). 2013;05:903–13. https://doi.org/10.4236/ns.2013.58109.
17. Samy-Kamal M, Shulezhko T, Lisitcyna N. Marine Endangered and Threatened Species in Russia: A Review of Current Conservation Strategies and Management Legislative Tools. Fishes. 2023;8:399. https://doi.org/10.3390/fishes8080399.
18. Milojević S. Quantifying the cognitive extent of science. J Informetr. 2015;9:962–73.
19. Sun X, Kaur J, Milojević S, Flammini A, Menczer F. Social dynamics of science. Sci Rep. 2013;3:1069. https://doi.org/10.1038/srep01069.
20. Conway WG. Buying time for wild animals with zoos. Zoo Biol. 2011;30:1–8. https://doi.org/10.1002/zoo.20352.
21. Beer HN, Shrader TC, Schmidt TB, Yates DT. The Evolution of Zoos as Conservation Institutions: A Summary of the Transition from Menageries to Zoological Gardens and Parallel Improvement of Mammalian Welfare Management. J Zoological Bot Gardens. 2023;4:648–64. https://doi.org/10.3390/jzbg4040046.
22. Spooner SL, Walker SL, Dowell S, Moss A. The value of zoos for species and society: The need for a new model. Biol Conserv. 2023;279:109925. https://doi.org/10.1016/j.biocon.2023.109925.
23. Mooney A, Conde DA, Healy K, Buckley YM. A system wide approach to managing zoo collections for visitor attendance and in situ conservation. Nat Commun [Internet] Springer US. 2020;11:1–8. https://doi.org/10.1038/s41467-020-14303-2.
24. Farquharson KA, Hogg CJ, Grueber CE. Offspring survival changes over generations of captive breeding. Nat Commun Nat Res. 2021;12:3045. https://doi.org/10.1038/s41467-021-22631-0.
25. Witzenberger KA, Hochkirch A. Ex situ conservation genetics: a review of molecular studies on the genetic consequences of captive breeding programmes for endangered animal species. Biodivers Conserv. 2011;20:1843–61. https://doi.org/10.1007/s10531-011-0074-4.
26. Brereton JE. What is the role of the studbook in zoo and aquarium research? Zoo Biol. 2024;43:22–31. https://doi.org/10.1002/zoo.21797.
27. Conde DA, Staerk J, Colchero F, da Silva R, Schöley J, Baden HM, et al. Data gaps and opportunities for comparative and conservation biology. Proc Natl Acad Sci. 2019;116:9658–64. https://doi.org/10.1073/pnas.1816367116.
28. Iwuchukwu CS, Ajang AJ, Bassey SA. Confinement for conservation: An ethical overview of zoos. Bull Pure Appl Sciences-Zool. 2020;39a:327–37. https://doi.org/10.5958/2320-3188.2020.00036.4.
29. Vincze O, Colchero F, Lemaître JF, Conde DA, Pavard S, Bieuville M, et al. Cancer risk across mammals. Nat Nat Res. 2022;601:263–7. https://doi.org/10.1038/s41586-021-04224-5.
30. Minteer BA, Maienschein J, Collins JP, Rabb G. The ark and beyond. University of Chicago Press; 2018. https://doi.org/10.7208/chicago/9780226538631.001.0001.
31. Species360 Zoological Information Management System (ZIMS). 2025. https://species360.org/zims/.
32. SPECIES360. Global data saving species. 2024. https://species360.org/. Accessed 03 June 2025.
33. Leite-Pitman MRP, Williams RSR. *Atelocynus microtis*. IUCN Red List of Threatened Species. Gland: IUCN; 2011. https://doi.org/10.2305/IUCN.UK.2011-2.RLTS.T6924A12814890.en.
34. Koester AD, de Azevedo CR, Vogliotti A, Duarte JMB. Ocorrência de *Atelocynus microtis* (Sclater, 1882) na Floresta Nacional do Jamari, estado de Rondônia. Biota Neotrop. 2008;8:232–4. https://doi.org/10.1590/S1676-06032008000400024.
35. Michalski F. The bush dog *Speothos venaticus* and short-eared dog *Atelocynus microtis* in a fragmented landscape in southern Amazonia. Oryx. 2010;44:300–3. https://doi.org/10.1017/S0030605309990871.

36. Champagne PS, Oliveira HFM, Payne CJ, Pitman RL. Endemic and elusive trophic interactions: The first comprehensive description of the diet of short-eared dogs (*Atelocynus microtis*) in Amazon rainforests. Food Webs. 2024;41:e00366. https://doi.org/10.1016/j.fooweb.2024.e00366.
37. Juarez KM, Marinho-Filho J. Diet, habitat use, and home ranges of sympatric canids in central Brazil. J Mammal. 2002;83:925–33. https://doi.org/10.1644/1545-1542(2002)083%3C0925:DHUAHR%3E2.0.CO;2.
38. Dalponte JC, Lima ES, Facure KG, Marinho-Filho JS. Intraspecific behavior patterns of hoary fox (*Lycalopex vetulus*), a solitary canid endemic to Cerrado, Central Brazil. Stud Neotrop Fauna Environ. 2024;59:630–45. https://doi.org/10.1080/01650521.2023.2225989.
39. Marinho PH, de Araújo FR, Grangeiro RP, de Azevedo FC, Lemos FG. Where does the fox stay? First camera trap records of the threatened hoary fox *Lycalopex vetulus* (Carnivora, Canidae) in a xeric habitat of a neotropical dry forest–savanna ecotone. Mamm Res. 2022;67:131–6. https://doi.org/10.1007/s13364-021-00606-2.
40. Beisiegel B, de Zuercher M. Speothos venaticus. Mammalian Species. 2005;783:1–6. https://doi.org/10.1644/783.1.
41. DeMatteo KE, Loiselle BA. New data on the status and distribution of the bush dog (*Speothos venaticus*): Evaluating its quality of protection and directing research efforts. Biol Conserv. 2008;141:2494–505. https://doi.org/10.1016/j.biocon.2008.07.010.
42. Lima ES, Jorge MLSP, Jorge RSP, Morato RG. The bush dog *Speothos venaticus*: area requirement and habitat use in cultivated lands. Oryx. 2015;49:64–70. https://doi.org/10.1017/S0030605314000076.
43. Macdonald DW. Social behaviour of captive bush dogs (*Speothos venaticus*). J Zool. 1996;239:525–43. https://doi.org/10.1111/j.1469-7998.1996.tb05941.x.
44. Beisiegel BDM, Ades C. The bush dog *Speothos venaticus* (Lund, 1842) at Parque Estadual Carlos Botelho, Southeastern Brazil. Mammalia. 2004;68:65–8. https://doi.org/10.1515/mamm.2004.009.
45. Birkle C, Pendlebury DA, Schnell J, Adams J. Web of science as a data source for research on scientific and scholarly activity. Quant Sci Stud. 2020;1:363–76. https://doi.org/10.1162/qss_a_00018.
46. Li K, Rollins J, Yan E. Web of Science use in published research and review papers 1997–2017: a selective, dynamic, cross-domain, content-based analysis. Scientometrics Springer Sci Bus Media B V. 2018;115:1–20. https://doi.org/10.1007/s11192-017-2622-5.
47. Burnham JF. Scopus database: A review. Biomed Digit Libr. 2006;3:1. https://doi.org/10.1186/1742-5581-3-1.
48. Baas J, Schotten M, Plume A, Côté G, Karimi R. Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. Quant Sci Stud MIT Press Journals. 2020;1:377–86. https://doi.org/10.1162/qss_a_00019.
49. Airyalat SAS, Malkawi LW, Momani SM. Comparing bibliometric analysis using PubMed, Scopus, and Web of Science databases. J Visualized Experiments. 2019;24:152. https://doi.org/10.3791/58494.
50. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med. 2009;6:e1000097. https://doi.org/10.1371/journal.pmed.1000097.
51. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A. Rayyan-a web and mobile app for systematic reviews. Syst Rev BioMed Cent Ltd. 2016;5:210. https://doi.org/10.1186/s13643-016-0384-4.
52. R Core Team. R: A Language and Environment for Statistical Computing. Vienna: R Foundation for Statistical Computing; 2025.
53. Bates D, Mächler M, Bolker BM, Walker SC. Fitting linear mixed-effects models using lme4. J Stat Softw Am Stat Association. 2015;67:1–48. https://doi.org/10.18637/jss.v067.i01.
54. Wickham H. In: Wickham H, editor. ggplot2: Elegant Graphics for Data Analysis. 2 ed. Cham: Springer International Publishing; 2016. https://doi.org/10.1007/978-3-319-24277-4.
55. Rocha DG, de Barros Ferraz KMPM, Gonçalves L, Tan CKW, Lemos FG, Ortiz C, et al. Wild dogs at stake: deforestation threatens the only Amazon endemic canid, the short-eared dog (*Atelocynus microtis*). R Soc Open Sci. 2020;7:190717. https://doi.org/10.1098/rsos.190717.
56. Langguth A. Ecology and evolution in the South American canids. In: Fox MW, editor. The wild canids: their systematics, behavioral ecology and evolution. New York: Van Nostrand Reinhold Co.; 1976. pp. 192–206.
57. Carvalho CT. Aspectos faunísticos do cerrado - o lobo-guará (Mammalia, Canidae). São Paulo; 1976.
58. de Carvalho JC, Souza FF, Kastelic JP, Ferreira JCP. Reproduction in South American wild canids—A review. Front Vet Sci. 2022;9:986030. https://doi.org/10.3389/fvets.2022.986030.
59. DeMatteo KE, Porton IJ, Kleiman DG, Asa CS. The effect of the male bush dog (*Speothos venaticus*) on the female reproductive cycle. J Mammal. 2006;87:723–32. https://doi.org/10.1644/05-MAMM-A-342R1.1.
60. Rocha EC, Silva E, Feio RN, Martins SV, Lessa G. Densidade populacional de raposa-do-campo *Lycalopex vetulus* (Carnivora, Canidae) em áreas de pastagem e campo sujo, Campinápolis, Mato Grosso, Brasil. Iheringia Ser Zool. 2008;98:78–83. https://doi.org/10.1590/S0073-47212008000100011.
61. Bocchiglieri A, Mendonça AF, Henriques RPB. Composição e diversidade de mamíferos de médio e grande porte no Cerrado do Brasil central. Biota Neotrop. 2010;10:169–76. https://doi.org/10.1590/S1676-06032010000300019.
62. Zanzini ACdaS, Machado FS, de Oliveira JE, de Oliveira ECM. Roadkills of medium and large-sized mammals on highway BR-242, midwest Brazil: a proposal of new indexes for evaluating animal roadkill rates. Oecologia Australis. 2018;22:248–57. https://doi.org/10.4257/oeco.2018.2203.04.
63. Lima VMF, Fattori KR, De Fátima Michelin A, Dos Santos Nogueira F, De Oliveira e Souza L. Evidence of *Leishmania* spp. Antibodies and DNA in bush dogs (*Speothos venaticus*) in Brazil. J Zoo Wildl Med. 2009;40:91–4. https://doi.org/10.1638/2008-0043.1.
64. Luppi MM, Malta MCC, Silva TMA, Silva FL, Motta ROC, Miranda I, et al. Visceral leishmaniasis in captive wild canids in Brazil. Vet Parasitol. 2008;155:146–51. https://doi.org/10.1016/j.vetpar.2008.04.024.
65. Roque ALR, Jansen AM. Wild and synanthropic reservoirs of *Leishmania* species in the Americas. Int J Parasitol Parasites Wildl Australian Soc Parasitol. 2014;3:251–62. https://doi.org/10.1016/j.ijppaw.2014.08.004.
66. Lainson R, Rangel EF. *Lutzomia longipalpis* and the eco-epidemiology of American visceral leishmaniasis, with particular reference to Brazil - a review. Mem Inst Oswaldo Cruz. 2005;100:811–27.
67. Sapatera NdeS, Gomes LB, Perusso CO, Bresciani KDS. Leishmaniose visceral em canídeos silvestres – revisão de literatura. Res Soc Dev. 2022;11:e30211427303. https://doi.org/10.33448/rsd-v11i4.27303.

68. Batista AIV, Andrade WWA, de Nascimento JO, da Silva WSI, Oliveira MR, dos Santos IG, et al. Leishmaniasis in wild, synanthropic and domestic animals on the Island of Itamaracá, Pernambuco, Northeastern Brazil. Res Soc Dev. 2022;11:e28511426659. https://doi.org/10.33448/rsd-v11i4.26659.
69. McGowan PJK, Traylor-Holzer K, Leus K. IUCN Guidelines for Determining When and How Ex Situ Management Should Be Used in Species Conservation. Conserv Lett. 2017;10:361–6. https://doi.org/10.1111/conl.12285.

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.