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Flora Diversity and Conservation Status Along an Altitudinal Gradient in the District of Sumbilca, Huaral, Peru

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Abstract

The tropical Andes are a global biodiversity hotspot, yet extensive areas of the Peruvian western slope, such as the district of Sumbilca (Huaral province, Lima), remain floristically understudied despite mounting pressure from agricultural expansion, overgrazing, and seasonal burning. This study aimed to determine floristic diversity and assess the conservation status of vascular plants along a 2400–4000 m altitudinal gradient in Sumbilca. Between July 2024 and June 2025, qualitative walking surveys were conducted across four altitudinal zones (Z1–Z4), and species richness, family composition, floristic similarity (Jaccard dissimilarity, hierarchical clustering), and conservation status (IUCN Red List and Peruvian Supreme Decree N.° 043-2006-AG) were analyzed. A total of 202 species, 140 genera, and 62 families were recorded, dominated by Asteraceae, Poaceae, Solanaceae, and Fabaceae, with herbs as the predominant growth habit (66.3%). Species richness peaked in Z2–Z3 (85 and 84 species) and declined sharply in Z4 (38 species), which was also the most floristically distinct zone. Twenty-one endemic species and 42 species with recognized conservation status were documented, including five nationally threatened taxa, along with several new records for Huaral province. These findings indicate that Sumbilca harbors considerable, previously undocumented floristic and conservation value, and provide an essential baseline for future ecological monitoring and management along the western Andean slope.

Keywords: altitudinal gradient; conservation status; endemism; floristic diversity; Peru; species richness; Sumbilca; tropical Andes

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1. Introduction

The tropical Andes are among the most biologically diverse regions on the planet and have been recognized as one of the global biodiversity hotspots [1,2]. Their complex geological and climatic history has given rise to a remarkable heterogeneity of landscapes and microclimates [3,4], in which marked altitudinal gradients in temperature and precipitation have favored speciation processes and the existence of a large number of endemic

species [5,6]. However, this very ecological uniqueness makes the Andes one of the most vulnerable regions on the planet, affected by habitat loss, the expansion of the agricultural frontier, and the effects of climate change [7,8].

Peru is a prime example of this landscape, home to approximately 25,000 species of vascular plants, of which about one-third are endemic [9,10]. Much of this diversity is concentrated in the Andean region, where the succession of ecological zones generates a wide variety of environmental conditions that determine unique patterns of floristic distribution [11,12]. The study of these altitudinal gradients is essential for understanding the mechanisms that regulate species distribution, as well as the factors that explain differences in diversity among localities and their potential response to anthropogenic and climatic disturbances [5,6,13].

Multiple studies conducted in different Andean regions have revealed significant variations in floristic richness and composition along altitudinal gradients [6,14,15], although the specific patterns differ depending on the geographic context. In Peru, research conducted in the central rainforest has documented these patterns, reporting high diversity in premontane and montane forests [16–18]. However, extensive areas of the Peruvian Andean highlands remain understudied from a floristic perspective, which limits the establishment of the baseline data necessary for their conservation.

This information gap is particularly noticeable in the district of Sumbilca, located in the province of Huaral on the western slope of the central Andes in Peru [19]. Its geographic scope spans a wide altitudinal range, extending from dry inter-Andean valleys to the puna (high mountain region and cold climate in the central Andes), and is home to complex vegetation characterized by xerophytic shrublands, grasslands, and pastures [20,21]. Although floristic research has been conducted in the province of Huaral and in adjacent watersheds on the Pacific slope, focusing on coastal hills or specific forested relicts [22–24], the continental ecosystems and intermediate gradients of Sumbilca have been scarcely evaluated. This absence of background information becomes even more serious in light of the constant expansion of the agricultural frontier, seasonal burning, and overgrazing, which threaten the functional integrity of these habitats [25,26].

Plant diversity is one of the fundamental components of ecosystems, as it supports key ecological processes, the stability of biotic communities, and the provision of essential ecosystem services, such as climate regulation, oxygen production, and the hydrological cycle [27–29]. Consequently, characterizing floristic composition and structure is an indispensable step in designing conservation and sustainable management strategies [30]. In this regard, floristic inventories serve as the basic methodological tool for estimating species richness, assessing the conservation status of vegetation, and prioritizing areas of interest for protection [31,32]. Consequently, the lack of systematic inventories prevents the identification of endemic taxa or those classified as threatened, thereby limiting the design of conservation measures. In light of this issue, the objective of this study was to determine the floristic diversity and assess the conservation status of vascular plant species along an altitudinal gradient in the Sumbilca district.

2. Materials and Methods

2.1. Study Area

The study was conducted between July 2024 and June 2025 in the district of Sumbilca, province of Huaral, department of Lima, Peru (Figure 1). Sumbilca is one of the twelve districts that make up the province of Huaral and is located in the central Andes of Peru. The district is characterized by marked geographic heterogeneity, resulting from its complex topography and a wide altitudinal gradient that spans various ecological zones, ranging from inter-Andean ravines to puna areas above 3500 m above sea level [21]. In the

lower elevations of the district (1500–2000 m above sea level), the climate is semi-arid and temperate, with little rainfall. In contrast, in the capital (3367 m a.s.l.) and higher-altitude areas (3000–4000 m a.s.l.), the climate becomes subhumid and cold, with an average annual temperature of 11 °C and rainfall from December through April exceeding 500 mm per year [33]. These conditions favor the development of a wide diversity of ecosystems and vegetation types, including Andean scrublands, grasslands, rocky outcrops, and remnants of native vegetation [34].

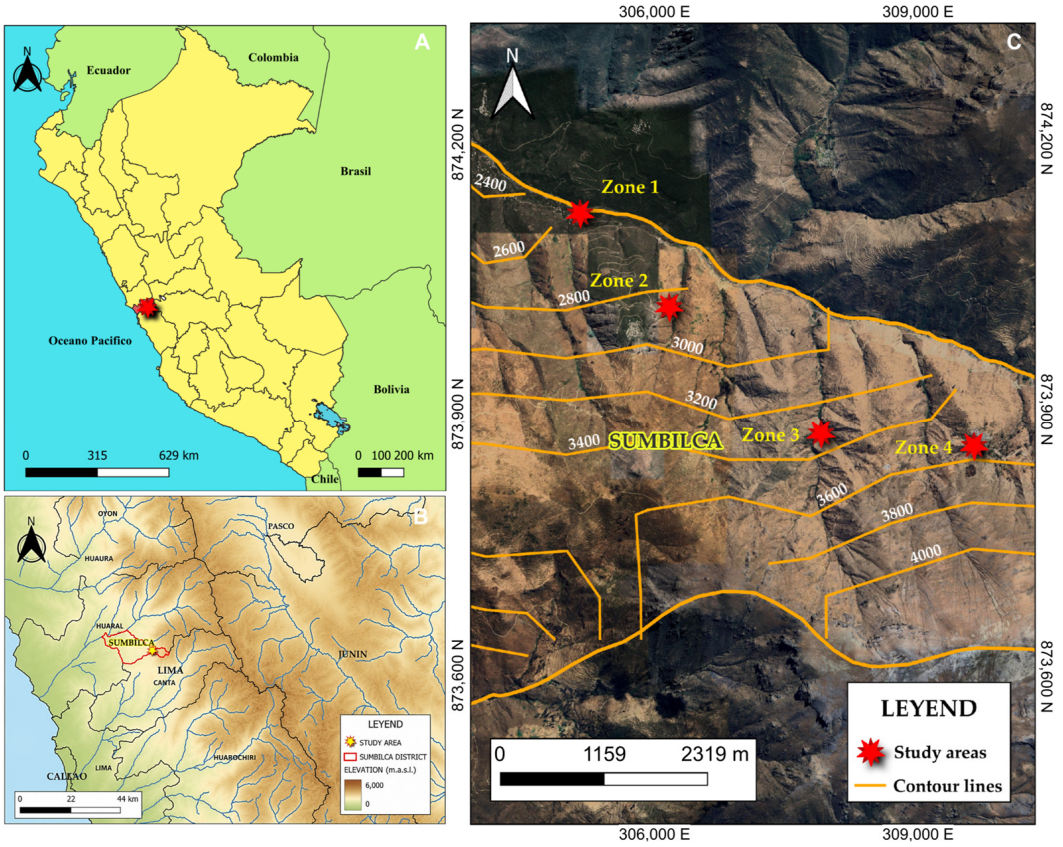


Figure 1. Location of the study area in Peru. (**A**) Geographic location of Peru in South America. (**B**) Location of the department of Lima and Huaral Province. (**C**) Study area in the district of Sumbilca, showing the altitudinal gradient and sampling zones.

2.2. Sampling Method

Floristic surveys were conducted between July 2024 and June 2025 through intensive field surveys across four altitudinal zones (Z1: 2400–2800 m; Z2: 2800–3200 m; Z3: 3200–3600 m; Z4: 3600–4000 m). The inventory was conducted using systematic walking surveys designed to maximize the detection of vascular plant species by exploring the environmental heterogeneity within each altitudinal belt. Surveys within each interval covered cumulative walking distances of 10–12 km per zone (~44 km total) using directional changes (zigzagging) along slopes, strategically spanning both ridgelines and valley bottoms (as well as intervening slopes). This qualitative approach is widely recognized as an effective strategy for floristic inventories because it allows comprehensive documentation of species occurring across different vegetation types and microhabitats while increasing the representativeness of the inventory [35,36]. At each sampling locality, the survey team systematically explored the altitudinal range and all representative habitats, recording vascular plant species in Andean shrublands, grasslands, rocky outcrops, ravines, cactus-dominated communities, and disturbed areas. Sites with difficult topography were

surveyed with the assistance of a local guide familiar with the terrain, facilitating access to poorly explored sectors and improving the spatial coverage of the inventory. Successive sampling localities were accessed by vehicle along the altitudinal gradient, enabling repeated surveys across different elevations and vegetation types to maximize floristic coverage of the study area. Similar sampling strategies have recently been employed in floristic inventories conducted in the central Andes of Peru, demonstrating their suitability for documenting vascular plant diversity and compositional turnover across heterogeneous mountain landscapes [37,38]. Overall, this sampling design provided a comprehensive characterization of the vascular flora along the altitudinal gradient by integrating extensive field exploration with the environmental heterogeneity of the study area [36–38].

2.3. Taxonomic Identification and Conservation Assessment

Plant individuals were photographed in situ, and representative material from individuals that could not be reliably identified in the field was collected for subsequent taxonomic determination. The collected material was processed and deposited in the Laboratory of Tropical Ecology and Data Analysis, Faculty of Biological Sciences, Universidad Nacional Mayor de San Marcos, Lima, Peru. Botanical samples were identified by comparison with herbarium specimens and specialized literature [39–41]. Botanical nomenclature was based on the W3-Tropicos database (www.tropicos.org). The conservation status of the recorded species was determined according to the Red List criteria and the Peruvian categorization of threatened plant species [42].

2.4. Statistical Analyses

Statistical analyses were performed in R, version 4.6.1, through the RStudio integrated development environment [43]. Community-level diversity, composition, and dissimilarity analyses were performed with the vegan package, version 2.6.10 [44]. Statistical tests were computed with the base stats package distributed with R, version 4.3.3. All graphs were generated with the ggplot2 package, version 4.0.2 [45]. Dendrogram segment data were extracted for plotting with the ggdendro package, version 0.2.0 [46], and composite heatmap–dendrogram figures were assembled with the patchwork package, version 1.3.2 [47]. The chord diagram was built with the circlize package, version 0.4.16 [48].

Species richness was evaluated by family, growth habit, and altitudinal zone using bar charts for the 18 most abundant families overall and the six most rich families per habit. Expected richness across zones was estimated via a species accumulation curve (Mao Tau solution: specaccum, method = “exact” in vegan [44]) with a $\pm$ 1 SD band. Genus-level richness across zones for the 25 most species-rich genera was examined via a hierarchically clustered heatmap using Euclidean distances (dist in stats) and Ward’s method (hclust, method = “ward.D2”), with dendrograms extracted via ggdendro [46] and combined using patchwork [47].

Floristic dissimilarity among zones was calculated using Sørensen (vegdist, method = “bray”, binary = TRUE) and Jaccard indices (method = “jaccard”) in vegan [44]. Sørensen distances were plotted as a heatmap, while Jaccard distances were hierarchically clustered via UPGMA (hclust, method = “average”) and rendered with ggdendro [46]. For the 21 endemic species, altitudinal distribution was visualized using a presence/absence heatmap and a chord diagram (circlize [48]), abbreviating species names for clarity.

3. Results

3.1. Floristic Inventory

A total of 202 plant species were recorded, grouped into 140 genera and 62 families, of which 40 had a conservation status assigned by the IUCN (Table 1). Eudicots account

for 78.2% of the taxa, with 158 species grouped into 50 families; monocots account for 19.3%, with 39 species; Equisetophytes account for 0.49%, represented solely by *Equisetum bogotense*; and the remaining 1.98% consists of monilophytes, with 3 species in 2 families. The most diverse families were Asteraceae (29 species), Poaceae (19 species), Solanaceae (14 species), Fabaceae (13 species), Amaranthaceae (7 species), and Cactaceae (7 species), which together accounted for 44.1% of the total number of species (Figure 2). The most well-represented genera were *Solanum* (6 species), *Senecio* (5 species), and *Poa*, *Calceolaria*, and *Oxalis* (4 species each), while 144 genera had a single species.

In terms of growth habits, herbaceous plants predominated, accounting for 66.3% of the recorded species. Shrubs accounted for 14.4%, followed by trees (6.4%). Succulents and vines accounted for 4.0%, while stolon-bearing herbaceous plants accounted for 3.0%. Epiphytes were rare (1.5%), and only one hemiparasitic species was recorded, accounting for 0.5% of the total. The taxonomic composition of growth forms showed a predominance of Asteraceae and Poaceae in the herbaceous stratum, while the other growth forms were represented by a smaller number of dominant families, whose main contributions are shown in Figure 3.

Table 1. Complete species checklist of the Huaral floristic inventory.

Family	Taxon	Plant's Habit	Endemic	Conservation Status	Zone
Acanthaceae	*Dicliptera* cf. *squarrosa* Nees	H	NO		2,3
	Dicliptera montana Lindau	H	NO		2,3
	Dicliptera peruviana (Lam.) Juss.	H	NO		2
Alstroemeriaceae	*Bomarea lopezii* Hofreiter & E.Rodr.	Li	NO		4
	Bomarea ovata (Cav.) Mirb.	Li	NO		4
	Bomarea sp.	Li	-		4
Amaranthaceae	*Alternanthera halimifolia* (Lam.) Standl. ex Pittier	H	NO		1,2
	Alternanthera porrigens (Jacq.) Kuntze	H	NO		2
	Amaranthus sp.	H	-		2
	Amaranthus spinosus L.	H	NO	LC	1,2
	Chenopodiastrum murale (L.) S. Fuentes, Uotila & Borsch	H	NO		3
	Chenopodium sp.	H	-		2,3
	Dysphania ambrosioides (L.) Mosyakin & Clemants	H	NO		3
Amaryllidaceae	*Ismene amancaes* (Ruiz & Pav.) Herb.	H	YES		1
	Stenomesson flavum (Ruiz & Pav.) Herb.	H	YES		3
Anacardiaceae	*Schinus molle* L.	T	NO	LC	1
Annonaceae	*Annona cherimola* Mill.	T	NO		1
Apiaceae	*Foeniculum vulgare* Mill.	H	NO		3
Asparagaceae	*Agave americana* L.	H	NO	LC	3
	Agave sp.	H	-		3
	Furcraea andina Trel.	H	NO		2
	Furcraea occidentalis Trel.	H	NO		1
	Oziroe biflora (Ruiz & Pav.) Speta	H	NO		2

Table 1. *Cont.*

Family	Taxon	Plant's Habit	Endemic	Conservation Status	Zone
Asteraceae	*Ageratina vallincola* (DC.) R.M.King & H.Rob.	Sh	SI		2
	Ambrosia artemisiifolia L.	H	NO		3
	Ambrosia peruviana Willd.	H	NO		2,3
Asteraceae	*Baccharis alnifolia* Meyen & Walp.	Sh	SI		3
	Baccharis sp.	Sh	-		3
	Barnadesia dombeyana Less.	Sh	NO		3
	Bidens pilosa L.	H	NO	LC	2
	Bidens andicola Kunth	H	NO		3
	Calendula officinalis L.	H	NO		3,4
	Conyza bonariensis (L.) Cronquist	H	NO		2
	Conyza sp.	H	-		3
	Cotula cf. *australis* (Sieber ex Spreng.) Hook. f.	H	NO		1,2
	Dahlia pinnata Cav.	H	NO		1,2
	Erigeron leptorhizon A.Gray	H	NO		3
	Mutisia acuminata Ruiz & Pav.	Li	NO		2,3
	Ophryosporus piquerioides (DC.) Benth. ex Baker	H	NO		3
	Paranephelius uniflorus Poepp. & Endl.	H	NO		4
	Paranephelius ovatus A.Gray ex Wedd.	H	NO		4
	Perezia multiflora (Bonpl.) Less.	H	NO		4
	Philoglossa purpureodisca H.Rob.	H	SI		4
	Senecio sp. 1	H	-		2
	Senecio collinus	H	SI		3,4
	Senecio ferreyrae Cabrera	H	SI		3,4
	Senecio nutans Sch. Bip.	H	NO		4
	Senecio sp. 2	H	NO		3
	Sonchus asper (L.) Hill	H	NO		3
	Sonchus oleraceus L.	H	NO		1,2
	Tagetes multiflora Kunth	H	NO		3,4
	Tagetes elpitica Sm.	H	NO		4
Basellaceae	*Ullucus tuberosus* Caldas	H	NO		3,4
Berberidaceae	*Berberis lutea* Ruiz & Pav.	Sh	NO	LC	2
Bignoniaceae	*Tecoma* sp.	T	-		1
Boraginaceae	*Heliotropium arborescens* L.	Sh	NO		1,2,3
	Heliotropium curassavicum L.	H	NO		1
	Heliotropium angiospermum Murray	H	NO		1
Brassicaceae	*Brassica rapa* L.	H	-		1,2,3
	Brassica nigra (L.) W.D.J. Koch	H	NO		1,2,3
	Nasturtium officinale W.T. Aiton	H	NO	LC	1
	Sisymbrium orientale L.	H	NO		1
	Sisymbrium altissimum L.	H	NO		4
Bromeliaceae	*Puya* sp.	H	-		2
	Tillandsia sp. 1	H	-		3
	Tillandsia latifolia Meyen	H	SI	LC	2
	Tillandsia sp. 2	H	-		2

Table 1. *Cont.*

Family	Taxon	Plant's Habit	Endemic	Conservation Status	Zone
Cactaceae	*Armatocereus matucanensis* Backeb. ex A.W.Hill	Sh	NO	LC	1
	Armatocereus sp.	T	-		3
	Echinopsis pachanoi (Britton & Rose) H.Friedrich & G.D.Rowley	Sh	NO	LC	1,2,3
	Haageocereus acranthus (Vaupel) Backeb.	Sh	SI	LC	3,4
	Loxanthocereus acanthurus (Vaupel) Backeb.	Sh	NO		1
	Neoraimondia arequipensis (Meyen) Backeb.	T	SI	LC	1
	Opuntia ficus-indica (L.) Mill.	Sh	NO	DD	2,3
Calceolariaceae	*Calceolaria pinnata* L.	H	SI		2,3
	Calceolaria sp.	H	-		1,4
	Calceolaria angustiflora Ruiz & Pav.	Sh	SI		4
	Calceolaria utricularioides Benth.	H	SI		2
Campanulaceae	*Siphocampylus tupaeformis* Zahlbr.	H	NO		1
Caricaceae	*Vasconcellea candicans* (A. Gray) A. DC.	T	NO	LC	2,3
Caryophyllaceae	*Cerastium* sp.	H	-		2,3
Commelinaceae	*Commelina fasciculata* L.	H	NO		1
	Tradescantia pallida (Rose) D.R. Hunt	H	NO		2
Convolvulaceae	*Ipomoea purpurea* (L.) Roth	Li	NO		1
	Ipomoea dubia Roem. & Schult	H	NO		1
Crassulaceae	*Echeveria deltoidea* Pino & Vilcapoma	H	SI		3
Cucurbitaceae	*Cucurbita maxima* Duchesne	Li	NO		1
	Cyclanthera pedata (L.) Schrad.	Li	NO		1
Cyperaceae	*Cyperus papyrus* L.	H	NO	LC	2
Ephedraceae	*Ephedra americana* Humb. & Bonpl. ex Willd.	H	NO	LC	3
Equisetaceae	*Equisetum bogotense* Kunth	H	NO		1,2,3
Escalloniaceae	*Escallonia resinosa* (Ruiz & Pav.) Pers.	Sh	NO	NT	1,4
Euphorbiaceae	*Croton alnifolius* Lam.	Sh	NO		2
	Croton ruizianus Müll. Arg.	Sh	NO		3
	Euphorbia heterophylla L.	H	NO	LC	1
	Ricinus communis L.	Sh	NO	LC	1,2,3
Fabaceae	*Caesalpinia spinosa* (Molina) Kuntze	T	NO	LC	1,2
	Desmodium cf. *incanum* DC.	H	NO	LC	2
	Indigofera humilis Kunth	H	NO		2,3
	Indigofera suffruticosa Mill.	Sh	NO		3
	Lupinus mutabilis Lam	H	NO		3,4
	Lupinus microphyllus Desr.	H	NO	LC	3
	Medicago lupulina L.	H	NO		1,2
	Medicago polymorpha L.	H	NO		2
	Medicago sativa L.	H	NO	LC	3
	Spartium junceum L.	Sh	NO		1

Table 1. *Cont.*

Family	Taxon	Plant's Habit	Endemic	Conservation Status	Zone
Fabaceae	*Vachellia macracantha* (Humb. & Bonpl. ex Willd.) Seigler & Ebinger	T	NO	LC	1,2
	Vicia faba L.	H	NO		1
	Vigna luteola (Jacq.) Benth.	H	NO	LC	1,2
Gentianaceae	*Gentianella* sp.	H	-		4
Geraniaceae	*Erodium mostachum* (L.) L'Hér.	H	NO		2
	Erodium malacoides (L.) L'Hér.	H	NO		1,2
Iridaceae	*Olsynium junceum* (E. Mey. ex C. Presl) Goldblatt	H	NO		4
Lamiaceae	*Mentha spicata* L.	H	-	LC	1
	Minthostachys mollis (Kunth) Griseb.	Sh	NO		3
	Minthostachys sp.	Sh	-		3
	Salvia rhombifolia Ruiz & Pav.	H	NO		1
	Salvia sp.	H	-		1,2
Lauraceae	*Persea americana* Mill.	T	NO	LC	1,2
Loasaceae	*Mentzelia scabra* Kunth	Sh	NO		1
	Nasa sp.	Sh	-		4
	Nasa magnifica (Urb. & Gilg)	Sh	SI		3
	Presliophytum incanum (Graham) Weigend	H	NO		1
Loranthaceae	*Tristerix longebracteatus* (Desr.) Barlow & Wiens	Sh	NO		3
Malvaceae	*Fuertisimalva* sp.	H	-		1
	Gaya cf. *weberbaueri* Ulbr.	H	SI		1
	Malva cf. *parviflora* L.	H	NO		3
	Malva sp.	H	-		3
	Sida rhombifolia L.	Sh	NO		2
Myrtaceae	*Eucalyptus globulus* Labill.	T	NO	LC	1,2
Nyctaginaceae	*Bougainvillea glabra* Choisy	Sh	NO	LC	1
Onagraceae	*Oenothera rosea* L'Hér. ex Aiton	H	NO		2
Orobanchaceae	*Castilleja* cf. *peruviana* Maxon	H	SI		3
	Castilleja sp.	H	-		1
Oxalidaceae	*Oxalis corniculata* L.	H	NO		2
	Oxalis tuberosa Molina	H	NO		2
	Oxalis lomana Diels	H	SI		2
	Oxalis megalorrhiza Jacq.	H	NO		1
Papaveraceae	*Argemone subfusiformis* G.B.Ownbey	H	NO		1
Passifloraceae	*Passiflora cf peduncularis* Cav.	Li	SI		3
Phyllanthaceae	*Phyllanthus niruri* L.	H	NO		1
Piperaceae	*Peperomia inaequalifolia* Ruiz & Pav.	H	NO		3
	Piper aduncum L.	Sh	NO	LC	3

Table 1. *Cont.*

Family	Taxon	Plant's Habit	Endemic	Conservation Status	Zone
Plantaginaceae	*Plantago major* L.	H	NO		2
	Plantago lanceolata L.	H	NO		2
Plantaginaceae	*Veronica persica* Poir.	H	NO		2
	Veronica anagallis-aquatica L.	H	NO	LC	2
Plumbaginaceae	*Plumbago caerulea* Kunth	Sh	NO		2
Poaceae	*Agrostis* sp.	H	-		3
	Arundo donax L.	H	NO	LC	1
	Bromus catharticus Vahl	H	NO		4
	Calamagrostis sp. 1	H	-		1,2,3
	Calamagrostis sp. 2	H	-		4
	Cinnagrostis brevifolia (J. Presl) P.M. Peterson, Soreng, Romasch. & Barberá	H	NO		4
	Echinochloa crus-galli (L.) P.Beauv.	H	NO	LC	3,4
	Eragrostis cf. *peruviana* (Humb. & Bonpl. ex Willd.) Trin.	H	NO		1,4
	Hordeum vulgare L.	H	NO		3,4
	Pennisetum sp.	H	-		2,3
	Pennisetum setaceum (Forssk.) Chiov.	H	NO		3
	Poa sp. 1	H	-		2,3
	Poa sp. 3	H	-		3
	Poa horridula Pilg.	H	NO		4
	Poa sp. 2	H	-		3,4
	Sorghum sp.	H	-		1,2,3
	Sorghum halepense (L.) Pers.	H	NO		3,4
	Triticum aestivum L.	H	NO		3,4
	Zea mays L.	H	-	LC	1,2
Polygalaceae	*Monnina herbacea* DC.	H	NO		2,3
Polygonaceae	*Polypogon* sp.	H	-		1,2,3
	Rumex obtusifolius L.	H	NO		1
	Rumex crispus L.	H	NO		2,3
Primulaceae	*Lysimachia arvensis* (L.) U. Manns & Anderb.	H	NO		2
Pteridaceae	*Adiantum* sp.	H	-		2
	Adiantum subvolubile Mett. ex Kuhn	H	NO		3
Rosaceae	*Kageneckia lanceolata* Ruiz & Pav.	T	NO	LC	2
	Prunus persica (L.) Batsch	T	NO		1,2
	Prunus serotina Ehrh	T	NO	LC	3,4
	Rosa sp.	Sh	-		1
	Rubus sp.	Sh	-		1
Salicaceae	*Salix humboldtiana* Willd.	T	NO	LC	1,3
Scrophulariaceae	*Buddleja incana* Ruiz & Pav	T	NO	LC	4
Solanaceae	*Browallia americana* L.	H	NO		1,2
	Brugmansia arborea (L.) Lagerh.	Sh	NO	EW	1,2

Table 1. *Cont.*

Family	Taxon	Plant's Habit	Endemic	Conservation Status	Zone
Solanaceae	*Cestrum auriculatum* L'Hér.	Sh	NO		2
	Jaltomata dentata (Ruiz & Pav.) Mione	H	NO		3
	Lycianthes lycioides (L.) Hassl.	Sh	NO		4
	Nicandra physalodes (L.) Gaertn.	H	NO		2,3
	Nicotiana paniculata L.	Sh	SI		1
	Physalis peruviana L.	H	NO		2,3
	Solanum americanum Mill.	H	NO		2,3
	Solanum peruvianum L.	H	NO	LC	1,2
	Solanum tuberosum L.	H	NO		2,4
	Solanum multiinterruptum Bitter	H	SI	LC	4
	Solanum sp. 1	H	-		3
	Solanum sp. 2	H	-		3
Alstroemeriaceae	*Bomarea lopezii* Hofreiter & E.Rodr.	Li	NO		4
	Bomarea ovata (Cav.) Mirb.	Li	NO		4
	Bomarea sp.	Li	-		4
Tropaeolaceae	*Tropaeolum tuberosum* Ruiz & Pav.	H	NO		1
	Tropaeolum majus L.	H	NO		1
Urticaceae	*Phenax hirtus* (Sw.) Wedd.	H	NO		2
	Urtica urens L.	H	NO		1,2
Verbenaceae	*Lantana* sp.	Sh	-		1
	Verbena litoralis HBK	H	NO		1,2,3
Woodsiaceae	*Wodsia* sp.	H	-		3

Recorded species classified by growth habit (H: herb; Sh: shrub; Li: vine; T: tree), their distribution across four altitudinal zones (Z1, Z2, Z3, and Z4), and their classification according to the IUCN (International Union for Conservation of Nature).

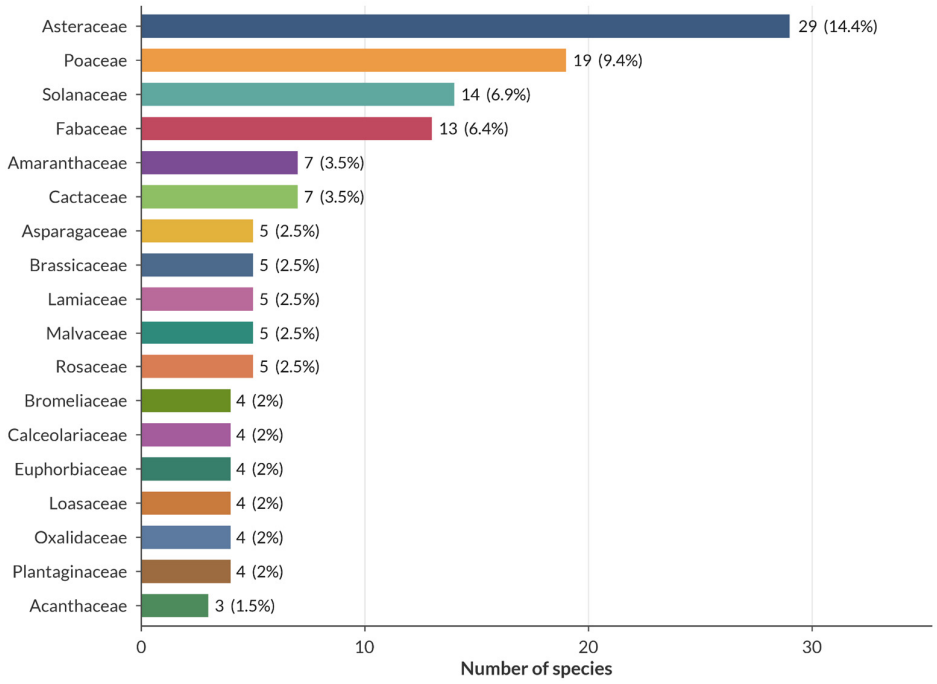


Figure 2. Species richness by plant family (top 18 of 62 families).

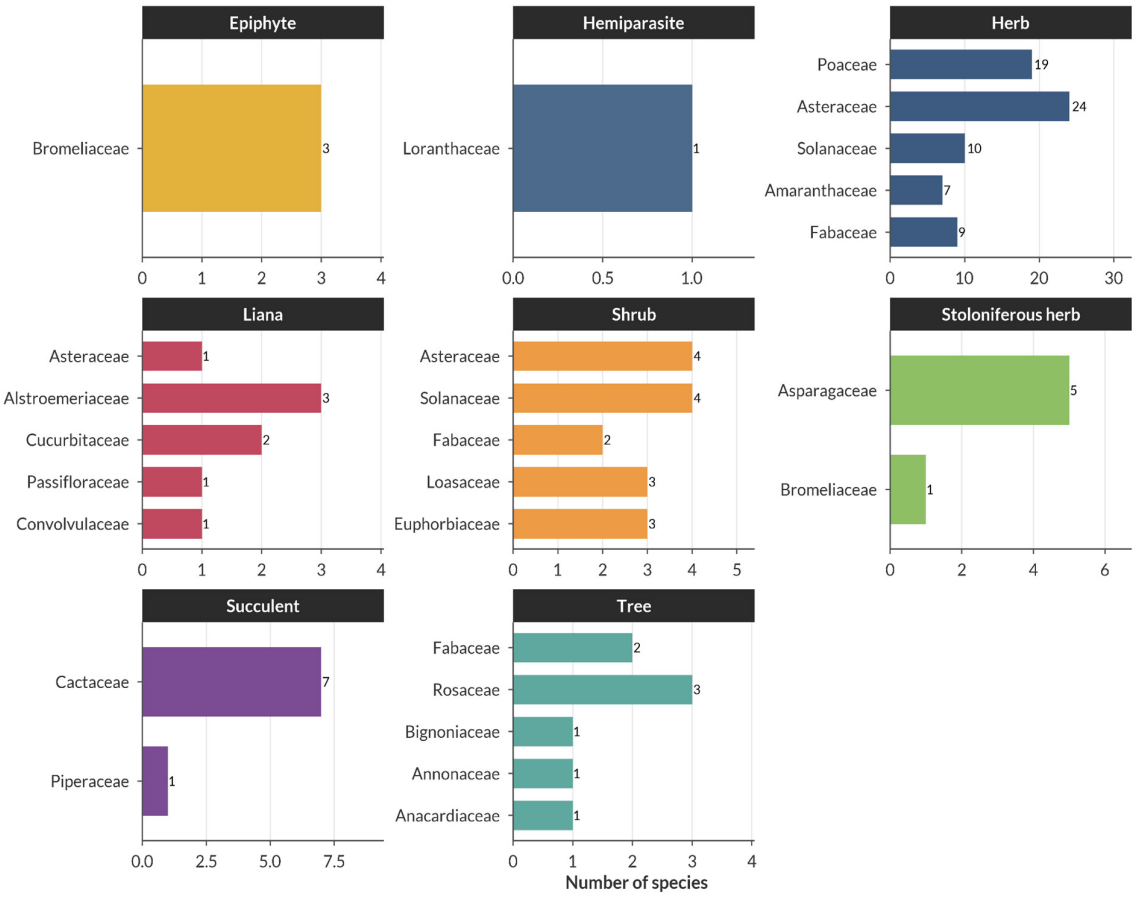


Figure 3. The most representative botanical families based on growth habit.

3.2. Ecosystems

In the analysis of species richness by altitudinal zone (Figure 4A), Zone 1 recorded 71 species. Species richness increased in Zone 2, where it peaked at 85 species, and remained virtually constant in Zone 3, with 84 species. Finally, Zone 4 showed a marked decrease, recording the lowest species richness along the gradient with 38 species. Meanwhile, the species accumulation curve (Figure 4B) showed a gradual increase in expected species richness as altitudinal zones were added. With one sampled zone, the expected species richness was 69.5 species; with two zones, 124.5 species; with three zones, 167.8 species; and with all four zones included, it reached a cumulative value of 201.2 species.

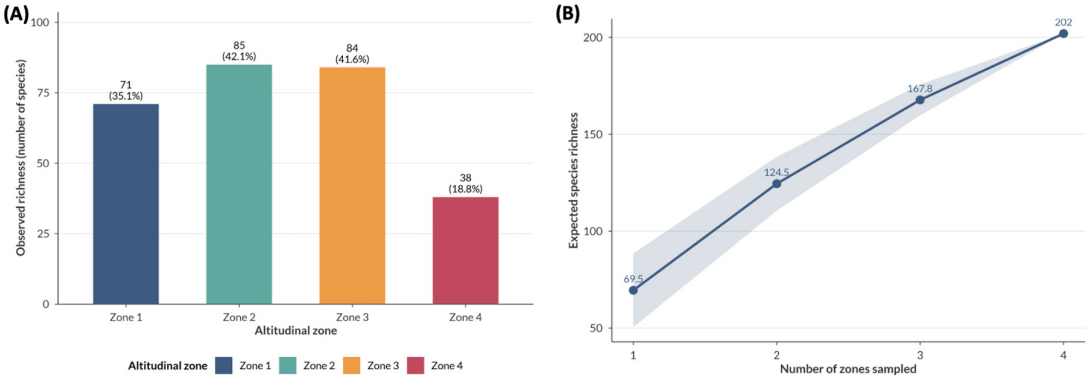


Figure 4. (**A**) Species richness observed by altitudinal zone. (**B**) Species accumulation curve for plant communities along the altitudinal gradient.

Species richness varied among the different growth forms along the altitudinal gradient (Figure 5). In all the areas evaluated, herbs were the predominant growth form, while the remaining groups were considerably less abundant and exhibited distinct distribution patterns across the altitudinal zones.

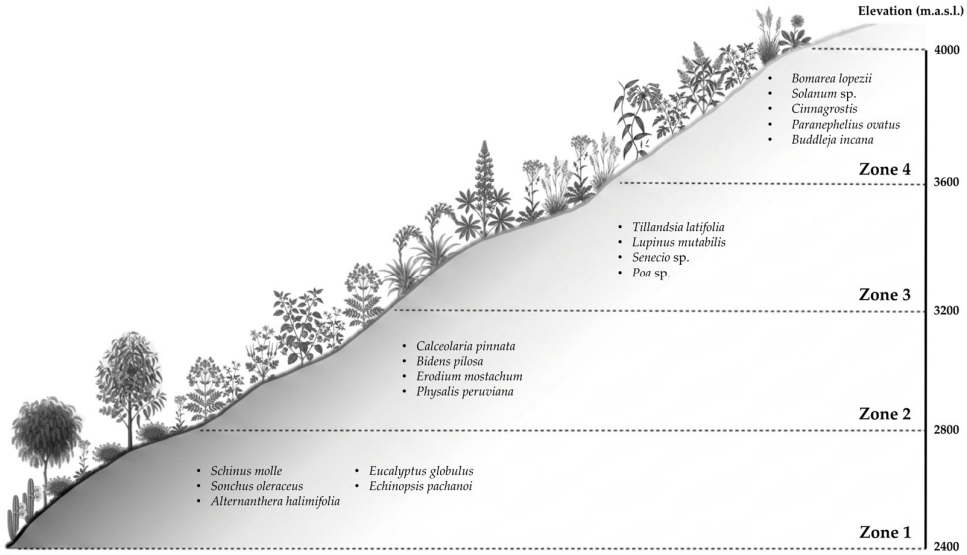


Figure 5. Vegetation profile along an altitudinal gradient in the Sumbilca district, Peru.

In Zone 1, herbaceous species predominated, with 45 species (63.4%), followed by shrubs (10; 14.1%) and trees (8; 11.3%). Succulents and vines accounted for 4 (5.6%) and 3 (4.2%), respectively, while stolon-bearing herbs were represented solely by Furcraea occidentalis (1; 1.4%). At the genus level, *Heliotropium* was the most diverse, with three species (*H. curassavicum*, *H. arborescens* (Figure 6A), and *H. angiospermum*), followed by *Brassica*, *Ipomoea*, *Salvia*, and *Tropaeolum*, with two species each.

In Zone 2, herbaceous species predominated, with 59 species (69.4%), followed by shrubs (10; 11.8%) and trees (8; 9.4%). Stolon-bearing herbs were represented by 3 species (3.5%), while succulents and epiphytes each accounted for 2 species (2.4%). Lianas were represented by a single species, *Mutisia acuminata* (Figure 7K), accounting for only 1.2%. At the genus level, the most diverse genera were *Dicliptera*, *Oxalis*, and *Solanum*, with three species each.

In Zone 3, herbaceous species predominated, with 59 species (70.2%), followed by shrubs (11; 13.1%) and succulent plants (5; 6.0%). Trees accounted for 3.6%, while vines and stolon-bearing herbs accounted for 2 (2.4%). Epiphytes were represented by a single species (1.2%), while hemiparasites also included a single species, *Tristerix longebracteatus* (Figure 7G); this was the only zone in which hemiparasitic species were recorded. At the genus level, the most diverse genera were *Solanum*, *Senecio*, and *Poa*, with three species each.

The heat map (Figure 8) revealed differences in the distribution patterns of botanical family richness along the altitudinal gradient. Asteraceae and Poaceae exhibited the highest richness values and a wide distribution across the evaluated zones, with a concentration in the highest-altitude zones (Z3 and Z4). In contrast, Solanaceae and Fabaceae showed variation in richness among zones, indicating changes in their composition along the gradient. Some families had a more restricted distribution; for example, Alstroemeriaceae was recorded exclusively in Z4.



Figure 6. *Argemone subfusiformis* (**A**), *Ricinus communis* (**B**), *Barnadesia dombeyana* (**C**), *Peperomia inaequalifolia* (**D**), *Nasa magnifica* (**E**), *Passiflora* cf. *peduncularis* (**F**), *Tristerix longebracteatus* (**G**), *Indigofera suffruticosa* (**H**), *Solanum peruvianum* (**I**), *Dicliptera montana* (**J**), *Mutisia acuminata* (**K**).



Figure 7. *Heliotropium arborescens* (**A**), *Physalis peruviana* (**B**), *Presliophytum incanum* (**C**), *Echeveria deltoidea* (**D**), *Rumex obtusifolius* (**E**), *Oenothera rosea* (**F**), *Lysimachia arvensis* (**G**), *Plumbago caerulea* (**H**), *Erodium malacoides* (**I**), *Jaltomata dentata* (**J**), *Nicandra physalodes* (**K**).

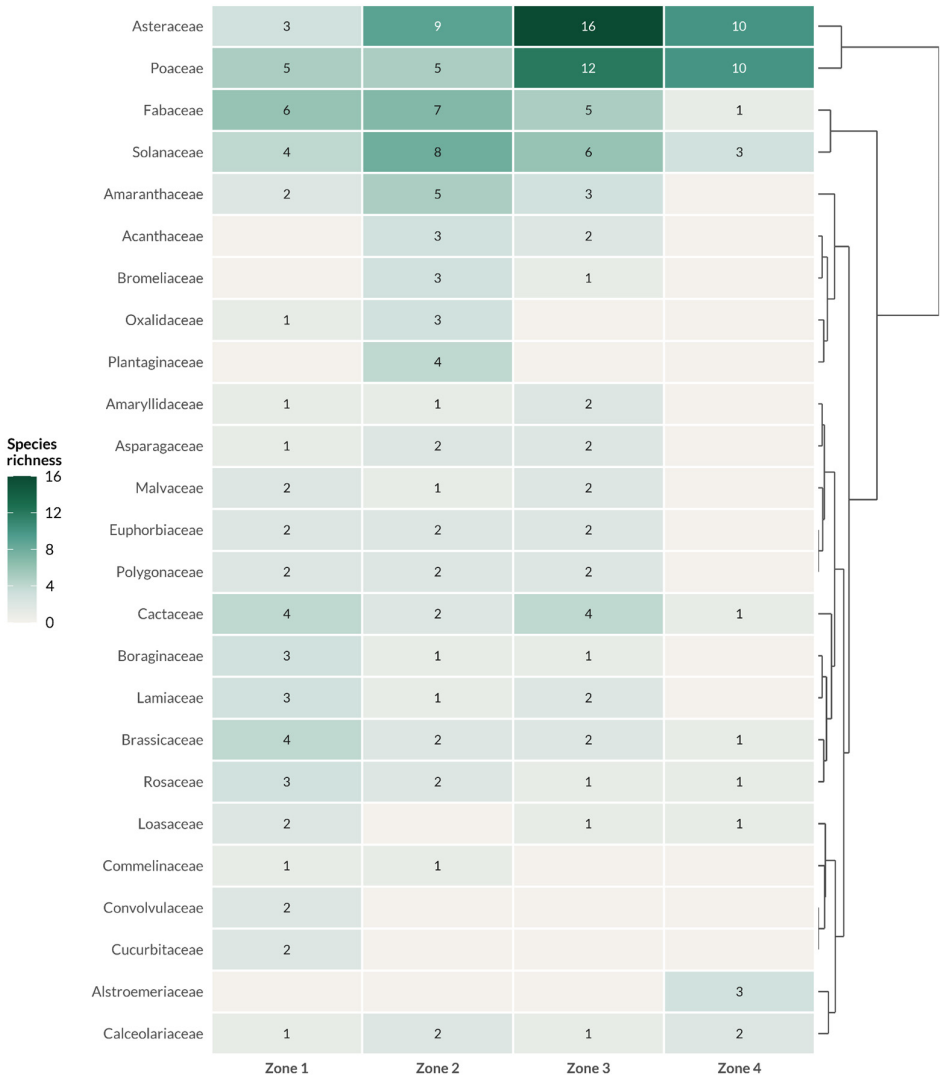


Figure 8. Number of recorded species and their distribution by botanical family across the four zones of the altitudinal gradient.

The dendrogram associated with the heat map grouped the families according to the similarity of their distribution patterns across altitudinal zones, primarily distinguishing families with greater species richness and wider distribution from those with lower species richness or more restricted distribution. In general terms, zones Z2 and Z3 had the greatest richness and diversity of families, while zone Z4 showed a decrease in the number of recorded taxa. However, zone Z4 still contained some exclusive or restricted-distribution families, reflecting differences in floristic composition among the various altitudinal levels.

3.3. Inferential Statistics

To assess the floristic exchange between the areas, the Jaccard dissimilarity was calculated (Figure 9A). The matrix showed that Zone 4 exhibited the highest levels of dissimilarity compared to Zone 1 (0.97), Zone 2 (0.99), and Zone 3 (0.88). In contrast, Zone 1 and Zone 2 showed lower dissimilarity (0.76), indicating greater homogeneity in their species composition. The hierarchical clustering dendrogram revealed patterns of floristic similarity among the evaluated zones (Figure 9B). Zones 1 and 2 showed the greatest compositional affinity, while Zone 3 was grouped at a greater distance. In contrast, Zone 4 stood apart as a distinct group, reflecting greater floristic distinctiveness compared to the other zones.

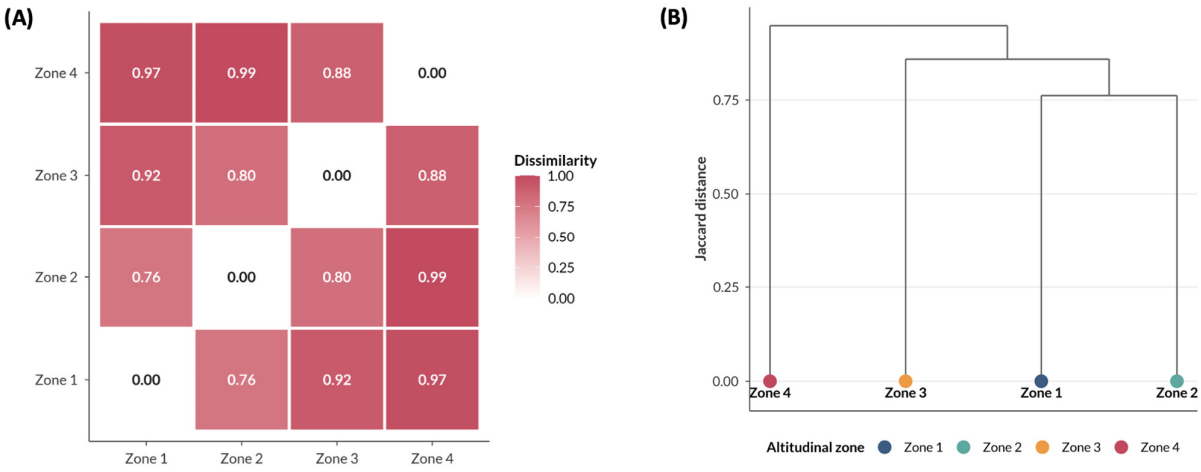


Figure 9. Analysis of floristic dissimilarity among study areas. (**A**) Heat map based on the Jaccard dissimilarity matrix. (**B**) Hierarchical clustering dendrogram showing patterns of floristic similarity among areas.

A total of 21 endemic species were recorded, with a heterogeneous distribution along the altitudinal gradient (Figure 10). Most were restricted to one or two zones, while only a small number occurred in three consecutive zones; no species was present in all four study zones. Overall, Zone 3 had the highest number of endemic species records, followed by Zones 2, 4, and 1.

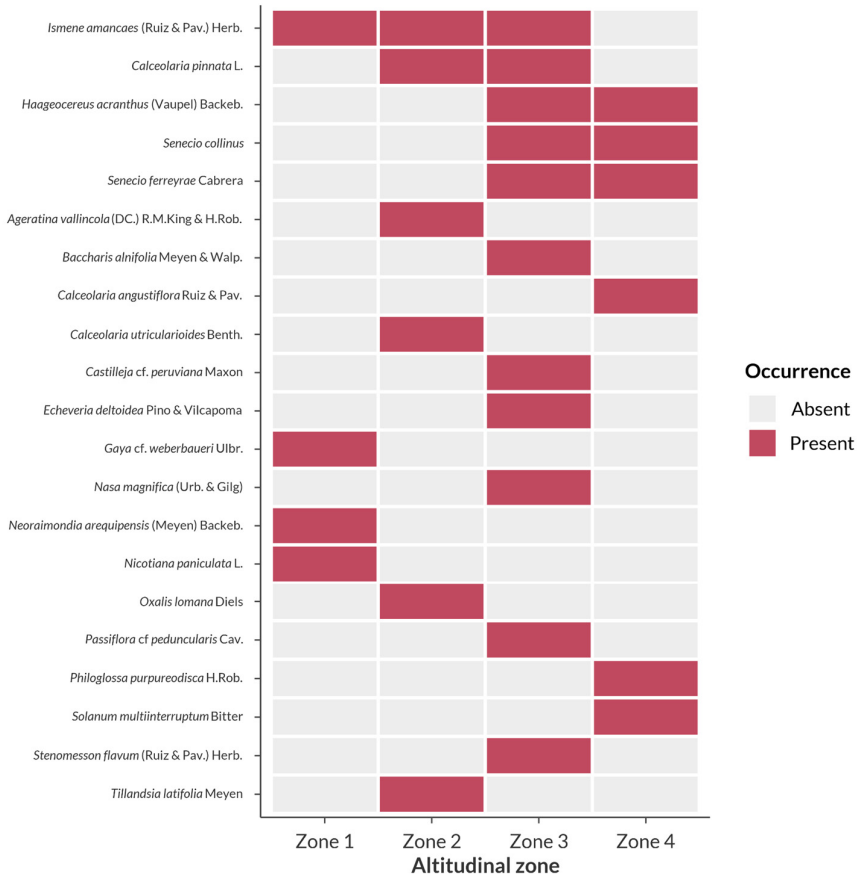


Figure 10. Presence–absence matrix of endemic plant species across the altitudinal gradient.

3.4. Threatened Flora

A total of 42 species were recorded with a conservation status recognized under national (Supreme Decree No. 043-2006-AG) and international (IUCN) criteria (Figure 11). According to the IUCN Red List, 40 species were assessed, of which 92.5% were classified as Least Concern (LC). The remaining categories included Near Threatened (NT), represented by *Escallonia resinosa*; Extinct in the Wild (EW), corresponding to *Brugmansia arborea*; and Data Deficient (DD), represented by *Opuntia ficus-indica*. Under the Peruvian legal framework (Supreme Decree No. 043-2006-AG), five species were classified into threat categories: *Buddleja incana* (critically endangered), *Caesalpinia spinosa* (vulnerable), *Ephedra americana* (near threatened), *Mutisia acuminata* (near threatened), and *Senecio nutans* (vulnerable).

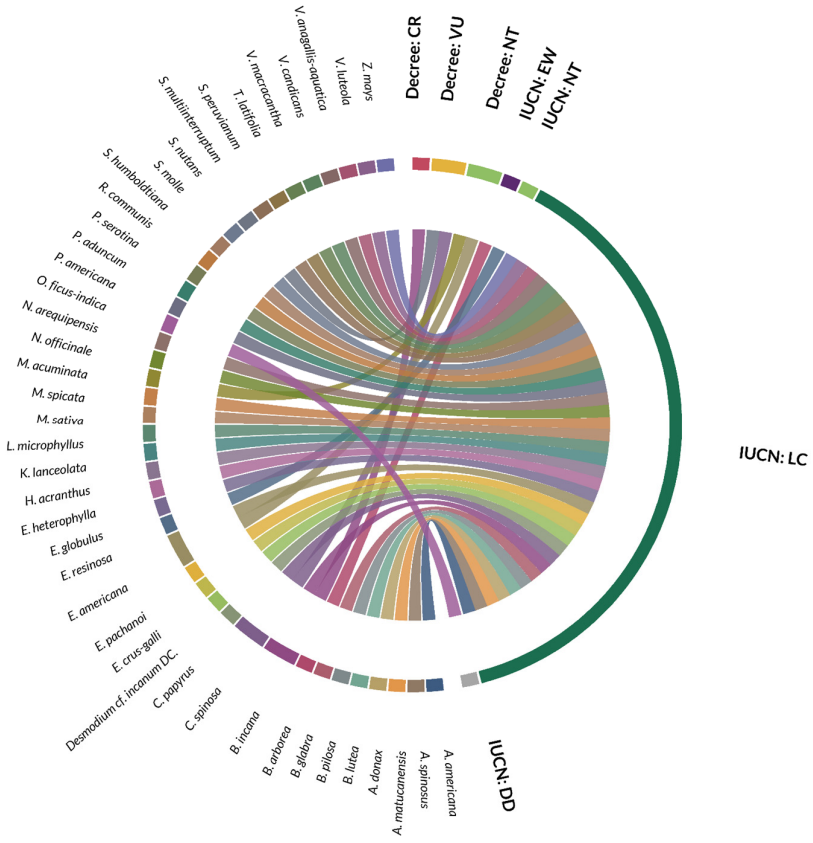


Figure 11. Flora listed as threatened according to the IUCN Red List and Supreme Decree No. 043–2006–AG.

4. Discussion

The high level of plant diversity recorded in the Sumbilca district (202 species, 140 genera, and 62 families) confirms that the ecosystems on the western slope of the Central Andes harbor considerable plant diversity, even in environments characterized by marked seasonal variations in water availability and significant topographic heterogeneity [37,49]. These results are consistent with the role of the tropical Andes as one of the world's major centers of plant diversification, where altitudinal gradients generate a wide variety of environmental conditions that favor species replacement and the coexistence of floristic elements from different ecological zones [5,6,12,37]. The predominance of Asteraceae, Poaceae, Solanaceae, and Fabaceae is a widely documented pattern in the flora of the Central Andes and reflects the adaptation of these groups to mountain environments subject to extreme variations in temperature, solar radiation, and water availability [37,38,50,51].

Beltrán and Galán de Mera [50], in their catalog of angiosperms for the department of Lima, identify Asteraceae, Poaceae, Solanaceae, and Fabaceae as the most species-rich families, with *Senecio* and *Baccharis* as the most diverse genera within the Asteraceae. Gonzáles [51], in his review of this family for the same department, also found *Senecio* to be the dominant genus, followed by *Baccharis* and *Werneria*, and noted that species diversity—both total and endemic—is concentrated between 3000 and 3500 m in elevation. A similar generic pattern was documented by Ceroni-Stuva and Vilcapoma-Segovia [52] in Cajatambo, where *Senecio*, *Baccharis*, and *Calceolaria* were found to be the genera with the highest species richness; these same authors note that the predominance of *Senecio* and *Baccharis* is also observed in Oyón [53], Huarochirí [54], Canta [55], and Yauyos [56].

Asteraceae, the most diverse family in this study, includes numerous taxa adapted to conditions of high solar radiation, seasonal drought, and poorly developed soils—characteristic of high-Andean environments, where daily temperature ranges are often extreme and soil nutrient availability is low [57,58]. Poaceae, on the other hand, dominates grassland and puna environments due to the tolerance for low temperatures and grazing exhibited by genera such as *Calamagrostis* and *Festuca* [37,59–61], and constitutes the most representative floristic component of high-Andean grasslands subjected to low temperatures and cold, dry winds [62]. In Cajatambo, an increase in Poaceae species richness was also recorded above 3800 m in elevation, associated primarily with the genera *Cinnagrostis* and *Poa* [37]. In contrast, Solanaceae and Fabaceae show their greatest diversification in inter-Andean and montane environments, where they occupy a wide variety of open habitats and areas subject to varying levels of disturbance, reflecting high ecological plasticity [12].

The altitudinal distribution of floristic richness observed in Sumbilca reveals a marked process of floristic replacement driven by environmental filtering along the altitudinal gradient [63]. At lower elevations, species associated with dry shrublands and environments with greater anthropogenic influence predominated, while at higher elevations, the representation of herbaceous and gramineous species characteristic of high-Andean grasslands and puna environments increased [5,6]. This pattern is consistent with the decrease in temperature and increase in humidity with altitude, factors that alter resource availability and vegetation structure [5,14,64,65]. In the tropical Andes, elevation acts as a composite gradient that integrates temperature, radiation, humidity, soil depth, and disturbance frequency, resulting in marked floristic differentiation among altitudinal zones [6,13,64,65].

The elevational pattern of floristic richness observed in Sumbilca is generally consistent with patterns reported across the tropical Andes, where species richness often reaches its highest values at intermediate elevations before declining toward higher altitudes. Similar patterns have been documented in the northern and central Andes, including Colombia [66], southern Ecuador [67,68], and the eastern slopes of Peru and Bolivia [37,38,69]. In these regions, vascular plant richness commonly reaches its highest values between approximately 1500 and 3500 m, although the elevation and intensity of the richness peak vary among localities. This pattern is also evident in Sumbilca, where richness increased from Z1 to Z2 and remained high in Z3, with the highest values concentrated between 2800 and 3600 m. In contrast, richness declined sharply in Z4, where only 38 species were recorded above 3600 m. This decrease may reflect the transition toward the more open and arid puna vegetation characteristic of the Pacific slope of the Central Andes. Overall, these findings suggest that although mid-elevation peaks in plant richness are common across Andean ecosystems, their expression at the local scale is strongly influenced by topographic heterogeneity, changes in moisture availability, and environmental filtering at higher elevations [6,70].

This differentiation reflects a constant process of species replacement, driven by environmental transitions along the gradient [71]. The greater floristic affinity among the lower zones suggests shared climatic, edaphic, and disturbance conditions, which favor the persistence of taxa adapted to scrubland and anthropogenic impacts [72,73]. In contrast, the high dissimilarity in the upper zones results from severe environmental filtering imposed by low temperatures, high solar radiation, wind exposure, and shallow soils [5,74]. These constraints exclude species from lower elevations and favor specialized taxa in high-Andean ecosystems, thereby increasing landscape heterogeneity [12,73,75]. Consequently, the floristic uniqueness of high-altitude communities highlights their high conservation value, as they contribute endemic and complementary components to regional diversity, especially in terms of floristic turnover and beta-diversity [6,76].

The new records also enhance the district's biogeographic value and highlight the importance of conducting systematic floristic inventories in intermediate areas of the western Andean slope, where significant distribution gaps persist [9,10]. The magnitude of this gap is directly related to the heterogeneity of local plant communities and the intensity of the sampling effort. Taxa such as *Senecio collinus*, *Senecio ferreyrae* and *Calceolaria angustiflora* are key examples of this pattern; their discovery in the area enriches the district's floristic catalog and provides valuable data for understanding biogeographic connectivity and the composition of plant communities in this sector of the Andes.

The floristic differentiation among the assessed areas also has implications for conservation. The presence of species with restricted distributions and taxa classified as threatened indicates that the altitudinal gradient of Sumbilca harbors plant communities of high conservation value. Scrubland and puna habitats function as reservoirs of biodiversity, but they face pressures from agricultural expansion, overgrazing, and seasonal burning, which can lead to a loss of vegetation cover that reduces ecological connectivity and compromises the stability of high-Andean communities [7,8]. Nor is this threat unique to Sumbilca, as Cuba-Melly and Odar [22] documented, for the Granados hills in the same province, the progressive replacement of native vegetation cover by crops. The fact that this anthropogenic pressure is evident in both the coastal and inland sectors of Huaral underscores the urgency of establishing floristic baselines and conservation measures along the entire altitudinal gradient of the province. The results obtained underscore the importance of incorporating complete altitudinal gradients into floristic monitoring and land-use planning programs, and of maintaining ecological continuity from the inter-Andean valleys to the puna, given that species replacement along the altitudinal gradient is one of the main mechanisms underpinning regional diversity [13,14,37].

To address these pressures across the Huaral altitudinal gradient, conservation efforts must combine the protection of native vegetation with sustainable land management and community-based approaches, which are increasingly recognized as essential components of high-Andean ecosystem conservation [77,78]. Similar strategies have already proven successful in Peru through initiatives such as the MERESE-FIDA project, which promoted the conservation and sustainable management of native forests, grasslands, and wetlands in close collaboration with local communities [78]. Implementing targeted measures such as native vegetation restoration and controlled grazing practices provides a particularly relevant framework for Sumbilca, where safeguarding local scrubland and puna habitats is critical to preventing further vegetation degradation [78,79]. In particular, prioritizing the protection of native grasslands and remnant *Polylepis* forests in Sumbilca is vital due to their key role in sustaining regional biodiversity and fundamental ecosystem functions at high elevations [77,78]. Ultimately, incorporating these site-specific approaches into broader land-use planning will safeguard the ecological continuity of the entire altitudinal gradient, maintaining essential functional connections from the inter-Andean valleys up to the puna.

This study has some limitations that should be taken into account when interpreting the results. The inventory was based on intensive sampling using directed search transects, a methodology that maximizes species detection but does not allow for accurate estimates of relative abundance or population structure within communities. Sampling effort was also not entirely consistent across microhabitats and seasons, so some species with seasonal flowering or fruiting patterns may have been underrepresented. Finally, although a broad altitudinal gradient was assessed, the number of study sites was limited, and quantitative environmental variables—such as vegetation cover, soil moisture, or disturbance intensity—were not incorporated, which limits the ability to establish causal relationships between the observed floristic patterns and the underlying ecological factors. Despite these limitations, this study represents the most comprehensive floristic assessment conducted to date for the Sumbilca district and provides a fundamental baseline for future studies in ecology, biogeography, and conservation in the central Andes of Peru.

5. Conclusions

This study documents a considerable level of floristic diversity in the district of Sumbilca (202 species, 140 genera, and 62 families), confirming that the ecosystems of the western slope of the central Andes harbor substantial plant diversity despite pronounced hydric seasonality and strong topographic heterogeneity. The distribution of this richness along the altitudinal gradient was non-linear: an increase from Zone 1 toward a shared maximum in Zones 2 and 3 was followed by a marked decline in Zone 4, a pattern consistent with the progressive replacement of xerophytic shrubland communities by herbaceous and graminoid communities characteristic of the puna. This compositional turnover was further reflected in the high Jaccard dissimilarity values between Zone 4 and the remaining zones, as well as in the greater compositional affinity observed between Zones 1 and 2. The predominance of Asteraceae, Poaceae, Solanaceae, and Fabaceae, together with the dominance of the herbaceous habit, is consistent with patterns previously reported for the central Andes. The recording of 21 endemic species, concentrated mainly in Zone 3, and of five species classified as threatened under Peruvian Supreme Decree N.° 043-2006-AG (*Buddleja incana*, *Caesalpinia spinosa*, *Ephedra americana*, *Mutisia acuminata*, and *Senecio nutans*), together with several new records for Huaral province (e.g., *Nasa magnifica*, *Tristerix longebracteatus*), indicates that Sumbilca had been floristically undersampled and holds considerable conservation value. The species accumulation curve, which approached its asymptote (201.2 of an expected 202 species), supports the representativeness of the inventory. Nevertheless, because sampling was qualitative and did not include abundance estimates or quantitative environmental variables, this work should be regarded as a baseline, the most comprehensive floristic assessment available to date for the district, upon which future monitoring, ecological, and conservation studies along the western Andean slope should be built.

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Conflicts of Interest: The authors declare no conflicts of interest.

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