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*Article*

# Red listing the flora of the Green Islands reveals high extinction risk in the Azores

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## Abstract

Oceanic islands are global biodiversity hotspots, yet they face disproportionate risks of species extinction. The Azores archipelago holds a unique flora composed of 94 endemic vascular plant taxa (species and subspecies) that are strictly endemic to the Azores, which represents about 32% of the native vascular flora. Here, we present the first comprehensive IUCN Red List assessment of the Azorean endemic vascular flora, based on more than 10,600 curated occurrence records, herbaria specimens, and recent field surveys. We found that nearly 60% of assessed taxa are threatened with extinction, Endangered being the most frequent IUCN category. Two species are confirmed Extinct, and 12 taxa remain Data Deficient due to unresolved taxonomy. The Red List Index (RLI) for Azorean endemics was calculated at 0.602, indicating a concerning level of extinction risk and, importantly, providing a reference point for monitoring future changes in conservation status. Spatial analysis revealed that endemic taxa richness is highly uneven, with most areas hosting few or no endemics. Notably, 12 hotspots occur outside the current protected area network, leaving key refuges for endemic taxa unprotected. These findings underscore the urgent need to expand legal protection, prioritise the management of invasive taxa, restore degraded habitats, and integrate newly described taxa into conservation frameworks. By establishing a baseline for monitoring extinction risk, this study provides a critical tool to guide conservation action in the Azores, and contributes to broader efforts to safeguard the unique natural heritage of oceanic islands.

**Keywords** Azores, Biodiversity Hotspots, Conservation, Endemic Taxa, IUCN Red List, Policy Making

## Introduction

Global biodiversity is experiencing an unprecedented rate of decline driven by human activities such as overexploitation, habitat alteration, and pollution [1]. Island ecosystems, in particular, are disproportionately affected because of their geographic isolation, high rates of endemism, and heightened vulnerability to habitat loss, invasive species, and climate change [2]. In this context, the accurate assessment and monitoring of species' threat status is essential for informing effective biodiversity conservation strategies. The Azores Archipelago, a remote group of nine volcanic islands in the North Atlantic Ocean (**Fig. 1**), harbours approximately 297 native vascular plant taxa, of which 94 are endemic (species and subspecies included) [3]. However, this distinctive flora faces increasing pressures from habitat degradation, invasive species, land-use changes, and climate-related stressors [4,5]. Notably, 69% of the Azorean vascular flora is non-native [6]. These introduced species pose serious risks to native plants through direct competition, disruption of plant–animal interactions, habitat alteration, and hybridization [7], all of which undermine the conservation of the archipelago´s unique flora. Given the ecological, scientific, and conservation value of these endemic species, understanding their conservation status is not only a regional priority but also a key contribution to global biodiversity knowledge and island conservation efforts.

Protected areas are among the most effective instruments for safeguarding biodiversity, providing critical refuges for species and habitats under increasing anthropogenic pressure [8–10]. Their effectiveness, however, can be limited when additional threats such as biological invasions, habitat degradation, or disrupted ecological interactions persist within protected boundaries [11,12]. Moreover, their effectiveness depends on adequate spatial coverage and representation of biodiversity, which is not always guaranteed, particularly in small island systems where endemic-rich hotspots may remain outside designated protection [13,14]. Linking species-level assessments with the distribution of the International Union for Conservation of Nature (IUCN) Protected Area Management Categories is therefore essential to identify conservation gaps and to guide strategies enabling the long-term persistence of threatened taxa [15].

Arguably the most authoritative tool for such assessments is the IUCN Red List of Threatened Species [16], which provides a standardised, globally recognised framework for evaluating extinction risk. This system and its criteria were first published in 1994 with the aim of enhancing objectivity and transparency in assessing species' conservation status [17]. Nowadays, the IUCN Red List plays an increasingly important role in helping governmental and non-governmental organizations determine priorities, shape policy, and allocate conservation resources [18]. As of the latest update, 74,700 plant species have been assessed, corresponding to only 18% of the world's documented flora, leading the IUCN and its Red List partners to identify plants as one of the major gaps in coverage [16]. Despite recent progress, plant assessments remain unevenly distributed across regions and taxonomic groups. Several studies have shown that tropical regions and island systems, particularly those with high levels of endemism, are among the most underrepresented in global threat assessments, potentially biasing perceived global patterns of extinction risk [19,20]. Endemic floras restricted to small islands are especially affected by these shortfalls, underscoring the importance of regionally focused assessments designed to improve the representativeness and resolution of extinction risk evaluations.

Beyond these coverage gaps, the application of the IUCN framework to small island systems presents particular challenges. Insular species are often naturally range-restricted, meaning that standard thresholds for Extent of Occurrence (EOO) and Area of Occupancy (AOO) can lead to an overestimation of threat categories [21]. In many oceanic islands, however, there is a considerable number of naturally rare and highly restricted species with stable populations, which are therefore at relatively low risk of extinction [22]. On the other hand, regional assessments can reveal elevated extinction risks that are not apparent at the global scale. For example, Fois et al. [23] highlight that many plant species considered non-threatened globally may be endangered within island contexts. For example, although nearly 90% of Cape Verde's endemic plants were listed as Critically Endangered under precautionary assessments, applying more evidentiary approaches allowed finer discrimination among taxa, thereby enhancing the contribution of Red List assessments to prioritise conservation action [24]. The integration of habitat-masked range maps offers an opportunity to generate more realistic estimates of AOO and to improve risk assessments on islands [25]. Assessments of island plant species (both native and endemic) are proportionally more frequent than those of mainland species, reflecting greater assessment coverage [26]. Yet 57% of island endemics fall into threatened categories (14% Critically Endangered, 23% Endangered, 14% Vulnerable, and 6% Near Threatened), and they account for 55% of all documented plant extinctions. This figure rises to 77% when non-endemic island species are included, in stark contrast with less than 0.1% extinction among mainland native plant species [26].



This apparent strength in island coverage does not hold for the Azores; the only comprehensive evaluation of its flora is an unpublished master's thesis, surveyed using 0.5 × 0.5 km squares [27] rather than the 2 × 2 km grid cells recommended by IUCN guidelines for global comparability [16]. Since the thesis employed a different survey scale, this discrepancy may introduce inconsistencies and biases when assessing species within the same taxonomic group [28]. While several individual studies have focused on single species or lineages [29–32], a comprehensive and systematic assessment of all endemic vascular plants in the archipelago using IUCN Red List criteria has not yet been conducted or consolidated into a single, unified resource. This lack of a centralised dataset constrains the ability of policymakers, conservation practitioners, and researchers to prioritise conservation actions and allocate resources accordingly.

Given this context, the present study aims to fill an important knowledge gap by providing a comprehensive and standardised IUCN Red List assessment of all endemic vascular plant species in the Azores. Specifically, we: (1)

evaluate the extinction risk of each species using the latest IUCN criteria and guidelines; (2) identify the key hotspots of endemic taxa across the archipelago; (3) establish a spatially explicit baseline for future monitoring and conservation planning in the Azorean archipelago; and (4) derive the first Red List Index (RLI) for Azorean endemic vascular plants, providing a snapshot of their current conservation status that will serve as a reference point for tracking future trends.

## Results

### Status of threatened plant species in the Azores

A total of 94 vascular plant taxa (species and subspecies) were assessed for their conservation status (**Table 1**). Of these, 12 taxa were classified as Data Deficient (DD) and were therefore excluded from the RLI calculation. Among the remaining 82 assessed taxa, 60.9% (n=50) were assigned to one of the three threatened categories (Vulnerable, Endangered and Critically Endangered). Moreover, the most common IUCN Red List category was Endangered (EN), which included 35 taxa, representing 37.2% of the evaluated flora. Least Concern (LC) taxa were also well represented, comprising 28 taxa. Vulnerable (VU) category accounted for seven taxa, while the Near Threatened (NT) and Critically Endangered (CR) categories included two and eight taxa respectively. Two taxa were listed as Extinct (EX) (**Fig. 2**).



Of the 94 taxa evaluated in this study, only 33 had been previously assessed under the IUCN Red List framework. A comparison between previous and current IUCN categories showed that 22 taxa retained their original classification, whereas 11 taxa changed category (**Table 1**). Two taxa were down-listed, one from Critically Endangered to Endangered and another from Vulnerable to Least Concern. In contrast, eight taxa were up-listed to higher threat categories, including four reclassified from Vulnerable to Endangered, one from Vulnerable to Critically Endangered, and three from Least Concern to Vulnerable. Moreover, one taxon moved from Least Concern to Data Deficient, reflecting increased uncertainty regarding its current status.

The Red List Index (RLI) calculated from this dataset was 0.602, indicating that a substantial proportion of the assessed Azorean endemic flora falls within higher extinction risk categories. This value reflects the strong influence of taxa classified as Vulnerable, Endangered, and Critically Endangered, despite the presence of several taxa listed as Least Concern (**Table 1).** Among the taxa assessed as Endangered, many were categorised under the IUCN criterion B2ab, reflecting restricted area of occupancy (AOO), severely fragmented populations, and/or continuing decline in habitat quality. Consistent with these patterns, the application of the IUCN Threats Classification Scheme revealed that invasive alien species and pasture creation associated with livestock grazing were the most frequently recorded pressures, together driving habitat degradation and, in some cases, hybridization linked to species introductions. Taxa assessed as Critically Endangered (**Table 1**) typically exhibited extremely limited ranges, with small, declining, and highly restricted populations, and were primarily assessed under criteria B1ab, C2a, and D. These taxa generally had an Area of Occupancy (AOO) below 20 $km^2$ and an Extent of Occurrence (EOO) generally under 100 $km^2$, underscoring their highly restricted distributions (**Table 1**). An exception is *Grammitis azorica* (H. Schaef.) H. Schaef., which, despite its higher EOO (9,431 $km^2$) due to its presence on several widely separated islands, remains classified as Critically Endangered because of its very small and fragmented populations. *Vicia dennesiana* H.C.Watson and *Armeria maritima* subsp. *azorica* Franco were not detected during targeted and repeated field surveys, which focused on all historically documented localities derived from herbaria vouchers and literature records and were conducted over multiple survey campaigns spanning several years. Their absence despite these efforts, combined with the fact that neither species is known to be represented in ex situ collections (e.g. botanical gardens or seed banks), supports their Red List classification as Extinct (EX) rather than Extinct in the Wild (EW).

Twelve taxa were classified as Data Deficient. They represent 12.8% of the assessed flora, highlighting the significant knowledge gaps and emphasising the need for further taxonomic, systematic, and ecological studies of the Azorean flora (**Table 1**). These taxa were concentrated in genera known to present taxonomic and systematic challenges including *Agrostis* L. (n=6, Poaceae), *Ammi* L. (n=2, Apiaceae), *Daucus* L. (n=1, Apiaceae), *Rubus* L. (n=1, Rosaceae) and *Taraxacum* F.H.Wigg. (n=2, Asteraceae), where phenotypic similarity, hybridisation and unresolved species boundaries hamper confident identification. Consequently, reliable data on their true distribution, population trends and threats prevented their placement into a definitive IUCN threat category.

**Legal protection status of Azorean endemic taxa**

Of the assessed taxa, 48.9% (n=46) were found to be legally protected under regional legislation, the Habitats Directive, or the Bern Convention, whereas 51.1% (n=48) had no formal legal protection (**Table 1**). Among the non-protected group, 15 taxa were classified in threatened IUCN categories (Critically Endangered, Endangered, or Vulnerable; **Table 1**); these included two taxa listed as Critically Endangered, ten as Endangered, and three as Vulnerable.

**Spatial patterns of endemic richness**

Endemic species richness across the Azorean archipelago showed a markedly skewed distribution, with the majority of grid cells containing few or no endemic taxa (**Fig. 3**). The histogram (**Fig. 3, A**) shows that most grid cells harboured zero to one endemic taxa (80.0%, n=8,713). Moreover, the empirical cumulative distribution function (ECDF; **Fig. 3, B**) indicated that 95% of occupied cells contain ≤ 4 endemic taxa. Based on this distribution, we adopted a threshold of five endemic taxa per grid cell to define the upper limit of the richness scale and to delineate hotspots across the archipelago. Considering the overall colour pattern (**Fig. 4**), Pico shows the highest average density of endemic taxa, followed by São Jorge and Terceira. In contrast São Miguel, Graciosa and Santa Maria display the whitest colouration, reflecting the lowest densities of endemics. Moreover, applying this threshold, a total of 80 richness hotspots were identified across the Azorean archipelago **(Fig. 4)**. Hotspots were unevenly distributed across islands (**Table 2**). São Miguel contained the highest number of hotspots, whereas Faial and Corvo supported the fewest. However, this pattern shifted when considering hotspot area: Pico clearly dominated in terms of total hotspot extent, while Santa Maria exhibited the smallest overall area. Mean hotspot size further highlighted contrasts among islands, with Pico and Faial combining relatively large hotspot areas with few sites, whereas São Miguel was characterised by numerous but comparatively small hotspots. Santa Maria consistently showed the smallest hotspot sizes (**Table 2**).

Cross-referencing the map of the legally protected areas (**Fig. 1**) with the spatial distribution of richness hotspots map **(Fig. 4)** we identified several coverage gaps. From the 80 identified hotspots, four are only partially encompassed by existing protected areas, their zones of highest endemic richness lying outside current boundaries (**Hotspots 1, 2, 3, and 6)**. The remaining eight hotspots lie entirely outside any legally protected boundaries **(Hotspots 4, 5, 7, 8, 9, 10, 11, and 12)**, indicating that their high endemic richness is not currently accommodated in the regional conservation network. On São Miguel, two such unprotected hotspots were identified: **Hotspot 4**, located in Porto Formoso, and **Hotspot 5**, situated in Maia. Porto Formoso **(Hotspot 4)** harbours seven endemic taxa, including taxa of conservation concern such as *Solidago azorica* Hochst. ex Seub. In Maia **(Hotspot 5),** 10 endemic taxa occur, with *Azorina vidalii* (H.C.Watson) Feer, *Rumex azoricus* Rech.f. and *Solidago azorica* as priority taxa. On Pico, two hotspots were located outside existing protected areas: Terra Alta **(Hotspot**

**7)** and Calheta do Nesquim **(Hotspot 8)**. These areas harbour 11 and seven endemic taxa, respectively, both including the Endangered taxon *Lotus azoricus* P.W.Ball. In the island of São Jorge only one unprotected hotspot was present **(Hotspot 9)**, located in the cliffs near Fajã de São João. It harbours eight endemic taxa, including *Cardamine caldeirarum* Guthnick ex Seub., a taxon categorised as Endangered. The remaining three unprotected hotspots were located in the island of Graciosa. Porto Afonso **(Hotspot 10)** harbours eight endemic taxa. The cinder cones in Serrinha **(Hotspot 11)** support 16 endemic taxa, several with conservation interest, such as *Centaurium scilloides* (L.f.) Samp., *Corema album* subsp. *azoricum* P.Silva, *Hypericum foliosum* Aiton, *Platanthera pollostantha* R.M.Bateman & M.Moura, and *Serapias cordigera* subsp. *azorica* (Schltr.) Soó). Lastly, the Baía do Filipe **(Hotspot 12)** hosts 10 endemic taxa, including the Critically Endangered *Tolpis graciosensis* Borges Silva L. & M. Moura.



## Discussion

This study provides the first comprehensive IUCN Red List assessment of the Azorean endemic vascular flora, providing a baseline for conservation prioritization across the archipelago, and addressing a widely recognised necessity highlighted by Caujapé-Castells et al. [7]. Our results show that 60.9% of the assessed taxa in the Azores fall into threatened categories, confirming its position as the second-most threatened archipelago of Macaronesia, surpassed only by Cabo Verde (78% of threatened taxa) [33]. Moreover, this value may still underestimate the true number of threatened taxa, as taxa that have been misclassified or poorly resolved can obscure genuine extinction risk.

Misclassified taxa [29,31,32,34] and previously described extirpated taxa constitute a *Wallacean shortfall* because they modify the known geographic range of taxa [35]. In the Azores, unresolved taxonomy in genera such as *Ammi* [36] and *Agrostis,* and in specific taxa such as *Daucus carota* subsp. *azoricus* Franco and *Rubus hochstetterorum* Seub., remain significant limitations. In fact, greater attention should be devoted to Data Deficient (DD) taxa, which are frequently excluded from conservation metrics such as the RLI despite evidence that many may face extinction risks similar to those of recognised threatened taxa. As highlighted by Bland et al. [37,38], although the IUCN recommends that DD taxa receive the same level of consideration as threatened ones, they are often neglected in research, policy, and funding priorities. This omission not only undermines the representativeness of biodiversity indicators but may also lead to substantial underestimation of extinction risk in regions with limited taxonomic and ecological data, such as oceanic islands. This issue is particularly relevant in island systems. The proportion of Data Deficient (DD) taxa observed in this study (12.8%) is high in the context of global plant assessments, where DD values vary among biogeographic realms, from very low proportions in the Nearctic (0.3%) and Antarctic (0%) to higher values in the Afrotropical (6.9%), Indomalayan (6.6%), Neotropical (4.3%), and Palearctic (6.8%) realms [39]. In contrast, a similar DD proportion has been documented for Cyprus (13.7%, [40]), whereas lower values have been reported for Cabo Verde (5.4%, [33]), highlighting variability among archipelagos that likely reflects differences in sampling intensity, taxonomic resolution, and historical research effort. At the same time, several taxa previously documented in the Azores have been extirpated from individual islands, further complicating conservation baselines. Examples include the disappearance of *Juniperus brevifolia* (Seub.) Antoine and *Prunus lusitanica* subsp. *azorica* (Mouill.) Franco from Santa Maria, and of *Taxus baccata* L. from São Miguel [41]. Although *Taxus baccata* is not endemic to the Azores, its local extinction highlights that conservation priorities, while primarily centred on narrow endemics, may also extend to native species [23], reinforcing the importance of considering regionally threatened taxa. Future assessments should therefore aim to integrate both endemic and non-endemic native species to provide a more comprehensive basis for conservation planning. While extirpations reflect severe local declines, documented extinctions represent an even more serious and irreversible loss of biodiversity. Although only one vascular plant taxon is formally recognised as globally Extinct in the Azores (*Vicia dennesiana*), this figure likely underestimates the true scale of biodiversity loss, as many extinctions probably occurred prior to the arrival of early scientific expeditions [42]. *Vicia dennesiana* was last observed in cultivation in the 19th century before disappearing completely [43]. *Armeria maritima* subsp. *azorica* was last seen in 1974 in the Velas, São Jorge (LISU 5696), and in this study we formally categorise it, for the first time, as Extinct. The loss of these taxa underscores the cumulative effects of anthropogenic pressures that continue to shape the conservation status of the Azorean endemic flora.

Currently, there is a huge amount of pressure experienced by the Azorean endemic flora, as 69% of species in the Azorean flora are non-native [44]. This proportion is markedly higher than in other island systems, where non-native species typically represent a much smaller fraction of the flora, such as in the Canary Islands (13%), Madeira (12%), Cabo Verde (30%), and Hawaiʻi (24%), highlighting the exceptional level of invasion pressure in the Azores [45]. They alter community composition across habitats, affecting ecosystem processes and, eventually, reducing the frequency and abundance of native taxa [44]. In the Azores, these impacts are driven primarily by a few highly aggressive invaders, including *Gunnera tinctoria* (Molina) Mirb., *Hedychium gardnerianum* Sheph. ex Ker Gawl., *Pittosporum undulatum* Vent., and *Hydrangea macrophylla* (Thunb.) Ser., which continue to expand and dominate native vegetation [46]. Furthermore, they have a cascade effect on the related biota, such as a decrease in insect [47] and bird richness [48]; for example, the range of the Azorean bullfinch (*Pyrrhula murina*) gradually reduced as non-native vegetation communities expanded [49]. Collectively, these processes drive a homogenization of island floras, eroding its unique ecological identity [50].

Taken together, the synthesis of individual IUCN assessments allows the overall extinction risk of the Azorean endemic flora to be quantified using a standardised metric. The Red List Index (RLI) measures trends in the overall extinction risk of a set of species, ranging from 1 when all species are classified as Least Concern to 0 when all species are extinct [51]. Furthermore, it is a powerful tool for monitoring conservation progress; by repeating assessments at regular intervals, the index can capture genuine changes in status and evaluate whether conservation actions are sufficient to reverse biodiversity loss [52]. In this study, we provide the first RLI for the endemic vascular flora of the Azores, obtaining a value of 0.602, which reflects a moderate but concerning level of extinction risk. As this represents an initial, archipelago-wide assessment, the RLI serves as a baseline for future monitoring rather than an accurate measure of change through time.

Nevertheless, meaningful insights can be gained by examining changes captured at the species level, where a comparison between former and current IUCN categories reveals both consistency and major shifts in the evaluated status of Azorean taxa. Most assessed taxa (n=22) retained their previous classification, indicating that the Red List framework has been applied consistently and that available data continue to support earlier assessments. However, the 11 taxa that changed categories highlight important conservation dynamics within the archipelago.

The reclassification of *Pericallis malvifolia* (L'Hér.) B.Nord. largely reflects improvements in data quality. Earlier assessments of *P. malvifolia* [53] were based solely on data for the narrowly distributed subspecies *P. malvifolia* subsp. *caldeirae* H.Schaef., previously thought to be restricted to the Faial Caldeira. Although both subspecies have recently been reduced to ecotype status [54], conservation efforts should nevertheless recognise and manage each distinct population separately, given their potentially unique evolutionary trajectories and local adaptations [55]. In contrast, our reassessment considered the species as a whole, incorporating all known occurrences across its full range. Conversely, previous assessments [56] of *Myosotis azorica* H.C.Watson substantially overestimated its AOO and EOO, reporting natural populations on Corvo, Flores, Faial, Pico, and São Jorge. Current evidence demonstrates that wild populations are in fact restricted to a single site on Corvo, whereas the individuals occurring on Flores represent reintroductions derived from Corvo [57]. The downlisting of *J. brevifolia* represents a genuine conservation success, this species having benefitted from targeted interventions, restoration of native forests, and control of invasive plant competitors by LIFE IP Azores Natura (https://www.lifeazoresnatura.eu/). The uplisting of *Leontodon filii*, *L. hochstetteri*, *L. rigens* (Dryand. in Aiton) Paiva & Ormonde, *Viburnum treleasei* Gand., *Aichryson santamariensis* M.Moura, Carine & M.Seq., *Isoetes azorica* Durieu, and *Frangula azorica* V.Grubow to higher threat categories reflects both their extremely narrow distribution ranges and the intensification of anthropogenic pressures. Habitat degradation caused by the spread of invasive taxa [4], nomadic grazing of goats, rabbits, and cattle [58], and increasingly pressure from tourism along hiking trails [59] continue to exert substantial impacts. In the case of *I. azorica*, eutrophication of lagoons constitutes an additional and particularly severe threat to its persistence [60].



Several taxa now placed within a threatened category were described only recently and, as a result, have not yet been incorporated into the main regional and international legal frameworks for species protection, including the EU Habitats Directive (Council Directive 92/43/EEC), the Bern Convention, and the *Decreto Legislativo Regional* n.º 15/2012/A. These comprise the Critically Endangered *Tolpis graciosensis* and *T. maritimoccidentalis* Borges Silva L. & M. Moura, as well as eight Endangered taxa (*Leontodon hochstetteri*, *L. rigens*, *Tolpis mariensis* Borges Silva L. & M. Moura, *T. maritima* Borges Silva L. & M. Moura, *T. maritimocentralis* Borges Silva L. & M. Moura, *T. micaelensis* Borges Silva L. & M. Moura, *T.*

*occidentalis* Borges Silva L. & M. Moura*, Juniperus brevifolia* subsp. *maritima* R. B. Elias & E. Dias) and three Vulnerable taxa (*Platanthera pollostantha, Aichryson santamariensis* and *Centaurium scilloides*) [29,31,61]. This omission exemplifies a broader challenge for island floras, where scientific discoveries and subsequent taxonomic decisions continue to outpace updates in policy instruments [62]. Furthermore, several long-recognised taxa remain without formal legal protection, underscoring that scientific recognition of their conservation importance has not been matched by corresponding policy action. This is particularly evident in taxa such as *Cardamine caldeirarum* and *Carex vulcani* Hochst. ex Seub. that, despite being classified as Endangered, currently lack any form of legal protection. As noted by Dietz et al. [60], such persistent gaps between the acknowledged biodiversity value of taxa and the establishment of effective legal safeguards reflect systemic deficiencies in current conservation frameworks.

Our spatial analysis of endemic plant richness across the Azorean archipelago highlights the highly uneven distribution of biodiversity and the limitations of the current protected area network. Most grid cells contained four or fewer endemic taxa, underscoring the extent to which centuries of land-use change and invasive taxa have profoundly degraded the archipelago's native vegetation [42,44,64]. Today, land use in the Azores is dominated by pastures (43%) and planted or alien dominated forests (22%). Natural vegetation occupies only 13% of the territory [65], further highlighting the limited space available for native vegetation. The distribution of hotspots revealed clear contrasts among islands. Pico supports extensive and contiguous areas of high endemic richness, in line with the observations of Elias et al. [66], who noted that Pico retains vegetation types that have experienced little or no anthropogenic disturbance. While global island biogeographic patterns [67] describe relationships between island size and plant diversity, our results suggest that, in the Azores, the spatial distribution of endemic richness is more closely linked to current anthropogenic pressures than to island size per se. Islands with lower levels of disturbance, such as Pico, retain higher concentrations of endemic taxa. In contrast, São Miguel, despite being the largest island and also the one experiencing the highest human pressure, is characterised by fragmented hotspots and extensive areas with very low endemic richness. This pattern also agrees with Elias et al. [66] who reported that native vegetation on São Miguel is both scarce and heavily invaded by *Clethra arborea* Aiton, *Pittosporum undulatum* Vent., and *Hedychium gardnerianum* Sheph. ex Ker Gawl. Such conditions reflect a long legacy of intensive land-use change following human colonization [68,69]. Although most high-elevation habitats are now included within island natural parks, many low-altitude areas rich in endemics remain poorly represented, particularly on São Miguel, Pico, São Jorge, and Graciosa. These environments have historically undergone the most profound anthropogenic transformations, driven by intensive agriculture (e.g. wheat cultivation and *Isatis tinctoria* L. production) [70,71], urban expansion, and associated land-use changes. As a result, much of the remaining lowland vegetation is secondary in origin, with present-day coastal woodlands providing a clear ecological signal of this long history of disturbance [66]. Taken together, these results emphasise that insular ecosystems, despite their small extent, harbour disproportionately high concentrations of rare and threatened endemic taxa [72]. This effect is even more pronounced on the smaller islands such as Graciosa, Corvo, Santa Maria, and Faial, where restricted land area combined with intense human pressures have confined endemics to just a few hotspots. Our findings therefore highlight the urgent need to extend the protected area network to encompass the eight unprotected hotspots identified in this study. However, establishing new protected areas is inherently complex because it must contend with competing land-use demands, as well as the socioeconomic costs of implementation. Clear species-prioritization procedures are essential to ensure that limited resources are directed towards sites with the highest conservation value [33]. Extending protected area networks in small island systems such as the Azores inevitably impinges on privately owned and traditionally managed lands, raising complex governance and socioeconomic challenges [73]. On islands where land is scarce and livelihoods depend on agriculture, livestock, and tourism, conservation actions that restrict land use can generate local opposition if not accompanied by tangible benefits or adequate compensation mechanisms [73]. Integrating land ownership considerations into spatial prioritization is therefore crucial to prevent conservation-induced inequities and to foster long-term stewardship [73]. Participatory approaches should engage local landowners and resource users early in the planning process, through co-management frameworks, voluntary conservation easements, or incentive-based schemes such as agri-environmental payments [73]. In fact, such co-operation can help reconcile biodiversity objectives with rural development needs. In this context, adaptive planning measures that recognise the mosaic of public and private landownership characteristic of small islands may provide a pragmatic pathway to expanding protection while sustaining the socio-economic viability of local communities [73].



## Conclusion

Our assessment demonstrates that the Azorean endemic vascular flora faces a high risk of extinction, with 60.9% of taxa threatened, two extinctions recorded, and several taxa extirpated from individual islands, placing the Azores as one of the most imperilled archipelagos in Macaronesia and yielding a Red List Index of 0.602. The spatial analyses reveal a highly uneven distribution of biodiversity, with several hotspots remaining unprotected despite serving as the sole refuges for numerous threatened taxa. Moreover, Data Deficient taxa and historically extirpated populations underscore important limitations, and indicate that current estimates may still underestimate true extinction risk. Continued taxonomic research, periodic reassessment using the IUCN framework, and the expansion of legal protection to unprotected hotspots are therefore essential to halt further losses and safeguard the unique endemic flora of the Azores. Addressing these gaps requires expansion of the protected area network to include such overlooked sites, alongside targeted control of invasive taxa, restoration of native vegetation, and the formal integration of newly described taxa into regional and European legal frameworks. Rather than letting the Azores turn “red” on the pages of extinction, our efforts must aim for a future where they remain green with native flora, safeguarding the islands’ unique natural heritage.

## Methods

### Study area

The research was conducted in the Azores Archipelago; a group of nine volcanic islands in the North Atlantic Ocean, located between 36°55′-39°43′ N and 24°46′-31°16′ W. The archipelago is divided into three island groups: Eastern (São Miguel, Santa Maria), Central (Terceira, Graciosa, São Jorge, Pico, Faial), and Western (Flores, Corvo). The Azores lie approximately 1,400 km west of mainland Portugal, their closest point to continental Europe, and about 1,900 km east of Canada, their nearest point to North America. Of volcanic origin, the Azores Archipelago exhibits a highly diverse and rugged geomorphology shaped by intense tectonic, and thus volcanic, activity. Elevation ranges from sea level to 2,351 meters at Pico Mountain on Pico island, the highest point in Portugal.



The Azores experience a temperate oceanic climate characterised by mild temperatures, high relative humidity (exceeding 95% on more than 50 days per year), and persistent cloud cover throughout the year [74]. The mean annual temperature is approximately 17.5 °C, with relatively small seasonal variation [75]. Annual precipitation ranges from 1,000 to 1,600 mm, decreasing from west to east; Flores and Corvo receive the highest rainfall, whereas Santa Maria records the lowest [74]. These conditions support lush, year-round vegetation, hence the name “green islands”.

The Azores have been significantly altered by centuries of human settlement and land use. Much of the original vegetation has been replaced by pastures, agricultural land, exotic tree plantations, particularly of *Cryptomeria japonica* (Thunb. ex L.f.) D.Don and the spread of invasive species such as *Hedychium gardnerianum* Sheph. ex Ker Gawl. and *Pittosporum undulatum* Vent.

Given the archipelago-wide scope of our assessment, field surveys and data collection were conducted across all nine islands (**Fig. 1**).

**Data collection**

This study assessed the conservation status of all vascular plant species endemic to the Azores archipelago. The list of endemic vascular plant species included in this study was compiled using historical records [43,76–83], herbaria specimens, online databases [3,6] and checklists of the Azorean flora [84–86]. Herbaria data were obtained from AZU (University of the Azores), LISU (University of Lisbon), LISE (University of Lisbon, Faculty of Sciences, Department of Plant Biology), LISI (Instituto Superior de Agronomia Herbarium, University of Lisbon), COI (University of Coimbra), BM (Natural History Museum, London), MO (Missouri Botanical Garden), TUB (Botanical Garden and Botanical Museum Berlin), P (Muséum National d'Histoire Naturelle, Paris), and the herbarium of the Carlos Machado Museum (Ponta Delgada). The validity and current taxonomic status of each name were reviewed according to Plants of the World Online [87] to resolve synonymies or confirm accepted names. When uncertainties remained, additional clarification was sought through expert consultation. The final list included 94 endemic vascular plant taxa identified as target species for the IUCN assessment.



For each species, we collected information on geographic distribution, habitat preferences, population trends, threats, and both ongoing and recommended conservation actions. Data sources ranged from the earliest naturalist records to present-day field surveys, online databases [3,6,88] and incorporating all herbaria specimens. All occurrence records from iNaturalist [84] were manually validated to ensure accurate species identification. For the Azores BioPortal [5], only georeferenced records with the highest spatial accuracy level (precision level 1) were considered, and their presence was cross-verified with expert input from specialists in the Azorean flora. Similarly, all distribution points obtained from Flora-on [3] were reviewed and their validity confirmed through consultation with regional botanical experts. Relevant published and unpublished reports from botanists working in the Azores were also incorporated to complement and verify the dataset. Information on threats was compiled using field observations, expert knowledge, and literature sources. Rather than a single time-point assessment, threats were identified based on their overall impact across each species' range, capturing the main and recurrent pressures affecting each taxon. The final database comprises approximately 10,600 individual records.

**IUCN assessments**

The threat status assessments were performed following the International Union for Conservation of Nature (IUCN) Red List Categories and Criteria, version 16 [89] using the IUCN Species Information Service (SIS) [90] between October 2024 and February 2025. Criteria B, C, and D were applied depending on data availability and quality. For each species, the Extent of Occurrence (EOO) and Area of Occupancy (AOO) were calculated using a minimum convex polygon and 2 × 2 km grid cells, respectively, with GeoCAT [91]. Although the full database includes all known records from the earliest naturalists to the present, only current, extant populations were used in the EOO and AOO calculations. Records representing extirpated populations or historically documented but no longer existing occurrences were excluded to ensure that the metrics reflect the species' present distribution. Subpopulations and locations were defined according to the IUCN's definition of threats operating within a specific area, and threat classification followed the IUCN Threats Classification Scheme (version 3.3). Population size and trend estimates were based on quantitative data when available. The evaluation of conservation status was carried out using the Species

Information Service (SIS) toolkit, available online at: https://sis.iucnsis.org, which helps to assess the Red List category of a species as accurately as possible.

Red List assessments were subject to internal peer review by regional experts. Each draft was evaluated by three botanists specialising in the Azorean flora, and discrepancies or uncertain cases were resolved through additional consultation or field verification. Final assessments included detailed justification narratives and were prepared for submission to the IUCN Red List Unit. Georeferenced occurrence data, along with information on threats and habitat assessments, were stored in a centralised database managed by the University of the Azores. These data are available upon request and will be submitted to the IUCN in accordance with their protocols for assessment documentation and data sharing.

**Red List Index**

The proportion of endemic species assigned to each IUCN Red List category was visualised using a pie chart, providing a clear overview of the conservation status distribution within the assessed flora. The Red List Index (RLI) was computed by assigning a numerical weight to each IUCN Red List category: 0 for Least Concern (LC), 1 for Near Threatened (NT), 2 for Vulnerable (VU), 3 for Endangered (EN), 4 for Critically Endangered (CR), and 5 for Extinct (EX). For each category, the number of species is multiplied by its corresponding weight. The weighted values are summed to obtain a total threat score. This score is then divided by the maximum possible threat score—defined as the total number of species multiplied by the maximum weight (5). The resulting proportion is subtracted from one to yield the final RLI value. This index ranges from 0 (indicating all species are Extinct) to 1 (indicating all species are of Least Concern), with lower values signifying a higher overall extinction risk for the assessed group. RLI calculations followed the methodology outlined by Bubb et al. [51].

**Spatial analysis**

Mapping and spatial analyses were conducted using R 4.3.2 software [92] and QGIS 3.34.3-Prizren. Employing the final database, we analysed spatial patterns of species richness across the Azores archipelago using geographic and species occurrence data. Geographic coordinates were converted into a spatial point object under the WGS84 coordinate reference system (EPSG:4326). To ensure accurate distance and area calculations, all spatial datasets were re-projected to the ETRS89 / UTM zone 29N coordinate system (EPSG:25829). The national boundary shapefile of Portugal was obtained from the GADM database of Global Administrative Areas (version 4.1) [93]. This shapefile was imported and processed as a spatial feature object using the sf package [94]. A uniform grid of 0.5 × 0.5 km was generated across the extent of the occurrence data, and each grid cell was assigned a unique identifier. To restrict the analysis to terrestrial areas, this grid was intersected with the Portuguese land area polygon, effectively removing offshore cells. To estimate species richness per grid cell, occurrence points of endemic species were spatially joined to the clipped grid. To avoid duplication, we retained only one record per unique taxon within each grid cell using the dplyr package [95]. Species richness was computed as the number of unique taxa per cell. Species richness values were associated with their corresponding grid geometries and visualised using the ggplot2 package [96]. The final richness map displays the number of endemic taxa per 0.5 × 0.5 km grid cell. Processed outputs, including the species richness grid and occurrence points, were exported as shapefiles for further analysis and integration with QGIS software.

Elevation data were obtained from the Azores Spatial Data Infrastructure (IDEA) through the regional government's WMTS service, providing raster layers for the study area. To enhance the visual representation of species richness, the vector-based shapefile containing richness values per 0.5 × 0.5 km grid cell was converted into a raster format using QGIS. The transformation was performed through Inverse Distance Weighting (IDW) interpolation, using the centroids of each grid cell as input points. This method estimates raster values based on the proximity of known data points, generating a continuous surface representation of endemic species richness. Areas lacking nearby centroid data were rendered as NoData (displayed as grey zones), due to the inherent limitation of IDW, which cannot extrapolate beyond the spatial influence of the input points when the data is unevenly distributed or clustered. The resulting interpolated raster was used exclusively for visualization purposes and does not represent predictive modelling. To define an appropriate upper limit for endemic richness in the final map, an empirical cumulative distribution function (ECDF) was used to select a suitable threshold. These approaches ensure the interpretability of the map while minimizing visual distortion caused by rare high-richness outliers. The distribution of richness values across grid cells was further explored through a bar plot displaying absolute counts above each bar, providing a clear depiction of endemic richness patterns across the study area. Based on the ECDF results, richness values were capped at a maximum of five endemic species per grid cell to maintain both visual clarity and representational accuracy. To emphasise hotspots within the richness heatmap, contour lines were generated from the raster layer using the "Contour" tool in QGIS. Contours were drawn only for grid cells with equal or more than five endemic species, with contour intervals set at one species. This procedure highlighted areas of particularly high richness while preserving a clear and interpretable visual hierarchy in the map



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**Author contributions**

**Conceptualization**: M.M., G.R., L.S., R. B. E.; **Methodology**: M.M., G.R., L.S., R.B. E.; **Data curation**: G.R.; **Formal analysis**: G.R.; **Fieldwork**: G.R., L.S., R.E., D.P., M.C., A.M., L.B.S., R. M. C. R., M.S., R.B., M.M.; **Writing –**

**original draft**: G.R.; **Writing – review & editing**: G.R., L.S., R.E., D.P., M.C., A.M., L.B.S., R. M. C. R., M.S., R.B., M.M.; **Supervision**: L.S., R.E., M.M.; **Project administration:** M.M.; **Funding acquisition**: M.M.

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**Competing interests**

The author(s) declare no competing interests.

**Data availability**

The datasets generated and/or analysed during this study include precise georeferenced locations of sensitive and highly threatened endemic plant species. To avoid potential risks associated with public disclosure, such as disturbance, illegal collection, or habitat degradation, these data are not openly available. The dataset is currently being used to support conservation planning and management actions in the Azores. Access to the data can be granted upon reasonable request to the corresponding author, particularly for research and conservation purposes, and may be subject to data-use agreements.

**Ethics declarations**

No ethical approval was required for this study.

**Table 1.** Endemic vascular plant taxa of the Azores archipelago with their current and previous IUCN Red List categories, IUCN assessment criteria, area of occupancy (AOO, in km²), extent of occurrence (EOO, in km²), and current legal protection status. n-dashes (-) indicate data not available. An asterisk (*) in the IUCN Category column indicates taxa whose threat status is published on the official IUCN Red List of Threatened Species website (https://www.iucnredlist.org/). Categories without an asterisk are based on assessments from scientific literature or expert evaluations not yet incorporated into the Red List. IUCN categories: **LC**, Least Concern; **NT**, Near Threatened; **VU**, Vulnerable; **EN**, Endangered; **CR**, Critically Endangered; **EX**, Extinct; **DD**, Data Deficient; ▲ indicates taxa up-listed to a higher threat category; ▼ indicates taxa down-listed to a lower threat category. Legal protection codes: **R**, listed in regional legislation *Decreto Legislativo Regional* n.º 15/2012/A; I (when preceding R), vascular plant species protected due to regional interest; **D**, listed in the EU Habitats Directive, with Roman numerals indicating the Annex; **B**, listed in the Bern Convention, with Roman numerals indicating the Annex.

| Taxon | Previous IUCN Category | IUCN Category | IUCN Criteria |
|---|---|---|---|
| *eubertianum* (H.C.Watson) Trel. | | DD | |
| *trifoliatum* (H.C.Watson) Trel. | | DD | |
| *a lignescens* Reduron & Danton | | EN | B2ab(i,ii,iii,iv,v) |
| *aerophyllum azoricum* Trel. | | EN | B2ab(i,ii,iii,iv,v) |
| *carota* subsp. *azoricus* Franco | | DD | |
| *ula azorica* Guthnick ex Seub. | | EN | B2ab(i,ii,iii,iv) |
| *ado* subsp. *azorica* (Loes.) Tutin | | LC | |
| *Hedera azorica* Carrière | | LC | |
| *ium azoricum* Lovis, Rasbach, K.Rasbach & Reichst. | LC* | LC | |
| *Bellis azorica* Seub. | | EN | B2ab(i,ii,iii,iv,v) |
| *Lactuca watsoniana* Trel. | EN* | EN | B2ab(i,ii,iii,iv,v); C2a(i) |

| | | | | |
|---|---|---|---|---|
| *lon filii* (Hochst. ex Seub.) Paiva & Ormonde | VU | EN▲ | B1ab(i,ii,iii)+2ab(i,ii,iii) | |
| *odon hochstetteri* M.Moura & Silva | VU | EN▲ | B1ab(i,ii,iii,v)+2ab(i,ii,iii,v) | |
| *todon rigens* (Aiton) Paiva & Ormonde | VU | EN▲ | B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v) | |
| *llis malvifolia* (L'Hér.) B.Nord. | CR* | EN▼ | B2b(ii,iii)c(ii) | |
| *ago azorica* Hochst. ex Seub. | | LC | | |
| *um perssonii* Plaglund ex Sahlin & Soest | | DD | | |
| *um pseudolandmarkii* Franco & Rocha Afonso | | DD | | |
| *lpis azorica* (Nutt.) P.Silva | EN | EN | B1ab(i,ii,iii,iv)+2ab(i,ii,iii,iv) | |
| *graciosensis* Borges Silva L. & M. Moura | CR | CR | B1ab(i,ii,iii,iv,v); C2a(i) | |
| *mariensis* Borges Silva L. & M. Moura | EN | EN | B2ab(ii,iii,iv,v) | |
| *maritima* Borges Silva L. & M. Moura | EN | EN | B1ab(iii,iv,v)c(iii)+2ab(iii,iv,v)c(iii) | 1 |
| *maritimocentralis* Borges Silva L. & M. Moura | EN | EN | B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v) | |
| *aritimoccidentalis* Borges Silva L. & M. Moura | CR | CR | B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v); C2a(i); D | |
| *nicaelensis* Borges Silva L. & M. Moura | EN | EN | B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v) | |
| *ccidentalis* Borges Silva L. & M. Moura | EN | EN | B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v) | |
| *rosotis azorica* H.C.Watson | VU* | CR▲ | B1ab(i,ii,iii,v); C2a(i,ii) | |
| *otis maritima* Hochst. ex Seub. | | EN | B2ab(i,ii,iii,iv,v) | |
| *mine caldeirarum* Guthnick ex Seub. | | EN | B2ab(i,ii,iii,iv) | |
| *ina vidalii* (H.C.Watson) Feer | EN | EN | B2ab(iii) | |
| *Viburnum treleasei* Gand. | LC* | VU▲ | B2ab(ii,iii,iv) | |
| *fum azoricum* Hochst. ex Seub. | | EN | B1ab(i,ii,iii)+2ab(i,ii,iii) | |
| *Silene* *ora* subsp. *cratericola* Franco | | CR | B1ab(iii)+2ab(iii) | |
| *gularia azorica* (Kindb.) Lebel | | VU | B2ab(ii,iii) | |
| *son santamariensis* M.Moura, Carine & M.Seq. | LC | VU▲ | D2 | |
| *rus brevifolia* (Seub.) Antoine | VU* | LC▼ | | |
| *us brevifolia* subsp. *maritima* R. B. Elias & E. Dias | | EN | B2ab(i,ii,iii,iv) | |

| | | | |
|---|---|---|---|
| *Juniperus* *folia* subsp*. brevifolia* (Seub.) Antoine | | LC | |
| *Carex demissa* subsp. *reutzii* (Fagerstr.) Jac.Koopman | | LC | |
| *hochstetteriana* J.Gay ex Seub. | | LC | |
| *x leviosa* Míguez, Jim.Mejías, .Schaef. & Martín-Bravo | LC | LC | |
| *pilulifera* subsp. *azorica* (J.Gay) Franco & Rocha Afonso | | LC | |
| *ex vulcani* Hochst. ex Seub. | | EN | B2ab(iii) |
| *biosa nitens* Roem. & Schult. | | EN | B2ab(ii,iii,iv,v) |
| *ris crispifolia* Rasbach, Reichst. & G.Vida | LC* | LC | |
| *Dryopteris* *media* subsp. *azorica* (Christ) Jermy | LC* | LC | |
| *album* subsp. *azoricum* P.Silva | | EN | B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v) |
| *cia azorica* Tutin & E.F.Warb. | | EN | B1ab(i,ii,iii,iv,v)+2ab(i,ii,iii,iv,v) |
| *ca azorica* Hochst. ex Seub. | | LC | |
| *ccinium cylindraceum* Sm. | LC* | LC | |
| *uphorbia azorica* Hochst. | | LC | |
| *horbia stygiana* H.C.Watson | | EN | B2ab(i,ii,iii,iv) |
| *rbia stygiana* subsp. *stygiana* H.C.Watson | | EN | B2ab(i,ii,iii,iv) |
| *Euphorbia* *a* subsp. *santamariae* H.Schaef. | CR* | CR | B1ab(iii,v)+2ab(iii,v); C2a(i); D |
| *Lotus azoricus* P.W.Ball | EN | EN | B2ab(iii) |
| *ia dennesiana* H.C.Watson | | EX | |
| *aurium scilloides* (L.f.) Samp. | | VU | B2ab(ii,iii,iv) |
| *Hypericum foliosum* Aiton | LC* | LC | |
| *Isoetes azorica* Durieu | VU* | EN▲ | B2ab(ii,iii,iv,v) |
| *la purpureosplendens* Seub. | | LC | |
| *rus azorica* (Seub.) Franco | LC* | LC | |
| *conia azorica* (Tutin) Knobl. | LC* | LC | |
| *latanthera azorica* Schltr. | | CR | B1ab(iii) |
| *nthera micrantha* (Hochst. ex Seub.) Schltr. | | EN | B2ab(iii,iv) |

| | | | |
|---|---|---|---|
| *hera pollostantha* R.M.Bateman & M.Moura | | VU | B2b(v)c(iv); C2a(i)b |
| *pias cordigera* subsp. *azorica* (Schltr.) Soó | | EN | B2ab(i,ii,iii,iv) |
| *phrasia azorica* H.C.Watson | | EN | B1ab(ii,iii,iv)+2ab(ii,iii,iv); D |
| *phrasia grandiflora* Hochst. | | EN | B1ab(ii,iii,iv)+2ab(ii,iii,iv) |
| *ica dabneyi* Hochst. ex Seub. | | CR | C2a(i) |
| *eria maritima* subsp. *azorica* Franco | | EX | |
| *m diasii* Fern.Prieto, T.E.Díaz & C.Aguiar | | LC | |
| *rostis congestiflora* Tutin & E.F.Warb. | | DD | |
| *rostis congestiflora* Tutin & Warb. subsp. *congestiflora* | | DD | |
| *s congestiflora* subsp. *oreophila* Franco | | DD | |
| *grostis gracililaxa* Franco | | DD | |
| *stis gracililaxa* Franco subsp. *gracililaxa* | | DD | |
| *Agrostis ililaxa* subsp. *mutica* Franco | | DD | |
| *eschampsia foliosa* Hack. | | NT | B2ab(ii,iii) |
| *a francoi* Fern.Prieto, C.Aguiar, E.Días & M.I.Gut. | | NT | B2ab(ii,iii) |
| *ca petraea* Guthnick ex Seub. | | LC | |
| *ia coarctata* (Link) T.Durand & Schinz | | LC | |
| *Holcus rigidus* Hochst. | | LC | |
| *Rostraria azorica* S.Hend. | | VU | D2 |
| *Rumex azoricus* Rech.f. | | EN | B2ab(i,ii,iii,iv) |
| *mmitis azorica* (H.Schaef.) H.Schaef. | CR* | CR | C2a(i) |
| *Polypodium nesicum subsp. azoricum* (Vasc.) .Ramsey, Carine & Robba | | LC | |
| *ysimachia azorica* Hook. | | LC | |
| *Myrsine retusa* Aiton | | LC | |
| *Frangula azorica* Grubov | LC* | VU▲ | B2ab(i,ii,iii,iv) |

| | | | |
|---|---|---|---|
| *Prunus* *nica* subsp. *azorica* (Mouill.) Franco | EN* | EN | B2ab(i,ii,iii,iv,v); C2a(i) |
| *bus hochstetterorum* Seub. | LC* | DD | |
| *a agostinhoi* Dans. & P.Silva | | LC | |
| *uthobium azoricum* Wiens & Hawksw. | | EN | B2ab(iii) |
| *milax azorica* H.Schaef. & P.Schönfelder | | LC | |

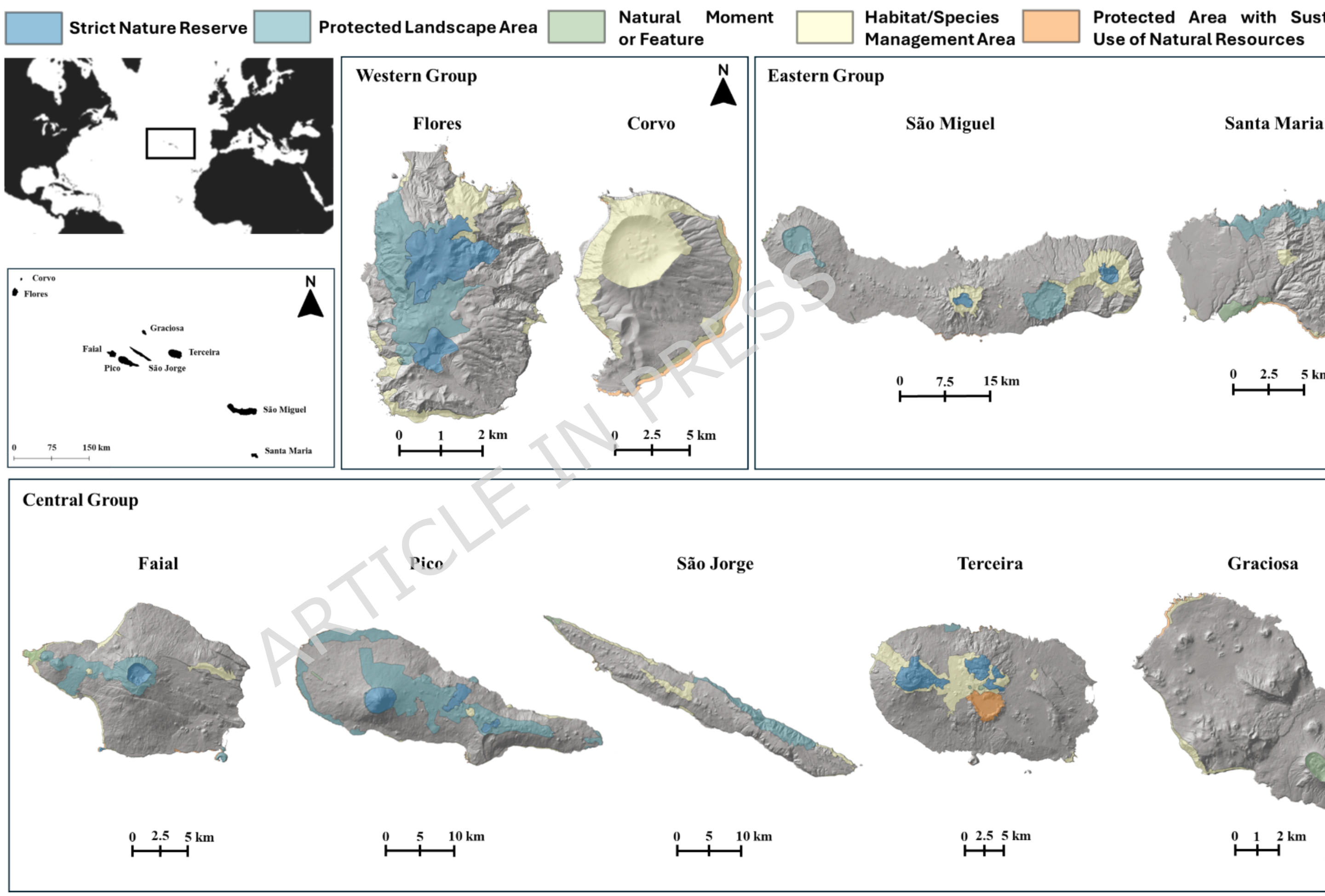




**Fig. 1.** Location of the Azores archipelago (Portugal) and the distribution of the protected areas under the IUCN protected areas management categories. These include Strict Nature Reserves (dark blue), Protected Landscape Areas (light blue), Natural Monument or Feature (green), Habitat/Species Management Area (Yellow), and Protected Areas with Sustainable Use of Natural Resources (orange). Scale bars are included for distance reference on each island.

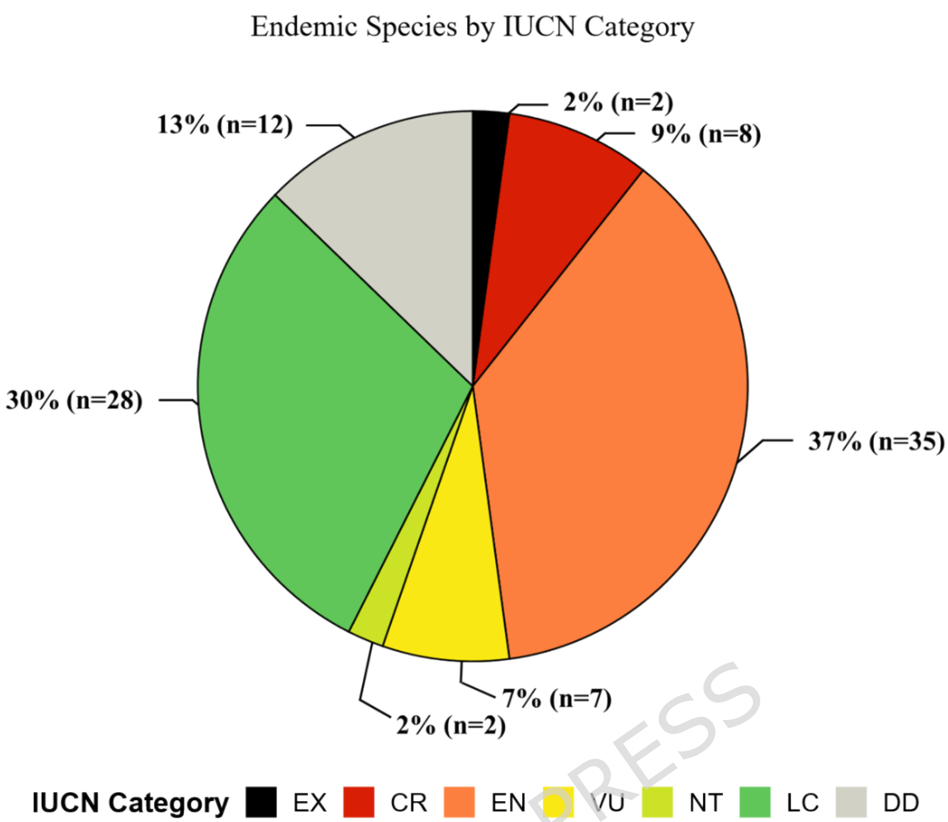


**Fig. 2** Distribution of Azorean endemic species across IUCN Red List categories. The chart shows the proportion of species in each category: EX (Extinct), CR (Critically Endangered), EN (Endangered), VU (Vulnerable), NT (Near Threatened), LC (Least Concern), and DD (Data Deficient). Percentages represent the proportion of species in each category, with the number of species shown in parentheses.



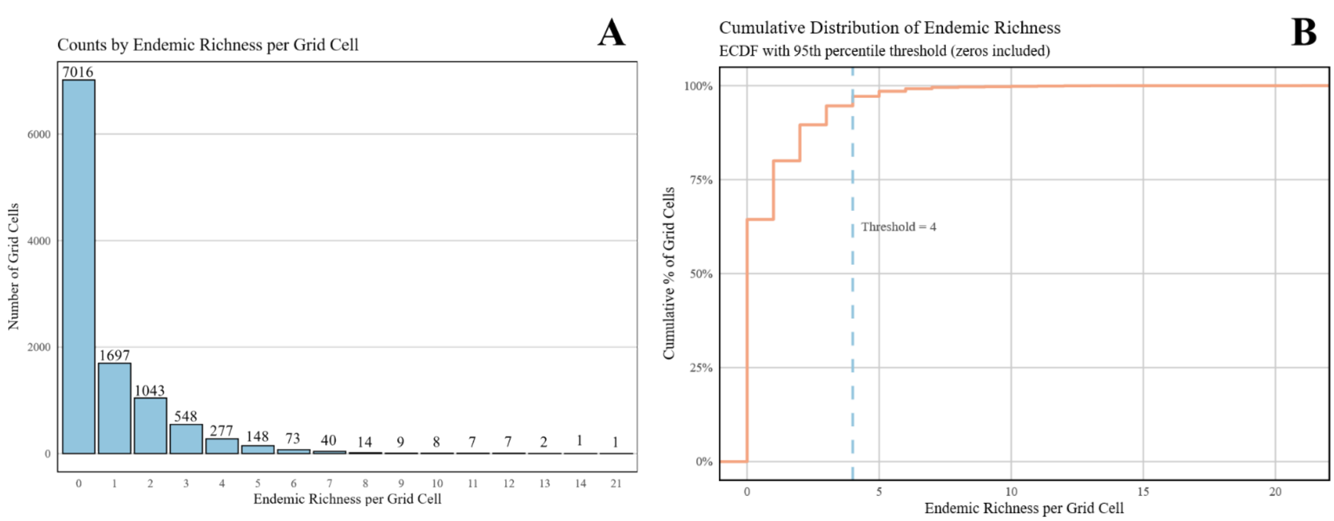

**Fig. 3** Distribution and cumulative frequency of endemic richness across grid cells. (**a**) Bar plot showing the number of grid cells for each endemic richness value, including cells with zero richness; absolute counts are displayed above each bar. (**b**) Empirical cumulative distribution function (ECDF) of endemic richness, with the dashed line indicating the 95th percentile threshold (richness = 4).

**Table 2** Number of hotspots, total hotspot area ($km^2$), and mean hotspot area ($km^2$) for each island of the Azores archipelago. Hotspots are defined as grid cells containing at least five endemic species.

| Island | Number of Hotspots | Total Area ($km^2$) | Mean Area ($km^2$) |
|---|---|---|---|
| Corvo | 2 | 5.138 | 2.569 |
| Faial | 2 | 8.155 | 4.077 |
| Flores | 7 | 11.048 | 1.578 |
| Graciosa | 7 | 5.851 | 0.836 |
| Pico | 17 | 68.318 | 4.019 |
| Santa Maria | 5 | 1.738 | 0.348 |
| São Jorge | 13 | 9.869 | 0.759 |
| São Miguel | 19 | 28.225 | 1.486 |
| Terceira | 8 | 25.958 | 3.245 |

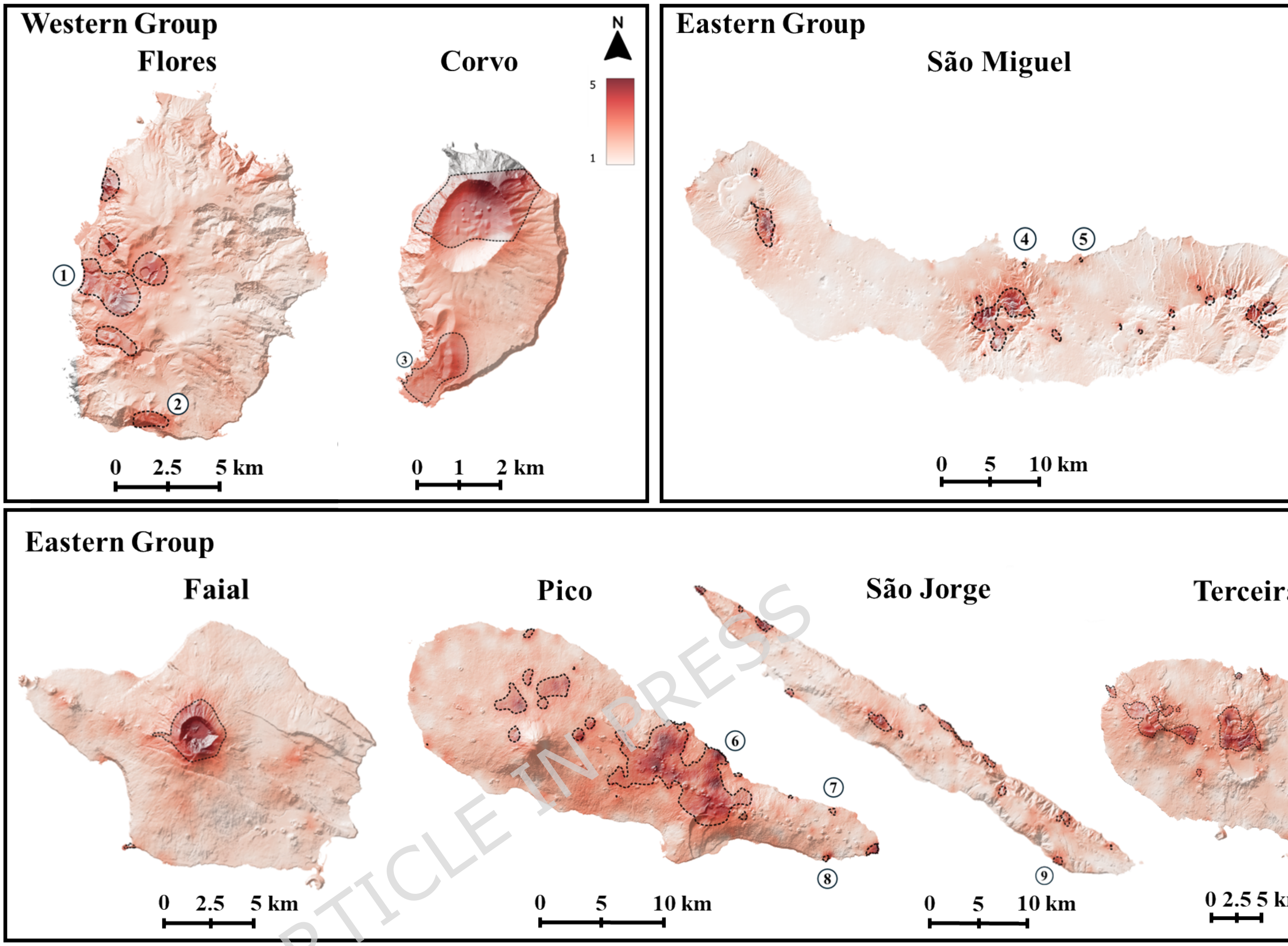


**Fig. 4** Spatial distribution of Azorean endemic plant richness and identified hotspots across the archipelago. Maps show richness values per grid cell; darker shading indicates higher richness. Dashed outlines represent richness hotspots, defined as cells with ≥ 5 endemic species. Numbered hotspots represent hotspot areas lacking legal protection.