Discovery and characterization of a large population of Parodia linkii (Lehm.) R. Kiesling (Cactaceae) in Southern Brazil: Challenges and conservation implications

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Discovery and characterization of a large population of *Parodia linkii* (Lehm.) R. Kiesling (Cactaceae) in Southern Brazil: Challenges and conservation implications

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ABSTRACT – (Discovery and characterization of a large population of *Parodia linkii* (Lehm.) R. Kiesling (Cactaceae) in Southern Brazil: Challenges and conservation implications). *Parodia* comprises 62 cactus species inhabiting the Pampas plains and Andes slopes. Notably, *Parodia linkii* is vulnerable to extinction in Brazil but classified as Least Concern by the IUCN. This study describes an area in Rio Grande do Sul, Brazil, where *P. linkii* occurs. Research was conducted in a transitional zone between the Pampa and Atlantic Forest biomes in Santiago municipality. Data collection involved 23 linear transects, each 25m long and spaced 1m apart, covering about 600 m². Individuals and sprouts from different colonies were quantified. For analysis, 14 quadrants (1 x 1 m) were established along the population, spaced 5m apart, including sloped and flat rocky areas with mixed vegetation. Diameter measurements and floral sprout recordings were taken. A total of 1,205 *P. linkii* individuals were recorded, thriving in basalt rock crevices, averaging 2.08 individuals per square meter, with approximately 50 (±2.39) individuals along each transect. The study highlights the importance of habitat cataloging for preserving *P. linkii*, especially in its transitional habitat. This research enhances understanding *of P. linkii'*s ecological needs and supports conservation efforts for diverse landscapes that sustain various biological communities, ensuring the species' long-term survival.
Keywords: Cactus, flora, Pampa, vulnerable to extinction

RESUMO – (Discovery and characterization of a large population of *Parodia linkii* (Lehm.) R. Kiesling (Cactaceae) in Southern Brazil: Challenges and conservation implications). O gênero *Parodia* compreende 62 espécies de cactos que habitam as planícies dos Pampas e as encostas dos Andes. Notavelmente, *Parodia linkii* é vulnerável à extinção no Brasil, mas classificada como Pouco Preocupante pela IUCN. Este estudo descreve uma área no Rio Grande do Sul, Brasil, onde *P. linkii* ocorre. A pesquisa foi conduzida em uma zona de transição entre os biomas Pampa e Mata Atlântica, no município de Santiago. A coleta de dados envolveu 23 transectos lineares, cada um com 25 m de comprimento e espaçados 1 m entre si, cobrindo aproximadamente 600 m². Indivíduos e brotações de diferentes colônias foram quantificados. Para a análise, 14 quadrantes (1 x 1 m) foram estabelecidos ao longo da população, espaçados 5 m entre si, abrangendo áreas rochosas inclinadas e planas com vegetação mista. Foram realizadas medições de diâmetro e registros de brotações florais. No total, 1.205 indivíduos de *P. linkii* foram registrados, crescendo em fendas de rochas basálticas, com uma média de 2,08 indivíduos por metro quadrado e aproximadamente 50 (±2,39) indivíduos ao longo de cada transecto. O estudo destaca a importância do mapeamento de habitats para a preservação de *P. linkii*, especialmente em seu habitat de transição. Esta pesquisa amplia a compreensão das necessidades ecológicas de *P. linkii* e apoia esforços de conservação para paisagens diversas que sustentam várias comunidades biológicas, garantindo a sobrevivência a longo prazo da espécie.
Palavras-chave: cactus, flora, Pampa, vulnerable to extinction

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Introduction

The genus *Parodia* Spegazzinii of the family Cactaceae comprises 62 species with main occurrence in the plain regions of the Pampas (Northeastern Argentina, Southern Brazil, Eastern Paraguay, and Uruguay) and on the slopes of the Andes (Northwestern Argentina and Eastern Bolivia) (Anceschi & Magli 2018). In Brazil, the genus comprises 48 species and 9 subspecies, distributed in the States of Paraná, Rio Grande do Sul, and Santa Catarina (Zappi & Taylor 2019).

Within these States, the occurrence of ecotones, transitional areas between two different ecosystems, is recorded (Dröse *et al.* 2019, Overbeck *et al*. 2007). The characteristics of these areas are determined exclusively by spatial and temporal scales (Holland 1988). The State of Paraná harbors ecotones between the Cerrado and Atlantic Forest biomes, while the State of Rio Grande do Sul encompasses ecotones between the Pampa and Atlantic Forest biomes (IBGE 2019). As a consequence, the southern region of Brazil contemplates a diverse range of plant formations, including areas of grasslands and forests, forming mosaics composed of forest and grassland phytophysiognomies (Bauermann *et al*. 2008, Redin 2017).

Among the Cactaceae individuals occurring in transition areas, *Parodia linkii* (Lehm.) R. Kiesling stands out as a native species of the State of Rio Grande do Sul, Brazil (Mansano *et al.* 2023). This species is characterized by its globose body and typically occurs in a gregarious or solitary manner (Moia *et al.* 2021). Distributed across Brazil, Argentina, Paraguay, and Uruguay, *P. linkii* is presently categorized as having a conservation status of Least Concern on the IUCN Red List of Threatened Species (Larocca, *et al.* 2017). However, in the southern region of Brazil, specifically within the State of Rio Grande do Sul, this species is deemed vulnerable to extinction in accordance with a State decree, owing to the processes of deforestation and degradation affecting its natural habitats, including the ecotones situated between the Pampas and the Atlantic Forest within the southern Brazilian region (RS 2014, Carneiro *et al.* 2016).

Parodia linkii is known to occur in different regions of Rio Grande do Sul State, Brazil, namely in the Pampa biome in São Gabriel (Dias *et al.* 2022), the Atlantic Forest biome in Santa Maria (Moia *et al*. 2021), and along the Toropi & Guassupi river banks (Marchiori *et al*. 2014). It is considered a potential ornamental plant for urban areas in Campos de Cima da Serra, with bees as pollinators (Araújo *et al*. 2022). The species also has ornamental potential in the Pelotas River basin region (Silva *et al*. 2016). Through analyses of databases, Marchioretto & Santos (2017) highlight that *P. linkii* occurs in 10 out of the 11 geographical regions in Rio Grande do Sul State defined by Borges-Fortes (1959), with the exception of the coastal region, emphasizing its preference for both dry and humid grasslands. However, the literature still lacks descriptive studies concerning the populations of this species, as well as descriptions of the places where they are found (Pontes 2017, Dias *et al.* 2022).

Therefore, the main objective of this study is to comprehensively catalog and characterize a large population of *P. linkii* in Southern Brazil. By detailing the species' distribution, habitat preferences, and population dynamics, this research aims to advance current understanding and offer essential insights for conservation strategies and biodiversity management in the region. This understanding not only aids in effective conservation planning but also highlights the ecological importance of *P. linkii* within its native habitat.

Materials and methods

Study area - The area of occurrence for the species *Parodia linkii* (Lehm.) R. Kiesling was identified in a transition zone between the Pampa and Atlantic Forest biomes, specifically in a basaltic rocky outcrop with a red argisol at an altitude of approximately 318 m, located in the municipality of Santiago, region west-central Rio Grande do Sul State, Brazil (figure 1).

The site is located amidst remnants of semi-deciduous seasonal forest and cattle pasture areas, where are located native Cactaceae, not documented in other locations in the region.

According to physiographic and climatic data, the study area is located at an altitude of about 320 m, with a predominantly humid subtropical climate (Cfa), according to the Köppen classification, with temperatures ranging from 13 ºC to 21 ºC, with a thermal average of 17.9 ºC and rainfall of 1,919 mm per year (Gomes 2004). The soil is of the Dark Red Alic Podzolic type (Red Argisol) (IBGE 2019).

The studied area can be classified as an ecological tension zone, where ecological tension is characterized by distinct phytogeological areas that overlap or interpenetrate (IBGE 1992). While the species is recorded within the State of Rio Grande do Sul, this marks the first report of the population to science (Carneiro *et al. 20*16).

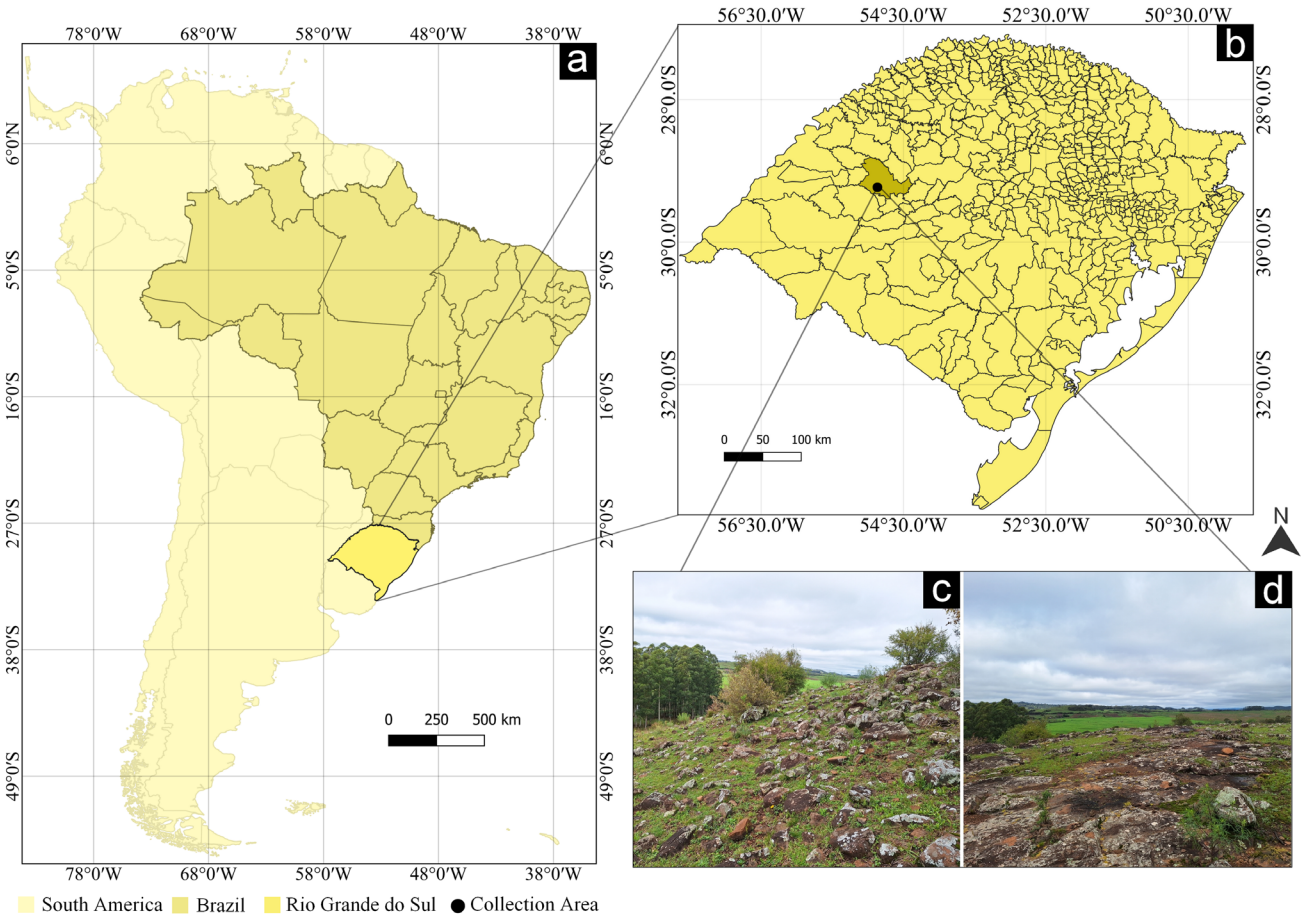

Figure 1. Map of the study area in Rio Grande do Sul State, Southern Brazil. a. South America and Brazil, with emphasis on Rio Grande do Sul State. b. Rio Grande do Sul State, pinpointing Santiago municipality, where *Parodia linkii* (Lehm.) R. Kiesling is located. c. Sloped area characterized by a heterogeneous mix of rocks, grasses, and mosses. d. Predominantly rocky flat area. Source: Authors (2023).

Figura 1. Mapa da área de estudo no Estado do Rio Grande do Sul, Sul do Brasil. a. América do Sul e Brasil, com destaque para o Estado do Rio Grande do Sul. b. Estado do Rio Grande do Sul, destacando o município de Santiago, onde Parodia linkii (Lehm.) R. Kiesling está localizada. c. Área inclinada caracterizada por uma mistura heterogênea de rochas, gramíneas e musgos. d. Área plana predominantemente rochosa. Fonte: Autores (2023).

Field work - Field excursions were carried out in September 2023, with the specimens being counted using a pencil and notebook. To assess species abundance, 23 linear transects, each approximately 25m in length and spaced 1m apart, were established, covering a total area of about 600 m². Each individual or sprout from different colonies was counted individually.

To perform morphological and statistical descriptions of the individuals, we placed 14 quadrants (1 x 1 m²) across the sampled population, arranged from North to South with a 5-meter spacing between each quadrant. These quadrants were distributed between two areas: one with a slope in a mixed environment of rocks, grasses, and mosses, and another flat area in a rocky environment with a higher presence of ferns such as *Anemia flexuosa* (Savigny) Sw. and *Pleopeltis* sp., along with mosses. Each individual or sprout was counted individually, with its diameter measured, and the number of floral sprouts recorded when present. Following Aguilar *et al.* (2022), individuals bearing reproductive structures were categorized as adults, while those lacking such structures were classified as juveniles.

A representative sample of the collected material was subsequently preserved and deposited at the Bruno Edgar Irgang Herbarium (HBEI), Universidade Federal do Pampa, with the registration number HBEI 1666. To determine the occurrence

area of *P. linkii*, coordinates were converted into binary data, and a map of the region was generated using QGIS version 3.16 software, incorporating data from the Brazilian Institute of Geography and Statistics (IBGE 2021). Data analysis was conducted using RStudio version 4.3.2, utilizing the Ggplot2 and GridExtra packages (Wickham 2016, Pavía Miralles 2020).

Results

In a study area covering 23 linear transects, 1.205 individuals of *Parodia linkii* (Lehm.) R. Kiesling were cataloged, predominantly observed growing in the fissures of the rocky outcrop (figure 2). An average of approximately 2.08 individuals per square meter was recorded, with an average of about 50 (±2.39) individuals along each of the 23 transects analyzed.

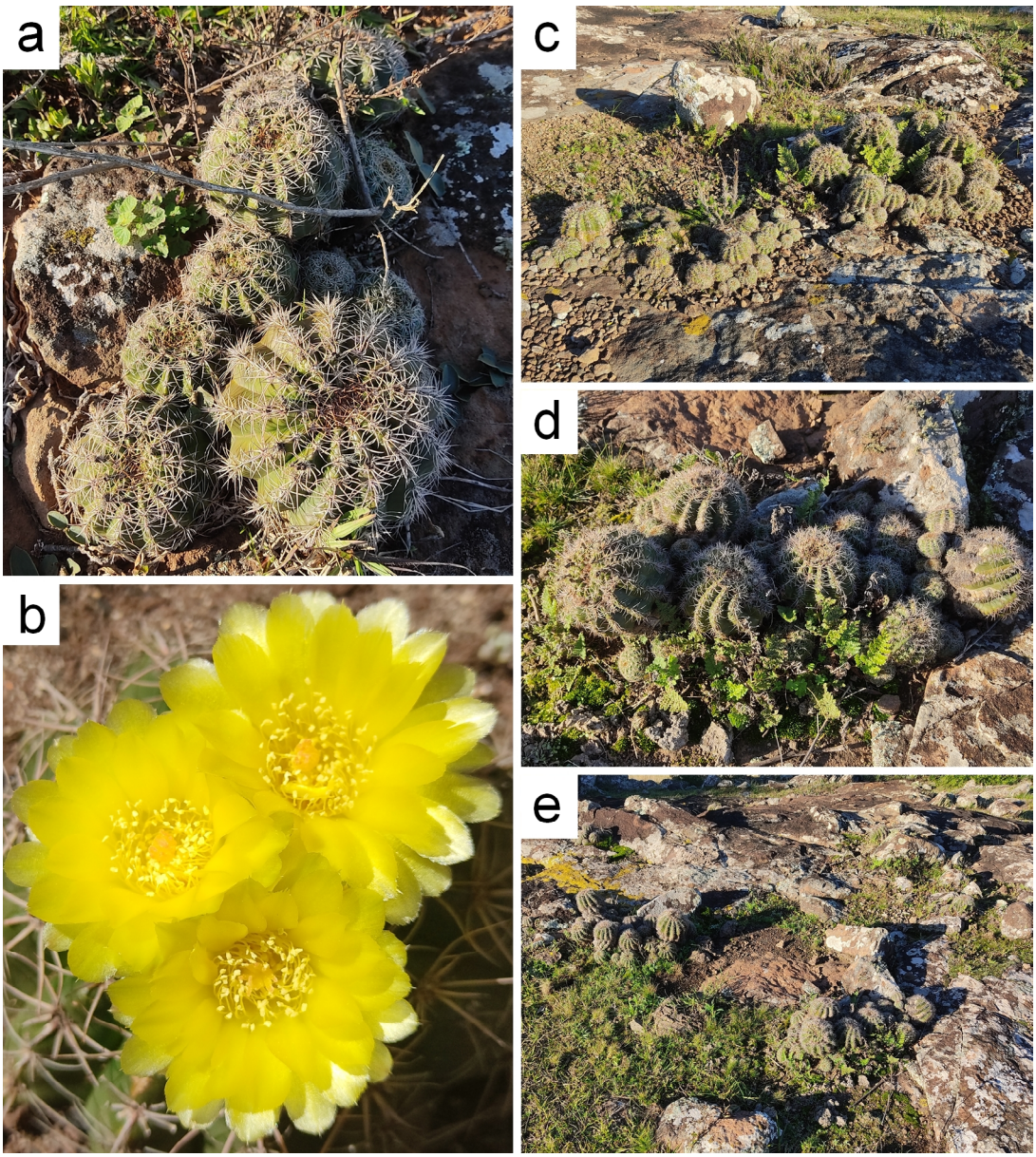

Figure 2. Sampling of *Parodia linkii* (Lehm.) R. Kiesling in Rio Grande do Sul State, Southern Brazil. a. Gregarious arrangement of specimens. b. Reproductive structure of the species (flower). (c, d, e) Specimens on basalt outcrop. Source: Authors (2023).

Figura 2. Amostragem de *Parodia linkii* (Lehm.) R. Kiesling no Estado do Rio Grande do Sul, Sul do Brasil. a. Arranjo gregário dos espécimes. b. Estrutura reprodutiva da espécie (flor). (c, d, e) Espécimes em afloramento basáltico. Fonte: Autores (2023).

Fourteen quadrants within the sampled area were assessed, totaling 338 individuals. Among the sampled population, 59.40% were observed in the adult reproductive stage, while juveniles accounted for 40.50%. The average size of all individuals evaluated was 10.25 cm in diameter, with an average of 6.5 flowers per individual. Furthermore, it was observed that the smallest adult individual found producing flowers measured 4.2 cm in diameter with four floral shoots, whereas the largest adult individual measured 14 cm in diameter with nine floral shoots. Additionally, large adult individuals measuring approximately 10 cm in diameter typically had three floral shoots.

The analysis of the quadrants revealed a distinct distribution of *P. linkii* across the two studied areas. In the sloped area, characterized by a heterogeneous mix of rocks, grasses, and mosses, 94 individuals were identified within 7 quadrants. Conversely, the predominantly rocky flat area exhibited a notably larger population, with 244 individuals distributed across the analyzed quadrants. These findings suggest a potential preference of *P. linkii* for rockier environments, indicating that the specific conditions of such habitats may be more conducive to the species' growth and survival. Additionally, the flat area, with its sparse vegetation, is less frequented by cattle. This reduced grazing pressure likely benefits the dispersion and development of *P. linkii* by preserving the habitat conditions essential for the species' persistence.

Furthermore, *Parodia glaucina* (F. Ritter) Hofacker & M. Machado was identified in the surveyed area (Supplementary material). In our study site, we observed that this species is present in low numbers (fewer than 20 individuals) compared to *P linkii*. *P. glaucina* can be readily distinguished from *P. linkii* by its distinctive morphological features, notably the arrangement of its spines, floral buds, and flowers.

Also, it is important to highlight that several conservation threats to *P. linkii* were identified at the study site. In general, the expansion of livestock farming and the increasing deforestation of native vegetation for pastureland creation can significantly impact the species' conservation by degrading its habitat and hindering its reproduction. Additionally, specific natural threats within the area were also observed, such as phytopathological diseases caused by fungi and predation of certain individuals by unidentified ants. These processes, although related to the ecological niche of the location, can have a drastic impact on the species' development.

Discussion

The collection site is located in a transition area with the Pampa biome, where most of the Cactaceae species cited for Rio Grande do Sul State are currently found (Carneiro *et al*. 2016). Other transitional areas between Brazilian biomes, such as the one along the northern part of Minas Gerais and eastern Bahia, are influenced by the Cerrado and Caatinga biomes, making them hotspots in Brazil for cacti occurrence (Goettsch *et al.* 2015). The region's soil exhibits low fertility, high acidity, and high exchangeable aluminum saturation, which limits the growth of annual crops or deep-rooted systems due to soil toxicity (Streck *et al.* 2018). This soil characteristic promotes the development of Cactaceae, which thrive in nutrient-poor soils. Few floristic surveys mention populations of this species, with notable populations in Campestre do Divino, Santa Maria (Rio Grande do Sul State, Brazil) (Pontes 2017), and Estância São José, São Gabriel (Rio Grande do Sul State, Brazil) (Dias *et al*. 2022).

Observing the structure of our population, it stands out that adult individuals make up the majority, at 59.40%, compared to juveniles, at 40.50%. In contrast, Aguilar *et al.* (2022) described in their study on *Mammillaria deherdtiana* subsp. dodsonii (Cactaceae) that the number of adult individuals was lower than juveniles, which represented 65.38% of the population. The average diameter of this monopodial growth population was 2.69 cm, whereas our study species, which grows by shoots, presented an average diameter of 10.25 cm. However, the lack of phytosociological studies on cacti highlights the insufficient exploration of this subject and the gaps in understanding the biology of these species.

Although several authors mention the occurrence of *Parodia linkii* (Lehm.) R. Kiesling in significant sample sizes, only Pontes *et al.* (2015) specifically identify the locality of Santa Maria (Rio Grande do Sul State) as a natural habitat for the species. This habitat is characterized by hills and hillocks of sandstone from the Botucatu and Caturrita formations, topped with volcanic basalt rocks (Pontes *et al.* 2015). Fontana (2015) notes that *P. linkii* thrives in basalt rock crevices, which is consistent with many of the habitats where the specimens in this study were found.

Our findings corroborate previous observations that *P. linkii* commonly inhabits basalt rocky outcrops. These locations provide optimal conditions of humidity and solar exposure. Furthermore, these areas are typically inhabited by species adapted to

extreme light conditions, nutrient-poor soils, and lithic and neosol soils, and are less suitable for plants with xerophytic characteristics (Pontes *et al.* 2015).

When evaluating the distribution of species in the analyzed area, it is important to note that the number of individuals in the slope area, which includes pasture amid rocky outcrops, is lower compared to the flat area with only rocky outcrops for flowering. This suggests, as observed by Dias *et al.* (2022), that cattle grazing may adversely affect the species population by reducing opportunities for individuals to establish themselves in suitable habitats.

The limited presence of *P. linkii* in areas frequented by cattle underscores the urgent need for enhanced conservation efforts. Establishing refuges to protect and promote the species' reproduction is crucial. According to Alves *et al.* (2022), refuge areas are characterized by significant sample sizes, reproductive capacity, and territorial extent. Our data, including sample sizes, species distribution in the studied area, and the presence of reproductive structures, indicate this location holds potential as a natural refuge for *P. linkii*. This underscores the necessity for increased scientific focus on the region.

Conserving areas like those studied benefits not only *P. linkii* but also other species in the region, such as *P. glaucina*, currently classified as 'Vulnerable' on the IUCN Red List (Larocca *et al.* 2017). *P. glaucina* is typically solitary, rarely forming groups (Carneiro *et al.* 2016). Discovering approximately 20 individuals of this species in our survey area suggests it could serve as a refuge for multiple species within the Cactaceae family. However, our data are primarily observational and morphological, highlighting the need for ecological index analyses to strengthen assertions, especially regarding the area's classification as a refuge.

The detailed cataloging of habitats for endangered species like *P. linkii* is crucial for their preservation. By expanding the known areas of occurrence, such cataloging not only highlights regions requiring conservation but also spurs further research into previously understudied vegetative landscapes. Our study underscores the importance of *P. linkii*'s habitat within a transitional zone between forest and pasture. This unique environment bridges the Pampa and Atlantic Forest biomes, showcasing a remarkable biodiversity that warrants protection.

Our findings show that *P. linkii* thrives in areas characterized by a mix of forest and pasture, underscoring the need to protect these transitional zones. By documenting the abundance and distribution of *P. linkii* in these habitats, our study provides essential data that can guide conservation efforts. This research not only enhances our understanding of *P. linkii*'s ecological preferences but also highlights the broader importance of preserving diverse landscapes that support various biological communities.

Ultimately, the insights gained from our research contribute to a more comprehensive approach to the conservation of *P. linkii* and similar species in a transitional ecosystem. Protecting these zones is crucial for maintaining the biodiversity and ecological integrity of the regions where these endangered species reside.

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Authors' Contributions

Fernando Augusto Bertazzo-Silva: conceived and designed the study

Fernando Augusto Bertazzo-Silva, Mariele Cristine Tesche Küster and Lilian Pedroso Maggio: conducted the fieldwork, data acquisition, and interpretation.

OBS: All authors contributed to the writing, discussion, review, and approval of the final manuscript.

Data availability statement

The dataset is contained within the manuscript itself.

Conflict Of Interest

The authors declare that there are no conflicts of interest related to this manuscript.

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