

1 **Publication Trends and Captive Population Dynamics: Complementary Insights for**
2 **Advancing Conservation Efforts of Endangered Brazilian Wild Cats**

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ABSTRACT

Due mainly to habitat destruction, feline species are threatened with extinction in Brazil. The future of feline research and conservation can benefit from the knowledge about these species and how they are managed in zoos. The present study analysed how the information contained in the Zoological Information Management System (ZIMS) and the scientific literature can be complementary to understanding the current scenario of studies on the species, highlighting the gaps in knowledge, and evaluating the *ex-situ* population dynamics. The results indicated that all threatened feline species are kept and bred in zoos. There was a population decline for *Leopardus tigrinus* and *L. colocolo* and an increase for *L. wiedii* and *L. guttulus*, while the other species showed stabilization in captive populations. Age pyramids suggest future growth for *Panthera onca* and *L. wiedii* captive populations. Species with restricted distributions, such as *L. colocolo* and *L. tigrinus*, are less frequent in zoos, reproduce less *ex-situ*, and the age pyramids indicate a future decline of captive populations. The most charismatic species, *P. onca* and *Herpailurus yagouaroundi*, have been the most studied. Despite the increase in studies in the 2000s, knowledge gaps remain, especially in genetic and reproductive studies. The findings of this study underscore the need for further research and the potential for zoos to play a significant role in the conservation of Brazilian wild felines, playing parts not only in the maintenance of viable *ex-situ* populations but also in filling knowledge gaps with individuals from their collections in scientific research.

Keywords: Brazil, scientometrics, conservation, *ex-situ*, Felidae, ZIMS.

1. Introduction

Wild cats (felines: Mammalia, Carnivora, Felidae) have always aroused interest in humanity, whether for their beauty or the conflicts they can have with humans (for example, they can prey on farm animals and domestic pets or attack people) (Salom-Pérez et al. 2007; Ripple et al. 2014; Tortato et al. 2021). These conflicts, associated with habitat loss and isolation of populations, are threatening with extinction of some of the feline species (Inskip and Zimmermann 2009; Antonio De La Torre et al. 2018; Menezes et al. 2021). For example, of the 10 native wild cat species of Brazil, seven are threatened with extinction, all classified as vulnerable by the Brazilian red list (the jaguarundi *Herpailurus yagouaroundi*, the Pampas cat *Leopardus colocolo*, the Geoffroy's cat *Leopardus geoffroyi*, the Southern tiger cat *Leopardus guttulus*, the Northern tiger cat *Leopardus tigrinus*, the Margay *Leopardus wiedii*, and the jaguar *Panthera onca*) (Ministério do Meio Ambiente 2022). Of these, two are also classified as vulnerable (*L. tigrinus* and *L. guttulus*) and two as near threatened (*P. onca* and *L. colocolo*) by the International Union for the Conservation of Nature's International Red List (IUCN 2024). The extinction of these species can affect the entire ecosystem (Woodroffe 2000; Crooks 2002; Yasuda 2004), threatening the stability of the biotic community (Silveira et al. 2003; Rabinowitz and Zeller 2010; Thompson et al. 2021). Thus, conservation measures are necessary, both *in-situ* and *ex-situ*.

Effective conservation measures rely on robust scientific research. However, such studies are often scarce for less charismatic or rarer species, especially in the wild (Prokop et al. 2023). Furthermore, revisions that compile existing knowledge about species and identify gaps in this knowledge are unavailable for most animal groups. One published study that compiled information about Brazilian wild cat studies was published in 2006 and evaluated only published material from zoology and mammalogy conferences, from 1994 to 2002 (Oliveira 2006). Another was published about the key environmental cues that influence the occupancy of small South American felids, using data from 2002 to 2020 (Gálvez et al. 2023). Therefore, scientometric studies, which summarise updated information available in the scientific

literature, are necessary to outline the situation and knowledge on the threatened Brazilian felines and highlight knowledge gaps in the study of Brazilian feline science. These studies can guide future research efforts on these species and provide subsidies for conservation programmes, especially *in-situ* actions (Milojević, 2015; Sun et al., 2013).

Some species of wild cats are very charismatic to humans (Corcoran and Fisher 2022). To be considered charismatic, a species must be evaluated by its "reputation" in society (how people understand and view the species), its aesthetics (how "pretty or cute" the species is), its potential to generate satisfaction (how interesting the species is to curious people and scientists) and its fame (how easy it is for the species to be detected and differentiated from other species by people) (Pardini et al. 2006; Ducarme et al. 2013). In Brazil, the jaguar and the jaguarundi met these criteria (Morato et al. 2006). Charismatic species are most often exhibited in zoo collections due to their power to attract the public (Skibins and Powell 2013; Skibins et al. 2017). Because they are more common in zoos, these species are often the target of studies, and thus, more information is produced about their biology (Conde et al. 2011; Marris 2013). On the other hand, less charismatic species, with small wild populations or very restricted distribution, are not common in zoo collections and, consequently, fewer studies and less information are produced about them, hindering their conservation and increasing the risk of their becoming extinct in the long term (Prokop et al. 2022).

For *ex-situ* conservation actions, the reproduction and long-term maintenance of viable populations of feline species in zoos is necessary. The dynamics of these species' captive populations are important for conservation programmes. This information can be accessed by evaluating the data on the Zoological Information Management System (ZIMS), operated by Species360 (Cohn 2006). With more than 1,200 institutions registered over more than 50 years of existence and more than 330 million records on animal species kept in human care (SPECIES360 2024), ZIMS is a conservation tool based on shared knowledge about biology and *ex-situ* management (Maple and Perdue 2013; Farquharson et al. 2021; Vincze et al. 2022).

The aim of this study was to evaluate the existing knowledge in the scientific literature on endangered Brazilian wild cats and assess the role of zoos in maintaining and reproducing these species *ex-situ*, analysing how this information can be complementary to understand the current scenario of studies on the species, to highlight the gaps in knowledge, and to evaluate the *ex-situ* population dynamics. The evolution of captive populations over time was evaluated, testing the influence of group size (number of males and females) on reproductive success. We hypothesised that zoos could contribute to the conservation of endangered Brazilian wild cats by maintaining reproductively active populations, showing growth in the number of individuals over time, with age pyramids indicative of growth, especially for the more charismatic species (jaguar and jaguarundi). We also hypothesised that greater reproductive success would be observed in zoos located in the natural geographic distribution of the species, that is, in the American continent. We predicted that more births would occur in South America, the native range of the species, and for species with larger populations. We also hypothesised that the number of published studies would be more significant for the larger and more charismatic feline species (jaguar and jaguarundi). Still, gaps will be identified for less charismatic and rarer species.

2. Material and Methods

2.1. Threatened Brazilian wild cat species

All seven species of Brazilian wild cats threatened with extinction (Ministério do Meio Ambiente 2022) were selected for this study. All are classified as vulnerable due to habitat loss, conflicts with humans, and diseases from domestic animals (Ministério do Meio Ambiente 2022) (Table 1). The only two species considered charismatic are the jaguarundi and the jaguar while the other five were classified as less charismatic (Morato et al. 2006). The jaguarundi habitat ranges from open shrublands to closed-canopy forests (Tófoli et al. 2009). As a primarily diurnal species, it is relatively easy to observe and consequently well-known. However, it is not abundant (Pro-Carnívoros 2024). With a distribution spanning from

the southern United States (very rare) to central Argentina (da Silva et al. 2016), the jaguarundi is classified as a wide-ranging species within our study (Table 1). The jaguar originally had a geographical distribution ranging from the southwestern United States to northern Argentina. However, jaguars are now officially extinct in the United States (Sunquist and Sunquist 2009). Despite this, the species is classified as having a wide distribution within the scope of our study (Table 1). This species inhabits various habitats, from forests such as the Amazon and the Atlantic Forest to open environments such as the Pantanal and the Cerrado. While being mostly nocturnal, they are not exclusively active at night (Pro-Carnívoros 2024).

The geographical distribution of the Pampas cat extends from the Andean region of Peru to the temperate portion of South America, including the Pantanal and central Brazil (Lucherini et al. 2009). In our study, this species was classified as having a partial southern distribution, as it is exclusively found in South America (Table 1). Pampas cats inhabit a variety of habitats, from open grasslands (most common) to forests with closed canopy cover (Walker et al. 2007). The activity period of this non-charismatic species is mainly nocturnal (da Silva Santos et al. 2018) (Table 1).

The Geoffroy's cats are solitary animals with a geographic distribution throughout southern Bolivia to southern Argentina and Chile (Tirelli et al. 2018; Pro-Carnívoros 2024). This species was categorized within our study as having a partial southern distribution (Table 1).

The southern tiger cat is Brazil's most common non-charismatic wild cat, occurring mainly in the Atlantic Forest. However, its range extends to north-western Argentina and throughout Paraguay (in our study, it is classified as having a partial southern distribution). While predominantly a forest dweller, this species has also been recorded in non-forested habitats (Pro-Carnívoros 2024) (Table 1).

The northern tiger cat is found in north and northeastern Brazil, Venezuela, the Guianas, and some regions of Central America (de Oliveira et al. 2020). This species was categorized

within our study as having a partial northern distribution, as it is exclusively found in South and Central America (Table 1). Primarily nocturnal, they hunt after dusk and during the night (Pro-Carnívoros 2024).

The Margay is a rare, essentially nocturnal species with a wide distribution ranging from northern Mexico to Uruguay and northern Argentina (classified as a species with a wide distribution in our study) (Espinosa et al. 2018; Horn et al. 2020; Marinho et al. 2024) (Table 1).

_____Insert Table 1 here_____

2.2. Scientometric data and statistical analyses

Scientific articles on threatened Brazilian wild cat species were surveyed in three electronic bibliographic search databases: Web of Science (WOS), Pubmed, and Scopus. We searched articles covering the period between 1975 and 2023. The starting year of 1975 was selected to align with the initial records in the ZIMS database.

The keywords used to search for articles were ‘Felidae AND Brazil*’ and ‘scientific name of the species AND Brazil*’. As an intercession, the asterisk symbol (*) and the word ‘AND’ were used as Boolean moderators to consider any and all variations of the keywords. The inclusion criteria for studies in the analyses were peer-reviewed articles about threatened Brazilian wild cat species. Book chapters, abstracts, and conference proceedings were excluded.

The search was carried out on 07 June 2023. All the relevant papers were exported to the Rayyan program, a free application for managing articles in systematic reviews (OUZANNI et al., 2016). For each article selected, the following information was obtained: title, year of publication, journal and impact factor, the country where the study was conducted, author(s), institution of the first author, wild cat species, type of environment where the study was

conducted (*in-situ* or *ex-situ*), type of study (ecology, veterinary, behaviour, physiology, *ex-situ* management or conservation), and sample sizes.

For the research design, articles were selected based on the recommendations for systematic reviews in the PRISMA statement (Principal Reporting Items for Systematic Reviews and Meta-analyses) (MOHER et al., 2009). The literature search yielded 5,308 articles, but 1,116 were included in the analyses (Figure 1).

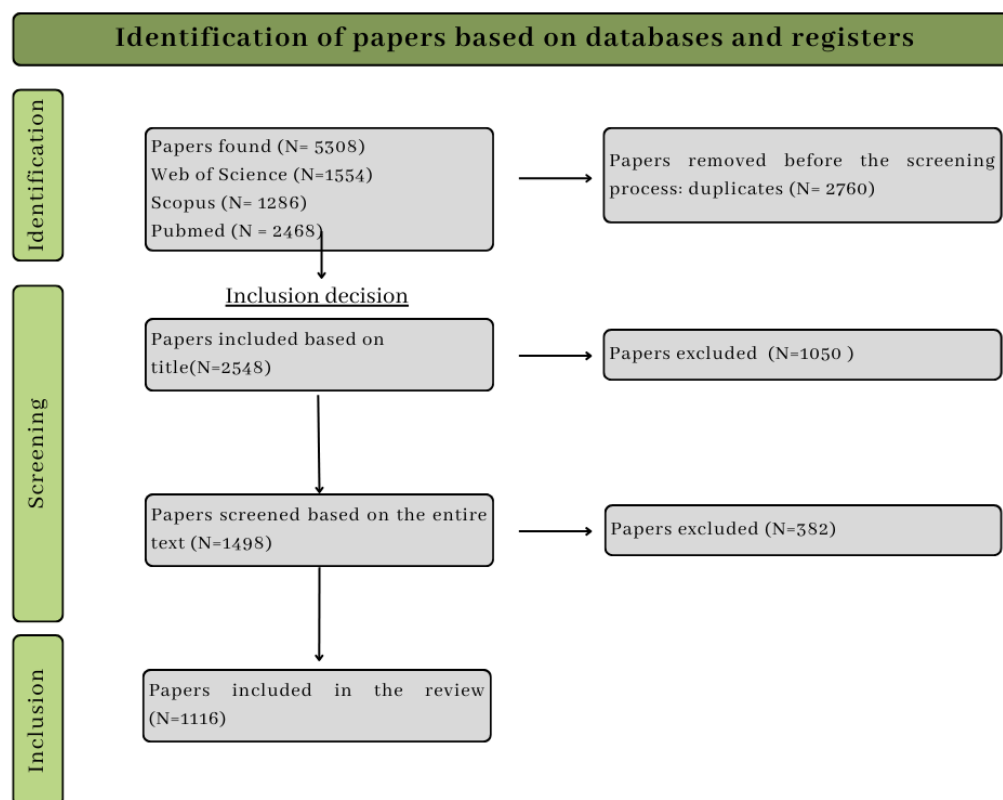


Fig. 1 Prisma Protocol applied to the scientometric analyses of the seven Brazilian wild cat species threatened with extinction.

Descriptive statistics were calculated for the data extracted from the scientometric analysis. The results were presented in absolute and relative numbers whenever necessary (some results add up to more articles than the total number of articles included because some studies evaluate more than one species of wild cats).

A piecewise regression was carried out to assess if there was a breaking point in the number of publications over the years, i.e., the point where there is a sudden increase in the number of publications on threatened felines. The analyses used R 4.3.2 software (R Core Team 2023).

Generalised Linear Mixed Models (GLMMs) were built to assess whether the number of publications (response variable) differed according to each type of study (ecology, behaviour, physiology, management, and conservation) (explanatory variable). The models were built separately for each species of wild cat. Year was used as a random variable in all models. The analyses were carried out using the R 4.3.2 software (R Core Team 2023); the glmer function from the lme4 package was used to build the models, while the graphs were built using the ggplot and ggplot2 packages (Bates et al. 2015). The Infogram© program was used to create maps of study distribution by countries that publish scientific data on the seven Brazilian threatened wild cat species.

2.3. ZIMS database and statistical analysis

The data on the management of wild cat species in zoos was obtained from the ZIMS database (Species360 Zoological Information Management System (ZIMS) 2024), based on a search on the Specie360 platform conducted by a subscriber to the data package on 30 January 2024. Records of the species of interest between 1975 and 2023 were considered. For each wild cat species analysed, the following information was extracted from the ZIMS database: country of the Institution and its geographical region (Africa, South America, North America, Europe, and Asia), number of individuals in the population, number of births, number of deaths, age pyramid and evolution of the captive population over time. This information made it possible to analyse the evolution of the population of each species over time, regardless of the institution assessed. Generalised linear models (GLMs) were constructed to determine whether the number of births of individuals in zoos (response variable) is influenced by geographical region and by the number of males and females in the population (explanatory variables). The analyses were carried out using Minitab 19 software.

3. Results

The number of studies increased between 1975 and 2023, with the highest number published in 2021 (96 articles) (Figure 2). However, no breakpoint was found (Figure 2).

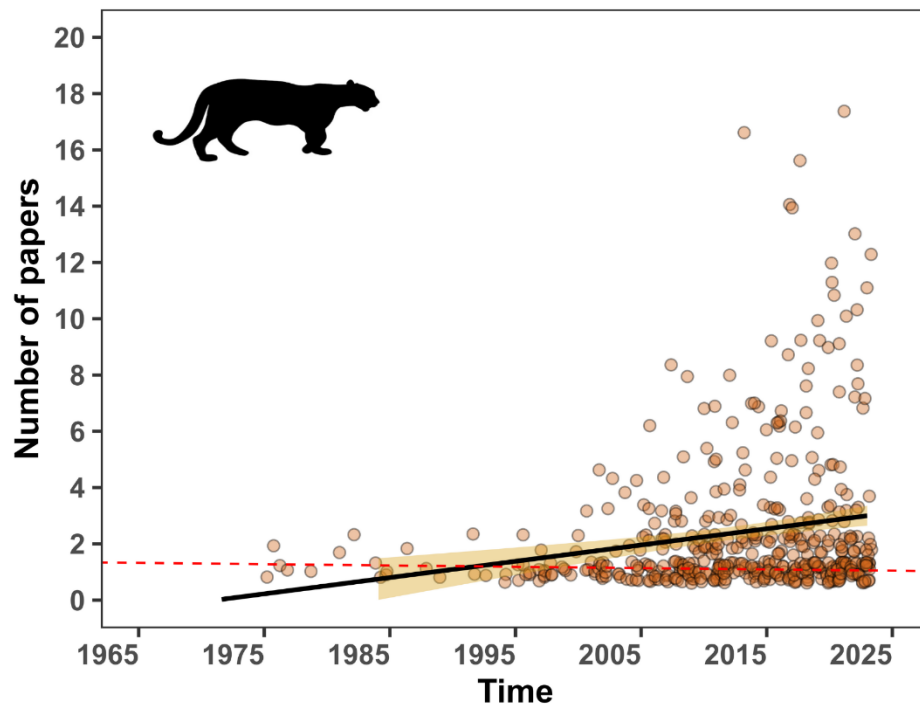


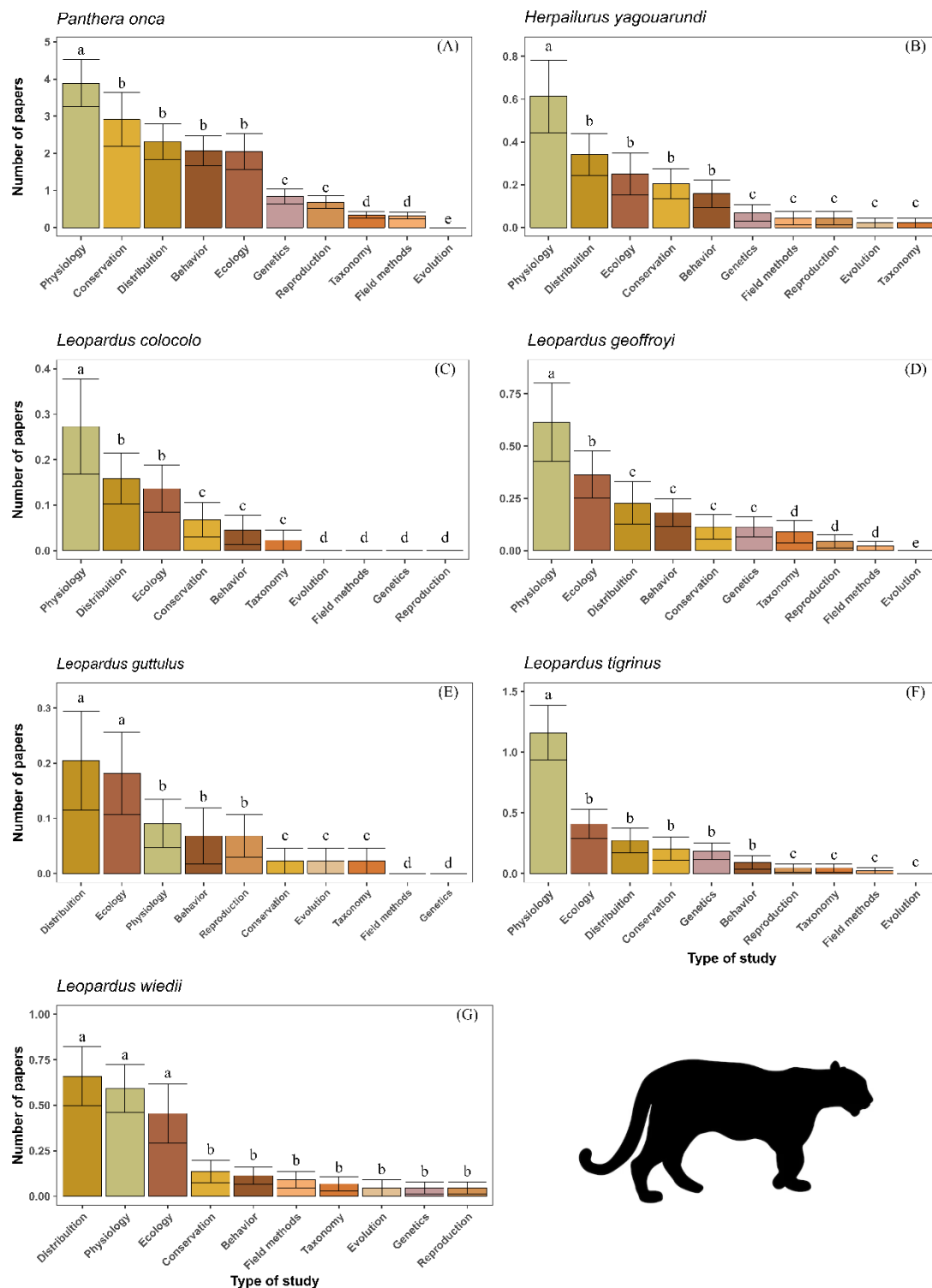
Fig. 2 Number of published articles per year on the seven Brazilian wild cat species threatened with extinction. The trend line shows no breakpoint, i.e. a point where the number of publications significantly differs between two years.

The species with the highest number of published studies was the jaguar, with 752 articles (67.3%), followed by the Margay, with 189 articles (16.9%), and the jaguarundi, with 188 articles (16.8%), the Northern tiger cat, with 163 articles (14.6%) and the Geoffroy's cat, with 140 articles (12.5%). The species with the lowest number of articles were the Pampas cat, with 75 articles (6.7%) and the Southern tiger cat, with 56 articles (5.1%).

For almost all species, the most frequent studies dealt with aspects of the animals' physiology (Figure 3), and these differences were statistically significant (Supplementary Material 1).

Only the Southern tiger cat and the Margay species had more studies about their distribution

(Figure 3). Genetic, behavioural, reproductive, and taxonomic studies were poorly developed for all species (Figure 3).



223

224 **Fig. 3** The number of articles separated by type of study for each species of threatened

Brazilian wild cats. Different letters in the columns indicate statistically significant differences.

Most studies (630, 47.09%) on the seven wild cat species were conducted in Brazil, followed by Mexico (164, 12.26%) and the United States (110, 8.22%) (Figure 4a). Most of these studies were conducted in the wild (*in-situ*: 1130, 72.20%; in zoos or *ex-situ*: 303, 19.36%). The countries with the most significant number of institutions registered in the ZIMS that housed at least one of the seven threatened Brazilian feline species are located in Europe, North America, and South America (Figure 4b). No zoo in Oceania keeps the feline species of interest, and Africa was the continent with the fewest representative zoos (Figure 4b).

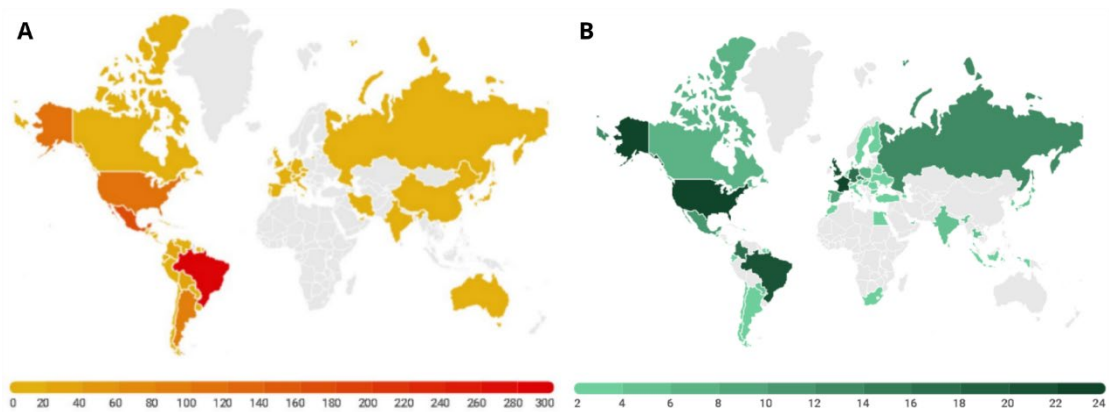


Fig. 4 A) Countries with the most publications on the seven species of Brazilian wild cats threatened with extinction. B) Worldwide geographical distribution of zoological institutions that keep one of the seven species of Brazilian wild cats threatened with extinction.

The jaguar appears in the collections of 171 zoological institutions, most in Europe and North America. In total, 411 jaguar individuals were kept in zoos in 2023, 204 males and 206 females. The species jaguarundi could be found in 34 zoos, spread across Europe, North America, South America, and Asia, with 68 specimens (32 males and 42 females). Nine Pampas cat individuals are found in three zoological institutions in South America: four males and five females. The Geoffroy's cat is distributed in zoos in Europe, South America, and a few institutions in North America, totalling 32 institutions and 69 individuals, 31 males and 38 females. The zoos that house the 22 individuals (12 males and 10 females) of the Southern

tiger cat are on the European and South American continents, concentrated in six zoological institutions. Thirty-seven zoos keep the species Margay, totalling 91 specimens, 39 males and 56 females. The Northern tiger cat is kept in institutions in Europe and North America, totalling 11 zoos and 37 individuals, 13 males and 24 females.

There has been a trend towards stability in the population of jaguars in captivity, with the population fluctuating around 400 individuals over the last 19 years, as well as in the number of institutions keeping this species, varying around 150 institutions over the last 19 years (Figure 5a). For the jaguarundi there was a decline in the number of animals in zoos in the 2000s, followed by a stabilisation of around 80 individuals in the last decade, while the number of zoos keeping this species has been stable at around 30 institutions (Figure 5b).

For the species Margay, there has been a trend towards an increase in the population and the number of keeping institutions over the last 19 years, with the population almost reaching 100 individuals by 2023 and the number of institutions reaching 40 (Figure 5c). For the Northern tiger cat, however, the number of institutions has stabilised at around 10, and the population kept under human care has declined in recent years, falling by half in the last decade (Figure 5d).

The Southern tiger cat population has grown considerably in the last decade, from less than five individuals to almost 25, as has the number of zoological institutions, which has also shown growth in recent years, albeit modestly (Figure 5e). For the species Geoffroy's cat, the captive population and the number of zoos has slightly increased in recent years (Figure 5f). Finally, the captive populations of the Pampas cat have fluctuated around 10 individuals in the last two decades, but the population has declined in the last five years; the number of keeping institutions has fluctuated around three (Figure 5g).

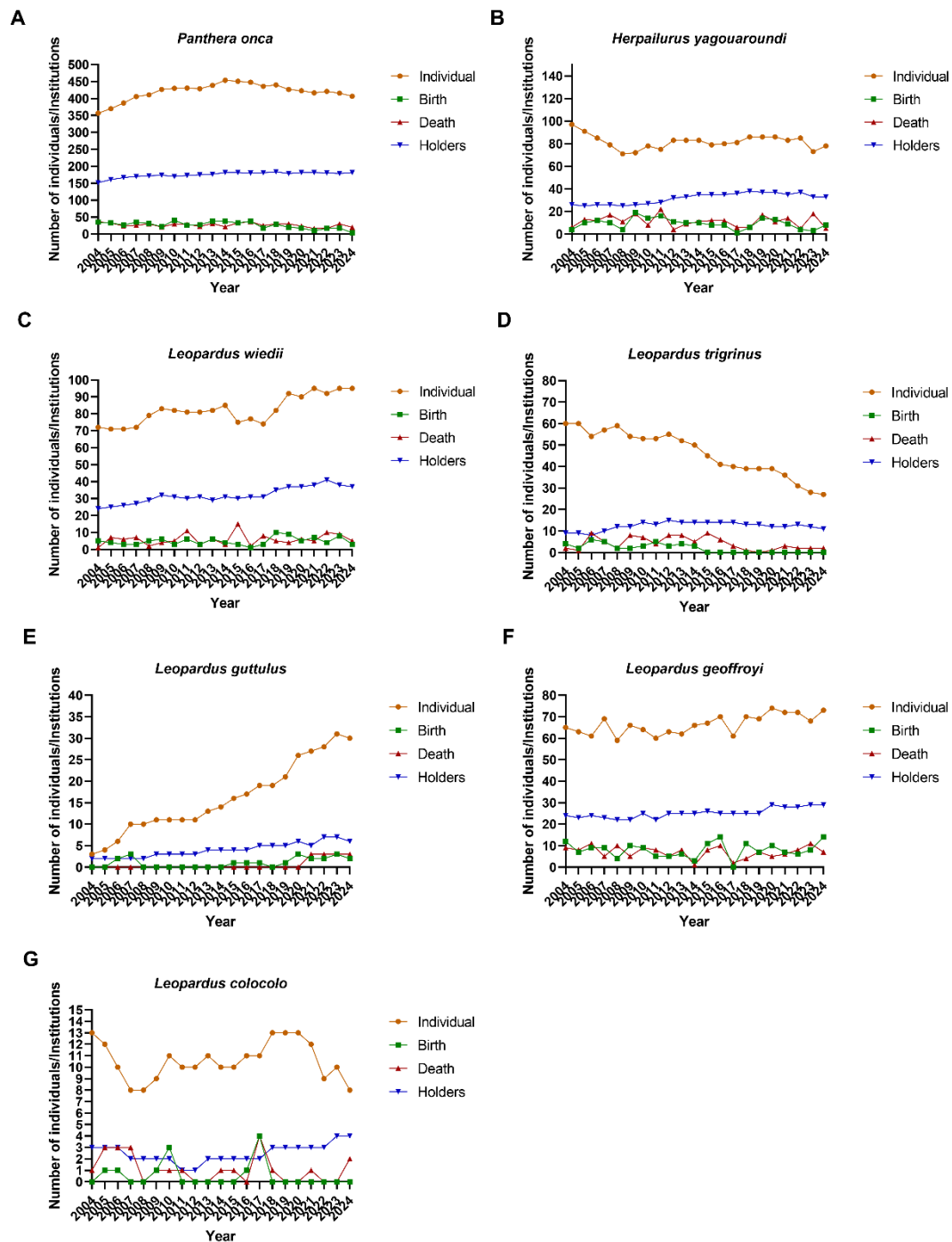


Fig. 5 Population dynamics of the seven threatened Brazilian wild cats in zoos over the last 19 years (2004 to 2023) (brown), along with the number of keeping institutions (blue), number of births (green), and number of deaths (red). A) jaguar *Panthera onca*; B) jaguarundi *Herpailurus yagouaroundi*; C) Margay *Leopardus wiedii*; D) Northern tiger cat *Leopardus tigrinus*; E) Southern tiger cat *Leopardus guttulus*; F) Geoffroy's cat *Leopardus geoffroyi*; G) Pampas cat *Leopardus colocolo*.

The age pyramids of the jaguar (Figure 6a) and the margay (Figure 6b) show more individuals at the base, which suggests captive population growth over the next years. The age pyramids of the Southern tiger cat (Figure 6c) and Geoffroy's cat (Figure 6d) show few individuals at the base of the pyramid or a homogeneous distribution of ages at the base and middle of the pyramid, respectively. These configurations may also indicate future growth for the Southern tiger cat and stabilisation for Geoffroy's cat.

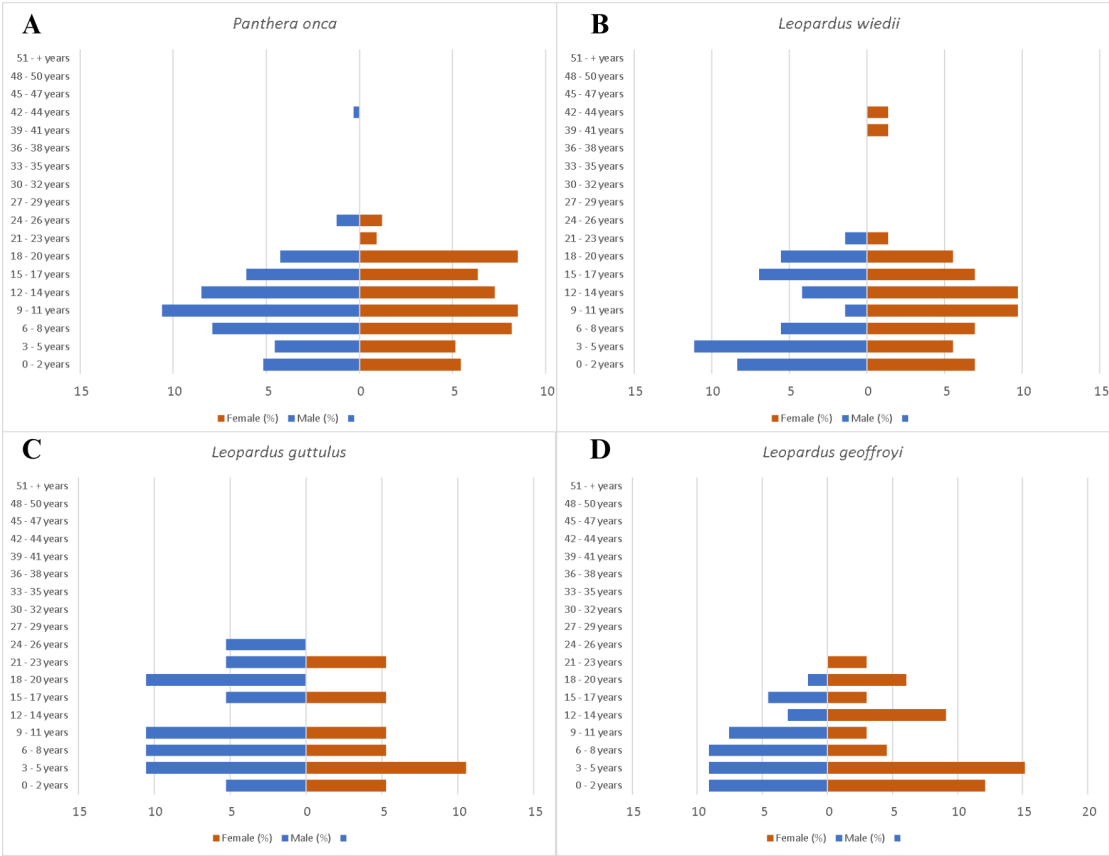


Fig. 6 Age pyramids of threatened Brazilian wild cat species kept in zoos around the world: (A) jaguar (*Panthera onca*); (B) Margay (*Leopardus wiedii*); (C) Southern tiger cat (*Leopardus guttulus*); (D) Geoffroy's cat (*Leopardus geoffroyi*).

On the other hand, the age pyramids of the Pampas cat (Figure 7a), the Northern tiger cat (Figure 7b), and the jaguarundi (Figure 7c) suggest a future captive population decline, as the smallest number of individuals is at the base of the pyramids or the number of individuals at each age is random.

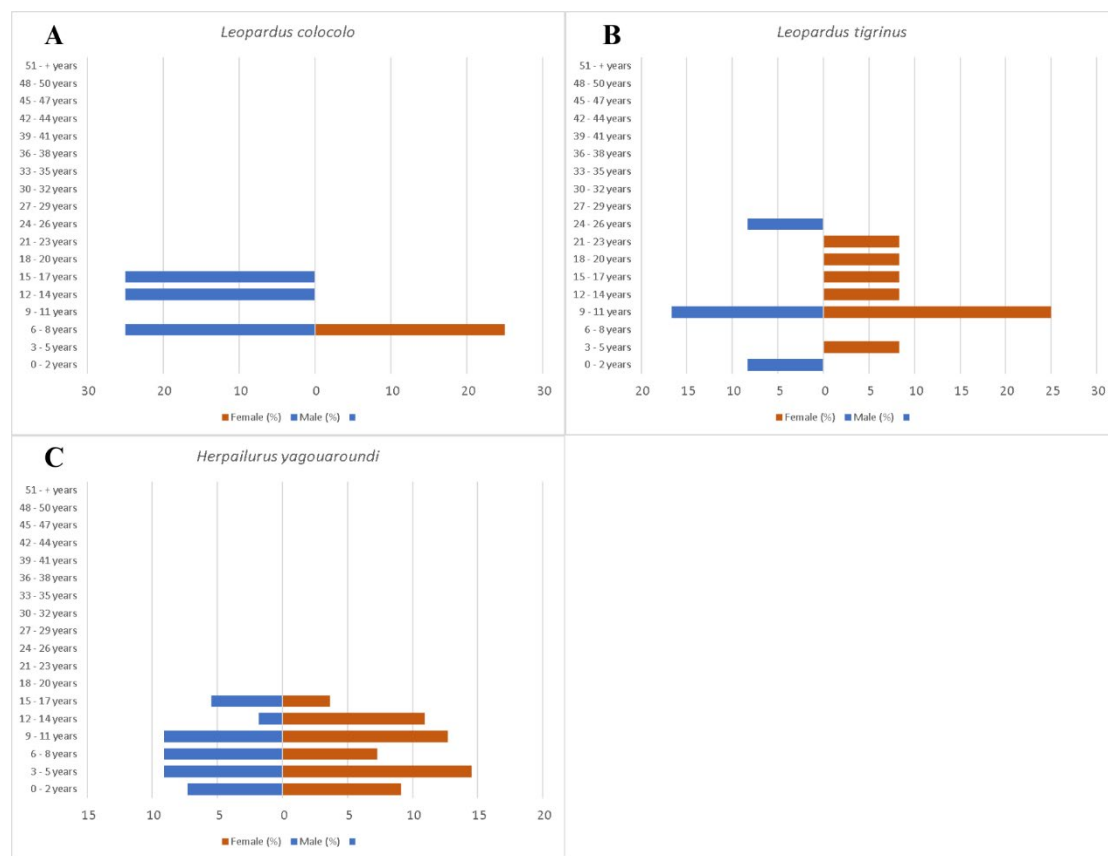


Fig. 7 Age pyramids of threatened Brazilian wild cat species kept in zoos around the world: (A) Pampas cat (*Leopardus colocolo*); (B) Northern tiger cat (*Leopardus tigrinus*); (C) jaguarundi (*Herpailurus yagouaroundi*).

Since 1975, the number of births has varied, but all species have bred in captivity (Table 2). The highest number of births was observed for the jaguar (*P. onca*: 330), while the lowest was observed for the Pampas cat (*L. colocolo*: 5) (Table 2). Only Southern tiger cat has a sexual ratio skewed towards males, with all other species showing a sexual ratio skewed towards females (Table 2).

Insert Table 2 here

Considering all assessed species of wild cats collectively, both the number of males ($F = 6.65$, $p < 0.001$, $DF = 7$) and females ($F = 2.14$, $p = 0.04$, $DF = 7$) exerted influence on reproductive success in captivity. At the same time, the geographical regions of the zoos where they are kept did not show a significant effect ($F = 1.47$, $p = 0.21$, $DF = 4$). Only for the jaguarundi,

the geographical region also influenced the number of births, with more births occurring in Europe than on other continents ($F = 6.92$, $p = 0.002$, $DF = 4$).

Higher birth rates were observed when captive populations comprised five females and three males. When the species were analysed separately, the number of males and females influenced the number of births only for the jaguar (male: $F = 9.94$, $p < 0.001$, $DF = 6$; female: $F = 5.46$, $p < 0.001$, $DF = 6$) and jaguarundi (male: $F = 18.75$, $p < 0.001$, $DF = 4$; female: $F = 2.83$, $p = 0.05$, $DF = 4$). For the jaguar, in zoos with three males and five females, there was a higher number of births, whereas, for the jaguarundi, two males and two females resulted in more births.

4. Discussion

We hypothesised that zoos could contribute to the conservation of endangered Brazilian wild cats by maintaining reproductively active populations, showing growth in the number of individuals over time, and with age pyramids indicative of growth. Our findings revealed that all seven species are housed in zoos worldwide and reproduce *ex-situ*. The populations kept in captivity show a decline only for the Northern tiger cat and for the Pampas cat and an increase only for the Margay and the Southern tiger cat. The remaining species exhibited stable population sizes. The sex ratio skewed towards females for most species, particularly individuals of reproductive age. The exception was the southern tiger cat, which exhibited a male-biased sex ratio. The age pyramids suggested future population growth only for the jaguar, Southern tiger cat, Geoffroy's cat, and Margay. Therefore, this hypothesis was partially corroborated.

Our second hypothesis explored the influence of the geographic location of the zoo and the number of males and females on birth rates. We predicted that more births would occur in South America, the native range of the species, and for species with larger populations. This hypothesis was partially rejected. Geographic location only influenced jaguarundi birth rates, with the highest number of births occurring in Europe. Similarly, the number of males and

females only influenced birth rates for jaguars and jaguarundis, with more offspring produced when both sexes had at least two individuals present.

The final hypothesis suggested that the number of published studies would be higher for larger and more charismatic wild cat species (jaguar and jaguarundi). This hypothesis was supported, as most published articles addressed these species. The margay was also extensively studied, reaching similar levels as the jaguarundi. Furthermore, the hypothesis that the number of studies would increase over time was supported. A substantial rise in publications focusing on all seven wild cat species was observed, particularly from the year 2000 onwards.

Most studies retrieved from bibliographic search platforms were obtained for the jaguar. The species with the fewest studies were the Pampas cat and the Southern tiger cat. This finding highlights a common trend in research and conservation where charismatic species often receive more attention and resources due to their popularity among the public (Veríssimo et al. 2012; Thornton et al. 2016). The jaguar is maintained in zoos worldwide due to its magnificence and visual appeal (Rueda-Zozaya et al. 2016). The captive environment facilitates studies on behaviour, health, and reproduction, contributing to a more comprehensive understanding of their biology (Gonzalez et al. 2017).

Beyond charisma, a species' ecological significance also influences the research focus (Kantek et al. 2021). The jaguar is a keystone species in many ecosystems, playing a crucial role in prey population control and maintaining ecological balance (Paviolo et al. 2016). This pivotal role likely motivates research into their impact on food webs (Duarte et al. 2023).

Despite its wide distribution, the jaguar faces significant threats such as habitat loss, human conflicts, and illegal hunting (Bogoni et al., 2023). These threats further drive research efforts to understand and mitigate these challenges, ultimately informing effective conservation strategies (Torres-Romero et al., 2023).

355 In contrast, less charismatic species, such as those in the *Leopardus* genus, are often
356 overlooked. Existing studies on these species focus on their physiology, distribution, and
357 ecology. This low quantity of articles may be attributed to smaller species, such as the
358 Northern tiger cat and the Southern tiger cat, which are less charismatic compared to bigger
359 felines. This “charisma gap” may influence the allocation of resources for research and
360 conservation, ultimately affecting public perception and scientific interest (Gálvez et al.
361 2023).

362 Furthermore, some *Leopardus* species have more restricted geographical distributions and
363 secretive lives, which may limit field research opportunities and reduce their presence in zoos.
364 The rarity of these species makes it challenging to observe them in their natural habitat,
365 hindering field studies and data collection. Similarly, their low frequency in zoos reduces
366 opportunities for captive studies, further limiting visibility and researcher access to these
367 species (Vanderhoff et al. 2011; Silva et al. 2021). Most studies have focused on
368 physiological aspects, primarily involving blood parameters, hormones, neuroscience,
369 anatomy, and clinical examinations. Exceptions were observed in the case of the margay and
370 Southern tiger cat, where studies on their distribution were most frequent. This predominance
371 can be explained by these species' reduced population sizes in the wild (Gonçalves 2023;
372 DeMatteo et al. 2023).

373 The scientometric analysis also identified a lack of studies focused on behaviour, reproduction,
374 and genetics for all species. These topics are notoriously challenging to investigate in the wild,
375 often requiring long-term observation or animal capture for biological sampling. Zoos can play
376 a crucial role in addressing these knowledge gaps. Behavioural field studies of primarily
377 nocturnal, solitary and secretive animals can be extremely difficult, thus zoos provide an
378 extraordinary opportunity to increase our understanding of the behaviour of such species
379 (Songsasen and Rodden, 2010).

380 Researchers from Brazil, Mexico, and the United States stood out, with approximately 47% of
381 studies on threatened Brazilian wild cats conducted in Brazil. This predominance can be
382 attributed to the geographical distribution of the species, which predominantly occur within
383 Brazilian territory (Pro-Carnívoros 2024). Mexico, the second country with the most studies
384 (12.26%), also plays an important role in feline research. Mexico's position can also be
385 influenced by the richness of felines in the country (Santos 2019). Although the United States
386 contributes a smaller percentage of studies (8.22%), it still represents a significant portion.
387 This participation can be attributed to research conducted by Brazilians in academic and
388 conservation institutions in the United States and to the ongoing interest in the conservation
389 of threatened species that occur outside their territory (Nora and Franco 2018; Main 2022).

390 Our results showed that most of the threatened Brazilian wild cats are found in zoos in
391 countries outside the species' natural range, such as the United States and France. This
392 concentration in European and North American zoos can be explained by developed countries
393 having more zoos registered in ZIMS, while underdeveloped countries, such as those in South
394 America, have fewer zoos registered in the platform. Only about 12% of zoological
395 institutions worldwide are registered in ZIMS (SPECIES360 2024); 153 institutions maintain
396 at least one threatened Brazilian wild cat species. Thus, it would be important to have as
397 many possible Institutions registered in ZIMS because this would allow us to draw a better
398 picture of the captivity populations of the species.

399 The jaguar is found in various zoological institutions, possibly due to global efforts to educate
400 the public about the importance of conserving these felines and their natural habitats.
401 Additionally, the jaguar's widespread zoo representation may indicate international
402 collaboration in conservation breeding programs, a strategy to ensure long-term species
403 survival. On the other hand, the rarity of Pampa's cat and Southern tiger cat in zoos raises
404 significant questions about the factors that may contribute to this disparity, such as the rarity
405 of these species in the wild. Lesser-known or less charismatic species generally receive less
406 attention and resources for zoo research and exhibition (Holmes et al. 2022; Prokop et al.

2023). Furthermore, some less-studied felids may face specific challenges adapting to captivity, potentially influencing zoo decisions regarding acquisition based on well-being considerations (Kleiman et al., 2010).

In contrast, the frequent presence of margays and Geoffroy's cats in zoos likely results from their abundance in the wild and public appeal. Furthermore, the available biological information facilitates their maintenance and adaptation to captivity. Zoos can significantly contribute to the conservation of these species through breeding programs, education initiatives, and reintroductions.

Analysis of captive populations of threatened Brazilian wild cats reveals a trend towards stabilisation, with some species showing a strong increase. Focusing on reproductive age and sex ratio reveals a female-biased population structure for most species, with a high proportion of individuals of reproductive age, suggesting a long-term maintenance of populations in zoos. However, for the Southern tiger cat, the absence of individuals of reproductive age for both sexes is a substantial concern, pointing to additional challenges in conserving this species.

The fact that ZIMS shows that all species have bred in captivity is of great importance for the study and future conservation of these species. The captive environment can facilitate reproductive studies by not only providing access to these species but also due to easier acquisition of biological samples (blood, semen, faeces). Research on reproductive physiology, semen collection, and cryopreservation techniques has been conducted on species like jaguars but needs to be expanded to other non-charismatic species (Swanson et al., 2003). These studies can help establish normative reproductive parameters and develop assisted reproduction techniques such as artificial insemination and in vitro fertilization.

Assisted reproduction presents a potential solution for Southern tiger cat and other species with limited population viability based on age pyramids (Bianchi et al., 2022). A comprehensive strategy to enhance reproductive rates in captive felines has already been

published, and highlights the importance of non-surgical approaches, such as transvaginal artificial insemination (AI) (Tsutsui 2006). Cryopreservation is a reality and should also be adopted as an *ex-situ* conservation strategy (Zahmel et al. 2022). However, a central obstacle lies in the limited knowledge about these species' behaviour and physiology. Reliable data on reproductive seasonality, oestrous cycles, ovarian sensitivity, maturity, reproductive senescence, and ovulation timing is critical for the success of assisted reproduction efforts (Swanson, 2022).

Zoos can further contribute to conservation by implementing naturalistic enclosures, developing environmental enrichment programs, and conducting continuous research on each species' biology (Jewgenow and Songsasen, 2014). These efforts can improve reproduction, health, and adaptability in captivity, potentially facilitating future reintroductions in the wild (Swanson 2022).

These suggestions emphasize the importance of a multifaceted approach, encompassing assisted reproduction techniques, careful animal selection, and management practices that promote an environment conducive to reproduction and well-being (Brando and Norman 2023). The coordinated implementation of these strategies can significantly contribute to increased reproduction and, consequently, successful conservation of these felids (Tuite et al. 2022; Ogle and DeSmet 2023).

5. Conclusions

In conclusion, the results showed that there are still many gaps in the knowledge about endangered Brazilian wild cat species. In this regard, there is a lack of studies on the factors influencing the reproductive success of species in captivity, especially Southern tiger cat and Pampas cat, species that are sparsely represented in zoos. Behavioural, genetic, and reproductive studies are still underdeveloped, and zoos can play an important role in filling these gaps. The performance of a scientometric review, combined with the analysis of data contained in the ZIMS platform, provided a global overview of the *status quo* regarding the

seven threatened Brazilian wild cat species. The effective contribution of zoos to wild cat conservation may be debatable, as for some species, the populations maintained are either very small or consist of individuals unfit for reproduction. In contrast, for others, populations are stable and exhibit age pyramids indicative of future population growth. The analysis of these two sources of information (publication trends and captive population dynamics) proved to be important in highlighting how studies emphasize certain areas of knowledge to the detriment of others and how zoological institutions maintain populations of certain species that are more likely to be maintained in the long term than others. Interestingly, few studies have been published on individuals kept in captivity, even though the gaps in the scientific literature could be filled with data from these individuals. Thus, the joint evaluation of these two sources of information can guide future studies, intensifying and improving conservation actions for endangered Brazilian feline species. Hence, the importance of a broad and equitable approach to promoting the conservation of all threatened Brazilian wild cat species is emphasized, with partnerships between institutions and researchers to increase knowledge about the species' biology, facilitating suggested conservation actions.

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Table 1: Characteristics of the vulnerable Brazilian wild cat species, with information about their distribution (wide: North, Central and South America; Partial southern: only in South America; Partial northern: Central and South America) and body weight (Ministério do Meio Ambiente, 2022; Sunquist and Sunquist, 2009).

Species	Common name	Body Weight	Distribution
<i>Herpailurus yagouaroundi</i> (Geoffroy, 1803)	Jaguarundi	3-9 Kg	Wide
<i>Leopardus colocolo</i> (Molina, 1782)	Pampas cat	3-4 kg	Partial southern
<i>Leopardus geoffroyi</i> (d'Orbigny & Gervais, 1844)	Geoffroy's cat	3-8 Kg	Partial southern
<i>Leopardus guttulus</i> (Hensel, 1879)	Southern tiger cat	2-4 Kg	Partial southern
<i>Leopardus tigrinus</i> (Schreber, 1775)	Northern tiger cat	1-4 Kg	Partial northern
<i>Leopardus wiedii</i> (Schinz, 1821)	Margay	2-5 Kg	Wide
<i>Panthera onca</i> (Linnaeus, 1758)	Jaguar	35-158 Kg	Wide

Table 2. Total number of males and females, sex ratio, and total number of males and females born from 1975 to 2023 for all seven species of threatened Brazilian wild cats kept in zoos around the world.

Species	N° male	N° female	Sexual ratio	Captive born males	Captive born females
<i>Panthera onca</i>	205	210	98	165	165
<i>Herpailurus yagouaroundi</i>	31	42	74	24	28
<i>Leopardus colocolo</i>	4	6	67	2	3
<i>Leopardus geoffroyi</i>	30	36	83	24	34
<i>Leopardus guttulus</i>	17	13	131	6	5
<i>Leopardus tigrinus</i>	7	21	33	5	9
<i>Leopardus wiedii</i>	41	54	76	29	33

710 **Supplementary Material 1:** Results of the generalised linear mixed model (GLMM)
 711 analyses to test the effect of the explanatory variable (type of study) on the response variable
 712 (number of papers), using year as a random variable. DF = degrees of freedom.

Species	Response variable	Explanatory variable	Distribution	DF	Deviance	p-Value
<i>Panthera onca</i>	Number of papers	Type of study	Poisson	13	1052.5	2.2e-16
<i>Herpailurus yagouaroundi</i>	Number of papers	Type of study	Poisson	13	349.91	1.24e-11
<i>Leopardus colocolo</i>	Number of papers	Type of study	Poisson	13	176.24	3.035e-07
<i>Leopardus geoffroyi</i>	Number of papers	Type of study	Poisson	13	354.76	7.291e-12
<i>Leopardus guttulus</i>	Number of papers	Type of study	Poisson	13	155.09	0.0004222
<i>Leopardus tigrinus</i>	Number of papers	Type of study	Poisson	13	402.75	2.2e-16
<i>Leopardus wiedii</i>	Number of papers	Type of study	Poisson	13	405.31	2.304e-16

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