



Areas of vascular plants endemism in the Monte desert (Argentina)

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Abstract

In order to identify concordant distributions of endemic vascular plants in the Monte desert, we analyzed the distributional data of 180 species endemic to the Monte desert with the optimality criterion implemented in the program VNDM. We detected 13 partially overlapping areas of vascular plant endemism. The main areas of endemism are distributed from north to south associated with the mountainous region of the Precordillera of the Andes towards the west of the study region. These main areas correspond to environments with important variation in elevation and aridity, whereas minor areas correspond to patches of the steppe vegetation towards the east of the study region. We also obtained extensive areas covering much of the Monte desert, coincident with the two classical biogeographic units proposed. In agreement with the general arid climate of the Monte, most of the endemic flora inhabits arid and/or semiarid environments.

Key words: areas of endemism, biogeography, flora, Southern Cone

Introduction

The Argentinean Monte desert, the southernmost part of the South American transition zone, separates the Neotropical Chacoan subregion from the Patagonia province of the Andean region from approx. 24°S to 44°S (Morrone 2006, 2014, 2015). The Monte desert is exclusively found in Argentina and is considered the most arid rangeland of this country (Fernández & Busso 1997). Mean annual rainfall varies between <100 and 450 mm and is strongly conditioned by the surrounding relief (Abraham *et al.* 2009). In the northern part of the Monte, precipitation mainly falls during the southern hemisphere summer, when the South American Monsoon System brings moist air to the region (Zhou & Lau 1998), while winter and spring rainfall become more abundant towards the south (Cabrera 1976, Martínez Carretero 2013). Attitudinally, the Monte ranges from sea-level to approx. 3000 m, depending on latitude (Morello 1958). Despite this elevation difference and a north south extension of approx. 2000 km, temperature changes are not significant within the Monte (Morello 1958). The average annual temperature varies approximately 4°C from north to south (Cabrera 1976). Based on geomorphologic characteristics the Monte has been divided into the High and Low Monte (Olson *et al.* 2001) (Fig. 1A). The High Monte is characterized by mountain and bolson landforms which are generally found in the northern part, while the Low Monte is characterized by piedmonts, hills, plains, and desert valleys (Roig 1981).

The Monte vegetation mainly consists of xeric scrubland dominated by species belonging to the family Zygophyllaceae (Cabrera 1976), and it has been recognized as a biogeographic unit since the late 19th century (Morrone 2014). The Monte is currently considered a biogeographic province (Morello 1958, Cabrera 1976, Morrone 2006, 2014) or ecoregion in Fig. 1A (Burkart *et al.* 1999, Olson *et al.* 2001) whose boundaries have been discussed in several publications (Morello 1958, Roig 1980, Roig-Juñent *et al.* 2001). None of the endemic plant taxa has a distribution range that is strictly coincident with the Monte area and the limits are currently set by the combined distribution of several species as well as by floristic characteristics (Roig *et al.* 2009). However, *Monttea aphylla* (Miers) Benth. & Hook. (Plantaginaceae), used by Morello (1958) to determine the boundary between the biogeographic provinces Monte and Espinal (Roig *et al.* 2009), is endemic to the Monte and considered one of the species whose distribution most closely coincides with the proposed boundaries (Martínez Carretero 1986, Roig *et al.* 2009, Martínez Carretero 2015).

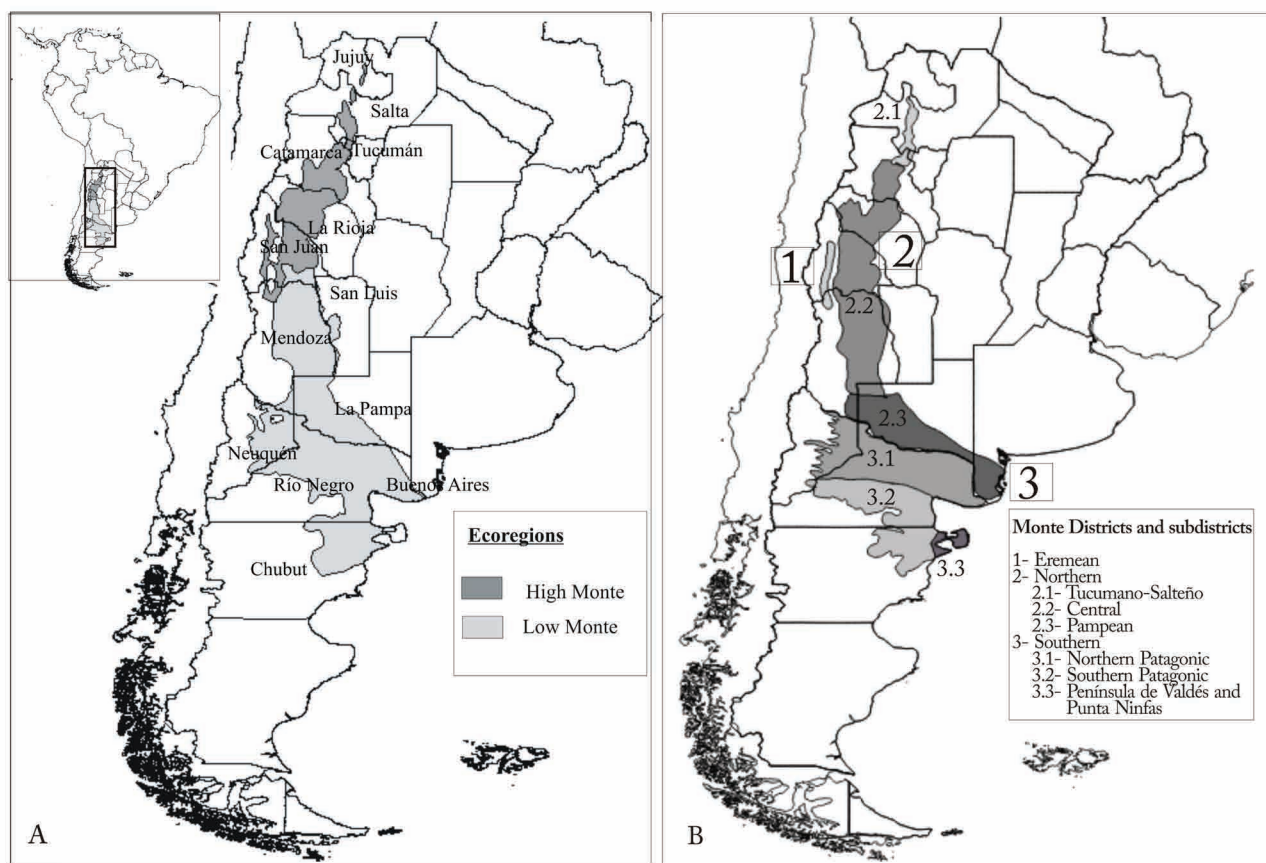


FIGURE 1. Study region: A. Classic biogeographic scheme based on Olson *et al.* (2001), B. regionalization of the Monte proposed by Roig *et al.* (2009), redrawn from Journal of Arid Environments 73 (2): 164–172.

Roig-Juñent *et al.* (2001) analyzed the boundaries of the Monte, and tested whether the Monte Desert constitutes a natural area by comparing insect species diversity and endemism between the Monte and the neighboring biogeographic unit the Chaco. When comparing insect biodiversity between the Chaco and the Monte, they found that the species richness is higher in the Chaco and the Monte includes a higher proportion of endemic taxa. The authors found that several species show a range of distribution more or less coincident with the limited of the Monte, as definite by its vegetation. However, as is in the case of vascular plants, the zoological records do not define the boundaries exactly. Based on distributional analyzes of four families of Coleoptera, the authors detected several endemic assemblages of species within the Monte that allowed subdividing the Monte Desert into five natural areas. These areas, which are distributed latitudinally from the north to the south, are: Northern, Central, Calingasta-Upspallata, Southern, and Península de Valdés.

Later, Roig *et al.* (2009) made a brief description of the proposed boundaries of the Monte, the natural areas within the Monte as defined by Roig-Juñent *et al.* (2001), and the relationship of the Monte to other biogeographic units of America. Based on distributional data of characteristic, typical, differential and/or endemic species, principally vascular plants, the authors divided the Monte Desert into three botanical districts (Fig. 1B) supporting the previous proposal: Northern, further subdivided in three sub-districts, containing the Northern area of Roig-Juñent *et al.* (2001) and parts of the Central and Southern areas of these author; Eremean, similar to the Uspallata-Calingasta area proposed by Roig-Juñent *et al.* (2001) and characterized by Le Houérou *et al.* (2006); and the Southern districts, further subdivided in three sub-districts, containing the Península de Valdés area and a part of the Southern area of Roig-Juñent *et al.* (2001); however, none of these analyses were based on quantitative methods.

At present, the Monte is experiencing seriously damaging effects due to overgrazing, mining, and oil exploration (Ojeda *et al.* 1998). There are few protected areas in the region, and those that do exist are mainly concentrated in the High Monte. The protected areas sum 588.112 ha representing 1.21 % of the Monte (Roig-Juñent & Claver 1999). However, conservation of the endemic flora is complicated by the fact that, despite the existence of several studies discussing the boundaries of and regionalization within the Monte, there are no quantitative analysis available for the endemic flora. Little is known about the number and distribution of vascular plant species endemic to the Monte desert.

Here we apply quantitative methods to analyse the spatial distribution of the endemic vascular flora of the Monte. We aim to identify the main areas of endemism within the region and compare the current regionalization of the Monte province with the distribution of the endemic flora.

Materials & Methods

Study Region

The study region comprises the biogeographical provinces of the Monte which traverses 13 Argentinean provinces (Fig. 1A). Attitudinally, the boundaries of the Monte are relatively sharp as they are determined by the Andean and pre-Andean mountains, where soil cryoturbation processes begin (Roig *et al.* 1980, Abraham *et al.* 2009). In western Mendoza this phenomenon occurs between 1500–1700 m, further north the boundary ascends, reaching 2800–3000 m in the province of La Rioja (Abraham *et al.* 2009), while from La Rioja towards the north, the boundary lies invariable above 3000 m (Morello 1958).

Data Set

According to the catalogue of the Southern Cone Flora (Zuloaga *et al.* 2008) 841 species of vascular plant are strictly endemic to one or more of the 12 Argentinean provinces that include Monte vegetation (excluding the Buenos Aires province). In the present analysis, we did not analyze species endemic to the northern part of the study region (north of ~32.5°S) as the distribution of these species were analyzed and discussed by Aagesen *et al.* (2012). Here we concentrate on distribution patterns found south of 32°S and only include species found north of this limit if their distribution patterns continue further south in to the regions which is the topic of the present analyses. We also excluded species whose elevation ranges fell exclusively above 2500 m, hence species endemic to high Andean environments with no presence in the Monte. Species that were only known from localities that could not be georeferenced were also excluded.

In the present study we analyze the distribution of 180 species that were compiled and georeferenced according to the point-radius method (Wieczorek *et al.* 2004). Species distributions were compiled from collections deposited in the herbaria BA, BAA, BAB, CORD, CTES, LIL, LP, LPS, MERL, and SI abbreviated according to Thiers (2015). To facilitate the process of georeferencing the data set, vouchers with elevation noted by the collector were preferred. If the herbarium vouchers were not sufficient to cover the distributions published in Southern Cone Flora (Zuloaga *et al.* 2008) we added published exsiccatae from the original descriptions. We considered a species sufficiently sampled when the distribution data reflected the distribution published in the catalogue of the Southern Cone Flora (Zuloaga *et al.* 2008).

Distribution analysis

We searched for areas of endemism using the program VNDM (Goloboff 2005), available at <http://www.zmuc.dk/public/phylogeny>. VNDM is a grid based method that identifies an area of endemism as the congruent distributions of two or more species (Szumik *et al.* 2002, Szumik & Goloboff 2004). The method implements an optimality criterion that explicitly considers the spatial location of the species in the study region. The study region is divided into cells and each of the species distributions are coded present/absent in each cell. Candidate areas of endemism are identified through an index of endemicity: all possible combinations of cells (=candidate areas) are evaluated on how well the species distributions fit the area, using a score between 0 and 1 for each species. The species score depends on the fit of the individual species to the given combination of cells (for details see Szumik *et al.* 2002, Szumik & Goloboff 2004). This optimality criterion penalizes both absence in part of the area as well as presence in adjacent cells outside the area (if species is present outside the area in non-adjacent cell it is not considered among the species supporting the area). The endemicity score of a given candidate area is the sum of the individual species scores, and depends therefore both on the number of species supporting the candidate area as well as the distribution of the supporting species within an around the area (Szumik *et al.* 2002, Szumik & Goloboff 2004). One of the advantages of VNDM is its ability to recognize overlapping distribution patterns if these are defined by different species groups. Overlapping patterns may be independent if defined by different sets of species, and are to be expected when distribution analyses are based on grids when more than a single environment is found in the same cell (Aagesen *et al.* 2009).

Grid and cell size

As discussed by Linder (2001), among other authors, the choice of grid size is important. The use of small cells would result in a finer and more detailed resolution. However, available species distribution data are usually incomplete; hence the number of artificially empty cells increases with decreasing grid size. This reduces the number of sympatric species, which also reduces the probability of detecting areas of endemism. Here we use three different cell sizes to explore both distribution patterns at different scales as well as the robustness of the resulting areas to changes in grid size. Grids with cell sizes $0.5 \times 0.5^\circ$, $1.0 \times 1.0^\circ$, and $2.0 \times 2.0^\circ$ were used where 1.0° is approximately equal to 100 km (Table 1). The use of several grid sizes increases the chance of finding different areas given the topographical complexity of the study area; moreover, using several grid sizes provides a sensitivity analyses for a particular area of endemism: those areas which survive changes in grid size can be considered more strongly and clearly supported by the data (Aagesen *et al.* 2009, 2012, Szumik *et al.* 2012).

Radius size

To minimize the number of artificially empty cells, VNDM allows establishing different filling values that assumes the presence of a given species in an empty cell, if this species is present in a neighbor cell. Using the option 'radius size' (ranging from 0–100% of the cell size) the user defines how far from the border of a given cell VNDM searches for observed points within the neighbor cells (for details see Aagesen *et al.* 2009). We used four different radius sizes: 5%, 10%, 50%, and 100% (Table 1). We used the small radius sizes ($5 \times 10\%$) to explore distribution patterns, considering a radius size that reflects the approximately mean error of the georeferenced records (~ 4 km, see Aagesen *et al.* 2009). The large radius size ($50 \times 100\%$) were either used when analyzing the small grid (where the problem of artificial empty cells is largest) or to search for geographically broad distribution patterns that are especially hard to detect due to the problem of incomplete distribution records (Table 1).

Search procedure

The searches were done using default settings with the following changes: swap two cells at a time; discard superfluous sets as they are found; replace a set if improved during swapping; pre-check duplicates; keep overlapping subsets if 20% of the species are unique. Searches were done by changing the seed for each search, without replacing existing sets, and deleting duplicate sets after each replicate. This search sequence was repeated until the obtained numbers of sets were stable.

Consensus rules

Due to ambiguous or contradicting patterns, endemicity analyses based on an optimality criterion may result in large numbers of candidate areas that differ only slightly in species composition, therefore some kind of consensus techniques is required to summarize the results (Aagesen *et al.* 2013). Two possible algorithms or rules for constructing consensus areas are available in VNDM: a tight and a loose consensus rule (Aagesen *et al.* 2013). Here we explored consensus areas using the loose consensus rule that merge a candidate area in the consensus set if it shares the selected user defined percentages of defining species with at least one other set in the consensus (see Aagesen *et al.* 2013 for details).

Elevation and aridity

To explore elevation and aridity within the obtained areas of endemism we extracted these variables from all georeferenced localities using the program QGIS (Quantum GIS Geographic Information System. Open Source Geospatial Foundation Project. <http://qgis.osgeo.org>). Elevation were obtained from BioClim at a spatial resolution of 2.5 arc-minutes while data of aridity were obtained from CGIAR-CSI (<http://www.cgiar-csi.org>). We used the following aridity values: $AI < 0.03$ Hyper Arid, $0.03 - 0.2$ Arid, $0.2 - 0.5$ Semi-arid, $0.5 - 0.65$ Dry sub-humid, > 0.65 Humid (Trabucco & Zomer 2009).

Results

The results are summarized in Table 1–3. In general, the number of area sets was highest for the intermediate cell size, but both cell size $1 \times 1^\circ$ and $2 \times 2^\circ$ produced overlapping distribution patterns that grouped into a single consensus area under the loose consensus rule and low cut values (Fig. 2A, Table 1). Here we explore the consensus areas by applying different percentages (consensus criterions) to combine the candidate areas as in Aagesen *et al.* (2013).

TABLE 1. Number of consensus areas obtained under different grid sizes, radius fill options, and consensus criterion. For each analyses number of obtained subsets and defining species (in parenthesis) are shown.

Consensus	0.5×0.5°		1×1°	
	50×100%	10×10%	100×100%	5×5%
	10 (24)	231 (84)	230 (140)	155 (123)
70%	17	118	59	74
65%	17	91	45	60
60%	16	20	33	37
55%	14	20	28	32
50%	11	15	16	21
45%	11	13	14	19
40%	11	2	12	18
30%	9	2	8	4
10%	8	1	4	1
5%	8	1	2	1

Of the three cells sizes used to analyze the area, we base our discussion on the results from analyzing cells of 1×1° (with a 10% radius) where most cells of the study region are assigned to one or more areas of endemism (Fig. 2B–I, Table 3). The different fill radius (100%) applied when analyzing the 1×1° grid produced similar results except that the bigger radius size yielded three new areas of endemism that correspond to patches of the steppe vegetation within the Monte (Fig. 2J–L, Table 3). When analyzing the 2×2° grid (with a 5% radius) we obtained extensive areas covering much of the Monte province (Table 3). The analysis using the biggest cells is only used to discuss distribution patterns that were not obtained under the 1×1° grid, and a fill option of 10%. When using the 0.5×0.5° grid size (with a radius 50×100%) we found seven areas that correspond to those obtained in the analysis using 1×1° cells (with a radius 10×10%), see Table 3. When these areas are recovered with the small grid size, they are, in general, smaller and supported by fewer species.

A total of 116 species supported some areas under at least one grid size, while 64 species did not support any area. Among the 116 species that did support areas, 31 are only known from a single or two localities, whereas the remaining species are distributed more widely within the region (Table 2).

When using a grid size of 1×1° and a 10% fill radius, the loose consensus rule produced a single main consensus area under consensus criteria between 5% and 25% (Table 1, Fig. 2A). In order to explore sub-areas of the general consensus area, this was decomposed by gradually increasing the consensus criterion (see Aagesen *et al.* 2012). We decomposed the areas both to extract the individual high endemic areas as well as to assign all endemic species to sub-areas with a closer association between area extension and distributions of the defining species. By this procedure several sub-areas, formed by fewer species, separate successively from the main consensus pattern (Table 1). Of these, seven areas are discussed below, while the remaining areas, defined by few species and low endemic score, were considered artifacts. Further increase in the consensus criterion caused a high number of small overlapping areas (Table 1).

When increasing the radius size to 100%, we obtained results combinable with those mentioned above, but in addition three new areas emerged in the south and/or eastern part of the lower Monte. These areas did not form part of the main consensus mentioned above even when using a consensus criterion of 10%. The three areas are La Pampa, Patagonian Monte, and Somuncurá/Golfo San Jorge (Table 3, Fig. 2J–L).

When analyzing the 2×2° grid with a 5% radius we obtained two extensive areas (Fig. 2M and 2N) that covered most of the studied area with an extension similar to the Monte province (*sensu* Cabrera 1976) and the Low Monte ecoregion (*sensu* Olson *et al.* 2001). One of these areas separated from the main consensus using a 40% criterion, while the second area separated from the main consensus using a 45% criterion (Table 3)

Of the 64 species that did not support any of the areas, 53 were assigned to one of the 13 obtained areas, according to their distribution. The remaining 11 species could not be assigned to any of the areas (Table 2).

Elevation and aridity. Our results indicate that the endemic species are distributed in elevations ranging from sea level to approx. 3500 m; although, nearly 90% of the endemics have been collect in elevations that do not exceed 3000 m (Table 2) a pattern that is consistent with the notion that the Monte *sensu* Morello (1958) extends up to 3000–3500

m in some regions such as within the High Monte (sensu Olson *et al.* 2001) or in the Prepuna sensu Cabrera (1976). Also in agreement with the general arid climate of the Monte, the arid environments appear as the principal habitat type for the endemic species. Nearly 83% of the endemic flora inhabits arid and/or semiarid environments (Table 2).

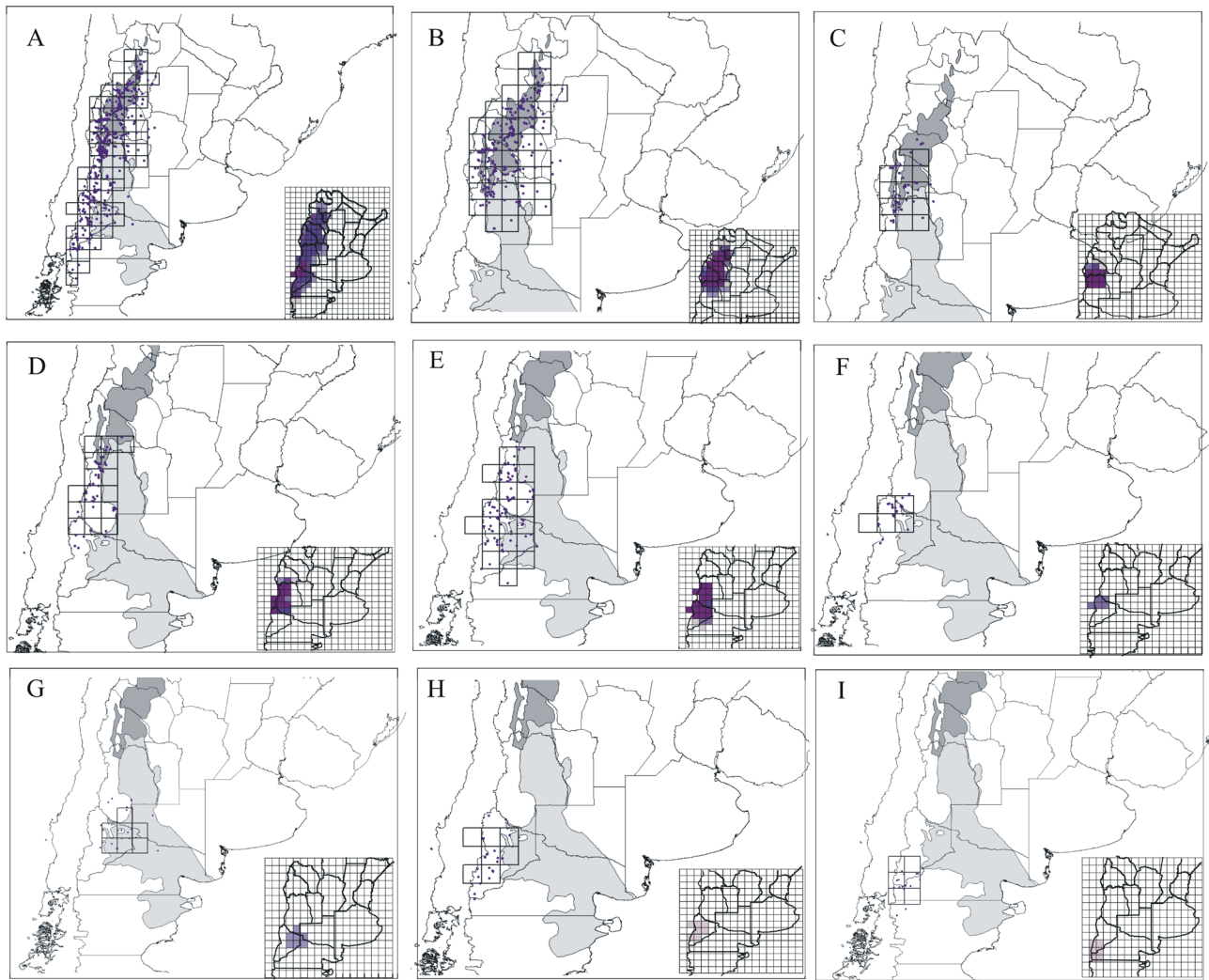


FIGURE 2. Areas of endemism obtained in the present study. The larger scale figures show size and position of the grid and the distribution records of the species that define each area. The small scale figures show the endemism score of cells in each area. The colour scale represents cells of higher (darker) versus lower (lighter) endemism score within the area. For max and min score within the individual areas see Table 3. A. main consensus, B. NOA, C. San Juan, D. Mendoza, E. Payunia, F. Northern Payunia, G. Eastern Neuquén, H. Neuquén, and I. Southeastern Neuquén.

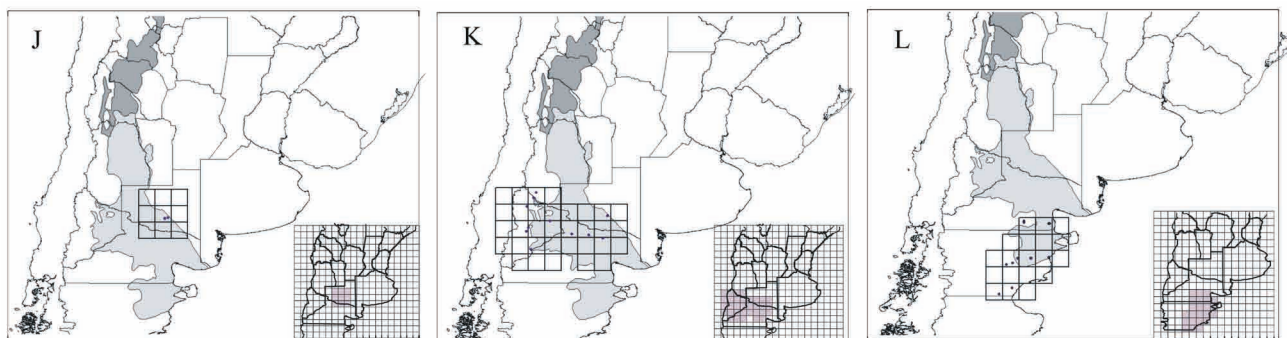


FIGURE 2. Continued. J. La Pampa, K. Patagonian Monte, and L. Somuncurá/Golfo San Jorge.

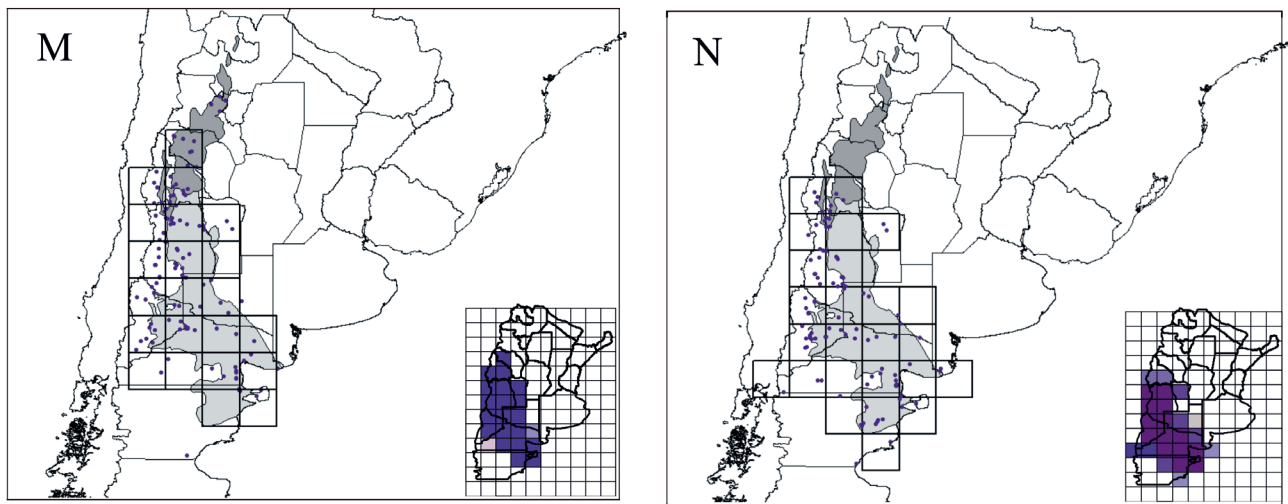


FIGURE 2. Continued. M. Monte, and N. Low Monte.

TABLE 2. List of endemic species included in the analysis, following the catalogue of the Southern Cone Flora (Zuloaga *et al.* 2008). Each species is assigned to the area of endemism in which it obtained the best endemism score. Elevational and aridity ranges are obtained from the georeferenced locations and therefore suggestive. Aridity values: AI<0.03 Hyper arid, 0.03–0.2 Arid, 0.2–0.5 Semi-arid, 0.5–0.65 Dry sub-humid, >0.65 Humid

Family/species	Record number	Cell size / Radius				Elevational range (m)	Aridity range	Area
		0.5×0.5°		1.0×1.0°				
		50×100%	10×10%	100×100%	5×5%			
Euphorbiaceae								
<i>Ditaxis malpighipilus</i> (Hicken) L.G.Wheeler	2		x			500–1800	0.13–0.13	Monte
Plantaginaceae								
<i>Monttea aphylla</i> (Miers) Benth. & Hook. f.	34				x	30–3400	0.09–0.40	Monte
Solanaceae								
<i>Jaborosa leucotricha</i> (Speg.) Hunz.	27				x	100–3000	0.85–0.34	Monte
Verbenaceae								
<i>Glandularia flava</i> (Gillies ex Hook.) Schnack & Covas	31				x	0–2700	0.07–0.58	Monte
<i>Glandularia mendocina</i> (Phil.) Covas & Schnack	12					300–3000	0.15–0.40	Monte
Acanthaceae								
<i>Justicia lilloana</i> Ariza	6		x			1200–2000	0.09–0.17	NOA
Amaranthaceae								
<i>Amaranthus persimilis</i> Hunz.	5		x			500–1700	0.10–0.22	NOA
Apiaceae								
<i>Asteriscium famatinense</i> Hieron. & H. Wolff	7		x			2000–2500	0.08–0.15	NOA
<i>Asteriscium glaucum</i> Hieron. & H. Wolff	13					600–3100	0.11–0.25	NOA
Asteraceae								
<i>Aphyllocladus san-martinianus</i> Molfino	6		x			1400–3100	0.07–0.24	NOA

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TABLE 2. (Continued)

Family/species	Record number	Cell size / Radius				Elevational range (m)	Aridity range	Area		
		0.5×0.5°		1.0×1.0°					2.0×2.0°	
		50×100%	10×10%	100×100%	5×5%					
<i>Artemisia echegarayi</i> Hieron.	10		x			1100–3100	0.10–0.33	NOA		
<i>Baccharis retamoides</i> Phil.	17		x			600–3100	0.06–0.19	NOA		
<i>Hysterionica cabrerai</i> Ariza	7		x			1700–3500	0.09–0.28	NOA		
<i>Senecio hualtaranensis</i> Petenatti, Ariza & Del Vitto	2					700–1800	0.14–0.25	NOA		
<i>Senecio toroanus</i> Cabrera	10		x			900–2700	0.05–0.20	NOA		
Bromeliaceae										
<i>Tillandsia angulosa</i> Mez	5			x		1000–1500	0.08–0.16	NOA		
Cactaceae										
<i>Denmoza rhodacantha</i> (Salm-Dyck) Britton & Rose	4		x			2000–2900	0.10–0.13	NOA		
<i>Pterocactus reticulatus</i> R. Kiesling	3		x			1600–2700	0.10–0.20	NOA		
<i>Pterocactus tuberosus</i> (Pfeiff.) Britton & Rose	4			x		400–2300	0.14–0.21	NOA		
<i>Tephrocactus aoracanthus</i> Lem.	6		x			800–1900	0.07–0.16	NOA		
<i>Trichocereus strigosus</i> (Salm-Dyck) Britton & Rose	9		x			300–2100	0.08–0.25	NOA		
<i>Tunilla corrugata</i> (Salm-Dyck) D.R. Hunt & Iliff	3		x			2000–3100	0.14–0.16	NOA		
Calyceraceae										
<i>Calycera calcitrapa</i> Griseb.	16		x			600–2400	0.07–0.17	NOA		
Chenopodiaceae										
<i>Atriplex lithophila</i> A. Soriano ex Múlgura	6		x			400–2100	0.06–0.25	NOA		
<i>Atriplex spgazzinii</i> A. Soriano ex Múlgura	15		x			400–2000	0.07–0.26	NOA		
Euphorbiaceae										
<i>Euphorbia catamarcensis</i> (Croizat) Subils	14		x			400–2200	0.09–0.29	NOA		
<i>Euphorbia ruiz-lealii</i> Subils	12		x			500–2100	0.07–0.22	NOA		
Fabaceae										
<i>Mimosa ephedroides</i> (Gillies ex Hook. & Arn.) Benth.	18		x			300–2500	0.07–0.20	NOA		
<i>Prosopis argentina</i> Burkart	10		x			600–1600	0.06–0.20	NOA		
<i>Prosopis torquata</i> (Cav. ex Lag.) DC.	20		x			400–3200	0.07–0.48	NOA		
Malvaceae										
<i>Sphaeralcea brevipes</i> (Phil.) Krapov.	24		x			400–2800	0.13–0.65	NOA		
Poaceae										
<i>Blepharidachne hitchcockii</i> Lahitte	12					400–3300	0.14–0.28	NOA		
<i>Munroa mendocina</i> Phil.	16		x			500–3400	0.08–0.23	NOA		
<i>Nassella carettei</i> (Hauman) Torres	6		x			1200–3000	0.10–0.44	NOA		

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TABLE 2. (Continued)

Family/species	Record number	Cell size / Radius				Elevational range (m)	Aridity range	Area		
		0.5×0.5°		1.0×1.0°					2.0×2.0°	
		50×100%	10×10%	100×100%	5×5%					
Polygalaceae										
<i>Bredemeyera colletioides</i> (Phil.) Chodat	8		x			1000–1600	0.07–0.14	NOA		
<i>Monnina lorenziana</i> Chodat	6		x			1000–2000	0.09–0.45	NOA		
Portulacaceae										
<i>Portulaca echinosperma</i> Hauman	8		x			400–1800	0.09–0.24	NOA		
Pteridaceae										
<i>Cheilanthes sarmientoi</i> Ponce	1					2000	0.09	NOA		
Solanaceae										
<i>Solanum kurtzianum</i> Bitter & Wittm.	18					800–3300	0.09–0.22	NOA		
Verbenaceae										
<i>Dipyrena glaberrima</i> (Gillies & Hook.) Hook.	6		x			900–2600	0.10–0.17	NOA		
Asteraceae										
<i>Brachyclados megalanthus</i> Speg.	12				x	0–500	0.10–0.80	Low Monte		
<i>Chuquiraga rosulata</i> Gaspar	17				x	200–2800	0.11–0.53	Low Monte		
<i>Conyza magnimontana</i> Cabrera	3				x	300	0.18	Low Monte		
<i>Gutierrezia solbrigii</i> Cabrera	19				x	0–2500	0.12–0.95	Low Monte		
<i>Senecio melanopotamicus</i> Cabrera	7				x	0–2300	0.14–0.41	Low Monte		
Fabaceae										
<i>Anarthrophyllum ornithopodum</i> Sandwith	3				x	0–1000	0.16	Low Monte		
<i>Anarthrophyllum pedicellatum</i> Sorarú	4				x	100–3200	0.17–0.34	Low Monte		
Poaceae										
<i>Jarava hypsophila</i> (Speg.) Peñail.	12				x	300–2100	0.16–0.44	Low Monte		
<i>Pappostipa semperiana</i> (F.A. Roig) Romasch.	6				x	300–3200	0.15–0.55	Low Monte		
<i>Pappostipa vatroensis</i> (F.A. Roig) Romasch.	5					0–1100	0.10–0.50	Low Monte		
Solanaceae										
<i>Nicotiana spgazzinii</i> Millán	14				x	100–3200	0.07–0.42	Low Monte		
<i>Pantacantha ameghinoi</i> Speg.	11				x	100–2700	0.16–0.63	Low Monte		
Verbenaceae										
<i>Neosparton aphyllum</i> (Gillies & Hook.) Kuntze	20					400–2900	0.11–0.42	Low Monte		
Asteraceae										
<i>Baccharis thymifolia</i> Hook. & Arn.	1	x				2000	0.20	San Juan		
<i>Chiliophyllum densifolium</i> Phil.	3			x		1700–2900	0.29–0.42	San Juan		
<i>Hieracium mendocinum</i> Sleumer	4		x			1400–3100	0.21–0.44	San Juan		
<i>Senecio glandulosus</i> Don ex Hook. & Arn.	4		x			2200–2800	0.21–0.34	San Juan		
<i>Senecio ragonesei</i> Cabrera	3		x			1900–2800	0.17–0.23	San Juan		

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TABLE 2. (Continued)

Family/species	Record number	Cell size / Radius				Elevational range (m)	Aridity range	Area		
		0.5×0.5°		1.0×1.0°					2.0×2.0°	
		50×100%	10×10%	100×100%	5×5%					
Cactaceae										
<i>Puna clavarioides</i> (Pfeiff.) R. Kiesling	3		x			2400–2700	0.09–0.22	San Juan		
Chenopodiaceae										
<i>Atriplex mendocensis</i> Speg.	2		x			500–1700	0.14–0.17	San Juan		
<i>Chenopodium ruiz-lealii</i> Aellen	1	x				1900	0.13	San Juan		
Ephedraceae										
<i>Ephedra boelckeii</i> F.A. Roig	2		x			600–700	0.11–0.12	San Juan		
Fabaceae										
<i>Adesmia tunuianica</i> Burkart	1			x		2000	0.31	San Juan		
<i>Astragalus cuyanus</i> Gómez-Sosa	2		x			1100–2600	0.16–0.20	San Juan		
<i>Astragalus ruiz-lealii</i> I.M. Johnst.	1	x				1900	0.21	San Juan		
Sapindaceae										
<i>Guindilia dissecta</i> Hunz.	1	x				1900	0.14	San Juan		
Sclerophylacaceae										
<i>Sclerophylax cuyanus</i> Di Fulvio	5		x			600–800	0.06–0.10	San Juan		
Asteraceae										
<i>Gaillardia cabrerai</i> Covas	1			x		400	0.26	La Pampa		
<i>Grindelia covasii</i> A. Bartoli & Tortosa	1			x		300	0.26	La Pampa		
Fabaceae										
<i>Adesmia lihuelensis</i> Burkart	1			x		400	0.26	La Pampa		
Poaceae										
<i>Cynodon laeviglumis</i> Caro & E.A. Sánchez	1					300	0.38	La Pampa		
Asteraceae										
<i>Senecio canchahuinganquensis</i> Cabrera	4		x			200–1100	0.1–0.24	Eastern Neuquén		
Convolvulaceae										
<i>Cuscuta yunckeriana</i> Hunz.	1			x		300	0.13	Eastern Neuquén		
Fabaceae										
<i>Anarthrophyllum macrophyllum</i> Sorarú	4		x			300–1400	0.11–0.27	Eastern Neuquén		
<i>Astragalus mendocinus</i> Gómez-Sosa	1					1700	0.15	Eastern Neuquén		
Frankeniaceae										
<i>Frankenia fischeri</i> Hicken	2		x			500	0.12–0.13	Eastern Neuquén		
Asteraceae										
<i>Flourensia hirtissima</i> S.F. Blake	3			x		200–1400	0.13–0.27	Patagonian Monte		
<i>Senecio steparius</i> Cabrera	2					0–1000	0.17–0.20	Patagonian Monte		
Brassicaceae										
<i>Mostacillastrum subscandens</i> (Speg.) Al-Shehbaz	4					0–700	0.15–0.50	Patagonian Monte		

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TABLE 2. (Continued)

Family/species	Record number	Cell size / Radius			Elevational range (m)	Aridity range	Area	
		0.5×0.5°	1.0×1.0°					2.0×2.0°
		50×100%	10×10%	100×100%				5×5%
Cactaceae								
<i>Pterocactus valentinii</i> Speg.	3				0–1500	0.19	Patagonian Monte	
Calyceraceae								
<i>Calycera boopidea</i> Hicken	2				x 300–1000	0.12–0.42	Patagonian Monte	
Fabaceae								
<i>Adesmia leptobotrys</i> Burkart	4			x	200–1300	0.18–0.22	Patagonian Monte	
<i>Astragalus anni-novi</i> Burkart	3				500–1400	0.19–0.46	Patagonian Monte	
<i>Astragalus moyanoi</i> Speg.	6				200–1200	0.20–0.74	Patagonian Monte	
Poaceae								
<i>Melica patagonica</i> Parodi	7				x 600–2700	0.19–0.88	Patagonian Monte	
Tropaeolaceae								
<i>Tropaeolum trialatum</i> (Suess.) L. Andersson & S. Andersson	2				0–600	0.16	Patagonian Monte	
Asteraceae								
<i>Grindelia pygmaea</i> Cabrera	1			x	1400	0.19	Somuncurá/Golfo San Jorge	
<i>Nassauvia chubutensis</i> Speg.	1			x	100	0.16	Somuncurá/Golfo San Jorge	
<i>Senecio megaoreinus</i> Zardini	2				300–2100	0.18–0.33	Somuncurá/Golfo San Jorge	
Fabaceae								
<i>Adesmia salamancensis</i> Burkart	2			x	200–500	0.17–0.20	Somuncurá/Golfo San Jorge	
<i>Adesmia serrana</i> M.N. Correa	2			x	1700–3300	0.21–0.73	Somuncurá/Golfo San Jorge	
Malvaceae								
<i>Lecanophora ruiz-realii</i> Krapov.	1			x	1400	0.19	Somuncurá/Golfo San Jorge	
Verbenaceae								
<i>Mulguraea tetragonocalyx</i> (Tronc.) N. O’Leary & P. Peralta	6			x	200–700	0.16–0.18	Somuncurá/Golfo San Jorge	
Asteraceae								
<i>Hysterionica glaucifolia</i> Solbrig	4		x		1700–3300	0.21–0.73	Mendoza	
<i>Senecio adrianicus</i> Cabrera	4		x		2200–3200	0.23–0.72	Mendoza	
<i>Senecio hjertingii</i> Cabrera	1		x		700–1800	0.14–0.25	Mendoza	
<i>Senecio obesus</i> Klatt	3		x		700–1100	0.15–0.20	Mendoza	
Chenopodiaceae								
<i>Atriplex boecheri</i> Aellen	2		x		2200	0.16	Mendoza	
<i>Atriplex sorianoii</i> Múlgura	3		x		1000–1900	0.06–0.16	Mendoza	
Fabaceae								
<i>Adesmia grandiflora</i> Gillies ex Hook. & Arn.	7		x		900–1700	0.14–0.28	Mendoza	
<i>Adesmia mendozana</i> Ulibarri	6		x		1600–2900	0.22–0.72	Mendoza	
<i>Astragalus bonariensis</i> Gómez–Sosa	2		x		0–1500	0.11–0.17	Mendoza	
<i>Astragalus tehuelches</i> Speg.	4		x		1200–2000	0.16–0.35	Mendoza	

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TABLE 2. (Continued)

Family/species	Record number	Cell size / Radius				Elevational range (m)	Aridity range	Area		
		0.5×0.5°		1.0×1.0°					2.0×2.0°	
		50×100%	10×10%	100×100%	5×5%					
Iridaceae										
<i>Olsynium bodenbenderi</i> Goldblatt	3		x			2300–2800	0.39–0.69	Mendoza		
Loasaceae										
<i>Loasa incurva</i> Crespo & R.L. Pérez-Mor.	5		x			2500–3400	0.59–0.79	Mendoza		
Polygalaceae										
<i>Polygala oreophila</i> Speg.	1					1600	0.31	Mendoza		
<i>Polygala williamsii</i> Böcher, Hjert. & Rahn	1		x			2100	0.54	Mendoza		
Poaceae										
<i>Koeleria inaequaliglumis</i> A.M. Molina	8		x			1100–2700	0.14–0.28	Mendoza		
<i>Pappostipa malalhuensis</i> (F.A. Roig) Romasch.	2			x				Mendoza		
<i>Sporobolus mendocinus</i> E. Méndez	3		x			1100–2900	0.14–0.57	Mendoza		
Solanaceae										
<i>Jaborosa kurtzii</i> Hunz. & Barboza	5		x			600–1600	0.11–0.71	Mendoza		
Alliaceae										
<i>Tristagma anemophilum</i> Ravenna	2	x				2200	0.45	Payunia		
Apiaceae										
<i>Oligocladus patagonicus</i> Pérez-Mor.	3		x			300–1300	0.13–0.25	Payunia		
Apocinaceae										
<i>Tweedia aucaensis</i> G.H. Rua	1			x		1200	0.11	Payunia		
Asteraceae										
<i>Aylacophora deserticola</i> Cabrera	3		x			600–800	0.11–0.12	Payunia		
<i>Conyza boelckeii</i> Cabrera	1	x				2300	0.73	Payunia		
<i>Nassauvia hillii</i> Cabrera	1			x		1000	0.57	Payunia		
<i>Nassauvia sublobata</i> Cabrera	4		x			1100–1900	0.18–0.90	Payunia		
<i>Perezia delicata</i> Vuilleum.	6		x			1000–2100	0.93–1.28	Payunia		
<i>Senecio comberi</i> Cabrera	1			x		900	0.93	Payunia		
<i>Senecio covuncensis</i> Cabrera	1			x		700	0.14	Payunia		
<i>Senecio huitrinicus</i> Cabrera	1	x				800	0.13	Payunia		
<i>Senecio perezii</i> Cabrera	3		x			800–1100	0.17–0.28	Payunia		
<i>Senecio pseudaspericaulis</i> Cabrera	1		x			2100	1.01	Payunia		
<i>Senecio sandwithii</i> Cabrera	1		x			1000	0.19	Payunia		
Berberidaceae										
<i>Berberis comberi</i> Sprague & Sandwith	2		x			800–1200	0.17–0.20	Payunia		
<i>Berberis copahuensis</i> Job	1		x			2200	0.35	Payunia		

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TABLE 2. (Continued)

Family/species	Record number	Cell size / Radius				Elevational range (m)	Aridity range	Area
		0.5×0.5°	1.0×1.0°		2.0×2.0°			
		50×100%	10×10%	100×100%	5×5%			
Boraginaceae								
<i>Cryptantha papillosa</i> R.L. Pérez-Mor.	1	x				2200	0.59	Payunia
Boraginaceae								
<i>Heliotropium kurtzii</i> Gangui	5		x			900–2500	0.17–0.60	Payunia
Fabaceae								
<i>Adesmia acuta</i> Burkart	2		x			1000–1800	0.17–0.35	Payunia
<i>Adesmia boelckeana</i> Burkart	2		x			400–1200	0.11–0.57	Payunia
<i>Adesmia glandulifolia</i> Steibel & Ulibarri	3		x			1200–1700	0.14–0.20	Payunia
<i>Adesmia ragonesei</i> Burkart	2		x			2000–2200	0.37–0.48	Payunia
<i>Adesmia sandwithii</i> Burkart	1			x		1300	0.27	Payunia
<i>Adesmia trifoliolata</i> Gillies ex Hook. & Arn.	2			x		500–1600	0.13–0.27	Payunia
<i>Anarthrophyllum capitatum</i> Sorarú	2		x			900–2200	0.60–0.88	Payunia
<i>Senna kurtzii</i> (Harms) H.S. Irwin & Barneby	4		x			1200–1600	0.13–0.30	Payunia
<i>Senna nudicaulis</i> (Burkart) H.S. Irwin & Barneby	1			x		2000	0.25	Payunia
Malvaceae								
<i>Tarasa albertii</i> Phil.	4		x			800–1700	0.17–1.68	Payunia
Poaceae								
<i>Pappostipa barrancaensis</i> (F.A. Roig) Romasch.	3		x			900–1000	0.16–0.22	Payunia
<i>Pappostipa parodiana</i> (F.A. Roig) Romasch.	4		x			500–1500	0.10–0.21	Payunia
Rhamnaceae								
<i>Condalia megacarpa</i> A. Cast.	2			x		1200–1800	0.11–0.15	Payunia
Rubiaceae								
<i>Galium comberi</i> Dempster	1			x		1500	0.89	Payunia
Scrophulariaceae								
<i>Calceolaria borsinii</i> Rossow	1			x		1900	0.74	Payunia
Verbenaceae								
<i>Mulguraea cedroides</i> (Sandwith) N. O'Leary & P. Peralta	5		x			900–1100	0.11–0.43	Payunia
Violaceae								
<i>Viola dasyphylla</i> W. Becker	1			x		2000	1.00	Payunia
Apiaceae								
<i>Bowlesia ruiz-lealii</i> Mathias & Constance	4		x			1100–2900	0.18–0.66	Northern Payunia
Asteraceae								
<i>Senecio maeviae</i> Cabrera	2					1300	0.30	Northern Payunia
Brassicaceae								
<i>Lithodraba mendocinensis</i> (Hauman) Boelcke	2		x			2200–2500	0.37–0.48	Northern Payunia

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TABLE 2. (Continued)

Family/species	Record number	Cell size / Radius				Elevational range (m)	Aridity range	Area		
		0.5×0.5°		1.0×1.0°					2.0×2.0°	
		50×100%	10×10%	100×100%	5×5%					
Cyperaceae										
<i>Carex boelckeiana</i> Barros	3		x			1900–2800	0.22–0.70	Northern Payunia		
Fabaceae										
<i>Anarthrophyllum burkartii</i> Sorarú	3		x			2000–2400	0.4–0.65	Northern Payunia		
<i>Prosopis castellanostii</i> Burkart	3		x			1100–2100	0.13–0.26	Northern Payunia		
<i>Prosopis ruizlealii</i> Burkart	4		x			1300–1900	0.20–0.34	Northern Payunia		
Asteraceae										
<i>Mutisia burkartii</i> Cabrera	1	x				1000	0.27	Neuquén		
<i>Senecio divaricoides</i> Cabrera	7					200–1800	0.17–0.99	Neuquén		
Boraginaceae										
<i>Heliotropium pinnatisectum</i> R.L. Pérez-Mor.	2		x			1000–1300	0.27–0.33	Neuquén		
Brassicaceae										
<i>Neuontobotrys choiquense</i> (Romanczuk) Al-Shehbaz	1	x				1000	0.17	Neuquén		
Caryophyllaceae										
<i>Silene cuspidata</i> Pedersen	3					1400–2100	0.72–0.99	Neuquén		
Fabaceae										
<i>Adesmia neuquenensis</i> Burkart	3		x			900–1300	0.27–0.45	Neuquén		
Gentianaceae										
<i>Centaurium ameghinoi</i> (Speg.) Druce	3					200–1200	0.12–1.08	Neuquén		
Violaceae										
<i>Viola pseudovulcanica</i> W. Becker	2	x				1500–1700	0.8–0.83	Neuquén		
Apiaceae										
<i>Diposis patagonica</i> Skottsb.	1		x			1000	0.50	Southeastern Neuquén		
Asteraceae										
<i>Chaetanthera australis</i> Cabrera	2		x			700–900	0.95–1.01	Southeastern Neuquén		
<i>Senecio carbonensis</i> C. Ezcurra, M. Ferreyra & S. Clayton	1		x			1600	1.14	Southeastern Neuquén		
<i>Senecio comberi</i> Cabrera	1		x			900	0.93	Southeastern Neuquén		
<i>Senecio diemii</i> Cabrera	3		x			1600–2000	1.17–1.56	Southeastern Neuquén		
Caryophyllaceae										
<i>Spergula calva</i> Pedersen	2		x			613–1440	0.32–0.82	Southeastern Neuquén		
Fabaceae										
<i>Anarthrophyllum strigulipetalum</i> Sorarú	3		x			600–900	0.22–0.56	Southeastern Neuquén		
Hymenophyllaceae										
<i>Hymenophyllum quetrihuense</i> Diem & J.S. Licht.	2		x			784–1049	0.84–1.55	Southeastern Neuquén		
Anacardiaceae										
<i>Schinus roigii</i> Ruiz Leal & Cabrera	8					600–2600	0.1–0.54	?		

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TABLE 2. (Continued)

Family/species	Record number	Cell size / Radius				Elevational range (m)	Aridity range	Area	
		0.5×0.5°		1.0×1.0°					2.0×2.0°
		50×100%	10×10%	100×100%	5×5%				
Apiaceae									
<i>Asteriscium argentinum</i> Chodat & Wilczek	6					1000–2500	0.35–0.67	?	
Asteraceae									
<i>Senecio sorianoii</i> Cabrera	3					90–500	0.89–515	?	
Brassicaceae									
<i>Menonvillea patagonica</i> Speg.	11					400–2800	0.16–1.01	?	
Juncaceae									
<i>Luzula ruiz-lealii</i> Barros	2					1000–3300	0.6–0.89	?	
Poaceae									
<i>Aristida trachyantha</i> Henrard	3					260–500	0.18–0.36	?	
<i>Piptochaetium brachyspermum</i> (Speg.) Parodi	1					0	0.28	?	
Polygalaceae									
<i>Polygala stenophylla</i> A. Gray	9					380–1500	0.11–0.48	?	
Scrophulariaceae									
<i>Calceolaria ruiz-lealii</i> Descole & Borsini	3					980–2700	0.44–1.44	?	
Solanaceae									
<i>Benthamiella graminifolia</i> Skottsb.	2					800–2300	0.19–0.39	?	
<i>Sclerophylax ruiz-lealii</i> Di Fulvio	3					770–1700	0.10–0.17	?	

Discussion

In the present study we analyzed the distribution of the vascular flora endemic to the Monte biogeographic unit, to define areas of endemism supported by the congruent distribution of several species. We found that the endemic species define 13 partial overlapping main areas with peaks of endemism found at the limit between the Monte and the Andes foothills (see Fig 2A–N, Table 3). The areas defined by the largest number of species are the NOA area (north western Argentina, Fig. 2B, (Table 3) and the Payunia area (Fig 2E, Table 3). While the NOA area is comparable to the High Monte ecoregion of Olson *et al.* (2001), the Payunia is part of the Patagonia biogeographic province (sensu Cabrera 1976, Martínez Carretero 2004, Morrone 2015). The Payunia area appears in the present study only because we included all species endemic to the political provinces that include Monte vegetation. In contrast, the areas defined by the smallest number of species, were the Monte area recovered as a unit (Fig. 2M, Table 3), the Low Monte (Fig. N, Table 3), as well as minor areas of endemism within the eastern part of the Monte (Fig. J–L, Table 3). Probably due to low sampling density of the endemic species within the latter distribution patterns, these areas only appeared when using large cell sizes and/or when considering a species present in an empty cell if it is observed in a neighbor cell (setting the fill option to 100%).

The areas with highest endemism score are located in the mountainous portion of the Monte region, especially in the transition zones between the Monte and the Puna and/or Patagonian biogeographic provinces (sensu Cabrera 1976). These areas include NOA, San Juan, Mendoza, Payunia, Northern Payunia, and Southwestern Neuquén. These areas include a variable degree of Monte vegetation as well as its transition zones, and are defined by species that are found both in the Monte as well as in the neighboring phytogeographic units. Based on the distribution of endemic vascular plants, Roig *et al.* (2009) proposed a subdivision of the Monte (Fig. 1B); see also Morrone (2014). The patterns of endemism detected in our study do often agree with the regionalization proposed by Roig and co-authors. In general, we obtained partial support for the following areas: the Northern district (the Central and the Pampean sub-district) and the Southern district (the Northern Patagonic, the Southern Patagonic, and the Peninsula de Valdés and

Punta Ninfa sub-district)—for details see “Areas supported in the study” below—. However, several of the species used by Roig *et al.* (2009) to define their sub-divisions did not match the areas in the present analysis (see “Areas supported in the study” below). These inconsistencies may be due to the application of a quantitative method in our study, as well as changes or updates in the information of species distribution in the region.

To explore how robust our results are to changes in grid size and analytical parameters, we varied both. The areas that were robust to these changes were mainly found in the north-western part of the region (the NOA and the San Juan areas and in south-western part of the region (Southwestern Neuquén). On the other hand, the obtained areas related to the Payunia region (Mendoza, Payunia, Northern Payunia, and Neuquén) varied both in size and species composition, when the analytic parameters were modified. To sort out these conflicting distribution patterns, the sampling effort need to be increased in the Payunia district of the Patagonian biogeographic province (*sensu* Cabrera 1976, Martínez Carretero 2004).

Below we discuss the habitat of the endemic species from the study region in general, as well as in the 13 individual main areas. Most of these areas merge into a single consensus area when applying loose consensus rules and criterions (Fig. 2A, Table 3). The consensus gradually decomposes into the 13 individual areas when raising the consensus criterion above 25% (Fig. 2B–N, Fig. 3), indicating that each area shares 25% or more of the defining species with at least one other area in the consensus. Below, and in Table 2, the endemic species are mentioned only for the area where each species obtained highest endemism score (*i.e.*, the area that best fits the distribution of the individual species).

TABLE 3. Areas of endemism obtained under cell sizes of $1 \times 1^\circ$ and $2 \times 2^\circ$, and radius size of 5%, 10%, and 100%, by gradually increasing the consensus criterion from 5% to 65%. Aridity values: $AI < 0.03$ Hyper arid, $0.03–0.2$ Arid, $0.2–0.5$ Semi-arid, $0.5–0.65$ Dry sub-humid, >0.65 Humid.

Area	Low $0.5 \times 0.5^\circ$ obtained	Subsets consensus number	Endemicity index	Family/ genera/species number	Elevational range (m)	Aridity range	Cell size	Radius size	Figure number	Separates from main areas
Monte	no	4	2.5–4.0	03/03/03	0–3000	0.07–0.58	$2 \times 2^\circ$	5%	2M	55%
NOA	no	67	2.0–5.4	14/25/28	300–3500	0.05–0.65	$1 \times 1^\circ$	10%	2B	45%
Low Monte	no	18	2.2–4.0	04/10/11	0–3200	0.071–0.95	$2 \times 2^\circ$	5%	2N	65%
San Juan	yes	10	2.8–5.2	06/07/08	500–3100	0.09–0.44	$1 \times 1^\circ$	10%	2C	45%
La Pampa	yes	1	3.0–3.2	02/03/03	300–400	0.26	$1 \times 1^\circ$	100%	2J	10%
Eastern Neuquén	yes	1	3.3–3.5	03/03/23	200–1400	0.10–0.27	$1 \times 1^\circ$	10%	2G	45%
Patagonian Monte	no	1	2.1–2.3	02/03/03	200–1400	0.13–0.27	$1 \times 1^\circ$	100%	2K	5%
Somuncurá/Golfo San										
Jorge	no	3	2.1–2.3	04/05/06	100–1400	0.16–0.20	$1 \times 1^\circ$	100%	2L	10%
Mendoza	yes	33	2.0–5.4	07/10/15	600–3400	0.11–0.79	$1 \times 1^\circ$	10%	2D	50%
Payunia	yes	28	2.3–6.1	08/12/20	300–2500	0.10–0.89	$1 \times 1^\circ$	10%	2E	50%
Northern Payunia	no	1	8.0–8.3	05/06/07	1100–2900	0.13–0.70	$1 \times 1^\circ$	10%	2F	45%
Neuquén	yes	2	3.5–4.0	03/03/03	900–2100	0.26–0.99	$1 \times 1^\circ$	10%	2H	45%
Southeastern Neuquén	yes	1	5.0–5.2	05/06/08	600–2000	0.56–1.17	$1 \times 1^\circ$	10%	2I	30%

Taxonomic considerations

Asteraceae are the most diverse family both in number of genera and species in the Southern Cone (Zuloaga *et al.* 1999), and Asteraceae endemics are numerous and especially diverse in arid environments (Funk *et al.* 2009). This general pattern is also present in the Monte region, where Asteraceae are the largest and most diverse family with 35 endemic species belonging to 18 genera. Asteraceae endemics are among the defining species in all areas obtained in the present study with exception of the Monte area in Fig. 2M. Furthermore, endemic Asteraceae species are recorded in a wide range of environments and elevations (Table 2), from arid (*e.g.* *Senecio toroanus* Cabrera) to humid (*e.g.* *Senecio diemii* Cabrera) environments, and from 100 m (*e.g.* *Nassauvia chubutensis* Speg.) to 3500 m (*e.g.* *Hysterionica cabrerai* Ariza). Nearly 50% of the endemic Asteraceae species belong to *Senecio*, a genus which includes 15 endemic species ranging from arid to humid environments, although most are found in arid and semiarid environments.

Fabaceae are the second largest family in the Monte region, with 31 endemic species classified in six genera, of these *Adesmia*, with 14 species, is the most numerous genus. As in Asteraceae, endemic species of Fabaceae support all areas found in this study, except for the Monte area in Fig. 2M. Also, endemic Fabaceae species are found in a

wide range of environments and elevations (Table 2), ranging from arid, e.g. *Mimosa ephedroides* (Gillies ex Hook. & Arn.) Benth., to humid (e.g. *Anarthrophyllum capitatum* Sorarú) habitats, and from lowlands near the coast line (e.g. *Anarthrophyllum ornithopodum* Sandwith) to mountain highlands at 2900 m (e.g. *Adesmia mendozana* Ulibarri).

Cactaceae are the third most important family with seven endemic species in the Monte region, belonging to six genera. Unlike Asteraceae and Fabaceae, endemic Cactaceae species only support areas covering the northern part of the study region, i.e., the NOA area and the San Juan area (Fig 2B, C, Table 2). This is in concordance with previous observations of Cabrera (1976), who mentioned that the family is most frequent in the northern part of the Monte. Also, endemic Cactaceae species inhabit only arid and semi-arid environmental from variable elevations (Table 2), from valleys lowlands at 300 m, e.g. *Trichocereus strigosus* (Salm-Dyck) Britton & Rose, to mountain highlands at 3100 m, e.g. *Tunilla corrugata* (Salm-Dyck) D.R. Hunt & Iliff.

Biogeographic considerations

While Cabrera (1951, 1953, 1976) based his biogeographical classification on the presence of endemic taxa, i.e., families, genera, and species, his proposal was not based on quantitative studies and does not use a consistent criteria for defining the biogeographic units (Ribichich 2002). Another proposed classification for the Monte region is found in Burkart *et al.* (1999) and used by Olson *et al.* (2001) who divided the Monte in two ecoregions, High Monte and Low Monte. This scheme is not based on quantitative analyses and mainly follows Cabrera (1976) although the authors considered additional, though informal, information on climate and geomorphologic characteristics to divide the Monte into a northern and southern unit. In our quantitative analysis based on the distribution of endemic species it is possible to define areas of endemism that are consistent with some of the previously biogeographical schemes as discussed below.

Agesen *et al.* (2012) showed, in their analysis of distribution patterns of endemic species in the southern central Andes that the Prepuna biogeographic province (sensu Cabrera 1976) could not be recover as a unit but formed part of the broader NOA pattern that also included high Andean species. In our analysis, although some of the areas that are identified include more than one biogeographic unit, the NOA area (Fig. 2B) is broadly consistent with the High Monte ecoregion (Fig. 1A), as defined by Burkart *et al.* (1999). Also, when using a larger grid of $2 \times 2^\circ$, two new areas emerge: the Monte area (Fig. 2M) and the Low Monte area (Fig. 2N) that are consistent with the Monte province as a unit, defined by Cabrera (1976), and the Low Monte ecoregion proposed by Burkart *et al.* (1999), and Olson *et al.* (2001), respectively. These two areas are supported by endemic species that are widespread within the study region. These two areas, that are only detected when using a large grid size, show the need to intensify the sampling in the low arid region of the Monte province. *Monttea aphylla*, an endemic species used to separate the Monte province from the Chaco (Morello 1958), and to identify the Monte boundaries (Roig *et al.* 2009), supports, in this study, an extensive area that includes the entire Monte area as a unit (Table 2, Fig. 2M). Roig *et al.* (2009) also cited *Condalia microphylla* Cav. and *Cercidium praecox* subsp. *glaucum* (Cav.) Burkart (formerly *Parkinsonia praecox* subsp. *glaucum*) as species whose distribution coincides closely with the Monte province. Nevertheless, these species were not included in our analysis, as they are also found in regions beyond the limits of Monte proposed by Cabrera (Zuloaga *et al.* 2008).

Areas supported in the study

Below, we discuss each obtained area in relation to previous proposed regionalization within the Monte. We compared the species used by other authors to define regionalization within the Monte and we provide details on environmental characteristics (elevation and aridity) of each obtained area.

Areas that included a large portion of the Monte biogeographic unit

- **Monte** (Fig. 2M): the Monte as a unit is recovered when using large grid size ($2 \times 2^\circ$). In the present study, the Monte is supported by three species with a wide distribution within the study region, covering an area from Tucumán to Río Negro. The Monte area includes arid, semiarid, and sub-humid environments from sea level to above 3000 m (Table 2, 3). *Monttea aphylla* is among the species that support the Monte area (Table 2). This species was mentioned by Morello (1958) as endemic to the Monte province and used by the author to define the Monte. The other two species that support the area are *Jaborosa leucotricha* (Speg.) Hunz., and *Glandularia flava* (Gillies ex Hook.) Schnack & Covas (Table 2).

- **NOA** (Fig. 2B): the NOA (north-western Argentina) area has an extensive distribution within the study region, extending approximately 1100 km from north to south, from the provinces of Jujuy to Mendoza. This area is supported by 28 species that grow in arid, semiarid, and sub-humid habitats, although most are found in arid and semi-arid sites (Table 2, 3); none of the species are found in humid environments. Attitudinally, the endemic species that define the

NOA distribution pattern cover a wide range from 300 to 3500 m (Table 2, 3). This region mostly agrees with the High Monte ecoregion as proposed by Olson *et al.* (2001), which extends from Jujuy to northern Mendoza.

Aagesen *et al.* (2012), in their analysis of the southern portion of the central Andes, found a distributional pattern that also covered the northwestern Argentina, from Jujuy to La Rioja. This patterns (also called NOA) was supported by 24 endemic species that inhabit in desert, semi-desert, and semi-arid habitats (according to the Martonne Aridity Index used by the authors, equivalent to arid and semi-arid habitats in CGIAR Index), and elevations ranging from 500 m to more than 4500 m. The NOA area of our analysis reaches northern Mendoza, and does not include high Andean species that were excluded from the present analyses, but otherwise it corresponds to the same pattern of distribution found by Aagesen *et al.* (2012).

Roig *et al.* (2009) delimited, in their sub-division of the Monte province, the “Northern” district (extending from Catamarca to Buenos Aires), composed of three sub-districts (Fig. 1B). The NOA area of our analysis includes two sub-districts of the Northern district sensu Roig *et al.* (2009), i.e., the Tucumán-Salta and the Central sub-districts (Fig. 2B). The third sub-district, La Pampa (Roig *et al.* 2009), is not included in the NOA area in Fig. 2A but overlaps with the homonymous area from our analysis, as mentioned below. Aagesen *et al.* (2012), who included the endemic species of the northern portion of the Monte, also found support for the Tucumán-Salta sub-district (sensu Roig *et al.* 2009), named by these authors as the Salta-Catamarca area.

Species that are characteristic in the northern part of the Monte biogeographic province, such as *Bredemeyera colletioides* (Phil.) Chodat, *Trichocereus strigosus*, *Prosopis argentina* Burkart, and *Mimosa ephedroides* (Cabrera 1976) support the NOA area (Table 2). Also, the NOA pattern grouped most of the endemic species of the Cactaceae family, present in the Monte region, in agreement with Cabrera (1976).

- **Low Monte** (Fig. 2N): like the Monte area above, the Low Monte is only recovered when using larger grid size (2°×2°). This area is defined by 11 species widely distributed from the province of La Rioja to Chubut. The endemic species are found in a wide range of environments and elevations, from arid to humid climate and from sea level to 3200m (Table 2, 3).

This area is similar to the Low Monte ecoregion proposed by Burkart *et al.* (1999) and Olson *et al.* (2001). Among the species that defined the Low Monte, *Chuquiraga rosulata* Gaspar (Table 2) was also cited by Roig *et al.* (2009), but as a “characteristic” or “differential” species of a less extensive district, the Southern district, located in the southern part of the study area (see Patagonian Monte below).

- **San Juan** (Fig. 2C): this pattern is nested within the NOA area and encompasses much of the San Juan province, and portions of Catamarca, and Mendoza. It is supported by 8 species found in a narrow range of aridity from arid to semi-arid environments. The elevations vary from 500 to 3100 m (Table 2, 3). Endemic species associated with this pattern are present in valleys, hills, and mountains.

A similar area, also named San Juan, was described by Aagesen *et al.* (2012). The San Juan area (sensu Aagesen *et al.* 2012) appeared as one of the most arid areas of the study, and was defined by 11 endemic species growing below 3000 m, inhabiting arid and semi-arid environments, as in our study. Given the similar geographic extension, and environmental characteristics, we consider that both areas define the same distributional pattern.

The San Juan area is compatible with the Central sub-district (Fig. 1B) mentioned by Roig *et al.* (2009). These authors cited, as “characteristic” or “typical” species of this sub-district, *Prosopis alpataco* Phil., *P. argentina*, *Ephedra boelckeii* F.A. Roig, and *Heliotropium kurtzii* Gangui. *H. ruiz-lealii* was included in the analysis of Aagesen *et al.* (2012) where it was found to support the San Juan area, but it is not reanalyzed in the present study. In our analysis, *Ephedra boelckeii* supports the San Juan area, while *P. argentina* supports the more extensive NOA area. *Prosopis alpataco* was not included here, because it is found in Bolivia and Chile as well.

The San Juan area includes the Eremean district (Fig. 1B) proposed by Le Houerou *et al.* (2006) and Roig *et al.* (2009), a narrow strip along the high pre-Andean valleys of San Juan and Mendoza (Fig. 1B). Roig *et al.* (2009) cited, as “characteristic” of the Eremean district, species such as *Puna clavarioides* (Pfeiff.) R. Kiesling and *Cistanthe densiflora* (Barnéoud) Hershk.; of these, the former supports the San Juan area in our analysis (Table 2), while the second was not considered as it exceeds the limits of Monte and those of Argentina (Zuloaga *et al.* 2008).

- **La Pampa** (Fig. 2J): this area is supported by 3 species growing in semi-arid environment and elevations ranging from 300 to 400 m (Table 2, 3). Species endemic to the La Pampa area are associated with the piedmont of the Sierra Lihuel Calel.

This pattern largely agrees with the La Pampa sub-district, belonging to the North district (Roig *et al.* 2009) scheme (Fig. 1B), as mentioned above. Roig *et al.* (2009) cited, as “differential” species of the sub-district, *Junellia connatibracteata* (Kuntze) Moldenke, *Schinus johnstonii* F.A. Barkley, *Elionurus muticus* (Spreng.) Kuntze and *Gutierrezia spathulata* (Phil.) Kurtz. However, these species were not included in our study, because they exceed the

limits of the Monte and, in the case of *E. muticus*, those of Argentina. It is worth mentioning that according to Martínez Carretero (2004) Lihuel Calel belongs to the Payunia region.

- **Eastern Neuquén** (Fig. 2G): this area includes part of Neuquén, Río Negro, and La Pampa. It is defined by 3 endemic species that inhabit arid and semi-arid environments from 200 to 1400 m (Table 2, 3). Species endemic to this area are associated with rivers and small mountains.

The Neuquén area partially overlaps with the Northern Patagonia sub-district (Fig. 1B) proposed by Roig *et al.* (2009) but the two areas do not share any of their defining species.

- **Patagonian Monte** (Fig. 2K): the area is supported by two species that are found in large portions of Neuquén and part of La Pampa, Mendoza, and Río Negro, in arid and semi-arid environments and elevations from 200 m to 1400 m (Table 2, 3).

This distribution pattern corresponds to the area of two sub-districts of the Southern district (Fig 1B) proposed by Roig *et al.* (2009): the Northern Patagonic and part of the Southern Patagonic sub-districts. We consider that the names Northern and the Southern Patagonic districts are unfortunate because both are found north of the biogeographic province Patagonia (*sensu* Cabrera 1976). Therefore, we propose to use the name “Patagonian Monte”. Roig *et al.* (2009) mentioned as “characteristic” or “differential” species of the Southern district *Aylacophora deserticola* Cabrera, *Tetraglochin caespitosum* Phil., and *Chuquiraga rosulata*. In our analysis, *A. deserticola* and *C. rosulata* supported the Low Monte and the Payunia areas (Table 2), respectively; see below. *T. caespitosum* was not included in our analysis because it is also found in the Santa Cruz province (Zuloaga 2008) which is outside of the Monte boundaries. Roig *et al.* (2009) cited, as characteristic of his Northern Patagonic sub-district, *Larrea ameghinoi* Speg., *Maihuea patagonica* (Phil.) Britton & Rose, and also *A. deserticola*—*Nardophyllum deserticola* (Cabrera) G.L. Nesom in Roig *et al.* (2009)-. The first two species were not included in our analysis, as they are also distributed outside of the Monte boundaries, reaching the province of Santa Cruz. For the Southern Patagonic sub-district proposed by Roig *et al.* (2009), the authors include *Chuquiraga avellanadae* Lorentz that is also found in Santa Cruz.

- **Somuncurá/Golfo San Jorge** (Fig. 2L): this distribution pattern is found in the eastern portions of Chubut and Río Negro provinces. The area is supported by six species distributed from 100 to 1400 m, mainly in arid environments, although some reach semi-arid sites too (Table 2, 3). Species endemic to this area are associated with the Somuncurá plateau as well as areas along the coastline of the political province Chubut.

The pattern covers part of the Southern district (Fig 1B) proposed by Roig *et al.* (2009), and discussed above (see Patagonian Monte). The area also includes the Península de Valdés and Punta Ninfas sub-district proposed by Roig *et al.* (2009). “Characteristics” or “differential” species from this latter area (Roig *et al.* 2009) include *Brachyclados lycioides* D. Don, *Baccharis triangularis* Hauman, *Jarava plumosa* (Spreng.) S.W.L. Jacobs & J. Everett (formerly *Stipa papposa* Delile), and *Nassella longiglumis* (Phil.) Barkworth (formerly *Stipa longiglumis* Phil.). None of these taxa were included in our study because none are endemic to the study region. Furthermore, some of these are found outside Argentina, such as *B. lycioides* (Chile) and *J. plumosa* (Chile, Brazil, and Uruguay) (Zuloaga *et al.* 2008).

Areas in other biogeographic units

Because we included all species endemic to the political provinces that include Monte vegetation, we obtained five areas discussed below, which include species from the neighboring biogeographic units.

-**Mendoza** (Fig. 2D): this area covers the western part of Mendoza and portions of the provinces of San Juan and Neuquén. It is supported by 15 species that occur in a wide environmental range, including arid, semi-arid, sub-humid, and humid habitats, and elevations from 600 m to 3400 m (Table 2, 3). Species endemic to this area are mainly associated with the Precordillera.

Geographically, this area overlaps to a small extent with the southern portion of the Central sub-district (Fig 1B) *sensu* Roig *et al.* (2009), but the two areas do not share defining species.

-**Payunia** (Fig. 2E): this area includes the province Neuquén and the western part of Mendoza. It is supported by 20 endemic species that grow in a variable range of environment, including arid, semiarid, sub-humid, and humid habitats, and elevations ranging from 300 to 2500 m (Table 2, 3).

- **Northern Payunia** (Fig. F): is supported by six species that grow in southern Mendoza and northern Neuquén, in arid, semiarid, dry sub-humid and humid habitats, from 1100 to 2900 m (Table 2, 3).

The partly overlapping areas Mendoza, Payunia, Northern Payunia, and Neuquén (which all have high endemism scores and include large numbers of endemic species) cover mainly the Payunia district included in the biogeographic province Patagonia (Cabrera 1976). The Payunia district extends along volcanic zones in Southern Mendoza and Northern Neuquén, between approximately 1400 and 2500 m, although the elevation limit varies depending on the region (Cabrera 1976; Martínez Carretero 2004). This biogeographic unit is characterized by harboring numerous

endemic species (Martínez Carretero 2004), among these, many of the species that support the four areas listed above, e.g. *Prosopis castellanosii* Burkart, *Berberis comberi* Sprague & Sandwith, *Condalia megacarpa* A. Cast., *Pappostipa barrancaensis* (F.A. Roig) Romasch., *Adesmia trifoliolata* Gillies ex Hook. & Arn., *A. boelckeana* Burkart, *A. acuta* Burkart, *Senna kurtzii* (Harms) H.S. Irwin & Barneby, *Anartrophyllum capitatum*, *Pappostipa vatroensis* (F.A. Roig) Romasch., and *Oligocladus patagonicus* Pérez-Mor. (Ruiz Leal 1955, 1972, Martínez Carretero 2004). Other species listed as endemic by the above authors, were not included in our analysis because their distributions extend to Santa Cruz and in some cases Chile, e.g. *Alstroemeria spathulata* C. Presl, *Senna arnottiana* (Gillies ex Hook.) H.S. Irwin & Barneby, *Polygala persistens* A.W. Benn., and *Diplolepis hieronymi* (Lorentz) Liede & Rapini.

Domínguez *et al.* (2006) analyzed areas of insect endemism in the Patagonian steppe using VNDM. The authors detected two distribution patterns in the Payunia region: the Payunia North area (in the province of Mendoza) and the Payunia South area (in the province of Neuquén). The Northern Payunia (Fig. 2F) and the Neuquén areas (Fig. 2H) identified in our analysis partially overlap with the North and South Payunia patterns detected by Domínguez *et al.* (2006), respectively. Morrone (2015) treated them as the Northern Payunia and the Southern Payunia districts, within the Payunia sub-province. Meanwhile, Martínez Carretero (2004) suggests that Payunia gathers the necessary elements to be considered as phytogeographical province dismembered from the Patagonian province.

- **Neuquén** (Fig. 2H): this area, which covers central and southern Neuquén, is defined by 3 species that inhabit semiarid, dry sub-humid, and humid environments, from 900 to 2100 m (Table 2,3).

- **Southwestern Neuquén** (Fig. 2I): this area, covering western Neuquén, is the southernmost distribution pattern within the study region. This pattern is defined by 8 species growing in semi-arid, dry sub-humid, and humid environments, at elevations ranging from 600 to 2000 m (Table 2, 3). It is associated with mountain and lake regions.

The Southwestern Neuquén area is found completely outside of the boundaries of the Monte, but its species were included in the analysis because they are endemic to the province of Neuquén.

Conclusions

The present distribution analysis of vascular plants endemic to the Monte, applying quantitative methods and a consistent optimality criteria (VNDM), show that the entire Monte (*sensu* Cabrera 1976, Morrone 2014) as well as the High and Low Monte ecoregions (*sensu* Olson *et al.* 2001) form areas of endemism that were recovered in the present study (Fig. 2M, B, N, Table 3).

The regionalization of the Monte proposed by Roig *et al.* (2009) was based partly on the distribution of endemic vascular plants and partly on dominant species. This regionalization therefore only coincided partly with our study. We obtained support for the areas: Northern district (the Central and the Pampean sub-district) and the Southern district (the Northern Patagonic, the Southern Patagonic, and the Península de Valdés and Punta Ninfa sub-districts). However, the Eremea district was not supported in the present study.

In agreement with the general arid climate of the Monte province, the arid environments appear as the principal habitat type for the endemic species. The results of this study provides basic information for conservation of the endemic flora in this arid region.

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