

Article

First Decade of European Starling in Brazil: Spatial Distribution, Expansion Rates and Insights of Nesting Biology

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Simple Summary

The European Starling is one of the world's most successful invasive bird species and has expanded its range across many regions outside its native distribution. In Brazil, however, information about its spread and breeding status is still limited. This study documents the first ten years of the species in the country. We analyzed the geographic expansion of the species and compiled evidence of reproduction. Our results show an increase in both the number of records and occupied areas, indicating that the species is establishing and expanding its population in southern Brazil. We also confirmed breeding activity in numerous locations, demonstrating that the species is reproducing successfully and continuing its spread. Understanding how invasive species expand in new environments is important because they may affect native wildlife, agricultural systems, and ecosystem processes. The information provided by this study establishes an important baseline for future monitoring and management actions and contributes to a better understanding of the European Starling invasions in Brazil and the Pampa biome.

Abstract

We compiled records of *Sturnus vulgaris* (European Starling) in Brazil over the ten years following its first documented occurrence in the country. The dataset included field campaigns and summarized data from citizen science platforms, field data, and reports from researchers and birdwatchers. A total of 2618 abundance records were compiled across 219 occurrences, with only five additional records distributed across the states of São Paulo, Rio de Janeiro, and Minas Gerais, while all others 97.7% came from Rio Grande do Sul state, the southern border of Brazil. In just one decade, the species has expanded across a considerable portion of the Brazilian Pampa, with a mean expansion rate ranging between 19.2 and 25.5 km²/year, with higher abundance along the border with Uruguay. We identified 55 nesting sites, most of which were located in cavities previously excavated by woodpeckers (Picidae), primarily in *Eucalyptus* trees. Breeding begins in September, peaks between October and November, and extends until the end of December. The data from this study indicates a high degree of behavioral plasticity in the species, facilitating its rapid adaptation and expansion within the Pampa biome.



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Keywords: Sturnidae; *Sturnus vulgaris*; exotic bird; invasive species; range expansion; invasion dynamics; nesting biology; Pampa biome

1. Introduction

The introduction of non-native species into new ecosystems is recognized as one of the primary drivers of global biodiversity loss and significant economic damage [1–3]. Among these, the European Starling (*Sturnus vulgaris* Linnaeus, 1758, hereafter starling), a member of the family Sturnidae native to Eurasia stands out as a remarkably successful global invader [3]. Since its initial introductions, it has established self-sustaining populations across vast territories, including the United States, Mexico, South Africa, Australia, New Zealand, Argentina, and various Pacific and Caribbean islands [4,5].

The species' success is associated with substantial ecological and economic impacts, characterized primarily by aggressive competition with native cavity-nesting birds and considerable agricultural losses resulting from crop damage and the consumption of animal feed [6]. In the United States alone, damage caused by starlings to agricultural crops has been estimated at approximately USD 800 million per year [7], in addition to substantial losses in sectors such as public health and aviation [8]. Beyond these impacts, understanding the mechanisms underlying its spread is essential to explain its invasion success. The rapid colonization of starling in agropastoral ecosystems in the Neotropics is facilitated by its dispersal capacity and high ecological plasticity [9]. The species also occupies urban areas, where the diversity of available resources offers favorable conditions for adaptation and expansion [10], potentially serving as hubs for the invasion of adjacent natural habitats [11,12].

Competition with native birds for nesting sites is one of the main concerns regarding the invasion of the starling and its effects on local bird communities. In Argentina, Di Giacomo [13], noted that the species nests in tree cavities, light towers, buildings, and artificial nest boxes. During the breeding season, it uses both natural and artificial cavities, including those excavated by the woodpeckers *Colaptes melanochloros* and *Colaptes campestris*, the nests of the rufous hornero (*Furnarius rufus*), as well as rooftops and light poles [14–16]. Outside the breeding season, the species gathers in large communal roosts, which in its native range can comprise thousands or even millions of individuals and are typically located in urban or semi-urban areas [17–19]. These roosts are dynamic and seasonal, typically found in dense-canopy trees or urban structures [18,20,21].

In South America, the species was first introduced in Argentina during the 1980s, with nesting records in the Buenos Aires region beginning in 1987 [22,23]. Since then, it has expanded throughout the Pampa biome in central and northern Argentina [9,12,24], reaching Uruguay [25], where the Pampa biome encompasses the entire national territory. More recently, the species has expanded into southern Brazil, where it was first recorded in the municipality of Lavras do Sul, Rio Grande do Sul, in 2014 [26].

In Brazil, the Pampa biome is restricted to the southern portion of Rio Grande do Sul, where it covers approximately 68% of the state's territory, encompassing an area of roughly 17.64 million hectares [27]. Grasslands constitute the dominant native vegetation type of the Pampa and are largely maintained by grazing, which limits the natural expansion of forest and shrub vegetation [28,29]. This biome harbors a rich and distinctive fauna and flora, characterized by high levels of biodiversity and endemism [30–35]. However, natural areas of the Pampa are increasingly being fragmented due to the expansion of agricultural activities and plantations of exotic tree species [36]. Over the last 40 years, areas covered by herbaceous and shrub vegetation (native grasslands) in the Brazilian Pampa have declined

from 9.6 million hectares (Mha) to 6.1 Mha, representing a reduction of approximately 36%. This decline has been driven primarily by the expansion of agriculture and silviculture, which increased by about 62% over the same period, from 5.4 Mha to 8.8 Mha [37,38]. Given its rapid expansion and potential impacts, understanding the dynamics of starlings in newly invaded regions is essential, particularly in the Pampa region, which provides optimal environmental conditions for the species' accelerated spread and significant population growth [9].

In this study, we analyze the expansion of the European Starling in Brazil during its first decade of colonization. We first reviewed all available information on the species by consolidating records from citizen science platforms and our own field observations. Second, we analyzed this dataset to report on the current status of the species in the country, assessing its spatial distribution, expansion rates, and population abundance over time. Third, we provided data on the nesting ecology of the species, including its breeding sites, nesting substrates, phenology, overall reproductive behavior, and interactions with native bird species; additionally, we included general observations on foraging habitat and behavior. We discuss the potential ecological and environmental factors that may have influenced this expansion process, as well as the associated impacts of the invasion.

2. Materials and Methods

2.1. Data Collection

A comprehensive survey of starling records in Brazil was conducted using the main citizen science platforms employed by ornithologists and birdwatchers: eBird, iNaturalist, Global Biodiversity Information Facility and WikiAves. Searches were performed using the species name *Sturnus vulgaris*, and all records available up to December 2024 were compiled. For each record, we extracted the geographic coordinates, municipality, date of observation, and number of individuals reported. It is important to note that several researchers and birdwatchers were directly contacted and provided valuable information, especially through the WikiAves platform, adding to the records they had previously published.

In addition to citizen science records, we incorporated opportunistic field observations made by the authors during long-term ornithological fieldwork and road trips associated with unrelated research projects, conducted between 2015 and 2024. These observations were not collected through standardized surveys targeting the starling, but rather incidental records obtained whenever the species was encountered. A total of 48 records generated by the author or our research group were included in the dataset and treated using the same data validation procedures applied to all other occurrence records.

For each record, the following information was noted: geographic coordinates, number of individuals observed, evidence of nesting (such as adults visiting nests or chicks observed in nests), and the observation date. Duplicate records were identified through manual inspection of observation date, locality, observer identity, number of individuals, and associated photographs when available. Records referring to the same observation event but reported on multiple platforms were counted only once. In such cases, only the record with the highest number of individuals per site was considered. This also prevented the overrepresentation of birdwatching hotspots in the sample after validation and removal of duplicate records, observations from citizen-science platforms, directly communicated records, and the authors' opportunistic field observations were merged into a single occurrence database for all subsequent analyses. We also compiled observations related to the species' behavior, including social interactions, nesting-related activities, and feeding behavior. These records were obtained from direct field observations.

2.2. Statistical and Spatial Analyses

All analyses were conducted in R 4.4.2 [39]. Occurrence data (coordinates and abundance) were imported using readxl [40] and processed with dplyr [41], enabling data filtering, selection, and aggregation. Spatial manipulation was performed using sf (simple features [42], converting occurrence records into geospatial objects for further analyses and visualization. To investigate the spatial expansion and distribution of starling in Brazil, we estimated the estimated occupied range (EOR) using alpha hulls (alpha-shapes), following recommendations of the International Union for Conservation of Nature [43], implemented with the alphahull package [44]. An alpha value of 100,000 was used to obtain a realistic delineation of the occupied area. For each year, cumulative occurrence records (including all records up to that year) were used to generate alpha hulls, representing the progressive expansion of the species distribution through time. The area of each alpha hull was calculated in km², annual expansion rates were calculated as both area increase (km²/year). All quantitative estimates of occupied area and expansion rates presented in this study were derived from alpha hull analyses.

The annual number of reported starling individuals was analyzed using a generalized linear model with a Poisson error distribution and a logarithmic link function. The response variable corresponded to the annual number of individuals reported in the occurrence database rather than estimates of the true population size. Therefore, this analysis was intended only to describe temporal changes in reported observations. Observation year was included as the predictor variable, and the model was fitted using the glm() function in R. The exponential equation ($\mu = \exp(b_0 + b_1 \times \text{Year})$) was derived from the regression coefficients. Model fit was assessed using Pseudo R² (Deviance), calculated as (null deviance – residual deviance)/null deviance. Model dispersion was evaluated by comparing the residual deviance with the residual degrees of freedom. Although overdispersion was detected, comparison with a Negative Binomial model did not improve model fit according to AIC. Therefore, the Poisson model was retained as a descriptive tool to summarize the temporal pattern in reported individuals.

3. Results

3.1. Species Expansion in Brazil

In Brazil, a total of 219 independent occurrences were recorded, totaling 2618 individuals. Of the total records, 214 records (97.7%) were located in 26 municipalities of Rio Grande do Sul and just five elsewhere in the country, in the states of São Paulo, Rio de Janeiro, and Minas Gerais (Figure 1). In just 10 years since its first record in Brazil, the species has already spread across much of the Brazilian Pampa (Figure 1). The records are concentrated in the extreme south of Brazil, along the border with Uruguay, consistent with a south-to-north expansion, likely involving individuals originating from Uruguay and Argentina.

Data from citizen science platforms, which rely on the collaboration of thousands of birdwatchers and researchers, enabled the mapping of the species' progressive distribution in Brazil over time. This spatial expansion is particularly evident in Rio Grande do Sul. Using data compiled in three-year intervals, we generated maps illustrating the species' range expansion in the state over the last decade (Figure 1).

Up to 2014, only a single record of the species was known in the south of Brazil. Four years later, this number increased to four occurrence records ($r = 4$) and 37 abundance records ($ar = 37$). By 2021, the species' presence had risen to 29 occurrence records and 110 abundance records. However, the most pronounced increase occurred in the last three-year interval: by 2024, records had surged to 214 (r) and 2613 (ar). Most municipalities with records of the species are located within the Brazilian Pampa. Nevertheless, in recent

years, records have also been reported in municipalities within the Atlantic Forest biome, as well as in southeastern Brazil. The latter may represent a secondary invasion event not directly associated with the dispersal of individuals from Argentina and Uruguay. The total area of the 26 municipalities in Rio Grande do Sul with records of starling (71,423 km²) corresponds to approximately 36.9% of the total area of the Brazilian Pampa and 25.3% of the area of Rio Grande do Sul [45].

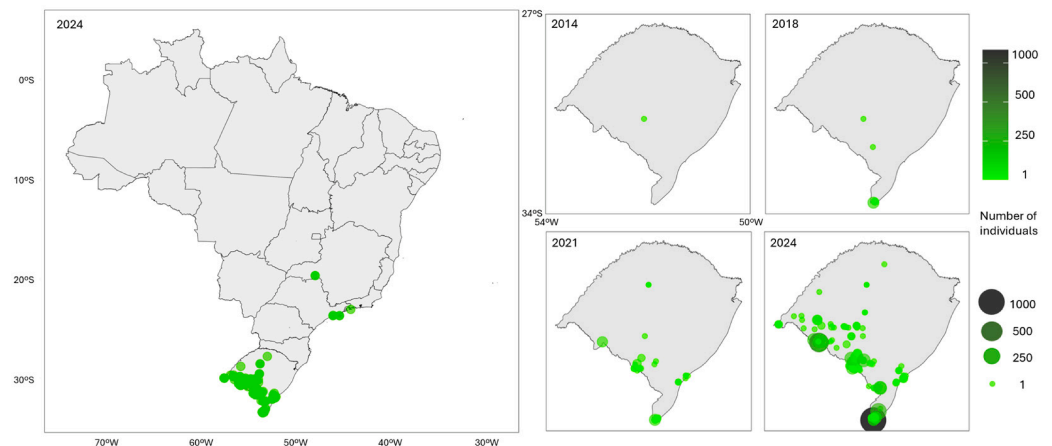


Figure 1. Current distribution of *Sturnus vulgaris* in Brazil. Spatial expansion of the species in Rio Grande do Sul from 2014 to 2024. The dots points correspond to the geographic coordinates of the records. The size and color of the dots represent the number of recorded individuals, with a gradient from light green (fewer individuals) to dark green/black (more individuals).

Between 2014 and 2016, no detectable annual increase in the occupied area was observed, indicating a lack of expansion, a low number of records, or both. From 2017 onward, a growth process began and intensified in subsequent years. The highest rates occurred between 2020 and 2022, particularly in 2021 (48.7 km²) and 2022 (46.9 km²), characterizing a period of more pronounced expansion in the species' distribution. In 2023 and 2024, a reduction in expansion rates was observed (29.2 km² and 9.8 km², respectively).

The cumulative estimated occupied range (EOR) of starling increased over time, indicating rapid spatial expansion. The occupied area expanded from an initially restricted distribution to a broad geographic range, encompassing a large portion of the Brazilian Pampa and the state of Rio Grande do Sul. The overlap of polygons indicates not only the expansion of the distribution but also the consolidation of records in previously occupied areas, suggesting a continuous process of colonization and establishment.

When considering expansion, a progressive increase was observed throughout the analyzed period, with a marked rise in recent years, indicating a phase of accelerated expansion rather than a stabilized distribution. An initial period of stability is evident between 2014 and 2017, followed by a gradual increase until 2021. From 2022 onward, however, a sharp increase in cumulative area is observed, indicating a recent phase of more rapid expansion.

The Poisson regression analysis revealed a significant positive exponential relationship between the observation year and the annual number of reported starling individuals (Figure 2). The fitted equation, $\mu = \exp(-1124.16 + 0.56 \times \text{Year})$, indicates an increase in the number of reported individuals over time. The positive coefficient (0.56) for "Year" suggests an exponential annual increase in reported individuals. The Pseudo R² of 0.521 shows that the model explains a considerable proportion of the observed variability, indicating a good fit. The increasing width of the confidence bands at higher fitted values reflects greater uncertainty associated with larger numbers of reported individuals. The exceptionally high number of reported individuals in 2023 may reflect localized aggregation events and/or

variation in reporting effort. Although the number of reported individuals declined slightly in 2024, it remained substantially higher than in the early years of the invasion, consistent with the continued spread and establishment of the species in Brazil.

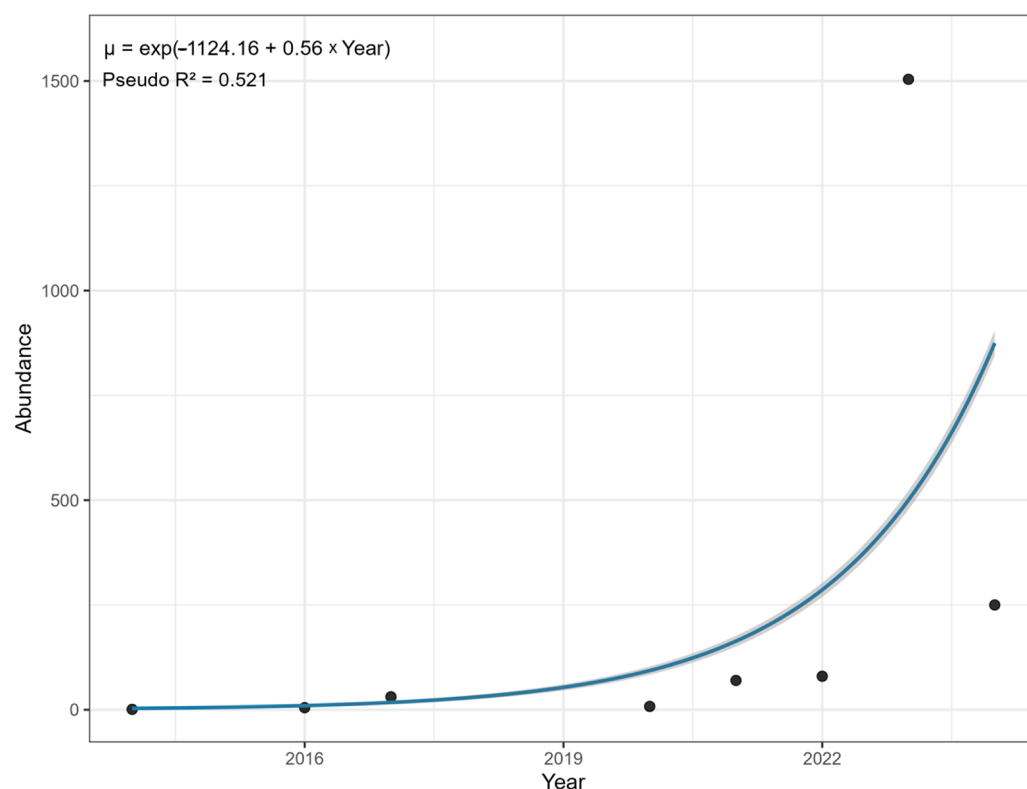


Figure 2. Poisson regression of *Sturnus vulgaris* abundance in Brazil as a function of observation year. Black points represent observed abundance data. The solid blue line indicates the abundance curve predicted by the Poisson regression model. The gray shaded area represents the error band (± 1 standard deviation) of the prediction, reflecting the uncertainty associated with the abundance estimate. The X-axis represents the year of observation, and the Y-axis represents the total abundance of individuals.

3.2. Breeding Ecology

A total of 55 starling nesting sites were identified, including sites with multiple nests (Figure 3). The most frequent nesting sites were tree cavities previously excavated by woodpeckers (Picidae) in *Eucalyptus* spp., plantations ($n = 43$ nests). Additionally, the use of natural cavities in trees such as *Alchornea triplinervia*, *Pinus elliottii*, and *Melia azedarach* was also recorded. In addition to using tree cavities and hollows, an interesting behavior was observed on two occasions, when the species used the nests of Firewood-gatherer (*Anumbius annumbi*).

In nests where it was possible to record the number of chicks, brood size ranged from one to four chicks per nest, with three being the most common value. During our field observations, we documented an interspecific event that may indicate interspecific competition, in which a starling attempted to take over a cavity occupied by a pair of *C. campestris*, which blocked the entrance to what was likely their nest in *M. azedarach*.

The species' nesting season in the Brazilian Pampa was observed to begin in the austral spring, starting in the second half of September. Most nesting records were documented between October and November, and active nests were recorded until the end of December. Likewise, records of juvenile individuals associated with monitored nests were obtained mainly during the last three months of the year.

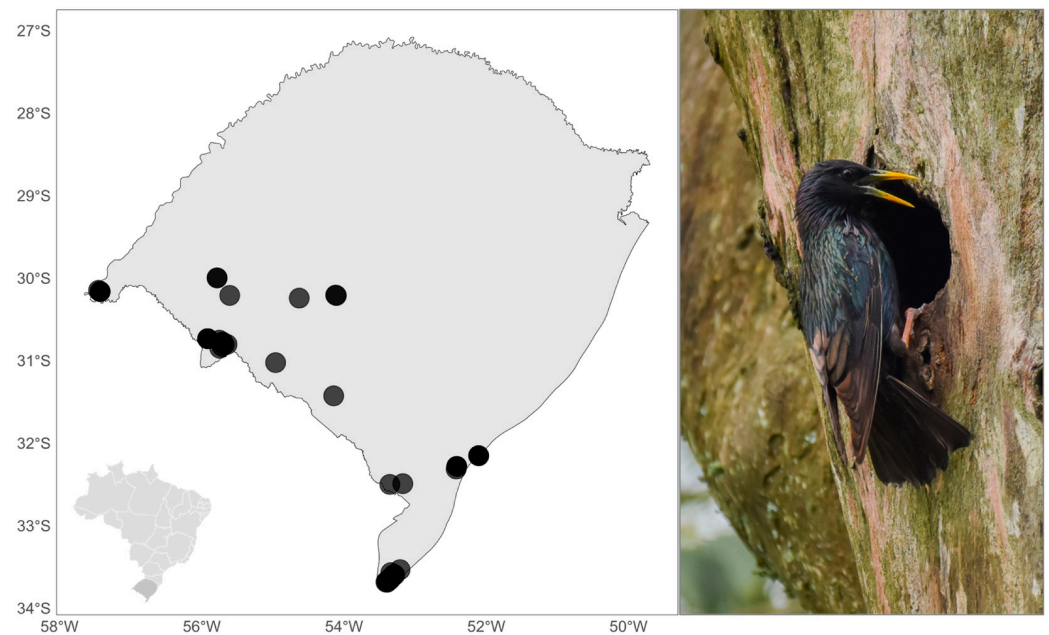


Figure 3. Nesting record locations of *Sturnus vulgaris* in the state of Rio Grande do Sul, southern Brazil. Adult *S. vulgaris* at the entrance of a nest excavated by a woodpecker in the state of Rio Grande do Sul. Photo credit: JPS Dias.

Regarding foraging behavior, we frequently observed flocks of starling feeding in short grasslands in extensive grazing areas, often alongside other bird species such as Shiny cowbird (*Molothrus bonariensis*). During parental care, adults captured invertebrates from the ground to feed their nestlings, including Orthoptera and Lepidoptera.

4. Discussion

Sturnus vulgaris is widely recognized as one of the most problematic invasive species in the world, currently occurring on every continent except Antarctica, exhibiting successful dispersal across a wide range of regions [3,9]. Its expansion rate has been documented in different areas, varying according to environmental and population factors. Since 1987, its average spread in Argentina has been estimated at 7.5 km/year [9]. More recent estimates indicate that its distribution in Argentina continues to expand, covering nearly 65,000 km², with a mean expansion rate of 22.2 km/year [12]. In southern Brazil, we estimated an areal expansion rate ranging from 19.2 to 25.5 km²/year. Because these values represent areal expansion, they are not directly comparable to radial expansion rates reported for Argentina or North America.

This expansion may be accelerating recently in Argentina; in Mar del Plata and Entre Ríos, records indicate expansion in a north-south direction at a rate of 18 km/year to 26 km/year, depending on the method of analysis [9]. Models based on European bird banding recovery data suggest that the expansion rate can reach between 46 and 78 km/year [46]. Data from Argentina indicate that the species behaves as a partial migrant. During the post-breeding season, the maximum recorded distances from the first sightings in the city of Buenos Aires were 375 km to the south and 400 km to the north, reflecting an estimated winter spread of 25–27 km/year [9].

Consistent with these patterns, our results indicate a rapid increase in records and spatial expansion in some regions of southernmost Brazil, particularly in municipalities located in the extreme south of the state. Other border areas with Uruguay, also concentrate a significant number of records. These localities stand out not only for the high number of occurrences of the species but also for being important nesting areas. This pattern suggests

a phase of rapid colonization of new areas, possibly associated with population growth, increased dispersal capacity, or intensified sampling effort. Although temporal changes in observer effort and reporting rates may have influenced the number of records available each year, the overall pattern of increasing occurrence and geographic expansion observed in this study is consistent with field observations conducted by the authors, suggesting that the reported trends reflect a genuine expansion process of the species in southern Brazil.

This scenario suggests that the Pampa biome offers favorable conditions for reproduction and dispersal. In addition, ongoing land-use changes in southern Brazil may further promote establishment and spread of this species. The expansion of agricultural activities and silviculture in the Pampa biome has led to extensive landscape modification, including the replacement of native grasslands by cultivated pastures and plantations of exotic tree species [36–38]. Given the high ecological plasticity of starling and its known association with human-modified environments [9,10], such changes may create favorable conditions for the species by increasing the availability of foraging habitats in agropastoral environments and nesting substrates in exotic trees.

Regarding nesting, we recorded that starling primarily occupies woodpecker cavities. *C. campestris* and *C. melanochloros* are the most common cavity-excavating species in the Brazilian Pampa, especially in *Eucalyptus* trees. This behavior has also been reported by other authors, such as Schmidtutz and Aguilán [23], who described the occupation of cavities excavated by *C. melanochloros* in the Argentine provinces of Buenos Aires and Mendoza. Similarly, Peris et al. [9], also in Argentina, found that most nests of starling were located in cavities made by *Colaptes* species.

In a study conducted in La Plata, Argentina, Palacio et al. [47] reported that more than half of the nests (53%) were located in man-made structures, while only 13% were in tree cavities, contrasting with our findings. In our opportunistic observations, we have not yet recorded the species nesting in urban environments in Brazil. Palacio et al. [47] also found a high frequency of nests built inside Rufous Hornero nests (17.3%). Similarly, Rizzo [15] reported the use of Rufous Hornero nests in Buenos Aires Province. However, this nesting substrate has not yet been recorded in Brazil. On the other hand, we did observe on two occasions the use of nests built by *A. annumbi*, another common species of Furnariidae, a behavior also recorded by Di Sallo et al. [48] in Buenos Aires Province.

The use of tree cavities for nesting in areas inhabited by starlings was also observed in several native bird species, including Scimitar-billed Woodcreeper (*Drymornis bridgesii*), American Kestrel (*Falco sparverius*), and White Woodpecker (*Melanerpes candidus*). Competition for nesting cavities between European Starlings and native species has been reported in other regions where the species has been introduced [9,15,49–51]. During our study, we recorded limited evidence of direct interspecific interactions involving nesting sites. Although these observations suggest the potential for competition over cavities, the extent to which European Starlings affect cavity availability or the reproductive success of native species in Brazil remains unknown and warrants further investigation.

Starling nests were found in four tree species: *Eucalyptus* spp., *Alchornea triplinervia*, *Pinus elliottii*, and *Melia azedarach*. Three of these species are exotic in Brazil, suggesting that European Starlings readily use a variety of available nesting substrates. Similar patterns have been reported in La Plata, Argentina, where nests were recorded in ever-green tree species, particularly the exotic palm *Phoenix canariensis*, as well as species of the genera *Pinus*, *Cupressus*, *Cedrus* and *Ficus elastica* [52]. Records of nesting in natural environments span several regions of Argentina, including Buenos Aires, Córdoba, and Mendoza [48,53,54]. On the other hand, ref. [13] mentioned that nesting sites may include not only tree cavities but also lighting towers, buildings, wall cavities, and artificial nest boxes. In Brazil, the use of these substrates by starling has not been recorded yet, possibly

because the birds have primarily been observed in rural and pastoral areas and have not, so far, established urban populations. This scenario contrasts with observations in Argentina, where, for example, roosts with more than 1000 individuals were reported in the city of La Plata [52]. The reproductive period observed in Brazil is similar to that in Argentina, where the species also begins breeding activity in September, extending through December [14], with nestlings observed in October [49] and juveniles recorded between November and January [9,15].

After fledging, juveniles may shift to a predominantly frugivorous diet, forming large flocks that attack a variety of crops, including grapes, strawberries, apples, cherries, blueberries, and other small fruits (the invasion of starling likely poses a direct threat to grape and olive production in southern Brazil, as large flocks can become a significant pest for soft fruit crops). In North America, blueberry crops are among the most affected by starling, along with grapes, olives, and cherries [55]. This estimated annual cost includes not only direct production losses, but also additional costs associated with control and mitigation strategies, such as protective netting, acoustic deterrents, and population management programs.

Given the species' documented ecological and agricultural effects [8,50,55–57], it is essential to deepen our understanding of the ecology of starling in the Neotropical region. Future studies should more thoroughly investigate its effects on native species, as well as its reproductive and feeding biology, allowing for a clearer understanding of its impact on the natural environments it occupies. Furthermore, considering its ongoing geographic and population expansion, continued research will be crucial to monitor its population dynamics and expansion patterns in native habitats. The continued expansion of this species highlights the importance of monitoring its spread, particularly in southern Brazil, which currently represents the main frontier of the invasion process. However, such measures may not be effective or logistically feasible, as no control plans currently exist for this purpose in the neighboring countries from which the species colonized Brazil.

5. Conclusions

Our study provides the first comprehensive assessment of the European Starling's distribution and expansion in Brazil during its first decade following establishment. Available records indicate a marked increase in the number of observations, geographic range, and known breeding sites, suggesting that the species is becoming increasingly widespread in southern Brazil. The estimated expansion rates are comparable to those reported in other invaded regions, highlighting the species' potential for rapid range expansion. Records of reproduction in multiple localities demonstrate that breeding populations are established across the occupied area. Given the ecological and economic impacts associated with European Starlings in other parts of the world, continued monitoring of their distribution, population growth, and interactions with native species is essential. Our results provide an important baseline for future studies and management strategies aimed at understanding and mitigating the potential consequences of this biological invasion in Brazil.

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Institutional Review Board Statement: Ethical review and approval were waived because the study was based exclusively on observational records and secondary data, without animal handling or experimental procedures.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data used in this study were obtained from publicly available databases, together with field records generated by the authors. Additional data is available from the corresponding authors upon reasonable request.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EOR Estimated occupied range

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