



## Original Paper

# Is it the end of the Cerrado domain in the west of state of Paraná (Brazil)? Floristic aspects of Cerrado fragments in Campo Mourão

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### Abstract

Currently only a few relicts of Brazilian savanna (Cerrado domain) remain sparsely distributed in state of Paraná. This study catalogued the species of vascular plants occurring in three Cerrado fragments of Campo Mourão. We analysed 4,125 herbarium specimens, 952 of which were collected in the Cerrado fragments, representing 368 species (25 exotic) distributed in 70 families and 241 genera. Fabaceae, Asteraceae, Myrtaceae, Euphorbiaceae, Poaceae, Bignoniaceae, Malvaceae and Apocynaceae were the richest families. Sixty species (16%) were only collected before 1999, with no re-collections after 2000. Among the native species, 51 are endemic to Brazil, and three are confined to the state of Paraná. Six species are regarded as officially endangered in Brazil. We also present the first record of *Jacaranda mutabilis* for Southern Brazil. Forty-two species are probably locally extinct in Campo Mourão. In the three Cerrado fragments within the municipality, the forest phytophysognomy is already predominant in these areas, indicating the expansion of Semideciduous Seasonal Forest within the Cerrado fragments. In addition, the presence of exotic species and the lack of legal, environmental protection in the two largest fragments put the future existence of these Cerrado fragments from Campo Mourão at risk.

**Key words:** angiosperms, conservation, endemism, Estação Ecológica do Cerrado, urban vegetation.

### Resumo

Atualmente restam poucos fragmentos relictuais de Cerrado distribuídos esparsamente no Paraná. Este estudo catalogou as espécies de plantas vasculares ocorrentes em três áreas de Cerrado de Campo Mourão: Estação Ecológica do Cerrado, Cerrado dos Perdoncini e Lote 7H. Analisamos 4.125 coletas, sendo 952 coletadas em áreas de cerrado, que representaram 368 espécies (25 exóticas), distribuídas em 70 famílias e 241 gêneros. Fabaceae, Asteraceae, Myrtaceae, Euphorbiaceae, Poaceae, Bignoniaceae, Malvaceae e Apocynaceae foram as famílias mais ricas. Sessenta espécies (16%) só foram coletadas antes de 1999, não existindo coletas após o ano 2000. Entre as espécies nativas, 51 são endêmicas do Brasil e três do Paraná, seis são consideradas oficialmente ameaçadas de extinção no Brasil. Este estudo cita pela primeira vez *Jacaranda mutabilis* para o sul do Brasil. Quarenta e duas espécies foram consideradas provavelmente extintas localmente em Campo Mourão. Nas três áreas de Cerrado que ocorrem no município já se observa a fisionomia predominantemente florestal sobre os fragmentos, indicando o avanço da Floresta Estacional Semidecidual sobre o Cerrado. Em adição, a presença de espécies exóticas e ausência de proteção legal nos dois maiores fragmentos, coloca em risco a existência dessas áreas de Cerrado de Campo Mourão.

**Palavras-chave:** angiospermas, conservação, endemismo, Estação Ecológica do Cerrado, vegetação urbana.

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## Introduction

The fragments of Brazilian savanna (Cerrado) in the state of Paraná are disjunct from the nuclear area of occurrence of this phytogeographic domain, representing relicts of semi-arid Pleistocene vegetation (Maack 1948; 2017) and the southern limit of this domain in Brazil. In the past, the Cerrado areas occupied approximately 1,740 km<sup>2</sup> in this state, but currently, only a few fragments remain in the municipalities of Arapoti, Campo Mourão, Carambei, Cianorte, Jaguariaíva, Pirai do Sul, Ponta Grossa, Sabáudia, Sengés, Tibagi, Tuneiras do Oeste, and Ventania (Hatschbach *et al.* 2005; Ritter *et al.* 2010; Moro 2012; Maack 2017; Villwock & Colavite 2020). Campo Mourão is located in the Campo Mourão plateau, part of the Third Plateau of Paraná. There are three types of vegetation phytophysionomies in this municipality: Mixed Ombrophilous Forest, marked by Coniferales and Laurales elements, with predominance of *Araucaria angustifolia* (Bertol.) Kuntze (Araucariaceae); Semideciduous Seasonal Forest, with an abundance of *Aspidosperma polyneuron* Müll.Arg. (Apocynaceae); and fragments of Cerrado with phytophysionomies and floristics similar to those of Central Brazil (Roderjan *et al.* 2002). The forested phytophysionomies are the predominant vegetation of the municipality, belonging to the Atlantic Forest ecoregion, one of the most threatened conservation hotspots in Brazil (Myers *et al.* 2000).

The discovery of Cerrado fragments in this municipality occurred around 1760, in state expeditions departing from Curitiba towards the west. The open vegetation found was called “Campos do Mourão”, from which the name Campo Mourão derives (Mourão in honour of the captain-general of São Paulo Captaincy) (Prado 2021). The region’s colonisation was slow until the establishment of the first settlements in the early 1900s. It was only in 1943 that the construction of the village, the future urban centre, began (Santos Júnior 2018; Prado 2021). The open grassland vegetation of the Cerrado domain, contrasting with the forested surroundings, enabled the use of these areas as early settlements for establishing peoples and the urban centre. Thus, since 1900, this vegetation has already undergone anthropic impacts and the reduction of its original area. Currently, the entire region has highly fragmented vegetation, and Tomadon *et al.* (2019) recorded that 97% of the forest fragments in the Mourão River basin were smaller than 0.5 km<sup>2</sup>. These fragments

add up to about 17% of the municipality’s area (J.H.D. Ferreira, personal communication), all with secondary vegetation.

According to Coutinho & Ferri (1960), the Cerrado fragments of Campo Mourão did not have the typical appearance of the Cerrado domain found in other locations of Brazil. It was a mixture of cosmopolitan species (*e.g.*, *Baccharis*, Asteraceae and *Aristida*, Poaceae), with species not exclusive to the Cerrado domain (*e.g.*, *Bauhinia*, Fabaceae, *Casearia*, Salicaceae, and *Vochysia*, Vochysiaceae) and also many typical species of this vegetation, such as *Didymopanax vinosus* (Cham. & Schltld.) Marchal (Araliaceae), *Erythroxylum suberosum* A.St.-Hil. (Erythroxylaceae), *Annona coriacea* Mart. (Annonaceae), *Duguetia furfuracea* (A.St.-Hil.) Saff. (Annonaceae), *Leptolobium elegans* Vogel (= *Sweetia elegans* (Vogel) Benth.) (Fabaceae), *Aspidosperma tomentosum* Mart. & Zucc. (Apocynaceae), *Andira humilis* Mart. *ex* Benth. (Fabaceae), *Byrsonima intermedia* A.Juss. (Malpighiaceae), and others. In Campo Mourão, the typical specimens of the Cerrado domain were generally of small stature with slender stems and the occurrence of few individuals of each species and numerous seedlings. This fact led Coutinho & Ferri (1960) to hypothesise that the colonisation of the Cerrado elements was relatively recent in the geological time, with *Stryphnodendron adstringens* (Mart.) Coville (Fabaceae) as the pioneer species. The observed area by these authors was possibly already regenerating, given the area’s occupation history.

Maack (2017) visited the Campo Mourão region in the 1940s and was the first author to hypothesize that the Cerrado domain in the state of Paraná would be relict areas of drier climates in the Pleistocene. Sedimentary studies confirm this hypothesis with palynomorphs (pollen grains, spores, and phytoliths), isotopic data and <sup>14</sup>C dating in the municipality (Ladchuk *et al.* 2016; Domingos-Luz *et al.* 2019). The results of Domingos-Luz *et al.* (2019) reflect the presence of grasses in the sampling location since ~48,800 years BP, including the Last Glacial Maximum, and suggesting the presence of Cerrado fragments since the Late Pleistocene. And since the Early Holocene, the arboreal vegetation has increasingly expanded over the Cerrado fragments in the last ~3280 cal yrs BP.

The Cerrado domain occupied an area of 102 km<sup>2</sup> in the Mourão river basin (Maack 2017), but agricultural, and real estate pressures reduced the

area to only 0.08% of its original area. Currently, there are 0.086 km<sup>2</sup> (86,000 m<sup>2</sup>) of Cerrado fragments in this municipality, divided into three small fragments: the Estação Ecológica do Cerrado Prof<sup>a</sup>. Diva Aparecida Camargo with 13,000 m<sup>2</sup>, the Cerrado dos Perdoncini with 50,000 m<sup>2</sup>, and the Lote 7H with 23,000 m<sup>2</sup> (Parolin *et al.* 2015; Tomadon *et al.* 2019). The Cerrado fragments from Campo Mourão comprise several rare species from the Paraná flora (Hatschbach & Ziller 1995), such as “algodão-do-cerrado” *Cochlospermum regium* (Mart. ex Schrank) Pilg. (Bixaceae). Although the general floristic knowledge of plant species in this state is extensive, with about 6,400 native vascular plants catalogued so far (Kaehler *et al.* 2014; Flora e Funga do Brasil 2022, continuously updated), there are still poorly studied areas and few publications on local floras. The few existing studies for the municipality of Campo Mourão focus on certain groups of plants, taxonomic and related ecological aspects, such as the floristic survey of climbers from the Parque Estadual Lago Azul (Santos *et al.* 2009), vascular epiphytes and their dispersion syndromes from Capela do Calvário (Geraldino *et al.* 2010), the palm trees of Campo Mourão (Caxambu *et al.* 2015), and the rocky outcrops flora of Campo Mourão (Monteiro-Ré *et al.* 2022b). Previous studies in the Cerrado fragments of Campo Mourão listed 21 families and 31 species of vascular plants (Caetanos & Nunes 2005), which was expanded by Hatschbach *et al.* (2005) to 40 families and 136 species, based on historical collections in the municipality between the 1960s-80s. For the Estação Ecológica do Cerrado area, Parolin *et al.* (2015) presented a list with 23 families and 40 species of vascular plants.

This study intended to present the first comprehensive checklist of vascular plants collected in Cerrado fragments in Campo Mourão, focusing on the occurrence of endemic species and evaluating the current conservation efforts in these areas. We tried to answer the following questions: I) What is the composition and richness of the vascular flora of Cerrado fragments from Campo Mourão? II) Is there an increase in the number of species when compared to previous checklists? III) What are the life forms and substrates used by these species? IV) Are there endemic, endangered, or rare species from Brazil in these fragments? V) Considering a more recent sampling period (the last 20 years), how many and which species were discovered, collected, and not collected in these Cerrado fragments? VI) Could any of these

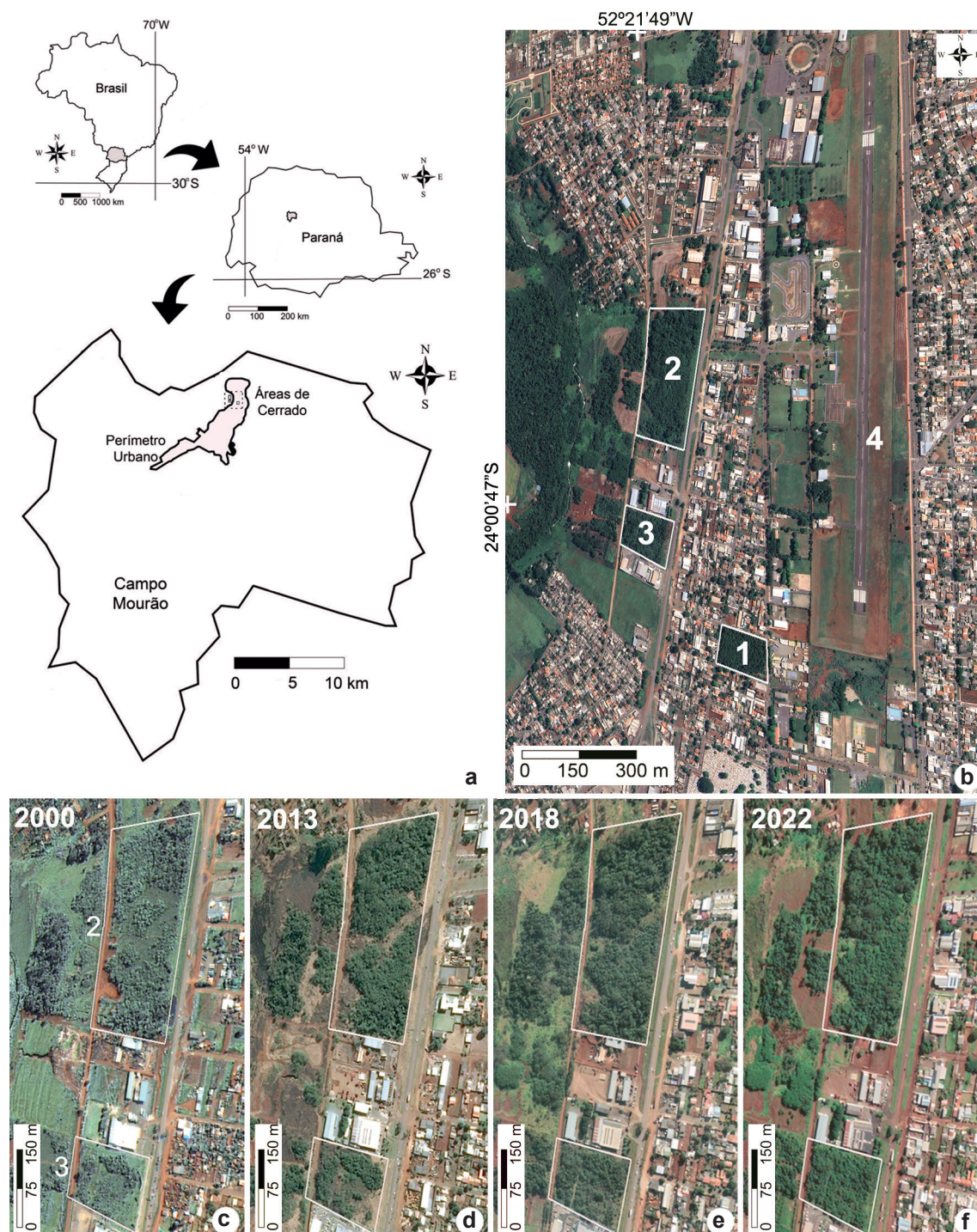
species not collected after 2000 be considered locally extinct? VII) With regard to the Brazilian Phytogeographic Domains, what is the range of occurrence of the species recorded in Cerrado fragments of Campo Mourão? VIII) Are there exotic species in these places, and can any of them be regarded as invasive?

## Material and Methods

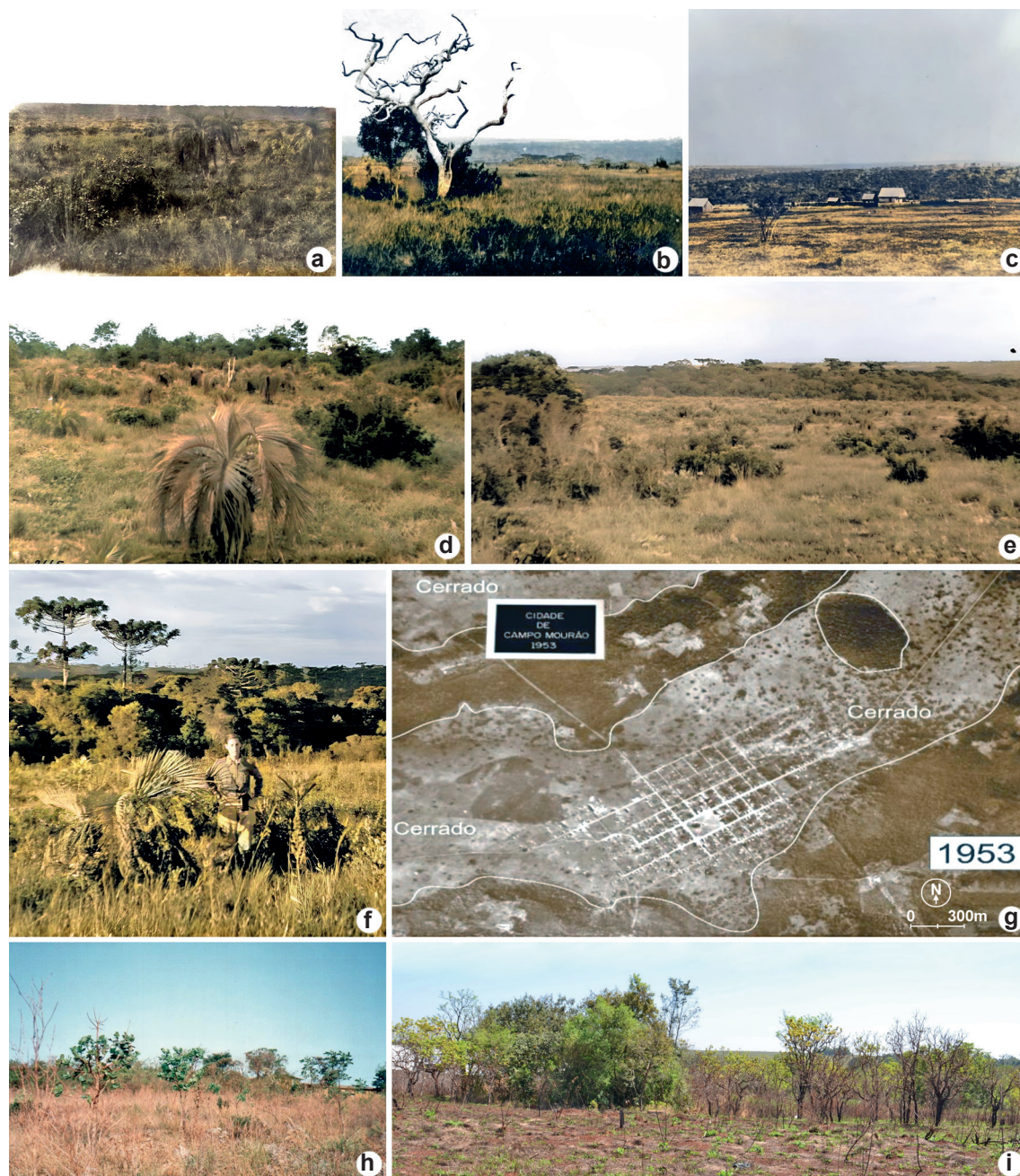
### Study area

The municipality of Campo Mourão (Fig. 1a) is located in the Third Plateau of the state of Paraná, in the subdivision called Plateau of Campo Mourão (Maack 2017), at the watershed of the Ivaí and Piquiri rivers, between the coordinates 24°17'57"–23°57'08"S and 52°10'59"–52°32'47"W. The municipality is part of the Central-Western Mesoregion of the state. The proximity to the Tropic of Capricorn influences the climatic conditions in the municipality, which are influenced by both the continental tropical and temperate climate, making it a region of climatic transition (Borsato & Massoquim 2019). The climate is the Cfa type: mesothermal humid subtropical according to the Köppen-Geiger classification. The average annual temperature varies from 19 °C to 23 °C. The annual rainfall varies from 1,400 to 2,000 mm, the relative humidity of the air has an annual average of 70 to 75%, and there is no water deficit (Nitsche *et al.* 2019). The predominant soil in the municipality is the Distroferric Red Latosol, with a deep clayey texture, characterised as having low fertility due to its high iron content. However, other pedological units may also occur, such as Litholic Neosols and Argisols (Santos *et al.* 2013).

The studied Cerrado fragments are located in the urban area of Campo Mourão (Figs. 1; 2; 3): 1. Estação Ecológica do Cerrado Prof<sup>a</sup>. Diva Aparecida Camargo (13,000 m<sup>2</sup>) was established in 1993 as the smallest Ecological Station in Brazil (Parolin *et al.* 2015) and the only protected area of Cerrado within the Mourão river Basin (Tomadon *et al.* 2019). It is in the process of vegetation succession with the presence of trees and climbers of the Seasonal Semideciduous Forest, the phytophysiognomy and phytoliths indicate a “Cerradão” vegetation, a forest formation type within the Cerrado domain (Monteiro *et al.* 2015); 2. Cerrado dos Perdoncini (50,000 m<sup>2</sup>) is a private area, without legal, environmental protection. It is mostly occupied with the initial phases of the succession of the Seasonal Semideciduous



**Figure 1** – a. Location of the municipality of Campo Mourão, state of Paraná, Brazil. b. Cerrado fragments (1 = Estação Ecológica do Cerrado; 2 = Cerrado dos Perdoncini; 3 = Lote 7H; 4 = Airport and surroundings). c-f. Temporal sequence (from years 2000 to 2022) of vegetation cover in the Cerrado dos Perdoncini (2) and Lote 7H (3). Satellite images: Google Earth®.



**Figure 2** – a-f. View of the Cerrado vegetation where the centre of Campo Mourão is currently located, on the horizon of these images, it is possible to observe the Mixed Ombrophilous Forest, all images digitally colored – a. between the years of 1910 and 1920, on the central right of the image, tall individuals of *Butia paraguayensis* palm trees are observed; b. in the 1930s; c. in the 1940s; d-f. in the year of 1948, in which several individuals of *Butia paraguayensis* are observed. g. aerial image of the municipality's central region in 1953, with the beginning of the construction of the urban area, in which Cerrado and forest fragments can be observed. h. Estação Ecológica do Cerrado in 1994, grassland vegetation where two individuals of *Annona coriacea* (Annonaceae) are observed (centre and left). i. Lote 7H between the years 1995 and 2000. (a-c. Herbarium collection from Campo Mourão Municipal Museum; d-f. Personal collection of J.J. Bigarella from the 1948 expedition carried out by Prof. Reinhard Maack, João José Bigarella, and Dra. Dora de Amarante Romariz; g. Herbarium collection of the Municipal Government of Campo Mourão; h-i. M. Parolin).



**Figure 3** – a-g. View of the Cerrado fragments of Campo Mourão after the year 2000 – a-b. Estação Ecológica do Cerrado in 2022; c-d. Lote 7H in 2022 – c. grassland vegetation where three young individuals of *Caryocar brasiliense* (Caryocaraceae) are observed. In the right background, some tree individuals of this species are observed; d. denser vegetation, in the centre, a *Kielmeyera coriacea* tree (Calophyllaceae) is observed, and on the sides, some *Caryocar brasiliense* trees are also observed; e-f. Cerrado dos Perdoncini in 2008 – e. grassland vegetation with forest in the background; f. on the upper left, a *Caryocar brasiliense* tree is observed alongside a *Butia paraguayensis* palm tree on the lower left side; g. denser vegetation at the Cerrado dos Perdoncini in the year 2022. (a-d, g. T. Monteiro-Ré; e-f. G.A. Dettke).

Forest, which gradually advances into the Cerrado formation, occupying about 10% of this area. There are occasional human-induced fires (burning of household waste), with the last ones recorded in the years 2008 and 2016; 3. Lote 7H (23,000 m<sup>2</sup>) is a private area without legal, environmental protection. Presents a predominance of shrub and tree species, the Cerrado formation occupies less than 20% of this area. Additionally, among the historical areas mentioned on specimen labels of historical collections, we have the Airport region and surroundings, where the Cerrado fragments are currently extinct. It corresponds to land covered with exotic grasses, with the maintenance of cutting by the city government for the Airport Coronel Geraldo Guia de Aquino (CBW) activities.

### Floristic composition

For the floristic characterisation of the Cerrado fragments of Campo Mourão, we analyzed specimens deposited at the HCF herbarium collected in the three fragments in this municipality from 2000 to 2022. Additionally, databases from other herbaria (national and international) were retrieved using the *SpeciesLink* network database (CRIA 2022). Thus, the herbarium collections of 42 herbaria with specimens collected in Campo Mourão were verified: ALCB, ASE, BHCN, CEPEC, CESJ, CGMS, DVPR, ECT, EFC, ESA, EVB, FCAB, FLOR, FUEL, FURB, HAS, HEPH, HST, HUCP, HUCS, HUEFS, HUEM, HURB, HUTO, IAC, ICN, IRAI, MBM, NYBG, R, RFA, SP, SPF, UB, UEC, UFG, UFMT, UFP, UNOP, UPCB, US, and VIES (Thiers, continuously updated). All herbarium specimens were checked for species identification by consulting the physical material or high-definition images of them, correcting or determining using taxonomic studies, consultation with specialists or even by comparison with material stored in reference herbaria. Also, all herbarium specimens were checked regarding the location of the collection, and only the sheets that clearly contained the indication of collection in the Cerrado fragments of Campo Mourão were selected. Furthermore, all herbarium collection numbers selected did not have duplicates. The three fragments were also visited in 2022 to verify the vegetation conditions.

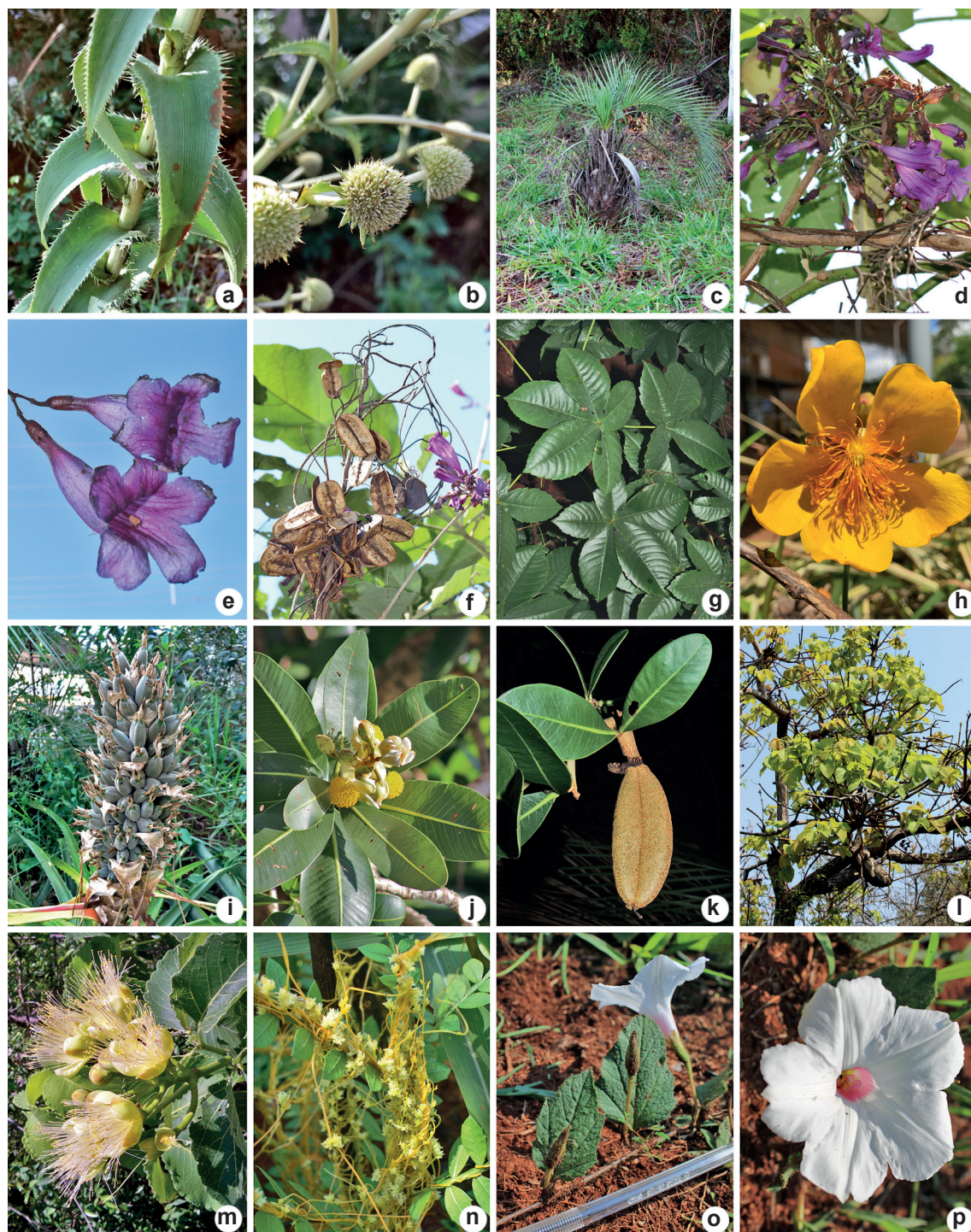
The classification of botanical families followed the APG IV (2016) for angiosperms, except for Passifloraceae and Turneraceae, which were kept as distinct families (Tokuoka 2012; Flora do Brasil 2020, continuously updated) and

the PPG I (2016) for ferns. The specific epithets and authors were checked in the “Flora e Funga do Brasil 2022” (continuously updated), International Plant Names Index - IPNI (2022) and Tropicos.org (Missouri Botanical Garden 2022). For the analysis of the temporal distribution of collections in the Cerrado fragments, the samples were divided into two periods: an older one, between 1960–1999 and a more recent one, between 2000–2022, after the establishment of the HCF herbarium (founded in 2000) and the intensification of field collections in these areas. Species collected or not in the most recent period and those collected only recently were quantified. The species that were not collected recently were evaluated for their presence in other fragments of the municipality (outcrop vegetation, anthropic areas, Seasonal Semideciduous Forest, and Mixed Ombrophylous Forest), and those that were considered exclusive to the Cerrado areas were classified as probably locally extinct (IUCN 2012).

The confirmed species were classified according to the life form and substrate, considering the information from the collection files and the “Flora e Funga do Brasil” database (2022); according to their origin (native to Brazil, cultivated or naturalised) (Flora e Funga do Brasil 2022, continuously updated); endemism in Brazil and the state of Paraná (Kaehler *et al.* 2014; Flora do Brasil 2020, continuously updated); the threat of extinction in Brazil (Brasil 2022); and as for the type of vegetation and the Phytogeographic Domain of occurrence (BFG 2015; Flora e Funga do Brasil 2022, continuously updated). All exotic species were evaluated for the invasive character (concepts according to Blackburn *et al.* 2011; Moro *et al.* 2012; Zenni 2015) considering the populations observed in the study sites and the list of invasive species in Paraná (Paraná 2015).

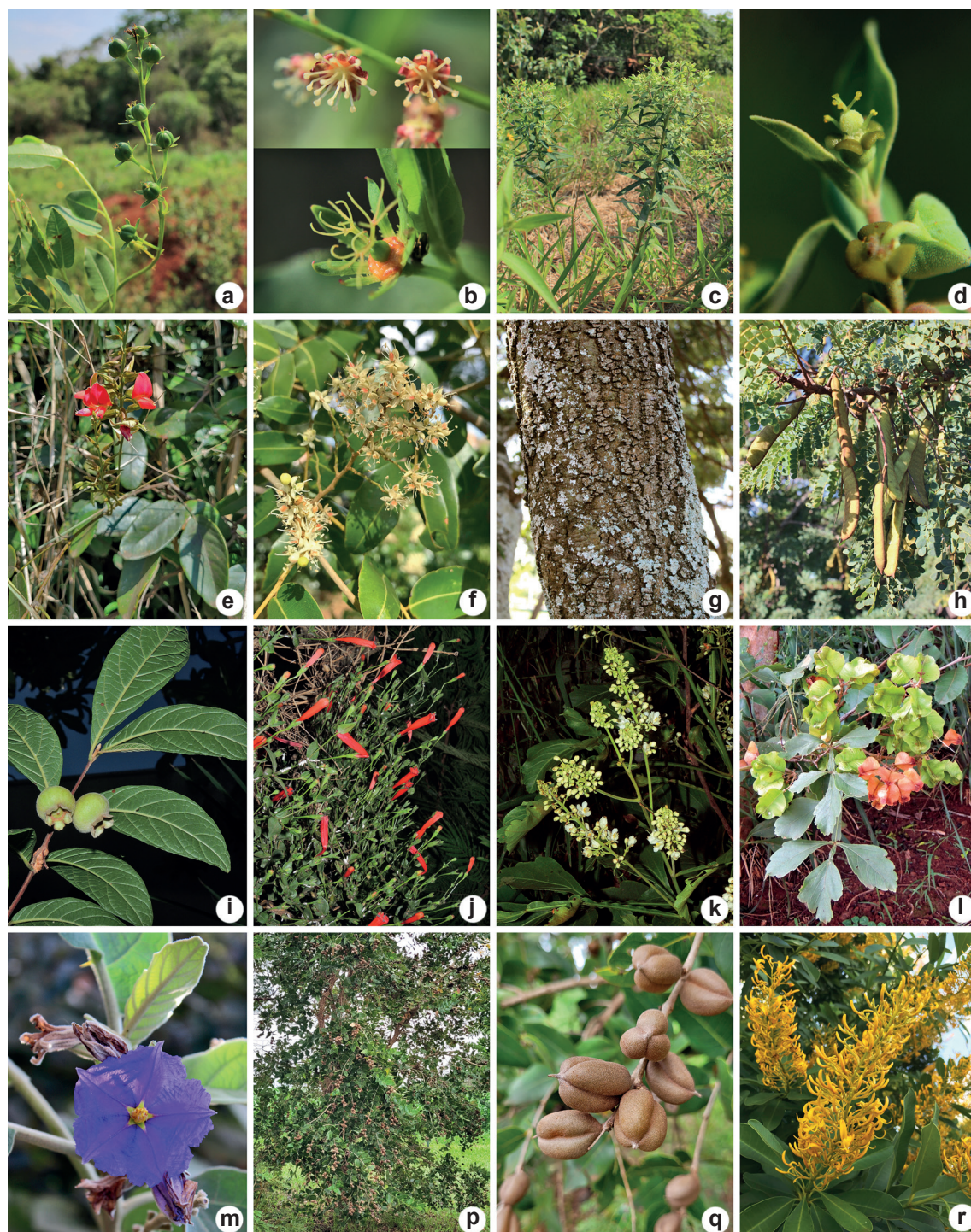
### Results

A total of 4,125 herbarium collections were analysed for Campo Mourão, nearly a quarter of which (952) were collected in the Cerrado fragments of this municipality. These collections confirmed the occurrence of 368 species distributed in 70 families and 241 genera of vascular plants in the Cerrado fragments of Campo Mourão (Tab. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.24179667.v1>>; Figs. 4-5). Ferns represent four genera and four species; the remainder is flowering plants. Regarding the origin, 343 species are native to Brazil, 15 are



**Figure 4** – a-p. Some species found in the Cerrado fragments of Campo Mourão – a-b. Apiaceae – *Eryngium rochei*; c. Arecaceae – *Butia paraguayensis*; d-f. Bignoniaceae – *Jacaranda mutabilis*; g-h. Bixaceae – *Cochlospermum regium*; i. Bromeliaceae – *Bromelia balansae*; j-k. Calophyllaceae – *Kielmeyera coriacea*; l-m. Caryocaraceae – *Caryocar brasiliense*; n-p. Convolvulaceae – n. *Cuscuta xanthochortos* parasitising *Schinus weinmanniifolia* (Anacardiaceae); o-p. *Distimake hasslerianus*. (a-f, h-j, l. T. Monteiro-Ré; g, k, n. G.A. Dettke; o-p. O.L.M. Silva).





**Figure 5** – a-p. Some species found in the Cerrado fragments of Campo Mourão – a-d. Euphorbiaceae – a-b. *Astraea cincta*; c-d. *Euphorbia papillosa*; e-h. Fabaceae – e. *Cerradicola elliptica*; f. *Copaifera langsdorffii*; g-h. *Stryphnodendron adstringens*; i. Myrtaceae – *Campomanesia sessiliflora*; j. Rubiaceae – *Manettia cordifolia*; k-l. Sapindaceae – *Serjania erecta*; m. Solanaceae – *Solanum lycocarpum*; n-p. Vochysiaceae – n-o. *Qualea cordata*; p. *Vochysia tucanorum*. (a-d. O.L.M. Silva; e-h, l-p. T. Monteiro-Ré; i-k. G.A. Dettke).

naturalised, and ten are cultivated. *Jacaranda mutabilis* Hassl. (Bignoniaceae) (Fig. 4d-f) is cited for the first time for southern Brazil, in the state of Paraná.

The richest families were Fabaceae (55 species), Asteraceae (48), Myrtaceae (21), Euphorbiaceae (16), Poaceae (16), Bignoniaceae (12), Malvaceae (12), Apocynaceae (12), Lamiaceae (11), Malpighiaceae (10), and Rubiaceae (10). These eleven families represent 61% of the species in Cerrado fragments of Campo Mourão. The remaining 59 families showed nine or fewer species, with 21 families having only one species. The genera with the highest number of species were *Eugenia* (Myrtaceae), with nine species, *Mimosa* (Fabaceae), *Myrcia* (Myrtaceae) and *Croton* (Euphorbiaceae) with six species each, and *Baccharis* and *Mikania* (Asteraceae) with five species each.

Life forms and substrate use are summarised in Table 1. The predominant life form in the Cerrado fragments was subshrubs (37% of species), followed by shrubs (33%), herbs (29%), trees (25%), climbers (13%), and palm trees (1%). Among the families of subshrub habit, the most representative were Fabaceae (29 species), Asteraceae (23), Euphorbiaceae (12), and Myrtaceae (9), which represented 53% of the species with this life form. The richest families in

the shrub life form were Myrtaceae (16 species), Fabaceae (16), and Asteraceae (15), representing 39% of this life form. Regarding the herbaceous life form, Poaceae (16 species), Asteraceae (13), Fabaceae (8), and Euphorbiaceae (8) were the richest families, representing 42% of the species with this life form. About two-thirds of the species occurring in Cerrado fragments of Campo Mourão showed a single life form, with the remainder showing variable life forms such as shrub/tree, shrub/subshrub, or herb/subshrub. Regarding substrate use, most species are terrestrial (98%), followed by rupicolous (5%), epiphytic, and parasitic (1% each). Only 5% of the species show variable substrate uses as rupicolous/terrestrial (Tabs. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.24179667.v1>>; 1).

Among the native species, 51 are endemic to Brazil (14%), and three are endemic to the state of Paraná (0.1%) (Tab. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.24179667.v1>>). Six species are considered officially threatened with extinction in Brazil, such as *Astraea cincta* (Müll.Arg.) Caruzo & Cordeiro (Euphorbiaceae) (Fig. 5a-b) and *Janusia occhioni* W.R.Anderson (Malpighiaceae) as Endangered (EN), and *Butia microspadix* Burret (Arecaceae), *Chrysolaena nicolackii* H.Rob.

**Table 1** – Summary of life forms and substrate uses of the vascular plant from the Cerrado fragments of Campo Mourão, state of Paraná, Brazil.

Life Forms	Number of species	%
Subshrub	137	37
Shrub	121	33
Herb	107	29
Tree	91	25
Climber	47	13
Palms	4	1
Variable	123	34
<b>Substrate uses</b>		
Terrestrial	361	98
Rupicolous	19	5
Epiphytic	3	1
Parasite	2	1
Variable	17	5

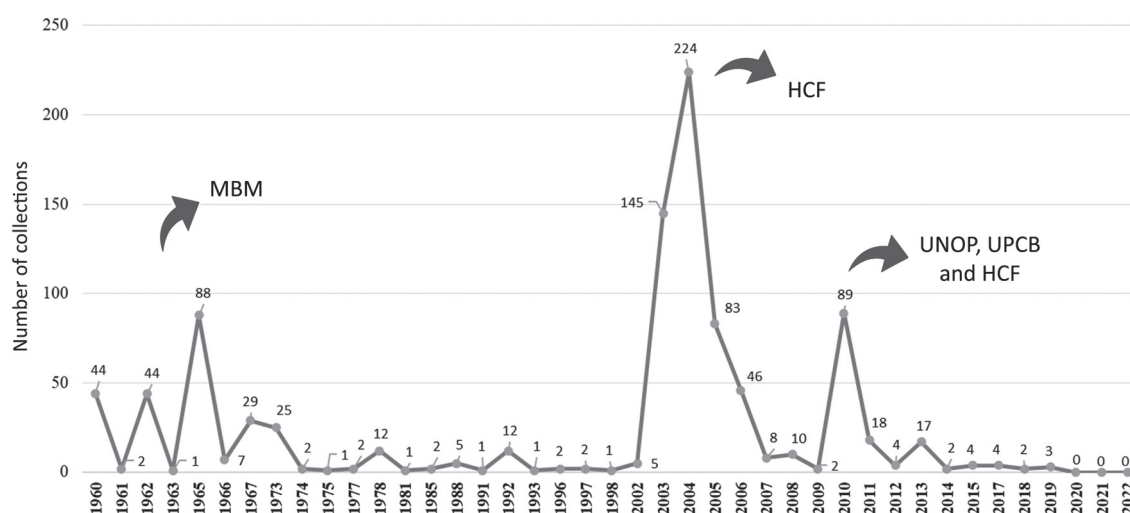
(Asteraceae), *Lessingianthus pumillus* (Vell.) H. Rob. (Asteraceae) and *Manihot procumbens* Müll. Arg. (Euphorbiaceae) as Vulnerable (VU).

Regarding the herbarium collections, of the 952 confirmed specimens, 286 (30%) were collected before 1999 and 666 (70%) after 2000. The species with the highest number of herbarium collections were: *Dalechampia guaranitica* Chodat & Hassl. (12 samples) and *D. weddelliana* Baill. (11) (Euphorbiaceae), *Peixotoa reticulata* Griseb. (13) and *Byrsonima intermedia* (11) (Malpighiaceae), *Campomanesia adamantium* (Cambess.) O. Berg (11) (Myrtaceae) and *Vochysia tucanorum* Mart. (10) (Vochysiaceae) (Fig. 5p). Figure 6 shows the collection of herbarium specimens over time. Three periods of greater herbarium collection activity are observed, between 1960–1965 for the MBM herbarium, between 2003–2005 for the HCF herbarium, and in 2010 for the UNOP, UPCB, and HCF herbaria (Fig. 6).

One hundred seventy-seven species (48%) were collected before the year 1999 and 307 (84%) after the year 2000 (Tab. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.24179667.v1>>). One hundred and sixteen species (31%) were collected before 1999 and recollected after the year 2000, and 191 of the confirmed species (52%) were only collected after the year 2000 (Tab. S1, available on supplementary material <[\[m9.figshare.24179667.v1\]\(https://doi.org/10.6084/m9.figshare.24179667.v1\)>\). Sixteen per cent of the species \(60 species\) were only collected before 1999, with no herbarium collections recorded after 2000. Of the total species, 18 also occur in other fragments in Campo Mourão according to recent collections \(after 2000\), but 42 species are exclusive to the Cerrado fragments of the municipality and were then classified as probably locally extinct \(Tab. 2\).](https://doi.org/10.6084/</a></p>
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Regarding the distribution of species recorded for the Cerrado fragments of Campo Mourão (Fig. 7) in the phytogeographic domains of Brazil, 89% occur in the Cerrado domains, and 83% also occur in the Atlantic Forest domain. About 37% of the species are common in Brazil and occur in four or more domains; 24% occur in three domains, 24% occur in two domains, and 15% occur in a single domain.

Considering the Brazilian vegetation types, the species from the Cerrado fragments of Campo Mourão are mostly recorded for the Cerrado (*lato sensu*) (74%), Grasslands (37%), Seasonally Semideciduous Forest (35%), Anthropogenic Areas (35%), or Ombrophilous Forest (Tropical Rainforest) (32%) (Fig. 8). Twenty-five species (7%) occur exclusively in the Cerrado (*lato sensu*) vegetation, with most of them having recent collections (in the past 20 years). Still, some have not been collected for the past 30 (*i.e.*, *Asemeia hebeclada* (DC.) J.F.B. Pastore & J.R. Abbott, Polygalaceae) or 55 years (*i.e.*,



**Figure 6** – Number of herbarium collections of the vascular plants from the Cerrado fragments of Campo Mourão, state of Paraná, Brazil, between 1960 to 2022, and indication of the herbaria responsible for the three periods of most collections.

**Table 2** – List of probably locally extinct species from the Cerrado fragments of Campo Mourão, state of Paraná, Brazil, and the date of the last collection.

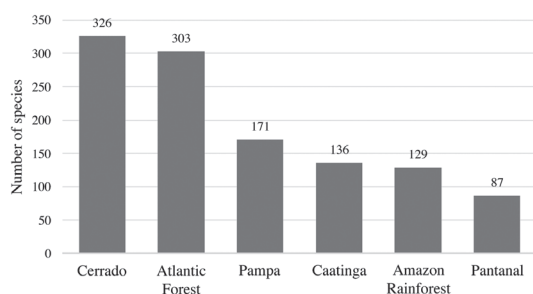
Families	Species	Last collection date
Acanthaceae	<i>Dyschoriste lavandulacea</i>	1965
	<i>Ruellia bulbifera</i>	1965
	<i>Ruellia geminiflora</i>	1998
Amaranthaceae	<i>Froelichia procera</i>	1967
	<i>Pfaffia gnaphaloides</i>	1965
Apocynaceae	<i>Asclepias mellodora</i>	1965
	<i>Mandevilla coccinea</i>	1960
	<i>Mandevilla illustris</i>	1965
	<i>Mandevilla virescens</i>	1965
	<i>Nautonia nummularia</i>	1973
Araliaceae	<i>Didymopanax vinosus</i>	1962
Arecaceae	<i>Butia microspadix</i>	1973
Asteraceae	<i>Chrysoleaena simplex</i>	1965
	<i>Dimerostemma arnottii</i>	1963
	<i>Lessingianthus grandiflorus</i>	1965
	<i>Mikania oblongifolia</i>	1962
Campanulaceae	<i>Lobelia hederacea</i>	1960
Convolvulaceae	<i>Convolvulus hasslerianus</i>	1973
	<i>Evolvulus sericeus</i>	1973
Cucurbitaceae	<i>Melothria campestris</i>	1960
Cyperaceae	<i>Bulbostylis sphaerocephala</i>	1965
Fabaceae	<i>Centrosema bracteosum</i>	1965
	<i>Clitoria epetiolata</i>	1965
	<i>Collaea stenophylla</i>	1967
	<i>Ctenodon histrix</i>	1965
	<i>Rhynchosia lateritia</i>	1973
Lamiaceae	<i>Clerodendrum ekmanii</i>	1962
	<i>Hyptis campestris</i>	1965
	<i>Hyptis comaroides</i>	1965
Malpighiaceae	<i>Aspicarpa pulchella</i>	1960
	<i>Janusia occhioni</i>	1962
Myrtaceae	<i>Eugenia puniceifolia</i>	1973
Passifloraceae	<i>Passiflora lepidota</i>	1967
Poaceae	<i>Aristida megapotamica</i>	1962
	<i>Eragrostis polytricha</i>	1960
	<i>Paspalum cinerascens</i>	1962

Families	Species	Last collection date
Poaceae	<i>Paspalum regnelli</i>	1962
	<i>Setaria globulifera</i>	1962
Polygalaceae	<i>Asemeia hebeclada</i>	1992
Rhamnaceae	<i>Crumenaria polygaloides</i>	1965
Symplocaceae	<i>Symplocos uniflora</i>	1965
Verbenaceae	<i>Lippia procurrens</i>	1967

*Lessingianthus grandiflorus* (Less.) H. Rob., Asteraceae; *Clitoria epetiolata* Burkart, Fabaceae; *Passiflora lepidota* Mast., Passifloraceae; and *Crumenaria polygaloides* Reissek, Rhamnaceae) (Tabs. S1, available on supplementary material <<https://doi.org/10.6084/m9.figshare.24179667.v1>>; 2).

## Discussion

The current Cerrado fragments from Campo Mourão correspond to 0.00114% of the total area of this municipality. When considering the original 102 km<sup>2</sup> of this vegetation in the municipality, the Cerrado coverage in Campo Mourão reached only 0.01%. Despite these areas being very small, 368 species of vascular plants were recorded in them, representing 25% of the flora recorded for this municipality (a total of 1,485 species, T. Monteiro-Ré, unpublished data). Considering the number of families (70), these areas comprise around 40% of the recorded families, demonstrating the importance that these Cerrado fragments in Campo Mourão still have for the conservation of regional biodiversity.



**Figure 7** – Number of vascular plant species from the Cerrado fragments of Campo Mourão, state of Paraná, Brazil, distributed in the Brazilian phytogeographic domains where they occur, following Flora e Funga do Brasil 2022 (continuously updated).

The list of species presented in this study significantly expands the list of Hatschbach *et al.* (2005), from 136 to 368 species recorded in the Cerrado fragments of Campo Mourão. Four species cited by Hatschbach *et al.* (2005) could not be confirmed in this study due to the lack of herbarium collections in the consulted herbaria: *Tapirira guianensis* Aubl. (Anacardiaceae), *Viguiera grandiflora* (Gardner) Gardner (Asteraceae), *Zornia latifolia* Sm. (Fabaceae), and *Angelonía integerrima* Spreng. (Plantaginaceae). Another 24 species were also not confirmed in this study since their herbarium collections did not clearly indicate that they were collected in the Cerrado fragments of this municipality or contained indications of different locations (such as “lajeados”, “campo limpo” or riverbanks).

A large portion of the species from the Cerrado fragments of Campo Mourão show a wide distribution in Brazil, being common in several phytogeographic domains and vegetation types, mainly in Cerrado (*lato sensu*), Grasslands, Semideciduous or Dense Seasonal Forests and Mixed Ombrophilous Forest. Considering the geographical location of the municipality of Campo Mourão, the Cerrado vegetation could have had a continuous distribution in the geological past, with the areas in the north-eastern state of Paraná (the municipality of Jaguariaíva and the state of São Paulo) and the areas to the northwest (state of Mato Grosso do Sul). Ratter *et al.* (2003) and Bridgewater *et al.* (2004) established six floristic provinces for the Cerrado domain based on the composition of trees and large shrubs. Analysing the 50 most common species indicated by Bridgewater *et al.* (2004) for the two closest provinces, the Southern cerrados (only the municipality of Jaguariaíva included in the study by Ratter *et al.* 2003) shared 22 species (44%) with the Cerrado fragments of Campo Mourão, while the Central-western cerrados shared only 11 species (22%).

According to Velazco *et al.* (2018), the structure of the Cerrado from the province of Misiones (Argentina) is floristically similar to the disjunct patches of the Cerrado in the state of Paraná and Paraguay, where the climatic conditions are quite similar. These Cerrados fragments share key species such as *Leptolobium elegans* (Fabaceae), *Allagoptera campestre* (Mart.) Kuntze (Arecaceae), *Casearia sylvestris* Sw. (Salicaceae), among others. There is an emphasis on pioneer forest species also found in the Cerrado fragments of Campo Mourão, *Tabernaemontana catharinensis* A.DC. (Apocynaceae), *Casearia sylvestris* (Salicaceae), *Solanum granulosoleprosum* Dunal (Solanaceae), and secondary succession species such as *Helietta apiculata* Benth. (Rutaceae) and *Matayba elaeagnoides* Radlk. (Sapindaceae).

This study reports the first record of *Jacaranda mutabilis* for the state of Paraná (and for Southern Brazil). This species is characterised by being a shrub, or small tree with 2–3 m tall, inflorescences concentrated in the terminal portions of the branches (Fig. 4d), and flowers puberulent with vinaceous corollas (Fig. 4e). *Jacaranda mutabilis* (Bignoniaceae) occurs in Paraguay and Brazil (Gentry & Morawetz 1992), in the Southeast (state of Minas Gerais) and Central-west (state of Distrito Federal, Goiás, Mato Grosso do Sul, and Mato Grosso), always associated with Cerrado vegetation (Farias-Singer 2022). In the state of Paraná, it was found in Campo Mourão, with collections from 2003, and in the municipality of Tuneiras do Oeste, also in a Cerrado fragment (herbarium collections HCF 9680 and HCF 10914) in the years 2011 and 2012. The populations were small, with less than ten individuals in each area. In Campo Mourão, the species is occasionally used by residents of the surrounding areas as an ornamental plant on sidewalks, flowering and fruiting from June to November.

Despite not being cited for the state of Paraná in the Flora and Funga do Brasil 2022, continuously updated, *Ichthyothere latifolia* (Benth.) Gardner (Asteraceae) (Gandara 2022) and *Cerradicola elliptica* (Desv) L.P.Queiroz (Fabaceae) (Fig. 5e) (Oliveira & Queiroz 2022) are cited for the Paraná flora by Koehler *et al.* (2014).

Among the endangered species in Brazil *Astraea cincta* (Euphorbiaceae) (Fig. 5a-b), *Chrysoleaena nicolackii* (Asteraceae), *Lessingianthus pumillus*. (Asteraceae) and *Manihot procumbens* (Euphorbiaceae) have been collected over the last 20 years, all from very small

populations, with less than ten individuals. *Janusia ochioni* (Malpighiaceae) and *Butia microspadix* (Arecaceae) have not been collected for at least 50 years in the municipality, despite recent field collection efforts, being probably extinct in the region.

There is a first version of the Red List of Endangered Vascular Plants for the state of Paraná (SEMA/GTZ-PR 1995). However, this list is outdated and needs a review with more clear criteria for the inclusion of endangered species at the state level. For Cerrado fragments of Campo Mourão, Tomadon *et al.* (2019) have already analyzed the species present in the Paraná Red List, indicating 32 species distributed in the Rare, Vulnerable, or Endangered categories.

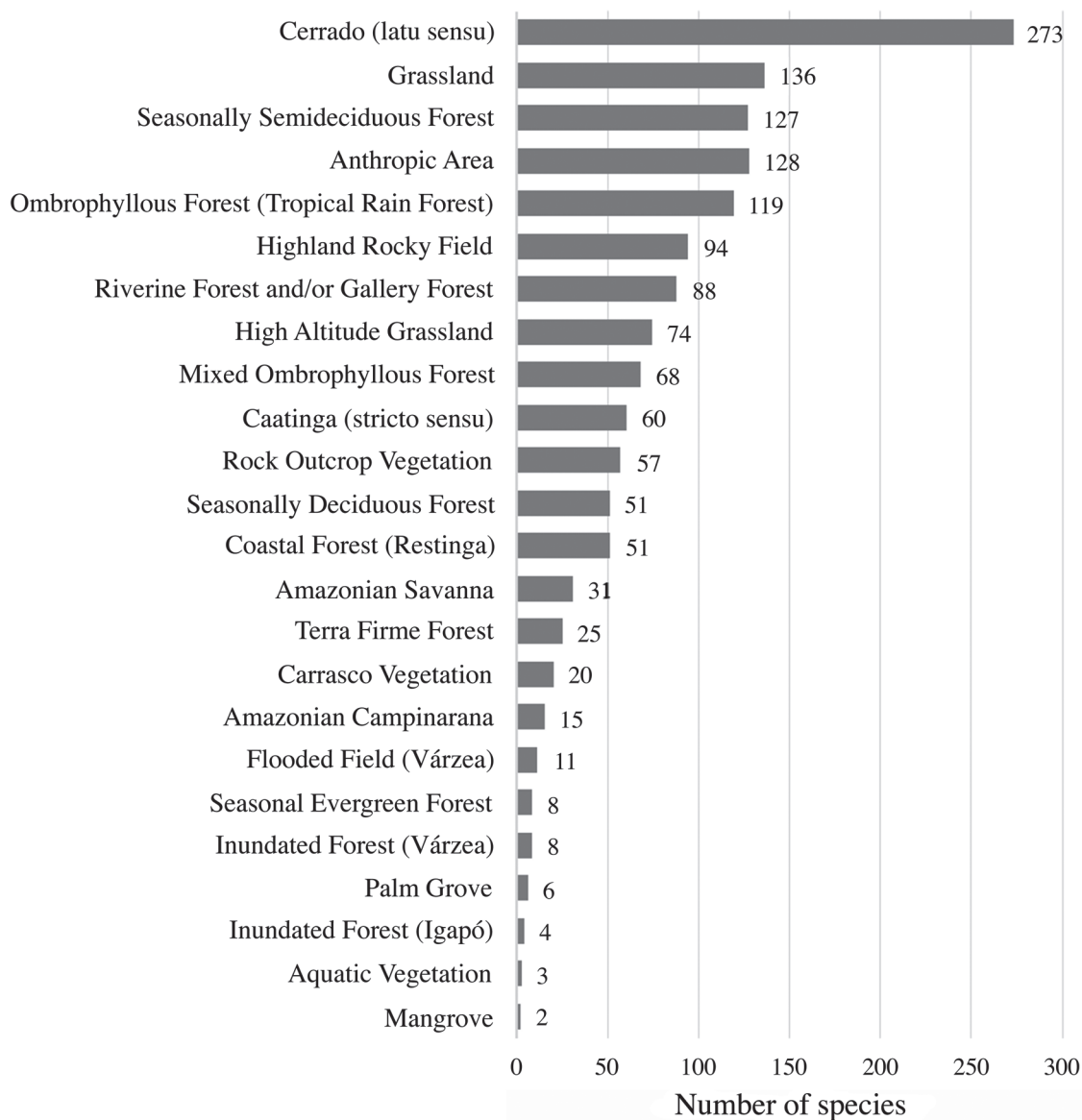
The local extinction of species is unfortunately a reality in several regions, including Brazil. The causes of extinction include several factors, *e.g.*, vegetation fragmentation, loss and change of habitat, the introduction of invasive exotic species, and climate changes (Diamond 1989; Thomas *et al.* 2004), and may result in a decrease in the size of populations until their absence from the environment. According to IUCN (2012), a taxon is Regionally Extinct (RE) when there is no reasonable doubt that the last individual potentially capable of reproduction has died or disappeared from the region. The most effective way to verify this is to study these locations and follow the population sizes in the field. Also, for intensely sampled areas, species records in herbaria can provide valuable information about taxon collection gaps, and, according to Lughadha *et al.* (2018), their use as a basis for extinction risk assessment is appropriate, necessary, and urgent. Long gaps in sighting records were previously used to infer the extinction of a species, and the pre-1995 IUCN threshold was 50 years (Yan *et al.* 2022). However, this information should not be used alone. Currently, according to IUCN (2012), it is not possible to set any general rules for a time period since the last observation in order to taxa to be classified as Regionally Extinct since this parameter would depend on efforts devoted to search for the taxon. For example, for the Brazilian Red List (Martinelli & Moraes 2013), minimum collection gaps of 20 or 30 years combined with great impacts on the environments of occurrence were sufficient to flag some species as probably locally extinct [*e.g.*, *Eschweilera tetrapetala* S.A.Mori and *Lecythis schwackei* (R.Knuth) S.A.Mori (Lecythidaceae), *Pabstia schunkiana*

V.P.Castro (Orchidaceae) and *Solanum bahianum* S.Knapp (Solanaceae)].

Considering the existing impacts on the Cerrado areas in Campo Mourão, e.g., the fragmentation of vegetation, the change to the more arboreal vegetation, the insertion of the urban environment (impacts of roads and clandestine garbage disposal), and the absence of recent collections, even after sampling efforts in these areas, we indicated 42 species as probably locally

extinct. It should be emphasized that, for most of these species, the absence of collections is longer than 50 years (40 of the 42 species listed). Only *Asemeia hebeclada* (Polygalaceae, last collection in 1992) and *Ruellia geminiflora* Kunth (Acanthaceae, last collection in 1998) have smaller but significant gaps.

Other species recorded in the Cerrado fragments of Campo Mourão, although occurring in neighbouring countries or other Brazilian states,



**Figure 8** – Number of species of vascular plants from the Cerrado fragments of Campo Mourão, state of Paraná, Brazil, distributed in the Brazilian vegetation types where they occur, following the categories recognized by the Flora e Funga do Brasil database (2022).

stand out for the rarity of collections in the state of Paraná, being recorded only in this municipality: *Eryngium rochei* Constance, Apiaceae (Fig. 4a-b); *Acrocomia hassleri* (Barb.Rodr.) W.J.Hahn, Areaceae; *Cochlospermum regium*, Bixaceae (Fig. 4g-h); *Distimake hasslerianus* (Chodat) A.R.Simões & Staples, Convolvulaceae (Figs. 4o-p); *Campomanesia sessiliflora* (O.Berg) Mattos, Myrtaceae (Fig. 5i), *Talisia angustifolia* Radlk., Sapindaceae and *Lippia balansae* Briq., Verbenaceae); or also in few other municipalities in this state: (*Butia paraguayensis* (Barb.Rodr.) Bailey, Areaceae (Fig. 4c); *Croton fuscus* (Didr.) Müll.Arg. and *Dalechampia guaranitica*, Euphorbiaceae, *Melochia hassleriana* Chodat, Malvaceae and *Pouteria torta* (Mart.) Radlk., Sapotaceae). All these species have been collected in the past 20 years in the Cerrado fragments of Campo Mourão, although they occur in very small populations, with less than ten individuals each.

Regarding exotic species, 25 were recorded (15 naturalised and ten cultivated). This high number is expected since the Cerrado fragments of this municipality essentially occupy portions of the urban area. From these species, eight are considered invasive in the state of Paraná (Paraná, 2015): *Tetrapanax papyrifer* (Hook.) K. Koch (Araliaceae), *Tecoma stans* (L.) Juss. ex Kunth (Bignoniaceae), *Leucaena leucocephala* (Lam.) de Wit (Fabaceae), *Melia azedarach* L. (Meliaceae), *Syzygium cumini* (L.) Skeels (Myrtaceae), *Melinis minutiflora* P.Beauv. and *Urochloa brizantha* (Hochst. ex A.Rich.) R.D.Webster (Poaceae) and *Grevillea robusta* A.Cunn. ex R.Br. (Proteaceae). Of these, the two Poaceae species are of concern in these areas in Campo Mourão, as well as *Leucaena leucocephala*, an easily dispersed tree that has become frequent in the municipality. We consider these three species as invasive of the Cerrado fragments of Campo Mourão. The other exotic species were found with few individuals in these areas and need only to be monitored.

In the three Cerrado fragments within this municipality, the tree forest phytophysiology can already be observed, indicating the advance of the Semideciduous Seasonal Forest over these Cerrado fragments. This colonisation has already been demonstrated by Monteiro *et al.* (2015) in the Estação Ecológica do Cerrado, where the authors classified this vegetation as “cerradão” with a denser and arboreal cover. Lote 7H comprises more open vegetation with a predominance of grasslands and few shrubs and trees in 2015, and these authors

classified the vegetation as Cerrado *sensu stricto*. A few years later, in 2022, a dense and arboreal cover was also observed in this area. The temporal analysis of aerial satellite images between 2000 and 2022 showed a clear change in coverage from grassland to a shrub-tree cover in Lote 7H and the Cerrado dos Perdoncini (Fig. 1c-f).

Considering the species list, we have a predominance of shrubs and subshrubs and a high proportion of tree species (25%) in these areas. Tree species typical of Seasonal or Ombrophilous Forests are already recorded in recent collections, such as several species of Fabaceae [*Inga marginata* Willd., *Libidibia ferrea* (Mart. ex Tul.) L.P. Queiroz, *Muelleria campestris* (Mart. ex Benth.) M.J. Silva & A.M.G. Azevedo, *Parapiptadenia rigida* (Benth.) Brenan], Meliaceae (*Trichilia catigua* A.Juss.), Myrtaceae [*Campomanesia xanthocarpa* (Mart.) O.Berg, *Eugenia hiemalis* Cambess.], Rutaceae (*Helietta apiculata*), as well as several typical forest climbing species, such as Asteraceae (*Mikania capricorni* B.L.Rob.), Bignoniaceae [*Dolichandra unguis-cati* (L.) L.G.Lohmann, *Pyrostegia venusta* (Ker Gawl.) Miers], Malpighiaceae (*Dicella nucifera* Chodat), Rhamnaceae (*Gouania ulmifolia* Hook. & Arn.) and Sapindaceae (*Cardiospermum halicacabum* L., *Serjania laruotheana* Cambess.).

Of the three existing areas of Cerrado, only the Estação Ecológica do Cerrado is located within an environmental protection area. Lote 7H and Cerrado dos Perdoncini are private areas that may soon have their vegetation cover suppressed to expand the urban centre. Considering that the municipal government does not see any interest in the protection and conservation of these two Cerrado fragments, some attempts were made to conserve ex-situ some rarer species, such as the transplantation of individuals to the UTFPR didactic garden and transfer of soil from these sites to the Estação Ecológica do Cerrado and to the UTFPR campus.

The reduction of Cerrado areas and the change to a forest phytophysiology, human pressure and the lack of seasonal fires are considered the main threats to the resilience of the Cerrado domain (Ratter 1992, 1997; Durigan & Ratter 2006, 2016; Durigan *et al.* 2020; Newberry *et al.* 2020; Abreu *et al.* 2021). The Estação Ecológica do Cerrado had its flora composition changed over the years due to the reduction of disturbances and fire suppression, increasing the number of forest species. Forest expansion over the Cerrado vegetation leads to changes in species composition,



vegetation structure, functionality and the structure of woody plant communities (Flake *et al.* 2021), and increased tree density in savanna areas reduces flammability over time, generating a cooler and more humid environment (Newberry *et al.* 2020). Fire is the main environmental filter against the recruitment of forest species in the savanna, and without them, trees attract seed dispersers and provide shade-triggering nucleation (Abreu *et al.* 2021). Fire suppression becomes economically and ecologically unsustainable (Durigan 2020), and tree cutting and fire should be indicated for restoration and fire management for Cerrado conservation purposes (Durigan 2020; Haddad *et al.* 2020). Initiatives in this sense have been tested at the Estação Ecológica do Cerrado, based on the Management Plan (Campo Mourão 2017), such as controlled burning of 10% of the area and removal or pruning of tree species. In these two methods, the germination of Cerrado species was observed, but after the burning, the germination of exotic species was also verified. Thus, for the Estação Ecológica do Cerrado, drastic pruning was more effective for the regeneration of the Cerrado (Monteiro-Ré *et al.* 2022a).

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### Data availability statement

In accordance with Open Science communication practices, the authors inform that all data are available within the manuscript.

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