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Rarity patterns and conservation priorities in Cactaceae species from the Southern Central Andes: a case study from the Calchaquíes Valleys, Salta, Argentina

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Abstract. In this study, 34 Cactaceae species from the Calchaquíes Valleys, Argentina, were studied to determine 1) species rarity level, 2) proportion of rare species among taxonomic and ecological groups and, 3) whether rareness is consistently distributed throughout the species geographical ranges. We used a model where rarity is defined by the geographic range and the local population size to define species rarity. Rareness was not concentrated in any particular taxonomic or ecological group of Cactaceae; however 28 species were rare at some level. In most species, rarity varied across the geographical range, only five species remained consistently rare in all the surveyed populations. Six species qualified as extremely rare, all from the Cactoideae subfamily, four endemic to the southernmost Central Andes and differing in their growth forms. Only two of the 34 studied species, appeared as both extremely and consistently rare across its distribution. Determining rarity levels is useful for identifying species that may be in danger and/or in need for further studies. Rarity, used as an indicator of species vulnerability, allowed us, to identify Cactaceae species that are more vulnerable to anthropogenic or natural disturbance, compared with common species. Many of the Cactaceae species identified here as rare were mentioned by IUCN at intermediate categories of extinction. Our approach seems then to yield useful results and rareness in the present context appears to be related with vulnerability to extinction within the southernmost Central Andes.

[Keywords: geographic range, local abundance, extinction risk, endemism]

Resumen: Patrones de rareza y prioridades de conservación en especies de Cactaceae del sur de los Andes Centrales: un estudio en los Valles Calchaquíes, Salta, Argentina. En este trabajo se estudiaron 34 especies de Cactaceae de los Valles Calchaquíes, Argentina, para determinar 1) el nivel de rareza de las especies, 2) la proporción de especies raras entre grupos taxonómicos y ecológicos, y 3) la consistencia espacial de la rareza a lo largo del rango de distribución. Se definió a la rareza a través de un modelo que combina medidas del rango geográfico de distribución y el tamaño poblacional local de cada especie. La rareza no se concentró en ningún grupo taxonómico o ecológico particular de Cactaceae; sin embargo, 28 especies presentaron algún nivel de rareza. En la mayoría de las especies, la rareza varió a lo largo del área de distribución geográfica; sólo cinco especies fueron consistentemente raras en todas las poblaciones evaluadas. Seis especies fueron calificadas como extremadamente raras; todas de la subfamilia Cactoideae, cuatro endémicas del sur de los Andes Centrales y difiriendo en su forma de crecimiento. Sólo dos de las 34 especies estudiadas presentaron una rareza extrema y constante a lo largo de toda su distribución. La determinación del nivel de rareza fue útil para identificar especies que pueden estar en peligro o que pueden necesitar más estudios. Este trabajo permitió indicar qué especies de Cactaceae son más vulnerables a las perturbaciones antropogénicas o naturales, en comparación con las especies comunes. Muchas de las especies Cactaceae identificadas aquí como raras fueron mencionados por la IUCN en las categorías intermedias de extinción, por lo que la rareza parece estar relacionada con la vulnerabilidad a la extinción en la parte más sur de los Andes Centrales.

[Palabras clave: rango geográfico, abundancia local, riesgo de extinción, endemismo]

Introduction

Rarity is one of the factors that determine a species probability of extinction. Rareness defines the present status of an organism in relation to its abundance and its geographic distribution (Reveal 1981). From a conservation perspective, rarity surveys are of interest because of their relationship with the extinction risk (Gaston 1994; Kunin & Gaston 1997; Johnson 1998; Duncan & Young 2000). Rare species have a major probability of extinction than common species do (Gaston & Blackburn 1995) and generally, all species become rare before they go extinct (Dobson et al. 1995). However, as rarity is not the only factor that determines extinction risk (Cardillo

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et al. 2005; Melbourne & Hasting 2008), it should be taken as a relative indicator of species extinction risk.

Rarity patterns can vary spatially (Gaston 1994; Murray et al. 2002; Murray & Lepschi 2004). A species can be geographically restricted and uncommon at a small scale but abundant and widespread at a larger scale (locally rare species) (Crain et al. 2011) or it can be rare at all geographical scales (globally rare species) (Crain et al. 2011). Both kinds of species are innately different and would need for different conservation strategies and efforts (Crain et al. 2011). Furthermore, species may be consistently rare across their entire geographic ranges (everywhere-sparse species) (Murray et al. 1999) or rare in some places and abundant in others (somewhere-abundant species) (Murray et al. 1999). Defining the scale of the study is essential because it affects which species will be regarded as rare and which will not, at that particular scale, which may lead to different priorities when aiming to conserve the biodiversity in a given area.

In vascular plants, patterns of rarity are still poorly understood. Most rarity studies have been performed at regional or larger geographic scales (Rabinowitz et al. 1986; McIntyre et al. 1993; Gaston 1994; Broennimann et al. 2005; Söderström et al. 2007), with few studies performed at local level (but see Kaye et al. 1997; Saravia-Tamayo 2006). Crain et al. (2011) emphasized that more local analyses within globally prioritized regions are needed to strengthen the understanding of that region. Moreover, these authors highlight that to protect a large variety of biodiversity, is necessary to preserve both global and local rare plants hotspots. Here, we provide rarity assessments based on abundance and distributional data, for Cactaceae species from the Calchaquíes Valleys, Argentina, a part of the southern Central Andes. The Central Andes constitute the southernmost Tropical Andes, one of the most important global hotspots of diversity and endemism, but also one of the most threatened and least studied (Myers et al. 2000).

The Cactaceae family, endemic to the American continent (Nobel 2002), presents high levels of rarity in many parts of its distribution (Hernández & Godinez 1994; Edwards & Westoby 2000; Godínez-Álvarez et al. 2003). However, most studies related to Cactaceae rarity have focused on the causes of rarity in punctual species (Clark-Tapia et al. 2005; Ruedas et al. 2006), or studied rareness based on one single variable such as geographic range (Hernández et al. 2010) or abundance (Esparza-Olguin et al. 2005). At present, several Cactaceae species are threatened and under risk of extinction in many parts of their distributions (Hernández & Godinez 1994; Hunt 1999; Godínez-Álvarez et al. 2003) and need conservation attention. Within the southern Central Andes, Argentina contains the third highest Cactaceae diversity core in the world (Ortega-Baes & Godínez-Álvarez 2006; Ortega-Baes et al. 2010a) with the north-western portion of the country (NOA) concentrating the highest levels of both cacti diversity and endemism (Zuloaga et al. 1999; Ortega-Baes et al. 2010a). Nonetheless, a recent study indicate that most of the NOA's endemic flora, included many Cactaceae species, is unprotected by the current system of protected areas (Godoy-Bürki et al. 2014). Furthermore, at present, many ecoregions of the area are being impacted by different anthropogenic activities (Grau et al. 2005) with unknown consequences for the biodiversity of the region.

Our aim is to assess the relative rarity levels of Cactaceae species in one of the most important Cactaceae diversity centres of the southern Central Andes, the Calchaquíes Valleys (Oldfield 1997). If rarity is the initial state of the extinction process, it may be used to indicate which species are vulnerable or will be vulnerable in a near future and consequently need to be monitored more closely. Thus, the present work has as principal objectives to 1) determine which the rare species of the Calchaquíes Valleys are and which the rarity level of each species is, 2) determine the proportion of rare species across taxonomic groups (subfamilies) and among ecological groups (growth forms and endemic vs. non-endemic species), and 3) determine the consistency of species rareness throughout their geographical ranges within the study region.

Material and Methods

Study area

The Calchaquíes Valley's, high mountain valleys of north-south orientation, extend across the province of Salta, Tucumán and Catamarca in Argentina. The study area corresponds to the portion of the Calchaquíes Valleys located in the Salta province, which is situated between 24°24′ S to 26°24′ S, and 66°43′ W to 65°36′ W (Figure 1).

The climate of the area is semiarid, defined as subtropical with a dry season, with summer precipitation (100-200 mm) from November to March, followed by a dry winter period (Bianchi & Yañez 1992). The precipitations vary from abundant on the east slopes to scarce on the western slopes (Minetti 2005), reaching between 97 mm in La Poma to 197 mm in Cafayate (Bianchi & Yañez 1992). The temperature also oscillates within the area, with large thermal amplitudes between day and night as well as frosts in some places (Minetti 2005). Generally, temperatures follow the altitudinal gradient (1500-3000 m.a.s.l.) ranging between 20 to 25 °C, with a maximum of 35 °C in summer and a minimum between 5 and -15 °C in winter (Bianchi 1996).

Rarity level

To define species rarity we applied the model used by Arita et al. (1990). This method considers that species rarity can be defined by the geographic range (wide or restricted) and the local population size (large or small) of the species. The combination of these two variants distinguishes four possibilities. Three correspond to different rarity levels (categories WS, RS, and RL) while the fourth combination is referring to common species (category WL). All species were categorized according to their geographic ranges and local population sizes as outlined below.

Data source. The georeferenced data to model species distributions were obtained from intensive field collections during the years 2007-2009 (184 sites) (Figure 1), and from the literature in cases where a species distribution extended beyond the study area (data from 373 new locations). Bioclimatic and altitude variables were obtained from Worldclim (www.worldclim.org) (Hijmans et al. 2005) at a resolution of 30 arc-seconds.

To obtain the local abundance data for the species, we sampled 55 sites across the Calchaquíes Valleys from July 2008 to July 2009. Because the marked altitudinal differences in the area hinder access to many sites, we chose locations near primary and secondary roads of the valleys. Each site was chosen in a distance of approx 1-2 km away from the road in order to avoid disturbance as much as possible.

Geographic ranges of species. We modelled the potential distribution of 34 Cactaceae species, several of which extend their ranges beyond the study area. Maxent niche-based modelling (Phillips et al. 2006) was used to model species distributions applying the 10 percentile threshold to exclude all areas where the species had low probabilities of being present (we followed Phillips & Dudik 2008). Many of the species which are found outside the study region have only been collected sparsely. By using Maxent software we achieve more accurate distributions as it outperforms other similar algorithms, particularly when few records of species occurrence are available (Elith et al. 2006; Hernández et al. 2006). Maxent also allows

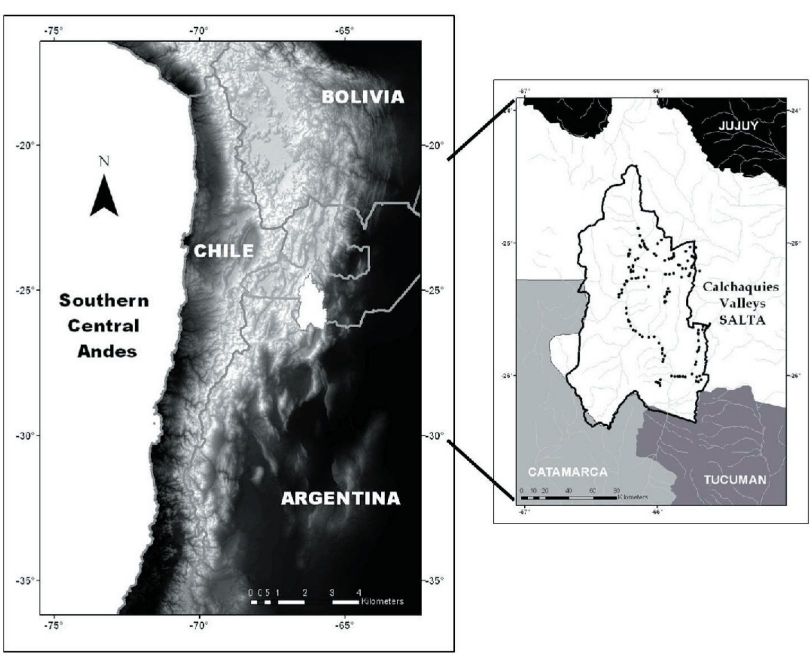

Figure 1. The study area: Calchaquíes Valleys, Salta, Argentina and its location in the Southern Central Andes.

Figura 1. Área de estudio: Valles Calchaquíes, Salta, Argentina y su ubicación en el sur de los Andes Centrales.

higher accuracy in species modelling by scheduling the software to obtain 100 replicates of each species distribution (Phillips & Dudik 2008). Furthermore, the AUC criterion (area under the curve) presented in the results allows evaluating effectiveness in the species distribution modelling. If the AUC values are smaller than 0.7, the model is not effective in predicting a correct species distribution (Pearce & Ferrier 2000; Phillips et al. 2006). In our study, all species register an AUC value higher than 0.8. The species geographic range (km^2) was calculated using *Calculate Area* tool from ArcGIS software (ESRI 2011).

Local population size. In each of the 55 sampled sites we registered the local

Table 1. Species categorization based on endemism, growth form, geographic range, local population size, rarity level and spatial variation of abundance. Taxonomy follows Zuloaga et al. (2008). O=Opuntioideae, C=Cactoideae, E=endemic to Southern Central Andes, NE=not endemic to the Southern Central Andes, RS=species with restrict geographic range and small population size, RL=species with restrict geographic range and large population size, WS=species with wide geographic range and small population size, WL=species with wide geographic range and large population size, CRS=consistently rare species, RCS=somewhere rare and somewhere common species, CCS=consistently common species.

Tabla 1. Categorización de especies según endemismo, formas de crecimiento, rango geográfico, tamaño poblacional local, nivel de rareza y variación espacial de la abundancia. La taxonomía sigue a Zuloaga et al. (2008). O=Opuntioideae, C=Cactoideae, E=endémica del sur de los Andes Centrales. NE=no endémica del sur de los Andes Centrales, RS=especies de rango geográfico restringido y tamaño poblacional pequeño, RL=especies con rango geográfico restringido y gran tamaño poblacional, WS=especies con rango distribucional amplio y pequeño tamaño poblacional, WL=especies con rango geográfico amplio y gran tamaño poblacional, CRS=especies consistentemente raras, RCS=especies raras en un sitio y comunes en otros, CCS=especies consistentemente comunes.

Species	Endemism	Growth Forms	Geographic Range	Local Population Size	Rarity	Abundance variation
Denmoza rhodacantha (C)	E	Barrel	Restricted	Small	RS	CRS
Echinopsis aurea (C)	NE	Barrel	Restricted	Small	RS	RCS
Echinopsis leucantha (C)	NE	Barrel	Restricted	Small	RS	Not evaluated
Trichocereus terscheckii (C)	E	Columnar	Restricted	Small	RS	CRS
Trichocereus thelegonus (C)	E	Columnar	Restricted	Small	RS	RCS
Gymnocalycium saglionis (C)	E	Globose	Restricted	Small	RS	RCS
Blossfeldia liliputana (C)	E	Globose	Restricted	Large	RL	Not evaluated
Echinopsis albispinosa (C)	E	Globose	Restricted	Large	RL	CCS
Echinopsis ancistrophora (C)	E	Globose	Restricted	Large	RL	Not evaluated
Trichocereus angelesiae (C)	E	Columnar	Restricted	Large	RL	RCS
Acanthocalycium thionanthum (C)	E	Barrel	Restricted	Large	RL	RCS
Gymnocalycium spegazzinii (C)	E	Globose	Restricted	Large	RL	RCS
Opuntia sulphurea (O)	NE	Articulate	Restricted	Large	RL	RCS
Parodia aureicentra (C)	E	Globose	Restricted	Large	RL	RCS
Parodia microsperma (C)	NE	Globose	Restricted	Large	RL	RCS
Tephrocactus molinensis (O)	E	Articulate	Restricted	Large	RL	RCS
Tephrocactus weberi (O)	E	Articulate	Restricted	Large	RL	RCS
Austrocylidropuntiaverschaffeltii(O)	E	Articulate	Wide	Small	WS	RCS
Cereus aethiops (C)	NE	Columnar	Wide	Small	WS	CRS
Cereus haenkeanus (C)	NE	Columnar	Wide	Small	WS	CRS
Cleistocactus smaragdiflorus (C)	E	Columnar	Wide	Small	WS	RCS
Maihueniopsis boliviana (O)	NE	Articulate	Wide	Small	WS	RCS
Trichocereus atacamensis (C)	NE	Columnar	Wide	Small	WS	CRS
Lobivia formosa (C)	NE	Barrel	Wide	Small	WS	Not evaluated
Gymnocalycium.schickendantzii(C)	NE	Globose	Wide	Small	WS	RCS
Harrisia pomanensis (C)	NE	Columnar	Wide	Small	WS	RCS
Opuntia anacantha (O)	NE	Articulate	Wide	Small	WS	RCS
Opuntia schickendantzii (O)	E	Articulate	Wide	Small	WS	No evaluated
Cleistocactus baumannii (C)	NE	Columnar	Wide	Large	WL	Not evaluated
Lobivia haematantha (C)	E	Globose	Wide	Large	WL	CCS
Trichocereus schickendantzii (C)	E	Columnar	Wide	Large	WL	CCS
Rebutia minuscula (C)	E	Globose	Wide	Large	WL	Not evaluated
Tunilla corrugata (O)	NE	Articulate	Wide	Large	WL	RCS
Airampoa ayrampo (O)	NE	Articulate	Wide	Large	WL	RCS

abundance of all species (defined here as number of individuals/10000 m^2). The plot size selected to measure abundances was 250 m^2 for small body size species, while for large body size species (such as *Trichocereus atacamensis, T. terscheckii* and *Denmoza rhodacantha*) we extended the plots size to 10000 m^2 (Table 1) (taxonomic names follow Zuloaga et al. 2008). Previous sampling demonstrated that large species appear as absent in plots smaller than 10000 m^2, despite been present at the location. We determined the local population size for each species, averaging the local abundances values registered for each species in all 55 sites.

Assignation of the species to the different rarity categories. To define the rarity of each species in relation to its geographic range and its local population size we determined the median of all geographic ranges and the median of all population sizes (Arita et al. 1990). The median of all geographic ranges was calculated from all species potential distribution (Me=13100 km^2), while the median of the local population size was determine from all local population sizes obtained in the field (Me=560/10000 m^2). A species was classified as widely distribute (W) if the species geographic range was larger than the median of all species. When the species geographic range was smaller than the median for all species, we classified the species as having restricted range (R). Likewise, when the local population size of a species was higher than the median for all species, we classified the species as having large populations (L). When the population size of a species was smaller than the median for all species, we classified the species as having small populations (S). Based on the combination of these two variables, species were assigned to relative rarity categories WS, WL, RS, and RL (Table 1).

Rarity patterns among taxonomic and ecological groups

Cactaceae species were categorized according to taxonomy in two subfamilies found in the Calchaquíes Valley's: Opuntioideae and Cactoideae (Table 1). Growth forms: columnar, barrel, articulate and globose (Table 1). Endemic/non endemic to the southern Central Andes (considered in this study from the 18° S to 33°30′ S (Strecker et al. 2007) (Table 1). Endemism was categorized according to the distributional data available in IUCN 2014 (www.iucnredlist.org). We found that 19 species of the 34 species evaluated are endemic to the Southern Central Andes (Table 1).

We examined rareness within subfamilies and among ecological groups: growth forms and endemic vs. non-endemic species applying the Fisher's exact test, which is applied when samples are very small (Fisher 1954). The analyses were performed using Infostat software (Di Rienzo et al. 2013). We examined the proportion of WS, WL, RS, and RL species in each taxonomic (Cactoideae / Opuntioideae) and ecological group (articulate / barrel / columnar / globose and endemic/ non endemic) in order to determine whether any of these groups presented significantly higher frequency of rare species compared to the proportion of rare species found in the pooled data set.

Rarity consistency throughout geographic range

Local abundances were registered for all Cactaceae species. However, the spatial variation in population size was calculated only for 27 species, as the seven remaining species were found in one site only. A new median was calculated for the 27 species evaluated (Me=320 plants/10000 m^2), and following Murray et al. (1999), we compared this value with the abundance value registered for each species in each sample site. We determined 1) consistently rare species (CRS), 2) consistently common species (CCS), and 3) species rare in some sites and common in others (RCS). A species was considered consistently rare if its local abundance in all sites was smaller than the median estimated for all species. If the local abundance for all sites was higher than the median calculated, the species was considered consistently common. In cases where a species presented both values (higher and lower than the median) it was classified as a rare species in some sites and common in others sites.

We then determine the proportions of CRS, CCS, and RCS species within each taxonomical and ecological group.

Results

Rarity level

Of the 34 species evaluated, 28 were identified as rare (categories WS, RS, or RL) and six as common (category WL) (Table 1). The rarest species (category RS, range restricted and with small populations) were

Denmoza rhodacantha, *Echinopsis aurea*, *E. leucantha*, *Gymnocalycium saglionis*, *Trichocereus terscheckii* and *T. thelegonus* (Table 1). The common species were *Airampoa ayrampo*, *Cleistocactus baumannii*, *Lobivia haematantha*, *Rebutia minuscula*, *Trichocereus schickendantzii* and *Tunilla corrugata* (Table 1).

Rarity patterns within taxonomic and ecological groups

Taxonomic groups. No differences were found among the patterns of rarity observed for the subfamilies with the patterns of rarity observed for the Cactaceae family (χ^2=2.86, g.l.=3, *P*=0.4134). Among the 25 evaluated Cactoideae species, 21 species were rare at some level (Table 1). In the Opuntioideae subfamily, seven of the nine studied species, were also rare in some form (Table 1).

All extremely rare species belonged to the Cactoideae subfamily (the RS category) (Figure 2, Table 1). However, geographically rare species with large populations were the most frequent in this subfamily (the RL category), followed by demographic rare species with wide distributions (the WS category) (Figure 2, Table 1).

The Opuntioideae subfamily had no range restricted species with small populations (the RS category) (Figure 2, Table 1). Most Opuntioideae species presented wide geographic ranges and small populations (WS category) (Figure 2, Table 1). In this subfamily, *Airampoa ayrampo* and *Tunilla corrugata* were the only common species (WL category) (Figure 2, Table 1).

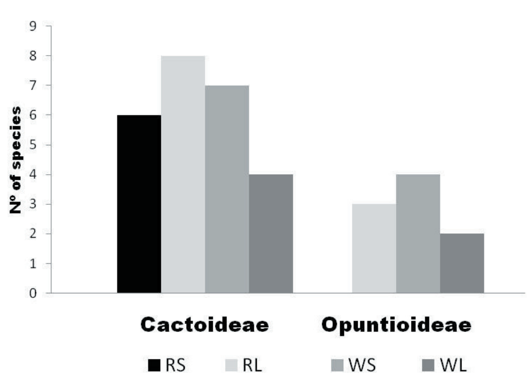

Figure 2. Rarity categories in each subfamily, Cactoideae and/or Opuntioideae, expressed in number of species.

Figura 2. Categorías de rareza en cada subfamilia, Cactoideae y/o Opuntioideae, expresadas en número de especies.

Growth forms. According to the Fisher exact test, there were no differences between the rareness patterns in each growth form with the rareness patterns registered for the family (χ^2=15.38, g.l.=9, *P*=0.0810). All barrel species and a high number of the columnar, globose, and articulate growth forms were rare at some level (category WS, RS or RL) (Table 1).

Three of the five barrel species were extremely rare (the RS category) (Figure 3, Table 1), while none of the articulate species qualified in this category. The articulate growth form was represented mostly by widespread species with small populations (the WS category) (Figure 3, Table 1). Half of the rare columnar species were widespread species with small population (the WS category) (Figure 3, Table 1). *Trichocereus terscheckii* and *T. thelegonus* represented the only two columnar species within the RS category (Table 1, Figure 3). The globose species were mostly restricted species with large populations (category RL) (Figure 3, Table 1).

Endemic versus non-endemic species. No differences between the pattern of rarity among the endemic and non-endemic species and the patterns observed for the family were found (χ^2=7.02, g.l.=3, *P*=0.0712). Sixteen endemic species and 12 non-endemic species were rare in some level (Table 1).

Among the endemic species, most had restricted ranges with large populations (the RL category) (Figure 4, Table 1). Only four of the endemic species evaluated were extremely rare (RS) (Figure 4, Table 1).

Among the non-endemic species, two species were extremely rare in the study region (*Echinopsis aurea* and *E. leucantha*) (Table 1), while most of the non-endemic species were widespread but with small populations (Figure 4, Table 1).

Rarity consistency throughout the geographic range

Cereus aethiops, *C. haenkeanus*, *Denmoza rhodacantha*, *Trichocereus atacamensis* and *T. terscheckii*, all from the Cactoideae subfamily, classified as CRS (consistently rare species) (Table 1). However, most species of the family fell in the RCS category (species rare in some sites but common in others) (Table 1). This category included all Opuntioideae species and more than a half of the species from the Cactoideae subfamily (Table 1). The remaining

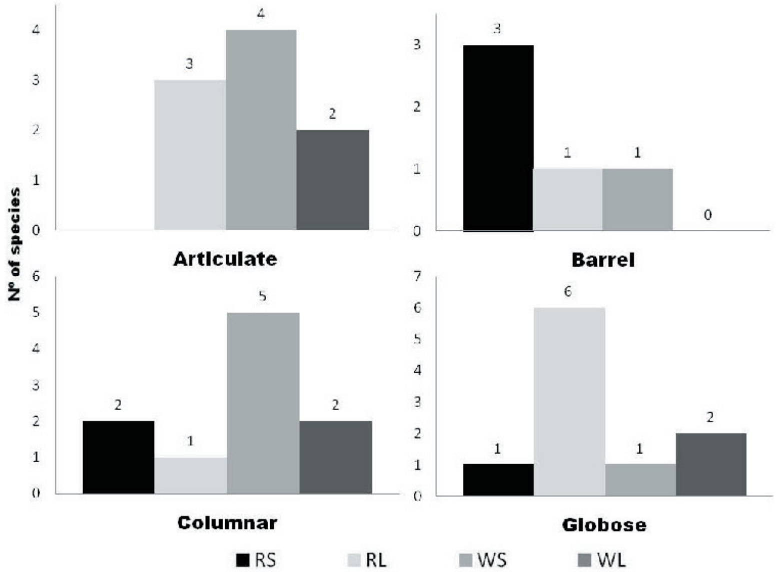

Figure 3. Rarity categories according to the growth forms: columnar, barrel, globose and articulate, expressed in number of species.

Figura 3. Categorías de rareza de acuerdo a las formas de crecimiento: columnar, barriliforme, globosa o articulada, expresadas en número de especies.

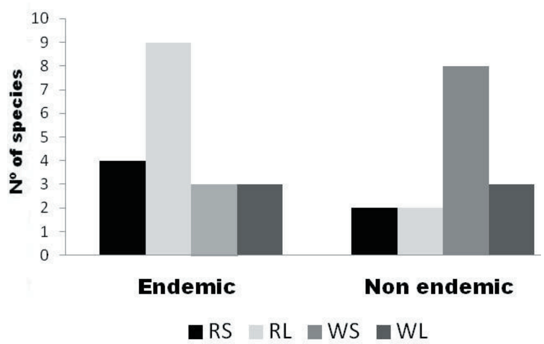

Figure 4. Rarity categories according to endemism (endemic or not endemic to the southern Central Andes), expressed in number of species.

Figura 4. Categorías de rareza según el endemismo (endémica o no endémica al sur de los Andes Centrales), expresadas en número de especies

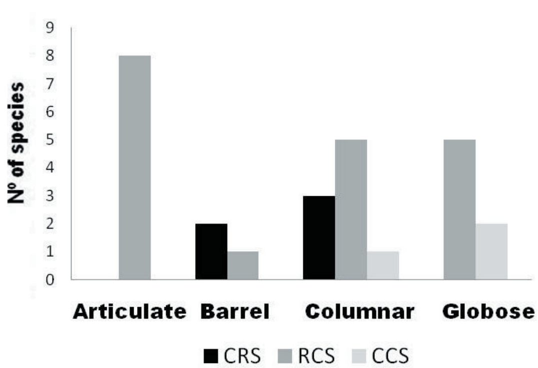

Figure 5. Number of CRS (consistently rare species), RCS (somewhere rare and somewhere abundant species) y CCS (consistently common species) based on growth forms.

Figura 5. Número de especies consistentemente raras (CRS), especies raras en algunos sitios y comunes en otros (RCS) y especies consistentemente comunes (CCS) según las formas de crecimiento.

of the Cactoideae species constituted the consistently common species category (CCS) (Table 1).

All consistently rare species (CRS category) had columnar or barrel growth forms (Figure 5, Table 1). The RCS category included all of the Cactaceae growth forms, though with a high number of articulate species (Figure 5, Table 1). Articulate and barrel species were absent in the CCS category (Figure 5, Table 1). The number of endemic and non-endemic species, in each abundance category, was similar, both having most species in the RCS category (Figure 5, Table 1).

Discussion

Rareness has been highlighted as one of the Cacataceae family characteristics (Hernández & Godínez 1994; Edwards & Westoby 2000; Godínez-Álvarez et al. 2003). Published studies suggest that Cactaceae species tend to be rare at local, regional, and global scales (see Hernández & Godínez 1994; Godínez-Álvarez et al. 2003; Saravia-Tamayo 2006). Therefore, many rarity studies within the family have focused on studying what causes rarity. Some attribute rareness to particular biological characteristics of the Cactaceae species (Godínez-Álvarez et al. 2003), while others point to climatic (Ruedas et al. 2006) or antropogenic factors (Ortega-Baes et al. 2010a) as the main cause. However, prior to evaluate the causes of rarity, it is important to know which species are rare and which are not, at a particular spatial scale.

We analyzed the rarity patterns among Cactaceae species in a part of the Southern Central Andes, in order to highlight species needing further conservation studies. Within the Calchaquíes Valleys, Cactaceae species tend to be rare as 28 of the 34 species evaluated were rare at some level (Table 1). We examined rarity within subfamilies (Figure 2), among growths forms (Figure 3) and among endemic compared to non-endemic species (Figure 4). None of these groups hold significantly larger proportion of rare species compared to what is observed at family level. Moreover, and coincident with other plants studies (Rabinowitz et al. 1986; Pitman et al. 1999; Murray & Lepschi 2004) consistently rare species (but not extremely rare species) represented a low percentage of the regional plant community while species rare in some sites but abundant in others were the most frequent (Table 1).

Among the extremely rare species (RS), we found *Denmoza rhodacantha*, *Echinopsis aurea*, *E. leucantha*, *Trichocereus terscheckii*, *T. thelegonus* and *Gymnocalycium saglionis* (Table 1). These species are geographically restricted and present small populations throughout the study region. All species belong to the Cactoideae subfamily present different growth forms and four of them are endemic to the Southern Central Andes (Table 1). Their extreme rarity could be natural or induced by human activities. In the present study, most of the extremely rare species (Table 1) presents low viable seed production (Ortega-Baes et al. 2010b) or are collected illegally as timber for coverings, furniture, and crafts (e.g., *T. terscheckii*) or for ornamental purposes (e.g., *E. aurea* [Ortega-Baes et al. 2010a]). Among the Cactaceae species evaluated in this study, these species are the most vulnerable to extinction whether caused by natural or anthropogenic disturbance so we suggest that these species should be monitored or included in special conservation programs as a precaution.

Denmoza rhodacantha and *T. terscheckii* presented consistent rareness in the entire area evaluated (Table 1), which suggest that these two species would need more attention in conservation matters. Saravia-Tamayo (2006) who analyzed different aspects of Cactaceae diversity within the same region pointed out that the scarce presence of *D. rhodacantha* is due to its limited distribution within the area, as *D. rhodacantha* is only found in the northern part of the valleys. However, the species is widely distributed beyond the study area (Zuloaga et al. 2008), hence its rarity or lack of abundance within the Calchaquíes Valleys may simply reflect that we have sampled the species at its geographic range limit where species abundance often decrease - compared to the abundance in the centre of a distribution (Gaston 2009). More studies are needed to assess the rarity status of this species outside the valleys, to evaluate whether *D. rhodacantha* appears as extremely rare across its entire distributional range. For the moment, we suggest that both *D. rhodacantha* and *T. terscheckii* should be monitored inside the protected areas where they are already present.

The remaining rare species (Table 1) are less vulnerable to environmental or human perturbations because they present demographic or geographic traits such as wide distributions and/or large populations, which improve their chance to persist. However, these species may still experience some threat or risk of extinction as a result of the regular human extractions for ornamental or commercial purposes (Ortega-Baes at al. 2010a) and/or the anthropogenic activities detected in the area of the Calchaquíes Valleys (Grau et al. 2005). We suggest to re-evaluated all species from time to time to verify their position within the rareness categories.

Of the 34 Cactaceae species here evaluated, some species are listed in the IUCN Red List of Threatened Species (2014) in the intermediate risk categories of extinction. Four are listed as "Vulnerable", two as "Near Threatened" and one as "Endangered". In general, we found a close match between IUCN's classification and our results. Of the species mentioned by IUCN (2014), all were classified as being rare in some form in the present analysis (Table 1). *Trichocereus angelesiae*, which is categorized as "endangered" by IUCN (2014), here found to be narrowly distributed but with large populations (RL) (Table 1). *Trichocereus terscheckii* and *T. thelegonus,* both defined here as extremely rare together with. *E. albispinosa* and *E. ancistrophora* (RL) (Table 1), were categorized as the "vulnerable species" by IUCN (2014) due to intensive land use change occurring in the Calchaquíes valleys. *Trichocereus atacamensis* (WS) (Table 1) and *Parodia aureicentra* (RL) (Table 1) appear as "Near Threatened" because they suffer from located threats such as collection/extraction from illegal collectors (IUCN 2014). None of the species here categorized as common species (Table 1) are currently affected by anthropogenic activities nor present in the IUCN list (2014). Our approach therefore seems to yield useful results as rareness in the present context appears to relate with vulnerability to extinction.

One of the basic challenges involved in the conservation of rare species is that the group to be protected is heterogeneous. There are no single conservation measures that will protect all species. If conducting this study at a larger geographic scale, some species may classify differently, as the locally rare species may change category when changing the scale of the study. However, the globally rare species found in the Calchaquíes Valleys *Trichocereus angelesiae*, *T. thelegonus*, *Echinopsis albispinosa*, *Parodia aureicentra* and *Tephrocactus molinensis* would still be rare. These species not only are endemic to the southern Central Andes (Table 1), but restricted to the Calchaquíes valleys; so, they would therefore maintain the same size of geographic range and abundances at larger scale. We recommend that these species should be considered for conservation, even if presenting large population sizes locally as they are vulnerable to any natural or human disturbance that occurs in the region. In agreement with Rabinowitz et al. (1986) and Crain et al. (2011), we argue that a rarity status that may vary over geographic scales is not a problem of the classification applied but rather emphasize that rarity must be considered at a variety of spatial scales, especially to achieve better conservation goals.

The results presented here will help to determinate the most adequate strategies for the conservation of each species according to the local population size and the geographic range described for the individual species (Table 1). Apparently, simply being present in a protected area, as many of the species classified as rare in the present study, is not enough to ensure a species long term conservation (Godoy-Bürki et al. 2014). The main efforts should focus on the implementation of "in situ" and "ex situ" protections strategies for the rarest species, on the development of efficient national regulations, and the control of national and international trade/collection of the most threatened (Oldfield 1997) in order to achieve an effective protection of Cactaceae species in the southernmost part of the Central Andes.

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