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Quantifying the role of protected areas for safeguarding the uses of biodiversity

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ABSTRACT

Protected areas (PAs) are one of the main strategies to protect biodiversity and its ecosystem services globally. Plants are a critical component of biodiversity, playing a key role in almost every aspect of life, and Fabaceae is the third most diverse plant family worldwide with many useful species. We evaluated the diversity of uses of Fabaceae, how much of this diversity is encompassed by the Argentina's PAs network, and the relationship between species' conservation status and their uses. To do so, we used literature review, species distribution models (SDM), diversity metrics of use, conservation status, and gap analysis. We found that 72% of species (520) had at least one reported use. *Prosopis* species were the taxa with the most uses. Environmental, Medicine, and Animal food were the most diverse use classes. PAs with low to medium species richness supported the highest proportion of species with uses, and in regions, with higher species richness, the redundancy of uses increased. Most of the Fabaceae species from Argentina provide a valuable resource for people and animals, and fortunately, many of these uses are represented in PAs network. However, all use classes have between 8 and 25% of their species threatened, and most species (548) did not achieve conservation targets, highlighting the need for conservation efforts to safeguard these species. We demonstrated that integrating different species characteristics, data sources, and diversity metrics is an effective way to evaluate the contribution of PAs to conserve the utilitarian aspects of biodiversity on a large-scale.

1. Introduction

Plants not only dominate the living biomass on Earth (Bar-On et al., 2018), they affect our lives on both physical and mental levels, have shaped our culture, and supplied numerous resources for our survival and economic development (DelSesto, 2020; Schaal, 2019). Worldwide, ~31,000 of the >400,000 described plant species (Cheek et al., 2020; Lughadha et al., 2016) have been documented as potentially edible for humans (Food Plants International, 2020), and ~ 27,000 are medicinal plants (MPNS, 2020). Moreover, plants are essential to adapt agriculture to ongoing climate change and supply food to the human population (Vincent et al., 2019). The uses provided by plants to animals or people are provisioning and cultural ecosystem services (Millennium Ecosystem Assessment, 2005); therefore, protecting species with use also could contribute to the protection of the ecosystem services they provide.

Protected areas (PAs) are a key strategy for conserving biodiversity and ecosystem services in the face of human pressure on natural resources (Chape et al., 2005; Gray et al., 2016). PAs are an indicator of the progress of biodiversity conservation targets (Chape et al., 2005) and contribute to achieving sustainable development goals (e.g., the United Nations' Sustainable Development Goals). Worldwide PAs cover 16.64% of terrestrial and freshwater environments and 7.74% of the marine realm (UNEP-WCMC and IUCN, 2021), short of the Aichi Biodiversity Target 11 of PAs protecting 17% of terrestrial and 10% of marine areas

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by 2020 (CBD, 2010). A post-2020 goal is to protect at least 30% of land and sea areas with particular importance for biodiversity through PAs and other area-based conservation measures by 2030 (CBD, 2020); thus, PAs will continue to be one of the most important conservation tools in the following decades.

PAs are often designed on the basis of biodiversity preservation; however, PAs provide multiple values, from poverty reduction to improving human health, and support climate change adaptation (Adams et al., 2019; Bebber and Butt, 2017; Buckley et al., 2019; Naidoo et al., 2019). PAs can serve as a pool of potential utilitarian services because species with uses may be present within PAs without necessarily being used. For instance, useful plants within PAs can be exploited directly or provide reproductive material (e.g., seeds or tissues) for commercial production. In many PAs, human presence is appropriately excluded or regulated; however, PAs often include active interactions with society via, e.g., "ecotourism" or due to the mobility and dispersal of useful species beyond their limits, such as game animals or plants propagules. Several valuable studies have investigated the utilitarian aspect of biodiversity as it is distributed in geographical space; however, most of them only considered one use type and did not assess conservation issues considering all potential uses of the species (e.g., de Oliveira et al., 2015; Kaky and Gilbert, 2016; van Zonneveld et al., 2021). Furthermore, few studies have employed spatially explicit diversity metrics of uses that integrate the diversity of species and their different uses (e.g., Khoury et al., 2019).

Here we evaluated the contribution of PAs to protect the use of biodiversity on large scales, and thereby their ecosystem services, by combining an extensive literature review to identify species-specific uses with species distribution model techniques, diversity metrics of use, and species' conservation status. We use as a case study species of the very diverse, widely distributed, and useful Fabaceae plant family and the PAs network within Argentina to assess (i) the diversity of uses of Fabaceae, (ii) how much of this diversity is encompassed by the country's PAs, (iii) and the relationship between species' conservation status and their uses.

2. Methods

2.1. Study area

Argentina extends longitudinally from 21°S to almost 60°S, presenting several climatic, topographic, and edaphic conditions. Average annual precipitation varies from ~19 to 2500 mm, and average annual temperature ranges from −15 to 22.78 °C (Bianchi and Cravero, 2010). Argentina encompasses 50 vegetation types, including grasslands, shrub-steppe, savannas, and forests (Oyarzabal et al., 2018). It harbors >9200 native plant species, 1731 being endemics. Fabaceae is the third most specious plant family in Argentina, with 713 species, 157 being endemic (Zuloaga et al., 2019).

2.2. Protected area network database

There are 497 PAs in Argentina, covering ~36 Mha (13.29%) of its continental territory (SAyDS, 2019). Argentinean PAs are managed by the national, provincial, and local governments, individuals, or private institutions. Some PAs match the IUCN categories Ia, II, III, and IV, while others had no IUCN categories equivalent (e.g., Wild Nature Reserve, Educational Nature Reserve, Interjurisdictional Park, and Defense Nature Reserve, SAyDS, 2019). Also, the country has Ramsar sites and Biosphere reserves. We obtained data of the network of PAs from the National Parks Administration of Argentina (Table S1). We included in the analyses only PAs with $\geq$50 km^2 (184 from 381 terrestrial PAs) to maintain consistency with the spatial scale of species distribution models (i.e., 10 km) and not overpredict the number of species in small areas. For PAs that cover both marine and land areas, we considered only their land portion.

2.3. Species occurrence data for the Fabaceae

Among thousands of plant families, Fabaceae stands out due to its high number of species (~22,000 species; Cheek et al., 2020) and the wide range of reported uses (Diazgranados et al., 2020; Lewis, 2005), making it an appropriate group as a proxy for understanding diversity and conservation issues of useful plants as a whole (Catarino et al., 2019; Yahara et al., 2013). This family is broadly distributed worldwide and inhabits a wide range of environmental conditions (Lewis, 2005). Fabaceae is one of the most economically important plant families with several species cultivated as crops globally (e.g., beans, soya, and lentil; Graham and Vance, 2003), and many others employed for food, medicine, and ornamental purposes (Lewis, 2005). Additionally, they play an important role in biogeochemical cycles because of their symbiosis with nitrogen-fixing rhizobia bacteria, useful for bioremediation or biofertilization (Pajuelo et al., 2011). The taxonomic and uses diversity of this important plant family is threatened by habitat degradation, resource overexploitation, climate change, and a low degree of protection (Khoury et al., 2019; Newbold et al., 2015).

We obtained a list of native Fabaceae species from Flora Argentina (Table S1). Based on this list, we compiled 418,703 species occurrences throughout their native distribution (i.e., occurring within and outside Argentina) from several sources, including Flora Argentina, Plants of Bolivia, BIEN, GBIF, and SNBD (see Table S1 for occurrence sources and links). We checked, corrected, and updated species names using Flora Argentina and Taxonomic Name Resolution Service (TNRS; Table S1). After a careful data cleaning of occurrences (see Appendix S1), the final occurrence database consisted of 124,909 records from 706 (98% of Argentina's) Fabaceae species.

2.4. Environmental variables and species distribution models

We constructed species distribution models (SDMs) using climatic and edaphic variables to represent the niche of terrestrial plant species more realistically than climate alone and improve models' performance (Velazco et al., 2017). We used 19 bioclimatic variables from Chelsa (Karger et al., 2017) and six physical and chemical variables from SoilGrids (Hengl et al., 2017), both at ~10 km resolution (Table S2). We performed a principal component analysis based on a correlation matrix to overcome predictor multicollinearity in modeling construction. We used the first nine derived principal components as new predictors variables, which explained >90% of the total variance (De Marco and Nóbrega, 2018; Table S3). For species with between 5 and 15 records, we only used the first three principal components to avoid model overfitting.

We used Gaussian Processes, Maximum Entropy, Random Forest, and Support Vector Machine as algorithms to construct SDMs (see Appendix S2 for more information about algorithm tuning). Pseudo-absences were randomly allocated in the area used to create each model (i.e., calibration areas), avoiding cells with presences. The number of pseudo-absences was equivalent to the number of presences. The calibration areas were delimited based on a convex hull polygon constructed by species presences plus a 300 km buffer surrounding the convex hull polygons' edges.

Models were evaluated by a k-fold cross-validation method with five folds. We used Boyce, Sorensen, and True Skill Statistic as performance metrics (Leroy et al., 2018). To select the best model set for each species, we sequentially selected models with Boyce >0.5, then Sorensen >0.8, and True Skill Statistic >0.4. In cases where more than one model was selected, we chose the model with the highest Boyce. If two or more models have the same maximum Boyce, we calculated an ensemble model by averaging cell suitability for those models. Most models performed well with high performance for all metrics (Fig. S1). The distribution of no modeled species (species with <5 records) was determined by a 20 km buffer around species presences (Zizka et al., 2020). Models were binarized by the threshold that maximizes the sum of the sensitivity and specificity (Liu et al., 2011). Because models that overpredict can overestimate diversity values within PAs (Velazco et al., 2020), we constrained the models by a convex hull polygon around species presences plus a buffer of 100 km (Mendes et al., 2020).

2.5. Diversity of uses

We searched for Argentinean Fabaceae species uses in congress annals, books, published papers, technical bulletins, thesis, and web pages. We also performed a species-specific search on Google Scholar (e.g., "*Adesmia lanata*" + "use" OR "uso" OR "used"). Finally, we recorded species uses from 200 sources, most from articles (52%) and books (21%). Aiming to compile a complete picture of potential species use, we compiled all reported species uses regardless of the geographical place where a use was recorded. Uses were reclassified based on classes of uses listed in the World Economic Plant database (Wiersema and León, 2013; https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomysearcheco; Table S4). We overlapped PAs' boundaries and species distribution data to obtain a list of species in each PA. The number of species (with and without use) within each PA represented (taxonomic) species richness. We estimated the relationship between species richness and uses within each PA using three diversity metrics related to uses: Proportion of richness with uses, Diversity of uses, and Redundancy of uses.

The proportion of richness with uses (S_u) indicate the proportion of species within a PA with identified uses. Values closer to one indicate a greater proportion of species with use. This was calculated as $S_u = \frac{N}{S}$, where N represents the total number of species with use within a PA, and S is the total number of species within that PA. The diversity of uses (D_u) was based on Simpson's diversity index. In terms of species uses, Simpson's diversity index measures the probability that two species randomly selected have different uses. To calculate D_u, we created a matrix with information about the number of species for a given use present in a PA, then D_u was calculated $D_u = \left(1 - \frac{\sum n(n-1)}{N(N-1)}\right)$; where n represents the number of species for each use class. Redundancy of uses (R_u) was based on the functional redundancy metric proposed by Mouillot et al. (2014), which, in our assessment, represents the number of species per use class. It was calculated as $R_u = \frac{N}{U}$, where N represents the total number of species with use within a PA and U the number of different uses of these species. We explored the relationship between these metrics associated with uses and species richness.

2.6. Species' conservation status and gap analysis

We evaluated the proportion of threatened species by use classes by counting the number of species for each conservation status and dividing it by the number of species within each use class. We used Delucchi and Hernández (2015) as a source of species conservation status, which provided information on the conservation status of Fabaceae species native to Argentina following the IUCN's Red List Categories and Criteria.

Gap analysis evaluates how a PAs network meets the representation target defined for a species based on species' range size (Rodrigues et al., 2004; Scott et al., 1993). According to this approach, the representation target for species with <1000 km^2 is 100%, while species with $>250{,}000$ km^2 should have at least 10% of their range in PAs, with interpolated targets for intermediate-range species between these extremes (Rodrigues et al., 2004). Based on the relationship between the species range and the level of representation target achieved, species were classified into four classes following Frederico et al. (2018): i) protected: achieved 90% of the target, ii) partial gap: 20%–90% of the target; iii) gap: up to 20% of the target; and iv) not protected: 0% of the target.

All analyses were performed in R v.4.0.2 (R Core Team, 2020). We used the CoordinateCleaner package (Zizka et al., 2019) combined with our R codes for occurrences data cleaning, the ENMTML package for creating SDMs (Andrade et al., 2020), and the MSDM for correcting model overprediction (Mendes et al., 2020).

3. Results

We found that 520 Fabaceae species (72.6%; Table S5) native to Argentina had at least one reported use, with 239 (46.1%) of those species represented by one use. The most common uses were Environmental ($n = 285$ species), Medicine ($n = 230$), Animal food ($n = 215$), and Materials ($n = 148$; Fig. 1a). The species with the most reported uses were *Vachellia aroma* ($n = 8$ uses) and *Prosopis nigra* (n = 8); several *Prosopis* species were among the species with the highest number of uses (Fig. 1b).

Argentina's PAs network had, on average, species richness of 86.50 (± 68.06), a proportion of richness with uses of 0.87 (± 0.05), diversity of uses of 0.90 (± 0.05), and redundancy of uses of 8.09 (± 5.44) species/use. On average, the richest use classes represented within the PAs network were Environmental (43.14 species ±24.52), Animal food (41.55 ± 33.34), and Medicines (40.20 ± 32.12). We found that at low species richness, there was high variability in the proportion of species with uses; however, the proportion of species with use decreased at higher species richness. Diversity of uses was high for almost the full range of PAs species richness, with diversity of uses dropping off only in some PAs with Fabaceae richness lower than ~75 species. Finally, we found a constant and positive relationship between redundancy of use and species richness (Fig. 2).

PAs with the highest species richness were in the northern portion of the country (Fig. 3). The proportion of richness with uses, in turn, was higher in the middle and southern regions of Argentina, while the diversity of uses was high in almost all territories except the southern region. The redundancy of uses presented a pattern consistent with richness (Fig. 3).

We found that all use classes are represented by 8–25% of threatened species (Fig. 4a). Uses classes with the highest proportion of threatened species were Environmental (25%), Fuels (19%), and Medicines (18%; Fig. 4a). Gap analysis reveals that only 14.6% of 684 species (with and without uses) are Protected, 80% are classified as Partial gap or Gap, and 5.6% are Not protected (Fig. S2). Most use classes were represented by species classified as Partial gap and Gap, and Protected species ranged between 0 and 33% among uses (Fig. 4b). The combination of threatened status and representation target reveals that most threatened species with and without uses are not currently protected; however, the number of threatened species not protected could be underestimated because most of the species were not evaluated regarding their threatened status (Fig. S3).

4. Discussion

Here we explored the diversity of uses of native Fabaceae species in Argentina by calculating the amount of use diversity represented within the PAs network, evaluating the relationship between species uses and their conservation status, and assessing the extent to which a PAs network meets species' protection targets. Overall, we found that 72% of Fabaceae species had at least one reported use. Furthermore, PAs with low to medium species richness can support a high diversity of uses, and the redundancy of uses increases at higher richness. In terms of conservation, all use classes are represented by 8–25% of threatened species, and most species with and without uses are partially or not represented within PAs.

Among the top 20 species with reported uses, seven are of the *Prosopis* genus, of which four are Partial gap, and three are Protected (Table S5). *Prosopis* is an ecological, environmental, and economically important genus in the Americas' arid and semiarid regions (Galera, 2000; Ruiz-Nieto et al., 2020; Sciammaro et al., 2016). In Argentina, *Prosopis* species were used by ancient cultures (as early as 10,000 before

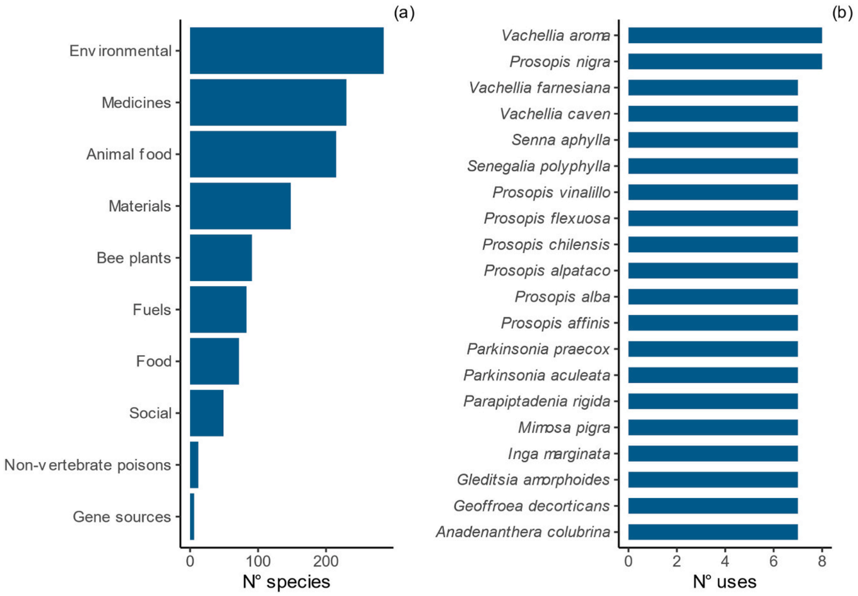

Fig. 1. Number of Fabaceae species native to Argentina reported for each use class (a) and number of uses reported for the 20 species with more reported uses (b).

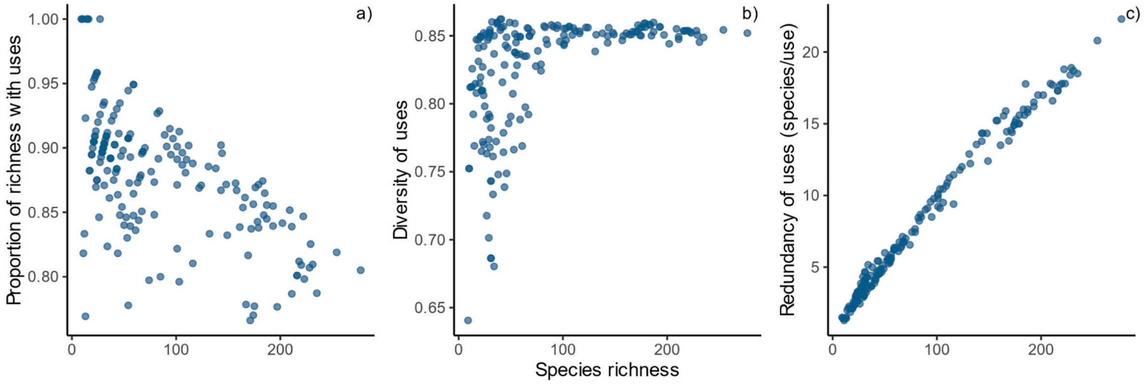

Fig. 2. Relationship between Proportion of richness with uses (a), Diversity of uses (b), and Redundancy of uses (c) with species richness of Fabaceae in protected areas (PAs) from Argentina (represented by points).

the present, Capparelli et al., 2015). In the Gran Chaco ecoregion, *Prosopis* species stand out as a wild food for indigenous people because of the volumes gathered and nutritional value (Scarpa, 2009; Sciammaro et al., 2016). Species like *P. nigra*, *P. alba,* and *P. flexuosa* provide food, wood, fuel, charcoal, and animal feed (Alvarez and Villagra, 2009; Tortorelli, 2009). In arid regions, these species are also used for soil restoration, forest plantations, and silvopastoral systems (Galera, 2000; Tortorelli, 2009).

We found that Environmental was the richest use class, mainly by encompassing subclasses like ornamental, restoration of degraded areas, agroforestry system, and soil improver (Table S6), which highlights the utility of Fabaceae species for ecological restoration and economic activities. Several species were reported as wild ornamental plants (i.e., they are not commonly cultivated), stressing the unexploited economic value of these plants. Animal food use has the same economic potential as the ornamental one; beyond the importance of Fabaceae for wildlife, livestock also consumes these native species. Native Fabaceae species can be an alternative livestock feed adapted to local conditions. As forage, tropical Fabaceae have environmental benefits such as N-fixation, high nutritive values, taxonomic and genetic diversity, and deep-reaching root systems (Schultze-Kraft et al., 2018). Medicines was the second richest use class; such a finding could be expected since this use is predominant in ethnobotanical studies of different ethnic groups in Argentina (e.g., Keller, 2007; Ladio et al., 2007; Scarpa and Rosso, 2014), emphasizing the importance of diverse medicinal plants for these communities. Despite the myriad environmental, economic, and societal benefits of Fabaceae, its most useful species have barely been studied (Graham and Vance, 2003; Morris, 1997; Schultze-Kraft et al., 2018).

The positive relationship between richness and redundancy of uses has implications for the future. In areas with low species diversity, a decline of a species' population may result in the loss of multiple plant resources for human communities that depend on them. PAs from the Patagonia region are a good example; despite their low species richness, they have a high diversity of uses and low redundancy. Patagonia steppes are affected by overgrazing and desertification, altering species richness, cover of livestock edible species, and soil functioning (Gaitán et al., 2018). In PAs with high species richness and low proportion of richness with uses (as those detected in the northern portion of Argentina), it would be expected that many species have potential uses not described so far, possibly because they are unknown, undervalued, or underutilized due to the presence of more popular species.

PAs offer goods and services to people within and around them. For instance, indigenous lands intersect ~40% of PAs worldwide (Garnett et al., 2018). In this case, PAs are a fundamental provider of essential resources such as medicine, food, fuel, or water (Campos-Silva et al., 2020; Flavien and Vanhove, 2016; Kala, 2005; Keller et al., 2006).

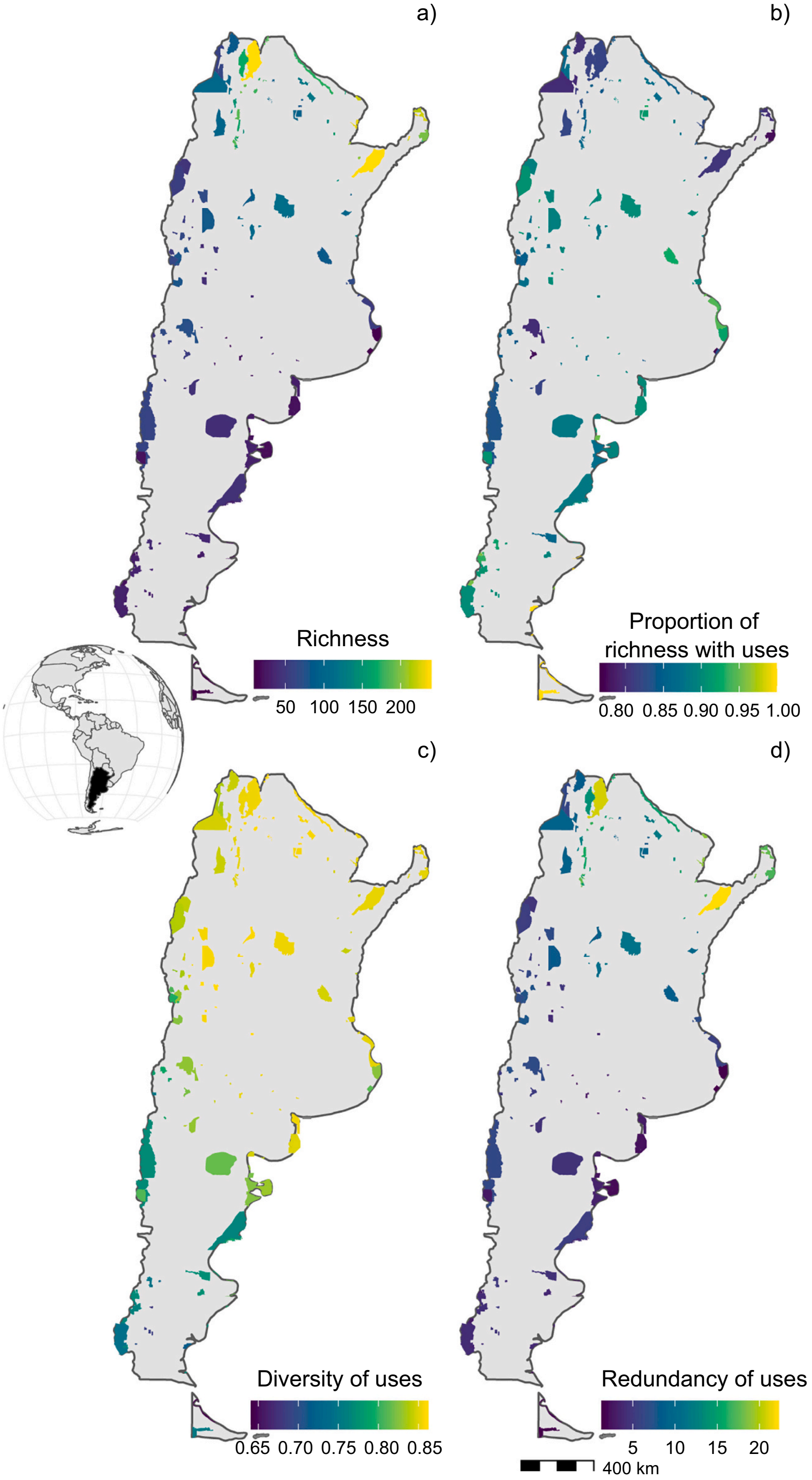

Fig. 3. Species richness (a), Proportion of richness with uses (b), Diversity of uses (c), and Redundancy of uses (d) of Fabaceae species native from Argentina within 184 PAs.

Nevertheless, human access to PAs resources and the conservation effectiveness varies between countries (e.g., Argentina does not have Indigenous Protected Areas, as in Australia or Brazil), depending on the interaction of several factors, including cultural, socioeconomic, management, and legislative (e.g., Sylvester et al., 2016; Specht et al., 2019; Campos-Silva et al., 2020; Vasquez and Sunderland, 2020) which will lead or not to sustainable resources use. In Argentina, the access regulations to PAs' natural resources will depend on their governmental levels (national, provincial, and local). In the case of National Reserves and Biosphere Reserves, human settlements and economic activities such as commercial, agricultural, and industrial are permitted (SAyDS, 2019). At the province level, several categories of PAs like Multiple Use

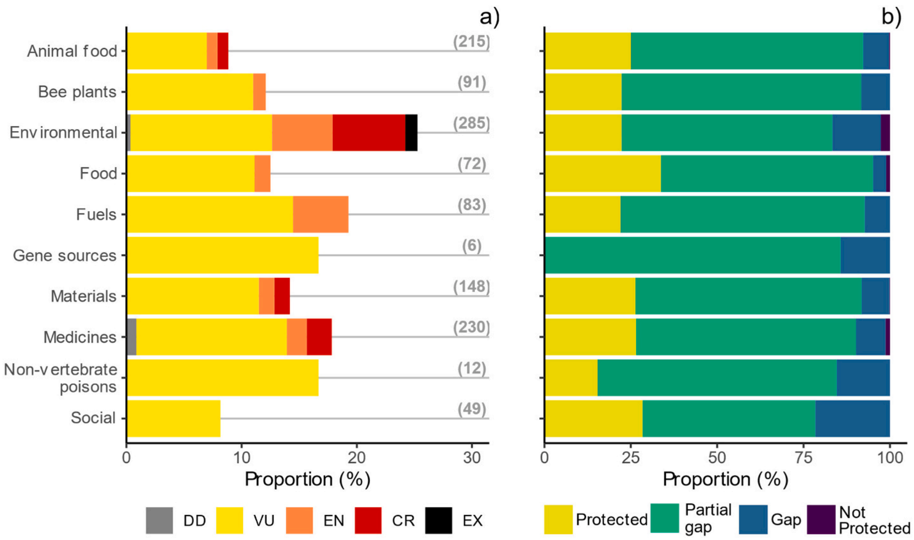

Fig. 4. Proportion of threatened species (a) and representation target in protected areas (b) of Fabaceae species native from Argentina for different use classes. Numbers in parentheses represent the total number of species by use. DD: data deficient, VU: vulnerable, EN: endangered, CR: critically endangered, EX: extinct.

Reserves and Private Reserves also allow human settlement and use of their resources. However, the management, access, and control of resources are not equal between different governmental levels, and in some cases, the uses allowed by provincial laws are unclear (Morea, 2014).

Conservation thinking has evolved over the last 50 years from prioritizing wilderness and intact natural habitats without people to a more integrated view that considers human societies and the natural environment (Mace, 2014). Therefore, it is relevant to highlight the contribution of PAs to the utilitarian aspect of biodiversity. Our findings emphasize the importance of PAs as reservoirs of economic and cultural plant resources. However, we found that many useful species are currently threatened and under-represented in PAs. Such under-representation could result from Argentina's PAs providing uneven protection of ecoregions (i.e., PAs are concentrated in a few regions) with locations biased to isolated areas near the country borders (Baldi et al., 2019). Factors such as loss of natural ecosystems, climate change, and overexploitation lead ~39% of vascular plants to be threatened (Díaz et al., 2019; Lughadha et al., 2020), and it is expected that several plants with uses may be at risk. For instance, ~11% of the worldwide edible plants (7014) are threatened with extinction (Ulian et al., 2020), and in Argentina, 163 Fabaceae species are threatened, and six were extinct (Delucchi and Hernández, 2015). The loss of these useful species affects both the provision of a specific service and promotes erosion in cultural terms due to the disappearance of a given traditional use. In this context, the current PAs network and its expansion will be fundamental to reducing the future extinction of species that contribute provisioning ecosystem services (Hannah et al., 2020).

As far as we know, our assessment to evaluate the utilitarian aspect of biodiversity by using spatially explicit indexes is novel. However, our research has some limitations – some PAs were not considered because of their small size, and results based on species threat categories could be underestimated because many species have not yet been evaluated. Future research could develop a spatial conservation prioritization analysis that integrates the spatially explicit use diversity indexes proposed here and other commonly used biodiversity attributes (e.g., taxonomic or phylogenetic).

5. Conclusion

Integrating different species characteristics, data sources, and metrics is a feasible way to evaluate the contribution of PAs to conserving the economic and cultural aspects of biodiversity on a large scale. Most of the Fabaceae from Argentina provide services and goods to people and animals, and fortunately, much of these uses are present in PAs network. Nonetheless, many species with uses are currently threatened with extinction or under-represented in the PAs network, highlighting the need for a PAs expansion and other conservation efforts to foster the protection of species and their services.

CRediT authorship contribution statement

Santiago José Elías Velazco: Conceptualization, Resources, Data curation, Formal analysis, Methodology, Software, Writing – original draft. **Natalia Alejandra Bedrij:** Resources, Data curation, Writing – review & editing. **José Lucas Rojas:** Resources, Data curation, Writing – review & editing. **Héctor Alejandro Keller:** Methodology, Writing – review & editing. **Bruno R. Ribeiro:** Methodology, Writing – review & editing. **Paulo De Marco:** Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that there is no conflict of interest.

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Appendix A. Supplementary data

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Glossary

PAs: protected areas
SDM: species distribution models