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RESEARCH ARTICLE

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Bosque Pehuén Park's Flora: A Contribution to the Knowledge of the Andean Montane Forests in the Araucanía Region, Chile

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ABSTRACT: In Chile, most protected areas are located in the southern Andes, in mountainous landscapes at mid or high altitudes. Despite the increasing proportion of protected areas, few have detailed inventories of their biodiversity. This information is essential to define threats and develop long-term integrated conservation programs to face the effects of global change. Consequently, the objectives of this study were to (1) describe the richness, conservation status, and species composition of the vascular flora found in Bosque Pehuén Park; and (2) analyze the relationships among altitude, species richness, and growth forms. Bosque Pehuén is one of the largest privately protected areas located within the Araucarias Biosphere Reserve, in southern Chile (39°S). The park is dominated by secondary forests that grew after intensive exploitation in the 1970s, with some remnant old-growth forests. Fifteen regularly distributed plots, 150 m in radius, were sampled. At each plot, all vascular plant species were recorded; 101 species were found, of which 79% are endemic, 10% are introduced, and 13% are currently listed in IUCN conservation categories. The highest richness was concentrated within the plots associated with riparian zones. The total richness tended to decrease with altitude. Epiphytes and climbers were only recorded at lower altitudes, making them the growth forms most influenced by altitude. The background information reported here is essential for effective park management and conservation of the vascular flora species found within this Andean montane forest.

Index terms: Araucarias Biosphere Reserve, privately protected areas, temperate Andean forest, vascular plants

INTRODUCTION

There are around 500,000 land plant species on Earth, of which approximately 462,000 correspond to vascular plants (Corlett 2016). According to the International Union for Conservation of Nature, there are 4763 threatened or even extinct vascular plant species in forest ecosystems (IUCN 2018). Plants are not only important because of their high species richness, they are also the main group defining terrestrial ecosystems (Josse et al. 2003; Brummit et al. 2015), in addition to their roles and services, such as producing oxygen, regulating the climate, and providing habitat and food for many other species. In spite of plants' importance, they have received less attention and resources for their conservation than other more charismatic taxonomic groups, such as animals (Jackson and Kennedy 2009). Nevertheless, relevant and worldwide recognized conservation strategies, such as biodiversity hotspots, are based on plant diversity. There are currently 35 areas in the world recognized as biodiversity hotspots, because they have at least 1500 species of endemic vascular plants and 70% of their surface area is threatened by habitat loss (Myers et al. 2000; International Conservation 2014). Therefore, hotspots are priority sites for conservation that are defined by the number of endemic vascular plant species they contain, but aim to protect all of the associated and threatened species that live within their boundaries.

One of the biodiversity hotspots is the Chilean Winter Rainfall-Valdivian Forests, which is located between 33°S and 45°S, covers 397,142 km^2, has around 4000 vascular plant species (of which more than a half are endemic), and at least 80 species of endemic animals (International Conservation 2014). In Chile, the National System of Government Protected Areas (SNASPE, an abbreviation of the Spanish title *Sistema Nacional de Áreas Silvestres Protegidas del Estado*) is the government's main conservation mechanism and covers 20% of the country, one of the highest percentages in Latin America (Sierralta et al. 2011). Despite the efforts of SNASPE and the importance of the natural protected areas (PA), which are the most effective tool for in situ conservation of biodiversity and ecosystem services (Rodrigues et al. 2004; Chape et al. 2008; Watson et al. 2016), only approximately 50,000 km^2 of the total area of this Chilean hotspot is protected by this system (International Conservation 2014). Also, most of these PAs are located above 42°S, while the most species-rich and endemic forests are concentrated between 36°S and 40°S (Armesto et al. 1998). Currently, this Chilean hotspot is not only threatened by direct human activities, but is also facing the threat of climate change. By the end of 2030, it is expected that temperatures will rise at least 0.5 °C, with a decrease in precipitation throughout southern-central Chile (Ministerio del Medio Ambiente 2017). Alarcón and Cavieres (2015) estimated that plant species associated with forest ecosystems in Chile will change their habitat size as a response to climate change effects, and many of them will need more PAs in order to guarantee the availability and protection of new potential niches. Under this scenario, conservation initiatives that provide additional support to government programs are urgently needed.

Private conservation initiatives carry out an important role as buffer zones or biological corridors among larger PAs—like government areas. They can also act as core ecosystems in highly degraded landscapes (Armesto et al. 2002). In Chile, over the last 20 y, many privately protected areas (PPAs) belonging to small (<200 ha), medium (200–1000 ha), and large (>1000 ha) landowners have been established and together protect more than 1,600,000 ha (Núñez-Ávila et al. 2013). A particularity in Chile is that most PPAs tend to be placed at lower altitude than government PAs. Therefore, the existing PPAs complement the protection provided by government areas since 50% of the total vegetation associations that are underrepresented or absent in the SNASPE are under the protection of PPAs (Calcagni et al. 1999; Pauchard and Villarroel 2002). Despite this, most PPAs lack basic species inventories, even though this information is essential to define their contribution to biodiversity conservation, to create management plans, to carry out environmental education programs, and to plan integrated management with other protected areas nearby (Oltremari and Thelen 2003; Squeo et al. 2008).

La Araucanía region (38.5°S) is located at the latitude with higher richness of vascular plant species within the Chilean hotspot (Villagrán and Hinojosa 2005). This area has also undergone an increase in deforestation activities since the beginning of the 1970s, including the replacement of native forest with exotic plantations, anthropogenic fires to create grasslands, and the extraction of highly valued timber of native species, such as *Nothofagus alpina* (Poepp. et Endl.) Oerst. (Otero 2006; Quezada 2008). The deforestation rate in this region during the period 1999–2008 was 2.9%, surpassing the previous peak, which occurred between 1973 and 1987 (1.7%; Miranda et al. 2015). Nevertheless, during the early 2000s La Araucanía region also experienced an increase in conservation initiatives in Andean zones (Pliscoff and Fuentes 2008), reaching a total of 29,716 ha protected by private conservation areas by 2013 (Núñez-Ávila et al. 2013).

One of the largest PPAs in the Andean zone of La Araucanía region is Bosque Pehuén Park. This protected area (882 ha) was established in 2006. It is located in the Andes mountain range, covering an altitude gradient between 860 and 1400 m.a.s.l., in a buffer zone within the Araucarias Biosphere Reserve (ABR), declared as a protected area by The United Nations Educational, Scientific and Cultural Organization (UNESCO) in 1983. This park is representative of many Andean forests in this area since it has suffered the exploitation of forest resources throughout the last 40 y (Quezada 2008), mostly during the 1970s due to the massive extraction of large *N. alpina* trees. Although Bosque Pehuén Park has been protected for over 10 y, there is still no comprehensive knowledge regarding the biodiversity currently inhabiting the park because no detailed species inventories have been carried out.

To evaluate the contribution of Bosque Pehuén to the conservation of vascular Andean plants, we carried out a floristic inventory using a rapid and systematic method to sample vascular plant richness. In addition, this PPA's altitudinal gradient allows for comparative analyses of species richness at different altitudes, which could permit the establishment of segregation patterns of species, similar to those reported in other works, such as Moreno et al. (2013) and Becerra and Cruz (2000). Growth forms were included in our study because these provide basic information regarding the structure of the vegetation, their functional roles, and life strategies (Díaz et al. 2015), which contribute to an explanation of the variations of species assemblies across the landscape (Kremers et al. 2015). Consequently, the objectives of this study were to (1) describe the richness, conservation status, and species composition of the vascular flora found within Bosque Pehuén Park; and (2) analyze the distribution of vascular species richness and growth forms across the park. This baseline information is important to determine the real input of this area to the conservation of montane Andean flora and to facilitate the development of adequate management strategies in addition to a long-term monitoring plan capable of detecting changes in plant diversity in the Araucarias Biosphere Reserve.

METHODS

Site Description

Bosque Pehuén Park (882 ha) is owned by Fundación Mar Adentro and is located in the foothills of the Quetrupillán Volcano (39°44′S, 71°74′W), in the southern Andes, La Araucanía Region, Chile (Figure 1). The park has an extensive plain, with less than 20° slope, surrounded by hills with slopes greater than 50°. The climate is temperate cold, with snowy winters and hot summers. The annual temperature and precipitation recorded at the nearest climatic station (Pucón town) are 10 °C and 2300 mm, respectively (Agromet-INIA 2015). Bosque Pehuén Park has lower temperatures than Pucón town due to its higher altitude, with frequent snowfall in the winter. In 2015, there were more than 60 days with temperatures below 0 °C. This park most likely receives less precipitation than the meteorological station located in Pucón due to the rain shadow effect produced by the Villarrica Volcano located directly to the west of the park.

The predominant vegetation type corresponds to an Andean temperate deciduous forest with dominant tree species such as *Nothofagus alpina* and *Nothofagus dombeyi* (Mirb.) Oerst. (Luebert and Pliscoff 2006). The lowlands (860–1000 m.a.s.l.) correspond mainly to secondary forests of *N. alpina*, *N. dombeyi*, and *Nothofagus obliqua* (Mirb.) Oerst, although occasional individual trees of *Saxegothaea conspicua* Lindl. and *Laureliopsis philippiana* Looser (Schodde) can be found on more humid, shady slopes. Most of the trees in these secondary forests are 20–30

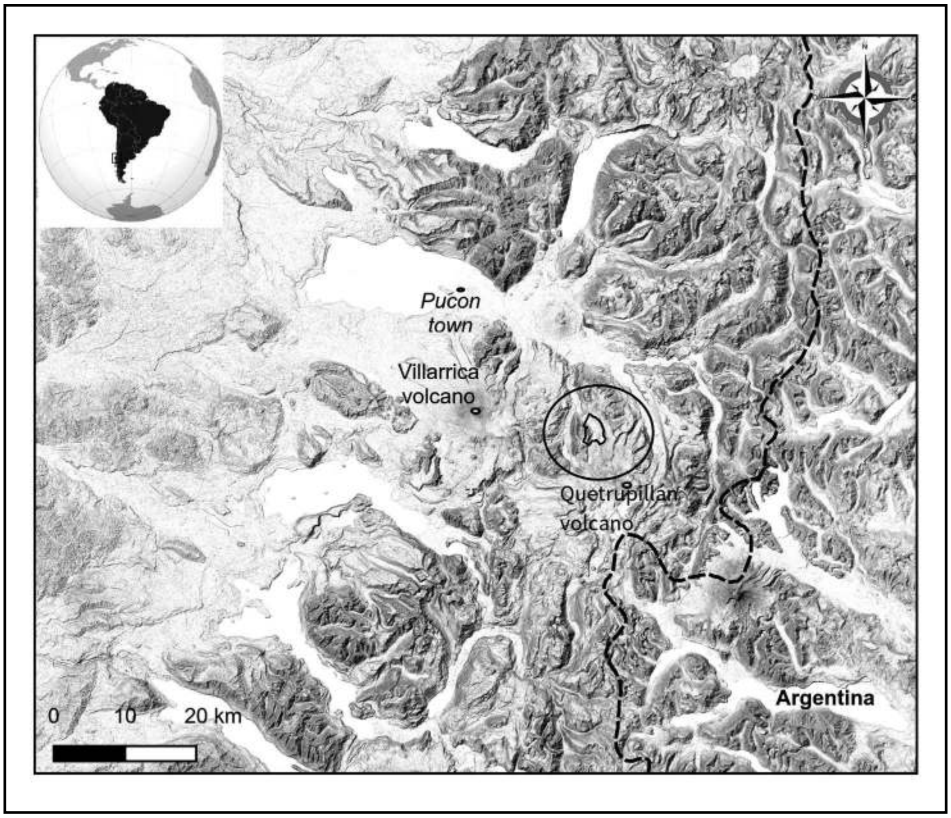

Figure 1. Location of Bosque Pehuén Park, La Araucanía Region, Chile.

cm in diameter at breast height (dbh), with occasional individuals of more than 120-cm dbh. In areas that are difficult to access, the secondary forest becomes more heterogeneous, with large trees mixed with young trees and a more complex vertical stratification. At mid-altitudes (1050–1200 m.a.s.l.) the vegetation corresponds to old-growth forest of *N. dombeyi* and *N. alpina*, with trees from 20-cm dbh to large *N. dombeyi* trees greater than 150-cm dbh. In the highest areas (above 1250 m) the vegetation type corresponds to an Andean temperate deciduous forest of *Nothofagus pumilio* (Mirb.) Oerst. and *Araucaria araucana* (Molina) K. Koch (Luebert and Pliscoff 2006). In these forests, occasional individuals of *N. dombeyi* are found, along with numerous signs of former fires. Individuals of *A. araucana*, *N. dombeyi*, and *N. pumilio* can reach over 100-cm dbh. Some grasslands of anthropogenic origin can be found across the area; these are dominated by introduced species such as *Taraxacum officinale* FH Wigg, *Lotus pedunculatus* Cav., *Prunella vulgaris* L., and *Holcus lanatus* L., with some native species including *Acaena ovalifolia* Ruiz et Pav. and *Acaena pinnatifida* Ruiz et Pav. These pastures were created for grazing cattle, and are currently being repopulated by second-growth *N. dombeyi*, *N. pumilio*, and *A. araucana* trees, as well as *Chusquea culeou* E. Desv. and other shrubs.

Field Collection Methods

Using a geographic information system (Quantum GIS), a grid of 900 × 900 m was drawn on a map of the park. At each node, a sampling plot 150 m in radius was defined, with a total of 15 plots established throughout the park (Figure 2). Eight of the 15 sampled plots were located in areas completely covered by secondary forest, only one was covered by old-growth forest, four were partly covered by secondary forest and grasslands, one was covered by both secondary forest and shrubland, and one plot's vegetation consisted of shrubland, secondary forest, and grassland. The plots covered an altitudinal gradient of 860–1340 m. Each plot comprised an area of 7 ha; thus, the total area of the 15 plots was 105 ha, 12% of the park's surface area. Each plot was divided into four quadrants according to the cardinal directions. A group of four researchers sampled the quadrants for 5 hr, covering, on average, 3 km of linear trajectory per point. Two plots had a slope greater than 70%; in these cases, the central point was moved 20 m for the researchers' safety.

All vascular plant species were recorded within the 15 plots, and samples of those species not recognized in the field were taken for later classification in the laboratory. The species were classified using information provided by Zuloaga et al. (2009). All species were thus classified as endemic from Chile and Argentina, native, or introduced. The growth forms used correspond to those used by Moreno et al. (2013). Information regarding the conservation categories of the registered species follows the Regulation for the Classification of Chilean Species (RCE abbreviated from the Spanish title *Reglamento para la Clasificación de Especies*), last updated in September 2014 (Ministerio del Medio Ambiente 2016). In addition, the International Union for the Conservation of Nature version 3.1 (IUCN 2017) and Hechenleitner et al. (2005) were also utilized to categorize the conservation status of certain species. Finally, for ferns we used the study carried out by Baeza et al. (1998) on the threatened pteridophytes of Chile. Within these categories, it was decided to include those species in the "Least Concern" category, since their classification alone reflects the fact that they have been evaluated under some cataloging process, even though they are not currently under threat. Most of the species found were herborized and currently form part of a reference herbarium in the Fundación Mar Adentro. The data obtained within these sampling plots were complemented with floristic records taken outside the plots by the authors of this study. These records were incorporated into the park's general list of species, but were not incorporated into data analyses. In this work, the flora found in the grasslands was excluded because it has an anthropogenic origin and is dominated by exotic species used as fodder for cattle. Therefore, this study was focused on native vascular species and

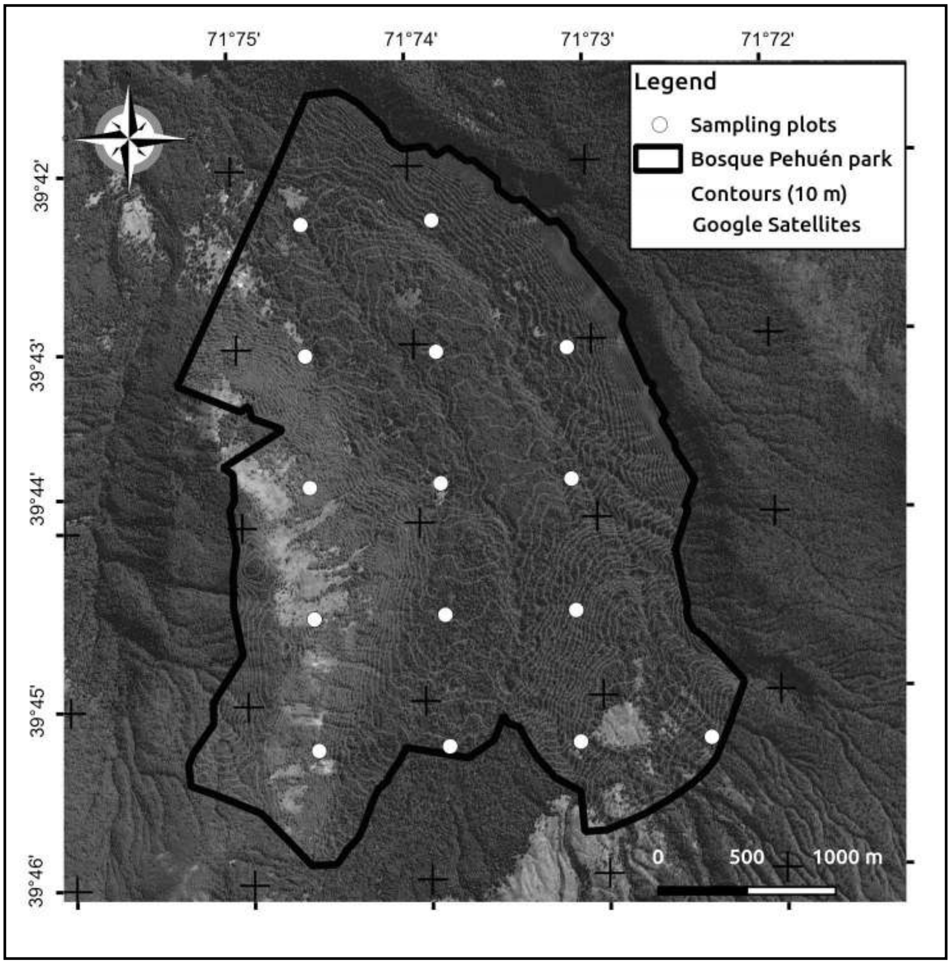

Figure 2. Grid of sampling plots distributed within the Bosque Pehuén Park boundaries.

exotic vascular plants, or non-grasses, and mostly forest oriented.

Statistical Analyses

The dataset collected corresponded to presence/absence of species per plot. A rarefaction analysis curve was carried out to determine if the sampling effort was suitable for detecting most of the species in the park, together with the estimation of the total number of possible species to be found using the Chao 2 estimator (Hsieh et al. 2016), which was deemed the most reliable estimator due to the limitations of the data obtained. The rarefaction curve was performed with R 3.2.2 software using the iNEXT and vegan packages (Hsieh et al. 2016; Oksanen et al. 2016). In addition, species composition was grouped into five altitude ranges (900–1000, 1000–1100, 1100–1200, 1200–1300, and 1300–1400 m.a.s.l.) and richness was related to altitude with a Spearman correlation. To describe the similarity in species composition among altitudes, the Jaccard similarity index was calculated using the EstimateS 8.20 software. To define the extent to which the flora at the highest altitudes was a subset of the flora at the lowest altitudes, a nesting analysis was conducted with the Nestedness program (Patterson and Atmar 1986). This analysis is based on defining how structured a community is, based on the T indicator, ranging from $T = 0$ (a complete nesting) to $T = 100$ (complete lack of structuring in the community). In addition, we compared the value of T for our data with a random T value generated based on 2000 iterations of the data, using a significance level of $P<0.05$. We show the nesting of species in accordance with altitude, where the presence was represented according to the different altitudes of all of the species found in more than two sampling plots.

RESULTS

Species Richness

We found 101 species of vascular plants classified into 71 genera and 54 families (Table 1). The most numerous families corresponded to Asteraceae (seven species), Hymenophyllaceae (seven species), Blechnaceae (six species), and Rosaceae (six species). The genera with the highest species richness were *Blechnum* (six species) and *Hymenophyllum* (six species), while four species of *Nothofagus*, *Calceolaria*, and *Gaultheria* were also recorded. The most frequent growth form corresponded to "herbs," with 45 species (45%), of which six belong to the Blechnaceae family, five to Calceolariaceae, and four to Orchidaceae. The second most abundant growth form was shrubs, with 26 species (26%), then trees with 16 species (16%), epiphytes with 10 species (10%), and finally climbers with only four species (Table 1). *Laureliopsis phillippiana*, *Ourisia rulleoides* (L.F.) Kuntze, *Lomatia ferruginea* (Cav.) R. Br., *L. hirsuta* (Lam.) Diels ex J.F. Macbr., and species of the genus *Calceolaria* and *Hymenophyllum* were found in nearby streams and ravines. It is important to note that a large proportion of the species described as "epiphytes" were found growing mainly on rocks or slopes of river beds, so they would strictly be classified as terrestrial or saxicolous, but since we used the classification of growth forms used by Moreno et al. (2013) which is based on the most common growth forms for Andean temperate forest species, they were thus classified as epiphytes. The rarefaction analysis showed that the curve of species accumulation, as a function of the number of plots sampled, tended to stabilize. The estimated total richness of vascular plants within the park, based on the Chao 2 estimator, reached 108 species with a confidence interval between 99 and 135 species (Figure 3).

Of the total recorded species, 79% are endemic (Table 1). Ten percent (n = 10) of the species found have been introduced,

Table 1. List of species of vascular plants registered in the Bosque Pehuén Park, their growth forms (herb, tree, climber, epiphyte, or shrub), their geographical origin (GO; E: Chile and Argentina Endemic, N: Native, I: Introduced). Species marked with * represent those found outside the sampling points; + indicates cultivated species.

Order/Family	Species	Growth form	GO
MAGNOLIOPSIDA			
Apiaceae	*Osmorhiza chilensis* Hook. *et* Arn.	herb	N
Araliaceae	*Raukaua laetevirens* (Gay) Frodin	tree	E
Asteraceae	*Adenocaulon chilense* Less.	herb	E
Asteraceae	*Baccharis magellanica* (Lam.) Pers.	shrub	E
Asteraceae	*Dasyphyllum diacanthoides* (Less.) Cabrera	tree	E
Asteraceae	*Mutisia spinosa* Ruiz *et* Pav.*	climber	E
Asteraceae	*Perezia pedicularidifolia* Less.	herb	E
Asteraceae	*Senecio chilensis* Less.	herb	E
Asteraceae	*Taraxacum officinale* H. F. Wigg*	herb	I
Berberidaceae	*Berberis darwinii* Hook.	shrub	E
Berberidaceae	*Berberis montana* Gay	shrub	E
Berberidaceae	*Berberis serratodentata* Lechl.	shrub	E
Berberidaceae	*Berberis trigona* Kunze ex Poepp. *et* Endl.	shrub	E
Buddlejaceae	*Buddleja globosa* Hope	shrub	E
Calceolariaceae	*Calceolaria biflora* Lam. *	herb	E
Calceolariaceae	*Calceolaria crenatifolia* Cav. *	herb	E
Calceolariaceae	*Calceolaria tenella* Poepp. *et* Endl. *	herb	E
Calceolariaceae	*Calceolaria valdiviana* Phil.	herb	E
Celastraceae	*Maytenus disticha* Molina	shrub	E
Celastraceae	*Maytenus magellanica* (Lam.) Hook.f.	tree	E
Cunoniaceae	*Weinmannia trichosperma* Cav.	tree	E
Desfontainiaceae	*Desfontainia fulgens* D.Don	shrub	N
Empetraceae	*Empetrum rubrum* Vahl ex Willd.	shrub	E
Ericacea	*Gaultheria insana* (Molina) D.J. Middleton	shrub	E
Ericacea	*Gaultheria phillyreifolia* (Pers.) Sleumer	shrub	E
Ericacea	*Gaultheria poeppigii* DC.	shrub	E
Ericacea	*Gaultheria tenuifolia* (Phil.) Sleumer	shrub	E
Escalloniaceae	*Escallonia alpina* Poepp. ex DC	shrub	E
Euphorbiaceae	*Dysopsis glechomoides* (A.Rich.) Müll. Arg.	herb	E
Fabaceae	*Lotus pedunculatus* Cav.*	herb	I
Flacourtiaceae	*Azara lanceolata* Hook. f.	shrub	E
Gesneriaceae	*Mitraria coccinea* Cav.	epiphyte	E
Glossulariaceae	*Ribes magellanicum* Poir.	shrub	E
Glossulariaceae	*Ribes valdivianum* Phil.	shrub	E
Gunneraceae	*Gunnera magellanica* Lam.	herb	N
Gunneraceae	*Gunnera tinctoria* (Molina) Mirb.	herb	E
Hydrangeaceae	*Hydrangea serratifolia* (Hook. *et* Arn.) F.Phil.	climber	E
Lamiaceae	*Prunella vulgaris* L.*	herb	I
Leguminosae	*Lathyrus magellanicus* Lam.	climber	N
Loasaseae	*Loasa acanthifolia* Desr.	herb	E
Monimiaceae	*Laureliopsis philippiana* (Looser) Schodde	tree	E
Myrtaceae	*Myrceugenia chrysocarpa* (O.Berg) Kausel	shrub	E
Myrtaceae	*Myrceugenia ovata* (Hook. *et* Arn.) O. Berg var. *nannophylla*	shrub	E

Continued

Table 1. (*Cont'd.*)

Order/Family	Species	Growth form	GO
MAGNOLIOPSIDA (*Cont'd*)			
Nothofagaceae	*Nothofagus alpina* (Poepp. *et* Endl.) Oerst.	tree	E
Nothofagaceae	*Nothofagus dombeyi* (Mirb.) Oerst.	tree	E
Nothofagaceae	*Nothofagus obliqua* (Mirb.) Oerst.	tree	E
Nothofagaceae	*Nothofagus pumilio* (Poepp. *et* Endl.) Krasser	tree	E
Onagraceae	*Fuchsia magellanica* Lam.	shrub	E
Oxalidaceae	*Oxalis corniculata* L.	herb	I
Papilionaceae	*Adesmia emarginata* Clos	herb	E
Proteaceae	*Embothrium coccineum* J.R.Forst. *et* G. Forst.	tree	E
Proteaceae	*Lomatia ferruginea* (Cav.) R. Br.	tree	E
Proteaceae	*Lomatia hirsuta* (Lam.) Diels ex J.F. Macbr.	tree	N
Rosaceae	*Acaena ovalifolia* Ruiz *et* Pav.	herb	E
Rosaceae	*Acaena pinnatifida* Ruiz *et* Pav.	herb	E
Rosaceae	*Fragaria chiloensis* (L.) Mill.	herb	N
Rosaceae	*Prunus avium* L.	tree	I
Rosaceae	*Rosa rubiginosa* L.	shrub	I
Rosaceae	*Rubus constrictus* P.J. Müll. *et* Lefévre	shrub	I
Rubiaceae	*Nertera granadensis* (Mutis ex L.f.) Druce	herb	N
Santalaceae	*Myoschylos oblongum* Ruiz *et* Pav.	shrub	E
Scrophulariaceae	*Digitalis purpurea* L.	herb	I
Scrophulariaceae	*Mimulus luteus* L.*	herb	E
Scrophulariaceae	*Ourisia ruelloides* (L.f.) Kuntze	herb	E
Solanaceae	*Solanum palustre* Poepp. ex Schltr.	shrub	E
Solanaceae	*Solanum valdiviense* Dunal	shrub	E
Urticaceae	*Urtica magellanica* Poir. *	herb	N
Violaceae	*Viola reichei* Skottsb.	herb	E
Winteraceae	*Drimys andina* (Reiche) R.Rodr. *et* Quezada	shrub	E
LILIOPSIDA			
Amaryllidaceae	*Alstroemeria aurea* Graham	herb	E
Cyperaceae	*Uncinia* sp.	herb	E
Dioscoreacea	*Dioscorea brachybotrya* Poepp.	climber	E
Juncaceae	*Juncus* sp.	herb	
Orchidaceae	*Chloraea gaudichaudii* Brongn.	herb	E
Orchidaceae	*Chloraea magellanica* Hook. f.	herb	E
Orchidaceae	*Codonorchis lessonii* (Brongn.) Lindl.	herb	E
Orchidaceae	*Gavilea odoratissima* Poepp.	herb	E
Poaceae	*Chusquea culeou* E. Desv.	herb	E
Poaceae	*Holcus lanatus* L.*	herb	I
PINOPHYTA			
Araucariaceae	*Araucaria araucana* (Mol.) K. Koch	tree	E
Pinaceae	*Pseudotsuga menziesii* (Mirb.) Franco +	tree	I
Podocarpaceae	*Saxegothaea conspicua* Lindl.	tree	E
PTERIDOPHYTA			
Aspleniaceae	*Asplenium dareoides* Cav.	epiphyte	E
Blechnaceae	*Blechnum chilense* (Kaulf.) Mett.	herb	E

Continued

Table 1. (*Cont'd.*)

Order/Family	Species	Growth form	GO
PTERIDOPHYTA (*Cont'd*)			
Blechnaceae	*Blechnum hastatum* Kaulf.	herb	E
Blechnaceae	*Blechnum magellanicum* (Desv.) Mett.	herb	E
Blechnaceae	*Blechnum microphyllum* (Goldm) C.V. Morton *	herb	E
Blechnaceae	*Blechnum mochaenum* G.Kunkel	herb	N
Blechnaceae	*Blechnum penna-marina* (Poir.) Kuhn	herb	N
Cystopteridaceae	*Cystopteris fragilis* (L.) Bernh.	herb	N
Dryopteridaceae	*Polystichum plicatum* (Poepp. ex Kunze) Hicken	herb	E
Grammitidaceae	*Grammitis magellanica* Desv.	epiphyte	E
Hymenophyllaceae	*Hymenophyllum falklandicum* Baker	epiphyte	E
Hymenophyllaceae	*Hymenophyllum ferrugineum* Colla*	epiphyte	N
Hymenophyllaceae	*Hymenophyllum krausseanum* Phil.	epiphyte	E
Hymenophyllaceae	*Hymenophyllum pectinatum* Cav.	epiphyte	E
Hymenophyllaceae	*Hymenophyllum plicatum* Kaulf.	epiphyte	E
Hymenophyllaceae	*Hymenophyllum tortuosum* Hook. *et* Grev.	epiphyte	E
Hymenophyllaceae	*Serpyllopsis caespitosa* (Gaudich.) C. Chr.	epiphyte	E
Lycopodiaceae	*Lycopodium paniculatum* Desv.	herb	E
Pteridaceae	*Adiantum chilense* Kaulf.	herb	N

with the most frequent being the shrubs *Rosa rubiginosa* L. and *Rubus conscrictus* P.J. Müll et Lefévre. Of the total species found in the Bosque Pehuén Park, 13% (*n* = 13) are currently classified in some conservation category. Most of these belong to the family of epiphytic ferns, Hymenophyllaceae (Table 2).

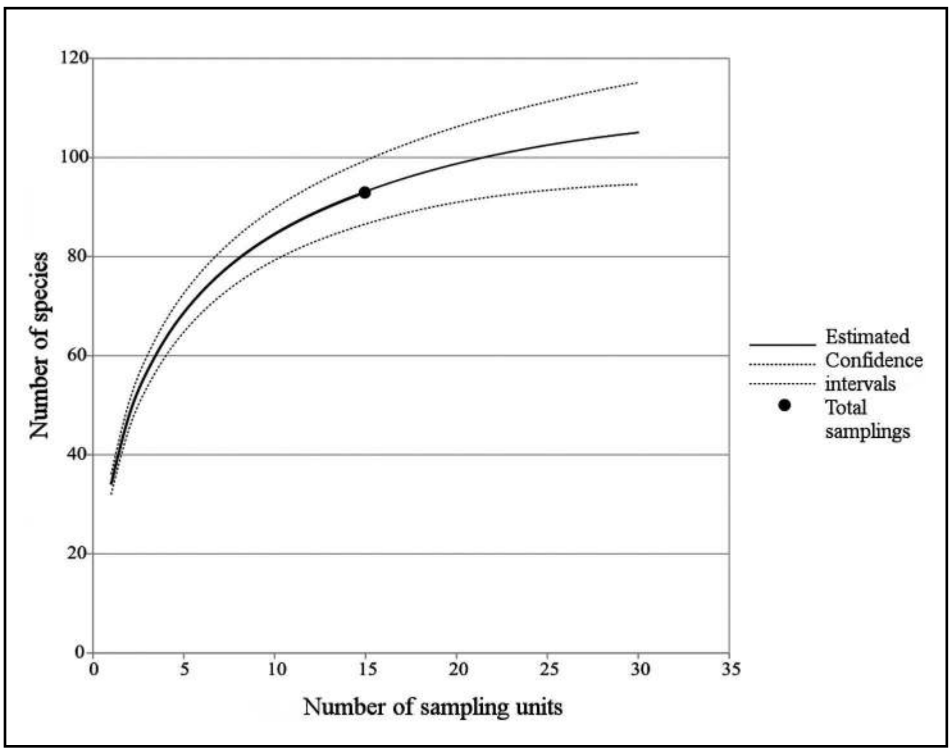

Figure 3. Rarefaction curve of vascular species for each plot.

Richness and Altitude

We detected differences in species richness and growth forms related to the altitude of the sampled plots. The total species richness tended to decrease with altitude (Rho = –0.47; Figure 4), and several species were present only at higher altitudes, while others were found only in lower lands (Figure 5). Epiphytes and climbers were observed to reach their greatest richness between 860 and 890 m.a.s.l. and did not exceed 1110 m.a.s.l. There was little variation of species richness for herbs, shrubs, and trees at different altitudes (Figure 4). In contrast, the species composition of forest understory did change with altitude; the forest understories located at the highest altitudes were dominated by *Drimys andina* (Reiche) R.Rodr. et Quezada, while the understories found in lower areas were dominated by *Chusquea culeou*. *Desfontainia fulgens* D.Don is another understory species that was found in all sampled areas, but was more frequent between middle and high altitudes. Shrublands were dominated by

Table 2. List of species with conservation problems in the Bosque Pehuén Park.

Family	Species	Conservation categories
Araucariaceae	*Araucaria araucana*	Vulnerable [1]
Aspleniaceae	*Asplenium dareoides*	Least concern [1]
Blechnaceae	*Blechnum chilense*	Least concern [1]
Grammitidaceae	*Grammitis magellanica*	Least concern [1]
Hymenophyllaceae	*Hymenophyllum falklandicum*	Least concern [1]
Hymenophyllaceae	*Hymenophyllum ferrugineum*	Least concern [1]
Hymenophyllaceae	*Hymenophyllum pectinatum*	Least concern [1]
Hymenophyllaceae	*Hymenophyllum tortuosum*	Least concern [1]
Hymenophyllaceae	*Serpillopsis caespitosa*	Least concern [1]
Lycopodeaceae	*Lycopodium paniculatum*	Vulnerable [3]
Nothofagaceae	*Nothofagus dombeyi*	Least concern [2]
Nothofagaceae	*Nothofagus alpina*	Near threatened [2]
Podocarpaceae	*Saxegothaea conspicua*	Near threatened [2,4]

[1] Regulations for the Classification of Species of the Environmental Ministry

[2] IUCN Red List version 3.1

[3] Native fern conservation categories (Baeza et al. 1998)

[4] Threatened plants of central-southern Chile (Hechenleitner et al. 2005)

species of shrubs belonging to the genera *Berberis* and *Gaultheria*. The similarity of species composition in accordance with altitude was higher among similar altitudinal levels, reaching values of 0.68 between 900 and 1100 m and 0.62 between 1200 and 1400 m (Table 3). The nesting analysis showed a value of $T = 36.7°$ ($P = 0.02$), indicating that the flora found in the higher areas tended to be a subset of the flora at lower altitudes.

DISCUSSION

Species Richness

The total richness of vascular plants registered in the Bosque Pehuén Park corresponds to 12% of the approximately 800 species recorded for the Valdivian ecoregion forests (35°S–55°S; Arroyo et al. 1996). The arboreal richness of the park is low, restricted to 14 species of the approximately 55 species described for La Araucanía Region (Villagrán and Hinojosa 2005). The distribution of species in terms of growth forms coincides with other studies (Table 4), where herbs fluctuate between 33% and 70% of the total richness of plants found in the different sampled areas, while trees represent 7%–29%. Epiphytes and climbers are the growth form group with the lowest proportion of species in most studies, except in Moreno et al. (2013), where these growth forms represented about 15% of the total species found, exceeding the richness of trees found in the same study site (12%). It should be noted that eight species of epiphytic ferns were recorded in Bosque Pehuén Park: six species of Hymenophyllaceae, as well as *Grammitis magellanica* Desv. and *Asplenium dareoides* Cav., which were not observed in study sites near Bosque Pehuén (Becerra and Faúndez 1999; Rojas et al. 2011). Species richness of Bosque Pehuén is low when compared with other PAs in the region (Table 4). Nevertheless, this comparative analysis must be made with caution, because most of the PAs presented in Table 4 are very large and encompass many different vegetation formations. This is the case of Lanín National Park (Argentina) and Villarrica National Park (Chile), whose extensions far exceed that of Bosque Pehuén, and include formations like wetlands, Andean shrublands, and Andean grasslands, among others (CONAF 2006). The sampling designs used to record species in these larger PAs were also quite different, which does not allow us to compare species richness among these and Bosque Pehuén Park.

The highest species richness in Bosque Pehuén Park was recorded within sampling plots associated with watercourses. Fifty species were registered in riparian zones, corresponding to 50% of the vascular plant richness in the park. It is likely that some species, such as *Hymenophyllum* ferns (Mellado-Mansilla et al. 2015) and others, can be favored by the greater water availability and protection from snowfall near watercourses. Further vegetation studies within the Araucarias Biosphere Reserve must pay special attention to watercourses, provided that these can support organisms that cannot otherwise inhabit this mountainous area. The richness found in our study area could increase if species inhabiting grasslands are recorded. It should be noted that grasslands also could contain invasive species.

The most frequent invasive species recorded was the shrub *Rosa rubiginosa*, which was found at seven sampling plots up to 1100 m. This species is classified with one of the highest invasion potentials in Chile due to its aggressive growth, high fruit production in autumn and winter, and its successful dispersion through endozoochory (Fuentes et al. 2014; Kutschker et al. 2015). In Chile, there are currently no control measures or natural predators to

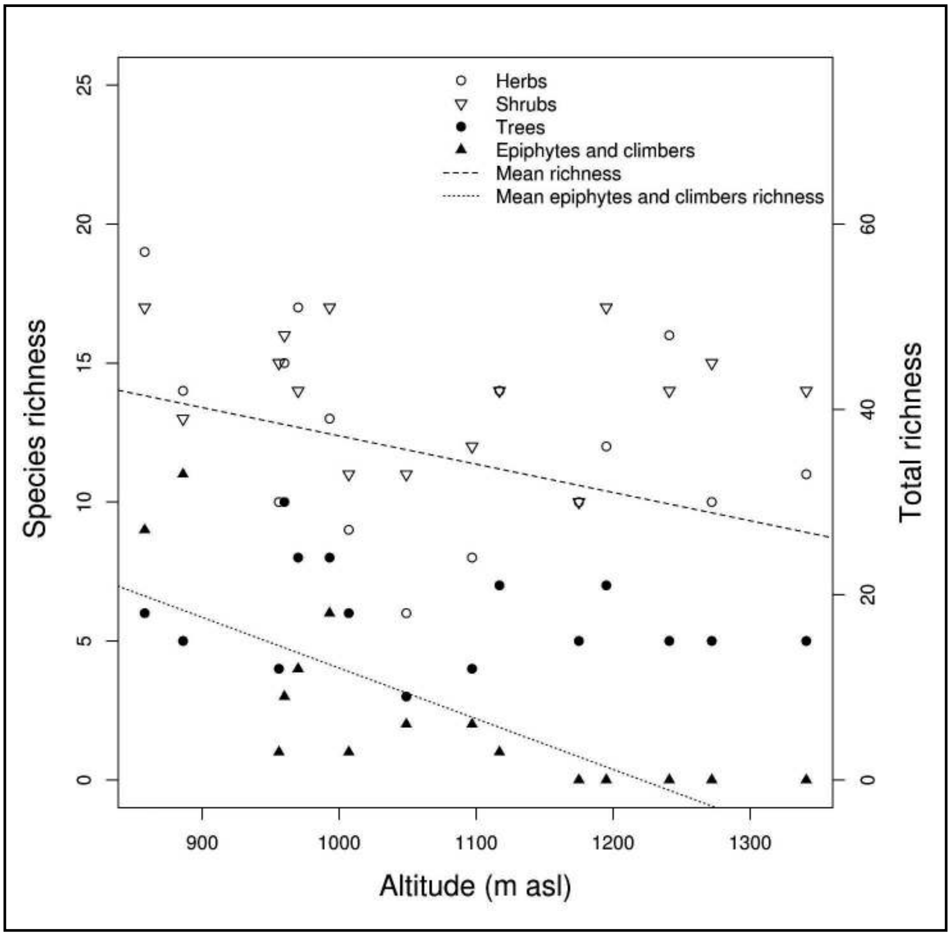

Figure 4. Species richness found at different altitudes in Bosque Pehuén park. Points show results for herbs, shrubs, trees, and epiphytes and climbers. A second *y* axis and two tendency lines were added to the plot to show general trends of total richness and epiphytic richness according to a Spearman rank correlation between total richness of vascular plants and altitude (rho = –0.47, *P* = < 0.05), and epiphytic richness versus altitude (rho = –0.87, *P* = 0.07).

regulate this species. If not controlled, *R. rubiginosa* could become a serious problem, as has already occurred in extensive forested areas of Argentina where it has displaced native species from open patches (Kutschker et al. 2015). Invasive species spread even more successfully when aided by climate change and ecosystem degradation (Sala et al. 2000; Shaver et al. 2000), thus representing an additional barrier for the conservation of native plant species.

Altitudinal Patterns

This PA's altitudinal gradient allows for comparative analyses of species richness at different altitudes, which could permit the establishment of segregation patterns of species, similar to those reported in other works, such as Moreno et al. (2013) and Becerra and Cruz (2000). Altitude plays a key role in the formation of different vegetation types (Whittaker 1973; Becerra and Cruz 2000) and in many ecosystems the highest and most diverse species richness has been found at lower altitudes (Rahbek 1995; Smith-Ramírez et al. 2005). In Chile, coastal and lowland forests have higher species richness, as well as higher levels of endemism, but both conditions tend to decrease in Andean forests (Villagrán and Hinojosa 1997). This coincides with our observations in Bosque Pehuén Park, where the lower-altitude zones concentrated the largest number of species and the set of plants found at higher altitudes was a subset of those found at lower altitudes.

As expected and explained by their autecology, species such as *Dasyphyllum diacanthoides* (Less.) Cabrera, *L. phillipiana*, and *Lomatia ferruginea* were associated with the lower zones of the park (860–1000 m), while others, such as *N. pumilio* and *A. araucana*, were associated with higher zones (1050–1340 m; Figure 5) (Donoso 2006). Variations in species richness and composition in relation to altitude have also been reported in other protected areas, such as the Malalcahuello National Reserve (Landrum and Nimlos 1975; Becerra and Cruz 2000), where woody species of the reserve were found to be segregated along the altitudinal gradient. The growth forms that presented the greatest variation with respect to altitude were epiphytes and climber plants, which were not found above 1150 m. This is most likely due to the low cold tolerance of this group of species; temperature conditions below zero and permanent snow could limit their persistence at higher altitudes (Krömer et al. 2005). It is important to note that epiphytes and climber plants were mainly found near watercourses (Mellado-Mansilla et al. 2015) and mostly growing as terrestrial, saxicolous, or in the lower parts of tree trunks. A sampling carried out in the canopy of large individuals of *N. dombeyi* trees in the park revealed the absence of vascular epiphytes and climber plants in the vertical profile of the forest, while non-vascular epiphytes were dominant (Mellado-Mansilla et al. 2017). It is likely that the physiological adaptations of non-vascular epiphytes, such as bryophytes, against cold and sunny conditions allow them to survive in more extreme environments (Proctor et al. 2007).

Conservation Implications

Terrestrial ecosystems are defined by the plant communities that inhabit landscapes with similar ecological features (Josse et al. 2003). Therefore, inventories of plant species and vegetation are an essential part of the knowledge base concerning ecosystems. This information aids in the identification of possible threats (like invasive organisms) and species that require special attention (like endemic or endangered species), while also helping us to understand the ecosystem's complexity in addition to how the environment affects it (Josse et al. 2003; Pliscoff and Fuentes

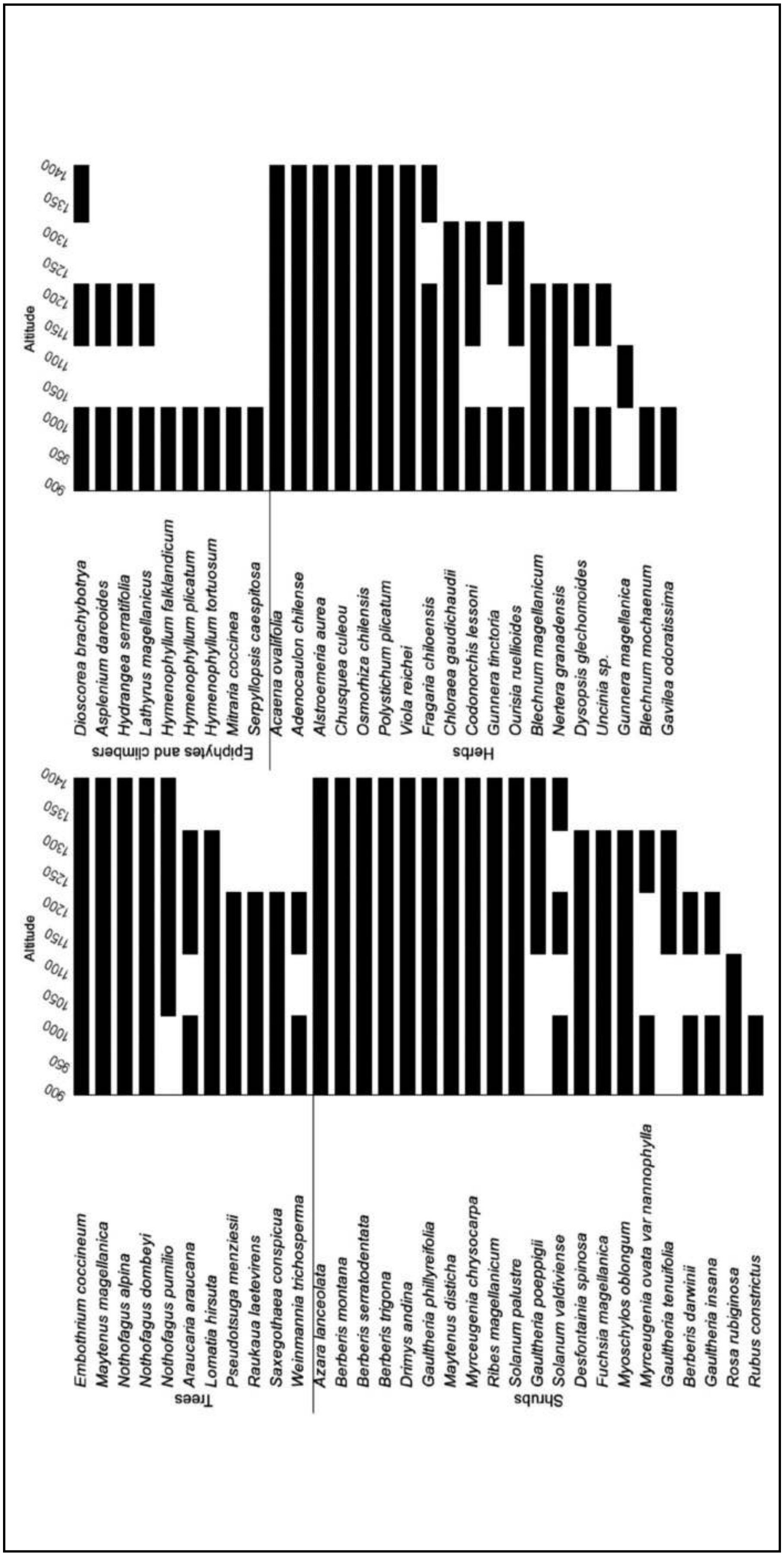

Figure 5. Presence of vascular species at different altitudes within Bosque Pehuén Park. Only species found in more than two sampling plots are plotted.

2008). This basic information regarding species representativeness is seriously lacking in many Chilean PAs. Even though Hymenophyllaceae species, as well as rare species such as *Gavilea odoratissima* Poepp. and *Gaultheria tenuifolia* (Phil.) Sleumer (Teillier et al. 2013) have now been identified in the Bosque Pehuén Park, in addition to other Andean forests, their representativeness in other protected areas in La Araucanía region is still unknown. With this information, conservation initiatives can more effectively define conservation targets and distribute resources, which are often scarce in PAs. Bosque Pehuén Park has great relevance in terms of conservation since it protects uncommon environments, such as old-growth forests, as well as emblematic species with serious conservation problems, such as the endangered *A. araucana* (IUCN 2017). The tree species *N. alpina*, classified as "almost threatened" by the IUCN, is widely distributed throughout the park, forming extensive secondary forests, which contribute to maintaining the regional population of this species. Although only 13 of the total species found in Bosque Pehuén Park are currently classified under some conservation status, this number should be interpreted with caution because many Chilean species have not yet been evaluated. The conservation status assessment of many plant species is necessary, especially when considering that the IUCN Red List—the most relevant tool of conservation status worldwide—has only assessed around 20,000 land plant species (IUCN 2018).

Bosque Pehuén Park represents the land-use history of many regional Andean forests, which have been subject to intensive wood extraction and deforestation for the last 40 y (Quezada 2008). However, Bosque Pehuén Park is particular because this exploitation ceased in 2006 when it became a PPA. This allowed the development of an extensive secondary forest where stumps and fallen logs from the original forest can be found, along with a belt of well-preserved old-growth forest. Bosque Pehuén Park is also part of the ABR, a conservation initiative created by UNESCO that has three main tasks: to conserve cultural and biological diversi-

Table 3. Jaccard similarity index for vascular plant species recorded at different altitudes in Bosque Pehuén Park.

Altitude (m)	900–1000	1000–1100	1100–1200	1200–1300
900–1000	1			
1000–1100	0.679	1		
1100–1200	0.543	0.527	1	
1200–1300	0.513	0.5	0.515	1
1300–1400	0.427	0.418	0.534	0.619

ty, promote sustainable development, and enhance logistic support through environmental education, research, and monitoring (UNESCO 2017). Within the ABR, Bosque Pehuén is considered a buffer zone (i.e., a zone surrounding or contiguous to core areas) in which only activities such as research, tourism, and education should be allowed (Batisse 1997; UNESCO 2017). Bosque Pehuén Park consequently meets with the ABR's spatial zoning goals. Nevertheless, although attractive, not all of the areas within the biosphere reserve achieve the tasks proposed by UNESCO, and the biosphere reserve often remains as nothing more than a bureaucratic label (Coetzer et al. 2013). This is in part explained by the poor or null cooperation between protected areas within the biosphere reserves, and the different conservation goals, legislations, and monetary resources at a regional scale (Walker and Solecki 1999; Coetzer et al. 2013). Thus, further cooperation is urgently needed among conservation initiatives in order to achieve the conservation of natural resources within these reserves through effective management practices.

In addition to government protected areas, PPAs like Bosque Pehuén play an important role in species conservation within the landscape, increasing the long-term population viability of species. According to the Chilean Environmental Ministry's data (Ministerio del Medio Ambiente 2018) concerning conservation initiatives, Bosque Pehuén is the fifth-largest privately protected area in the Araucanía region (N = 22) and corresponds to the largest PPA within the ABR. In southern Chile, protected areas as small as 40 ha can conserve at least 80% of the landscape's biodiversity, thus helping to maintain ecological processes and services in addition to serving as biological corridors and propagule sources (Armesto et al. 2002). The latter becomes even more relevant under the current threat of climate change's fast advance, where the best scenario suggests that some plant species will migrate to "climate refuges," while those that cannot will go extinct (Corlett and Westcott 2013). Alarcón and Cavieres (2015) modeled the representativeness of 118 plant species in PAs in southern Chile (29 of these species were also recorded in this study) under different climate scenarios predicted for 2050. In their study, focused on *Nothofagus* trees and *Nothofagus*-associated species, growth forms were important to detect different responses to the effects of climate change; for example, understory ferns differed from *Nothofagus* trees, where the former tended to increase their habitat while the latter tended to decrease their territory under future climatic conditions. They also concluded that PPAs increased the additional conservation for 74% of the assessed species in the future scenarios. Thus, private conservation initiatives located at higher altitudes, such as Bosque Pehuén, could be relevant to maintaining the biological diversity of temperate rainforests in the future, considering that many species will lose their northern and lower ranges due to the expected decreases in precipitation, and may survive by migrating to higher and southern zones where conditions will be less extreme (Ministerio del Medio Ambiente 2014; Alarcón and Cavieres 2015).

CONCLUSIONS

Bosque Pehuén Park protects many plant species of the Andean forest, including some threatened and many endemic species. Conservation initiatives like this must be maintained throughout time due to their important role for biodiversity conservation in the present and especially under future global change scenarios. The monitoring and control of invasive plant species is imperative to accomplish the conservation goals within the park and at a regional scale. The conservation of watercourses not only ensures water availability, but also the environmental conditions needed by many associated species, increasing biodiversity and ecological functions. The methodology

Table 4. Floristic richness in accordance with the growth forms recorded in samples taken between 38° and 40°S. * Total hectares sampled. ** Only land plant species. *N*: Total richness; Tr: Trees; Sh: Shrubs; He: Herbs; Ep: Epiphytes and climbing plants.

Site	*N*	Tr	Sh	He	Ep	Area (ha)	Study
Bosque Pehuén Park	101	16	26	45	14	882	This study
Villarrica National Park	374	-	-	-	-	63	Conaf 2006
Malalcahuello National Reserve	211	12	39	153	7	12.789	Becerra & Faundez 1999
Pre-Andean zone, La Araucanía Region	110	31	28	36	15	48*	Rojas et al. 2011
Futangue Park	290	35	49	162	44	12.5	Moreno et al. 2013**
Biological Reserve Huilo-Huilo	407	33	45	297 (approx.)	27	100	Teillier et al. 2013**
Lanín National Park	706	-	-	-	-	412	Antocini 2012

used in this study allowed for a rapid sampling of plant species by clearly defining the sampled areas and thus avoiding a possible bias in the information collected. Systematic sampling also permitted us to obtain an estimate of the effectiveness of the sampling effort and the expected total richness within the park. Furthermore, the results of this study can be compared with others that utilize similar protocols, thus allowing for a broader perspective, which can be a significant advantage when making decisions related to resource management and conservation efforts. Biodiversity inventories provide the basic knowledge necessary to properly define conservation targets, detect threats, and establish zoning considering not only the PAs but the landscape as a whole. This basic information is essential in order to guarantee species communities' long-term viability in the Araucarias Biosphere Reserve.

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