



## ECOSYSTEM

# Peripampasic Arc: a route of dispersion for lichens

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**Abstract:** The Peripampasic Arc is a set of low mountains / hills that connects the Andes, as it scatters to the East forming mountainous areas of lower heights in north-eastern Argentina, with the Atlantic coastal range of the Serra do Mar in Brazil. Numerous studies proved its important biogeographic connection for plant and animal phylogenies, but no information of this pattern is known to lichens. The aim of this work is to establish if the dispersion route of the lichenbiota follows the previously known Peripampasic Arc. For this reason, a comparative study of each area regarding its similarities was analyzed, with emphasis on the biota of the Buenos Aires' Sierras. We quantified the similarity and  $\beta$  diversity of 104 saxicolous lichens species. There was a strong similarity between the Sierra de la Ventana and Tandil biota, which in turn is linked to the biotas of Uruguay, the Pampean Sierras and the northwest of Argentina. The lack of subgroups in the Peripampasic Arc implies the arc acts as a functional unit of dispersion, which is the most likely cause for the present lichens' distribution.

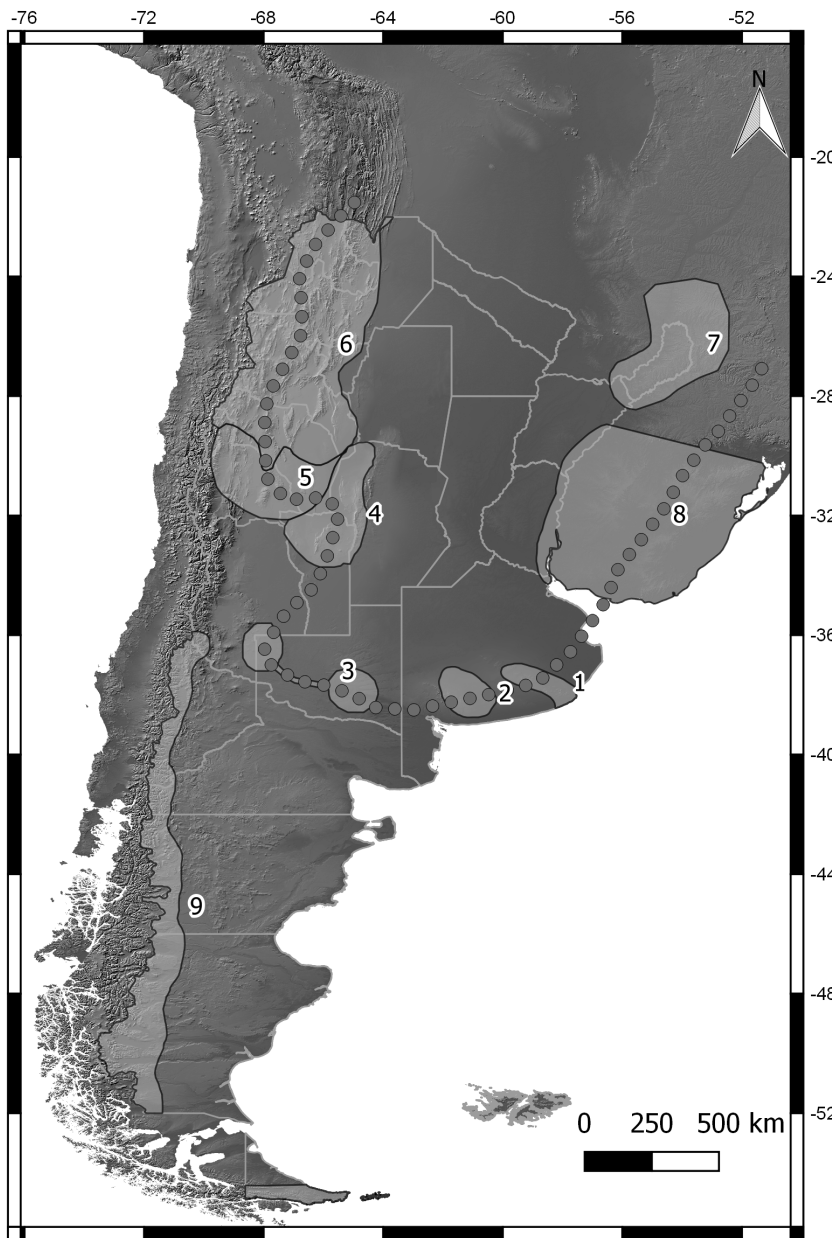
**Key words:** Biota, linkages, lichens, peripampasic, south, diversity.

## INTRODUCTION

The high Andean mountain range runs from North to South along the western side of South America, passing through western Argentina. In central and eastern Argentina, there is a set of scattered hills or 'Sierras' that form together with those of southern Uruguay, the so-called Peripampasic Arc (Figure 1, Frenguelli 1950). This Arc, owing to its unique biota, has attracted the interest of geologists and biologists (Darwin 1846, Cabrera 1938, Teruggi & Kilmurray 1975) as it harbours a large number of endemic species (Crisci et al. 2001, Grela 2004, Pinto da Rocha et al. 2005, Aagesen et al. 2009). The component sierras of the Arc share various degrees of similarity in their biota, after millions of years of geographic separation (Ringuet 1961, Acosta 1989, 1993, Mattoni & Acosta 1997, Crisci et al. 2001) and they are important for biodiversity

conservation from a biogeographic perspective (Szumik et al. 2007, Navarro et al. 2009, Nori et al. 2011). The rocky outcrops of the sierras are separated by forests or grasslands which provide at the same time isolation and connectivity (Aptroot & James 2002, García 2018).

Hicken (1919) proposed that the biotas of the Andes and Brazil were connected through the Sierras Pampeanas and of Buenos Aires (Ventania y Tandilia) and the Southern Brazilian Highlands. De la Sota (1967, 1972, 1973, 1985) and de la Sota et al. (2004) proposed that the Sierras Pampeanas and of Buenos Aires constituted intermediary stations for Pteridophytes between the Andean and Pampean and the southernmost South American or Austral and Antarctic and Austral and southern Brazilian floras. They proposed four routes of dispersion (Austral-Antarctic, Austro-Brazilian, Peripampasic and Andean). Arana et al. (2013) add new groups of Pteridophytes



**Figure 1. Peripampasic Arc**

● Study areas: 1-Tandilia; 2-Ventania; 3-San Rafael-Mahuida; 4-Pampean center's Hills; 5-Cuyan Pampeans hills and Precordillera; 6-North-West; 7-North-East; 8-Uruguay; 9-Patagonic mountain range.

and corroborated this hypothesis this time using panbiogeography; and added a new route to northwestern Argentina. This connection between the biotas of the Peripampasic Arc has also been shown for Asteraceae (Crisci et al. 2001), and some Arthropods (Maury 1973, Acosta 1989, 1993, Mattoni & Acosta 1997, Acosta 2002, Ferretti et al. 2012).

Lichens are biological entities capable of growing on a wide range of substrates, natural

or artificial, some species are substrate specific, while others are generalist (Holien 1996, Hauck & Spribille 2005). The ubiquity of lichens, together with the small size of their propagules (spores, soredia and isidia) and their slow rates of evolution have resulted in a large number of species being distributed worldwide (Kärnefelt 1990, Galloway 2008). Jørgensen (1983), based on the relatively low rate of evolution and the longevity of lichens, suggested that their

distribution could be an indicator of historic geological events. Following the hypothesis of Jørgensen (1983) and the review by Rodríguez et al. (2011) of the saxicolous species of *Usnea*, we undertook a study of the lichens of Peripampasic Arc to establish their biogeographic connections within the sierras of the Arc and with the Andes and other mountain ranges of South America.

The aim of this work is to establish if the lichen biota of the Buenos Aires Sierras follows peripampasic distribution pattern and to establish its biogeographic linkages with the rest of the mountainous areas of Southern South America.

## MATERIALS AND METHODS

Distributional data of 104 lichens species (Table I) were compiled from the collections of lichens of the Herbarium of the Instituto Spegazzini (LPS), the authors' personal herbaria, the GBIF (2017) database and from the literature (Osorio 1987, Stenroos et al. 1992, Athi 2000, Messuti & Vobis 2002, Adler & Calvelo 2007, Knudsen et al. 2008, Messuti & de la Rosa 2009, Rodríguez 2011, de la Rosa & Messuti 2014, Lavernia et al. 2016, Rodríguez et al. 2016). The species included were grouped by their substrate requirement (saxicolous, terricolous, lignicolous).

We compared the composition of eight areas, delineated by de la Sota et al. (2004) on the basis of orography, geology and regional biota, for distributional similarities (Figure 1); San Rafael-Mahuida, Area 3 of de la Sota et al. (2004) had no lichen records and it was not included in this study. For the comparison of the eight areas an out group was added (Isla Martín García) with its 47-strong epiphytic riparian forest lichenobiota and 3 species that are shared with rocky areas (García & Rosato 2015). A data

matrix of presence/absence of the 1359 records available was constructed for the 151 species, for the eight areas plus the out group (IMG).

For the analysis of  $\beta$ -diversity including the 104 species of the eight areas, and without including the out group, the Whittaker and Cody indices were selected to quantify and compare these sites because they are preferred in cases where differences in species richness between samples (or communities) need to be reflected in the measurement of  $\beta$  diversity (Cardoso et al. 2009). For the single link cluster analysis PAST (Paleontological Statistics) version 3.17 software was used to observe the similarities between the sites. In the Cody index the difference between sites is shown, therefore their values are lower if the sites are similar and increase as the sites differentiate. On the other hand, in the Whittaker index the values range from 0 (sites that share all the species) to 1 (sites without shared species).

To measure the similarity between the proposed areas, the Jaccard index was selected because it is recommended for presence-absence data (Real & Vargas 1996). To avoid the 'double-zero problem' (species absent from two sites), the asymmetrical Sørensen-Dice binary coefficient was selected, since it gives double weight to double presences, as absences may be due to various factors and does not necessarily reflect differences in the environment; double-presence, on the contrary, is a strong indication of resemblance (Legendre & Legendre 2012).

The maps were prepared with the use of the free software Quantum Gis and the shapefiles were downloaded from the IGN (Instituto Geográfico Nacional).

**Table I. Species presence in each of the 8 areas proposed and the outgroup. 1.Tandilia, 2.Ventania, 4.Pampean center's Hills, 5.Cuyan Pampeans hills and Precordillera, 6.North-West, 7.North-East, 8.Uruguay, 9.Patagonic mountain range, IMG. Isla Martín García (out group).**

Species	1	2	4	5	6	7	8	9	IMG
<i>Acarospora lorentzii</i>	1	1	1	0	1	0	1	0	0
<i>Acarospora malmeana</i>	0	0	0	0	0	0	0	0	0
<i>Acarospora rhabarbarina</i>	1	1	0	0	1	0	0	0	0
<i>Acarospora xanthophana</i>	0	0	0	0	1	0	0	0	0
<i>Bacidina pallidocarnea</i>	0	0	0	0	0	0	0	0	1
<i>Brownliella cinnabarina</i>	1	1	0	0	0	0	1	1	0
<i>Buellia glaucescens</i>	1	1	0	0	0	0	0	0	0
<i>Buellia punctatula</i>	1	0	0	0	0	0	0	0	0
<i>Buellia stellulata</i>	0	1	0	0	0	0	1	0	0
<i>Caloplaca americana</i>	0	1	0	0	0	0	0	0	0
<i>Caloplaca cerina</i>	0	0	0	0	0	0	0	0	1
<i>Caloplaca crocea</i>	0	0	0	0	0	0	0	0	1
<i>Caloplaca microphyllina</i>	0	1	0	0	0	0	0	1	0
<i>Caloplaca puiggarii</i>	0	1	0	0	0	0	0	0	0
<i>Caloplaca rugulosa</i>	1	1	0	0	0	0	0	0	0
<i>Candelaria concolor</i>	1	1	1	0	1	0	1	1	0
<i>Candelaria fibrosa</i>	1	0	1	0	1	0	1	0	1
<i>Candelariella aurella</i>	0	1	0	0	0	0	0	0	0
<i>Canoparmelia austroamericana</i>	0	0	0	0	0	0	0	0	1
<i>Canoparmelia crozalsiana</i>	0	0	0	0	0	0	0	0	1
<i>Canoparmelia rupicola</i>	0	1	0	0	0	0	0	0	0
<i>Canoparmelia texana</i>	0	0	0	0	0	0	0	0	1
<i>Carbonea latypizodes</i>	0	1	0	0	0	0	1	0	0
<i>Catillaria chalybaeoides</i>	1	0	0	0	0	0	0	0	0
<i>Chrysothrix candelaris</i>	1	0	0	0	0	0	1	1	0
<i>Chrysotrix candelaris</i>	0	0	0	0	0	0	0	0	1
<i>Cladia aggregata</i>	1	1	0	0	1	1	1	1	0
<i>Cladonia caespiticia</i>	1	0	0	0	0	0	0	0	0
<i>Cladonia chlorophaea</i>	0	1	0	0	1	0	1	1	0
<i>Cladonia furcata</i>	1	0	1	0	1	0	1	1	0
<i>Cladonia litoralis</i>	1	0	0	0	0	0	0	0	0
<i>Cladonia pleurota</i>	0	1	0	0	0	0	1	1	0
<i>Cladonia pyxidata</i>	1	1	1	0	0	0	0	0	0
<i>Cladonia subcariosa</i>	0	0	0	0	0	1	1	0	0
<i>Cladonia subsquamosa</i>	0	0	1	0	1	1	1	0	0
<i>Coenogonium isidiosum</i>	0	0	0	0	0	0	0	0	1
<i>Collema subconveniens</i>	1	0	0	0	0	0	0	0	0

**Table I. Continuation**

<i>Diploschistes actinostomus</i>	0	1	0	0	0	0	1	0	0
<i>Diploschistes cinereocaesius</i>	0	1	1	0	1	0	1	0	0
<i>Diploschistes diacapsis</i>	1	0	0	0	0	0	0	0	0
<i>Diploschistes ochraceus</i>	0	1	0	0	0	0	0	0	0
<i>Endocarpon pusillum</i>	1	0	0	0	0	0	0	0	0
<i>Flavoparmelia exornata</i>	0	0	0	0	0	0	0	0	1
<i>Flavoparmelia haysomii</i>	1	1	1	0	1	0	0	0	0
<i>Flavoparmelia papillosa</i>	1	1	1	0	1	0	1	0	0
<i>Flavoplaca austrocitrina</i>	1	1	0	0	0	0	0	0	0
<i>Glyphis cicatricosa</i>	0	0	0	0	0	0	0	0	1
<i>Graphis geraënsis</i>	0	0	0	0	0	0	0	0	1
<i>Graphis submarginata</i>	0	0	0	0	0	0	0	0	1
<i>Haematomma fenizianum</i>	1	0	0	0	0	0	1	0	0
<i>Haematomma persoonii</i>	0	0	0	0	0	0	0	0	1
<i>Hafellia fraudans</i>	0	0	0	0	0	0	0	0	1
<i>Hafellia parastata</i>	0	0	0	0	0	0	0	0	1
<i>Heterodermia comosa</i>	0	0	0	0	0	0	0	0	1
<i>Heterodermia diademata</i>	0	0	0	0	0	0	0	0	1
<i>Heterodermia squamulosa</i>	0	1	0	0	1	0	1	0	0
<i>Hyperphyscia adglutinata</i>	0	1	0	0	0	0	0	0	0
<i>Hyperphyscia adglutinata</i>	0	0	0	0	0	0	0	0	1
<i>Hyperphyscia syncolla</i>	1	1	0	0	0	0	0	0	0
<i>Hyperphyscia syncolla</i>	0	0	0	0	0	0	0	0	1
<i>Hypotrachyna livida</i>	1	0	0	0	1	1	1	0	0
<i>Hypotrachyna osorioi</i>	1	1	1	0	0	0	1	0	0
<i>Ingvariella bispora</i>	0	1	0	1	0	0	1	1	0
<i>Lecanora farinacea</i>	0	1	1	0	1	0	1	1	0
<i>Lecanora fusca</i>	1	1	0	0	0	0	1	0	0
<i>Lecanora helva</i>	0	0	0	0	0	0	0	0	1
<i>Lecanora microcarpa</i>	1	0	0	0	0	0	0	0	0
<i>Lecanora tropica</i>	0	0	0	0	0	0	0	0	1
<i>Lepraria gracilescens</i>	0	1	0	0	0	0	0	0	0
<i>Leptogium azureum</i>	0	0	0	0	0	0	0	0	1
<i>Leptogium cyanescens</i>	0	0	0	0	0	0	0	0	1
<i>Malmiella leptoloma</i>	0	0	0	0	0	0	0	0	1
<i>Normandina pulchella</i>	1	1	0	0	0	0	0	1	0
<i>Ochrolechia tartarea</i>	1	0	0	0	0	0	0	0	0
<i>Parmotrema austrosinense</i>	0	1	1	1	1	1	0	0	0
<i>Parmotrema cetratum</i>	1	1	0	0	0	0	0	0	0
<i>Parmotrema cetratum</i>	0	0	0	0	0	0	0	0	1

**Table I. Continuation**

<i>Parmotrema conferendum</i>	1	0	0	0	1	0	0	0	0
<i>Parmotrema eciliatum</i>	0	1	0	0	1	1	1	0	0
<i>Parmotrema eciliatum</i>	0	0	0	0	0	0	0	0	1
<i>Parmotrema fistulatum</i>	1	0	0	0	0	0	0	0	0
<i>Parmotrema perlatum</i>	1	0	0	0	1	0	0	0	0
<i>Parmotrema pseudobreviciliatum</i>	1	0	0	0	0	0	0	0	0
<i>Parmotrema reticulatum</i>	1	1	1	0	0	0	0	0	0
<i>Parmotrema reticulatum</i>	0	0	0	0	0	0	0	0	1
<i>Parmotrema tandilense</i>	1	1	0	0	0	0	0	0	0
<i>Parmotrema uruguense</i>	1	1	0	0	1	1	1	1	0
<i>Parmotrema ventanicum</i>	1	1	1	0	0	0	0	0	0
<i>Pertusaria patagonica</i>	1	1	0	0	0	0	0	1	0
<i>Physcia aipolia</i>	0	0	0	0	0	0	0	0	1
<i>Physcia alba</i>	0	0	0	0	0	0	0	0	1
<i>Physcia cinerea</i>	1	0	0	0	0	0	0	0	0
<i>Physcia convexella</i>	0	1	0	0	0	0	0	0	0
<i>Physcia crispa</i>	0	0	0	0	0	0	0	0	1
<i>Physcia erumpens</i>	0	0	0	0	0	0	0	0	1
<i>Physcia phaeocarpa</i>	1	0	0	0	0	0	0	0	0
<i>Physcia poncinsii</i>	0	1	1	0	0	0	0	1	0
<i>Physcia rolfii</i>	0	0	0	0	0	0	0	0	1
<i>Physcia sinuosa</i>	0	0	0	0	0	0	0	0	1
<i>Physcia stellaris</i>	0	0	0	0	0	0	0	0	1
<i>Physcia tribacia</i>	0	1	1	0	1	0	0	0	0
<i>Physcia undulata</i>	1	1	1	0	0	0	0	0	0
<i>Physcia undulata</i>	0	0	0	0	0	0	0	0	1
<i>Physciella chloantha</i>	1	0	1	0	0	0	0	0	0
<i>Porina nucula</i>	0	0	0	0	0	0	0	0	1
<i>Psora icterica</i>	1	1	0	0	1	0	1	1	0
<i>Punctelia borrieri</i>	1	0	0	1	1	0	1	1	0
<i>Punctelia colombiana</i>	1	0	1	0	1	1	0	0	0
<i>Punctelia constantimontium</i>	1	0	0	0	1	0	1	0	0
<i>Punctelia constantimontium</i>	0	0	0	0	0	0	0	0	1
<i>Punctelia hypoleucites</i>	1	1	1	0	1	0	1	0	0
<i>Punctelia hypoleucites</i>	0	0	0	0	0	0	0	0	1
<i>Punctelia perreticulata</i>	1	1	0	0	0	0	0	0	0
<i>Punctelia punctilla</i>	1	1	1	0	1	0	0	0	0
<i>Punctelia punctilla</i>	0	0	0	0	0	0	0	0	1
<i>Punctelia rudecta</i>	0	1	0	0	1	0	1	0	0
<i>Punctelia semansiana</i>	1	1	1	0	1	0	1	0	0

**Table I. Continuation**

<i>Punctelia subpraesignis</i>	1	1	1	0	1	0	1	0	0
<i>Pyrenula pyrenuloides</i>	0	0	0	0	0	0	0	0	1
<i>Pyxine berteriana</i>	0	0	0	0	0	0	0	0	1
<i>Pyxine cocoës</i>	0	0	0	0	0	0	0	0	1
<i>Pyxine subcinerea</i>	0	0	0	0	0	0	0	0	1
<i>Ramalina aspera</i>	0	0	0	0	0	0	0	0	1
<i>Ramalina celastri</i>	1	0	1	0	1	1	1	0	1
<i>Ramalina peruviana</i>	0	0	0	0	0	0	0	0	1
<i>Rhizocarpon disporum</i>	1	1	0	0	0	0	0	1	0
<i>Rhizocarpon interferunulum</i>	0	1	0	0	0	0	0	0	0
<i>Rhizocarpon superficiale</i>	0	1	0	0	0	0	0	0	0
<i>Teloschistes chrysophthalmus</i>	0	1	1	0	1	1	1	0	1
<i>Teloschistes exilis</i>	0	0	0	0	0	0	0	0	1
<i>Tephromela atra</i>	0	1	0	0	0	0	1	1	0
<i>Toninia sedifolia</i>	0	1	0	0	0	0	0	0	0
<i>Umbilicaria haplocarpa</i>	0	1	0	0	1	0	0	0	0
<i>Umbilicaria krempelhuberi</i>	1	1	0	0	0	0	0	0	0
<i>Usnea amblyoclada</i>	1	1	1	0	1	0	1	1	0
<i>Usnea densirostra</i>	1	1	0	0	0	0	1	1	0
<i>Usnea exigua</i>	1	1	0	0	0	0	1	0	0
<i>Usnea fastuosa</i>	1	1	0	0	0	0	1	0	0
<i>Usnea strigosa</i>	0	0	0	0	0	0	0	0	1
<i>Verrucaria aethiobola</i>	0	1	0	0	0	0	0	1	0
<i>Xanthoparmelia conspersa</i>	1	1	1	0	1	0	1	1	0
<i>Xanthoparmelia farinosa</i>	0	1	1	0	1	1	1	1	0
<i>Xanthoparmelia hypopsila</i>	1	0	1	0	1	0	0	0	0
<i>Xanthoparmelia microspora</i>	1	1	0	0	0	0	0	0	0
<i>Xanthoparmelia saxeti</i>	0	1	0	0	0	0	0	0	0
<i>Xanthoparmelia scabrosa</i>	0	1	0	0	1	0	0	1	0
<i>Xanthoparmelia squamans</i>	0	1	0	0	0	0	0	0	0
<i>Xanthoparmelia tinctina</i>	1	1	0	0	0	0	0	0	0
<i>Xanthoparmelia ulcerosa</i>	0	1	1	0	1	0	1	1	0
<i>Xanthoparmelia wrightiana</i>	1	1	1	0	1	0	1	0	0
<i>Xanthoria parietina</i>	1	0	0	0	0	0	1	0	0

## RESULTS

Both the Dice (Table II) and Jaccard (Table III) similarity indices showed a similar relationship among the groups. There was a central group formed by (((4 6) 8) 1) 2) ( $D = >0.5$ ,  $J = >0.4$ ). Within this, cluster 4 (Pampean center's Hills) and 6 (North-west) were the most similar ( $D = 0.676$  and  $J = 0.51$ ). Sites 9 (Patagonic mountain range), 7 (North-East) and 5 (Cuyan Pampeans hills and Precordillera) were grouped with the central cluster (Figures 2 and 3); the outgroup (IMG) was separated from the cluster of eight groups of the Arc.

The highest values of turnover (TO) using the Whittaker index (Table IV) were found between Area 5 and the rest, with Area 1 being the most different from Area 5. The lowest values of TO were between Areas 1 and 2, 6 and 8 and 4 and 6, with the last group with the lowest TO. TO calculated by using the Cody Index (Table V) showed highest differences between Areas 5 and 7 and Areas 1 and 2; the smallest was found between Areas 5 and 9 and 5 and 7 (the latter being the lowest of all), both of them outside of the Peripampasic Arc.

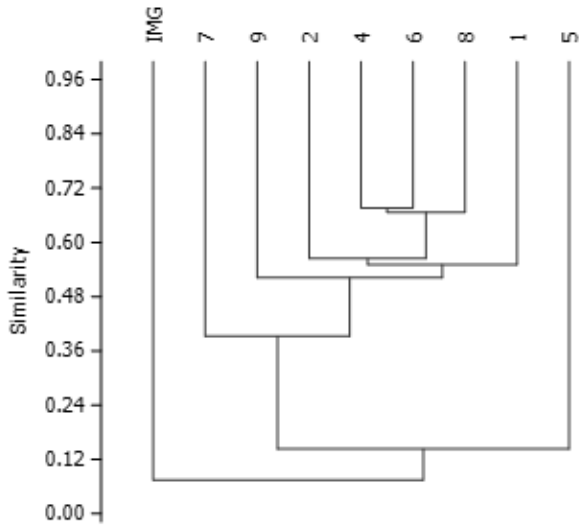
**Table II. Asymmetrical binary coefficient of Sorensen-Dice, for the 9 areas and the 151 species.**

	1	2	4	5	6	7	8	9	IMG
1	1	0.551	0.458	0.029	0.476	0.132	0.495	0.311	0.035
2		1	0.462	0.053	0.496	0.143	0.564	0.449	0.016
4			1	0.059	0.676	0.286	0.507	0.286	0.074
5				1	0.093	0.143	0.085	0.143	0.000
6					1	0.392	0.667	0.400	0.067
7						1	0.327	0.167	0.066
8							1	0.522	0.064
9								1	0
IMG									1

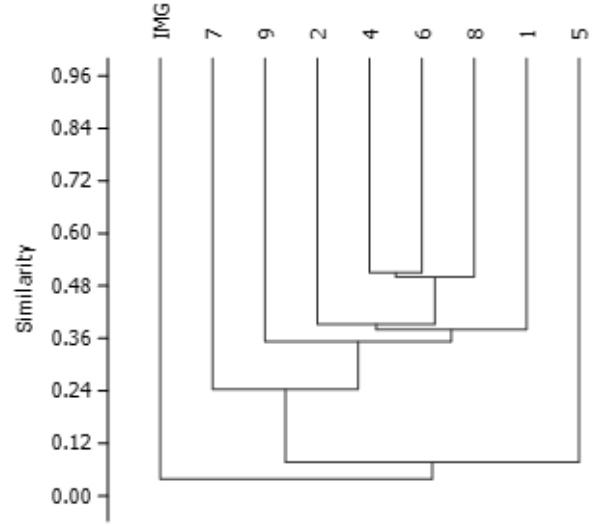
**Table III. Similarity coefficient of Jaccard, for the 9 sites and the 151 species.**

	1	2	4	5	6	7	8	9	IMG
1	1	0.4	0.297	0.015	0.313	0.07	0.329	0.184	0.0177
2		1	0.3	0.027	0.329	0.077	0.393	0.289	0.008
4			1	0.03	0.511	0.167	0.339	0.167	0.038
5				1	0.0488	0.077	0.044	0.077	0
6					1	0.244	0.5	0.25	0.034
7						1	0.196	0.091	0.034
8							1	0.353	0.033
9								1	0
IMG									1





**Figure 2.** Cluster of the coefficient of Sorensen-Dice, for the 9 areas and the 151 species. Cophenetic correlation= 0.932.



**Figure 3.** Cluster of coefficient of Jaccard, for the 9 areas and the 151 species. Cophenetic correlation= 0.935.

**Table IV.** Index of  $\beta$  diversity of Whittaker, for the 8 sites and the 104 species.

	1	2	4	5	6	7	8	9
1	0	0.44286	0.54639	0.97101	0.5283	0.84615	0.4955	0.71111
2		0	0.54286	0.94805	0.50877	0.83721	0.42857	0.57143
4			0	0.94118	0.32394	0.72093	0.5	0.70909
5				0	0.90698	0.86667	0.91667	0.85185
6					0	0.1538	0.34118	0.625
7						0	0.64912	0.88889
8							0	0.50725
9								0

**Table V.** Index of  $\beta$  diversity of Cody, for the 8 sites and the 104 species.

	1	2	4	5	6	7	8	9
1	0	31	26.5	33.5	28	33	27.5	32
2		0	28.5	36.5	29	36	25.5	28
4			0	16	11.5	15.5	19	19.5
5				0	19.5	6.5	22	11.5
6					0	16	14.5	20
7						0	18.5	16
8							0	17.5
9								0

## DISCUSSION

Hicken (1919) and Brade (1942) have postulated the existence of a biogeographical dispersal route of vascular plants from the Andes to Brazil, through the Pampean ranges, Ventania, Tandilia, and Uruguay up to the south-eastern Brazilian mountains. This has been confirmed by several studies (de la Sota 1985, de la Sota et al. 2004, Ferretti et al. 2012, 2014, Arana et al. 2013). This is the first time an analysis of this route encompassing the lichen biota of southern South America has been carried out.

A great similarity is observed between Areas 2 (Ventania) and 1 (Tandilia), as it has been observed by other authors and for various species, this close union is not only because of the proximity between them, but because it is part of one of the routes of the Peripampasic Arc (Cabrera & Willink 1973, Frangi & Bottino 1995, Acosta 2002, Rodríguez & Estrabou 2008, Ferretti et al. 2012, Arana et al. 2013, Culebra Mason et al. 2017). Both analyses of similarity have shown that there is a strong relation between the biotas from Ventania and Tandilia, which in turn is linked to the biotas of Uruguay, the Pampean Sierras and north-west Argentina, corresponding to the Peripampasic Arc proposed by Frenguelli (1950). The  $\beta$  diversity analyses show a lower turnover between the sites within the Peripampasic Arc and with those outside it, such as Patagonia and the pre-Cordillera. This could be explained by the fact that the dispersion range is variable among species, so although there is a relationship between the biota, the dispersal capacities of each species will allow some species to be present at all sites while others will not be present. As it has been observed for other organisms (de la Sota 1985, de la Sota et al. 2004, Ferretti et al. 2012, 2014, Arana et al. 2013), the link between the biotas from the Peripampasic Arc is evident, although there is also some indication of relations with the biota that is outside it (de la Sota et al. 2014).

In the Ventania area, the basin was tectonically active from Lower to Upper Palaeozoic (Sellés-Martínez 2001). Tandilia, on the other hand, was part of the Rio de La Plata craton (together with north-eastern Argentina, eastern Paraguay, Uruguay and south-eastern Brazil) before the end of the Precambrian (570 Ma) (Pankhurst et al. 2003, Rapela et al. 2007). Lichens belong to a very ancient group, some of them even present from the Early Devonian (Taylor et al. 1997, Karatygin et al. 2009), many species have a low mutation rate and a very extended life, with some species even following a Gondwanan distribution which indicates their presence prior to the separation of the continents (Rikkinen & Poinar 2002, Galloway 2008). Therefore, lichens could have occupied these mountain ranges and from there reached the rest of the Peripampasic Arc; unfortunately, there is little fossil evidence that can corroborate this assertion.

The distributions of the biota of the southern South America were affected mainly by climatic and geomorphological phenomena that began during the second part of the Tertiary: during the marine transgression, the lands that emerged corresponded to the mountain ranges of Tandilia, Ventania, Pampean and Subandean (Ortíz-Jaureguizar & Cladera 2006). The other major event took place from the Miocene to Pliocene, when the climate changed and became drier in southern South America due to the slow rise of the Andean chain and the cold Humboldt Current that intensified aridity (Villagrán & Hinojosa 1997, Gregory-Wodzicki 2000, Zachos et al. 2001, Crisci et al. 2001, Ferretti et al. 2012, 2014). De la Sota (1967, 1972, 1973, 1985) established in numerous works that the mountains of Buenos Aires and Sierras Pampeanas are intermediary stations in the migration between the Andean-Pampean biotas and the Australantartic and Austrobrasilian biotas. This supports the existence of an ancestral biota fragmented by tectonic events or climatic changes (Crisci et al. 2001, Arana et al. 2013). Given the evidence of this

biota fragmentation along the Peripampasic Arc by natural events, it is not far-fetched to assume that the lichen biota that existed at that time also suffered the same events of fragmentation. The Peripampasic Arc differs from its surroundings in being a rocky structure surrounded by a matrix of grasslands and forests (Cabrera & Willink 1973), many of the lichen species depend on a rocky substratum, so they are unable to grow in the environments that surround the mountains, as was postulated for ferns (de la Sota 1967), Therefore, the majority of species will be dispersed only between the components of the Peripampasic Arc and with other mountain ranges.

Outside the Peripampasic Arc there are other areas that also show links, although with less connection, possibly due to the geographical distances, barriers and climatic conditions that make even anemochory dispersion difficult (Heinken 1999, Muñoz et al. 2004). There is also a relationship with the austral biota (Area 9), as observed for Pteridophytes (de la Sota et al. 2004); in this case, the mesoclimatic characteristics of the sierras of Buenos Aires favour the establishment of species from colder climates (Kristensen & Frangi 1995, 1996). This similarity between the groups of lichens and Pteridophytes can be due to their similar requirements (both groups of saxicolous species require rock as a substrate) (Brodo 1973, Barrington 1993, Tuomisto & Ruokolainen 1994, Shirazi et al. 1996) and are dependent on the wind to transport their reproduction structures (Ingold 1971, Pyatt 1973, Geiger et al. 2007, Noblin et al. 2012). Area 7 is peripheral, showing a little relationship with the Peripampasic Arc, although it is far away and possibly related to the lichen biota of southern Brazil and Paraguay (de la Sota et al. 2004). In this type of tropical environments, the vegetation of vascular plants usually covers the rocky outcrops, leaving little space for the saxicolous lichen, which also explains the low richness of the area. On the other hand, the separation of Area 5 is striking,

since it is located in the Peripampasic Arc, but in this case the distance in terms of its biota can be explained by the lack of references of lichen that exist for this area (Liberatore et al. 2002). Although there are some species that can grow on both rock and bark, the inclusion of the external group (IMG) shows that there is a great difference between the biota of the areas within the Peripampasic Arc and those outside of this dispersal route.

## CONCLUSION

In this first analysis of the lichen biota on Peripampasic Arc, the lack of subgroups between the Areas studied suggest the importance of this Arc for the distribution of these lichens, strongly implying the Arc as a functional unit for their dispersion.

The lichen biota of the Peripampasic Arc may have been fragmented by natural events, being separated by large extensions of flat land, but maintaining a relationship between them and showing the existence of relationships with other lichen biotas existing outside this arc.

There are great gaps in the knowledge of the lichens of Argentina which make difficult the understanding of their dispersal patterns. Nonetheless this preliminary analysis on the basis of both bibliography records and collections (both from public and private herbariums), for the first time, allows to discern a general pattern, which resemble the ones proposed for other organism with similar habitat requirement. Further studies of the lichen biota of this area, will fill this gap, allowing a better understanding of the biogeographical relation of the South American lichen biota.

## Acknowledgments

We want to thank Federico Lozano, Vilma Rosato and to the anonymous reviewers who with their contributions improved this manuscript. This research did not receive

any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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#### How to cite

GARCÍA RA & DEL PALACIO A. 2021. Peripampasic Arc: a route of dispersion for lichens. *An Acad Bras Cienc* 93: e20191208. DOI 10.1590/0001-3765202120191208.

*Manuscript received on October 03, 2019;*  
*accepted for publication on January 12, 2020*

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Alejandro del Palacio: Investigation, Methodology, Formal analysis, Writing - review & editing.

