Prioritization of Important Plant Areas for conservation of frailejones (Espeletiinae, Asteraceae) in the Northern Andes

Clara Morales-Rozo
Pontificia Universidad Javeriana
Ian S. Acuña-Rodríguez
Universidad de Talca
Juan Carlos Benavides Duque
Pontificia Universidad Javeriana
Víctor Julio Rincon-Parra
Alexander von Humboldt Biological Resources Research Institute
Mauricio Diazgranados (m.diazgranados@kew.org)
Royal Botanic Gardens

Research Article

Keywords: IPAs, in situ conservation, threatened species, botanical richness, Andean region

Posted Date: September 13th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-3338341/v1

Abstract

The Tropical Andes region harbors highly significant and threatened biodiversity areas. However, due to its misidentification, conservation initiatives in these regions are limited and need more substantial support. Identifying Important Plant Areas (IPAs) offers a valuable methodology for establishing conservation priorities, a particularly complex task in a mega-biodiverse region such as the Andean tropics. Due to its iconic recognition and conservation value, this study focused on the Espeletiinae subtribe (Asteraceae) as a reference group, and we compiled species distribution data for 138 taxa from 5,560 georeferenced records. Using the IPA, we divided the study area into 220 Units of Analysis (UA) represented by 10 × 10 km plots. Refined distribution areas, incorporating richness, threatened species, and ecosystem-based richness distributions, were analyzed using newly generated maps. Most UAs were concentrated in Colombia's Eastern Cordillera, extending into Venezuela. Our analysis identified 176 UAs using sub-criterion cA1 (with 59 species) and 51 UAs using sub-criterion cB (with 76 species). We classified 11 UAs as high-priority, 58 as medium-priority, and 143 as low-priority, highlighting the IPAs that require focused conservation efforts. Key findings from our study include: *i*) the first regional-level application of IPA methodology; *ii*) the potential of implementing criteria A and B to support global biodiversity recovery targets; and *iii*) the suitability of Espeletiinae as a focal group for systematic conservation planning in the region. Accordingly, we consider that our results establish a spatial planning procedure and analytical tool for decision-makers to guide conservation management and actions across the tropical Andean region.

INTRODUCTION

Biodiversity is declining at an accelerated rate. About 25% of the animal and plant species assessed worldwide are under some risk of extinction, suggesting that nearly one million species face possible disappearance (Antonelli et al. 2020; Nic Lughadha et al. 2020). Conservation efforts focused on plant diversity are often hampered by a lack of information, limited access to up-to-date information, or outdated information that prevents prioritizing conservation actions (Darbyshire et al. 2017; Neo et al. 2021; Paton et al. 2020). Animal wildlife groups are most used to determine conservation areas (e.g., specific points of residence) and their management priorities, for example, through initiatives such as the Important Bird Areas (IBA) and Key Biodiversity Areas (KBA) (BirdLife 2014; Smith et al. 2018). Nevertheless, despite the essential ecological role of plants as primary producers, they are often under-represented in conservation research (Di Marco et al. 2017) and are frequently absent in global or national conservation planning schemes (Corlett 2016). Moreover, fewer plant-based conservation initiatives receive substantially less support than those focusing on animals (Darbyshire et al. 2017; Margulies et al. 2019; Westwood et al. 2020). In this regard, the identification of Important Plant Areas (IPAs) (Darbyshire et al. 2017; Plantlife 2018) may contribute to the more effective achievement of the current conservation challenges, especially in biodiverse regions such as the tropics, in which where a wide variety of plant communities coexist at local scales, underpinning ecosystems ecology structurally, with exceptional concentrations of endemic species, as well as being a key source and sink of Neotropical plant diversity (Myers et al. 2000; Pérez-Escobar et al. 2022).

The IPAs methodology considers species richness and geographical extent, prioritizing both threatened plants and habitats, by identifying critical sites in which conservation efforts should be focused (Plantlife 2018). The methodology is based on three criteria: threatened species (A), botanical richness (B), and threatened habitats (C). Each criterion is assessed systematically across the area of interest under different metrics, and IPAs are selected as those zones in which adequate conditions of each criterion converge. IPAs have been implemented in many countries in the last two decades, showing their value by providing information to practitioners and policymakers involved in conservation at national and regional levels. In Europe, this approach has been implemented in places such as Ireland (Walsh et al. 2019), Italy (Blasi et al. 2011; Marignani and Blasi 2012), Spain (Sánchez de Dios et al. 2017), and the United Kingdom, in which candidate sites for IPAs were identified based on the knowledge of both the vascular flora and fungal diversity (Clubbe et al. 2020). Outside Europe there are some examples in Malaysia(Hamidah et al. 2020) and Saudi Arabia (Al-Abbasi et al., 2010), from which several lists of threatened and endemic plant species have been produced (Couch et al. 2019a; Couch et al. 2019b; Darbyshire et al. 2019). In the Americas, the IPAs methodology has been mainly implemented in low-lands tropical ecosystems (i.e.: rainforest, cloud forests, and montane habitats) through the Tropical Important Plant Areas (TIPAs) program (Anderson et al. 2016), this, due to their characteristic as biodiversity hotspots (Myers et al. 2000). In addition, a methodology for IPA identification in Colombia has been proposed based on the global IPA criteria, adjusting for the country's rich diversity and the lack of reliable species distribution data to promote plant information in biodiversity conservation planning (Diazgranados and Castellanos 2018). This methodology has been recently applied to evaluate selected number of useful plants from Colombia (Kor et al. 2022; Kor and Diazgranados 2023).

In this context, the tropical Andes arises as a regionally significant biome for conservation, attributed not only to its exceptional biodiversity and pronounced endemism rates within a patchwork of ecosystems shaped by its climatic, topographic, and soil diversity (Herzog et al. 2012; Jørgensen et al. 2012; Myers et al. 2000), but also to the substantial anthropogenic impact on its ecological systems (Young 2014). The tropical Andes extend for over 158 million hectares, ranging from 11°N in the northernmost tip of South America to 23 °S in northern Argentina (Agudelo-Hz and Armenteras 2017). Different essential ecosystem services are derived from the tropical Andes (i.e., water supply and carbon sequestration), supporting more than 50 million people living in or near them (Cincotta et al. 2000). The Andes are one of the hotspots of global biodiversity (Barthlott et al. 2005; Myers et al. 2000), concentrating about 6.7% of the global endemic plants (Myers et al. 2000) and 55% of the flora of South America (Jørgensen et al. 2012), which highlights its regional priority for conservation planning and research efforts (Mittermeier et al. 2011). However, the region is most impacted by anthropic activities responding to demographic and economic growth demands, resulting in a highly transformed and fragmented landscape (Llambí et al. 2019; Reece and Noss 2014; Le Roux et al. 2019). Moreover, the tropical Andes is highly vulnerable to environmental changes and serves as an amplifier of global warming signals, according to research conducted by Pepin et al. (2015). In addition, this region is one of the most affected by human activities, and its sensitivity to climate change makes it more prone to biodiversity loss (Gonda 2020).

The Espeletiinae (Asteraceae) is one of the most widely distributed and distinct groups in the tropical Andes, showcasing remarkable taxonomic, morphological, and ecological diversification among tropical taxa inhabiting high elevations (Diazgranados 2012a; Diazgranados and Barber 2017; Mavárez et al. 2019; Pouchon et al. 2021). This group exhibits high endemism and restricted distribution, and represents an outstanding example of adaptive radiation (Cuatrecasas 2013; Diazgranados 2012a). The subtribe Espeletiinae has a high ecological diversification along the elevation gradient and can be found from the lower limit of the montane cloud forests (~ 1,300 m) to the edge of the tropical glaciers (~ 4,600 m) (Diazgranados 2012a). In this context, their species are faced with confronting diverse conditions of humidity, ranging from wet bogs to xéric periglacial slopes and rocky outcrops, and a wide variation in solar irradiation, from clearings in the montane forest to open vegetation as paramo grasslands, hence having different biotic interactions (Cuatrecasas 2013; Mavárez et al. 2019). They also provide ecosystem services such as soil protection, erosion control, water regulation, and the provision of commercial and cultural raw materials (Diazgranados et al. 2021). In addition, this group of plants has been extensively studied, so there is sufficient information on the threat categories based on the IUCN Red List of Threatened Species (IUCN 2022) and accessible geographical data on their geographic distribution (Diazgranados, personal communication, May 20, 2023), enabling the implementation of the IPA methodology.

Building on the previous work on identifying IPAs in tropical countries (Diazgranados and Castellanos 2018), we aimed to apply the IPA methodology in a highly biodiverse region such as the tropical Andes. One of the challenges in prioritizing areas for the conservation of biodiversity in tropical regions and developing countries is the lack of abundant and reliable data. Here we gathered high-quality georeferenced data for all the Espeletiinae species across their distribution entire range, covering Ecuador, Colombia, and Venezuela. We identified potential IPAs for these plants and discussed the methods and criteria, and the challenges in managing occurrence data and associated metadata. This study represents the first regional-level application of the IPA concept in the northern Andes, and provides a practical example of a systematic conservation approach to Espeletiinae.

MATERIALS AND METHODS

Study area

Our study aimed to prioritize conservation areas for the Espeletiinae subtribe in the northern Andes region. We encompassed all Espeletiinae species occurring at elevations above 1,000 m across Ecuador, Colombia, and Venezuela (Diazgranados 2012a). The study area was delimited by geographic coordinates 66°W to 81°W and 6°S to 12°N, encompassing a total area of 320,502.79 km² (Fig. 1).

We created a mask to include the land above 1,000 m of elevation, by utilizing the contour tool from ArcMap v10.5 (ESRI 2011). This polygon was based on the 90-m resolution DEM from the Shuttle Radar Topographic Mission (SRTM) (Jarvis et al. 2008) and the plant record coordinates. Subsequently, we rasterized the study area polygon into 10 × 10 km cells, which acted as the units of analysis (UA) for the entire study area. The R package "raster" (Hijmans 2017) was used to create the rasterized polygon. We assigned a unique identification number to each UA, to assess the IPA criteria, resulting in the identification of a total of 4,101 UAs.

Quality assessment of data and georeferencing

We used georeferenced occurrence data of the subtribe Espeletiinae (hereafter: the “records”) available from the Global Biodiversity Information Facility (GBIF 2022), and Instituto de Investigación de Recursos Biológicos Alexander von Humboldt (Castellanos and Diazgranados 2016). We based our taxonomic classification system on Diazgranados and Barber (2017) and Cuatrecasas (Cuatrecasas 1976), which is still broadly used by many herbaria. This classification includes 8 genera: *Carramboa* Cuatrec., *Coespeletia* Cuatrec., *Espeletia* Mutis ex Humb. & Bonpl., *Espeletiopsis* Cuatrec., *Libanothamnus* Ernst, *Ruilopezia* Cuatrec. *Tamania* Cuatrec. (Cuatrecasas 1976) and *Paramiflos* Cuatrec. (Cuatrecasas 1995). A recent classification (Mavárez 2021) proposes only one genus (*Espeletia*). Being aware there are ongoing efforts by various labs to redefine the classification of the group, we decided to maintain Cuatrecasas’ system. Full species names including authors can be found in the supplementary information (Online Resource TS1).

The compiled information was checked for quality and precision following a set of standardized criteria: i) duplicate coordinates were removed; ii) records whose coordinates only had one or no decimal positions or with a precision lower than 10 km were revised in Google Earth Pro (v. 7.3.6.9345), validating the reported data only if the record occurred in the geographic areas reported for the subtribe (Diazgranados 2012b, 2012a; Mavárez et al. 2019; Mavárez 2021); iii) records found within anthropic Corine land cover types (Tsendbazar et al. 2020), such as Cultivated (n = 161, 3%) or Urban / built up (n = 26, 0.5%), as well as those on permanent water bodies (n = 9, 0.2%) or Snow and Ice lancovers (n = 6, 0.1%), were filtered out; iv) species names were reconciled using the taxonomic backbone of Plants of the World Online (POWO, 2023; http://www.plantsoftheworldonline.org), which was also used as a reference for the genera classification; and v) species were considered threatened according to the classification on the IUCN Red List (IUCN 2022) including: critically endangered (CR), vulnerable (VU), or endangered (EN). As a result of the quality-check process, we consolidated the most up-to-date species data for the Espeletiinae subtribe, with updated calculations based on threat and richness criteria.

IPAs criteria

Our work builds upon a previous proposal to implement IPAs (Diazgranados and Castellanos 2018). We applied thresholds defined in the methodology under criteria A and B only (see below), as our focus is on the Espeletiinae subtribe as biodiversity surrogates (Table 1; Fig. 2). The exact sub-criteria applied were chosen based on the data availability. We do not evaluate the third criterion (C) that indicates “The area constitutes an extraordinary case of habitat, vegetation type or ecosystem in a national, regional or global context”, considering that this research focused on a botanical group and not on an area or habitat. The methods applied for the different criteria and sub-criteria are described below. All processes were automated in the R language and statistical environment v4.2.2 (R Core Team, 2022), using the packages: *rgdal* (Bivand et al. 2017), *raster* (Hijmans 2017), *sp* (Bivand et al. 2013), *ggplot2* (Wickham 2016) and *vegan* (Oksanen et al. 2014).

We applied criterion A (cA), which entails that “The site supports significant, viable or potentially viable populations of one or more globally, regionally or nationally threatened species” has six sub-criteria (or indicators), where the cA1, cA2, and cA3 based on the extinction risks of the different species, the cA4, and cA5 on endemism's and the cA6 on species of particular interests (axiophytes) (Table 1). Based on the consolidated dataset, we focus on cA1, cA3 (assuming it includes cA2), cA4, and cA5. For criteria cA1 and cA3, we used global threat IUCN classifications, and those with a national classification were considered (Diazgranados and Castellanos-Castro 2021; IUCN 2022). For criterion cA1, we selected the species under the prioritized threat categories, considering the count of their occurrences within UA. We calculated the occurrence for each species in a UA over the total possible number of species in a UA. Based on this value, we evaluated those UAs that contained at least 1% of the threatened species. We followed the same procedure to evaluate cA3, selecting the UAs that contained at least 10% of the species.

We used the highly restricted range (HRR) for criterion cA4, whose area of occurrence was ≤ 100 km^2. Criterion cA5 considered the restricted range (RRE) whose extension area of occurrence was > 100 km^2 but ≤ 5.000 km^2, following the concepts for Diazgranados and Castellanos (2018) and IUCN (2022b) (Table 1). To obtain sub-criteria cA4 and cA5, we calculate the extent of occurrence (EOO) for each species by determining its minimum convex polygon for each species with function “ConBatch” available in the R-package *rCAT* (Joppa et al. 2016; Moat 2020). We counted species within each UA considering the previously mentioned areas (HRR and RRE) and calculated each UAs’ occurrence percentage over the total, prioritizing those UAs that contained at least 10% of the total estimated species richness of each ecosystem.

We also applied criterion B (cB), which is about species richness: “The area has exceptional richness in a national context, in relation to its ecosystem”. It has two sub-criteria (or indicators): cB1: Highest estimated plant richness of the ecosystem type; and cB2: Areas that together support 10% of ecosystem's diversity. We used the function “Specpool” available in the R-package *vegan* to calculate the Chao1 index as an abundance estimator according to the Espeletiinae records for each species within a UA and ecosystem types. Then, we selected the UA with the highest estimated richness based on the Chao1 index for cB1 (Chao and Jost 2012), understanding coverage as the total relative abundance of a given species in the sample, ranging from 0 to 1. From the pixels prioritized in cA1, those with their complementary species were used to calculate cB2. For this, we added those UAs with different species until at least 10% of the total complementary richness per ecosystem was reached. The World Terrestrial Ecosystems datalayer (Sayre 2022), with a spatial resolution of 250 m, was used to delimit the ecosystems for this analysis in each UA. This map integrates world climate and terrain setting and world vegetation and land cover types, identifying 431 distinct ecosystems worldwide (Sayre et al. 2020, 2022).

Mapping IPAs

We considered records (occurrence/presence) that met the thresholds for each criterion within a UA and reclassified the results on a continuous scale (score) to visualize the UAs. Furthermore, we grouped the results of each sub-criterion, assigning the highest value to species with highly restricted range endemism (HRR) for criterion cA [cA1 = 1, cA3 = 2, cA4 = 4, cA5 = 3]. We assume that the extent area of occurrence is more crucial than the threat and was measured and quantified. For cA species richness per UA, we also prioritized a continuous scale for reclassification [1–2 spp.=1, 3–4 spp.=2, 5–8 spp.=3], where the lowest value corresponds to the lowest species richness, and the highest value corresponds to the highest species richness per UA. This allowed us to consolidate the outputs, which included i) the number for each sub-criteria of cA and ii) the richness of species for each sub-criteria of cA that met the thresholds to accomplish any UA. The same exercise was carried out for the cB, reclassifying the richness values. To establish the relationship between cB criteria and each UA, we overlaid the results with the World Terrestrial Ecosystems map. To spatially represent this information, we utilized ArcMap's "Identify" geoprocessing tool for each country. In addition, we showed the hotspot of richness occurrence per ecosystem per UA for the cB criteria (this information includes cB1). Finally, to generate the IPAs index, we summarize the results of cA and cB and create a final reclassification by sum the previous classifications of criteria through the "Calculate Field" tool that allowed a geographical representation of IPAs relevance (low = 1; intermediate = 2; and high priority = 3). In this way, those IPAs with high priority contain the major number of meted criteria, as well as the highest rank within each of them.

RESULTS

Criteria Evaluation and IPAs-Identification

We identified 138 taxa belonging to eight genera within the subtribe Espeletiinae: *Coespeletia*, *Espeletia*, *Espeletiopsis*, *Libanothamnus*, *Paramiflos*, *Ruilopezia*, and *Tamania*. These taxa were derived from a comprehensive analysis of 5,560 records across 220 UA (Online Resource TS1). Initially, we had 7,129 records, but after applying filtering criteria, we narrowed the database down to 5,560 records (78% of the original). Most discarded records were due to geographical issues, such as low-precision coordinates, or plant records outside the designated study area (26% of the total), most likely because of issues with the coordinates. By implementing quality control measures for georeferencing and data assessment, we compiled a robust database that provides valuable insights into the distribution patterns, richness, conservation status, and extent of occurrence of the Espeletiinae subtribe. The top five species with the largest number of records of species in the database were: *E grandiflora* (569 records, 10%), *E. schultzii* (338, 6%), *E. pycnophylla* (301, 5%), *E. corymbosa* (299; 5%), and *E. hartwegiana* (277; 5%). Most records corresponded to species within the genus *Espeletia* (3,428 records, 62%), followed by *Espeletiopsis* (908; 16%), *Ruilopezia* (394; 7%), *Coespeletia* (332; 6%), *Libanothamnus* (269; 5%), *Carramboa* (112; 2%), *Paramiflos* (79; 1%) and *Tamania* (38; 1%).

For cA1 (UAs with proportion of globally threatened species above 1%), we identified 176 of the 4,101 UAs assessed (4.3%). The 176 selected UAs contained 59 species (39%) represented by 343 records (6%) (Table 2). The main species under a globally threatened species category were: *Paramiflos glandulosus*–VU (20 UAs), *Espeletia conglomerata*–VU (18 UAs), *E. brassicoidea*–VU (17 UA), *E. tunjana*–EN (15 UA), *Tamania chardonii*–EN (13 UA) and *Espeletiopsis jimenez-quesadae*–VU (12 UA) (Online Resource TS2).

Complementarily, for criterion cA3 (UAs with nationally threatened species above 10%), we found that 51 species (33%) with 141 records (3%) triggered 80 UAs (2%) (Online Resource TS3). The main species with the highest number of records in UA were *Libanothamnus divisoriensis*–EN (6 UA), *E. annemariana*–EN, *Espeletiopsis purpurascens*–EN and *E. brassicoidea*–VU (5 UA). For cA4 (UAs with species area of occurrence ≤ 100 km^2), 75 records (1%) were found in 57 UAs (1%) (Table 2), corresponding to 49 species (32%). The species with the highest number of records in UA in cA4 were *Ruilopezia cardonae* and *R. emmanuelis* (4 UA), *E. discoidea*, *E. tenorae* and *R. ruizii* (3 UA) (Online Resource TS4). For criterion cA5 (UAs with species area of occurrence > 100 km^2 but $\leq$ 5,000 km^2), similar results were obtained, with 75 records (1%) found in 57 UAs (1%), corresponding to 49 species (32%). The species with the highest number of records in UA were *R. cardonae*, *R. emmanuelis* (4 UA), *E. discoidea*, *E. tenorae* and *R. ruizii* (3 UA) (Table 2, Online Resource TS5).

We found that the eastern cordillera in Colombia and Venezuela had the highest scores for each cA sub-criterion based on their results and reclassification using a continuous scale. The criteria that exhibited the highest values for thresholds of IPAs were cA1 (globally threatened species) and cA3 (nationally threatened species). In contrast, a lower number of UAs were observed to meet the thresholds to accomplish the criteria cA4 (HRR species) and cA5 (RRE species) (Fig. 3). In terms of species richness for cA, low values (1–3) and medium values (4–5) are concentrated in the eastern Colombian mountain range, extending into Venezuela, with scattered areas of high values (> 6). Dispersed areas of high values are also evident in the Colombian Massif, Eastern Cordillera, and Serranía del Perijá (Fig. 3. Supplementary Material 1). Table 2 shows the number of species and spatial coverage (in km^2), where assessments were conducted for each evaluated criterion in each country.

For the assessment of cB1, the Chao1 index was applied as an abundance estimator according to the Espeletiinae records (Table 3). We cross-referenced our study area with the World Ecosystems layer finding for the cB1 criterion 22 of the 431 identified ecosystems. We identified 15 ecosystems within 51 UAs by calculating the areas with estimated complementary richness based on this value, which together adds up to 10% of the total biodiversity of the ecosystem (Online Resource TS6). Colombia had 12 ecosystems and contained 41 UAs, where 49 species were concentrated. Venezuela had the second largest area, with 6 UAs in 4 ecosystems, and 27 species. Ecuador had 4 UAs in 2 ecosystems, with a 2 species (Table 3). The top 5 ecosystems that presented the highest estimated richness according to the Chao1 index were: Warm Temperate Dry Cropland on Plains (3 spp., Chao1 = 0.75), Cool Temperate Moist Shrubland on Mountains (9 spp., Chao1 = 0.47), Warm Temperate Moist Settlement on Mountains (4 spp., Chao1 = 0.44), Polar Moist Forest on Mountains (3 spp., Chao1 = 0.43) and Cool Temperate Moist Forest on Mountains (5 spp., Chao1 = 0.36) (Table 3, Fig. 4). We identified 50 UAs contained 76 species (50%) in 1,232 records (30%)

Espeletiinae IPAs distribution in the tropical Andes

Based on the obtained results from each criterion, we identified high-priority IPAs throughout the eastern cordillera of Colombia and Venezuela (52 UA). IPAs of medium (79 UA) and low priority (89 UA) are distributed in the central mountains of Colombia and Venezuela, with some UAs in the eastern mountains of Colombia and northern Ecuador (Fig. 5. Online Resource TS7). Colombia had the highest number of records (3,620; 65%) and reported species (94). Venezuela was the second country with the highest diversity of Espeletiinae, with fewer records (1,753; 31.5%) and species (71). Ecuador had the lowest number of records (187 records; 3.4%) with only three species: *Espeletiopsis corymbosa* (1 record), *E. hartwegiana* (1 record), and *E. pycnophylla* (185 records). The highest priority IPAs are likely associated with "paramo" ecosystems (sensu: Van der Hammen and Cleef, 1986) in the eastern cordillera of Colombia towards Venezuela, such as the Sumapaz, Cruz Verde, Pisba, Rechíniga, Cocuy, and Almorzadero páramos.

DISCUSSION

Aiming to provide actualized tools that facilitate the development of public and private conservation initiatives in the tropical Andes, we implemented the IPA methodology with a multi-criteria perspective, focusing on the current distribution of an iconic taxa for this region such as the Espeletiinae subtribe. We were able to identify 220 units of analysis (i.e.: 10 × 10 km grid cells) that fulfill the requirements for an IPA designation, representing 5.4% of the total UAs established within the subtribe's distribution range. However, since these IPAs differ in their criteria estimation, they were not equally relevant in terms of the methodological assessment. After prioritizing the selected IPAs based on their observed criteria values, we defined three levels of priority: high-priority (11 IPAs, 5%), medium-priority (58 IPAs, 26%), and low-priority (143 IPAs, 65%); suggesting that most of the subtribe diversity is highly clustered in specific areas of the tropical Andes region.

One important aspect of this methodology is its multicriteria approach, which incorporate not only aspects of the richness and diversity of the referred taxa, but also information regarding the spatial distribution of their associated ecosystems and the threaten level of both species and environments (Florentín et al. 2022; Hamidah et al. 2022; Maxwell et al. 2018; Özden et al. 2016). Consequently, our assessment of the IPA criteria was based on the concept of "important populations of global, regional, or national conservation concern" (Diazgranados and Castellanos 2018), which explicitly include the assessment of the extinction risk among the analyzed species, and their related ecosystems, at different special scales (*i.e.*, global, regional, or national). In this regard, through the analysis of criteria cA1 and cA3, we found, for example, that 44% of species (68 spp.) for cA1 and 38% (58 spp.) for cA3 had some risk of extinction according to the IUCN (2022b) and Diazgranados and Castellanos-Castro (2021). These findings highlight that the Espeletiinae subtribe exhibits high extinction threat assessments when compared to the estimates reported in the IUCN, where only 15% of plant diversity has been evaluated on the Red List, and approximately 40% of vascular plant species have some category of extinction threat at a global scale in Southern America, Northern America, and tropical Asia (Nic Lughadha et al. 2020). Consequently, the identified IPAs will contribute to protecting and managing sites of importance for the subtribe by focusing the attention of potential decision makers on the most threatened species within the analyzed group (Anderson 2002; Darbyshire et al. 2017).

Nevertheless, besides the aforementioned compilation of secondary information describing the conservation status of the subtribe species, the application of criteria cA4 and cA5 of the IPA methodology also generates an empirical estimation of how conserved the Espeletiinae species in the region are. In this sense, through the calculation of the extent of occurrence (EOO) for each species, we were able to establish for all taxa if they were a Highly Restricted Range Endemic (HRR) species (cA4) or a Range-Restricted Endemic (RRE) species (cA5). In this way, while the EOO was reported in the IUCN for 88 species of the subtribe (Diazgranados and Castellanos-Castro 2021; IUCN 2022; Mavárez 2019), we recalculate it for all species on our list, providing an actualization of this estimations for those species that were already evaluated, and new preliminary conservation assessments for other 65 species (Darbyshire et al. 2017). Interestingly, the results were similar between criteria (34% (58 spp.) for cA4 and 37% (57 spp.) for cA5), suggesting that besides RRE species have a relatively wider distribution compared to HRR species, likely facing similar conservation challenges due to their limited range. Consequently, despite HRR species are theoretically more sensitive to threats associated with habitat degradation and land-use changes(Pérez-Escobar et al. 2018) as well as climate change (Diazgranados 2012; Mavárez et al. 2019b; Valencia et al. 2020), their similar proportion suggests that the observed pattern could be influenced by the geography of the Andes and climatic fluctuations, which have played a role in the diversification and concentration of the subtribe within its distribution range (Cuatrecasas 2013). According to Pouchon et al. (2021), the distribution of the subtribe is associated with various ecological niches that align with typical environmental gradients found in the páramos. Phylogenetic relationships between species traits shape these niches, encompassing factors such as climate and habitat. As a result, adaptation syndromes have emerged for both vegetative and reproductive traits. One such adaptation syndrome could attribute to the ecotone between closed vegetation (such as forests and subpáramo) and open vegetation (referred to as true páramo), where distinct lineages have repeatedly differentiated based on specific vegetative traits associated with tree and rosette morphotypes (Monasterio and Sarmiento 1991). Additionally, the transitions between herbaceous/rosette and woody growth forms, which are characteristic of open and closed habitats among Andean taxa, contribute to the overall pattern of adaptation (Dušková et al. 2017; Kolář et al. 2016). Another adaptation syndrome is linked to reproductive traits, particularly the emergence of a morphological development syndrome in the larger capitula, corollas, and achenes in specific lineages occurring at higher elevations or super-páramo habitats, suggesting a limitation in long-distance pollination and seed dispersal (Berry and Calvo 1994; Diazgranados and Barber 2017), which may be the underlying cause of these results.

The implementation of criteria that involve extinction risk assessments in the IPAs protocol allows the spatialization of the conservation status for a complex group of species, in our case the Espeletiinae subtribe. Indeed, the evaluation of the extinction risk has been suggested as a tool to supports and inform the planning and prioritization of important conservation areas where plant diversity is actually threatened (Clubbe et al. 2020; Darbyshire et al. 2017; Nic Lughadha et al. 2020). For instance, in Europe, this approach has been applied to managing and conserving fungi (Dahlberg et al. 2010). Red List assessments, including National Red Lists, have been used to identify areas of significance for fungi in the United Kingdom (Genney et al. 2009) and the United States (Molina et al. 2006). Similarly, Couch et al. (2019) described how extinction risk assessments have facilitated conservation funds for populations classified as Endangered or Critically Endangered in Senguelen (Guinea), leading to modifications in construction plans and supporting the financing of seed storage programs and the development of propagation protocols. This became of high relevance for the tropical Andes since it represents a complex territory in which the development of human communities has had a profound impact on local ecosystems resulting in a rapid and ongoing land use and cover transformation driven by current development models (Guarderas et al. 2022). Moreover, despite previous assessments of the IPA methodology in tropical regions (Bolivia, British Virgin Islands, Cameroon, Ethiopia, Guinea-Conakry, Indonesia New Guinea, Mozambique, and Uganda) (Darbyshire et al. 2017), this study is the first to conduct such effort in the Tropical Andes region, using the entire distribution range of an iconic plant group.

The implementation of the IPA methodology also contributed to providing information about the local ecosystems, as demonstrated by the cB criterion. Analyzing the distribution of species richness within each ecosystem type, this analysis highlighted the importance of incorporating local environmental variability in the conservation assessment. In our case, most of the identified IPAs were located in five ecosystems (sensu: Sayre 2022), *i.e.*: Warm Temperate Dry Cropland on Plains, Warm Temperate Moist Settlement on Mountains, Cool Temperate Moist Forest on Mountains, Cool Temperate Moist Shrubland on Mountains, and Polar Moist Forest on Mountains. This clearly reflects the ecological relationship between Espeletiinae and high-mountain ecosystems and can explain the presence of IPAs in these environments. As one of the most representative, abundant, and diverse groups in the páramo ecosystems, Espeletiinae exhibits adaptations that allow them to grow in moist depressions in high valleys, on exposed dry slopes, or within Andean forests, including the treeline, to enable them to experience a wide range of geographical conditions at different elevations and locations (Mavárez et al. 2019b; Peyre et al. 2018; Pouchon et al. 2021; Valencia et al. 2020).

The resulting IPAs reveal consistent distribution patterns for the subtribe between the observed areas of conservation importance and the biogeographic history of the subtribe. Primarily concentrated in the Eastern Cordillera of Colombia and extending into Venezuela (Diazgranados and Barber 2017; Pouchon et al. 2021), the observed clustering of areas at regional and local scales aligns with recent studies and hypotheses on the subtribe's geographic diversification (Cuatrecasas 2013; Diazgranados and Barber 2017; Monasterio and Sarmiento 1991). The adaptive radiation and biogeographic history of the Espeletiinae subtribe can explain this distribution, originating from a common ancestor in the Venezuelan Andes (Pouchon et al. 2018), colonizing the Eastern Cordillera of Colombia and the Ecuadorian Andes southward, followed by a migration northward to the Central and Western Cordilleras of Colombia (Cuatrecasas 2013). The spatial analysis conducted in this study confirmed the distribution patterns reported for the Espeletiinae subtribe, with peaks of high diversity in the Eastern and Central Cordilleras associated with páramo and high-Andean Forest ecosystems, which exhibit higher diversification rates among plant lineages, even compared to other rapidly evolving lineages such as those in the Brazilian Cerrado (Madriñán et al. 2013).

While the results obtained by the implementation of the IPA methodology are useful for prioritizing in situ conservation measures, it is necessary to delve into the potential management of these areas (Diazgranados and Barber 2017). For instance, it is crucial to evaluate the role of the protected area system in addressing climate change, human activities, and their impact on plant distribution (Valencia et al. 2020). IPAs can support existing legally protected areas, such as Protected Areas and Protection Forests under Permanent Reserve Forests, in the same way as Key Biodiversity Areas, Important Bird Areas, and High Conservation Value Forests (Brancalion et al. 2019; Chazdon et al. 2009; Donald et al. 2019; KBA Secretariat 2022; Plumptre et al. 2019). The designation of these multiple-use areas should be considered complementary and mutually supportive as they provide necessary site-based protection for biotic assemblages and the ecosystem (Blasi et al. 2011; Hamidah et al. 2020; Marignani and Blasi 2012). Site-based protection also conserves ecosystem services. In the case of Espeletiinae, many of these services are derived, including soil protection, erosion control, water regulation, and the provision of construction materials, medicinal compounds, and cultural use, among others (Diazgranados and Castellanos-Castro 2021). Therefore, from a conservation perspective, protecting a botanical group also helps sustain the ecosystems they are found in, and it is crucial in formulating and implementing management plans for the assessed areas, promoting shared responsibility between decision-makers and users of ecosystem services. This underscores the importance of long-term commitments to manage, conserve, and implement areas and species while providing legal protection (Hamidah et al. 2020, 2022). It is important to note that even if a species occurs within the boundaries of a protected area, there is no guarantee of its effective management due to resource and scientific knowledge inadequacies (Clubbe et al. 2020; Corlett 2016; Nic Lughadha et al. 2020).

Prospects and Directions for the Future Implementation of IPAs

Our species list of the Espeletiinae subtribe represents the most up-to-date compilation available. However, during our analysis, we discovered that some species presence records date back to 1800, highlighting the importance of validating record information and verifying the existence of these species under current in situ conditions. Consequently, our findings may overlook valuable information regarding the identification of IPAs. Similar observations have been documented in other studies focused on conservation planning, including those specifically addressing IPAs (Blasi et al. 2011; Hamidah et al. 2020). To ensure data accuracy, confirming species distribution within the current ecological and ecosystem context is essential, particularly for outdated occurrence records (Cuesta et al. 2017). Various approaches can be employed to mitigate data limitations, such as using alternative data sources like surrogate taxa (Beier et al. 2015) or employing environmental predictor variables to develop species distribution models (SDMs) (Guisan and Thuiller 2005; Zurell et al. 2020). On the other hand, obtaining biological information is the initial phase of a multifaceted process of identifying conservation areas, which should encompass social, political, and economic factors (Darbyshire et al. 2017; Kress et al. 1998). Complementarily, the habitat-based Criterion C of the IPA methodology, although not applied, can enhance the approach, providing a broader perspective for research, thus strengthening efforts to understand species and their distribution.

We want to emphasize that our data only represents the total number of species recorded in a particular area and do not assess the "quality" of these species. Some researchers have suggested that absolute numbers are not the best indicator of genetic diversity; thus, other criteria such as phylogenetic uniqueness and position (Erwin 1991), phylogenetic distance (Sánchez de Dios et al. 2017), Environmental DNA (eDNA) sampling (Thomsen and Willerslev 2015) the concentration of endangered taxa, or richness of indicator taxa (Darbyshire et al. 2017; Yahi et al. 2012), may be a better measure for conservation purposes. Additionally, when identifying regions with high diversity, it is necessary to consider additional biological information about the species that can be provided by taxonomists, field biologists, decision-makers, and local naturalists (Anderson et al. 2016; Hamidah et al. 2022; Sanchez et al. 2021).

Conclusions

From a practical perspective, the predictions focused on species can be utilized to prioritize risk assessment (Pelletier et al. 2018). The identification of UAs as IPAs represents a crucial step for future studies. The evaluated IPA methodology in this study exemplifies applying a systematic conservation approach to a well-known plant group, representing the first regional-level implementation of the IPA methodology. The analysis of occurrence data emphasizes the significance of the subtribe's distribution, addressing information gaps and providing data for reviewing and updating richness, threatened species, ecosystems, and physical planning applications that recognize the importance of identifying biodiversity traits that contribute to the significance of a site (Halpern et al. 2006).

Applying the methodology presented here is extremely valuable as it effectively explores available data and provides crucial information for policy and decision-makers responsible for resource allocation in conservation risk investigation. It can contribute to enhance conservation efforts' efficiency and amplify the impact of biodiversity data in public repositories. Our approach can be adapted to specific needs and circumstances in each region when assessing the criteria independently or in combination. By applying the IPA methodology, researchers and conservation practitioners are equipped with a comprehensive list that aids decision-making in resource allocation for conservation, irrespective of the classification system used in any geographic area. The combined implementation of criteria can be used to develop strategies that establish or sustain conservation actions, safeguarding important geographical regions, key ecological systems, and ecosystem services. These data can be combined with information on global funding distribution and prioritize conservation measures to maximize their impact (Waldron et al. 2013). Furthermore, they underscore the significance of long-term commitments to manage, conserve, and protect areas and species through legal measures (Hamidah et al. 2020, 2022).

Declarations

Acknowledgments

We are grateful to all the collaborators and contributors of the Global Biological Information Facility (GBIF) for making their data available. This study would not have been possible without the support of the Vicerrectoría Académica of the Pontificia Universidad Javeriana through the teaching and research assistance program framework. We thank Alejandra Narvaez-Vallejo and Fabio Ávila for their helpful comments on an earlier version of the manuscript.

Data availability

The generated data set supporting this article and related TS is available in the Figshare data repository (https://figshare.com/s/bbaa7e32b42c6ff71394

References

1. Agudelo-Hz, W. J., & Armenteras, D. (2017). Cambio Climático en Ecosistemas Andinos de Colombia: una revisión de sus efectos sobre la Biodiversidad. In *Biodiversidad y cambio climático en Colombia: Avances, perspectivas y reflexiones*, 48–64. https://doi.org/10.1111/btp.12453.Vanderbilt
2. Al-Abbasi, T. M., Al-Farhan, A., Al-Khulaidi, A. W., Hall, M., Llewellyn, O. A., Miller, A. G., & Patzelt, A. (2010). Important plant areas in the arabian peninsula. *Edinburgh Journal of Botany*, *67*(1), 25–35. https://doi.org/10.1017/S0960428609990217
3. Anderson, S. (2002). Identifying Important Plant Areas. *Plantlife International*, 1–52. https://www.cbd.int/doc/pa/tools/Identifying important plant areas.pdf
4. Anderson, S., Darbyshire, I., & Halski, B. (2016). *Important Plant Areas. In: RBG Kew, State of the World's Plants Report-2016*. https://espas.secure.europarl.europa.eu/orbis/sites/default/files/generated/document/en/Kew Gardens - State of the Worlds Plants report 2016_0.pdf
5. Antonelli, A., Fry, C., Smith, R. J., Simmonds, M. S. J., Kersey, P. J., Pritchard, H. W., Abbo, M. S., Acedo, C., Adams, J., Ainsworth, A. M., Allkin, B., Annecke, W., Bachman, S. P., Bacon, K., Bárrios, S., Barstow, C., Battison, A., Bell, E., Bensusan, K., … Zhang, B. G. (2020). *State of the World's Plants and Fungi 2020*. https://doi.org/doi.org/10.34885/172

6. Barthlott, W., Mutke, J., Rafiqpoor, D., Kier, G., & Kreft, H. (2005). Global Centers of Vascular Plant Diversity. *Nova Acta Leopoldina NF*, *92*(342), 61–83. https://www.researchgate.net/publication/215672852
7. Beier, P., Sutcliffe, P., Hjort, J., Faith, D. P., Pressey, R. L., & Albuquerque, F. (2015). A review of selection-based tests of abiotic surrogates for species representation. *Conservation Biology*, *29*(3), 668–679. https://doi.org/10.1111/cobi.12509
8. Berry, P. E., & Calvo, R. N. (1994). An overview of the reproductive biology of Espeletia (Asteraceae) in the Venezuelan Andes. In P. W. Rundel, A. P. Smith, & F. C. Meinzer (Eds.), *Tropical Alpine Environments. Plant Form and Function*, 229–250. Cambridge University Press.
9. BirdLife. (2014). *Important Bird and Biodiversity Areas: A global network for conserving nature and benefiting people*. 28. http://datazone.birdlife.org/userfiles/file/IBAs/pubs/SOWIBAs2014.pdf
10. Bivand, R., Keitt, T., & Rowlingson, B. (2017). *rgdal: bindings for the geospatial data ab- straction library. R package version 1.2-8*. https://cran.r-project.org/web/packages/rgdal/index.html
11. Bivand, R., Pebesma, E. J., Gomez-Rubio, V., & Pebesma, E. J. (2013). *Applied spatial data analysis with R (Vol. 2)*. Springer.
12. Blasi, C., Marignani, M., Copiz, R., Fipaldini, M., Bonacquisti, S., Del Vico, E., Rosati, L., & Zavattero, L. (2011). Important Plant Areas in Italy: From data to mapping. *Biological Conservation*, *144*(1), 220–226. https://doi.org/10.1016/j.biocon.2010.08.019
13. Blasi, C., Marignani, M., Fipaldini, M., & Copiz, R. (2011). Between global priorities and local urgencies: The important plant areas programme in Italy. *Fitosociologia*, *48*(2 SUPPL. 1), 137–143.
14. Brancalion, P. H. S., Niamir, A., Broadbent, E., Crouzeilles, R., Barros, F. S. M., Almeyda Zambrano, A. M., Baccini, A., Aronson, J., Goetz, S., Leighton Reid, J., Strassburg, B. B. N., Wilson, S., & Chazdon, R. L. (2019). Global restoration opportunities in tropical rainforest landscapes. *Science Advances*, *5*(7), 1–12. https://doi.org/10.1126/sciadv.aav3223
15. Chao, A., & Jost, L. (2012). Coverage-based rarefaction and extrapolation: standardizing samples by completeness rather than size. *Ecology Ecology*, *93*(12), 2533–2547.
16. Chazdon, R. L., Harvey, C. A., Komar, O., Griffith, D. M., Ferguson, B. G., Martínez-Ramos, M., Morales, H., Nigh, R., Soto-Pinto, L., Van Breugel, M., & Philpott, S. M. (2009). Beyond reserves: A research agenda for conserving biodiversity in human-modified tropical landscapes. *Biotropica*, *41*(2), 142–153. https://doi.org/10.1111/j.1744-7429.2008.00471.x
17. Cincotta, R. P., Wisnewski, J., & Engelman, R. (2000). Human population in the biodiversity hotspots. *Nature*, *404*(6781), 990–992.
18. Clubbe, C., Ainsworth, M., Bárrios, S., Bensusan, K., Brodie, J., Cannon, P., …, & Fay, M. F. (2020). Current knowledge, status, and future for plant and fungal diversity in Great Britain and the UK Overseas Territories. *Plants People Planet*, *2*(5), 557–579.
19. Corlett, R. T. (2016). Plant diversity in a changing world: Status, trends, and conservation needs. *Plant Diversity*, *38*(1), 10–16. https://doi.org/10.1016/j.pld.2016.01.001
20. Couch, C., Cheek, M., Haba, P., Molmou, D., Williams, J., Magassouba, S., Doumbouya, S., & Diallo, M. Y. (2019a). *Threatened habitats and Tropical Important Plant Areas (TIPAs) of Guinea, West Africa*. https://doi.org/10.34885/169
21. Couch, C., Magassouba, S., Rokni, S., Canteiro, C., Williams, E., & Cheek, M. (2019b). Threatened plants species of Guinea-Conakry: A preliminary checklist. *PeerJ Preprints*, *7: e3451v4*. https://doi.org/doi.org/10.7287/peerj.preprints.3451v4
22. Cuatrecasas, J. (1976a). A new subtribe in the Heliantheae (Compositae): Espeletiinae. *Phytologia*, *35*, 43–61. https://doi.org/10.5962/bhl.part.2608
23. Cuatrecasas, J. (1976b). A systematic study of the subtribe Espeletiinae. *Phytologia*, *35*, 1–689.
24. Cuatrecasas, J. (1995). A new genus of the Compositae: Paramiflos (Espeletiinae) from Colombia. *Proceedings of the Biological Society of Washington*, *108*(4), 748–750.
25. Cuesta, F., Peralvo, M., Merino-Viteri, A., Bustamante, M., Baquero, F., Freile, J. F., Muriel, P., & Torres-Carvajal, O. (2017). Priority areas for biodiversity conservation in mainland Ecuador. *Neotropical Biodiversity*, *3*(1), 93–106. https://doi.org/doi.org/10.1080/23766808.2017.1295705
26. Dahlberg, A., Genney, D. R., & Heilmann-Clausen, J. (2010). Developing a comprehensive strategy for fungal conservation in Europe: current status and future needs. *Fungal Ecology*, *3*(2), 50–64.
27. Darbyshire, I., Anderson, S., Asatryan, A., Byfield, A., Cheek, M., Clubbe, C., Ghrabi, Z., Harris, T., Heatubun, C. D., Kalema, J., Magassouba, S., McCarthy, B., Milliken, W., de Montmollin, B., Lughadha, E. N., Onana, J. M., Saïdou, D., Sârbu, A., Shrestha, K., & Radford, E. A. (2017). Important Plant Areas: revised selection criteria for a global approach to plant conservation. *Biodiversity and Conservation*, *26*(8), 1767–1800. https://doi.org/10.1007/s10531-017-1336-6
28. Darbyshire, I., Timberlake, J., Osborne, J., Rokni, S., Matimele, H., Langa, C., Datizua, C., de Sousa, C., Alves, T., Massingue, A., Hadj-Hammou, J., Dhanda, S., Shah, T., & Wursten, B. (2019). The endemic plants of Mozambique: Diversity and conservation status. *PhytoKeys*, *136*(2019), 45–96. https://doi.org/10.3897/phytokeys.136.39020
29. Diazgranados, M. (2012a). A nomenclator for the frailejones (Espeletiinae Cuatrec., Asteraceae). *PhytoKeys*, *16*(0), 1–52. https://doi.org/10.3897/phytokeys.16.3186
30. Diazgranados, M. (2012b). *Phylogenetic and Biogeographic relationships of Frailejones (Espeletiinae, Compositae): An ongoing radiation in the Tropical Andes*. Saint Louis University.
31. Diazgranados, M., & Barber, J. C. (2017). Geography shapes the phylogeny of frailejones (Espeletiinae Cuatrec., Asteraceae): A remarkable example of recent rapid radiation in sky islands. *PeerJ*, *2017*(2), 1–35. https://doi.org/10.7717/peerj.2968
32. Diazgranados, M., & Castellanos, C. (2018). Metodología para la identificación de área de importancia para plantas (AIPs) en Colombia.
33. Diazgranados, M., & Castellanos-Castro, C. (2021). *Frailejones en peligro* (M. Diazgranados, C. Castellanos Castro, & L. Giraldo Martínez, Eds.; 1 edición). Unión Europea. Instituto de Investigación de Recursos Biológicos Alexander von Humboldt.

34. Diazgranados, M., Tovar, C., Etherington, T. R., Rodríguez-Zorro, P. A., Castellanos-Castro, C., Rueda, M. G., & Flantua, S. G. A. (2021). Ecosystem services show variable responses to future climate conditions in the Colombian páramos. *PeerJ*, *9*, 1–33. https://doi.org/10.7717/peerj.11370
35. Di Marco, M., Watson, J. E. M., Possingham, H. P., & Venter, O. (2017). Limitations and trade-offs in the use of species distribution maps for protected area planning. *Journal of Applied Ecology*, *54*(2), 402–411. https://doi.org/10.1111/1365-2664.12771
36. Donald, P. F., Fishpool, L. D. C., Ajagbe, A., Bennun, L. A., Bunting, G., Burfield, I. J., Butchart, S. H. M., Capellan, S., Crosby, M. J., Dias, M. P., Diaz, D., Evans, M. I., Grimmett, R., Heath, M., Jones, V. R., Lascelles, B. G., Merriman, J. C., O'brien, M., Ramírez, I., … Wege, D. C. (2019). Important Bird and Biodiversity Areas (IBAs): the development and characteristics of a global inventory of key sites for biodiversity the evolution of the IBA concept. *Bird Conservation International*, *29*, 177–198. https://doi.org/10.1017/S0959270918000102
37. Dušková, E., Sklenář, P., Kolář, F., Vásquez, D. L. A., Romoleroux, K., Fér, T., & Marhold, K. (2017). Growth form evolution and hybridization in Senecio (Asteraceae) from the high equatorial Andes. *Ecology and Evolution*, *7*(16), 6455–6468. https://doi.org/10.1002/ece3.3206
38. Erwin, T. L. (1991). An evolutionary basis for conservation strategies. *Science, New Series*, *253*(5021), 750–752. https://www.jstor.org/stable/2879114
39. ESRI. (2011). *ArcGIS desktop: Release 10. Redlands*. CA: Environmental Systems Research Institute.
40. Florentín, J. E., Salas, R. M., Jarvie, S., Svenning, J.-C., & Gomez, J. M. D. (2022). Areas of endemism and conservation status of Galianthe species (Spermacoceae, Rubiaceae) in the Neotropics. *Systematics and Biodiversity*, *20*(1), 1–20. https://doi.org/10.1080/14772000.2022.2025946
41. GBIF. (2022, April 16). *GBIF Occurrence*. The Global Biodiversity Information Facility. https://doi.org/10.15468/dl.gfsdsm
42. Guidelines for selection of biological SSSIs Rationale Operational approach and criteria Detailed guidelines for habitats and species groups Chapter 20 Grassland fungi, Joint Nature Conservation Committee 1 (2009). http://www.jncc.gov.uk/page-2303
43. Gonda, C. (2020). Cambio Climático y Biodiversidad en los Andes Tropicales. In *Cambio Climático y Biodiversidad en los Andes Tropicales*. Fundación Ambiente y Recursos Naturales (FARN).
44. Guarderas, P., Smith, F., & Dufrene, M. (2022). Land use and land cover change in a tropical mountain landscape of northern Ecuador: Altitudinal patterns and driving forces. *PLoS ONE*, *17*(7 July). https://doi.org/10.1371/journal.pone.0260191
45. Guisan, A., & Thuiller, W. (2005). Predicting species distribution: offering more than simple habitat models. *Ecology Letters*, *8*, 993–1009. https://doi.org/10.1111/j.1461-0248.2005.00792.x
46. Halpern, B. S., Pyke, C. R., Fox, H. E., Chris Haney, J., Schlaepfer, M. A., & Zaradic, P. (2006). Gaps and Mismatches between Global Conservation Priorities and Spending. *Conservation Biology*, *20*(1), 56–64. https://doi.org/10.1111/j.1523-1739.2006.00258.x
47. Hamidah, M., Mohd Hasmadi, I., Chua, L. S. L., Lau, K. H., Faridah-Hanum, I., Yong, W. S. Y., & Pakhriazad, H. Z. (2020). Towards identification of important plant areas (IPA) for Peninsular Malaysia. Methodology and future directions. *Heliyon*, *6*(7), 11. https://doi.org/10.1016/j.heliyon.2020.e04370
48. Hamidah, M., Mohd Hasmadi, I., Chua, L. S. L., Yong, W. S. Y., Lau, K. H., Faridah-Hanum, I., & Pakhriazad, H. Z. (2022). Development of a protocol for Malaysian Important Plant Areas criterion weights using Multi-criteria Decision Making - Analytical Hierarchy Process (MCDM-AHP). *Global Ecology and Conservation*, *34*(October 2021), e02033. https://doi.org/10.1016/j.gecco.2022.e02033
49. Herzog, S., Martínez, R., Jørgensen, P. M., & Tiessen, H. (2012). Cambio Climático y Biodiversidad en los Andes Tropicales. In S. Herzog, R. Martínez, P. M. Jørgensen, & H. Tiessen (Eds.). Cambio Climático y Biodiversidad en los Andes Tropicales. Instituto Interamericano para la Investigación del Cambio Global (IAI) y Comité Científico sobre Problemas del Medio Ambiente (SCOPE).
50. Hijmans, R. J. (2017). *raster: Geographic Data Analysis and Modeling. R package version 2.6-7*. https://CRAN.R-project.org/package=raster.
51. Instituto de Investigación de Recursos Biológicos Alexander von Humboldt Castellanos (2016). Frailejones de Colombia. 2900 registros, aportados por: Castellanos, C. (Contacto del recurso), Diazgranados, M. (Creador del recurso, Autor, Proveedor de metadatos). http://i2d.humboldt.org.co/ceiba/resource.do?r=rrbb_colombia_espeletias_2017
52. IUCN. (2022a). *Red List of Threatened Species*. https://doi.org/10.5860/choice.49-6872
53. IUCN, S. and P. C. (2022b). Guidelines for using the IUCN Red List Categories and Criteria. version 15. *European Journal of Taxonomy*, 116. https://doi.org/10.5852/ejt.2021.733.1219
54. Jarvis, A., Reuter, H. I., Nelson, A., & Guevara, E. (2008). *Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database*. https://doi.org/10.5066/F7PR7TFT
55. Joppa, L. N., Butchart, S. H. M., Hoffmann, M., Bachman, S. P., Akçakaya, H. R., Moat, J. F., Bohm, M., Holland, R. A., Newton, A., Polidoro, B., & Hughes, A. (2016). Impact of alternative metrics on estimates of extent of occurrence for extinction risk assessment. *Conservation Biology*, *30*(2), 362–370. https://doi.org/10.1111/cobi.12591
56. Jørgensen, P. M., Ulloa, C. U., León, B., León-Yánez, S., Beck, S. G., Nee, M., Zarucchi, J. L., Celis, M., Bernal, R., & Gradstein, R. (2012). Regional Patterns of Vascular Plant Diversity and Endemism. In *Climate change and biodiversity in the tropical Andes* (pp. 192–203). http://www.iai.int/files/communications/publications/scientific/Climate_Change_and_Biodiversity_in_the_Tropical_Andes/chapter13.pdf
57. KBA Secretariat. (2022). Key Biodiversity Areas Proposal Process: Guidance on Proposing, Reviewing, Nominating and Confirming sites. Version 1.1.
58. Kolář, F., Dušková, E., & Sklenář, P. (2016). Niche shifts and range expansions along cordilleras drove diversification in a high-elevation endemic plant genus in the tropical Andes. *Molecular Ecology*, *25*(18), 4593–4610. https://doi.org/10.1111/mec.13788
59. Kor, L., & Diazgranados, M. (2023). Identifying important plant areas for useful plant species in Colombia. *Biological Conservation*, *284*(110187). https://doi.org/10.1016/j.biocon.2023.110187
60. Kor, L., Lopez-Gallego, C., Castellanos-Castro, C., & Diazgranados, M. (2022). Assessing extinction risk coverage and identifying geographical hotspots to guide conservation action for Colombia's useful plants. In *Catalogue of Useful Plants of Colombia*, 3–15. https://www.researchgate.net/publication/364254252

61. Kress, W. J., Heyer, W. R., Acevedo, P., Coddington ±, J., Cole, D., Erwin ±, T. L., Meggers Àà, B. J., Pogue, M., Thorington, R. W., Vari, R. P., Weitzman, M. J., & Weitzman, S. H. (1998). Amazonian biodiversity: assessing conservation priorities with taxonomic data. *Biodiversity and Conservation*, *7*, 1577–1587.
62. Le Roux, J. J., Hui, C., Castillo, M. L., Iriondo, J. M., Keet, J. H., Khapugin, A. A., Médail, F., Rejmánek, M., Theron, G., Yannelli, F. A., & Hirsch, H. (2019). Recent Anthropogenic Plant Extinctions Differ in Biodiversity Hotspots and Coldspots. *Current Biology*, *29*(17), 2912-2918.e2. https://doi.org/10.1016/J.CUB.2019.07.063
63. Llambí, L. D., Becerra, M. T., Peralvo, M., Avella, A., Baruffol, M., & Díaz, L. J. (2019). Construcción de una Estrategia para el Monitoreo Integrado de los Ecosistemas de Alta Montaña en Colombia. *Biodiversidad En La Práctica. Documentos de Trabajo Del Instituto Humboldt*, *4*(1), 150–172. http://documentacion.ideam.gov.co/openbiblio/bvirtual/023886/Estrategia_EMA.pdf%0Ahttps:// www.researchgate.net/publication/333220451_Construccion_de_Una_Estrategia_para_el_Monitoreo_Integrado_de_Los_Ecosistemas_de_Alta_Montana_er
64. Madriñán, S., Cortés, A. J., & Richardson, J. E. (2013). Páramo is the world’s fastest evolving and coolest biodiversity hotspot. *Frontiers in Genetics*, *4*, 1–7. https://doi.org/10.3389/fgene.2013.00192
65. Margulies, J. D., Bullough, L., Hinsley, A., Ingram, D. J., Cowell, C., Goettsch, B., Klitgård, B. B., Lavorgna, A., Sinovas, P., & Phelps, J. (2019). Illegal wildlife trade and the persistence of “plant blindness.” *Plants, People, Planet*, *1*(3), 173–182. https://doi.org/10.1002/ppp3.10053
66. Marignani, M., & Blasi, C. (2012). Looking for important plant areas: Selection based on criteria, complementarity, or both? *Biodiversity and Conservation*, *21*(7), 1853–1864. https://doi.org/10.1007/s10531-012-0283-5
67. Marignani, M., & Blasi, C. (2020). The Nature of Espeletia Species. *BioRxiv*, 50. https://doi.org/10.1101/2020.09.29.318865
68. Mavárez, J. (2019). A Taxonomic Revision of Espeletia (Asteraceae). The Venezuelan Radiation. *Harvard Papers in Botany*, *24*(2), 131–244. https://doi.org/10.3100/hpib.v24iss2.2019.n8
69. Mavárez, J. (2021). A Taxonomic Revision of Espeletia (Asteraceae). II. Updated List of Taxa, Nomenclature, and Conservation Status in the Colombian Radiation. *Harvard Papers in Botany*, *26*(1), 131–157. https://doi.org/10.3100/hpib.v26iss1.2021.n9
70. Mavárez, J., Bézy, S., Goeury, T., Fernández, A., & Aubert, S. (2019a). Current and future distributions of Espeletiinae (Asteraceae) in the Venezuelan Andes based on statistical downscaling of climatic variables and niche modelling. *Plant Ecology and Diversity*, *12*(6), 633–647. https://doi.org/10.1080/17550874.2018.1549599
71. Mavárez, J., Bézy, S., Goeury, T., Fernández, A., & Aubert, S. (2019b). Current and future distributions of Espeletiinae (Asteraceae) in the Venezuelan Andes based on statistical downscaling of climatic variables and niche modelling. *Plant Ecology and Diversity*, *12*(6), 633–647. https://doi.org/10.1080/17550874.2018.1549599
72. Maxwell, J., Allen, S., Brooks, T., Cuttelod, A., Dudley, N., Fisher, J., Langhammer, P., Patenaude, G., & Woodley, S. (2018). Engaging end-users to inform the development of the global standard for the identification of key biodiversity areas. *Environmental Science and Policy*, *89*, 273–282. https://doi.org/10.1016/j.envsci.2018.07.019
73. Mittermeier, R. A., Turner, W. R., Larsen, F. W., Brooks, T. M., & Gascon, C. (2011). Global biodiversity conservation: the critical role of hotspots. In *Biodiversity hotspots: distribution and protection of conservation priority areas*, 3–22. https://doi.org/10.1007/978-3-642-20992-5
74. Moat, J. (2020). *rCAT: Conservation assessment tools. R Package Version 0.1.6.* (R package version 0.1.6). https://cran.r-project.org/web/packages/rCAT/index.html
75. Molina, R., Marcot, B. G., & Lesher, R. (2006). Protecting Rare, Old-Growth, Forest-Associated Species under the Survey and Manage Program Guidelines of the Northwest Forest Plan. *Conservation Biology*, *20*(2), 306–318. https://doi.org/10.1111/j.1523-1739.2006.00386.x
76. Monasterio, M., & Sarmiento, L. (1991). Adaptive radiation of Espeletia in the cold Andean Tropics. *Trends Ecol. Evol.*, *6*(12), 387–391. https://doi.org/10.1016/0169-5347(91)90159-u
77. Myers, N., Mittermeler, R. A., Mittermeler, C. G., Da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*(6772), 853–858. https://doi.org/10.1038/35002501
78. Neo, L., Tan, H. T. W., & Wong, K. M. (2021). Too little, too late? Conservation exigencies for Borneo inferred from biogeographic considerations of its endemic plant genera against intense landscape modifications. *Biodiversity and Conservation*, *31*, 59–76. https://doi.org/10.1007/s10531-021-02320-6
79. Nic Lughadha, E., Bachman, S. P., Leão, T. C. C., Forest, F., Halley, J. M., Moat, J., Acedo, C., Bacon, K. L., Brewer, R. F. A., Gâteblé, G., Gonçalves, S. C., Govaerts, R., Hollingsworth, P. M., Krisai-Greilhuber, I., de Lirio, E. J., Moore, P. G. P., Negrão, R., Onana, J. M., Rajaovelona, L. R., … Walker, B. E. (2020). Extinction risk and threats to plants and fungi. *Plants People Planet*, *2*(5), 389–408. https://doi.org/10.1002/ppp3.10146
80. Oksanen, J., Blanchet, F. G., Kindt, R., Legendre, P., Minchin, P. R., O’Hara, R. B., Simpson, G. L., Solymos, P., Stevens, M. H. H., & Wagner, H. (2014). *Vegan: Community Ecology Package. R Package Version 2.2-0.*
81. Özden, O., Mustafa Kemal, M., & Salih, G. (2016). Important Plant Areas Along the Kyrenia Mountains, Cyprus. *International Scientific Publications*, *10*, 349–359.
82. Paton, A., Antonelli, A., Carine, M., Forzza, R. C., Davies, N., Demissew, S., Dröge, G., Fulcher, T., Grall, A., Holstein, N., Jones, M., Liu, U., Miller, J., Moat, J., Nicolson, N., Ryan, M., Sharrock, S., Smith, D., Thiers, B., … Dickie, J. (2020). Plant and fungal collections: Current status, future perspectives. In *Plants People Planet*, 2(5), 499–514. Blackwell Publishing Ltd. https://doi.org/10.1002/ppp3.10141
83. Pelletier, T. A., Carstens, B. C., Tank, D. C., Sullivan, J., & Espíndola, A. (2018). Predicting plant conservation priorities on a global scale. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(51), 13027–13032. https://doi.org/10.1073/pnas.1804098115
84. Pepin, N., Bradley, R. S., Diaz, H. F., Baraer, M., Caceres, E. B., Forsythe, N., Fowler, H., Greenwood, G., Hashmi, M. Z., Liu, X. D., Miller, J. R., Ning, L., Ohmura, A., Palazzi, E., Rangwala, I., Schöner, W., Severskiy, I., Shahgedanova, M., Wang, M. B., … Yang, D. Q. (2015). Elevation-dependent warming in mountain regions of the world. *Nature Climate Change*, *5*(5), 424–430. https://doi.org/10.1038/nclimate2563

85. Pérez-Escobar, O. A., Cámara-Leret, R., Antonelli, A., Bateman, R., Bellot, S., Chomicki, G., Cleef, A., Diazgranados, M., Dodsworth, S., Jaramillo, C., Madriñan, S., Olivares, I., Zuluaga, A., & Bernal, R. (2018). Mining threatens Colombian ecosystems. In *Science*, 359 (6383), 1475. American Association for the Advancement of Science. https://doi.org/10.1126/science.aat4849
86. Pérez-Escobar, O. A., Zizka, A., Bermúdez, M. A., Meseguer, A. S., Condamine, F. L., Hoorn, C., Hooghiemstra, H., Pu, Y., Bogarín, D., Boschman, L. M., Pennington, R. T., Antonelli, A., & Chomicki, G. (2022). The Andes through time: evolution and distribution of Andean floras. *Trends in Plant Science*, *27*(4), 364–378. https://doi.org/10.1016/j.tplants.2021.09.010
87. Peyre, G., Balslev, H., & Font, X. (2018). Phytoregionalisation of the Andean páramo. *PeerJ*, *2018*(6), 1–27. https://doi.org/10.7717/peerj.4786
88. Plantlife. (2018). Identifying and conserving Important Plant Areas (IPAs) Around the world: A guide for botanists, conservationists, site managers, community groups and policy makers. *Plantlife, Salisbury*, 37.
89. Plumptre, A. J., Ayebare, S., Behangana, M., Forrest, T. G., Hatanga, P., Kabuye, C., Kirunda, B., Kityo, R., Mugabe, H., Namaganda, M., Nampindo, S., Nangendo, G., Nkuutu, D. N., Pomeroy, D., Tushabe, H., & Prinsloo, S. (2019). *Conservation of vertebrates and plants in Uganda: Identifying Key Biodiversity Areas and other sites of national importance*. https://doi.org/10.1002/csp2.7
90. Pouchon, C., Fernández, A., Nassar, J. M., Boyer, F., Aubert, S., Lavergne, S., & Mavárez, J. (2018). Phylogenomic analysis of the explosive adaptive radiation of the Espeletia complex (Asteraceae) in the tropical Andes. *Systematic Biology*, *67*(6), 1041–1060. https://doi.org/10.1093/sysbio/syy022
91. Pouchon, C., Lavergne, S., Fernández, Á., Alberti, A., Aubert, S., & Mavárez, J. (2021). Phylogenetic signatures of ecological divergence and leapfrog adaptive radiation in Espeletia. *American Journal of Botany*, *108*(1), 113–128. https://doi.org/10.1002/ajb2.1591
92. POWO. (2023). *Plants of the World Online*. Facilitated by the Royal Botanic Gardens, Kew. http://www.plantsoftheworldonline.org
93. R Core Team. (2022). *R: A language and environment for statistical computing* (Version 4.2.2). R Foundation for Statistical Computing. http://www.r-project.org/
94. Reece, J. S., & Noss, R. F. (2014). Prioritizing species by conservation value and vulnerability: A new index applied to species threatened by sea-level rise and other risks in Florida. *Natural Areas Journal*, *34*(1), 31–45. https://doi.org/10.3375/043.034.0105
95. Sánchez de Dios, R., Cabal Ruano, C., Domínguez Lozano, F., Sainz Ollero, H., & Moreno Saiz, J. C. (2017). The role of criteria in selecting important areas for conservation in biodiversity-rich territories. *Diversity and Distributions*, *23*(4), 368–380. https://doi.org/10.1111/ddi.12535
96. Sanchez, M. D., Clubbe, C., Woodfield-Pascoe, N., Bárrios, S., Abbott, J. S., Heller, T., Harrigan, N., Grant, K., Titley-O'Neal, C., & Hamilton, M. A. (2021). Tropical Important Plant Areas, plant species richness and conservation in the British Virgin Islands. *Nature Conservation*, *45*, 11–39. https://doi.org/10.3897/natureconservation.45.73544
97. Sayre, R. (2022). *World Terrestrial Ecosystems (WTE) 2020: U.S. Geological Survey data release*. U.S. Geological Survey. https://doi.org/10.5066/P9DO61LP
98. Sayre, R., Karagulle, D., Frye, C., Boucher, T., Wolff, N. H., Breyer, S., Wright, D., Martin, M., Butler, K., Graafeiland, K. Van, Touval, J., Sotomayor, L., McGowan, J., Game, E. T., & Possingham, H. (2020). An assessment of the representation of ecosystems in global protected areas using new maps of World Climate Regions and World Ecosystems. *Global Ecology and Conservation*, *21*(e00860), 1–21. https://www.sciencebase.gov/catalog/item/6296791ed34ec53d276bb293
99. Smith, R. J., Bennun, L., Brooks, T. M., Butchart, S. H. M., Cuttelod, A., Di Marco, M., Ferrier, S., Fishpool, L. D. C., Joppa, L., Juffe-Bignoli, D., Knight, A. T., Lamoreux, J. F., Langhammer, P., Possingham, H. P., Rondinini, C., Visconti, P., Watson, J. E. M., Woodley, S., Boitani, L., … Scaramuzza, C. A. de M. (2018). Synergies between the key biodiversity area and systematic conservation planning approaches. *Conservation Letters*, *12*(1), 1–10. https://doi.org/10.1111/conl.12625
100. Thomsen, P. F., & Willerslev, E. (2015). Environmental DNA – An emerging tool in conservation for monitoring past and present biodiversity. *Biological Conservation*, *183*(Special Issue Article: Environmental DNA), 4–18.
101. Tsendbazar, N. E., Tarko, A., Linlin, L., Herold, M., Lesiv, M., Fritz, S., & Maus. V. (2020). *Copernicus Global Land Service: Land Cover 100m: Version 3 Globe 2015-2019: Validation Report*. https://doi.org/10.5281/zenodo.3938974
102. Valencia, J. B., Mesa, J., León, J. G., Madriñán, S., & Cortés, A. J. (2020). Climate Vulnerability Assessment of the Espeletia Complex on Páramo Sky Islands in the Northern Andes. *Frontiers in Ecology and Evolution*, *8*. https://doi.org/10.3389/fevo.2020.565708
103. Van der Hammen, T., & Cleef, A. M. (1986). Development of the high andean páramo flora and vegetation. In F. Vuilleumier & M. Monasterio (Eds.), *High Altitude Tropical Biogeography*, 153–201.
104. Waldron, A., Mooers, A. O., Miller, D. C., Nibbelink, N., Redding, D., Kuhn, T. S., Timmons Roberts, J., & Gittleman, J. L. (2013). Targeting global conservation funding to limit immediate biodiversity declines. *Proceedings of the National Academy of Sciences*, *110*(29), 12144–12148. https://doi.org/10.5061/dryad.p69t1
105. Walsh, A., Sullivan, C. A., Waldren, S., & Finn, J. A. (2019). Development of a scoring method to identify important areas of plant diversity in Ireland. *Journal for Nature Conservation*, *47*(June 2018), 1–11. https://doi.org/10.1016/j.jnc.2018.10.002
106. Westwood, M., Cavender, N., Meyer, A., & Smith, P. (2020). Botanic garden solutions to the plant extinction crisis. *Plants People Planet*, *3*(1), 22–32. https://doi.org/10.1002/ppp3.10134
107. Wickham, H. (2016). *ggplot2: Elegant Graphics for Data Analysis.* Springer-Verlag New York. https://ggplot2.tidyverse.org
108. Yahi, N., Vela, E., Benhouhou, S., De Belair, G., & Gharzouli, R. (2012). Identifying Important Plants Areas (Key Biodiversity Areas for Plants) in northern Algeria. *Journal of Threatened Taxa*, *04*(08), 2753–2765. https://doi.org/10.11609/jott.o2998.2753-65
109. Young, K. R. (2014). Ecology of Land Cover Change in Glaciated Tropical Mountains. *Rev. Peru. Biol.*, *21*(3), 259–270. https://doi.org/10.15381/rpb.v21i3.10900

110. Zurell, D., Franklin, J., König, C., Bouchet, P. J., Dormann, C. F., Elith, J., Fandos, G., Feng, X., Guillera-Arroita, G., Guisan, A., Lahoz-Monfort, J. J., Leitão, P. J., Park, D. S., Peterson, A. T., Rapacciuolo, G., Schmatz, D. R., Schröder, B., Serra-Diaz, J. M., Thuiller, W., … Merow, C. (2020). A standard protocol for reporting species distribution models. *Ecography*, *43*(9), 1261–1277. https://doi.org/10.1111/ecog.04960

Tables

Table 1. **Evaluated criteria and applied methodology**. List of criteria applied in this evaluation for the development of the conservation proposal of Espeletiinae based on the Important Plant Areas (IPAs) methodology. The assessment thresholds applied (Diazgranados and Castellanos, 2018) are listed compared to those proposed globally (Darbyshire et al., 2017).

IPA higher level and sub-criteria	**Thresholds** (Diazgranados and Castellanos, 2018)	**Global thresholds** (Darbyshire et al., 2017)
(A) Threatened species		
cA1: Globally threatened species	Sites supporting ≥ 1% of the global, ≥ 5% of the regional, or ≥ 10% of the national population	Sites are known, thought, or inferred to contain ≥ 1% of the global population AND/OR ≥ 5% "best sites" for that species nationally, whichever is most appropriate.
cA3: Nationally threatened species (criterion A3 was taken as inclusive of A2)	Sites supporting ≥ 1% of the global, ≥ 5% of the regional, or ≥ 10% of the national population	
cA4: Highly restricted range endemic (HRR) species	Sites supporting ≥ 1% of the global, ≥ 5% of the regional, or ≥ 10% of the national population	
cA5: Range-restricted endemic (RRE) species	Sites supporting ≥ 1% of the global, ≥ 5% of the regional, or ≥ 10% of the national population	Not included
(B) Exceptional botanical richness		
cB1: Highest estimated plant richness of the ecosystem type	Sites that contain at least 10% of the total estimated species richness of each ecosystem	For each habitat or vegetation type: up to 10% of the national resource can be selected within the whole national IPA network OR the 5 “best sites” nationally
cB2: Areas that together support 10% of an ecosystem’s diversity	Areas with estimated plant richness complementary to B1 so that together they add 10% of the total ecosystem biodiversity	Not included

Table 2. **Results of the analysis for each evaluated criterion**. Information is displayed on the number of species and spatial coverage (areas in km^2) where assessments occurred by each evaluated criterion in each country. The area corresponds to the sum of UA that had results. The percentage corresponds to the total number of species found for each criterion.

Criteria		Country		
		Colombia	Venezuela	Ecuador
cA1	Species of globally threatened species	54 (92%)	14 (24%)	0
	UAs area under cA1	154	28	0
cA3	Species threatened at the national level	51 (100%)	7 (14%)	0
	UAs area under cA3	77	7	0
cA4	Species in EOO species equal to or less than 100 km^2	26 (53%)	24 (49%)	0
	UAs area under cA4	26	32	0
cA5	Species in EOO greater than 100 km^2 but less than or equal to 5,000 km^2	26 (53%)	24 (49%)	0
	UAs area under cA5	26	32	0
cB2	Species richness	46 (66%)	24 (34%)	2 (3%)
	UAs area under cB2	41	6	4
IPAs combining criteria	cA (UAs). UA shared: 8	155	37	0
	cA richness (UAs). UA shared: 8	155	37	0
	cB richness by ecosystems (UAs)	41	6	3
	Total IPAs (UAs)	168	41	3
		220		

Table 3. Evaluation of cB, richness and ecosystems. Presents the estimated richness by ecosystem, assessed using the Chao1 index, for the Espeletiinae subtribe. The table displays the ecosystems with the highest estimated richness based on the World Terrestrial Ecosystems map. It includes the number of species occurring in each ecosystem, the Chao1 index calculation, and the representativeness, representing the proportion of species richness estimates based on Chao1. The table also indicates the ecosystems that coincide with the UA polygon and information on the country and the area (in km^2) of occurrence. The table also provides the total richness, the number of UAs, and their distribution in each country.

Ecosystem	Number of species	Chao1 Index	Representativeness (%)	Colombia	Venezuela	Ecuador
				Total UAs: 168 (76%)	Total UAs: 41 (19%)	Total UAs: 3 (1%)
				Total Richness: 1,025	Total Richness: 266	Total Richness: 7
				Area (km^2)		
Cool Temperate Moist Cropland on Mountains	13	27	0.22	131.75	3.73	34.48
Cool Temperate Moist Forest on Mountains	9	14	0.36	378.63	10.24	37.96
Cool Temperate Moist Grassland on Mountains	8	47	0.17	59.42	29.03	0
Cool Temperate Moist Shrubland on Mountains	11	19	0.47	300.13	3.19	0.64
Polar Moist Forest on Mountains	5	7	0.43	323	0.66	78.3
Polar Moist Grassland on Mountains	30	93	0.13	441.94	97.38	3.82
Polar Moist Shrubland on Mountains	20	53	0.15	463.87	1.27	28.31
Warm Temperate Dry Cropland on Mountains	13	28	0.32	98.83	16.61	0
Warm Temperate Dry Cropland on Plains	5	4	0.75	77.27	0	0
Warm Temperate Dry Forest on Mountains	5	15	0.33	18.34	38.11	0
Warm Temperate Moist Cropland on Mountains	28	57	0.26	481.39	30.31	86.48
Warm Temperate Moist Grassland on Mountains	11	50	0.22	168.36	8.04	0.04
Warm Temperate Moist Settlement on Mountains	4	9	0.44	57.35	0	0.25
Warm Temperate Moist Shrubland on Mountains	5	23	0.22	260.4	6.97	0
Sub-Tropical Dry Forest on Mountains	2	3	0.33	0	143.99	0
Total area of ecosystems in UA				3,260.67	389.53	270.27

Figures

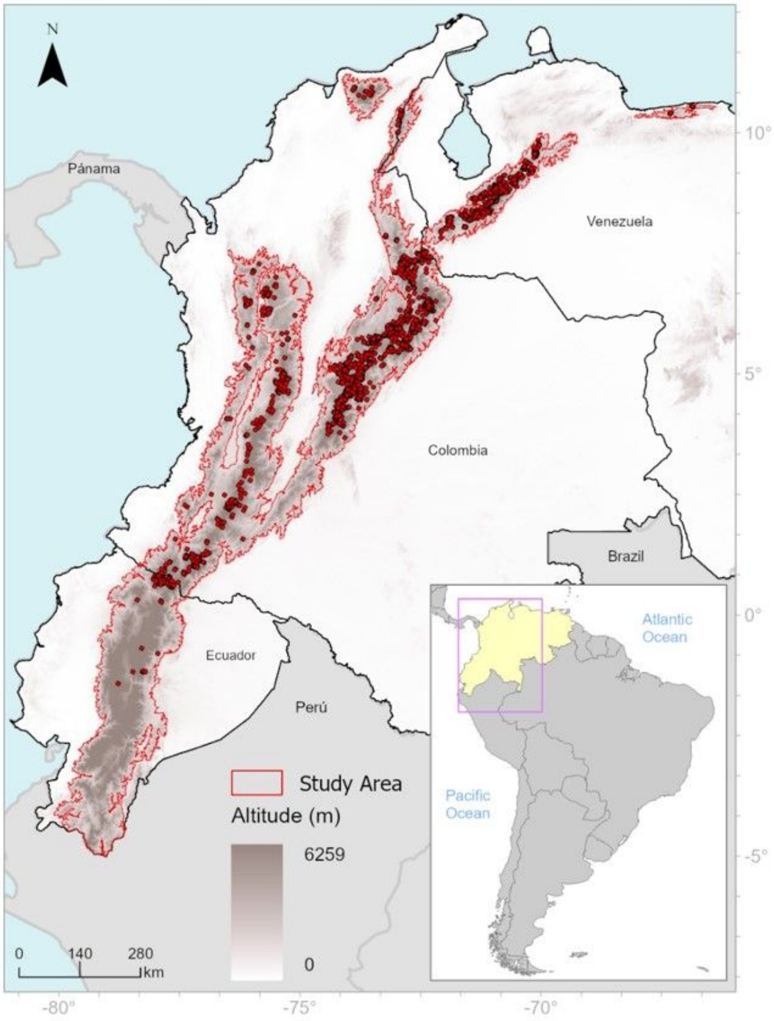

Figure 1

The study area delineated in red highlights the distribution of the subtribe Espeletiinae. The dots on the map represent records containing geographic coordinates of the subtribe Espeletiinae, which we utilized to identify Important Plant Areas (IPAs).

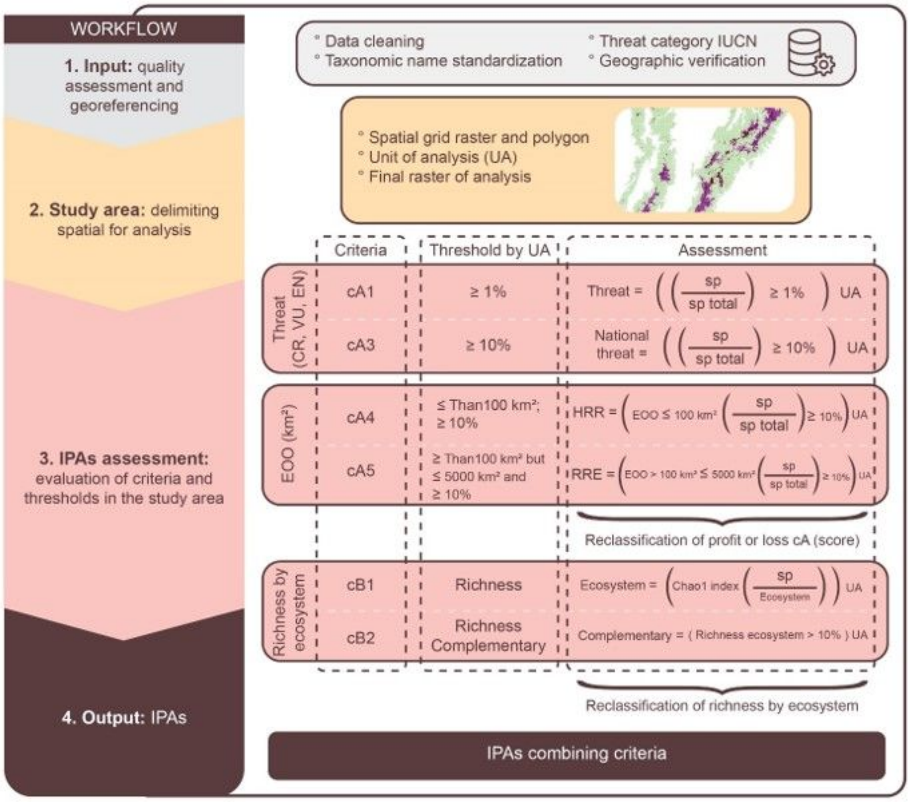

Figure 2

Workflow illustrates implementing the IPA methodology for Espeletiinae in the Tropical Andes region. Showing the steps followed during the IPA analysis including data collection, cleaning, preparation, and analyses for the occurrence areas of the records for the subtribe Espeletiinae, applying the proposed methodology proposed by Diazgranados and Castellanos (2018).

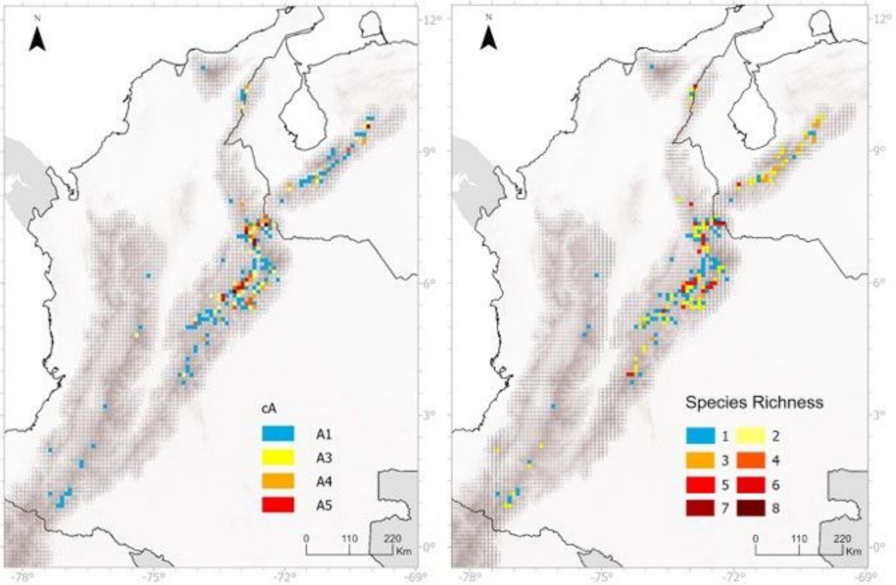

Figure 3

UAs and species richness combined for sub-criteria cA. The distribution results for sub-criterion A are presented. The left figure illustrates the distribution of each sub-criterion by UA, while the right figure displays the distribution of species richness, representing the number of species per UA.

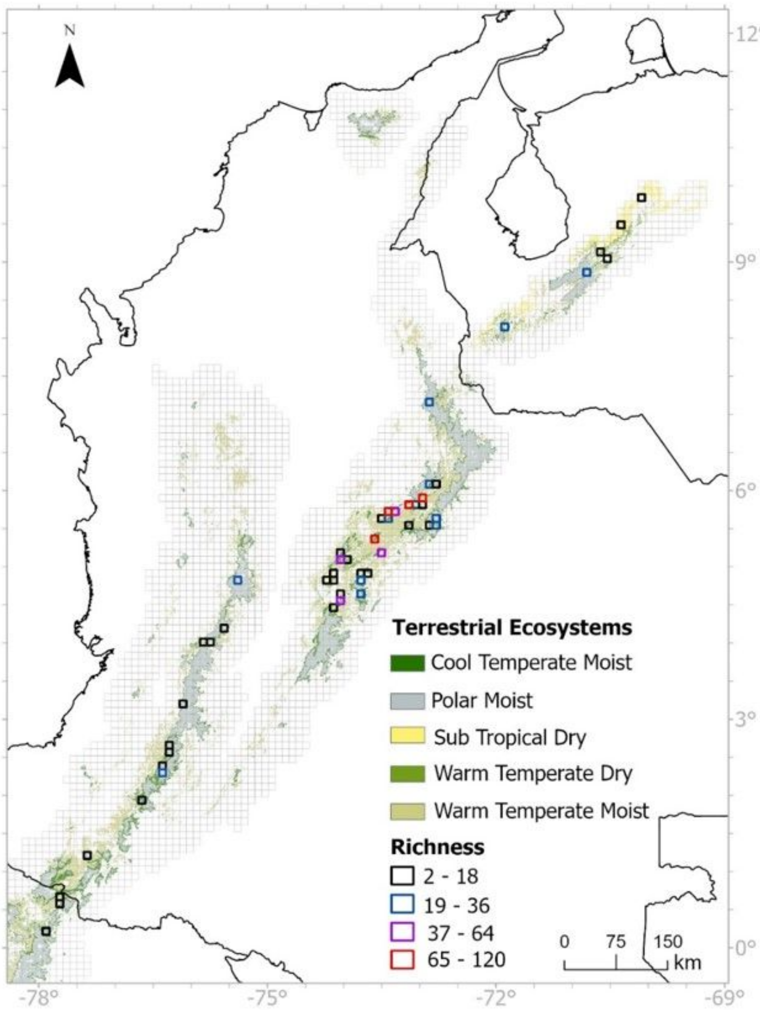

Figure 4

Spatial distribution of ecosystems within the study area. The highest estimated richness of Espeletiinae has been identified in the UA corresponding to cB2, which complements cB1 and accounts for 10% of the total diversity per ecosystem. Each of the UAs displays the number of contained richness. The legend displays the ecosystems with a general classification to enhance their visualization.

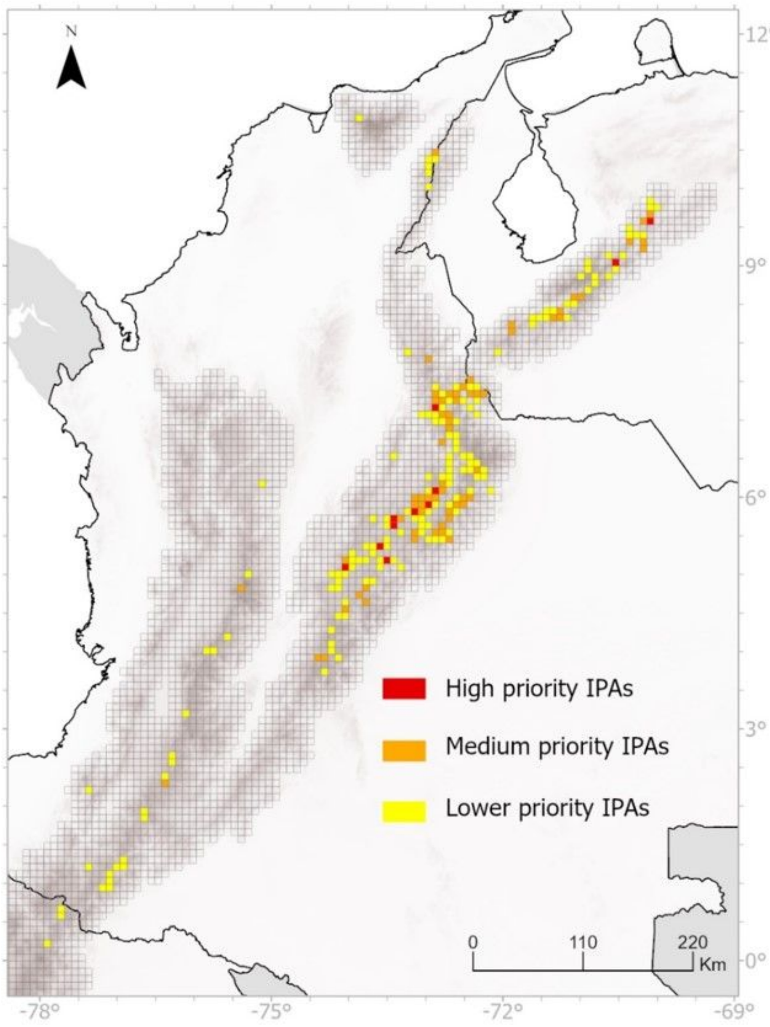

Figure 5

Important Plant Areas in Tropical Andes region for Espeletiinae. Identified grid cells contain the most significant number by species records: high-priority (11 IPAs), medium-priority (58 IPAs), and low-priority (143 IPAs). Supplementary Material 1, provides a detailed list of the high-priority IPAs. TS7 presents information regarding the centroids for each IPA rank.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterial1.docx