



Multiscale partitioning of cactus species diversity in the South Brazilian grasslands: Implications for conservation



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ABSTRACT

We investigated how cactus diversity at the regional level (γ -diversity) is distributed into within-unit diversity (α -diversity) and among-unit diversity (β -diversity), and analyzed the contribution of dissimilarity due to species replacement (turnover) and dissimilarity due to species loss (nestedness) to β -diversity patterns of cacti. We quantified the diversity of endangered small cacti using data from 34 $1^\circ \times 1^\circ$ cells spanning most of the South Brazilian grasslands (ca. 75%). We used the contribution diversity approach (richness-based) derived from additive partitioning and unit distinctiveness, and additive partitioning of β -diversity into turnover and nestedness components. Most of the γ -diversity was partitioned among units, showing that β -diversity played a fundamental role in determining the contribution of units to the region. The relative diversity contribution for 12 grid cells was higher than the average of all units, indicating a high distinctiveness and a high conservation value for these units, most of them ($N = 10$), inserted into the Pampa biome. Species turnover was responsible for most of the total β -diversity, suggesting an important role for spatial and/or historical constraints (e.g., dispersal limitation) in determining changes in cactus species composition in the study region. We suggest that cacti conservation strategies in the South Brazilian grasslands should preferentially include the Pampa grasslands along to borders with Argentina and Uruguay and that this will lead to an intensification of nature conservation efforts in general in the region.

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Introduction

Understanding how species diversity is distributed geographically within a region is a topic of key importance for the development of conservation strategies that intend to maximize biodiversity protection. As diversity levels are clearly scale-dependent (Whittaker, Willis, & Field 2001), efforts to maximize biodiversity protection at local and regional scales requires distinct conservation strategies. While maximizing species-level conservation at finer scales involves basically selection of one or more sites with highest species richness, maximizing conservation at

large scales (e.g., landscape, region, biome) involves selection of an adequate number of sites in which species compositions are dissimilar to one another (i.e., a set of sites with unusual species combinations) (Baselga 2010; Van Dyke 2008). When selecting sites with strongly different species composition (high beta diversity), regional-scale conservation can enhance the effectiveness of preservation of endemic and specialist species as well as of different evolutionary lineages (Van Dyke 2008). Furthermore, regional-scale conservation can help to maintain the requirements of species with high habitat specificity and poor dispersal ability such as the small globular cacti studied here.

The different levels of diversity are often described through three components (Whittaker 1960, 1972): alpha diversity (α) that measures species richness at a single site; beta diversity (β) that measures how diversified the sites are in species composition within a region; and, gamma diversity (γ) that measures the overall diversity within region, i.e., the species richness of a large number of sites in a geographic area (Legendre & De Cáceres 2013). Among

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these, β -diversity has played a major role to provide insights both for ecological-theory related research (e.g., which processes create and maintain biodiversity) and for conservation-oriented questions (e.g., how different communities are in a given area) (Jost et al. 2010; McKnight et al. 2007; Myers et al. 2013). In the conservation context, the concept of β -diversity has helped to identify sites with high compositional uniqueness or regions of rapid species turnover (Legendre & De Cáceres 2013; McKnight et al. 2007). Recently, Baselga (2010, 2012) pointed out that β -diversity reflects two different phenomena: the replacement of some species by others among sites (spatial turnover) and the species loss linked to variation in richness among sites (nestedness). Nestedness is characterized by the poorest site being a strict subset of the richest site, where no species is replaced by other (Baselga 2012).

Here, we measure the species diversity of low-growing cacti in the South Brazilian grasslands in order to (i) assess how diversity at the regional level (γ -diversity) is distributed into within-unit diversity (α -diversity) and among-unit diversity (β -diversity), and (ii) examine the contribution of dissimilarity due to species replacement (turnover) and dissimilarity due to species loss (nestedness) to β -diversity patterns of cacti. We quantified the diversity of endangered small cacti using data from $34\ 1^\circ \times 1^\circ$ cells (referred to herein as units) spanning most of the South Brazilian grassland region (grasslands in the state of Rio Grande do Sul). It is noteworthy that the necessity of conservation actions for cactus species in Brazil has recently been recognized in an action plan by the Brazilian Ministry of the Environment (MMA 2011), however, no concrete action has been taken so far. In particular, the study region, forming part of a global centre of diversity for small globular cacti (Boyle & Anderson 2002; Oldfield 1997), is biodiversity-rich and poorly studied in general (Overbeck et al. 2007), and more so regarding cacti (Saraiva & Souza 2012).

Methods

Study area

Brazil's southernmost state, Rio Grande do Sul (RS), contains approximately 75% of the grassland area of the South Brazilian grassland region (*Campos sulinos*, in Portuguese) (see Overbeck et al. 2007, for a review). Rio Grande do Sul, with a total area of 282.184 km², is under temperate climate (Cfa and Cfb types), with hot summers and cool winters, without a dry season (Peel et al. 2007). Grasslands form the natural vegetation of most of region (174.855 km²) (Cordeiro & Hasenack 2009); they are considered to be relicts from cooler and drier climatic conditions during glacial and post-glacial time, maintained until today through the action of grazing and fire (Behling & Pillar 2007).

In the northern part of RS, grasslands form mosaics with Araucaria forests in areas with undulating and strongly undulating relief, high precipitation (1500–2000 mm) and mean annual temperature ranging from 16 to 22 °C (Overbeck et al. 2007). In the southern half, grass-dominated vegetation types prevail, with many herb, shrub and treelet species co-occurring within the grass matrix in areas with flatter and slightly undulating relief, where annual precipitation (ca. 1200–1600 mm) and mean annual temperatures (13–17 °C) are both lower (Overbeck et al. 2007). In the Brazilian biome classification (Instituto Brasileiro de Geografia e Estatística 2004), the northern portion of RS was considered as part of the Mata Atlântica biome and southern portion as part of Pampa biome.

Data collection

The occurrence of cactus species was plotted onto a grid of cells ($N=34$) with a spatial resolution of 1° , covering most of the South Brazilian grasslands. Data on species occurrence were

compiled from regional herbaria, primary and secondary literature, and online databases, supplemented by our unpublished field data. We consulted the following indexed herbaria: ICN (Universidade Federal do Rio Grande do Sul, Porto Alegre, RS); PACA (Universidade do Vale do Rio dos Sinos, São Leopoldo, RS); and, HAS (Fundação Zoobotânica, Porto Alegre, RS) (Holmgren, Holmgren, & Barnett 1990). As the group in question has a considerable collectors' appeal and is well represented in hobby collections across the world, a vast amount of available qualitative descriptions on occurrence, morphology and taxonomy of the South Brazilian cacti is available in journals on cacti and succulents. The primary and secondary literature consisted of journal articles, reference texts (e.g., Anderson 2001; Hunt, Taylor, & Charles 2006) and journals on cacti and succulents published by the Cactus and Succulent Society of America (CSSA), British Cactus and Succulent Society (BCSS), International Cactaceae Systematics Group (ICSG) and International Society of the Friends of Notocacti (INTERNOTO). Online databases were represented by the Cactus and Succulent Field Number Query (<http://ralph.cs.cf.ac.uk/Cacti/fieldno.html>), which compiles field data from internationally recognized cactus collectors, and Cactus in Habitat (<http://www.cactusinhabitat.org/>), with information on taxonomy, distribution and conservation of cactus species in South America. When descriptions from these sources did not provide geographical coordinates of the habitats, we included only those that specifically reported the location where the specimens were recorded.

Although our study included only cacti with globular growth form, it is worth mentioning that there are other terrestrial growth forms in the study region, such as opuntoid cacti, *Opuntia elata* Link & Otto ex Salm-Dyck and *O. monacantha* (Willd.) Haw., columnar cacti, *Cereus hildmannianus* K. Schum., and clambering shrub or climbing vine cactus, *Pereskia aculeata* Mill. Nomenclatural details for individual names followed the ICSG (Hunt 1999; Hunt et al. 2006); the names currently accepted for the cactus species and subspecies were checked in the online database The Plant List (<http://www.theplantlist.org/>). A complete list of references used for compilation of data is available upon request from the authors.

The sampling design of this study included a large spatial extent (282.184 km²) and a spatial grain of 1° square (110 km aside). We consider, for practical reasons, $1^\circ \times 1^\circ$ cells as the minimum quadrat size (i.e., finest resolution) permissible given the large extent covered by study and collecting gaps that exist.

Data analysis

We applied the contribution diversity approach (species richness-based) by using additive partitioning ($\gamma = \alpha + \beta$) and unit distinctiveness ($\beta = \gamma - \alpha$) as proposed and described by Lu, Wagner, and Chen (2007). Under this approach, additive partitioning of diversity is given on the average number of species that occur within a unit and the average number of species absent from a randomly-chosen unit (Crist, Veech, Gering, & Summerville 2003). We then partitioned the contributions of the units into α and β components, and compare the relative importance of these components for species diversity at the regional level (γ) by help of a differentiation coefficient ($D_{ST} = \beta/\gamma$). The relative contribution values are expressed as their signed deviation from their mean, thus they may be positive or negative. According to Lu et al. (2007), a positive value means that the contribution of a unit to α , β or γ is higher than the average of all units, whereas a negative value indicates a below average contribution. Values of $D_{ST} > 0.5$ mean that most of the γ -diversity is distributed among sampling units. The grid cells with positive γ -diversity were considered as having high conservation priority and depicted in a map. As γ is the average amount of the diversity each unit contributes to the region, the units with positive γ -diversity are those that contribute more

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