

Unveiling floristic diversity in the High Atlas: Insights from a protected reserve in a global Mediterranean biodiversity hotspot

S. Elgadi*, **, H. Zine***, Y. Dallahi****, A. Ouhammou**

*IMBE, Aix Marseille University, Avignon University, CNRS, IRD, Marseille, France

**Cadi Ayyad University, Marrakech, Morocco

***Mohammed VI Polytechnic University, Ben Guerir, Morocco

****Mohammed V University in Rabat, Rabat, Morocco

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IMBE, Aix Marseille University, Avignon University,
CNRS, IRD, Marseille, France. Tel.: +212-670-69-32-23.
E-mail: sara.elgadi@imbe.fr

Laboratory of Microbial Biotechnologies, Agrosciences, and
Environment (BioMAGE), Labeled Research Unit-CNRS
N°4, Faculty of Sciences Semlalia, Cadi Ayyad University,
Marrakech, 40000, Morocco. Tel.: +212-676-52-20-39.
E-mail: ouhammo.u@gmail.com

Geology and Sustainable Mining Institute (GSMI),
Mohammed VI Polytechnic University, Ben Guerir, 43150,
Morocco. Tel.: +212-670-19-57-63.
E-mail: zine.hamza@um6p.ma

Laboratory of Plant Biotechnology and Physiology (BioPV),
Research Center on Plant and Microbial Biotechnology,
Biodiversity and Environment, Faculty of Sciences, Moham-
med V University in Rabat, Rabat, 10000, Morocco.
Tel.: +212-657-25-10-60.
E-mail: youssef.dallahi@fsr.um5.ac.ma

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Plant species represent a hierarchical expression of vegetation, influenced by various environmental factors. With the growing awareness of the importance of ecological restoration and conservation, there is an increasing need to study and understand flora, its species composition, and its distribution to facilitate preservation and conservation efforts. This study aimed to investigate the floristic composition, plant diversity, and provide a comprehensive phyto-ecological analysis of the Amassine Reserve within the Toubkal National Park in Morocco. To achieve this, quantitative ecological techniques were employed to sample vegetation. In total, 154 phyto-ecological surveys were conducted, recording 116 vascular plant species, which belong to 101 genera and 40 different families. Asteraceae represented 16.2% of the species, followed by Lamiaceae and Leguminosae, each represent 7.7% of the total flora. The phytoecological analysis combined with principal correspondence analysis of the floristic composition revealed four distinct plant formations: Frankeniaceae, newly characterized shrub stands of saline areas, *Tetraclinaria*, *Juniperia*, and holm oak plant stand. Each of these plant formations is described by its geographical distribution, its floristic composition and its ecological conditions. This study provides crucial baseline data of the flora of this area. The findings offer a valuable resource for stakeholders involved in decision-making and the development of effective conservation strategies for this protected area.

Keywords: biodiversity; flora; plant ecology; mountains; Morocco.

Introduction

Morocco, one of the richest countries in the Mediterranean region in terms of biodiversity and patrimonial habitats, boasts 64 key biodiversity areas (Critical Ecosystem Partnership Fund, 2017. Ecosystem Profile: Mediterranean Basin Biodiversity Hotspot). This richness and high rate of endemism are primarily shaped by the country's diverse ecological conditions, which are among the most varied in the Mediterranean (Ben Salem et al., 2023). Morocco's unique geographical positioning – bordered by the Atlantic Ocean and the Mediterranean Sea, with its majestic mountain ranges (the Rif and Atlas Mountains, including Toubkal, North Africa's highest peak at 4,167 m), and the desert in the south and southeast – significantly influences its biodiversity (Médail & Quézel, 1997). The cold Canary Island currents further enhance Morocco's bioclimatic variety, contributing to its ecological diversity (Benabid, 2000). This ecological abundance supports 3,913 vascular plant species, including 1,298 subspecies spread across 981 genera and 155 families (Fennane & Ibn Tattou, 2012). Morocco is notable for its high number of endemic taxa (878), which represent 22% of its flora, with 250 endemic taxa located in the Atlas Mountains alone (Fennane, 2004; Rankou et al., 2013). Such richness underscores the importance of the High Atlas (HA) as a key diversity area in Morocco. However, degradation and modification of landscapes and natural resources pose serious challenges, particularly in developing countries like Morocco (Taleb & Fennane, 2019). The predominantly rural population's dependence on these resources has led to habitat fragmentation and a decline in species richness, presenting major environmental

and societal challenges (Hammada et al., 2004). As a result, the scientific community and national stakeholders heavily rely on protected areas, especially natural fenced areas such as the Amassine Reserve, to protect and sustainably exploit natural resources (Alaoui et al., 2011).

In natural ecosystems, environmental gradients directly and indirectly influence vegetation dynamics and structure (Whittaker, 1967). Microclimatic conditions shape plant characteristics and traits, contributing to vegetation heterogeneity (Kömer, 2003). Vegetation is classified based on physiognomy, functional combinations, or component species defining its physical form (Kent, 2012). Species with similar structural, floristic traits, and environmental tolerances are grouped into distinct plant communities, which form the foundation of Earth's largest biomes (Mueller-Dombois & Ellenberg, 1974). Understanding vegetation structure, habitat, niche, and species interactions is crucial for ecological studies (Tilman, 1982). Researchers have explored the interplay between environmental factors and vegetation structure and composition (Austin & Smith, 1989). Topography (slope, aspect, and elevation) affects climate, temperature, and evapotranspiration, influencing vegetation diversity (Bennie et al., 2008). Edaphic factors, impacted by climate, topography, time, organisms, and parent materials, also determine plant growth (Jenny, 1994). Scientists employ quantitative analysis to revise vegetation features and assess their effects on vegetation dynamics and associated flora.

Traditionally, ecologists classified vegetation using the concept of dominant species to define potential plant communities and associations (Braun-Blanquet, 1964). Recently, multivariate statistics offered a more objective, less biased method for grouping vegetation (McCune & Grace,

2002). The Amassine Reserve, located in the foreland of the High Atlas of Marrakech within the peripheral area of Toubkal National Park, has not been studied using phyto-ecological methods combined with multivariate statistical approaches. This site was selected for its significant scientific interest regarding floristic diversity and its crucial role in conserving threatened wildlife, particularly the Barbary sheep (*Ammotragus lervia* Pallas, 1777) population (Ramzi et al., 2018; Bachiri et al., 2021).

This research aims to evaluate plant community formation, the driving factors, and indicator species of each group using robust phytoecological and floristic analyses. It seeks to explain complex plant distribution patterns and species composition. The study hypothesizes that different environmental factors contribute to the formation of distinct plant communities, each characterized by specific indicators. The research questions whether an indicator species approach can identify plant communities in relation to environmental factors.

Materials and methods

Study area. The study area is a fenced enclosure spanning approximately 1,000 hectares (31°11' to 31°12' N and 8°01' to 8°02' W; 950–1,300 m a.s.l.), established in 1996 to promote the conservation of *Ammotragus lervia* (Pallas, 1777), commonly known as the Barbary sheep (Bachiri et al., 2021). This protected zone is situated within the peripheral region of Toubkal National Park (Fig. 1), nestled on the nor-

thern side of the Western High Atlas Mountain range in Morocco. Located 56 km south of Marrakech and near Asni village, the study area lies close the epicenter of the Al Haouz earthquake. Geographically, it forms an integral part of the N'fiss watershed. The diverse topography and elevation gradient within the enclosure create a rough landscape with complex geomorphology, making it an interesting site for conservation efforts and scientific research. According to climatic data (2001–2020) downloaded from <https://power.larc.nasa.gov>, the climate is typically semi-arid Mediterranean type. The dry period lasts 4–5 months (June–October). January is the coldest month with an average temperature of 5.38 °C, and July is the hottest. Rainfall is low and erratic with pronounced inter-annual variations (Fig. 2).

The study area is located on the northern margin of the High Atlas of Marrakech, encompassing geological formations dating back to the Permo-Triassic period. The region's geology can be divided into three distinct zones. Western Zone: this area is characterized by Triassic basalt dolerite intrusions, accompanied by saliferous mudstone and gypsiferous deposits. Central Zone: Cretaceous formations dominate this region, primarily consisting of gray clay and red conglomerates. Peripheral Zones: quaternary formations are prevalent in these areas, particularly along the waterways (Fig. 2). The hydrographic network of the study area is defined by the Assif Amassine, a tributary that feeds into the Assif Marigha. This seasonal river originates at an altitude of 1200 m, at a col (mountain pass) that separates the Marigha basin from neighboring watersheds.

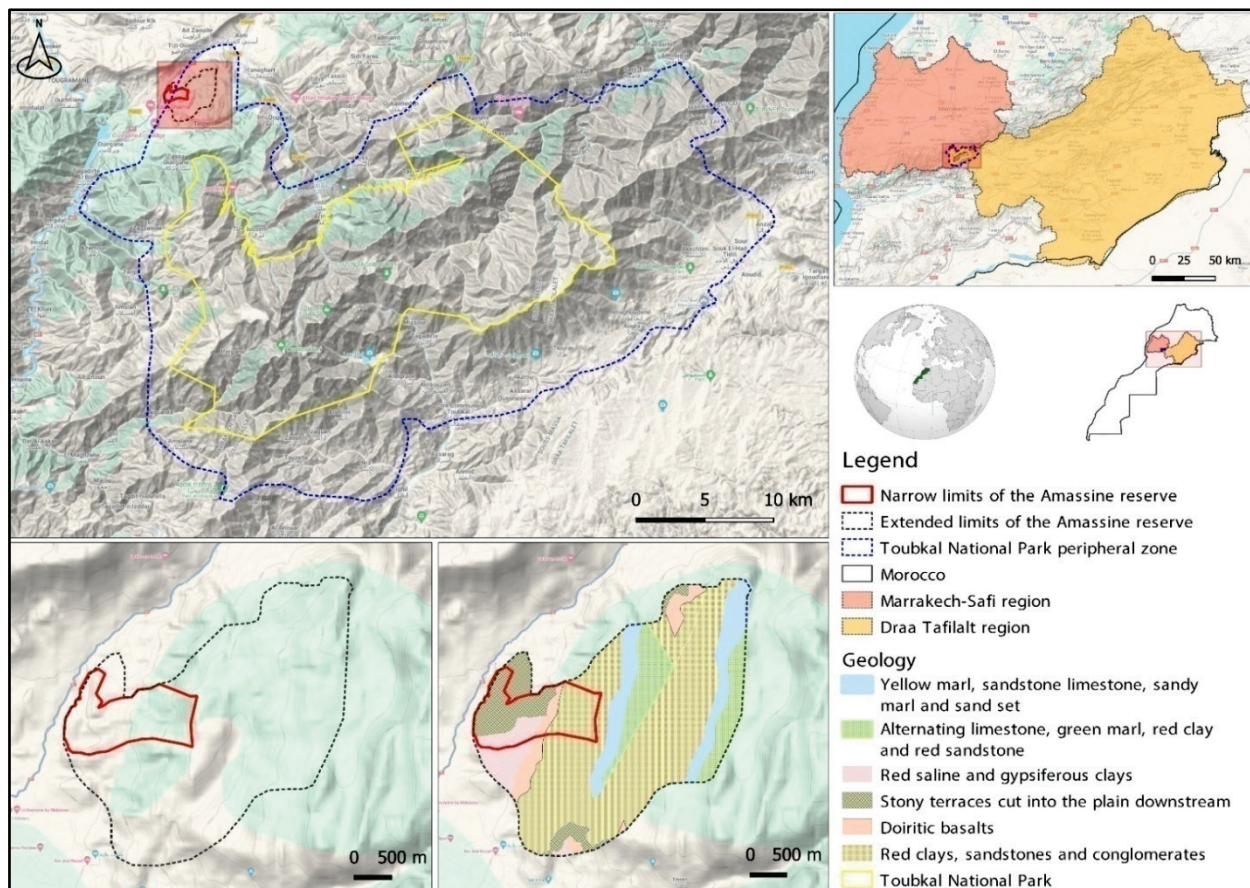


Fig. 1. Geographical location and geological composition of the Amassine Reserve, High Atlas, Morocco

Sampling method. Our research aimed to conduct a comprehensive assessment of the study area's plant communities, employing the phytoecological methodology outlined by Mueller-Dombois & Ellenberg (1974). The field surveys were conducted during the peak phenological period from February to June, coinciding with the anthesis of most perennial species and the flowering of numerous therophytes. Floristic relevés were performed using a stratified random sampling approach, with site selection based on species richness, geomorphological heterogeneity, and the altitudinal gradient (970–1120 m a.s.l.). At each relevé of an area of ranging from 200 to 400 m² and adapted to changes in vegetation types or

station parameters, as well, we recorded geospatial data (latitude and longitude), elevation, and compiled exhaustive species inventories. The relative abundance of each plant species within the sampled relevé was quantified using the Braun-Blanquet cover-abundance scale. These phytoecological surveys encompassed 156 relevés, adhering to the Braun-Blanquet method (1964) for vegetation analysis. The floristic data collection focused on (i) species composition and richness; (ii) horizontal distribution patterns and (iii) plant community and assemblages. This comprehensive approach allowed for a robust assessment of the area's plant community composition, structure, and spatial distribution, facilitating the

identification of distinct phytocoenoses and their ecological relationships within the landscape.

Taxonomic identification of the documented taxa was conducted using the comprehensive "Flore pratique du Maroc" (Fennane et al., 1999, 2007, 2014) as the primary reference. To ensure adherence to current

systematic standards, plant nomenclature was subsequently updated in accordance with the Angiosperm Phylogeny Group IV classification system (APG IV, 2016). The functional diversity of the flora was assessed through the classification of species into Raunkiaerian life-form categories (Raunkiaer, 1934; Ellenberg & Mueller-Dombois, 1967).



Fig. 2. Climatic features of the Amassine Reserve area, High Atlas, Morocco

Statistical analysis. To delineate distinct plant assemblages, we employed Correspondence Factorial Analysis (CFA) as a multivariate ordination technique. This statistical approach facilitated the analysis of complex ecological data matrices and the identification of floristically homogeneous vegetation units. The CFA was applied to abundance species composition data, enabling the detection of underlying ecological gradients and the subsequent classification of surveys into coherent plant groups. The resulting ordination biplot provided a visual representation of the multidimensional ecological space, effectively discriminating between plant stands based on their floristic affinities.

Results

Plants diversity and floristic analysis. Despite the limited size of the study area, our floristic survey uncovered considerable taxonomic richness (Fig. 1). The comprehensive plant inventory, as detailed in Table 1, identified 116 vascular plant species from 101 genera across 40 families.

This diversity highlights the area's significant contribution to regional phytodiversity. A taxonomic analysis revealed a distinct dominance hierarchy among families, with Asteraceae being the most species-rich, followed by Lamiaceae and Leguminosae (each representing 7.9% of total species richness). Asparagaceae and Poaceae jointly held the third rank (each contributing 6.8%). A notable feature of the site's floristic composition is the high proportion of monotypic family representation, with approximately 57.5% of all families represented by a single species. This taxonomic singularity includes a wide variety of families such as Resedaceae, Aizoaceae, Anacardiaceae, Apocynaceae, Areaceae, Asclepiadaceae, Boraginaceae, Convolvulaceae, Ephedraceae, Euphorbiaceae, Fagaceae, Frankeniaceae, Geraniaceae, Globulariaceae, Linaceae, Malvaceae, Plumbaginaceae, Polygonaceae, Polypodiaceae, Primulaceae, Rhamnaceae, Rutaceae, and Tamaricaceae.

Table 1

Plant species checklist at the Amassine Reserve in Morocco's High Atlas mountains

Plant family	Species	Code	Life form
Aizoaceae	<i>Aizoanthemopsis hispanica</i> (L.) Klak	Ai.hi	Th
Brassicaceae	<i>Alyssum simplex</i> Rudolphi	Al.si	Th
Asclepiadaceae	<i>Apteranthes europaea</i> (Guss.) Murb.	Ap.eu	Ch
Asteraceae	<i>Artemisia herba-alba</i> Asso	Ar.he	Ch
Asparagaceae	<i>Asparagus acutifolius</i> L.	As.ac	NPh
Asparagaceae	<i>Asparagus albus</i> L.	As.al	NPh

Plant family	Species	Code	Life form
Asparagaceae	<i>Asparagus horridus</i> L.	As.ho	Ch
Asparagaceae	<i>Asphodelus ramosus</i> L.	As.ra	G
Polypodiaceae	<i>Asplenium ceterach</i> L.	As.ce	G
Asparagaceae	<i>Astragalus</i> sp. L.	As.de	Hém
Asteraceae	<i>Atractylis cancellata</i> L.	At.ca	Th
Chenopodiaceae	<i>Atriplex halimus</i> L.	At.ha	Nph
Poaceae	<i>Avena sativa</i> L.	Av.sa	Th
Asteraceae	<i>Bellis annua</i> L.	Be.an	Th
Brassicaceae	<i>Biscutella didyma</i> Pall.	Bi.di	Th
Leguminosae	<i>Bituminaria bituminosa</i> (L.) C.H.Stirt.	Bi.bi	Hém
Poaceae	<i>Bromus intermedius</i> Guss.	Br.in	Th
Boraginaceae	<i>Buglossoides arvensis</i> (L.) I.M.Johnst.	Bu.ar	Th
Apiaceae	<i>Bupleurum dumosum</i> Coss. & Balansa	Bu.du	Ch
Asteraceae	<i>Calendula arvensis</i> L.	Ca.ar	Th
Asteraceae	<i>Carlina brachylepis</i> (Batt.) Meusel & A.Kastner	Ca.br	Hém
Asteraceae	<i>Centaurea involucreta</i> Desf.	Ce.in	Th
Areaceae	<i>Chamaerops humilis</i> L.	Ch.hu	NPh
Chenopodiaceae	<i>Chenopodium murale</i>	Ch.mu	Th
Oleaceae	<i>Chrysojasmium fruticosum</i> (L.) Banfi	Ch.fr	Nph
Cistaceae	<i>Cistus creticus</i> L.	Ci.cr	Ch
Cistaceae	<i>Cistus salvifolius</i> L.	Ci.sa	Ch
Asteraceae	<i>Cladanthus arabicus</i> (L.) Cass.	Clar	Th
Convolvulaceae	<i>Convolvulus althaeoides</i> L.	Co.al	Hém
Leguminosae	<i>Coronilla viminalis</i> Salisb.	Co.vi	Nph
Poaceae	<i>Dactylis glomerata</i> L.	Da.gl	Th
Apiaceae	<i>Daucus crinitus</i> Desf.	Da.cr	G
Brassicaceae	<i>Diplotaxis tenuisiliqua</i> Delile	Di.te	Th
Asteraceae	<i>Dittrichia viscosa</i> (L.) Greuter	Di.vi	Ch
Asparagaceae	<i>Drimia maritima</i> (L.) Steam	Di.m	G
Asparagaceae	<i>Drimia undata</i> Steam	Di.un	G
Leguminosae	<i>Eberus pinnata</i> Aiton	Eb.pi	Ch
Asteraceae	<i>Echinops strigosus</i> L.	Ec.st	Th
Ephedraceae	<i>Ephedra fragilis</i> Desf.	Ep.fr	Nph
Geraniaceae	<i>Erodium malacoides</i> (L.) L'Hér.	Er.ma	Th
Apiaceae	<i>Eryngium tricuspdatum</i> L.	Er.tri	Hém
Apiaceae	<i>Eryngium triquetrum</i> Vahl	Er.tr	Hém
Euphorbiaceae	<i>Euphorbia nicaeensis</i> All.	Eu.ni	Hém
Poaceae	<i>Festuca coerulescens</i> Desf.	Fe.co	Hém
Asteraceae	<i>Filago germanica</i> (L.) Huds.	Fi.ge	Th
Frankeniaceae	<i>Frankenia corymbosa</i> Desf.	Fr.co	Ch
Cistaceae	<i>Fumana laevipes</i> Spach	Fu.la	Ch
Cistaceae	<i>Fumana thymifolia</i> Spach	Fu.th	Ch
Papaveraceae	<i>Glaucium corniculatum</i> (L.) Curtis	Gl.co	Th
Globulariaceae	<i>Globularia alypum</i> L.	Gl.al	Ch
Cistaceae	<i>Helianthemum croceum</i> (Desf.) Pers.	He.cr	Ch
Cistaceae	<i>Helianthemum hirtum</i> Mill.	He.hi	Ch

Plant family	Species	Code	Life form	Plant family	Species	Code	Life form
Brassicaceae	<i>Hirschfeldia incana</i> (L.) Lagr.-Foss.	Hi.in	Hém	Crassulaceae	<i>Petrosedum sediforme</i> (Jacq.) Grulich	Pe.se	Ch
Poaceae	<i>Hyparrhenia hirta</i> (L.) Stapf	Hy.hi	Hém	Asteraceae	<i>Phagnalon saxatile</i> (L.) Cass.	Ph.sa	Ch
Asteraceae	<i>Hypochoeris achyrophorus</i> L.	Hy.ac	Th	Oleaceae	<i>Phillyrea angustifolia</i> L.	Phan	Ph
Cupressaceae	<i>Juniperus oxycedrus</i> L.	Ju.ox	Ph	Anacardiaceae	<i>Pistacia lentiscus</i> L.	Pi.le	Ph
Cupressaceae	<i>Juniperus phoenicea</i> L.	Ju.ph	Ph	Plantaginaceae	<i>Plantago afra</i> L.	Plaf	Th
Plantaginaceae	<i>Kickxia aegyptiaca</i> (L.) Nábelek	Ki.ae	Th	Plantaginaceae	<i>Plantago ovata</i> Forsskal.	Pl.ov	Th
Asteraceae	<i>Launaea arborescens</i> (Batt.) Murb.	La.ar	Nph	Polygalaceae	<i>Polygala munbyana</i> Boiss. & Reuter	Po.mu	Ch
Lamiaceae	<i>Lavandula dentata</i> L.	La.de	Ch	Polygalaceae	<i>Polygaloides balansae</i> (Coss.) O.Schwarz	Po.ba	Nph
Lamiaceae	<i>Lavandula tenuisecta</i> Coss.	La.te	Ch	Asteraceae	<i>Pulicaria mauritanica</i> Batt.	Pu.ma	Ch
Asparagaceae	<i>Leopoldia comosa</i> (L.) Parl.	Le.co	G	Fagaceae	<i>Quercus ilex</i> L.	Qu.il	Ph
Plumbaginaceae	<i>Limonium lobatum</i> Kuntze	Li.lo	Th	Resedaceae	<i>Reseda alba</i> L.	Re.al	Th
Plumbaginaceae	<i>Limonium ornatum</i> (Ball) O. Kuntze	Li.or	Hém	Resedaceae	<i>Reseda lutea</i> L.	Re.lu	Th
Linaceae	<i>Linum numidicum</i> Murb.	Li.nu	Ch	Rhamnaceae	<i>Rhamnus lycioides</i> L.	Rh.ly	Nph
Leguminosae	<i>Lotus corniculatus</i> L.	Lo.co	Hém	Asteraceae	<i>Rhodanthemum gayanum</i> (Coss. & Durieu)	Rh.ga	Ch
Leguminosae	<i>Lotus maroccanus</i> Ball.	Lo.ma	Hém	B.H.Wilcox, K.Bremer & Humphries			
Poaceae	<i>Lygeum spartum</i> Loeff. ex L.	Ly.sp	G	Polygonaceae	<i>Rumex bucephalophorus</i> L.	Ru.bu	Th
Primulaceae	<i>Lysimachia arvensis</i> (L.) U.Manns & Anderb.	Ly.ar	Th	Rutaceae	<i>Ruta chalepensis</i> L.	Ru.ch	Ch
Poaceae	<i>Macrochloa antiatlantica</i> (Barena & al.) H. Scholz & Valdes	Ma.an	Hém	Chenopodiaceae	<i>Salsola oppositifolia</i> Desf.	Sa.op	Nph
Malvaceae	<i>Malva parviflora</i> L.	Ma.pa	Th	Chenopodiaceae	<i>Salsola vermiculata</i> L.	Sa.ve	Ch
Lamiaceae	<i>Marrubium vulgare</i> L.	Ma.vu	Ch	Lamiaceae	<i>Salvia aegyptiaca</i> L.	Sa.ae	Ch
Leguminosae	<i>Medicago scutellata</i> (L.) Mill.	Me.sc	Th	Asteraceae	<i>Senecio vulgaris</i> L.	Se.vu	Th
Leguminosae	<i>Melilotus sulcatus</i> Desf.	Me.su	Th	Lamiaceae	<i>Sideritis hirsuta</i> L.	Si.hi	Ch
Plantaginaceae	<i>Misopates oranense</i> (Faure) D.A.Sutton	Mi.or	Th	Caryophyllaceae	<i>Silene vulgaris</i> (Moench) Garcke	Si.vu	G
Plantaginaceae	<i>Misopates orontium</i> (L.) Rafin.	Mi.oro	Th	Asteraceae	<i>Sonchus tenerrimus</i> L.	So.te	Th
Amaryllidaceae	<i>Narcissus bulbocodium</i> L.	Na.bu	G	Lamiaceae	<i>Stachys</i> sp. L.	Star	Th
Amaryllidaceae	<i>Narcissus tazetta</i> L.	Na.ta	G	Asteraceae	<i>Staelina dubia</i> L.	St.du	Ch
Apocynaceae	<i>Nerium oleander</i> L.	Ne.ol	Nph	Poaceae	<i>Stipa capensis</i> Thunb	St.ca	Th
Oleaceae	<i>Olea europaea subsp. oleaster</i> (Hoffm. & Link) Negodi	OLeu	Ph	Tamaricaceae	<i>Tamarix gallica</i> L.	Ta.ga	Ph
Leguminosae	<i>Ononis natrix</i> L.	On.na	Ch	Cupressaceae	<i>Tetraclinis articulata</i> (Vahl) Masters	Te.ar	Ph
Asteraceae	<i>Pallenis spinosa</i> (L.) Cass.	Pa.sp	Hém	Lamiaceae	<i>Teucrium fruticans</i> L.	Te.fr	Nph
Papaveraceae	<i>Papaver rhoeas</i> L.	Pa.rh	Th	Lamiaceae	<i>Thymus saturejoides</i> Cosson	Th.sa	Ch
Caryophyllaceae	<i>Paronychia argentea</i> Lam.	Pa.ar	Hém	Leguminosae	<i>Tripodion tetraphyllum</i> (L.) Fourr.	Tr.te	Th
				Crassulaceae	<i>Umbilicus horizontalis</i> DC.	Um.ho	G

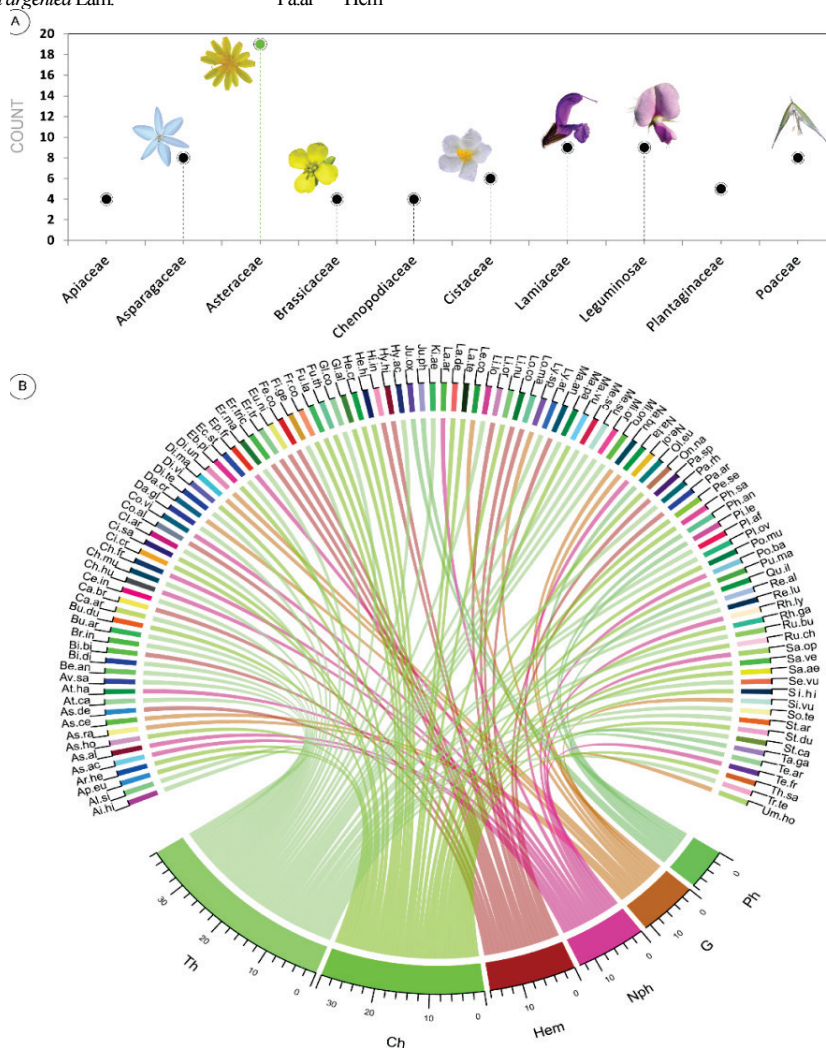


Fig. 3. Global taxonomic family diversity, their specific richness (a) and biological spectrum of the flora in the Amassine Reserve, High Atlas, Morocco: Pha – phanerophyte; Nphan – nanophanerophyte; Hem – hemicytophyte; Cham – chamaephyte; Geo – geophyte; Th – therophyte

The floristic inventory also revealed a diverse array of Raunkiaerian life forms, each varying in abundance (Fig. 3). Therophytes were the dominant life form, with 38 taxa constituting 32.8% of the total flora. Chamaephytes were the next most abundant, making up 25.9% (30 species) of the surveyed flora, which suggests adaptations to harsh environmental conditions and grazing pressure. Hemicryptophytes had a moderate presence with 16 species (13.8%), while nanophanerophytes, geophytes, and phanerophytes were less prevalent, representing 11.2%, 9.5%, and 6.9% of the flora, respectively.

Endemic and threatened flora. Our floristic inventory revealed a significant endemic component, with 15 taxa exhibiting various degrees of geographic restriction. Notably, six species demonstrate strict Moroccan endemism: *Bupleurum dumosum* Coss. & Balansa, *Coronilla viminialis*

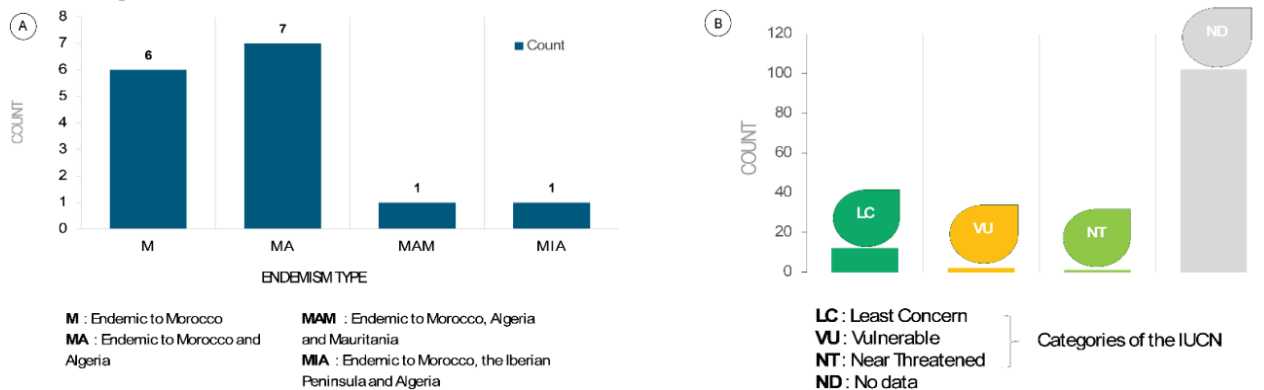


Fig. 4. Endemic plant species (a) and the threatened flora according to the IUCN Red List categories (b) in the Amassine Reserve, High Atlas, Morocco

Phytocoological analysis and plant grouping. The phytocoological analysis and ecological characterization of vegetation assemblages in the study area were conducted based on physiognomy and ecological determinants. A preliminary ordination of all relevés, using indicator species analysis, aimed to delineate floristically homogeneous units and identify distinct plant communities. These phytocoenoses were described and characterized by their unique floristic composition and specific ecological drivers. The selection of diagnostic species for each community was based on their frequency across the constituent relevés.

The Factorial Correspondence Analysis (FCA) (Fig. 5) elucidates the relationships, dependencies, and correlations among variables within the data matrix. In pursuit of this objective, we have compiled the data from the relevés, which includes a comprehensive overview of plant species, environmental parameters. The eigenvalues, indicative of the variance explained by each axis in the scatter plot, are remarkably high. This suggests a well-defined block partition structure within the data. The factorial plane, defined by the first two dimensions, accounts for 50.8% of the total inertia of the analyzed dataset, highlighting the predominance of dimension 1, which alone explains 32.9% of the inertia and demonstrates the Guttman effect. The robustness of these dimensions in capturing the dataset's inertia underscores the utility of FCA in ecological studies, where understanding the multidimensional relationships between species and environmental variables is essential.

The FCA analysis facilitated the distinction of four plant groups: (I) *Frankenia corymbosa* dominated halophytic communities (Frankenaie), (II) *Tetraclinis articulata* woodlands (Tetraclinaie), (III) *Juniperus phoenicea* formations (Juniperaie), and (IV) *Quercus ilex* formation (Chenaie). Each of these phytocoenoses exhibits a defined spatial distribution within the landscape matrix.

Given the predominance of *Tetraclinis* and *Juniperus* formations in the study area, accounting for 58.4% (90 relevés) and 25.4% (39 relevés) of the samples respectively, these communities were further stratified into distinct facies. This subclassification was based on topographical variables, specifically aspect (categorized into north and south facing sectors) and altitudinal gradients, to elucidate fine scale vegetation patterns and potential ecotonal transitions. This hierarchical classification of plant communities provides insights into the β - diversity and niche partitioning within the landscape.

Frankeniaceae. The halophytic community dominated by *Frankenia corymbosa* predominantly occupies low elevations, depressions, and

Salisb., *Lavandula tenuisecta* Coss., *Limonium ornatum* (Ball) O. Kuntze, *Macrochloa antiatlantica* (Barrena et al.) H. Scholz & Valdes, and *Polygalaoides balansae* (Coss.) O. Schwarz. The floristic inventory of the study area reveals a notable presence of taxa with conservation significance, as evaluated by both global and national threat assessment frameworks. Figure 4 illustrates the distribution of species across various IUCN Red List categories. Two plant species, *Thymus saturejoides* Cosson and *Limonium ornatum* (Ball) O. Kuntze, are categorized as Vulnerable (VU) according to IUCN criteria, indicating a high risk of extinction. Furthermore, *L. ornatum* is also classified as Near Threatened (NT) in the Moroccan Red Book, underscoring its national conservation importance. Additionally, 12 plant species fall within the Least Concern (LC) category of the IUCN Red List.

projecting ledges within the study area. This edaphically specialized formation is exclusively confined to saline substrates within the enclosure, and the present study represents its inaugural phytocoological racterization. The diagnostic species assemblage of this halophytic community includes *Frankenia corymbosa*, *Lygeum spartum*, *Limonium ornatum*, and *Salsola vermiculata*, with the former two exhibiting pronounced halophytic adaptations. Despite the restrictive edaphic and topographic parameters defining this community (high salinity, low elevation, and minimal slope), it harbors a surprisingly high α -diversity, encompassing 30 vascular plant species. Notably, this assemblage includes two Moroccan endemics: *Limonium ornatum*, which is also classified as a Moroccan endemic. Additionally, the presence of *Polygala munbyana*, an Algero-Moroccan endemic, further underscores the biogeographical significance of this formation.

Juniperaie. The *Juniperus phoenicea* dominated formation exhibits a broad altitudinal amplitude, spanning from 900 to 2200 m a.s.l., predominantly occupying south facing, steep slopes. This sclerophyllous shrubland community, established on Triassic substrates, is characterized by an open canopy structure with appreciable cover of phanerophytes. The diagnostic species assemblage includes *Juniperus phoenicea*, *Tetraclinis articulata*, *Pistacia lentiscus*, *Phagnalon saxatile*, *Ebenus pinnata*, *Paronychia argentea*, and *Lavandula dentata*. This formation exhibits notable internal heterogeneity, differentiated into four distinct facies based on topographic and edaphic variables:

– Northern *Juniperaie* – Low altitude: This prevalent facies (11 relevés) develops on muddy clay substrates with gentle slopes at a mean elevation of 997 m. The dominant species include *Stipa capensis*, *Bituminaria bituminosa*, and *Malva parviflora*.

– Southern *Juniperaie* – Low altitude: Occurring at a mean elevation of 1025 m, this facies is characterized by 33 species and develops on Triassic clay soils. Differential species include *Artemisia herba alba* and the Moroccan endemic *Macrochloa antiatlantica*, with *Phyllirea angustifolia* and *Launaea arborescens* as predominant taxa. Notably, this facies harbors two range restricted species: *Bupleurum dumosum* (Moroccan endemic) and *Polygala balansae* (Ibero Moroccan endemic).

– Southern *Juniperaie* – High altitude: This facies occupies south facing upper slopes at a mean elevation of 1256 m, developing on calcareous clay substrates with steep gradients. The floristic composition includes 25 vascular plant species, including two Moroccan endemics: *Macrochloa antiatlantica* and *Lavandula tenuisecta*. Differential species include

Filago germanica, *Lavandula tenuisecta*, *Bellis annua*, and *Caralluma europaea*.

– Northern *Juniperiaie* – High altitude: This least represented facies (four relevés) occur at a mean elevation of 1226 m in relatively mesic environments. It is differentiated by two endemic species: *Thymus satureioides* and *Pulicaria mauritanica*, both present in Morocco and Mauritania.

Tetraclinaie. The *Tetraclinaie* formation is prominently represented in this region, covering more than two-thirds of the area of interest and being represented in this study by 78 relevés. The dominant species within this formation is *Tetraclinis articulata*, accompanied by *Juniperus phoenicea*, *Ebenus pinnata*, *Stipa capensis*, and *Pistacia lentiscus*. Within the watershed of the Oued Rdat, this formation manifests through five distinct ecological facies, including *Olea europaea*, *Quercus rotundifolia* (*Quercus ilex*), *Ceratonia siliqua*, *Pinus halepensis*, *Juniperus phoenicea*, *Juniperus oxycedrus*, *Pistacia lentiscus*, and *Phillyrea angustifolia*. The lower stratum is dominated by *Cistus monspeliensis* and *Polygala balansae*, together with species such as *Globularia alypum*, *Thymus satureioides*, and *Thymus pallidus*.

This region's *Tetraclinaie* formation has been categorized into six facies. The first is the southern sector low-altitude facies, found at an average altitude of 1013 meters. This facies is notably distinguished by *Drimia undata* and *Plantago ovata* and is located on mid-slopes. It hosts four endemic species: *Thymus satureioides*, *Pulicaria mauritanica*, *Macrochloa antiallantica*, and *Limonium ornatum*. The second facies is the northern *Tetraclinaie* of low altitude, marked by species such as *Lavandula tenuisecta*, *Coryledon umbilicus*, *Bellis albus*, *Kikxia aegyptiaca*, *Eryngium tricuspidatum*, *Fumana thymifolia*, and *Coronilla viminalis*. This facies is situated on a Triassic substrate with predominately steep slopes at an average altitude of 1023 meters. The third facies is the northern *Tetraclinaie* of

mid-altitude, distinct due to a floristic composition largely comprising *Hyparrhenia hirta*, *Dactylis glomerata*, *Ericastrum incanum*, *Hypochaeris achyrophorus*, and *Filago germanica*. It resides on limestone and clay soils on steep slopes. The fourth facies, located in the southern sector at mid-altitudes, is characterized by the prevalence of xerophytic species such as *Cistus creticus*, *Asparagus albus*, and *Launaea arborescens*. The fifth facies, the northern *Tetraclinaie* of high altitude, occupies areas at about 1262 meters on argillaceous calcareous substrates with significant slopes. *Thymus satureioides*, *Dactylis glomerata*, *Cladanthus arabicus*, *Lotus corniculatus*, *Sonchus oleraceus*, *Jasminum frutescens*, and *Ephedra fragilis* dominate the flora, indicating the more humid conditions of this facies. The final facies is the southern sector high-altitude *Tetraclinaie*, characterized by relatively lower species richness, comprising 25 species. Prominent species include *Phillyrea angustifolia*, *Lavandula dentata*, *Cistus creticus*, and *Thymus satureioides*. These species are well-adapted to the sunny, rocky conditions prevalent on limestone substrates.

Green oak formation. The green oak formation in Morocco is commonly referred to as *Quercus ilex* L. (commonly known as "chêne vert," "Kerouch," or "Ballout lakhder"). In the Amassine area, this formation is less prevalent than previously reported, represented in this study by 17 relevés at altitudes ranging from 1304 to 1505 meters. The vegetation cover of this formation is significant, ranging from 40% to 80%, reflecting its mesic character and the predominance of the herbaceous layer. The dominant species within this formation is *Quercus ilex*, with *Juniperus phoenicea* and *Thymus satureioides* also prominent. Additional common species include *Globularia alypum*, *Juniperus oxycedrus*, *Olea europaea*, *Phillyrea angustifolia*, and *Pistacia lentiscus*, which are adapted to saline (halophilic) and warm (thermophilic) conditions. Differential species in this formation include *Bituminaria bituminosa* and *Cistus villosus*.

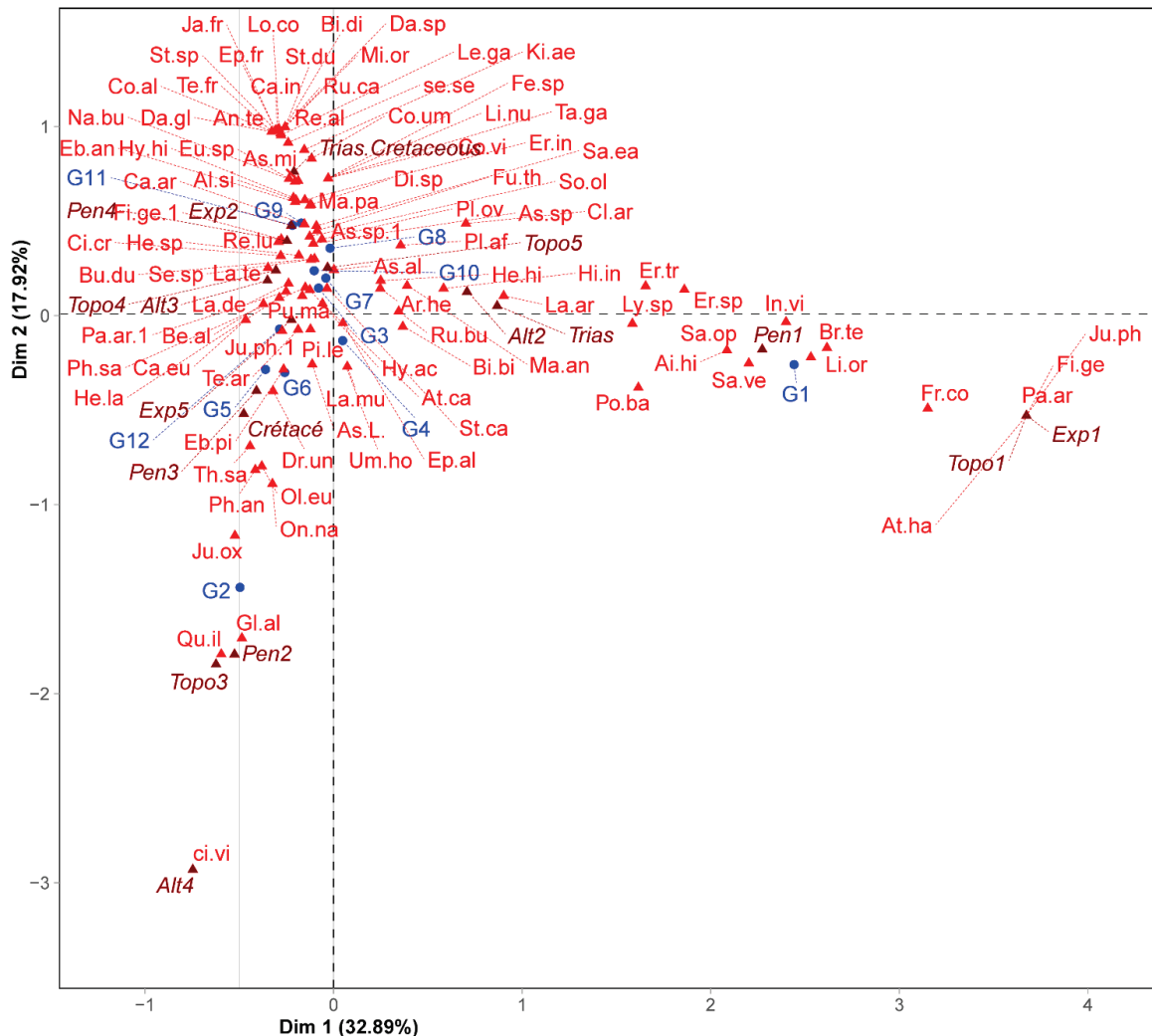


Fig. 5. Factorial correspondence analysis of vegetation surveys in the Amassine Reserve, High Atlas, Morocco

Discussion

Plants diversity. This familial distribution aligns with typical Mediterranean phytodiversity patterns (Maamar et al., 2018), particularly the prominence of Asteraceae, Poaceae, and Leguminosae (Blondel et al., 2010). The preeminence of Asteraceae corroborates its global status as the most diverse angiosperm family (World Flora Online. www.worldfloraonline.org), reflecting its remarkable adaptive radiation and niche diversification capabilities. The observed familial spectrum provides insights into the community's ecological dynamics. The dominance of Asteraceae, Lamiaceae, and Leguminosae suggests a community well adapted to Mediterranean climate regimes characterized by seasonal drought and recurrent disturbances. These families exhibit various adaptations, including sclerophylly, drought deciduousness, and nitrogen fixation, enhancing their resilience to environmental stressors (Cowling et al., 1996). Furthermore, the significant representation of Poaceae indicates the presence of a well-developed herbaceous layer, potentially influencing ecosystem processes such as nutrient cycling and fire regimes (Keeley et al., 2012). The notable diversity within Asparagaceae, atypical for many Mediterranean regions, warrants further investigation into potential local environmental or historical factors favoring this family. This taxonomic structure serves as a robust bioindicator of Mediterranean floristic affinities and offers valuable insights for conservation strategies. The high diversity within dominant families suggests the presence of numerous congeners, potentially leading to intense intrageneric competition and fine scale niche partitioning (Silvertown et al., 2006). This phenomenon may contribute to the overall community resilience but also presents challenges for conservation efforts focused on maintaining this intricate ecological balance. In the context of global change, understanding the adaptive capacities of these dominant families becomes crucial. Recent studies have shown differential responses of Mediterranean plant families to climate change, with some exhibiting greater phenological plasticity than others (Peñuelas et al., 2004). Long term monitoring of familial composition and abundance could provide early indicators of ecosystem shifts in response to environmental changes. Future research should focus on exploring the functional diversity within these dominant families, as functional traits often prove more informative than taxonomic identity in predicting ecosystem responses to environmental change (Díaz & Cabido, 2001).

This pattern of high monotypic family representation warrants further ecological interpretation (Rana & Ranade, 2009). The observed taxonomic structure may be indicative of several underlying ecological processes, such as (i) niche differentiation, given that presence of numerous monotypic families suggests a high degree of niche partitioning, potentially reflecting the diverse microhabitats within the study area, and/or (ii) biogeographical influences, since the site could represent a confluence of different floristic elements, incorporating species from various biogeographical realms. The high proportion of monotypic family representation also has implications for biodiversity conservation. These unique taxa may represent important components of phylogenetic diversity and could be particularly vulnerable to environmental changes or disturbances. Future research should focus on understanding the ecological requirements and population dynamics of these monotypic representatives to inform conservation strategies. Additionally, this floristic pattern presents an opportunity for comparative studies with other Mediterranean ecosystems to elucidate regional variations in community assembly processes and phylogenetic structure. Such investigations could provide valuable insights into the ecological and evolutionary mechanisms shaping plant communities in Mediterranean-type ecosystems globally. The preponderance of annual species is characteristic of semi-arid Mediterranean bioclimates, reflecting adaptations to seasonal water scarcity and unpredictable rainfall patterns (Naqinezhad et al., 2009; Zine et al., 2023). This life form spectrum provides insights into the community's ecological strategies and resilience. The dominance of therophytes suggests a community well adapted to temporal resource fluctuations, employing an escape strategy through rapid life cycles (Bellard et al., 2012). The significant presence of chamaephytes indicates adaptations to both climatic stress and disturbance regimes, often associated with increased ecosystem stability in Mediterranean environments (Gómez-González et al., 2017; Díaz-Barradas et al., 2020). The relatively low proportion of phanerophytes and nanophanerophytes may reflect his-

torical land use patterns, climatic constraints, or both. This pattern aligns with observations in other Mediterranean ecosystems where woody vegetation is limited by water availability and anthropogenic pressures (Blondel et al., 2010).

The life form distribution observed here has implications for ecosystem functioning and response to environmental change. Therophyte dominated communities often exhibit high temporal variability in biomass production and species composition, potentially affecting ecosystem services such as carbon sequestration and soil stabilization (Seligman & Henkin, 2003). This therophytization is attributed, on the one hand, to anthropogenic activities and, on the other hand, to the harsh climatic conditions. This phenomenon reflects the overall floristic richness of the herbaceous layer in these locations, while also highlighting the aridity of the environment. Conversely, the presence of perennial life forms (chamaephytes, hemicryptophytes, and phanerophytes) contributes to community stability and resistance to short term environmental fluctuations (Matesanz & Valladares, 2014). Long term monitoring of life form shifts could provide early indicators of ecosystem transitions and inform adaptive management strategies in Mediterranean type ecosystems (Vittoz et al., 2009).

Endemic and threatened flora. The study area, situated within the peripheral zone of Toubkal National Park (TNP), exemplifies the exceptional phytodiversity characteristic of Mediterranean Basin hotspots (Médail & Quézel, 1999). This region is distinguished by its remarkable floristic richness and high levels of endemism, serving as a crucial biodiversity refuge within a matrix of anthropogenically altered landscapes. This high proportion of endemic taxa underscores the area's significance as a center of neo and paleoendemism, reflecting both recent evolutionary radiations and the persistence of relict lineages (Thompson, 2005). The composition of threatened and near threatened taxa within the study area highlights its significance as a reservoir of biodiversity with conservation value. The presence of vulnerable species suggests that the site may serve as a refuge for populations facing decline elsewhere in their range. This aligns with the concept of "biodiversity hotspots" within Mediterranean ecosystems, where areas of high endemism often coincide with elevated extinction risk (Myers et al., 2000). The occurrence of *T. saturejoides* and *L. ornatum*, both with vulnerable status, warrants particular attention. These species may be indicative of specific habitat conditions or ecological processes that are becoming increasingly rare in the broader landscape. Their presence could be used to inform conservation prioritization and management strategies, as suggested by the "umbrella species" concept in conservation biology (Roberge & Angelstam, 2004). The predominance of LC species in the inventory, while seemingly less critical from a conservation perspective, should not be overlooked. These taxa contribute to the overall ecosystem functioning and may play crucial roles in supporting the persistence of more threatened species through various ecological interactions (Gaston & Fuller, 2008).

From a conservation perspective, the species composition presents both challenges and opportunities. The presence of threatened taxa necessitates targeted conservation efforts to mitigate extinction risks. Conversely, the coexistence of threatened and LC species within the same area provides an opportunity to implement integrated conservation strategies that maintain overall ecosystem integrity while addressing species specific threats (Heywood & Iriondo, 2003). Future research should focus on elucidating the ecological requirements and population dynamics of the vulnerable and near threatened species. Understanding their life history traits, reproductive biology, and responses to environmental stressors will be crucial for developing effective conservation measures. Moreover, investigating potential climate change impacts on these species' distributions and abundances is essential for proactive conservation planning (Thuiller et al., 2005). Long term monitoring of population trends for all IUCN listed species in the area is recommended to detect early signs of decline and inform adaptive management strategies. Additionally, exploring the genetic diversity within these populations could provide insights into their evolutionary potential and resilience to environmental changes (Frankham, 2005).

Plant grouping. Studies such as those by ter Braak and Šmilauer (1988) emphasize the significance of multivariate analyses like FCA in unravelling complex ecological datasets by highlighting patterns and gradients that may not be readily apparent through univariate analyses. Thus,

employing FCA offers a nuanced understanding of how specific plant species respond to varying environmental conditions, which is crucial for informing effective biodiversity conservation strategies and environmental management plans. The prevalence of *Tetraclinis* and *Juniperus* dominated formations suggests their role as foundation species, potentially exerting strong influences on community assembly processes and ecosystem functions (Ellison et al., 2005). The identification of these distinct phyto-coenoses serves as a foundational step for understanding the area's vegetation dynamics and conservation value. Each community type likely represents a unique assemblage of plant functional traits and evolutionary histories, contributing to the overall ecosystem resilience and biodiversity (Diaz & Cabido, 2001). Further research should focus on quantifying the environmental variables driving the distribution of these plant communities, such as edaphic factors, microclimatic conditions, and biotic interactions. Additionally, investigating the phylogenetic structure within and among these communities could provide insights into their evolutionary assembly and potential responses to environmental change (Webb et al., 2002). From a conservation perspective, this community level approach allows for the development of targeted management strategies that consider not only individual species but also the integrity of entire ecological assemblages. This is particularly crucial in Mediterranean ecosystems, where complex interspecific interactions often underpin community resilience (Blondel, 2006).

Frankeniaceae. The coexistence of halophytic specialists and endemic taxa within this spatially constrained community presents an intriguing case study in niche differentiation and evolutionary adaptation. This phenomenon aligns with the concept of edaphic endemism, where unique soil conditions drive speciation and promote the persistence of range-restricted taxa (Rajakaruna, 2004). The presence of both halophytic and endemic species suggests a complex interplay between environmental filtering and historical biogeography in shaping community composition. The high species richness observed in this formation, despite its apparent environmental constraints, may be explained by the "habitat heterogeneity hypothesis" (Stein et al., 2014). Micro-topographic variations and salinity gradients within the community likely create a mosaic of microhabitats, facilitating species coexistence through niche partitioning. From a conservation perspective, this halophytic community represents a unique component of the regional biodiversity. Its restricted distribution and specialized species composition render it particularly vulnerable to environmental changes, especially in the context of climate-driven alterations to hydrological regimes and salt dynamics (Flowers & Colmer, 2015). The presence of endemic species within this halophytic matrix is of particular interest. It suggests that these saline habitats may have served as refugia during past climatic fluctuations, allowing for the persistence and potentially the evolution of specialized lineages (Molina-Venegas et al., 2017). This underscores the importance of conserving not just individual species, but entire edaphic complexes that may harbor unique evolutionary histories.

Future research should focus on elucidating the ecophysiological adaptations of the endemic species to these saline conditions, as well as investigating potential facilitative interactions between halophytes and non-halophytic endemics. Understanding these mechanisms could provide valuable insights into community assembly processes in harsh environments and inform conservation strategies for edaphically specialized flora. Moreover, long-term monitoring of this community is crucial, given its restricted distribution and unique species composition. Changes in community structure or species abundance could serve as early indicators of broader environmental changes affecting the region (Bellard et al., 2012).

Juniperaie. The complex vegetation mosaic exemplifies the concept of diversity driven by topographic and edaphic heterogeneity (Stein et al., 2014). The differentiation of facies along altitudinal and aspect gradients aligns with the "alpine stress gradient hypothesis," which posits that abiotic factors become increasingly important in structuring plant communities with increasing elevation and exposure (Callaway et al., 2002). The presence of multiple endemic taxa across different facies underscores the role of this *Juniperus phoenicea* formation as a reservoir of unique biodiversity. This pattern of endemism may be attributed to historical climatic fluctuations, with these diverse microhabitats serving as refugia during unfavorable periods (Médail & Diadema, 2009). The observed floristic com-

position, particularly the co-occurrence of sclerophyllous and drought adapted species, reflects adaptations to the Mediterranean climate regime characterized by summer drought and winter precipitation. This community structure aligns with the "stress gradient hypothesis," suggesting that facilitative interactions may play a crucial role in maintaining species coexistence under harsh environmental conditions (Bertness & Callaway, 1994). From a conservation perspective, the altitudinal stratification of this formation presents both challenges and opportunities. While it may provide potential migration pathways for species under climate change scenarios, it also highlights the vulnerability of range restricted taxa occupying specific elevation bands (Lenoir & Svenning, 2015).

Tetraclinaie. The observed facies differentiation within the *Tetraclinaie* formation reflects the complex interplay of environmental factors, including altitude, substrate, and microclimatic conditions. This pattern aligns with findings from other Mediterranean ecosystems, where topographic and edaphic heterogeneity contribute to high beta diversity (Médail & Quézel, 1999). The presence of endemic species, particularly in the southern low-altitude facies, underscores the biogeographic importance of this area for plant conservation (Thompson, 2005). Furthermore, the xerophytic adaptations observed in several facies highlight the resilience of these plant communities to water stress, a crucial trait in the face of climate change in Mediterranean regions (Valladares et al., 2014). Future research should focus on quantifying the functional diversity within and among these facies to better understand ecosystem resilience and potential responses.

Quercus ilex. The limited occurrence is partly due to the topographical shelter provided by surrounding mountain peaks, such as the Kik plateau to the north and Jbel Tighardine to the west. This sheltering effect is not present in the Ourika basin, where the *Quercus ilex* formation appears at altitudes as low as 900 meters and extends up to 2900 meters in the Igrî Oufella region. The structural complexity and species composition of these woodlands highlight their ecological significance in maintaining biodiversity and supporting various ecosystem services. Studies have shown that such Mediterranean-type ecosystems with dominant *Quercus* species are crucial for carbon sequestration, soil conservation, and as habitats for diverse faunal communities (Marañón et al., 2019). Understanding the distribution and dynamics of these formations is essential for formulating effective conservation and management strategies.

Conclusion

The present study focuses on valorizing the Amassine area by analyzing its flora and vegetation under the influence of local environmental conditions. It encompasses a comprehensive description of the natural environment, highlighting geographical location, geology, hydrology, topography, and climate, which are crucial for understanding the distribution patterns of flora and vegetation. Additionally, this study has facilitated the creation of a detailed database of the flora and vegetation of the Amassine Reserve.

Amassine represents a promising biodiversity hotspot, characterized by a high number of species and a notable level of endemism. The region's flora includes 116 species of vascular plants. Through the study of vegetation using 154 phytoecological relevés conducted over multiple field visits, four distinct plant formations have been identified: *Frankeniae*, *Juniperae*, *Tetraclinae*, and the holm oak (*Quercus ilex*) formation.

For enhanced conservation and effective management, further investigations should focus on assessing the threats to biodiversity, including those arising from human activities and climate change. Conservation strategies should prioritize maintaining the biological diversity of this area. It is also recommended to develop conservation plans that acknowledge Amassine's status as part of Morocco's first national park, Toubkal National Park. Given the ecological significance of this region, protecting its unique biodiversity will not only preserve its ecological integrity but also contribute to the global conservation efforts. Studies have shown that protected areas like these are critical for mitigating climate change impacts and preserving genetic diversity, which are essential for ecosystem resilience. Therefore, proactive measures tailored to the specific ecological characteristics of Amassine will be crucial for its long-term preservation.

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