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ARTICLES

Vascular flora of Konün Wenu Hill (La Araucanía, Chile): composition and ecological relevance of a forest fragment in a rural-urban matrix

Jimmy Pincheira-Ulbrich
Environmental Studies Core and Land Use Planning Laboratory, Department of Environmental Sciences, Natural Resources Faculty, Catholic University of Temuco. Temuco, Chile.

Daniela Alvarado
PhD in Land Use Planning and Sustainability and Gender Studies Center, Catholic University of Temuco. Temuco, Chile.

Javiera Bravo
Direction of Environmental Relations, Vice-Rector of Relations and Public Affaires, Catholic University of Temuco. Foundation Mapu Kimün, Padre Las Casas, Araucanía Region, Chile.

Genoveva Antinao
Foundation Mapu Kimün, Padre Las Casas, Araucanía Region, Chile.

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Abstract. Konün Wenu Hill (38°46' S, 72°38' W) is a prominent insular hill of considerable historical and cultural significance, located in the Mediterranean-temperate transition of south-central Chile. It hosts a ca. 10 ha remnant of native vegetation embedded within a matrix of grasslands and *Pinus radiata* D. Don (Pinaceae) plantations. Through a habitat-stratified floristic inventory covering the forest interior and adjacent habitats, we recorded 158 vascular plant taxa (Tracheophyta), comprising 90 native species (including 26 Chilean endemics) and 68 alien species. The forest remnant itself contained 62 native and 17 alien species. According to national conservation assessments, the flora includes two Vulnerable species—*Asplenium trilobum* Cav. (Aspleniaceae) and *Citronella mucronata* (Ruiz & Pav.) D. Don (Cardiopteridaceae)—and one Near Threatened species, *Gardoquia multiflora* (Phil.) Kuntze (Lamiaceae). The richest families were Asteraceae (24 spp.), Poaceae (14), Fabaceae (11), and Rosaceae (10). Canopy species such as *Cryptocarya alba* (Lauraceae), typical of Mediterranean sclerophyllous forests, *Nothofagus obliqua* (Mirb.) Oerst. (Nothofagaceae), characteristic of south-central deciduous forests, and *Eucryphia cordifolia* Cav. (Cunoniaceae), a temperate evergreen element from southern Chile, co-occur in the fragment and reflect the site's transitional biogeographic character. The surrounding grasslands contributed a suite of heliophilous elements, notably *Chloraea* Lindl. spp. (Orchidaceae). Isolated trees scattered throughout the grassland mosaic served as distinct microsites compared to the surrounding open areas, facilitating the establishment of species more typical of forest or shrubland environments—such as taxa associated with closed-canopy forest (e.g., *Francoa appendiculata* Cav.) or sclerophyllous shrubland (e.g., *Myrceugenia obtusa* (DC.) O. Berg). Hierarchical clustering with SIMPROF (10,000 permutations, $\alpha = 0.05$) showed that local road and forestry plantation each harboured floristic compositions statistically distinct from forest, edge, and grassland—and from one another—while these latter three habitats did not differ significantly among themselves. Despite its small size and isolation, Konün Wenu supports a substantial proportion of regional plant species richness and harbours taxa of conservation concern, underscoring the ecological value of both the remnant and the microhabitat network sustained by isolated trees across the surrounding matrix.
Keywords: Vascular flora, habitat fragmentation, biodiversity hotspot, grasslands, ecotone.

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Introduction

Remnant forest patches embedded within agroforestry matrices serve as refuges for a substantial proportion of biodiversity in landscapes heavily transformed by human activity. These relics often harbour native and endemic species of high ecological value, sustain essential ecosystem functions, and provide opportunities for landscape-level restoration and connectivity (Machado *et al.*, 2016; Ferreira *et al.*, 2016). Even forest fragments smaller than 10 ha can play a critical role in maintaining ecological connectivity between protected areas (Ribeiro *et al*., 2022). Moreover, they support pollinator communities that enhance ecosystem services within intensively managed agricultural settings (Proesmans, 2019). Recognising such fragments as micro-reservoirs of biodiversity has both scientific and policy implications, informing spatial planning, participatory conservation, and ecological restoration efforts (Langbehn, 2020).

The strategic value of native forest remnants is particularly evident in regions where the original forest cover has been drastically reduced. In Chile, deforestation began during the colonial period, driven by agricultural expansion, intensive logging of high-value species such as *Nothofagus glauca* (Phil.) Krasser and *Nothofagus alpina* (Poepp. & Endl.) Oerst., and human settlement (Torrejón & Cisternas, 2003; Camus *et al*., 2014). Throughout the twentieth century, wildfires, soil erosion, and production-oriented policies further accelerated the replacement of native forests by fast-growing exotic plantations—primarily *Pinus radiata* D. Don and *Eucalyptus spp*.—thereby consolidating a territorial matrix dominated by agricultural and forestry monocultures (Nahuelhual *et al*., 2012; Heilmayr *et al*., 2016). In Chile's Mediterranean and its transition to temperate zones, more than 67% of sclerophyllous forest has disappeared since 1975, and in the Central Valley, the remaining fragments represent just 5–10% of their historical extent, primarily due to industrial forestry and intensive agriculture (Echeverría *et al*., 2006).

Within this context, even small native forest fragments embedded in plantation-dominated matrices have been shown to retain a floristic composition similar to that of continuous forests, supporting high levels of native species richness (e.g., remnant Maulino forest patches in the Coastal Range of central Chile surrounded by *Pinus radiata* plantations; Becerra & Simonetti, 2020). Such attributes render them priority areas for conservation (Fahrig, 2017). Recognizing these remnants as micro-reservoirs of biodiversity provides a technical foundation for land-use planning, participatory conservation, and landscape-scale ecological restoration (Derak *et al*., 2023).

The urgency of protecting these relics is further heightened by climate change. Native forest patches can serve as climatic microrefugia, buffering extreme environmental conditions such as heatwaves and droughts, and acting as biological corridors for species undergoing altitudinal or latitudinal range shifts (Serra-Díaz *et al*., 2015; Bátori *et al*., 2021). Despite their ecological potential, many of these fragments remain undocumented in official records and are excluded from conservation or spatial planning frameworks. Documenting and inventorying their biodiversity is therefore essential to support effective conservation, restoration, and adaptive management (Machado *et al*., 2016).

Nonetheless, floristic inventories of such fragments have historically been overlooked (Sobral-Souza *et al*., 2021). This gap is especially pronounced in Latin America, where limited coverage by monitoring programmes has led to significant information deficits, particularly outside protected areas. In Chile, even officially protected sites often lack updated floristic data, underscoring the need for current, geographically explicit primary information to guide conservation and restoration planning (Urbina-Casanova *et al*., 2016).

Many native vegetation remnants persist in agricultural landscapes not only due to ecological processes, but also because of the functional recognition they receive from local communities. Their continued presence is frequently linked to the provision of essential ecosystem services, including shade and fodder for livestock, thermal regulation, soil moisture retention, firewood, wild fruits, and other locally used resources (Barbosa & Villagra, 2015; De la Barrera *et al*., 2019). In areas inhabited by Indigenous or rural communities, such fragments may also possess sociocultural value, becoming integral to traditional livelihoods and knowledge systems (Pilquimán, 2016). The active involvement of territorial actors—such as neighbourhood councils, farmers' associations, and Mapuche communities—enhances the legitimacy and long-term viability of conservation strategies (Sullivan, 2011).

One such remnant is the native forest preserved on Konün Wenu Hill, in the La Araucanía Region. This site stands out for its floristic richness and longstanding cultural significance to local Mapuche communities, who have recognised it as a sacred space—altu mapu—traditionally used for ceremonial, productive, and spiritual purposes (Flores, 2014; Díaz de Araneda, 2022). However, territorial transformation, urban expansion, and the erosion of customary access have weakened these ties in recent decades. In contrast to nearby Ñielol Hill—situated north of Temuco (38°44' S) and protected since 1939 (Anon., 2008) —Konün Wenu lacks formal conservation status despite its strategic location as an "insular hill" within an urban–rural mosaic (Picon *et al*., 2023). Its topographic and microclimatic features suggest notable ecological potential, both in terms of supporting native plant diversity and enhancing regional ecological structure. Against the backdrop of renewed territorial recognition and preliminary evidence of its biological richness, local stakeholders have shown increasing interest in its protection and sustainable management.

This study aimed to characterise the vascular flora of the native forest remnant on Konün Wenu Hill and to evaluate the floristic contribution of the surrounding grasslands, pine plantations and local road. We posed three descriptive research questions: (i) What are the species richness and taxonomic composition of the remnant forest flora? (ii) How do the adjacent habitats contribute to the site's overall diversity, particularly with respect to endemic and introduced species? (iii) Which plant families and growth forms dominate the whole assemblage and each habitat type?

To address these questions, we combined straightforward descriptive metrics (species counts and taxonomic/life-form spectra) with a presence–absence Jaccard similarity analysis to compare community composition among habitat types. The ultimate goal was to establish an ecological baseline to inform conservation, restoration, and territorial planning initiatives, while also contributing to the revitalisation of biocultural relationships between the local community and this forest fragment.

Material and Methods

Study area

Konün Wenu Hill (from Mapudungun Konün Wenu, meaning "gateway to the sky" or "entrance to the cosmos") is located in the municipality of Padre Las Casas, La Araucanía Region, Chile (38°46' S, 72°38' W). It forms part of a low-altitude mountain chain that traverses the Central Valley and extends eastward towards the Andes (Figure 1). Soils are granular, with high clay content and localised rocky outcrops of the underlying substrate (Anon., 1997).

The hill reaches an elevation of 345 m asl and is bordered to the south by the city of Temuco, to the west by the urban centre of Padre Las Casas, and to the north and east by agricultural lands and Mapuche communities. Its immediate surroundings comprise a fragmented landscape matrix dominated by smallholdings, croplands, scattered dwellings, and forestry plantations (Figure 1).

The climate is temperate and humid with Mediterranean influence. Mean annual precipitation is approximately 1,325 mm, falling predominantly between March and November, with a marked dry season in summer (December to February). The mean annual temperature is 12 °C, with average monthly maxima reaching 25.3 °C in the warmest month and minima dropping to 4.1 °C in the coldest (Luebert & Pliscoff, 2006).

Native vegetation has been almost entirely removed from the hill, with only a few small forest remnants persisting. This study focused on a ca. 10 ha remnant located on the southern slope. Despite showing signs of structural degradation, the fragment retains a recognizable forest architecture and a species composition characteristic of temperate deciduous forest and sclerophyllous shrubland. Representative tree species include *Nothofagus obliqua* (Mirb.) Oerst., *Eucryphia cordifolia* Cav., and *Cryptocarya alba* (Molina) Looser, accompanied by a diverse understory of shrubs, herbs, ferns, epiphytes, and climbing plants. For the purposes of sampling design, the grasslands bordering the forest were divided into four sectors (grasslands 1–4), according to their naturally distinct spatial distribution within the study area. In addition, only the smallest forestry plantation, located to the northwest of the site, was surveyed.

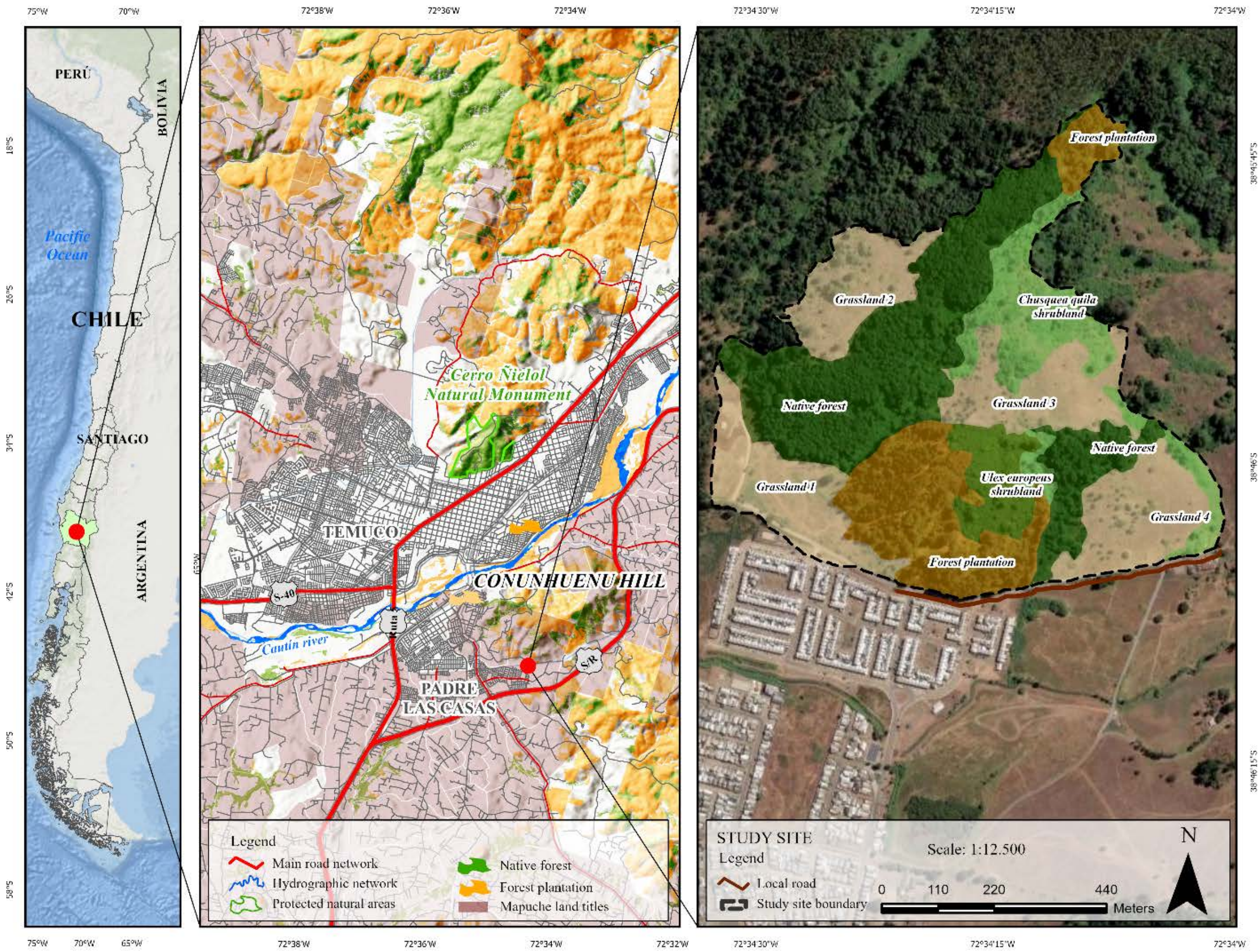

Figure 1. Study area on Konün Wenu Hill, Temuco Municipality, La Araucanía Region, Chile.

Sampling

A floristic inventory was conducted using a targeted, preferential sampling strategy designed to capture the widest possible range of microhabitats and to detect species with localised distributions or low frequency (Diekmann *et al.*, 2007; Croft & Chow-Fraser, 2009). Prior to fieldwork, satellite imagery (Google Earth) was reviewed to estimate the distribution of the main vegetation/land cover types in the vicinity of the fragment, distinguishing sectors dominated by grassland and shrubland; this preliminary analysis guided access routes towards areas expected to exhibit greater floristic richness.

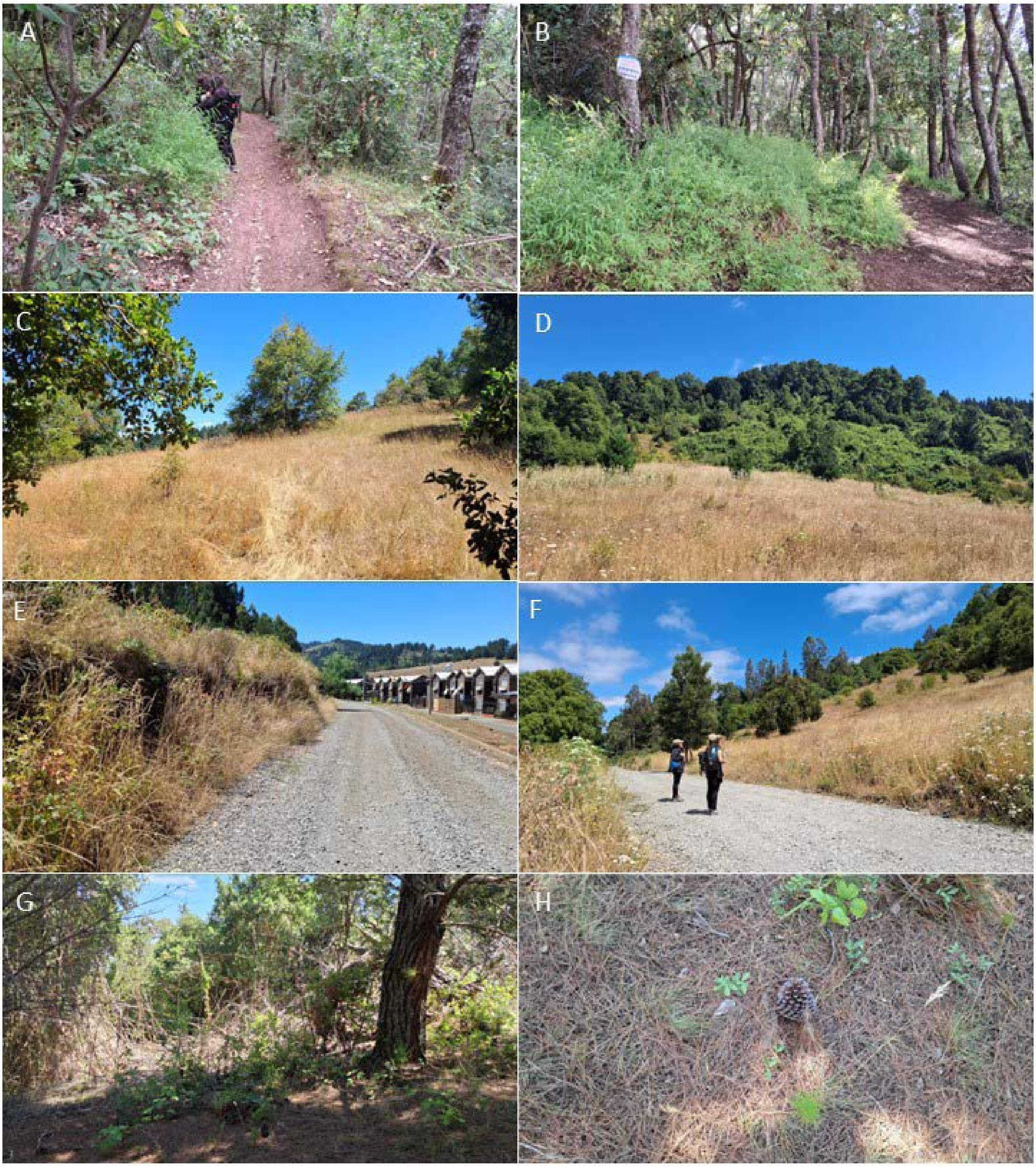

Figure 2. Representative habitat types surveyed on Konün Wenu Hill. A–B, Interior of the native forest fragment, where *Nothofagus obliqua* dominates in certain areas. The trees exhibit a juvenile structure, with small-diameter stems consistent with a secondary forest origin. The understorey forms a dense thicket of *Chusquea quila*. C–D, Grassland sectors 2 and 3 at the end of the dry season, both dominated by exotic Poaceae. In D, the white dots visible in the foreground—corresponding to grassland sector 4—are the inflorescences of *Achillea millefolium*, while the lighter green patches in the background indicate regrowth of *Chusquea quila*. E–F, Margin of the local gravel road with ruderal vegetation: *Dactylis glomerata* and *Rubus praecox* are prominent on the cut slopes (E), while *A. millefolium* dominates the verge in F, accompanied by annual Poaceae. G–H, *Pinus radiata* plantation, showing a sparse native shrub layer with undetermined *Rubus* spp. (G), and a thick litter layer formed by pine needles (H), where seedlings of *Maytenus boaria* emerge among the duff.

Fieldwork was carried out over six separate days between January and September 2025, with approximately 6 hours of survey effort per day. To maximise spatial coverage, existing footpaths were followed and treated as linear transects for systematic survey, supplemented by off-trail inspections wherever feasible, including detailed examination of forest edges and microsites surrounding isolated trees in the grassland.

During sampling, field notes and photographic records were taken and subsequently systematised in the laboratory. As part of a collaborative approach, local residents who regularly visit the hill were invited to contribute photographs of plants taken in situ. These images were examined and, where appropriate, the depicted species were subsequently verified in the field. This integration of citizen science provided valuable complementary

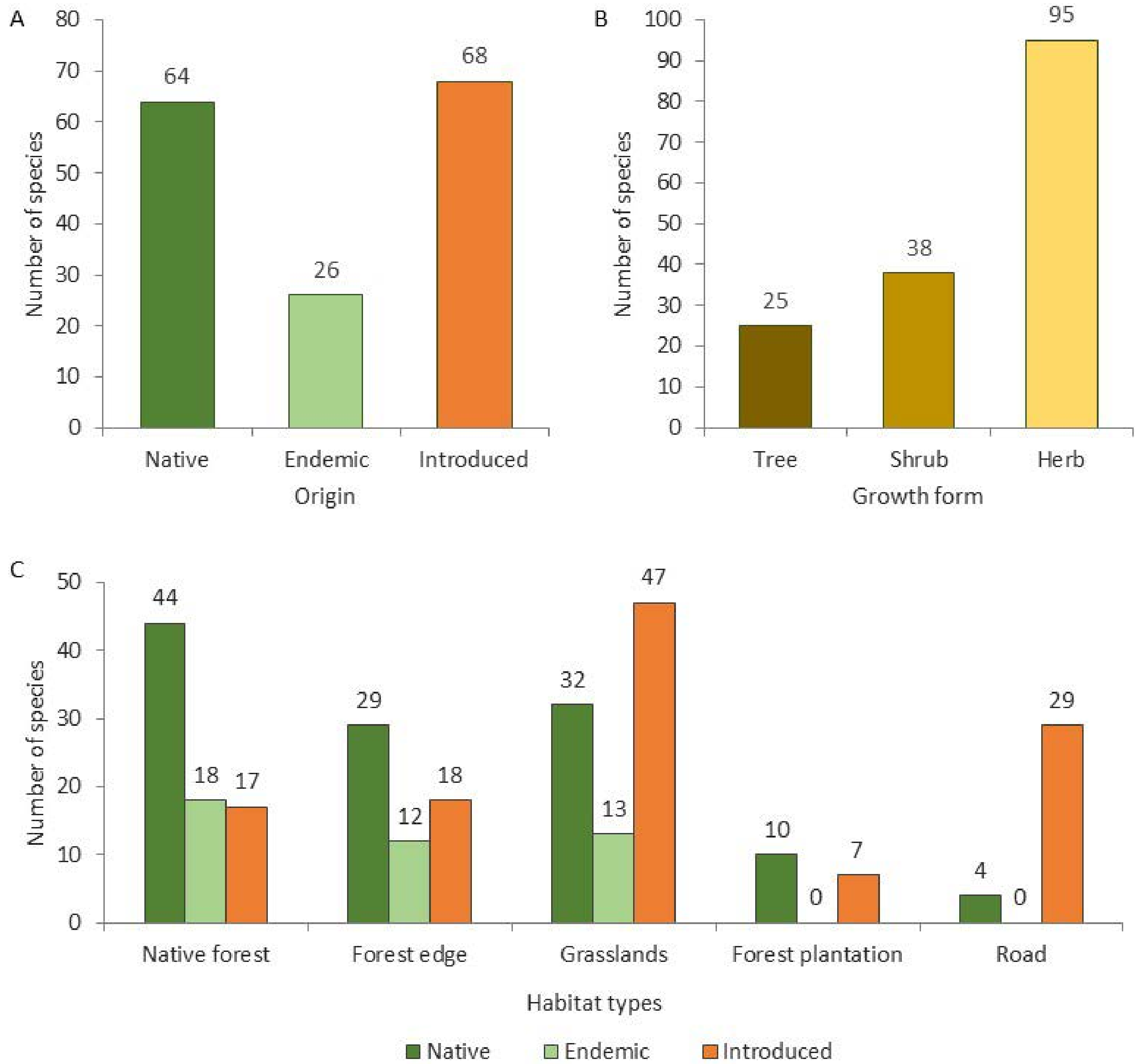

Figure 3. Number of vascular plant species recorded on Konün Wenu Hill. A, Number of native, endemic, and introduced species recorded across the entire study area. "Native" refers to taxa occurring within their natural geographic range; "Endemic" includes species restricted to Chile; and "Introduced" designates species occurring outside their native range as a result of human activity. B, Growth forms grouped as trees, shrubs, and herbs. C, Distribution of native, endemic, and introduced species across the five habitat types defined in the study. The same colour scheme is applied to origin categories in panels A and C.

data and is aligned with best practice in local biodiversity research (Aceves-Bueno *et al*., 2015).

In the field, we recorded species identity, constancy (qualitatively estimated using a four-point scale: very frequent, frequent, occasional, scarce), and habitat type (native forest, forest edge, grassland sectors 1–4, forestry plantation, or local road; Figure 2). These estimates were based on the observer's perception and supported by photographic evidence. No herbarium voucher specimens were collected during the survey.

Species identification was based on macroscopic morphological characters observed in the field and verified using standard Chilean floristic literature, including all published volumes of the Flora de Chile (Marticorena & Rodríguez, 1995–2011), the recent monograph on *Carex* by Muñoz-Schüler *et al*. (2023), and other specialised works such as Puntieri & Chiapella (2019) for introduced Fabaceae, as well as complementary references for specific groups, including Finot *et al*. (2022) for *Poa* (Poaceae), Finot *et al*. (2018) for *Alstroemeria* (Alstroemeriaceae), and Katinas *et al*. (1992) for *Triptilion* (Asteraceae). In cases where identification could not be confirmed with certainty—due to the absence of diagnostic characters or close resemblance to congeners—the abbreviation cf. was placed before the specific epithet to indicate a provisional determination. Such cases are explicitly indicated in Supplementary Table S1.

We also collected information about further species attributes, including biogeographic origin (native, introduced, or endemic), conservation status (MMA, 2024), and national distribution. Species nomenclature, biogeographic origin, and distribution were primarily based on Rodríguez *et al*. (2018), which served as the main taxonomic framework for this study. For taxa not included in that source (e.g., *Linum bienne* Mill.), we consulted the online catalogue of Chilean vascular flora (catalogoplantas.

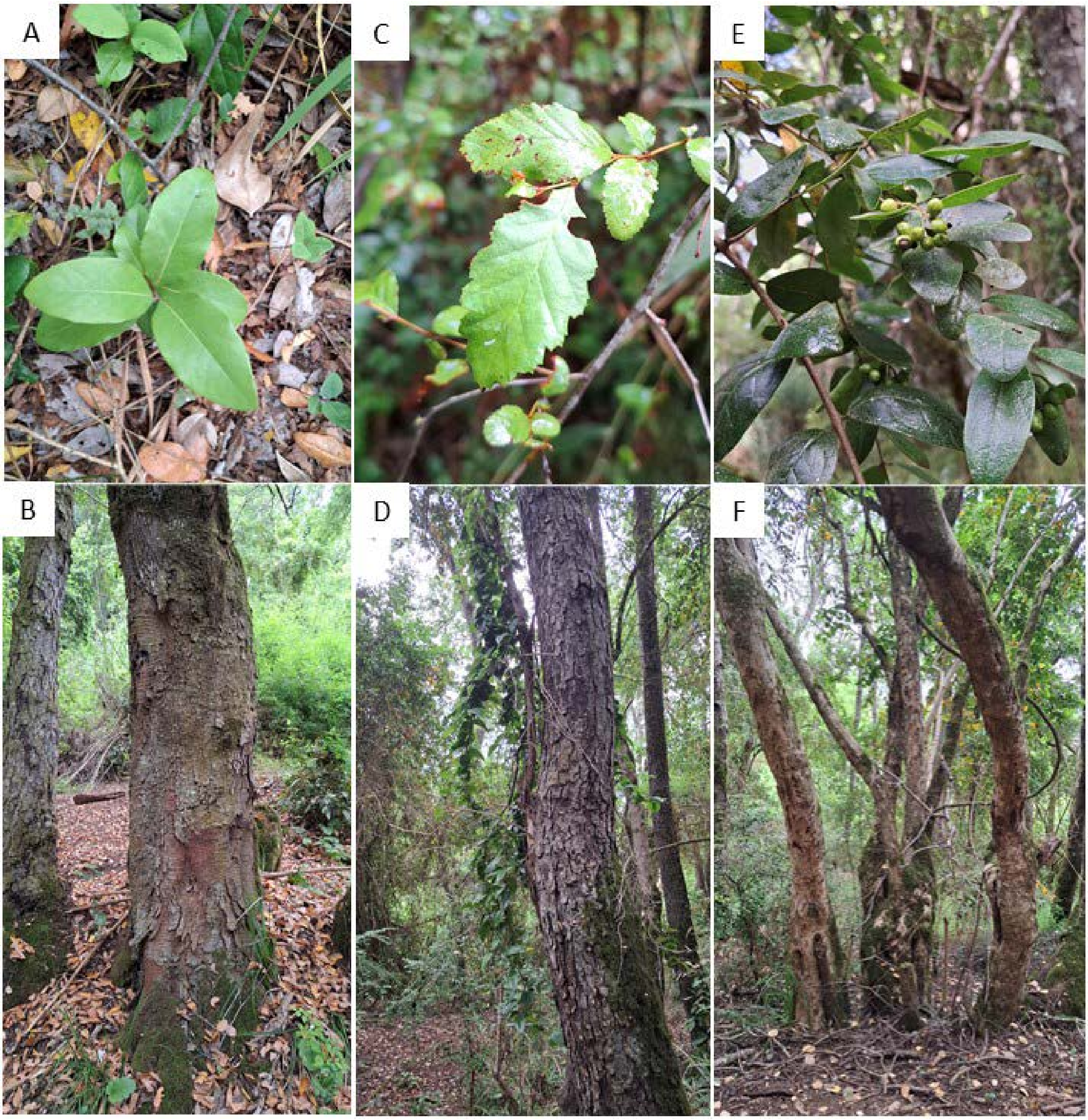

Figure 4. Morphological features of common tree species recorded in the study area. Each pair of images shows a leaf (above) and trunk (below) of the same individual. A-B, *Cryptocarya alba* (Lauraceae): evergreen tree with entire, ovate leaves displaying variable degrees of sclerophylly; when crushed, the leaves emit a distinctive and pleasant aroma. The trunk exhibits a smooth to slightly fissured bark in mature individuals; the photograph shows partial bark peeling near the base. C-D, *Nothofagus obliqua* (Nothofagaceae): deciduous tree with lanceolate to ovate leaves, characterized by a prominently double-serrated margin. The bark is thick and deeply fissured; in the image, the climbing species *Lapageria rosea* is visible on a decaying branch to the left of the trunk. E-F, *Peumus boldus* (Monimiaceae): evergreen tree with oblong to ovate, coriaceous leaves, rough to the touch and highly aromatic, with prominent venation. The photograph shows immature green drupes, which are edible when ripe. The trunk has pale, rough bark with small, darker patches that tend to exfoliate in older individuals.

udec.cl). In exceptional cases (e.g., *Malus domestica* (Suckow) Borkh.), we relied on IPNI for nomenclatural validation.

Floristic similarity analysis

A binary species-by-habitat matrix (presence = 1, absence = 0) was constructed for the five habitat types. Pairwise floristic similarities were calculated in PRIMER v7 (Clarke & Gorley, 2015) using the Jaccard coefficient, which excludes joint absences and is suitable for incidence-based data. Hierarchical agglomerative clustering was subsequently applied using the unweighted pair-group method with arithmetic mean (UPGMA), in order to visualise broad floristic affinities among habitats. Given that each habitat type was represented by a single exhaustive sampling unit, the analysis was exploratory and intended to illustrate general compositional relationships, rather than to test statistically significant differences between groups, which would require within-group replication.

Cluster support was evaluated using the Similarity Profile (SIMPROF) test, which permutes species incidence vectors within each putative cluster to generate a null distribution of similarity profiles. The null hypothesis (H_0) stated that the internal similarity

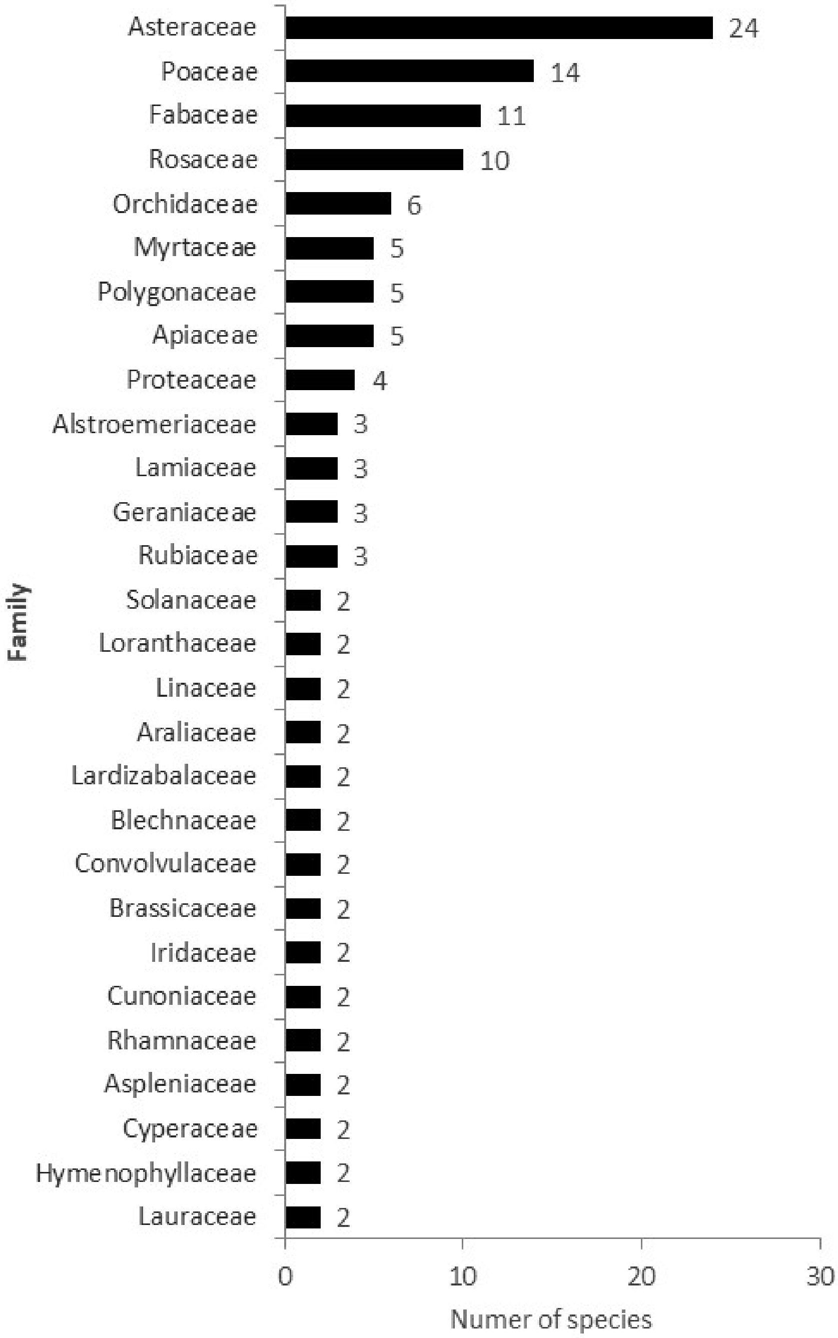

Figure 5. Number of species per botanical family recorded on Konün Wenu Hill. Only families containing at least two species are shown; for the remainder, see Supplementary Table S1.

of a cluster does not differ from that expected under random allocation of species across its samples. Statistical significance was assessed using 10,000 permutations and an $\alpha = 0.05$ threshold. Clusters were considered supported when their observed internal similarity exceeded that expected under the null distribution.

Results

Species richness and floristic composition

Konün Wenu Hill supports a vascular flora comprising 158 species across 61 families and 132 genera. Of these, 64 are native –including 26 endemics to Chile– and 68 introduced. The species are distributed among five habitat types within the study area–native forest, grasslands, forest edge, local road margins, and exotic plantations. Native and endemic taxa are most strongly represented in the native-forest fragment, whereas introduced species are more common in open habitats such as grasslands, edges, and road verges (Figure 3A).

In terms of growth form, herbs were the most numerous (95 spp.), followed by shrubs (38 spp.) and trees (25 spp.) (Figure 3B). Among the shrubs, less frequent life forms were also recorded, including the hemiparasites *Notanthera heterophylla* (Ruiz & Pav.) G. Don and *Tristerix corymbosus* (L.) Kuijt (Loranthaceae); climbing shrubs such as *Luzuriaga radicans* Ruiz & Pav. and *Lardizabala biternata* Ruiz & Pav. (Lardizabalaceae); and the epiphyte

Figure 6. A selection of Chilean endemic flora recorded in the study area. A, *Alstroemeria aurea* (Alstroemeriaceae): perennial geophyte with resupinate leaves and brightly colored zygomorphic flowers; the image shows individuals with vivid orange tepals and reddish nectar guides in open grassland. B, *Chloraea gavilu* (Orchidaceae): terrestrial orchid with predominantly yellow flowers and green venation, and a prominent column; the image captures a close-up of the labellum and internal floral structures. C, *Francoa appendiculata* (Francoaceae): perennial herb with reniform leaves arranged in basal rosettes; shown here growing along a shaded forest trail with compound racemose inflorescences. D, *Gardoquia multiflora* (Lamiaceae): shrub classified as Near Threatened in Chile, with magenta tubular flowers; photographed in the interior of the native forest. E, *Rhamnus diffusus* (Rhamnaceae): shrub commonly found in semi-shaded areas of native forest, with alternate ovate leaves and mature black berries, each typically containing three pyrenes; a single ripe fruit is visible. F, *Sarmienta scandens* (Gesneriaceae): epiphytic shrub with fleshy leaves and pendent red tubular flowers; the image shows a flowering individual growing on the trunk of *Peumus boldus*. G, *Triptilion spinosum* (Asteraceae): perennial herb with dissected, spiny leaves and bluish-violet flowers arranged radially around a central tuft of white florets; the image highlights two solitary capitula with a woolly and spiny involucre.

Sarmienta scandens (J.D. Brandis ex Molina) Pers. (Gesneriaceae) (see Supplementary Table S1).

With respect to habitat, grasslands harboured the highest number of species (92 spp.), followed by the native forest fragment (79 spp.), forest edge (59 spp.), road margins (33 spp.), and Pinus radiata plantations (17 spp.) (Figure 3C). The native forest hosted 44 native and 18 endemic species, while grasslands supported 32 native and 13 endemic taxa. Introduced species were most frequent in grasslands (47 spp.) and along roadsides (29 spp.), but also present in all other habitats. Notably, endemic taxa were absent from plantations and road verges. The high species count observed in grasslands was partly attributable to the inclusion of microhabitats around isolated remnant trees, such as *Laurelia sempervirens* (Ruiz & Pav.) Tul.

The forest canopy featured characteristic trees of the Mediterranean–temperate transitional zone, such as *Cryptocarya alba* (Lauraceae), *Nothofagus obliqua* (Nothofagaceae), and *Peumus boldus* Molina (Monimiaceae) (Figure 4). The understorey hosted transition-zone herbs including *Alstroemeria aurea* Graham and *Bomarea salsilla* (L.) Mirb. (Alstroemeriaceae), while scattered large individuals of *Laurelia sempervirens*, *P. boldus*, and *N. obliqua* were also recorded in grassland patches.

At the family level, Asteraceae was the most diverse group, comprising 24 species (15% of the total), of which 10 were native. It was followed by Poaceae (14 spp.) and Fabaceae (11 spp.), and Rosaceae (10 spp.). Poaceae and Rosaceae included three native species each, whereas Fabaceae was composed exclusively of 11 introduced species (Figure 5). At the class level, Magnoliopsida was dominant (115 spp., 72%), followed by Liliopsida (32 spp., 20%), Polypodiopsida (8 spp., 5%), and Pinopsida, represented solely by P. radiata D. Don (Pinaceae) (see Supplementary Table S1).

Several species showed pronounced habitat specificity, occurring in only one environment. In the native forest, humid microsites supported the forest-floor herb *Arachnitis uniflora* Phil. (Corsiaceae), the epiphytic fern *Asplenium dareoides* Desv. (Aspleniaceae), and the climber *Elytropus chilensis* (A. DC.) Müll. Arg. (Apocynaceae) was also restricted to this environment. The forest edge, in turn, hosted occasional or scarce taxa not observed elsewhere, including *Baccharis magellanica* (Lam.) Pers. (Asteraceae), *Gaultheria phillyreifolia* (Pers.) Sleumer (Ericaceae), and the hemiparasite *Notanthera heterophylla* (Loranthaceae), *parasitising Peumus boldus*. Notably, several species—including *Alstroemeria aurea*, *Blechnum microphyllum* (Goldm.) C.V. Morton, and *Raukaua valdiviensis* (Gay) Frodin—were recorded only once or in very localised groups, further underscoring the patchy and spatially restricted nature of some occurrences.

Open grasslands were characterised by typical heliophilous species such as *Baccharis racemosa* (Ruiz & Pav.) DC. (Asteraceae), *Cliococca selaginoides* (Hook. & Arn.) A. DC. (Linaceae), and the introduced grasses *Holcus lanatus* L. and *Briza maxima* L. Native orchids of the genus *Chloraea* were particularly abundant in sector 2. By contrast, sector 4 comprised a south-facing grassland with scattered trees and locally elevated soil moisture. In addition to the open-habitat herbs, several forest-affiliated species were present in shaded microsites beneath isolated trees. Noteworthy among them were *Francoa appendiculata*, also recorded in the forest interior, and *Myrceugenia obtusa* (DC.) O. Berg, which occurred only sparsely both in the forest and in these sheltered grassland sites. In the same grassland (sector 4), *Myrceugenia planipes* (Hook. & Arn.) O. Berg and *Blepharocalyx cruckshanksii* (Hook. & Arn.) Nied. were found in a small wet zone near a natural spring at the edge of the forest.

The *Pinus radiata* plantation supported the poorest flora among the five habitats, hosting fewer species than even the local road verge. Of these, only the introduced climber *Hedera helix* L. (Araliaceae) was exclusive to this habitat.

Across the five habitat types, 26 species endemic to Chile were documented (Figure 6), underscoring the site's value as a refuge for narrowly distributed native flora.

According to Chile's official Red List framework (MMA, 2024), three species recorded in this study currently hold a recognised conservation status: *Citronella mucronata* (Cardiopteridaceae) and *Asplenium trilobum* (Aspleniaceae) are listed as Vulnerable (VU), *while Gardoquia multiflora* (Lamiaceae) is classified as Near Threatened (NT). Additionally, six taxa are listed as Least Concern (LC): *Aextoxicon punctatum* (Aextoxicaceae), *Adiantum chilense* (Pteridaceae), *Asplenium dareoides* (Aspleniaceae), *Hymenophyllum dentatum* and *H. plicatum* (Hymenophyllaceae), and *Persea lingue* (Lauraceae). The remaining 81 native and endemic species documented here have not yet been formally evaluated under the national system (see Supplementary Table S1).

Finally, several signs of human disturbance were recorded. Within the forest, evidence included culm harvesting of *Chusquea culeou* E. Desv., a past illegal felling of an adult *Persea lingue* (>50 cm dbh), trampling, bark incisions, litter accumulation, and the presence of domestic dogs. In adjacent areas, recurrent fire damage was noted in shrubland dominated by *Ulex europaeus* L. (Fabaceae) and in *P. radiata* plantations.

Floristic similarity among habitats

Pairwise floristic similarities among habitat types were generally low (ca. 9 to 30%). The highest values were observed among forest, forest edge, and grassland, all around 30%, indicating that even the closest habitats shared only about one third of their species.

Hierarchical clustering based on these similarities (UPGMA) mirrored this pattern (Figure 7). SIMPROF testing (10,000 permutations, α = 0.05) identified two supported branches: (i) local road, which was statistically distinct from all other habitats, and (ii) within the remaining group, forestry plantation, which differed significantly from the assemblage of forest, edge and grassland. Subdivisions within this assemblage lacked statistical support and therefore cannot be considered independent floristic units. Taken together, these results indicate that both local road and forestry plantation maintain floristic compositions that are statistically distinct —and comparatively species-poor—not only from the group formed by forest, edge and grassland, but also from each other.

Notably, although forestry plantation and edge shared a relatively high similarity (25%), they did not form a significant cluster, suggesting that compositional overlap alone does not imply floristic coherence.

Overall, the dendrogram depicts a simplified structure, with local road standing apart, forestry plantation separating from the rest, and inter-habitat similarity remaining consistently low (< 30%).

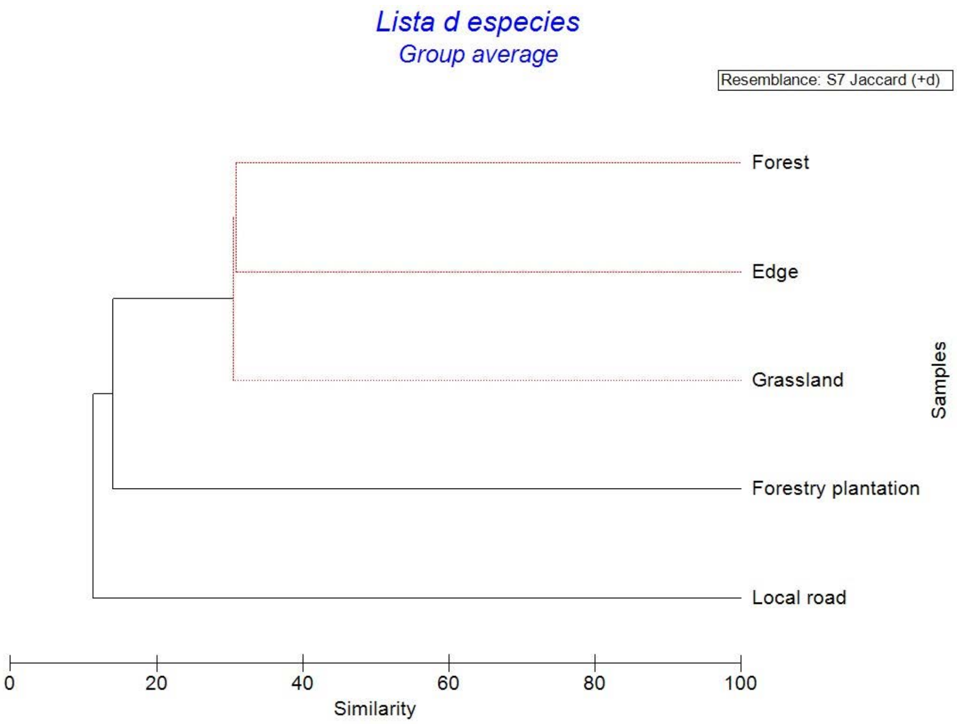

Figure 7. Hierarchical clustering (UPGMA) based on Jaccard similarity calculated from a species presence–absence matrix. Black lines denote clusters with significant support from the SIMPROF test (10,000 permutations, α = 0.05), while red dotted lines indicate unsupported substructure. Two main branches are distinguished: (i) local road, which was statistically distinct from all other habitats, and (ii) forestry plantation, which also separated significantly from the assemblage of forest, edge and grassland. Thus, both local road and forestry plantation maintained floristic compositions that were statistically distinct, not only from that assemblage but also from each other. The horizontal axis represents floristic similarity (%) between habitats.

Discussion

Floristic richness of Konün Wenu Hill

Konün Wenu Hill—a ten-hectare remnant located in the Mediterranean–temperate transition of south-central Chile—harbours 158 vascular plant species: 64 native (including 26 endemic to Chile) and 68 introduced. This level of α-diversity is remarkable for such a small fragment and also reflects a high diversity of microhabitats within the site.

While ideally one would compare forest fragments of similar structure, successional stage, disturbance history, and other standard biometric variables, such alignment is rarely attainable in practice. In this context, three inventories are directly comparable in scale and method: Cerro Ñielol Natural Monument (89.5 ha), with 136 native and 101 introduced species (Hauenstein *et al.*, 1988); Rucamanque estate (438 ha), with 147 native and 43 introduced (Ramírez *et al.*, 1989); and the Hualpén Terrestrial Biology Station (70 ha), which supports 124 native and 170 introduced species (Moreno-Chacón *et al.*, 2018) – see Supplementary Table S2. Expressed as native species per unit area, Konün Wenu reaches 9 native spp ha-^{1}, far exceeding Hualpén (1.77), Ñielol (1.52), and Rucamanque (0.34).

The proportion of introduced species is the same at Konün Wenu and Ñielol (43%), lower than the 57% observed at Hualpén, and nearly twice the 23% recorded at Rucamanque. These differences appear consistent with variations in site accessibility, proximity to urban areas, and intensity of recreational use (González-Moreno *et al.*, 2013).

Similar patterns are observed at the regional scale in temperate forest systems. In pre-Andean *Nothofagus* fragments in La Araucanía (12–29.6 ha), a total of 110 vascular species have been reported (89 native, 65 woody; Rojas *et al.*, 2011); Konün Wenu alone supports nearly the same native richness (n = 90) and almost the same number of woody taxa (n = 63). In the Los Riscos sector on the coast of Purranque (1.6–55 ha), only 11 to 13 woody species have been recorded (Pincheira-Ulbrich *et al.*, 2008; 2012). As these particular studies focused primarily on lianas, epiphytes, and their host trees, their figures are included here merely as a conservative reference. Farther south, on Chiloé Island, 51 evergreen rainforest fragments (0.1–10,000 ha) collectively harbour 46 woody species (Echeverría *et al.*, 2007), whereas Konün Wenu alone harbours 63, nearly 1.4 times the number of woody species.

At the gamma-diversity scale, Konün Wenu remains ecologically relevant. Along the coastal range between Valdivia, Osorno, and Llanquihue, 158 woody species have been documented (Smith-Ramírez *et al.*, 2005), while three reserves of coastal sclerophyll forest in the Maule Region hold 196 species (Arroyo *et al.*, 2005). The 63 native woody species at Konün Wenu thus represent approximately 40% and 32% of those respective regional pools.

To provide climatic analogues beyond South America, two well-documented European inventories were selected. In central Italy, 18 peri-urban deciduous forest fragments (3–278 ha) collectively support 146 vascular species, though each fragment averages only 20–26 species (Rosati *et al.*, 2010). In Spain's Guadalquivir Valley, 237

Mediterranean relics (0.3–752 ha) contain a total of 143 woody species (Aparicio *et al*., 2008). At the regional scale, the native vascular flora of Konün Wenu represents about 62% of that reported for Italy and nearly 44% of the woody flora documented for Spain. While structurally distinct, these European cases reinforce the ecological importance of small forest remnants in Mediterranean-type ecosystems.

Overall, the evidence suggests that area alone—though a useful comparative reference—is insufficient to fully explain the floristic richness observed. The high species density at Konün Wenu may be partly attributable to its transitional location, which favours the coexistence of lineages with contrasting biogeographic affinities (Kark, 2013), and to the residual presence of a mature canopy and marked microtopographic heterogeneity. The latter is exemplified by grasslands with depressions and gentle slopes, where isolated trees create sheltered conditions that support species more typical of forest environments. Moreover, the co-occurrence of *Nothofagus obliqua* with laurophyllous taxa of Valdivian affinity and sclerophyllous evergreen species of Mediterranean origin is consistent with successional pathways documented for the Central Valley of La Araucanía, where disturbance-driven dominance of *N. obliqua* tends over time to shift towards laurophyllous assemblages (Frank & Finckh, 1999).

Possibly, the interaction of historical land use, matrix quality, and fine-scale habitat diversity (Saunders *et al*., 1991; Fahrig, 2017) underpins the elevated α-diversity observed.

Although comparable inventories remain scarce, the available evidence positions Konün Wenu Hill as a key reservoir of native and endemic biodiversity within the Mediterranean–temperate transition zone of Chile. Expanding standardised floristic surveys across the region will refine site comparisons and strengthen conservation priorities.

Conservation considerations for the forest

Konün Wenu Hill warrants high-priority conservation attention due to the multiple pressures currently threatening its ecological integrity. SIMPROF analysis showed that Forest, edge and Grassland did not differ significantly from each other, yet together they harbour a high proportion of native and endemic species, reinforcing their value as a conservation focus. In contrast, both local road and forestry plantation supported statistically distinct and comparatively species-poor floristic compositions, underscoring the influence of matrix elements in shaping plant assemblages and highlighting the need to consider them as differentiated conservation targets rather than as a uniform background. Chief among the current pressures is urban–rural expansion, which reduces the fragment's connectivity with surrounding natural systems and heightens its exposure to edge effects (Fernández *et al*., 2019; Picon *et al*., 2023). Additional pressures include the proliferation of informal footpaths, the accumulation of solid waste, and direct understorey disturbance—such as the harvesting of *Chusquea culeou* culms—all of which contribute to soil compaction, alter vertical structure, and facilitate the spread of invasive alien species such as *Rubus praecox* and *Ulex europaeus*.

These processes may gradually erode microclimatic heterogeneity—that is, the fine-scale spatial variation in temperature and humidity characteristic of closed-canopy forest interiors. As this heterogeneity declines, so does the understorey's capacity to buffer climatic extremes, ultimately constraining the regeneration of native flora (Greiser *et al*., 2024; Csölleová *et al*., 2024).

Within this framework, forest remnants such as Konün Wenu gain strategic relevance as climatic microrefugia, sustaining cooler, moister microenvironments than the surrounding anthropogenic matrix. This thermal buffering effect favours organisms sensitive to desiccation or elevated temperatures—including epiphytes, ferns, and slow-regenerating seedlings—and may enhance ecological resilience by offering temporally stable, spatially discrete refuges for species adaptation or persistence under climate change scenarios (Kemppinen *et al*., 2024).

Beyond the forest core, isolated trees scattered throughout the surrounding grasslands (Grasslands 1–4) function as structural legacies and microrefugia, maintaining cooler, shaded, and litter-rich microsites that replicate essential forest-floor conditions. These trees supported the presence of forest- or shrubland-affiliated species, including *Francoa appendiculata* and *Blechnum hastatum* Kaulf. —both also found within the forest interior—. In addition to their buffering role, these remnant trees act as stepping stones across the open matrix, facilitating the dispersal and establishment of forest elements within a fragmented landscape. Conservation strategies should thus prioritise the retention of such legacy trees and the enrichment of their microsites with native understory species, to expand woodland influence and promote biotic continuity under ongoing environmental change.

Ecological restoration aimed at enhancing structural complexity and microclimatic heterogeneity has been proposed as an effective strategy to strengthen the resilience of forest remnants (Lindenmayer, 2019). Interventions such as the selective planting of native woody species—e.g., *Nothofagus obliqua* or *Eucryphia cordifolia*—together with the retention of coarse woody debris and organic litter, can foster the development of stable microsites that buffer against heatwaves and prolonged droughts (González *et al*., 2015). In degraded sectors, establishing exclusion zones or assisted recovery areas is essential to reduce ongoing disturbance and promote natural regeneration processes (Gómez-Fernández *et al*., 2023).

As noted in territories characterised by high ecological complexity and limited institutional coordination (Valdivia-Orrego & Peña-Cortés, 2024), the effective conservation of forest fragments such as Konün Wenu requires management strategies grounded at the local scale. Participatory frameworks involving municipal authorities, Mapuche communities, universities, and civil society organisations are essential for legitimising and sustaining long-term conservation efforts. Such platforms not only help define shared priorities and secure funding, but also enable the integration of technical expertise with situated territorial knowledge.

In this regard, citizen-science initiatives (Aceves-Bueno *et al*., 2015)—supported by digital tools and environmental volunteer brigades—could contribute to the monitoring of key variables such as phenological events, the emergence of invasive species, or microclimatic trends, thereby generating data that support adaptive management strategies.

Conclusions

Konün Wenu Hill harbours a structurally complex and diverse vascular flora, with 158 species belonging to 61 families and 132 genera. Of these, 90 are native, including 26 endemics to Chile, and 68 are introduced, distributed across habitats such as native forest, grasslands, and forest edges. This constitutes remarkable richness for a 10-hectare site, underscoring the role of Konün Wenu as a biodiversity reservoir within a fragmented urban–rural matrix.

Floristic composition varied markedly among habitats, with similarity values ranging from 9% to 30% and several exclusive species reinforcing this heterogeneity. Native taxa were concentrated mainly in the forest and, to a lesser extent, in grasslands. Exclusive elements were found in both environments: species such as *Arachnitis uniflora* (Corsiaceae) and *Asplenium dareoides* (Aspleniaceae) were restricted to humid forest microsites, while grasslands supported distinctive taxa including *Cliococca selaginoides* (Linaceae), *Baccharis racemosa* (Asteraceae), and native orchids. In grasslands, shaded microsites beneath isolated trees hosted additional taxa associated with forest and shrubland, such as *Francoa appendiculata* (Francoaceae) and *Myrceugenia obtusa* (Myrtaceae), both also occurring in the forest interior.

Multivariate analyses refined this picture. Hierarchical clustering (UPGMA) and SIMPROF testing (10,000 permutations, α = 0.05) detected significant differences only between local road and Forestry Plantation—both floristically distinct and comparatively species-poor when contrasted with the other habitats. In contrast, Forest, Forest Edge, and Grassland did not differ significantly at the community level, which highlights their importance for conservation.

The assemblage also encompassed a broad range of growth forms, from dominant herbs, shrubs, and trees to less frequent functional groups such as epiphytes, climbers, and hemiparasites. This structural and functional diversity reflects pronounced microenvironmental heterogeneity, suggesting that Konün Wenu operates as a local climatic microrefugium for species sensitive to desiccation and warming.

Three species recorded at Konün Wenu are recognised in Chile's official Red List: *Citronella mucronata* (Cardiopteridaceae) and *Asplenium trilobum* (Aspleniaceae) as Vulnerable, and *Gardoquia multiflora* (Lamiaceae) as Near Threatened. However, ongoing degradation—including culm extraction, illegal felling, dumping, trampling, invasive species (*Ulex europaeus*, *Hedera helix*), and recent wildfires in adjacent areas—threatens the persistence of these and other native taxa, compromising the ecological functionality of Konün Wenu under increasing urban encroachment.

In this context, Konün Wenu emerges as a forest relict of both ecological and biocultural significance. Its role in sustaining native flora, enhancing ecological connectivity, and preserving cultural heritage—as a traditional Mapuche ceremonial site—justifies its incorporation into territorial planning. Safeguarding key microhabitats, advancing ecological restoration, and fostering participatory governance are therefore essential to promote integrated, multiscalar management. Ultimately, Konün Wenu exemplifies the conservation value of small forest remnants in fragmented landscapes.

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Authorship

J.P.-U.: Conceptualization, Methodology, Field investigation, Data curation, Formal analysis, Writing – original draft, Writing – review and editing. Lead author, responsible for overall study design, taxonomic identifications, and manuscript preparation; D.A.: Methodology, Discussion, Writing – review and editing. Contributed to study design and interpretation of results; J.B.: Field investigation, Community engagement, Writing – review and editing. Contributed contextual information and community collaboration during fieldwork; G.A.: Field investigation, Resources (local knowledge), Validation, Writing – review and editing. Provided local insights supporting data interpretation and contextual understanding.

Conflicts of interest

None.

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Supplementary Material

Appendix S1. Floristic list of vascular plant species recorded at Konün Wenu Hill, including taxonomic, ecological, and distributional attributes.

Appendix S2. Summary of vascular plant richness in selected native forest fragments of south-central Chile.