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Vascular plant species richness and distribution in the Río de la Plata grasslands

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Effective scientific efforts and conservation actions transcend political boundaries, encompassing entire ecological units. We compiled a vascular plant species list for the Río de la Plata grassland ecoregion, one of the largest continuous grassland ecosystems, in the Americas. Our list is based on existing regional plant lists, online databases and published literature, is taxonomically verified and is complemented by additional information on species distribution in the three countries (Argentina, Brazil and Uruguay) and on the origin of the species. We compiled 4864 accepted species names belonging to 194 families. About eight percent of the species are endemic; naturalized non-native species comprise slightly > 10% of the dataset. This dataset will be useful in supporting conservation planning in the region and scientific efforts in understanding species distribution patterns and processes.

ADDITIONAL KEYWORDS: Campos – checklist – ecoregion – endemism – naturalized species – Pampa – Pastizales – species richness – taxonomically verified species list.

INTRODUCTION

The Río de la Plata grassland (RPG) region, constituting one of the largest continuous grassland ecoregions in the Americas, occupies *c.* 750 000 km^2 (28°S–38°S, 50°W–61°W) (Soriano, 1992; Dixon *et al.*, 2014). These grasslands ('Campos' in Portuguese, 'Pastizales' or 'Pampa' in Spanish) cover vast plains of central-eastern Argentina, Uruguay and part of southern Brazil (Fig. 1). Uruguay is fully included in the ecoregion. In Argentina, it consists of parts of Buenos Aires, Córdoba, Corrientes, Entre Ríos, La Pampa, Misiones, Santa Fé and San Luis provinces. The Brazilian portion corresponds to the southern half of Rio Grande do Sul state. The RPG encompasses a considerable climatic gradient, with mean annual temperature decreasing southward from 20 °C to 13 °C, and precipitation decreasing

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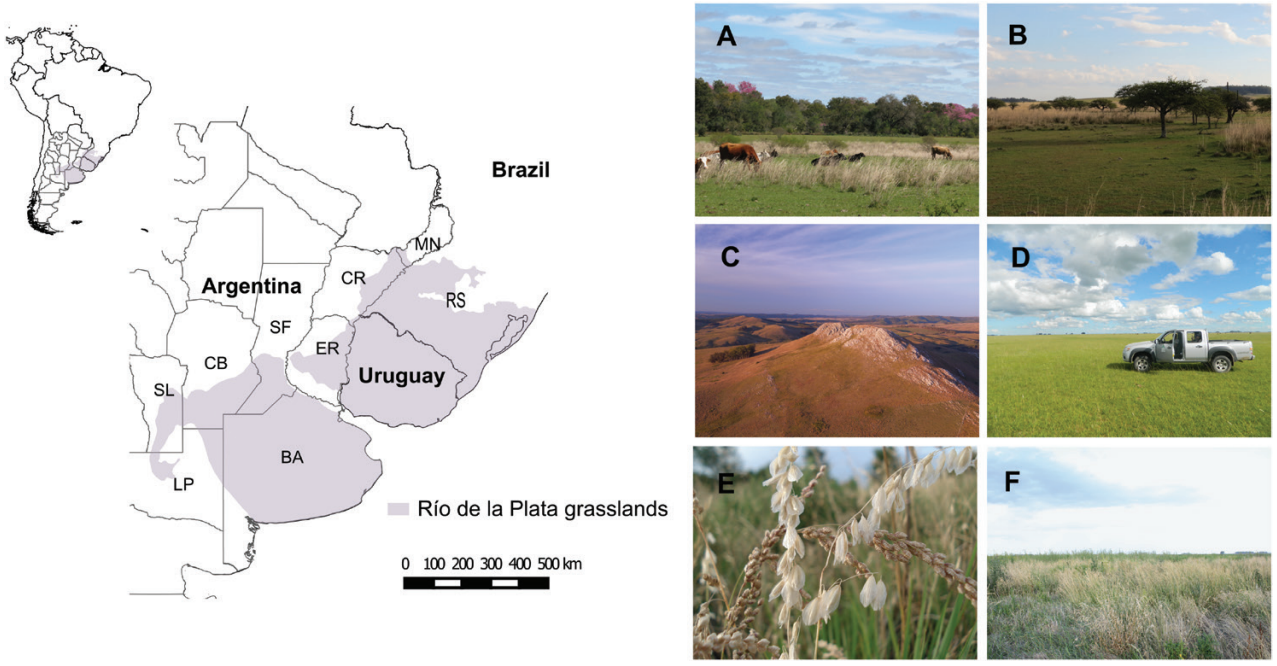

Figure 1. Geographical localization of the Río de la Plata grasslands in South America and a photographic sample of representative native grassland from the three countries. In the map, the state of Rio Grande do Sul (RS) and Provinces of Argentina are highlighted as follow: MN: Misiones, CR: Corrientes, ER: Entre Ríos, SF: Santa Fé, CB: Córdoba, SL: San Luis, LP: La Pampa, BA: Buenos Aires). Photographs are arranged by country increasing in latitude. A, Santo Antonio das Missões, RS, Brazil © B.O. Andrade. B, Quaraí, RS, Brazil © B.O. Andrade. C, Sierras del Este, Uruguay © M. Bonifacino. D, East part of Uruguay © F. Lezama. E and F are non-grazed sites in southeast part of Argentina © P. Tognetti.

from 1800 mm to 400 mm from the north-east to the south-west, respectively (SAGE, Atlas of the Biosphere, https://nelson.wisc.edu/sage/data-and-models/atlas/maps.php). In consequence of this climatic situation, one of the particularities of the ecoregion is the coexistence of C_3 and C_4 grasses, with a higher number of C_3 grass species towards the south (Still *et al.*, 2003).

The RPG ecoregion is characterized by the dominance of grassland throughout. Forests, however, are also present and are found principally, although not exclusively, along riverbanks and in regions with accentuated topography. Forests in the region show decreased species richness when compared to the more tropical forest further north, and markedly less tropical elements (Oliveira-Filho *et al.*, 2015). In grasslands, the contribution of temperate grasses increases towards the south (Fiaschi & Pirani, 2009). RPG borders the formations of the Chaco in the west, the Monte shrublands in the south and the Atlantic Forest ecosystem complex in the north. The Chaco differs from RPG by being a xerophytic type of vegetation dominated by shrubs and trees, with high importance of 'mimosoid clade' species (Fabaceae subfamily Caesalpinioideae) and a tussock grass layer; in its eastern part, wetlands and palm savannas also occur (Oyarzabal *et al.*, 2018). In the southern part of the Atlantic Forest region, i.e. just to the north of the RPG ecoregion, species-rich grasslands are found in mosaics with forest on the South Brazilian plateau (Andrade *et al.*, 2016). Even though these grasslands share many species with the grasslands in the RPG ecoregion, they are floristically distinct (Overbeck *et al.*, 2007; our unpublished data), corresponding to the limit between biogeographical provinces (Pampean vs. Paraná province; Cabrera & Willink, 1973). To the west, due to the still important traditional land use of extensive livestock production, the boundaries of the RPG remain clear, whereas in the south, where the natural landscape has been completely transformed into agricultural land in the past centuries, it is difficult to establish a natural limit.

The RPG has high species diversity. Past estimates suggested the occurrence of *c.* 3000 vascular plant species in grasslands in the state of Rio Grande do Sul, i.e. exceeding the limits of the RPG (Boldrini, 1997), of 1600 species in the Argentinean part (Bilenca & Miñarro, 2004) and of 2500 in Uruguay (Bilenca & Miñarro, 2004). Several previous studies have led to

reliable richness data for specific regions, including, for example, studies of historical importance that compiled 2274 native species for the vascular flora of Uruguay (Herter, 1930, 1933) and 430 vascular species for the north-western part of Rio Grande do Sul and the surroundings of Porto Alegre (Bornmueller, 1934, 1935). More recent studies indicate the occurrence of > 700 grassland plant species in the granitic hills of Porto Alegre in the northernmost part of the RPG (Setubal, Boldrini & Ferreira, 2011), the presence of 533 shrub and tree species in forests in the state of Rio Grande do Sul, including the forests in the Pampa (Sobral *et al.*, 2006), 274 vascular plants in the grasslands of the Basaltic region of Uruguay (Lezama *et al.*, 2006), 430 vascular plants in the grasslands of the Flooding Pampa, Argentina (Perelman, León, Oesterheld, 2001) and 545 vascular species in a remnant of *Butia yatay* (Mart.) Becc. palm savanna (Batista *et al.*, 2014). However, no overall synthesis of species richness exists for the ecoregion or specific plant groups. This information is important both for a better understanding of ecological features of the RPG ecoregion and for planning conservation priorities and strategies.

The necessity of taxonomically verified databases for research and conservation purposes has recently been discussed based on a new species list for the Amazon, for which previous lists built without proper verification of species taxonomy had given inflated numbers (Cardoso *et al.*, 2017). For the RPG ecoregion as a whole, much less previously published information is available; numbers on species richness are mostly estimates and only cover a specific region. Here, we present an updated, taxonomically verified checklist of vascular plant species recorded in the RPG, with additional information of species distribution in each of the three countries that make part of the region. We concisely describe the database that is available as supplementary material (see Supporting Information, Appendices S1 and S2) and suggest potential uses for the information it contains.

MATERIAL AND METHODS

We built a working list of vascular species of the RPG by compiling accurate data from four species lists: (1) *The catalogue of vascular plants of the Southern Cone* (Zuloaga *et al.*, 2015); (2) *List of angiosperm grassland species of Rio Grande do Sul* (Boldrini II, Schneider AA, Trevisan R, Setubal RB, Andrade BO, unpubl. data); (3) *Brazilian Flora 2020* (http://floradobrasil.jbrj.gov.br/) and (4) *List of vascular plant species of Uruguay* (Marchesi E, unpubl. data). All taxa were carefully revised regarding taxonomic nomenclature and distribution. Synonyms used in the literature were cross-checked one by one in online databases, such as TROPICOS (http://www.tropicos.org), the World Checklist of Selected Plant Families (WCSP, http://wcsp.science.kew.org) and Brazilian Flora 2020 (http://floradobrasil.jbrj.gov.br/) and by consulting taxonomic literature and monographs (see Supporting Information, Appendix S3). In cases where we found divergences among databases concerning author names, we opted to follow the International Plant Name Index (IPNI [IK]; www.ipni.org). Species distribution data was confirmed or obtained consulting the Global Biodiversity Information Facility database (GBIF, http://www.gbif.org) and SpeciesLink network (http://www.splink.org.br/index). Selected taxonomic groups were additionally revised by taxonomists specialized in the group in question (see Acknowledgements). The use of a large body of scientific literature and, whenever necessary, consultation of specialists is important as online databases such as GBIF may contain information that has not been properly verified (Goodwin *et al.*, 2015). Family names follow APG IV (APG IV, 2016) and PPG I (PPG I, 2016). We divide our list into the following taxa: ferns, lycopods, gymnosperms, monocotyledons (monocots), Nymphaeales, magnoliids and eudicotyledons (eudicots). For each species, we compiled information on the distribution pattern (endemic to the RPG or not), origin (native, non-native) and distribution by country (Argentina, Brazil and Uruguay), based on the lists and data sources mentioned above. Cultivated species were not included, unless occurring spontaneously. Due to the considerable latitudinal extension of the Argentinean part of the RPG, the occurrence record not only indicates the three countries Brazil, Uruguay and Argentina, but also Argentinean provinces. For this, only provinces found within the RPG were considered (no information of species occurrence in other provinces, when species were not endemic to the RPG; see below).

We considered as endemic species those that are restricted to the RPG ecoregion as an ecological unit, irrespective of political boundaries (see Ferreira & Boldrini, 2011). To confirm a species as endemic, species occurrence data were obtained from herbarium records found in online databases (i.e. GBIF and SpeciesLink network), papers presenting occurrences data and taxonomic monographs, whenever available. Some species were classified as probably endemic because of the absence of information of the exact locality (i.e. municipality occurrence or georeferenced point) in herbarium specimens. An example is *Microstachys stipulacea* (Müll.Arg.) Esser & M.J.Silva, which had last been collected in the 19th century by the German naturalist F. Sellow. Although the specimen label did not give clear information, the trajectory of the naturalist at the time can be traced based on historical

records, allowing us to determine that the specimen was collected between Alegrete (Brazil) and Uruguay (Silva & Esser, 2011). It thus can be considered an endemic species.

RESULTS

The checklist contains 4864 accepted species names (or 4836 species following WCSP recommendations) belonging to 194 families and 1324 genera (Table 1). Asteraceae, Poaceae and Fabaceae are the families with the largest number of species (659, 645 and 399, respectively), followed by Cyperaceae (184), Orchidaceae (149), Malvaceae (147), Euphorbiaceae (146), Solanaceae (140), Verbenaceae (94) and Rubiaceae (91). These ten families represent 54.5% of the entire diversity of the ecoregion. The ten richest genera were *Baccharis* L. (86 species), *Mimosa* L. (65), *Paspalum* L. (65), *Solanum* L. (61), *Croton* L. (43), *Senecio* L. (39), *Cyperus* L. (37), *Euphorbia* L. (35), *Nassella* (Trin.) Desv. (35) and *Eleocharis* R.Br. (34) that together accounted for 10% of all recorded species. Almost half (48.6%) of the genera in the RPG ecoregion genera have only one species.

The Argentine part of the RPG ecoregion harbours the highest plant species richness (3833), followed by Brazil (3530) and Uruguay (2756) (Fig. 2). This means that the Brazilian part holds more than twice as many species per unit area as the Argentinian part (0.020 species/km^2 in Brazil, 0.017 species/km^2 in Uruguay and 0.009 species/km^2 in Argentina). Of the entire RPG flora, 403 species (8%) are endemics and 496 are non-native (10%). Even though 1931 species are shared by the three countries, a noteworthy number of species is restricted to only one: 750 species only found in Argentina, 664 only in Brazil, and 126 only in Uruguay. The number of endemic species decreased towards the south (Brazil: 278, Uruguay: 218, Argentina: 118 endemic species), whereas non-native species showed an opposite pattern (Argentina: 454, Uruguay: 325, Brazil: 225 non-native species). Of the species restricted to Brazil, 136 are endemics of the RPG and 119 of those restricted to Argentina are non-natives.

DISCUSSION

Here we have compiled the so far most comprehensive taxonomically verified checklist of plant species in the Río de la Plata ecoregion. The importance of this kind of list has recently been pointed out by Cardoso *et al.* (2017) for the Amazon region, and this also applies to our region. Before our study, any estimation of plant species richness for the entire RPG ecoregion was impossible, mainly because previous aggregated lists were largely assembled with focus on regional delimitations (e.g. Perelman *et al.*, 2001; Sobral *et al.*, 2006; Lezama *et al.*, 2006; Setubal *et al.*, 2011), and no overall numbers were available. The lower species richness per unit area in Argentina is probably a consequence of increasing latitude and the lower environmental heterogeneity in terms of geology and topography; possibly, high land use change in this part of the RPG region has an additional effect (Paruelo *et al.*, 2007). The total number (4864) of vascular plant species across a total extent of 750 000 km^2 clearly establishes the RPG ecoregion as a highly biodiverse region in South America. Average species number per unit area is higher than for the Southern Cone of South America region (Argentina, Chile, Paraguay, southern Brazil and Uruguay) as a whole (18 139 vascular plant species in 4 708 617 km^2, Zuloaga *et al.*, 2015) and almost equal to that registered for the Brazilian Cerrado (12 356 vascular plant species in 2 000 000 km^2, Mendonça *et al.*, 1998), the largest continuous tropical grassland and savanna region in

Table 1. Synopsis of plant taxa in the Río de la Plata grasslands

Taxa	Families	Genera	Native species (endemics)	Non-native species	Total, including non-native species
Lycopods	3	7	16 (1)	0	**16**
Ferns	26	82	172 (1)	10	**182**
Gymnosperms	3	3	5 (0)	0	**5**
Monocotyledons	30	317	1250 (158)	124	**1374**
Nymphaeales (angiosperm early diverging order)	2	3	5 (0)	0	**5**
Magnoliids (angiosperm early diverging group)	6	15	73 (1)	0	**73**
Eudicotyledons	124	897	2847 (242)	362	**3209**
Total	**194**	**1324**	**4368 (403)**	**496**	**4864**

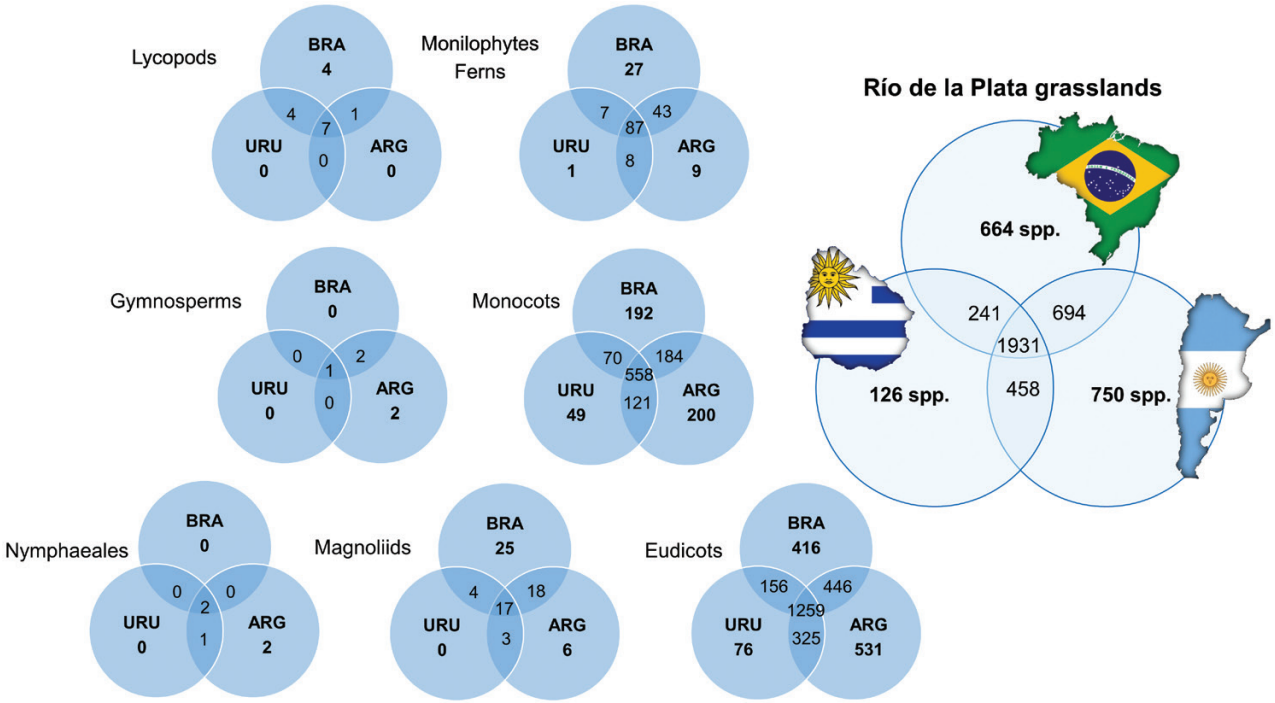

Figure 2. Venn diagrams showing shared species among Brazil (BRA), Uruguay (URU) and Argentina (ARG) in Río de la Plata grasslands for different taxa groups, and a synthesis for all species.

the Americas. This high species richness found in RPG is probably due to its location in a biogeographical overlap zone (i.e. subtropical to temperate transition zone) (Burke *et al.*, 1998). A gradient of reduction in soil water availability can be verified towards the south, varying from an incipient water excess in its subtropical part to an incipient soil water deficit in the temperate part (Soriano, 1992). The high geological diversity of the ecoregion (Soriano, 1992) affects primarily nutrient availability, soil water drainage and the terrain stability over time. Differences in geology, including geological age and substrate, may enhance regional diversity by forming distinct landscapes with great differences in species richness, as postulated by Hopper (2009). However, formal analyses of the influence of these factors based on quantitative data are still missing for the region as a whole.

The transitional situation also makes the ecoregion prone to hold a considerable number of non-native species, as more temperate species occur in the south, and somewhat more tropical species in the north. Previous studies have explored the drivers that make the ecoregion diverse in non-native species (Perelman *et al.*, 2007), but until our study, the total number of non-native species and their distribution in the three countries that compose the RPG were unknown. Man is an important agent of biodiversity change in the RPG ecoregion, increasing plant species richness by management or introduction of exotic species, but often reducing it, e.g. by land use change, habitat fragmentation (Staude *et al.*, 2018) and resulting degradation (Andrade *et al.*, 2015).

One of the targets of the *Global Strategy for Plant Conservation* (GSPC) is to have information on the entire flora of the globe for 2020. For conservation planning in specific regions, regionalized data needs to be available and this should be based not only on political, but also on ecological units (Ferreira & Boldrini, 2011). For the Río de la Plata grasslands, previously neglected in conservation (Overbeck *et al.*, 2007), a considerable amount of floristic knowledge was gathered in the last decades. However, studies are scattered and no efforts to integrate data from the entire ecoregion has been conducted so far. The present checklist provides information on overall plant species richness for the ecoregion and is a source for both scientific and conservation work. For ecological studies, our list constitutes a baseline information for plant identification. The list also opens possibilities for deeper understanding the evolutionary dynamics and ecology of RPG ecoregion, especially if linked with traits, phylogenetic diversity and ecological datasets. Additionally, the list will be useful for national or regional flora initiatives. The Brazilian Flora 2020, still under construction, for example, is a national initiative to reach the goal of the GSPC. By the time we finished our data compilation, we found that only 47% of Brazilian taxa compiled by us has been cited

in the Brazilian Flora 2020 for this region (Brazilian Pampa biome, regional name for the Brazilian part of the RPG). This highlights the gaps in biodiversity knowledge for the region, which impacts conservation policies (Overbeck *et al.*, 2015). It is our hope that the list presented here will be helpful for continuing work on the Brazilian Flora 2020 and similar initiatives in the other countries.

Our list represents a first step towards enhanced understanding of the biogeography and ecology in the RPG biome. From a conservation perspective, we hope it will be the basis for a better understanding of how human activities affect local biodiversity patterns and for definition of conservation actions and responsibilities. Even with the rather broad division of the RPG into countries and provinces that we adopted here in this first version of the list, it becomes evident that the environmental gradient from north to south is accompanied by clear patterns in the regional flora, such as the decrease of endemic plant species on the one hand and the increase of non-native plant species on the other. When linking the current dataset with more detailed species occurrence and phylogenetic data, we will be able to better understand the evolutionary and ecological mechanisms driving current plant distribution.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

S1 List of vascular plant species of the Río de la Plata grasslands.
S2 Metadata for the List of vascular plant species of the Río de la Plata grasslands.
S3 Reference lists from relevant taxonomic literature and monographies consulted for the present study.