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Posted Date: 3 February 2025

doi: 10.20944/preprints202502.0129.v1

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Article

Floristic Composition and Phytoecological Characterization of Plant Communities in the M'Goun Geopark, Hight Atlas of Morocco

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Abstract: The vegetation cover in Morocco is impacted profoundly by human activities and climate change. However, the majority of ecosystems are not yet assessed. Using the sampling of vegetation, climate data, substrate (geological) map and altitudes (Digital Elevation Model) the phytoecology of species is constructed. The study revealed that the geopark contain 565 species. Floristic analysis, using correspondence analysis test, demonstrates that species are grouped into six distinct blocks. Block 1 comprises a set of *Quercus ilex* forests. Block 2 encompasses *Juniperus phoenicea* lands and transition zones between *Q. ilex* and *J. phoenicea*. Block 3 represents *Pinus halepensis* forests and pine occurrences within *Q. ilex* and *J. phoenicea* stands. Block 4 indicates the emergence of xerophytic species alongside the aforementioned species, suggesting the upper limits of Blocks 1, 2, and 3. Block 5 corresponds to formations dominated by *Juniperus thurifera* in association with xerophytes. Block 6 groups together a set of xerophytic species characteristic of high mountain environments. The formations species sampled are: *Q. ilex* that colonizes the subhumid zones, *J. phoenicea*, *Tetraclinis articulata* and *P. halepensis* occupy the hot part of the semi-arid while the *J. thurifera* and xerophytes inhabits its cold part. The thermo-Mediterranean vegetation level occupies low altitudes and is dominated by *Tetraclinis articulata*, *J. phoenicea*, and *Olea europaea*. The meso-Mediterranean level extends to intermediate altitudes and is dominated by *Q. ilex* and *J. phoenicea*. The supra-Mediterranean level, also found at intermediate altitudes, is dominated by *Q. ilex*, *Arbutus unedo*, and *Cistus creticus*. The mountain Mediterranean level, located in high mountains, is dominated by *J. thurifera* associated with xerophytes. Finally, the oro-Mediterranean level, found at extreme altitudes, is dominated by xerophytes. Generally, *Q. ilex* formations prefer limestone substrates. *P. halepensis* occupies limestone, clays, and conglomerates. *J. phoenicea* is more commonly associated with clays and sandstones. Xerophytic species and *J. thurifera* tend to inhabit limestone substrates. Some species within this region are endemic, rare, and threatened. Consequently, the implementation of effective conservation and protection policies is crucial.

Keywords: Floristic Analysis; Vegetation levels; vegetation levels; bioclimate; phytoecology.

1. Introduction

The concept of biodiversity encompasses all genes, species, habitats, and ecosystems on Earth (Séné, 2010). It has key roles at all levels of the ecosystem services, firstly as a regulator of ecosystem processes, as a final ecosystem service and as a good that is subject to economic or otherwise valuation (Mace et al., 2012). However, habitat degradation, intensive agriculture, overexploitation of

renewable resources, and climate change have reached unprecedented levels (Bureau et al., 2020). Biodiversity loss is now recognized as a major and urgent environmental issue, warranting swift action to mitigate it (Mauz & Granjou, 2010). In addition, Biodiversity is a vital sector for its socioeconomic development (Meniou, 2018).

The Mediterranean region is one of the most degraded regions in the world, having undergone significant changes in its primary natural ecosystems. Additionally, the region is recognized as a biodiversity hotspot (Médail & Diadema, 2006), making it the third richest hotspot in the world in terms of plant diversity (Mittermeier et al., 1999), it is home to approximately 30,000 plant species, with over 13,000 of them being endemic, found nowhere else in the world (Derneği, 2010). However, this diversity is threatened due to human population density, urban area and agriculture (Underwood et al., 2009). In addition, the loss, fragmentation and degradation of habitats due to human activities is the main threat to this richness (Cuttelod et al., 2009).

Morocco is home to approximately 24,000 animal species and 7,000 plant species (Benryane et al., 2022), due to a wide variety of geological substrates, topographies, and climates (Ilmen & Benjelloun, 2013). Morocco inhabits large scale ecosystems diversity, such as, coastal and marine ecosystems; inland aquatic ecosystems and wetlands; terrestrial forest and pre-forest, steppe and pre-steppe ecosystems; rocky and high mountain ecosystems; agroecosystems; desert and oasis ecosystems (Y. Gharnit et al., 2023). Indeed, Morocco encompasses a wide coastline along Atlantic Ocean and Mediterranean (3500 Km), two ranges of Mountains (High Atlas, Middle Atlas, Anti-Atlas in the center and Rif in the North), as well as the Oases and deserts ecosystems in the South (Y. Gharnit et al., 2023).

The High Atlas is one of the most important Moroccan region in terms of biological diversity, and one of the major Mediterranean biodiversity hotspot (Mohamed Fennane & Ibn Tattou, 2012). Furthermore, High Atlas meadows, inhabits 4200 species were recorded distributed in 940 genus and 135 families where 550 species are endemic to Morocco (Mostakim et al., 2021). The M'Goun Geopark (situated in Central High Atlas) has a rich and varied geological and biological diversity (El Alami et al., 2021). The High Atlas inhabits an outstanding richness in terms of geology and geosites (Ouzoud Cascades, Imi nifri natural bridge, dinosaurs' footprints and skeletons, Cathedral Msfrane cliff ...), tradition practices building, and patrimony sites (Y. Gharnit et al., 2023). These performances lead to recognize a great part of the High Atlas, by UNESCO (2014) as a Geopark M'goun UNESCO site. However, the region attracts a large number of tourists and camping activity, which cause the pollution, and exacerbate the pressure on the biodiversity of the region. In addition, the vegetation cover in High Atlas and Geopark Mgoun undergo unprecedented pressure, the climate change and anthropogenic activities contribute in the loss of 79% of dense forests and 30% of medium dense cover (Youssef et al., 2024). Gharnit et al. (2025) have assessed the region rangelands diversity and proved that these rangelands host 509 species where at least 27.73% of the assessed species are threatened according to the IUCN. The endemism rate is 21%, with 49.5% of these endemic species restricted solely to Morocco. Rarity criteria indicate a 17.43% rarity rate, including 8.4% considered very rare, 4.42% rare and three vulnerable (Gharnit et al., 2025).

Global biodiversity is in rapid decline and halting biodiversity loss is one of the most important challenges humanity must tackle now and in the immediate future (Damiani et al., 2023). Species diversity is one of the most widely adopted metrics for assessing patterns and processes of biodiversity, at both ecological and biogeographic scales (Chiarucci et al., 2011), allowing the detection of rare and threatened species; indeed, monitoring of threatened species and threatened ecosystems is critical for determining population trends, identifying urgency of management responses, and assessing the efficacy of management interventions (Lindenmayer et al., 2020). Species diversity as measured by inventories is crucial for selection of areas of conservation and management (Green et al., 2009). In addition, inventories permit detecting the effect of non-native species on native biodiversity with potentially devastating consequences (Pauchard et al., 2018). In addition, ecological studies on restoration has largely focused on community ecology and ecosystem ecology, particularly, plants (Youssef Gharnit, Moujane, et al., 2024; Vaughn et al., 2010). Therefore, the importance of elaborate not only the diversity of a site but also the ecology and photoecology.

Therefore, our aim is to identify the flora richness and composition of the entire Geopark Mgoun (Morocco), and reveal rarity rate and endemism. Then construct the phytoecology of the site.

2. Methodology

2.1. Study Area

The UNESCO Global Geopark of M'Goun constitutes the majority of the massifs of the Central High Atlas in Morocco located in the center of Morocco. The highest point is Ighil M'Goun (4,068 m) (Bussard, Martin, Monbaron, Reynard, & El Khalki, 2022), The area of the Geopark, shown in Figure 1, recognized by UNESCO in 2014, is 5,700 km². It encompasses 15 rural communes, housing 200,000 inhabitants(Y. Gharnit et al., 2023).

From a geological perspective, this part of the High Atlas is composed of a thick, folded Meso-Cenozoic cover that almost entirely overlays the underlying Paleozoic basement (Frizon de Lamotte et al., 2008), and a highly diverse geological substrate, comprising limestone, clays, dolomites, marls, volcanic rocks, detrital formations, and others (Youssef et al., 2024). 22 geosites inventoried in the UNESCO Global Geopark of M'Goun: Eight sites are purely geological (observation of a geological section or structure), six are paleontological sites (dinosaur footprints), four sites have an anthropogenic origin (rock engravings, architectural heritage, dam lake), and four sites are geomorphological (the Ouzoud waterfalls, the travertine bridge of Imi-n-Ifri, the Tizi-n-Tighza landslide, and the Mastfrane rock (Bussard, Martin, Monbaron, Reynard, & Khalki, 2022; Y. Gharnit et al., 2023).

The region features a variety of topographic and climatic characteristics. The terrain is generally mountainous between 540 and 3700 m, and the bioclimatic zones range from semi-arid or subhumid to humid (with precipitation between 550 mm and 700 mm)(Y. Gharnit et al., 2023; Taïbi et al., 2019; Youssef et al., 2024).

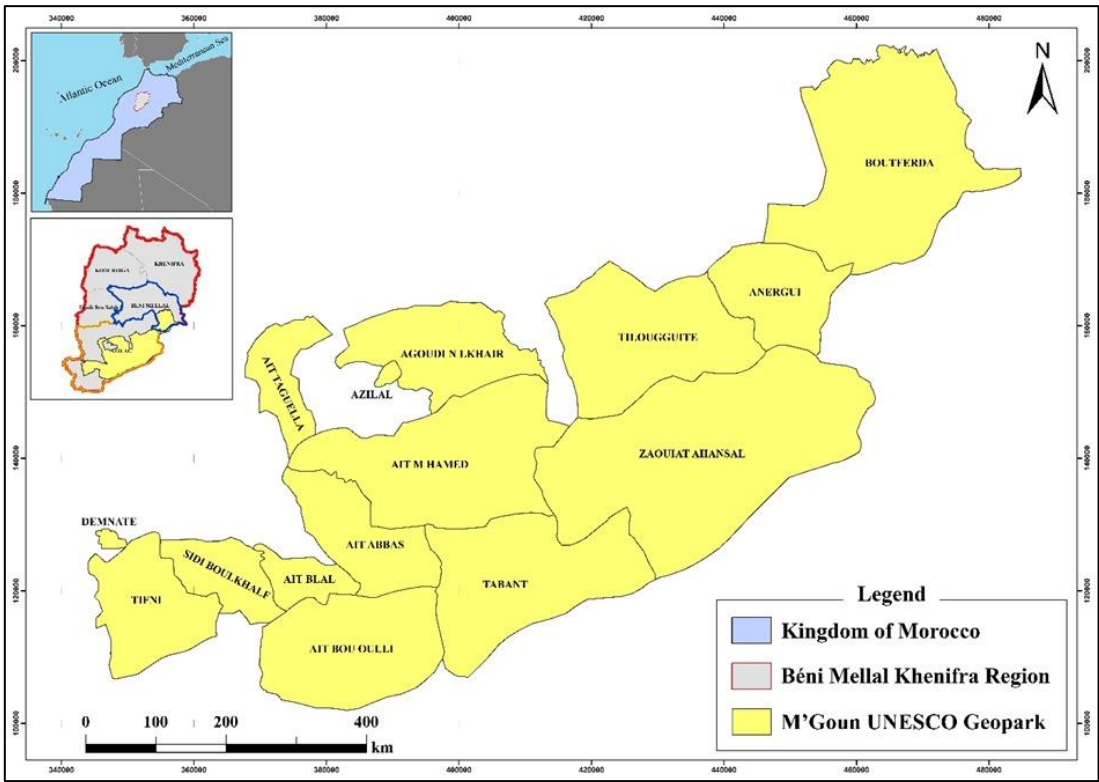


Figure 1. Study area location.

2.2. Methods

2.2.1. Sampling, Species Identification and Floristic Analysis

A survey carried out generally during the period of vegetation development, when the majority of plant species are visible and easily recognizable (flowering and/or fruiting) (Ozenda, 1982). In the field, different transect sizes were managed for sampling. The sampling surveys in the M'Goun Geopark were conducted in March, April, May, and June of 2022, 2023, and 2024. In total, we implement 206 floristic surveys. This means that we conducted surveys at various points within the area. The transects varied in length, ranging from 50 m to 200 m.

L'identification et la localisation des espèces, en utilisant la flore pratique du Maroc (M Fennane, 1998). La classification adoptée était l'APG III et l'APG IV (Angiosperm phylogeny group, 2009, 2016). In order to identify the different vegetation groups, the Correspondence analysis (CA) method is utilized.

2.2.2. Phytoecology

Concerning The Ecological Factors; The map of bioclimatic zones is constructed using Emberger's Pluviometric Quotient (Q2) for the Mediterranean climatic zone (Daget, 1977),

$$Q_2 = \frac{1000P}{\frac{(M - m)(M + m)}{2}}$$

Q2: Quotient bioclimatic indices, P: Annual precipitation (mm), M: Maximum temperature of the warmest month (K), m: Minimum temperature of the coldest month (K).

The Q2 permits the characterization of the bioclimatic zones, and the minimum temperature during the coldest month aids in defining climatic variants. The selected bioclimatic zones include the Saharan zone, arid zone, semi-arid zone, sub-humid zone, humid zone, and per-humid zone (Quézel & Barbero, 1982).

Vegetation levels are vertical distribution or altitudinal organization of plant cover, generally adopted by exploitation of the synthetic climate of Emberger, Quézel and Barbero (Achhal et al., 1979b; Y. Gharnit et al., 2023), the vegetation strata are thermos-Mediterranean, meso-Mediterranean, Infra-mediterranean, Oro-Mediterranean, mountain Mediterranean (Abdelmalek Benabid, 1985).

The life form is determined based on the Raunkiaer system: **T** for therophyte; **C** for Cryptophyte; **H** for Hemicryptophytes; **Cm** for chamerophytes; and **P** for phanerophytes.

Endemism is elaborated using the 'Flore Pratique du Maroc' as follows: **E**: Moroccan endemic, **EA**: Morocco-Algerian, **EC**: Morocco and Canary Islands, **EP**: Morocco and Iberian Peninsula. **EAP**: Morocco-Algerian and Iberian Peninsula, **EAT**: Morocco-Algerian and Tunisia.

Concerning rarity, the catalog of threatned and endemics plants is exploited. Indeed, based on the localities where the species are inventoried Fennane and ... have classified Moroccan plant species on: extremely rare (RR) for the species encountered in less five localities, and (RR?) for the suspected very rare species. Rare species (R) for the species reported in 2 divisions in Emberger & Maire 1941. The suspected rare species are noted (R?). The species undergoes profound changes or under extreme exploitation are indicated as vulnerable (V). and the species with unknown status are pointed as (??).

The Worldclim is used to access spatial climate data (<http://www.worldclim.org>). this data is harnessed to create the temperatures map, precipitations, the bioclimate zones and vegetation levels. The ecological factors considered are altitude and substrate type. Later, the climatic parameters are determined based on the coordinates of the transect occurrences, projected onto the map of various parameters: Tmin, Tmax, and precipitation. While the substrates are determined using the coordinates of transects and the geological map of Morocco (<https://www.mem.gov.ma/en/Pages/secteur.aspx?e=8>).

3. Results

3.2. Plant Richness and Floristic Analysis

The flora of the M'Goun Geopark encompasses 565 vascular plant species, distributed among 74 families. The Asteraceae family is the richest in species, accounting for 17.7 % of those inventoried in the M'Goun Geopark (accounting for 100 species). Fabaceae are classified in the second place, with 60 species and represent 10.62 %. Poaceae occupy third place accounting 37 species (6.55%). Lamiaceae are represented by 32 species (5.75%). Caryophyllaceae had a total number of 31 species

representing 5.48 % of the Geoparc flora. While Brassicaceae have 30 species (5.31%). Apiaceae 25 species representing 4.42 % of the totalspecies. Plantaginaceae are represented by 17 species (3%). Rubiaceae are represented by 13 species (2.3%). Asparagaceae by 11 species 1.94% and Amaranthaceae, Caprifoliaceae Cistaceae by 10 species each. Euphorbiaceae and Ranunculaceae 9 species each. While Campanulaceae, Crassulaceae, Geraniaceae, Rosaceae are represented by 8 species each.

The most represented genera are Astragalus represented by nine, followed by Euphorbia and Medicago with eight each. The Centaurea is represented by seven species Galium, Silene, Convolvulus and Genista are representeb by six species each. And Trifloium and Campanula are represented by 5 species.

The CA plot (Figure 2) and table 1 reveal that the species are gathered into six blocks, each bloc may be subdivided into subsets, hence 21 subgroups of species are revealed:

Bloc 1: The floristic composition indicates holm oak (*Quercus ilex*) forests and their clearings in the region. These are semi-arid forests of the area. Generally, the subgroups of this bloc are homogenous in terms of floristic composition.

Bloc 2: This group is heterogeneous: F4 and F5: The presence of *Q. ilex* and *J. phoenicea* suggests that these subgroups are ecotones (transition zones) between *Q. ilex* and *J. phoenicea* forests. F6 represents *J. phoenicea* forests in a warm semi-arid climate (abundant: *Ceratonia siliqua*, *Tetraclinis articulata*, *Ziziphus lotus*). F7: is another transition zone between *Q. ilex*, *J. phoenicea*, and *P. halepensis*.

Bloc 3: F8 represents *Pinus halepensis* forests. F9 represents clearings in *P. halepensis* forests, with primarily *Glubularia nainii* and *Anarrhinum fruticosum*. F10 and F11 represent co-occurrence zones of *J. phoenicea* and *P. halepensis*.

Bloc 4: The floristic composition of this group indicates that it is the zone of appearance of xerophytes: *Euphorbia niceensis*, *Marrubium ayardii*, *alyssum spinosum*, *Bupleurum spinosus*, *Astragalus granatensis*. These are the upper limits of the different groups mentioned above.

Bloc 5: F15 and F16 are formations of *J. thurifera* associated with xerophytes. Deforestation is significant at this level, consequently only xerophytes persist (F17). The bundnat species at this level are: *Cytisus balansae*, *Euphorbia niceensis*, *Juniperus thurifera*, *Scorzonera caespitosa*, *Artemisia herba alba*, *Ormenis scariosa*.

Bloc 6: This is the domain of spiny xerophytes of high mountains, highly rich by *Arenaria pungens*, *Valla mairii*, *alyssum spinosum*, *Erinacea Anthyllis*, *Bupleurum spinosum*, *Cytisus balansae*, *Euphorbia niceensis*, *Euphorbia megatlantica*, *Scorzonera caespitosa*.

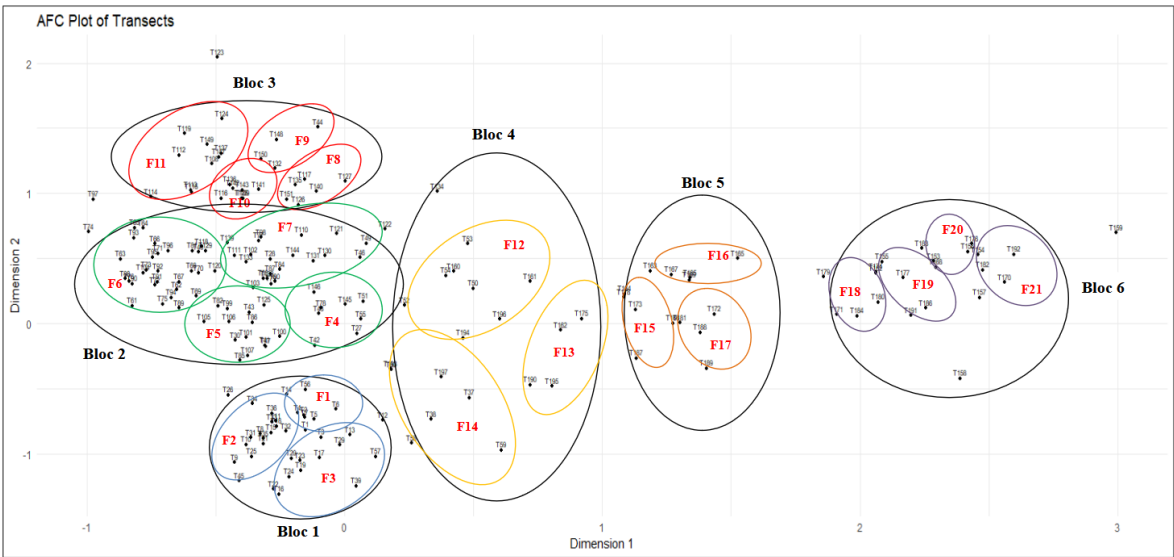


Figure 2. The AFC plot of floristic composition in the study area.

Table 1. The floristic assemblages and their floristic composition.

Blocs	Transects	Abundant Species
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Bloc 1	F1	T6, T14, T4, T2, T5, T1, T56, T7	<i>Quercus ilex, Anchusa azurea, Astragalus incanus, Bromus madritensis, Campanula filicaulis, Catananche caerulea, Echinops spinosissimus, Lactuca tenerrima, Silene vulgaris, asperula hirsuta, Picnomon acarna,</i>
	F2	T34, T36, T32, T15, T8, T35, T31, T10, T25, T9, T45, T18, T11	<i>Galium tricornicum, Papaver rhoeas, Bromus madritensis, Quercus ilex, Anchusa azurea, Medicago minima, Mantisalca salmantica, Plantago afra, Scolymus hispanicus, Beta macrocarpa, Medicago monspeliaca, Silene vulgaris, Sonchus asper</i>
	F3	T3, T13, T29, T17, T57, T39, T20, T23, T19, T24, T22, T16	<i>Quercus ilex, Hordeum murinum, Asphodelus macrocarpus, Galium tricornicum, Romulea bulbocodium, Anchusa azurea, asperula hirsuta, Astragalus hamosus, Echinaria capitata, Echinops spinosissimus, Ononis cristata, Salvia verbenaca</i>
	F4	T146, T78, T145, T51, T55, T27, T42, T46	<i>Quercus ilex, Clematis cirrhosa, Echinops spinosissimus, Artemisia herba alba, Bromus madritensis, Buxus balearica, Carlina hispanica, Chamaerops humilis, Convolvulus althaeoides, Hordeum murinum Juniperus phoenicea</i>
	F5	T100, T47, T41, T107, T85, T30, T101, T86, T125, T43, T106, T99, T82, T105	<i>Juniperus phoenicea, Anchusa azurea, Quercus ilex, Silene vulgaris, Alyssum alyssoides, Asperula arvensis, Atractylis cancellata, Avena fatua, Dactylis glomerata ; Erodium cicutarium, Hedypnois rhagadioloides, Isatis tinctoria, Lactuca tenerrima, Medicago minima, Papaver rhoeas, schismus barbatus, Torilis leptophylla</i>
	F6	T89, T69, T120, T75, T94, T62, T67, T68, T72, T118, T129, T81, T61, T92, T96, T66, T71, T95, T73, T104, T63, T81, T49, T88, T91, T93, T90, T101, T64, T93, T63	<i>Juniperus phoenicea, Stipellula capensis, Chamaerops humilis, Bromus madritensis, Pistacia lentiscus, Atractylis cancellata, A. sterilis, Torilis nodosa, Ceratonia siliqua, Cladanthus arabicus, Sonchus oleraceus, Tetraclinis articulata, Ziziphus lotus, Euphorbia resinifera...</i>
Bloc 2	F7	T139, T111, T133, T102, T77, T98, T28 T84, T87, T80, T103, T110, T144, T130, T131, T121, T49, T46	<i>Juniperus phoenicea, Picnomon acarna, Pinus halepensis, Buxus balearica, Quercus ilex, Thymus algeriensis, Lactuca tenerrima, Thymus saturejoides, Ajuga iva, Chondrella jencea, Crambe filiformis, Dactylis glomerata, Deverra scoparia, Genista scorpius, Globularia nainii, Lactuca viminea, Phagnalon saxatile, Phillyrea angustifolia, Salvia verbenaca, Teucrium polium, Thymus zygis</i>
	F8	T127, T140, T117, T135, T151, T126	<i>Pinus halepensis, Globularia nainii, Buxus balearica, C. corymbosa, Centaurea melitensis, Cistus creticus, Euphorbia niceensis, Fraxinus angustifolia, Fumana ericoides, Narsturia officinalis, Polygala balansae, Sedum sediforme, Stipellula capensis</i>
	F9	T44, T148, T132, T150	<i>Thymus zygis, Anarrhinum fruticosum, Globularia nainii, Arbutus unedo, Astragalus incanus,</i>
Bloc 3			

			<i>Euphorbia taurinensis, Ononis pusilla, Fraxinus angustifolia, Schismus barbatus, Ajuga iva,</i>
			<i>Juniperus phoenicea, Xanthium spinosus, Ajuga iva, Andryala integrifolia, Capparis spinosa, Crambe filiformis, Dittrichia viscosa, Erodium cicutarium, Globularia alypum, Melilotus sulcatus, Mentha peligium, Mentha suaveolens, Nerium oleander, Pinus halepensis, Pistacia lentiscus, Polypogon minspeliensis, Schismus barbatus</i>
F10	T141, T143, T116, T136, T142, 128,		<i>Globularia nainii, Hirschfeldia incana, Lythrum junceum, Pinus halepensis, Pistacia lentiscus, Polygala balansae, Teucrium polium, Bombycilaena erecta, Centaurea calcitrapa, Chondrella jencea, Cistus creticus, Juniperus phoeniceae, Nerium oleander, Populus negra, Schismus barbatus, Veronica polita, Anarrhinum fruticosum, Centaurea melitensis, Cistus albidus, Dianthus nudiflorus, Dittrichia viscosa</i>
F11	T124, T119, T112, T149, T137, T108, T114, T113, T115, T147		<i>Euphorbia niceensis, Fraxinus angustifolia, Polycarpon tetraphyllum, Bellis annua, Eryngium campestre, Lactuca tenerima, poclama brevifolia, Quercus, Astragalus incanus, Bromus madritensis, Crambe filiformis, Euphorbia terracina, Globularia nainii, Marrubium ayardii</i>
Bloc 4	F12	T52, T54, T160, T53, T50, T194, T196, T161	<i>Teucrium chamaedrys, alyssum spinosum, Polycarpon tetraphyllum, Arenaria pungens, asperula hirsuta, Bupleurum spinosus, Cerastium arvense, Helianthemum cinereum, Jurinea humilis, Minuartia funkii, Thymelaea virgata, Thymus zygis</i>
	F13	T175, T162, T195, T190	<i>Quercus ilex, Astragalus granatensis, Campanula filicaulis, Ononis spinosa, Polycarpon tetraphyllum, Scutellaria orientalis, Teucrium chamaedrys, Aegilops geniculate, asperula hirsuta, Bromus madritensis, Cirsium acaule, Convolvulus lineatus, Coronilla minima, Crataegus lacinata</i>
	F14	T193, T58, T38, T197, T37, T59	<i>Cytisus balansae, Euphorbia niceensis, alyssum spinosum, Hirschfeldia incana, Anthyllis vulneraria Arthemisia herba alba</i>
	F15	T187, T173, T164, T178	<i>Buxus balearica, Cirsium dyris, Coronilla minima, Delphinium gracile, Helianthemum apenninum, Juniperus thurifera, Jurinea humilis, Ormenis scariosa, Quercus ilex, Scorzonera caespitosa</i>
Bloc 5			<i>Arthemisia herba alba, Ormenis scariosa, Euphorbia niceensis, Sanguisorba minor, alyssum spinosum, Asperula cynanchica, Avena barbata, Bupleurum spinosum, Coronilla minima, Erinacea Anthyllis, Helianthemum cinereum, Hieracium pseudopilosella, Vella maierii</i>
	F16	T163, T167, T185, T165	<i>Euphorbia niceensis Ribes uva-crispa, Coronilla minima, Erinacea Anthyllis, Alyssum</i>
	F17	T172, T188, T181, T189	

		<i>serpyllifolium, Buxus balearica ; Cytisus balansae, Juniperus thurifera, Raffenaldia platycarpa, Scorzonera angustifolia, Scorzonera caespitosa, Thymelaea virgata,</i>
Bloc 6	F18 T179, T171, T184	<i>Alyssum spinosum, Scorzonera caespitosa, Thymus pallidus, Arenaria pungens, Carduncellus atractyloides, Centaurea takredensis, Convolvulus sabatius, Delphinium gracile, Erinacea Anthyllis, Euphorbia niceensis, Euphorbia sagitalis, Juniperus thurifera</i>
	F19 T186, T191, T180, T177, T155, T152, T174	<i>Alyssum spinosum, Bupleurum spinosum, Carduncellus atractyloides, Centaurea takredensis, Cytisus balansae, Erinacea Anthyllis, Euphorbia niceensis, Vella maierii, Ribes uva-crispa, Arenaria serpyllifolia, Arenaria pungens, Berberis vulgaris, Bupleurum atlanticum, Cirsium dyris, Delphinium gracile, Juniperus thurifera, Minuartia funkii, Ormenis scariosa, Prunus prostrata, Rahmnus liscoides, Thymus pallidus</i>
	F20 T183, T153, T168	<i>Euphorbia niceensis, Alyssum spinosum Erinacea Anthyllis, Juniperus thurifera L. Scorzonera caespitosa, Vella mairii, Arthemisia herba alba, Bupleurum, atlanticum, Bupleurum spinosum, Convolvulus lineatus, Ormenis scariosa,</i>
	F21 T176, T154, T182, T170, T157, T192, T156	<i>Arenaria pungens, Valla mairii, alyssum spinosum, Erinacea Anthyllis, Bupleurum spinosum, Clinopodium alpinum, Cytisus balansae, Euphorbia niceensis, Euphorbia megatlantica, Scorzonera caespitosa, Berberis vulgaris, Coronilla minima, Ormenis scariosa, Papaver atlanticum, Ruta montana, Stipa nitans</i>

3.2. Endemism and Rarity

46 species are extremely rare in Morocco, 4 are suspected very rare, 24 are rare, 24 are suspected rare, 3 are vulnerable and 3 had unknown status.

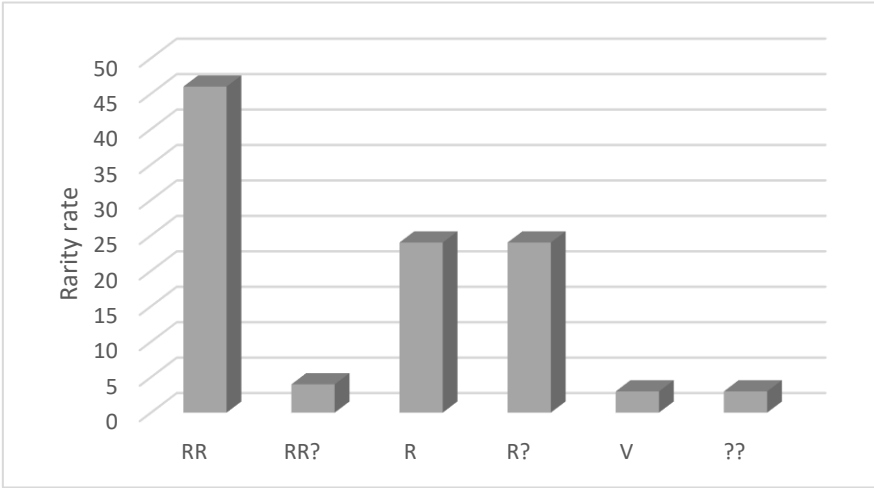


Figure 3. The rarity rate in the area.

24 species are endemics of Morocco, while 13 inhabits only Moroccan and Algerian territory, 7 species are endemics of Morocco, peninsula Iberia, 14 inhabits species are endemics of Morocco, Algeria and peninsula Iberia, and 2 are endemics of Morocco, Algeria and Tunisia (figure 4).

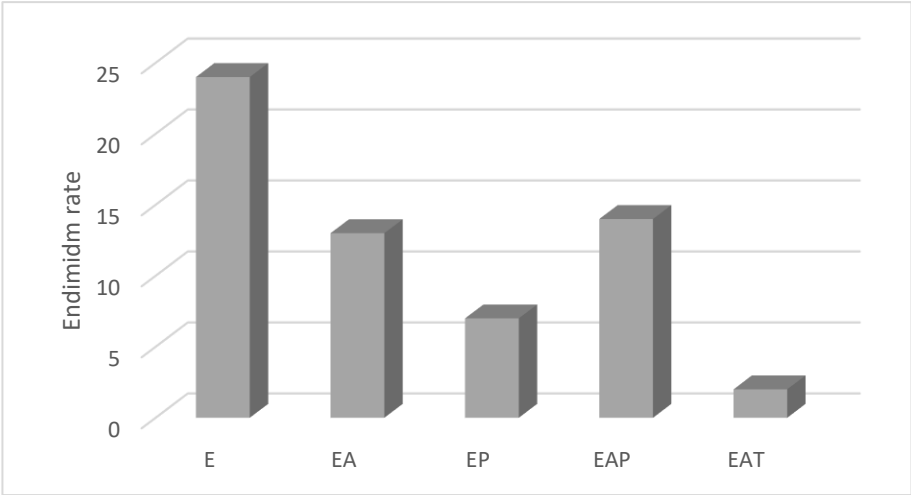


Figure 4. The endemism rate in the study area.

3.3. Rainfall Distribution

The lowest levels are found in the middle of the Geopark and the highest levels are found in the crests of the Atlas Mountains and the plains. The distribution of precipitation (Figure 5) shows a gradient both in terms of altitude and length, linked to the combined effects of oceanic moisture currents and the Atlas Mountain barrier. Moreover, we observe the presence of two large precipitation depressions linked to site effects and topography. They are located in the Zaouit Ahansal valley, where precipitation does not exceed 350 mm on average, with a total average between 356 and 622 mm.

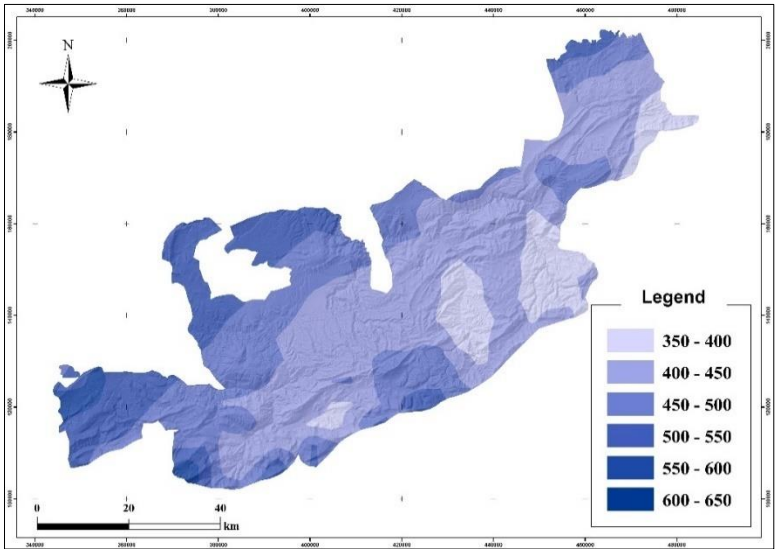


Figure 5. Precipitation map of the M'Goun Geopark area.

3.4. Temperature

The spatial distribution of minimum, maximum, and annual average temperatures for the entire M'Goun Geopark (Figure 6) illustrates a continentality effect associated with the altitude effect in the Atlas Mountains and the plain. The average annual, maximum, and minimum temperatures are respectively around, (-9.37°C), and (26.4°C) at the mountain peaks and, (3°C), and (34.42°C) at lower altitudes.

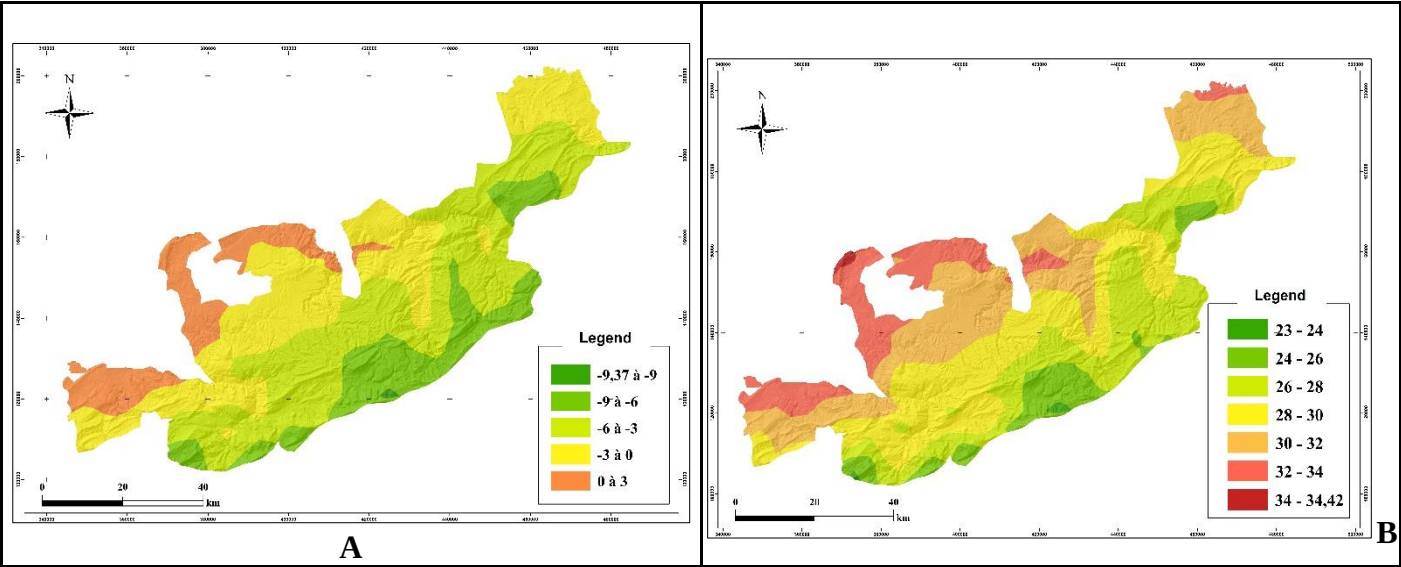


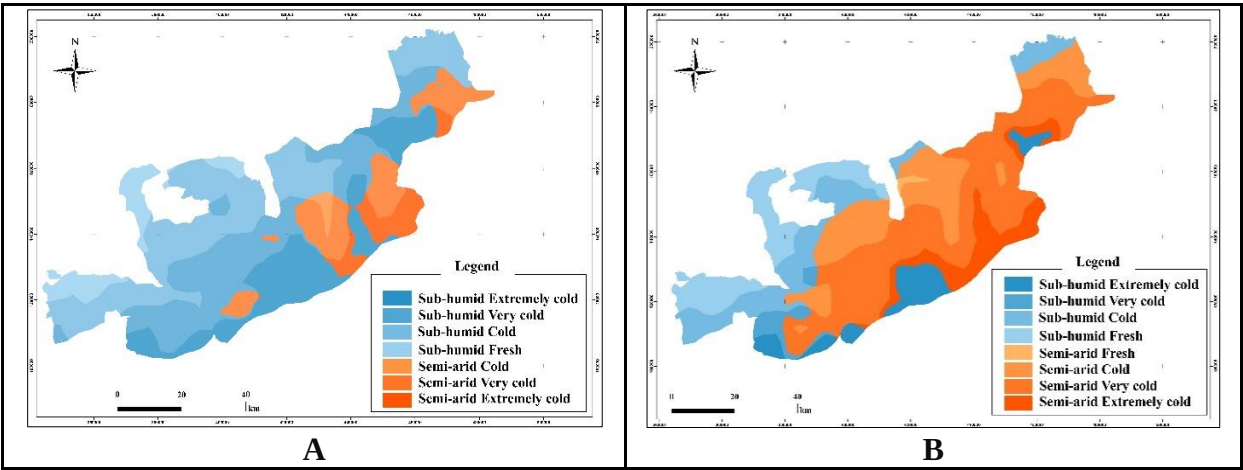
Figure 6. A: Minimum temperature map, B: Maximum temperature map.

3.5. Bioclimatic Zones

Variations in minimum and maximum temperatures (Table 2), as well as precipitation, act as the primary drivers of shifts in humid and sub-humid bioclimatic zones, including their variety such as extremely cold, very cold, cold, and cool zones (Figure 7). These changes, induced by climatic fluctuations, are not uniform and can be observed at various temporal and spatial scales. The sub-humid varieties are extremely cold, very cold, cold, and fresh, while the semi-arid bioclimate with extremely cold, very cold, cold, and fresh varieties.

Table 2. The climate patterns fluctuations between 1960 and 2019.

Period	Tmin (min-max) en °C	Tmax (min-max) en °C	Precipitations (min-max) en mm	Q2 (min-max)
1960-1969	-9,97 - 2,18	20,9- 30,83	369,67 - 658,68	42,63 - 77,62
1970-1979	-9,37 - 3,12	23,5 - 34,42	350,32 - 605,81	37,92 - 66,91
1980-1989	-10 - 2,34	23,5 - 34,63	295,56 - 506,28	31 - 54,39
1990-1999	-9,74 - 2,89	23,87 - 35,17	307,88 - 541,58	32,34 - 58,25
2000-2009	-8,86 - 2,39	24,42 - 35,65	309,58 - 533,49	32 - 57,67
2010-2019	-9,39 - 3	24,60 -36,12	329,25 - 571,19	33,96 - 60,76



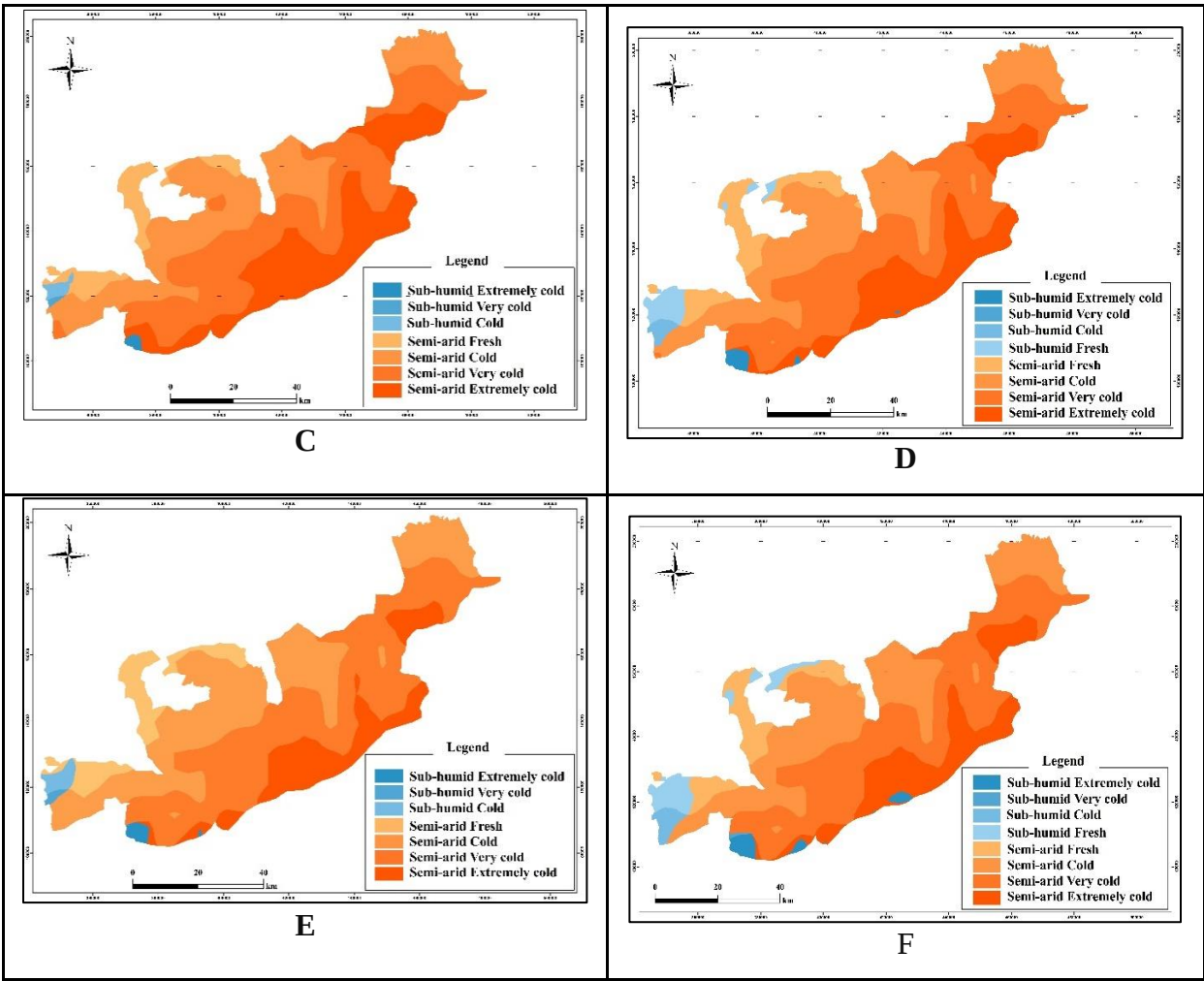


Figure 7. Spatial distribution of bioclimatic zones (A-1977), (B-1999), (C-2014) (D-2018) in the M'Goun Geopark.

According to the geographic occurrences of the species, 30.53% of species are sampled only in the subhumid climate zone, while 22% occupy the semi-arid level; 52% of them are located in semi-arid fresh and temperate (hot) areas at low altitudes, and the rest are situated in the semi-arid cold areas of high mountains. Furthermore, 14% of species are found in both semi-arid hot and subhumid zones, 17% inhabit both subhumid and semi-arid cold zones, while 7% of species colonize all bioclimates in the region (Figure 8).

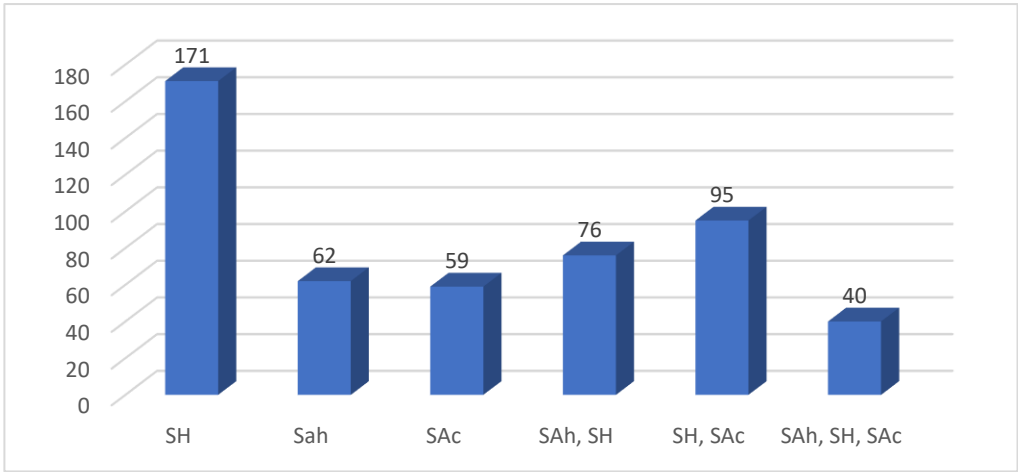


Figure 8. species distribution according to climate zone.

The figure 9 depict the elevations variation of the study area, the elevation oscillates between 544 m and 3708 m, while the mean elevation of the site is 1588 m.

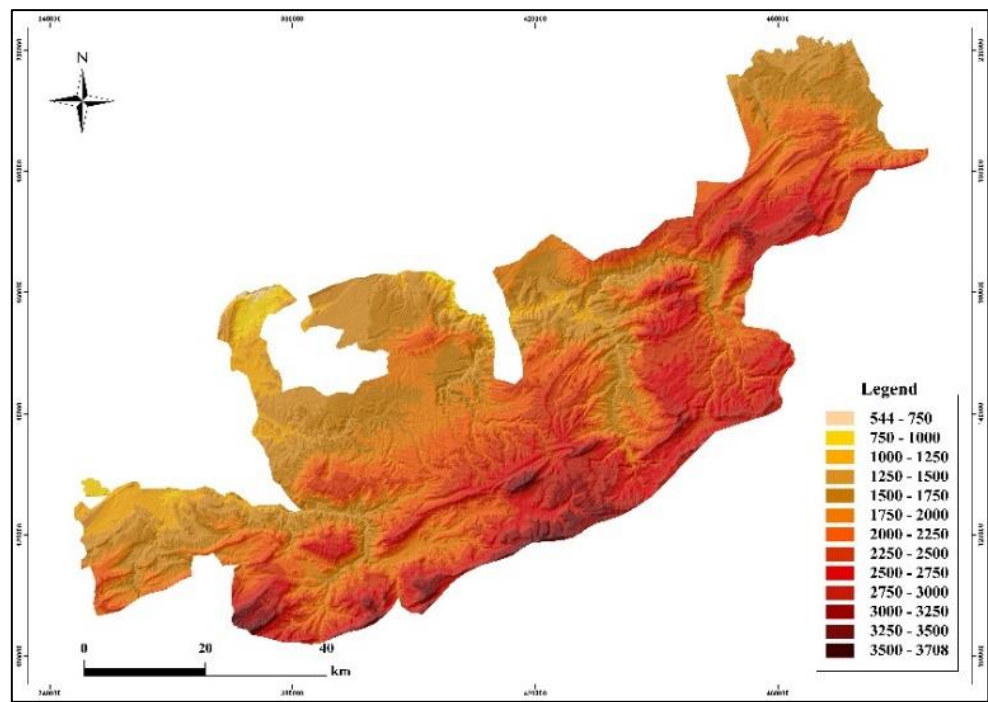


Figure 10. Elevations map of the geopark M’goun (in meters).

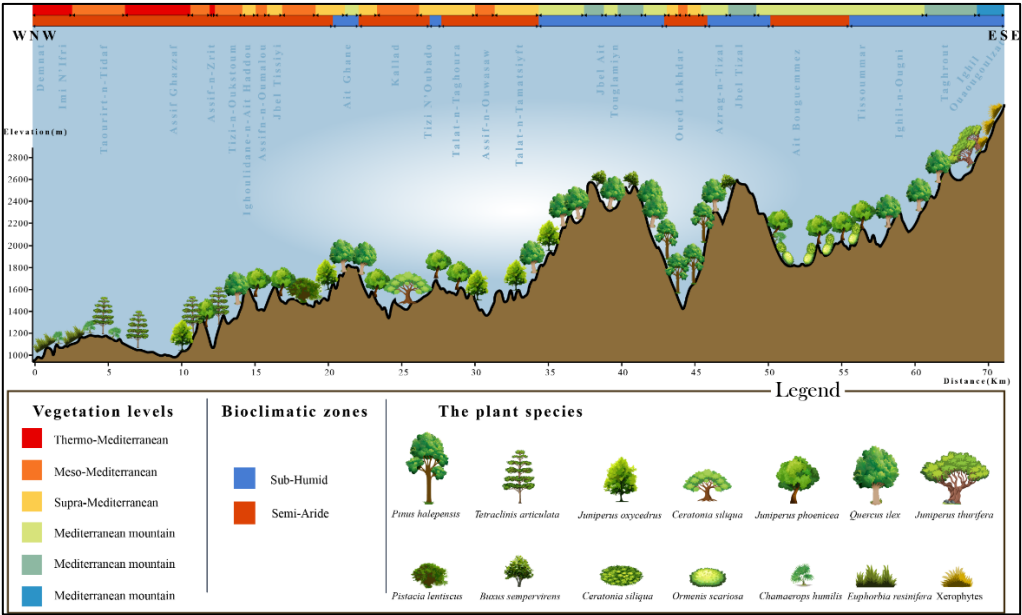
3.6. The Vegetation Cover

For the A axis (figure 8A), starting from the north, the northern slopes are characterized by *Euphorbia resinefera*. Then, *Tetraclinis articulata*, mixed with *Juniperus phoenicea* and *Ceratonia siliqua* which becomes dominant. At 1400 meters, *Tetraclinis articulata* disappears, and *Juniperus phoenicea*, *Ceratonia siliqua*, and *Pistacia lentiscus* continue. Around 1600 meters, these formations give way to *Quercus ilex*. In the humid valley of Ait Abbas, *Pinus halepensis* flourishes between 1200 and 1700 meters. The upper limit of *Pinus halepensis* is inhabited by *Juniperus phoenicea* between 1800 and 2000 meters, followed by *Quercus ilex* up to 2200 meters, where high-mountain xerophytes thrive. The same pattern is repeated on the southern slope (from the Jbel Tizzal summit to the Ait Bougemmez valley), except for the presence of *Ormenis scariosa*, especially in the *Quercus ilex* level. After Ait Bougemmaz, *Juniperus phoenicea* thrives at low elevations, followed by *Quercus ilex* as the elevation rises. Then, *Juniperus thurifera* takes over, generally mixed with xerophytes that dominate the landscape starting from 2300 meters, where *Juniperus thurifera* declines.

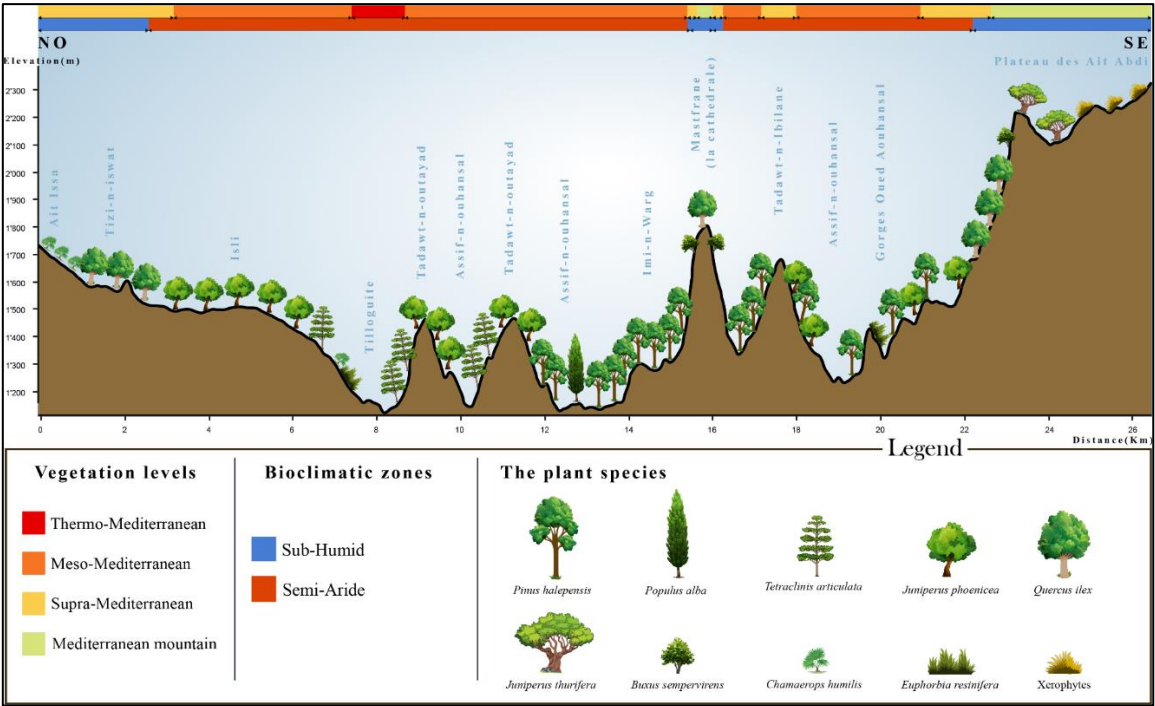
Concerning Axis B (Figure 8B) at the northeastern limit, *Chamaerops humilis* occupies large areas, occasionally mixed with *Quercus ilex* (at about 1800 m). *Quercus ilex* later becomes dominant. Afterward, *Juniperus phoenicea* appears as the elevation decreases. At low altitudes in the Tillouguit site, scattered *Tetraclinis articulata* trees can be found about (1300-1400). Moving towards the Mesfrane cliff, *Juniperus phoenicea* becomes the main formation but gradually declines (as the elevation rises) in favor of *Pinus halepensis*, which dominates the Mesfrane region. The *Pinus halepensis* and *Juniperus phoenicea* shape the space, with *Juniperus phoenicea* dominating the upper limits. The humid parts (northern slopes) are occupied by *Buxus balearica* and *Quercus ilex*. At around 1700 meters, *Pinus halepensis* and *Juniperus phoenicea* disappear, and *Quercus ilex* takes over. *Buxus balearica* thrives on rocky soils and cliffs around 2100 meters, followed by *Juniperus thurifera*, which is often mixed with xerophytes (up to 2500 m). These xerophytes become the only species adapted to the extreme elevations. Table 3 represents some of the main features of the main vegetation formations.

Table 3. Ecological Synthesis of the main formation in the M’Goun Geopark the High Atlas of Morocco.

Habitat	Altitude (m)	Tmin (°C)	Tmax (°C)	Precipitation (mm)	Bioclimate	Climatic Variation	Vegetation Zone
<i>Quercus ilex</i>	Up to 2800	5.61–6.26	18.69–19.33	299.01–548.25	Semi-arid and subhumid	All variants	Supra-, Meso-, Thermo-, and Montane Mediterranean
<i>Juniperus phoenicea</i>	Up to 2000	6.92–7.88	19.95–20.56	313.2–571.99	Semi-arid and subhumid	Except very cold and cold	Meso- and Thermo-Mediterranean
<i>Pinus halepensis</i>	Up to 2200	6.29–7.36	19.13–19.72	278.23–501.08	Subhumid and semi-arid	Cool and cold	Supra- and Meso-Mediterranean
Xerophytes	Up to 3700	2.24–3.26	15.14–15.79	291.93–532.19	Subhumid and semi-arid	Cold and very cold	Montane and Oro-Mediterranean
<i>Chamaerops humilis</i>	Up to 2000	6.62–7.69	20.98–21.43	302.59–545.73	Subhumid and semi-arid	Cold	Supra-Mediterranean
<i>Juniperus thurifera</i>	Up to 2700	3.41–4.42	16.26–16.98	288.48–499.47	Subhumid and semi-arid	Cold and very cold	Montane Mediterranean
<i>Euphorbia resinifera</i>	Up to 1800	8.05–9.06	21.69–22.13	305.13–552.85	Semi-arid and subhumid	Moderate and cold	Meso-Mediterranean
<i>Buxus sempervirens</i>	Up to 3000	1.99–2.93	14.9–15.51	281.61–478.13	Subhumid and semi-arid	Cold and very cold	Montane Mediterranean



A



B

Figure 8. The vegetation profiles, A: Demnat - Ait Bougemmaz axis, B: axis Tillouguite - Zauit Ahensal.

3.7. The Vegetation Levels and Associated Vegetation

The vegetation levels in the study area are: Thermo-Mediterranean, Meso-Mediterranean, Supramediterranean, Mountain mediterranean and Oro-mediterranean. The thermomediterranean geographic zone is limited to the northern part of the geopark at altitude approximately located between (544-1100 meters). The species that characterize this level in the area are *Ziziphus lotus* and *Tetraclinis articulata*. This part exhibits significant diversity, as these species are mixed with *Juniperus phoenicea*, *Pistacia lentiscus*, *Pistacia atlantica*, *Ceratonia siliqua*, and others. As the elevation rises, the mesomediterranean approximately located between (530-1800 meters). takes over, with the appearance of *Quercus ilex*, which is well adapted to its condition, and mixed with the same species reported in the previous level at the lower. In the supramediterranean approximately located between (1100-2700 meters), in extensive forests of *Quercus ilex* dominate the landscape, mixed with *Juniperus oxycedrus*. In the semi-arid parts of this level, *Pinus halepensis* forests thrive, generally mixed with *Juniperus phoenicea* and others. The mountain Mediterranean is approximately located between (1200-2300 meters) hosts the upper limits of *Quercus ilex* forests and the majority of *Juniperus thurifera*, mixed with xerophytes. The bioclimates are generally semi-arid with cold variants at these levels, with some features of the subhumid climate at their lower limits. Finally, the oromediterranean dominates high mountains, inhabited by xerophytes, the lower oromediterranean is approximately located between (1900-3700 meters), while the average oromediterranean level is approximately located between (2800-3700 meters) (Figure 9). The table 4 represent the Phytocological synthesis of the main plants formation and species of the geopark Mgoun of High Atlas of Morocco.

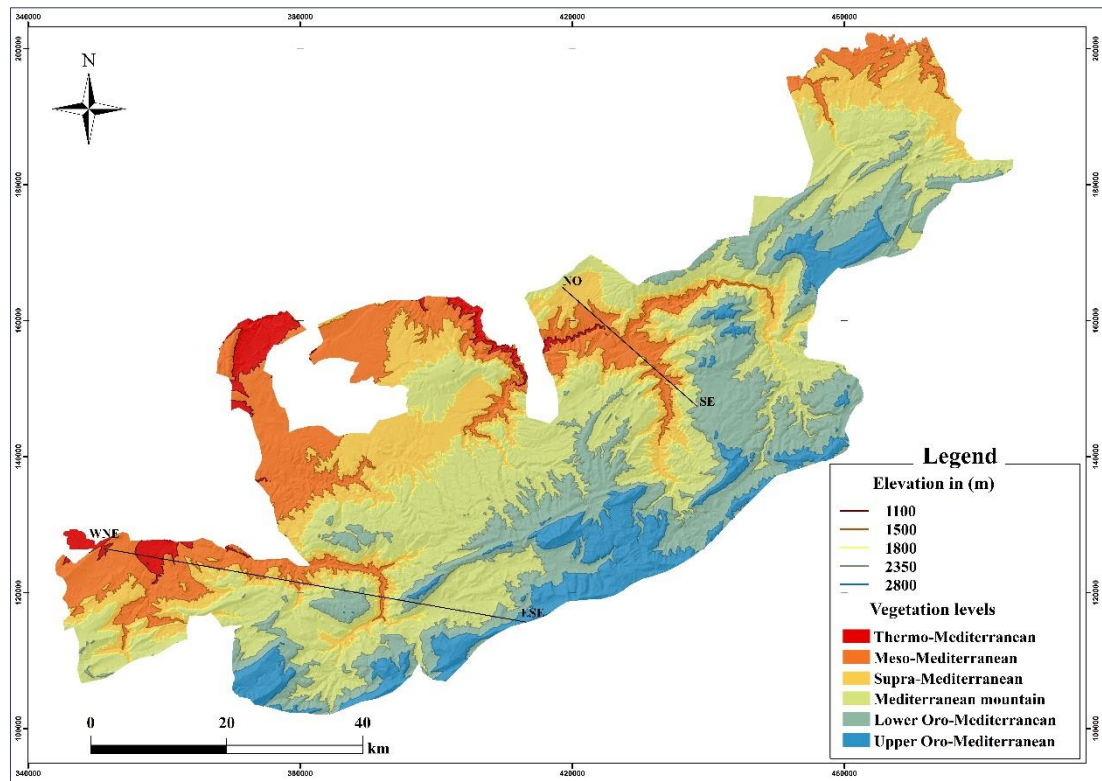


Figure 9. : The vegetation levels in the study area.

Table 4. Detailed Ecological Characteristics of Vegetation Formations in the Geopark M'goun.

Symbo	Dominant	Companion	Altitud	Bioclimati	Vegetation	Tmi	Precipitatio	Substrate
l	Species	Species	e	c Stage	Zone	n & Tma	n	type
						x		
F1	<i>Quercus ilex</i> , <i>Anchusa azurea</i> , <i>Astragalus incanus</i>	<i>Bromus madritensis</i> , <i>Campanula filicaulis</i> , <i>Catananche caerulea</i>	544–1000	Semi-arid fresh	Supra-Mediterranean	-4°C, 30°C	300–600 mm	Limstones
F2	<i>Galium tricornicum</i> , <i>Quercus ilex</i> , <i>Anchusa azurea</i>	<i>Bromus madritensis</i> , <i>Medicago minima</i> , <i>Silene vulgaris</i>	800–1500	Semi-arid fresh	Meso-Mediterranean and Supra-Mediterranean	-2°C, 28°C	350–650 mm	Limstones
F3	<i>Quercus ilex</i> , <i>Hordeum murinum</i> , <i>Asphodelus macrocarpus</i>	<i>Galium tricornicum</i> , <i>Romulea bulbocodium</i> , <i>Anchusa azurea</i>	1000–1900	Subhumid fresh	Supra-Mediterranean	-5°C, 32°C	400–700 mm	Limstones
F4	<i>Quercus ilex</i> , <i>Clematis cirrhosa</i> , <i>Echinops spinosissimus</i>	<i>Artemisia herba-alba</i> , <i>Juniperus phoenicea</i>	1200–2100	Subhumid fresh	Meso-Mediterranean and Supra-Mediterranean	-3°C, 29°C	250–500 mm	Limstones

F5	<i>Juniperus phoenicea, Anchusa azurea, Quercus ilex</i>	<i>Silene vulgaris, Avena fatua, Dactylis glomerata</i>	1600–2000	Semi-arid fresh	Supra-Mediterranean and Montane Mediterranean	-6°C, 30°C	400–650 mm	Limestones
F6	<i>Juniperus phoenicea, Stipellula capensis, Chamaerops humilis</i>	<i>Atractylis cancellata, Euphorbia resinifera</i>	1500–2200	Subhumid fresh	Montane Mediterranean	-8°C, 25°C	350–600 mm	Clays and sandstone
F7	<i>Juniperus phoenicea, Pinus halepensis, Buxus balearica</i>	<i>Thymus algeriensis, Lactuca tenerrima, Genista scorpius</i>	1800–2400	Semi-arid cold	Montane Mediterranean	-7°C, 22°C	400–700 mm	Clays and limestone conglomerates
F8	<i>Pinus halepensis, Globularia nainii, Buxus balearica</i>	<i>Centaurea melitensis, Cistus creticus, Euphorbia niceensis</i>	1900–2500	Semi-arid cold	Montane Mediterranean	-10°C, 15°C	200–400 mm	Clays and limestones
F9	<i>Thymus zygis, Anarrhinum fruticosum, Globularia nainii</i>	<i>Arbutus unedo, Astragalus incanus, Ononis pusilla</i>	1700–2800	Semi-arid very cold	Montane Mediterranean	-8°C, 20°C	250–500 mm	Limestones and rocky limestones
F10	<i>Juniperus phoenicea, Xanthium spinosus, Ajuga iva</i>	<i>Capparis spinosa, Crambe filiformis, Nerium oleander</i>	1500–2200	Subhumid fresh	Supra-Mediterranean	-5°C, 28°C	300–600 mm	Clays and sandstones
F11	<i>Globularia nainii, Hirschfeldia incana, Lythrum junceum</i>	<i>Pinus halepensis, Polygala balansae, Teucrium polium</i>	1700–3000	Semi-arid very cold	Montane Mediterranean	-9°C, 18°C	300–500 mm	Clays
F12	<i>Euphorbia niceensis, Fraxinus angustifolia, Polycarpon tetraphyllum</i>	<i>Bellis annua, Lactuca tenerrima, Quercus ilex</i>	1400–2400	Semi-arid cold	Supra-Mediterranean	-4°C, 28°C	350–600 mm	Limestones
F13	<i>Teucrium chamaedrys, Alyssum spinosum,</i>	<i>Arenaria pungens, Bupleurum spinosus,</i>	1700–3000	Semi-arid very cold	Montane Mediterranean	-8°C, 20°C	300–500 mm	Limestones, marls and dolomites

	<i>Polycarpon tetraphyllum</i>	<i>Cerastium arvense</i>					
F14	<i>Quercus ilex, Astragalus granatensis, Campanula filicaulis</i>	<i>Ononis spinosa, Polycarpon tetraphyllum, Teucrium chamaedrys</i>	1800–3100	Semi-arid very cold	Montane Mediterranean n	-9°C, 18°C	300–600 mm Limestones
F15	<i>Cytisus balansae, Euphorbia niceensis, Alyssum spinosum</i>	<i>Hirschfeldia incana, Cirsium dyris, Coronilla minima</i>	1800–3200	Semi-arid very cold	Meso-Mediterranean n	-4°C, 26°C	350–600 mm Limestones
F16	<i>Artemisia herba-alba, Ormenis scariosa, Euphorbia niceensis</i>	<i>Sanguisorba minor, Alyssum spinosum, Bupleurum spinosus</i>	2000–3500	Semi-arid extremely cold	Montane Mediterranean n	-7°C, 25°C	400–650 mm Limestones
F17	<i>Euphorbia niceensis, Ribes uva-crispa, Coronilla minima</i>	<i>Erinacea anthyllis, Alyssum serpyllifolium, Juniperus thurifera</i>	1800–3500	Semi-arid extremely cold	Montane Mediterranean n	-10°C, 18°C	300–600 mm Limestones
F18	<i>Alyssum spinosum, Scorzonera caespitosa, Thymus pallidus</i>	<i>Arenaria pungens, Carduncellus atractyloides, Euphorbia niceensis</i>	2000–3708	Semi-arid extremely cold	Montane Mediterranean n	-12°C, 15°C	200–400 mm Limestones
F19	<i>Alyssum spinosum, Bupleurum spinosum, Carduncellus atractyloides</i>	<i>Cytisus balansae, Erinacea anthyllis, Euphorbia niceensis</i>	2000–3708	Semi-arid extremely cold	Montane Mediterranean n	-10°C, 17°C	250–500 mm Limestones
F20	<i>Euphorbia niceensis, Alyssum spinosum, Erinacea anthyllis</i>	<i>Juniperus thurifera, Vella mairii, Ormenis scariosa</i>	2000–3708	Semi-arid extremely cold	Montane Mediterranean n	-9°C, 16°C	200–400 mm Limestones
F21	<i>Arenaria pungens, Vella mairii, Alyssum spinosum</i>	<i>Erinacea anthyllis, Bupleurum spinosum, Cytisus balansae</i>	2000–3708	Semi-arid extremely cold	Montane Mediterranean n	-11°C, 14°C	200–400 mm Limestones

4. Discussion:

4.1. Floristic Richness

The study is encompassing a highly importance species richness. Indeed, 565 species are sampled in the study area. The most abundant family is Asteraceae 100 species, followed by Fabaceae, Lamiaceae, Brassicaceae, Caryophyllaceae. Gharnit et al. (2024) have demonstrated that rangelands of the study area contain 509 species, while the most prominent botanical family is Asteraceae, Fabaceae and Poaceae (Gharnit et al., 2025). Based on a recent inventory, 155 families, 981 genera, 3913 species, and 426 subspecies of vascular plants are reported (Mohamed Fennane & Ibn Tattou, 2012). Regarding genera, *Silene*, with 68 species, is the richest in Morocco. *Centaurea*, *Teucrium*, *Ononis*, *Euphorbia*, *Astragalus*, *Trifolium*, and *Linaria* each have between 40 and 50 species (Ibn Tattou & Fennane, 1989). The richest families are Asteraceae, Fabaceae, and Poaceae; they total 1329 species. Five other families are also among the richest with more than 200 species (Brassicaceae, Lamiaceae, Caryophyllaceae) and 100 species each (Apiaceae, Scrophulariaceae) (Mohamed Fennane & Ibn Tattou, 2012).

These species are organized into six groups as revealed by CA plot. Block 1 comprises *Quercus ilex* forests and their clearings, representing the semi-arid forests of the region. Block 2 is heterogeneous, encompassing ecotones between *Q. ilex* and *Juniperus phoenicea* (F4, F5), *J. phoenicea* forests in a warm semi-arid climate (F6), and a transition zone between *Q. ilex*, *J. phoenicea*, and *Pinus halepensis* (F7). Block 3 includes *P. halepensis* forests (F8), their clearings (F9), and co-occurrence zones with *J. phoenicea* (F10, F11). Block 4 marks the appearance of xerophytes, indicating the upper limits of the previous blocks. Block 5 comprises *J. thurifera* formations associated with xerophytes, with F17 representing areas dominated by xerophytes due to deforestation. Block 6 represents the domain of spiny xerophytes of high mountains, characterized by species such as *Arenaria pungens*, *Valla mairii*, *Alyssum spinosum*, *Erinacea Anthyllis*, *Bupleurum spinosum*, *Cytisus balansae*, *Euphorbia niceensis*, and *Euphorbia megatlantica*. Other executed research in the area demonstrates the same tendencies; Gharnit et al. (2024) demonstrate that *Quercus ilex*, represents 27.53%; dominates up to 3000 meters in elevation. *Juniperus phoenicea* (14.78%) occupies lower altitudes (up to 2000 meters) and is characteristic of semi-arid regions. *Pinus halepensis* (1.38%) flourishes between 1100 and 2000 meters. *Juniperus thurifera* (1.33%) and xerophyte cushions (6.84%) thrive at high elevations (Gharnit et al., 2024).

Numerous threats of degradation or extinction threaten the flora of the M'Goun Geopark, due to uncontrolled development leading to significant destruction of the vegetation cover and its habitat. It should be noted that the M'Goun Geopark is constantly impacted by human activity, whether it be through grazing, agriculture, harvesting of medicinal plants or tourism. The effects of these activities on floral biodiversity are irreversible (Youssef et al., 2024). 21 % are endemic and 50 % species are endemics of Morocco. Strict endemic taxa are estimated at 951, representing 21% of Moroccan vascular plants (Fougrach et al., 2007).. The Asteraceae, Lamiaceae, and Fabaceae families are the richest in endemics, with 98, 77, and 63 species respectively (Ibn Tattou & Fennane, 1989). Morocco harbors 422 plant species listed as threatened in the IUCN Red List, of which 43 are endemic (Fennane & De Montmollin, 2015). 6% of species adapted to the geopark are listed in the IUCN Red List. While the rarity rate is 18 %, distributed as follows; 46 are extremely rare in Morocco, 24 are rare and three are vulnerable. Morocco is home to 126 families with rare species, and hosts 2185 rare species and 634 rare subspecies (M Fennane, 1998). The High Atlas has been reported and identified by several authors as true hotspots of the Mediterranean region with the most important endemism and rarity (Mohamed Fennane & Tattou, 1998; Medail & Quezel, 1997). The vascular flora of the High Atlas (excluding cultivated species) consists of approximately 1916 plant species (Teixidor-Toneu et al., 2022).

4.2. Phytoecology

Morocco presents a variety of climates due to the combined influence of several factors (Maliha et al., 2008). Two bioclimate zones are located in the area, these levels swap the localities each year in response to the recent climate anomalies. However, combine the climate and vegetation climax permit the characterization and cartography of these levels in the study area. Generally, the semiarid with temperate variants occupy low elevation (lower limit), while its cold and very cold variants dominate, the high elevation along with the subhumid. Indeed, the semi-arid regions of the

Geopark's rangelands, *Tetraclinis articulata* and *Juniperus phoenicea* occupy moderate and fresh variants, while the cold variant is inhabited by *Juniperus thurifera*, while the subhumid par is inhabited by *Q. ilex* (Gharnit et al., 2024).

The vegetation levels in the study area are Thermo-Mediterranean, Meso-Mediterranean, Supramediterranean, Mountain mediterranean and Oro-mediterranean. On the High Atlas Mountains, Defaut classifies the altitudinal zones as follows: Above 3,708 m corresponds to the nival zone; from 2,800 m to 3,708 m (+ 100 m) reflects upper oro-Mediterranean; from 2,350 m to 2,800 m (+ 200 m) presents lower oro-Mediterranean, from 2,350 m to 1,800 m hosts mountain Mediterranean, from 1,500 m to 1,800 m the supra-Mediterranean prevails, from 1,100 m to 1,500 m meso-Mediterranean dominates; while elevations bellow 1,500 m are dominated by thermo- and infra-Mediterranean (Defaut, 2015). Generally, The thermo-Mediterranean level hosts Carob, Olive-Mastic shrubland, Mediterranean conifers; meso-Mediterranean contains sclerophyllous forest; while supra-Mediterranean hosts deciduous forest; Mediterranean mountain is inhabited by mediterranean mountain conifers (Black Pine, Cedar, Fir, etc.); and the oro-Mediterranean encompasses thurifer junipers (Achhal et al., 1979a; Barbero & Quézel, 1976).

The thermo-Mediterranean zone is the most widespread in Morocco, covering both large horizontal and vertical areas. It is also the most biodiverse. It stretches from sea level up to approximately 1,000-1,400 meters, varying with latitude (Benabid, 1982). In addition this level is characterized by *Tetraclinis articulata*, some *Juniperus phoenicea*, *Olea europaea* var. *syvestris*, *Quercus suber* forests, *Cupressus atlantica* (Bernard, 2015). Thermo-Mediterranean zone within the Geopark is characterized by summer temperatures can reach highs between 36-36.12°C, while most precipitation occurs during the winter months, totalling 500-569 mm. This zone generally occupies altitudes between 661 and 1324 m within the Geopark, although variations may occur due to local conditions and topography. This level contains a rich and diverse flora, including a remarkable set of plant species: *Pistacia atlantica*, *Ziziphus lotus*, *Tetraclinis articulata*, *Juniperus phoenicea*, *Juniperus oxycedrus*, *Polygala balansae*, *Rhus pentaphylla*, *Cistus salvifolius*, *Teucrium fruticans*, *Olea europaea*, *Ceratonia siliqua*, *Chamaerops humilis*, *Pistacia lentiscus*.

The mesomediterranean contain *Juniperus phoenicea*, *Pistacia lentiscus*, *Pinus halepensis*, *Tetraclinis articulata* and *Quercus ilex* (Ozenda, 1975). Its altitudinal range fluctuates between approximately 900 and 1,400 meters in the Rif, and 1,100 and 1,500 meters in the High Atlas. In addition, the holm oak (*Quercus rotundifolia*) forms at this level more or less open forest formations which become increasingly tall and dense with altitude (Benabid, 1985). The mesomediterranean zone represents a transitional area between the thermomediterranean zone and more continental climates. It is characterized by a reduction in the seasonal contrasts observed in the thermomediterranean zone. Summers are less hot and dry compared to the thermomediterranean, with more frequent precipitation (500-550 mm). Winters are colder, with occasional frosts, and precipitation is distributed over a longer period, but is distinguished by a lower diversity. Its altitudinal extension is approximately between 522 and 2067 meters. The characteristic bioclimates of this level are semi-arid to subhumid, with essentially cool variants. Frosts are relatively frequent. This level is home to a specific flora, of which the dominant species is Holm oak (*Quercus ilex*); this species finds its optimal development in this level. Ozenda (1975) indicate that this level encompasses also Cork oak (*Quercus suber*) presents forming a few individuals inside the holm oak domains. Strawberry tree (*Arbutus unedo*), Wild olive tree (*Olea europaea*) Algerian thuya (*Tetraclinis articulata*) Carob tree (*Ceratonia siliqua*) Mastic tree (*Pistacia lentiscus*) Dwarf palm (*Chamaerops humilis*). The mesomediterranean zone is characterized to have complex cover formed by *Q. callipinos*, *Qu. suber*, pines, and other conifers (Ozenda, 1975).

The Supramediterranean is dominated by sclerophyllous oak forests (Benabid, 1985). Within the Geopark, it occupies altitudes ranging from 1017 to 1800 m, characterized by cooler and wetter climatic conditions. Maximum temperatures, generally cooler than lower altitudes with more pronounced thermal amplitudes. Precipitation is more abundant and distributed over a longer period of the year, averaging between 400-450 mm. This level corresponds to deciduous oak forests and mixed deciduous-coniferous formations. The characteristic bioclimates of this level in the study area are of a semi-arid type to subhumid, with essentially cool variants. Snow precipitations are frequent.

Holm oak (*Quercus ilex*) forests dominate the lower parts of this level, along with *Arbutus unedo*, *Cistus creticus*, and *Thymus zygis*... In the mediterranean, this belt dominates in high mountains between 800 and 1700 m.a.s.l., occupied by pine trees accompanied by some other conifers, mixed temperate forests of conifers, oaks (*Quercus pyrenaica*, *Q. pubescens*), strawberry trees (*Arbutus unedo*, *A. andrachne*) and a prickly juniper (*Juniperus oxycedrus*) (Vargas, 2020). While in Morocco, this level lies between approximately 1400 and 1800 m, and is characterized by sclerophyllous oak forests (*Q. rotundifolia*, *Q. suber*) in relatively dry areas, deciduous oak forests (*Q. faginea*, *Q. canariensis*, *Q. pyrenaica*) in humid areas, and coniferous formations (*Cedrus atlantica*, *Abies maroccana*) in humid areas where the thermal factor eliminates deciduous broadleaves at higher altitudes (Abdelmalek Benabid, 1982). The supramediterranean zone is typified by deciduous oak forests, along with *Ostrya* and other broad-leaved trees (Ozenda, 1975)

Mountain mediterranean highlights the transition between the milder Mediterranean climates of the plains and the harsher mountain climates at higher altitudes. Altitudes typically range between 1800-2350 meters, but can vary depending on topography and site features (Aspect, slope, wind and climate ...). Among the major forest species, we observe *Quercus rotundifolia* and *Juniperus thurifera*. This level is found only in the high mountains of Morocco. It is the high-altitude forest level of the cold and very cold variants of the subhumid, humid, and perhumid bioclimates, exceptionally semi-arid. The base of the belt level reaches 2,000 m in the High Atlas, while its ceiling reaches 2,600 m (Abdelmalek Benabid, 1985).

Oro-mediterranean is the culminating vegetation stage, observed only on the highest peaks of the Geopark. Its altitudinal limits are difficult to determine precisely. Pre-forest groups disappear giving way to cushion-forming xerophytic groups which reach 3700 m. The lower arboreal part corresponds to the lower oro-Mediterranean. We can estimate that very cold subhumid and extremely cold, however the semi-arid bioclimates characterize these altitudinal levels. Certain pre-forest series of the lower oro-mediterranean, the *J. thurifera* series and cushion-forming xerophytes, extend over the highest peaks of the Geopark, and under extremely cold semi-arid and subhumid sub-bioclimates. This belt occurs around 2,300 meters in the Middle Atlas and 2,600 m in the High Atlas. In turn, the pre-forest formations disappear between 2,800 and 3,200 meters, making way for xerophytes, which can reach altitudes of 3,600 to 3,800 m (Abdelmalek Benabid, 1982). The thorny xerophytes dominate high altitudes in the areas of Ait Boulli, Ait Bouguemmez, Zauit Ahansal and Anergui. These species include: *Bupleurum spinosum* or *Bupleurum atlanticum*, *Alyssum spinosum*, *Erinacea Anthyllis*, *Cytisus Balansae* or *Cytisus purgans*, *Ormenis scariosa* and *Arenaria pungens*... It begins at an altitude of 2000 to 3200 m and grows generally on a calcareous substrate.

The soil nature in the area is generally limestones associated with dolomite or marls and the clays accidentally associated with sandstones (Youssef Gharnit, Moujane, et al., 2024; Youssef et al., 2024). Our study confirms that the *Quercus ilex* formations are typically found on limestone substrates. *Pinus halepensis* occupies a wider range of substrates, including limestone, clays, and conglomerates. *Juniperus phoenicea* is more commonly associated with clays and sandstones. Xerophytic species are often found in association with *J. thurifera* and tend to inhabit limestone substrates. Furthermore the region is characterized by volcanic soils generally basaltic (Gharnit et al., 2023).

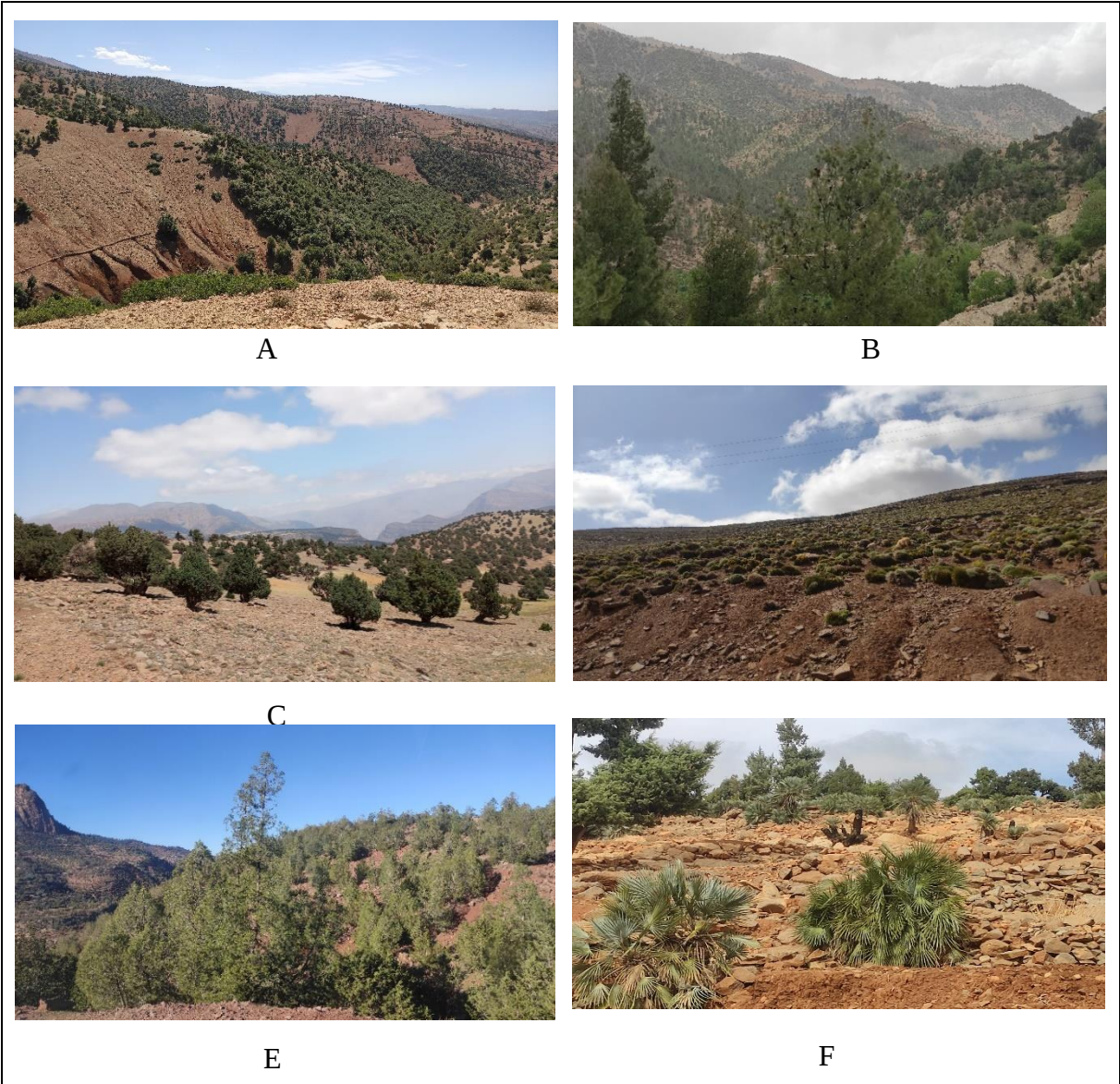


Figure 9. Aspects of habitats in the study area: A) Holm oak (*Quercus ilex*), B) Aleppo pine (*Pinus halepensis*), C) *Juniperus thurifera*, D) Spiny xerophytes, E) Phoenician juniper (*Juniperus phoenicea*) and *Tetraclinis articulata*, F) *Chamaerops humilis*.

The figure 10 shows the general aspects of some vegetal formation in the area. This region showcases the remarkable biodiversity of the High Atlas ecosystems, yet it's crucial to underscore that many species within these ecosystems are facing significant degradation and threats. This biodiversity decline is further exacerbated by the impacts of climate change. The local population heavily relies on these natural resources for their livelihoods, utilizing them for wood, rangelands, and livestock forage. Therefore, these forests are vital for maintaining biodiversity and supporting sustainable development policies. As a result, the protection and conservation of these forests are of paramount importance to avoid the severe consequences of their loss.

5. Conclusions

The Moroccan flora exhibits exceptional diversity, a fact underscored by the outstanding species richness found in Geopark Mgoun and the High Atlas Mountains. The region's vegetation cover comprises a mosaic of habitats, including holm oak, Phoenician juniper, *Tetraclinis*, and juniper *thurifera*. Moreover, these species form communities adapted to a wide range of ecological conditions, encompassing variations in temperature, precipitation, soil type, elevation, and cover nature.

The status of the majority of species remains unknown, and their true levels of rarity and the threats they face are unclear. This study identifies species that urgently require management and conservation policies, particularly in the context of increasing concerns about climate change. Rising temperatures, declining precipitation, and unprecedented heatwaves are exacerbating these threats. These factors, combined with destructive human activities such as uncontrolled exploitation of natural resources, particularly wood and charcoal production, and extensive overgrazing, have a significant impact. To mitigate these challenges, it is imperative to implement urgent conservation measures for threatened species and effective management strategies for the forests of the High Atlas of Morocco.

Acknowledgments: We extend our sincere gratitude to all those who assisted us during this research.

Conflicts of Interest: The authors declare no competing interests, and the study did not receive any specific grant from any funding source. We declare that this work has not been previously published, it is not under consideration for publication elsewhere.

Authors contributions: Material preparation, data collection, and analysis were performed by Outourakht Aboubakre and Youssef Gharnit. The first draft of the manuscript was written by Outourakht Aboubakre and Youssef Gharnit, Moujane Abdelazize. Supervision and guidance: Abdelali Boulli and Aziz Hassib. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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