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Environmental & Socio-economic Studies

environ ses

DOI:10.2478/environ-2025-0009

Environ. Socio.-econ. Stud., **2025, 13, 2: 21-34**

Original article

Floristic diversity and degradation status of incense juniper (*Juniperus thurifera* L.) communities in the Aurès region of eastern Algeria

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ABSTRACT

In the Aurès region, *Juniperus thurifera* L. is a crucial part of the local ecological heritage. However, it is highly threatened and is mainly found in relict populations. The aim of this study was to assess the diversity and floristic richness of *J. thurifera* stands in the Aurès region of eastern Algeria. Surveys were carried out at four sites to improve our understanding of the plant taxa associated with *J. thurifera* and to assess the extent of this endemic species in this region. Through systematic sampling, we identified 83 species from 30 families and 70 genera, with Asteraceae and Fabaceae being the most dominant families at all sites. Several ecological parameters were analysed: Shannon's diversity index ranged from 4.72 to 5.63 bits. While Pielou's evenness index, ranging from 0.89 to 0.98, indicates a relatively high level of species diversity and even distribution within the plant communities. Analysis of the biological spectrum reveals a predominance of chamaephytes (32%), followed by hemicryptophytes (29%) and therophytes (27%). Disturbance indices indicate a higher anthropogenic influence at lower altitudes, ranging from 57% disturbance at Zana (1680 m) to 48% at Chélia (1993). The floristic composition is predominantly Mediterranean (66%). A study of hierarchical ascending classification (HAC) enabled us to differentiate four groups of plants, highlighting the incense juniper. These results provide a valuable baseline for monitoring changes in *J. thurifera* stands in response to climate variability and human pressures. Conservation and preservation efforts are imperative to prevent further degradation of this unique ecosystem.

KEY WORDS: *Juniperus thurifera* L., floristic diversity, degradation, Aurès

ARTICLE HISTORY: received 27 January 2025; received in revised form 13 April 2025; accepted 2 May 2025

1. Introduction

The understanding, classification, characterisation and conservation of the different taxa are internationally recognised scientific imperatives for biodiversity assessment and management (COTTERILL, 1995). The current situation of Algerian forest ecosystems is the most critical in the Mediterranean region (IKERMOUD, 2000).

Regular fires, which destroyed an average of 35,025 hectares of forest per year between 1985 and 2010, have contributed to the significant regression of cedar forests in Belezma and the Aurès. This is what MEDDOUR ET AL. (2012) pointed out as a regressive trend in the various Algerian forest ecosystems.

Juniperus thurifera L. (LINÉE, 1753), commonly known as incense juniper, is a mountain species of the western Mediterranean with a fragmented distribution. In Algeria, *J. thurifera* is only found in the Aurès, where it is threatened with extinction and protected by national legislation. High altitude steppe formations, mainly characterised by this species, represent some of the most degraded paraforest environments in the Aurès (BEGHAMI, 2013).

J. thurifera occurs on both the northern and southern slopes of the Aurès, within an altitudinal range of 1,300 to 2,000 metres. Its formations have an open physiognomy, typically appearing as sparsely populated monospecific stands or as mixed stands dominated by other forest species, such as cedar (*Cedrus atlantica*), Aleppo pine (*Pinus halepensis*) and holm oak (*Quercus ilex*) (BELKASSIR & TEMAGOULT, 2001).

The regressive dynamics of thurifer populations are characterised by the absence of sufficient natural regeneration, resulting from the low germination rate of seeds and the presence of over exploitation and extension of xerophilous thorny plant formations. This could indicate an advanced stage of degradation and the beginning of steppisation (ABDERREZEK, 2017).

Therefore, it is imperative that an urgent conservation strategy is formulated for this species in its natural environment and that comprehensive propagation techniques are employed for future reintroduction (MORSLI, 2015). Despite the paucity of research conducted on incense juniper populations in the Aurès, it is imperative to recognise the potential for this species to contribute to the conservation of the region. WOUOKOUÉ (2018) emphasises that effective conservation of resources in the face of various degradation factors requires a comprehensive understanding of floristic diversity. Furthermore, MBAIYETOM ET AL. (2021) have emphasised the pivotal role of vegetation data in addressing ecological challenges, particularly as a predictive instrument for future ecological shifts and as a decision-making aid for ecosystem management.

The aim of this study was to enhance our understanding of the plant taxa associated with *J. thurifera* and to evaluate the extent of ecological degradation of this species in the Aurès region through floristic diversity.

2. Methods

2.1. Study area

The present study was conducted in the Aurès massif, which traverses the Saharan Atlas in the provinces of Batna and Khenchela in northeastern Algeria, approximately 250 km south of the Mediterranean Sea. The massif exhibits a pronounced asymmetric structure, characterised by a double east-west slope, extending approximately 100 km in each direction. The study area lies between 35°10' and 35°30' north latitude and 6°20' and 6°40' east longitude (Fig. 1).

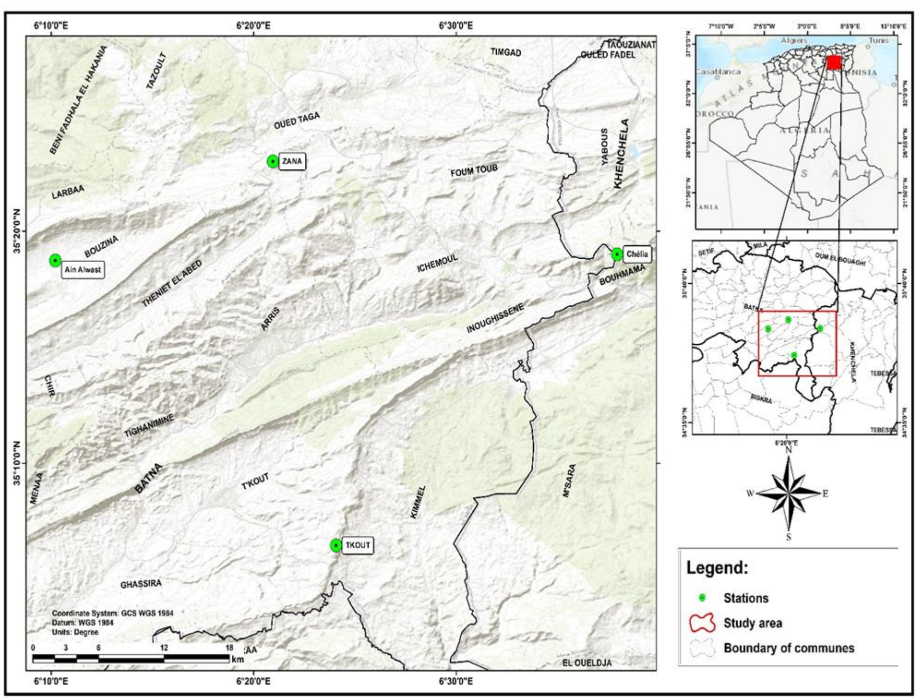

Fig. 1. Geographical location of sampling sites in the *Juniperus thurifera* zone (north-east Algeria) (Abderrezek, 2024)

The Aurès region is distinguished by its marked climatic and topographical variability. The terrain, primarily composed of Cretaceous and Quaternary formations, exhibits a variety of geological layers, including sandy, marl-calcareous, flysch and dolomitic deposits (BEGHAMI, 2013). The influence of altitude, exposure and slope on the region's climate is significant, resulting in a landscape characterised by contrast, with bioclimatic zones ranging from semi-arid to sub-humid. The region has experienced significant precipitation variability, with annual rainfall ranging from 128 to 747 mm between 1982 and 2020. Concurrently, temperatures have fluctuated within the range of 7 °C to 22 °C (GARAH, 2020).

2.2. Sampling methods

In order to achieve the aims of the present study, a comprehensive floristic inventory was conducted. This was done in order to assess the current status of *J. thurifera* stands, to examine vegetation dynamics and to determine the influence of various ecological factors. The study focused on four different sites in the Aurès massif (Fig. 2), with a sampling strategy designed to collect phyto-sociological data at a variety of locations. The sampling strategy encompassed a range of altitudes, exposures and orographic conditions (Table 1). The selection of sites was based on the principles of floristic and ecological homogeneity, employing subjective sampling methods (GOUNOT, 1969) and the Braun-Blanquet phytosociological approach (BRAUN-BLANQUET, 1951).

Field sampling was conducted from March to May 2021, coinciding with the peak vegetation period. A total of 38 surveys were conducted within the designated study area, encompassing an area of 400 m² (20 m × 20 m), a standard area in forest ecology for assessing the ecology of vascular plants (DAGGETT & GODRON, 1982). The selection of sampling sites was conducted with the consideration of vegetation characteristics, topographical features (including exposure and slope) and altitude. Identification of plant species was based onthe works of OZENDA (1977), QUÉZEL & SANTA (1962–1963) and DOBIGNARD & CHÂTELAIN (2010-2013).

Fig. 2. *J. thurifera* population in Ain Alwast located at an altitude of 1700 m (Abderrezek, 2024)

Table 1. Ecological characterisation of four *J. thurifera* sites in the Aurès massif

Sites	x	y	Altitude [m]	Exhibition	Slope [%]	Population structure	Bioclimatic stage
Chélia	35° 18’61" N	6°37’57" E	1930 - 1939	Northwest	35 - 40	*Juniperus thurifera* mixed with cedar (cedar forest)	Sub-humid with very cold winter
Zana	35°22’30" N	6°22’57" E	1600 - 1800	Northeast	15 - 40	Pure Thuriferae (Matorral)	Sub-humid with cold winter
Tkout	35°07’55" N	6°23’ 99" E	1750 - 1850	Southeast	30 - 35	Pure Thuriferae (Matorral)	Semi-arid with cold winter
Ain Alwast	35°18’22" N	6°12’ 67"E	1500 - 1700	Northwest	13 - 40	Pure Thuriferae (Matorral)	Semi-arid with cold winter

The biogeographical types of the species were determined on the basis of the work of QUÉZEL & SANTA (1962) and DOBIGNARD & CHÂTELAIN (2010-2013). The various chorological types are represented as follows: Endemic (End), North African endemic (N.A. End), Algerian-Moroccan endemic (Alg. Mar End), Eurasian (Eura), European (Euro), Euro-Mediterranean (Euro-Med), Mediterranean-Atlantic (Med-Atl), Mediterranean (Med), Central Mediterranean (C-Med), Circum-Med, Eastern Mediterranean (E-Med), Western Mediterranean (W-Med), Southern Mediterranean (S-Med), Ibero-Mauritanian (Ibero-Maur), Oro-Mediterranean (Oro-Med), Paleo-Subtropical (Pal. Sub. Trop), Subtropical (Sub. Trop), Oro-South-European (O.S. Eur), Macaronesian-Mediterranean (Mac. Med), Euras-Mediterranean (Euras. Med), Oro-West-Mediterranean (O.W. Med), Canari-Mediterranean (Can. Med).

We used the classification of RAUNKIAER (1934), which is based on the position occupied by dormant meristems relative to ground level during the adverse season and is therefore subdivided into phanerophytes, chamaephytes, hemicryptophytes, therophytes and geophytes.

2.3. Data analysis

The data collected were analysed, the list of inventoried species and their taxonomies were compiled in order to assess the floristic composition. The floristic diversity essential for the characterisation of a stand (RAMADE, 1994) was measured by species richness (S), the Shannon index (H') (FRONTIER, 1983; MAGURRAN, 1988), and the Pielou index (E) (DAJOZ, 2003; RAMADE, 2003).

The abundance frequency of a species (F) is the number of surveys in which this species is present in relation to the total number of observations. This index is used to express regularity of the distribution of a species within a plant community, which is given by the following formula:

$$F\,(\%) = \frac{ni}{N} * 100$$

ni: the number of surveys in which the species exists / N: the total number of surveys made.

DURIETZ proposed five classes of abundance in 1920:

Class 1: Very rare species $0 < F < 20\%$
Class 2: Rare species $20 < F < 40\%$
Class 3: Quite frequent species $40 < F < 60\%$
Class 4: Frequent species $60 < F < 80\%$
Class 5: Constant species $80 < F < 100\%$

The Shannon diversity index is employed to evaluate the composition of stands, incorporating the number of species and their respective relative abundances. Shannon diversity index (H′) is given by the following relationship:

$$H' = -\Sigma\, pi \times \log_2 pi$$

H' = Shannon diversity index, expressed in bits. It generally varies from 1 to 5 bits.
Pi: The specific contribution of species i, calculated using the formula ($P\,i = ni/\sum ni$, where ni is the absolute frequency of species i, assessed by its estimated cover abundance)

The Piélou equitability index (E) is a measure of the degree to which diversity has been achieved in relation to the theoretical maximum. The index ranges from 0 to 1, with 0 representing a situation in which almost all individuals belong to a single species, and 1 representing a situation in which all species have an equal share of the total area. The index is calculated by the following formula:

$E = H' / H\,max$, where $H\,max = \log_2 S$ (S is the total number of species)

Additionally, we assessed the extent of disturbance caused by human activities across the sites by computing the disturbance index (DI) (LOISEL & GAMILA, 1993), as defined by the following formula:

$$DI = \frac{\text{Number of chamaephytes} + \text{Number of therophytes}}{\text{Total number of species}} * 100$$

The present study employed R software (R CORE TEAM, 2023) to perform a hierarchical ascending analysis (HAC) on the original matrix, which consisted of 38 surveys × 83 species. In this search, we employed the abundance-dominance index, a method frequently used to target the search for groups of plants (DAHMANI, 1997). A frequently employed mathematical method in the study of vegetation is hierarchical ascending classification (BOUXIN, 2004).

As ESCOFIER & PAGES (1998) demonstrate, the lower the minimum variation, the greater the similarity between plant species within these well-individualised groups or clusters.

This technique has been used extensively in various vegetation studies, for ex ample: BONIN & ROMANE, (1996), DAHMANI (1984), TAIBAOUI ET AL. (2020). The calculation of a Euclidean distance matrix, which measures the dissimilarity between surveys, forms the basis for the application of HAC to the study of plant communities. Surveys are then progressively amalgamated through a linking method (WARD, 1963) to generate hierarchical clusters, which are presented in the form of a dendrogram.

The multivariate analysis was conducted using several specialised R packages, including vegan (OKSANEN ET AL., 2020), cluster (MAECHLER ET AL., 2022) and factoextra (KASSAMBARA, 2020). The determination of the optimal number of clusters was facilitated by the implementation of statistical measures, including the silhouette index and the deviation statistic.

3. Results and discussion

3.1. Systematics and floristic composition

The floristic inventory conducted across the four sites (Chélia, Zana, Tkout, and Ain Alwast) accounted for a total of 83 species of vascular plants, belonging to 30 families (Table 2). The number of taxa varied from 39 in Ain Alwast to 55 in Zana. Beghami (2013) identified 185 species in the thuriferies of (Tkout, Chélia and Sgag). While Menassri (2014), in his study of the floristic diversity of three ecosystems (thuriferae, pinerae and chênae) in the Aurès region, showed that the specific richness of thurifer juniper is relatively low compared with oak and pine forests.

A comparison of the species list for thuriferous juniper in Morocco and that established through work carried out in the Aurès region, and specifically at the study sites, revealed that, despite a certain similarity between the two, the species list for thuriferous juniper in Morocco is quite rich in terms of taxonomy.

Table 2. Systematic list, biological types and biogeographic origins of plant species inventoried in the stands of incense junipers in the region of Aurès. (+) Presence; (-) Absence; Names of plants following Dobignard and Châtelain (2010–2013); Biogeographical classification of plants following Quézel and Santa (1962–1963)

Families	Taxa	Plant life-form	Biogeographical types	Site Chelia	Site Zana	Site Tkout	Site Ain Alwast
Apiaceae	*Bupleurum spinosum* L.	Chamaephyte	Ibero-Maur	+	+	+	+
	Thapsia garganica L.	Hemicryptophyte	Eur. Med	-	+	+	+
	Eryngium campestre L.	Hemicryptophyte	Eur. Med	+	+	+	+
	Eryngium triquetrum Vahl.	Hemicryptophyte	Med. Euras	-	+	-	-
Asparagaceae	*Asparagus horridus* L. f.	Nanophanerophyte	Med	-	-	-	+
Asteraceae	*Centaurea pullata* L.	Hemicryptophyte	Med	-	+	+	+
	Carduus nutans L.	Hemicryptophyte	Euras	+	+	+	+
	Artemisia campestris L.	Geophyte	Med	-	+	+	+
	Carduncellus pinatus (Desf.) DC.	Hemicryptophyte	Med	+	+	-	-
	Atractylis humilis L.	Therophyte	Circ. Med.	-	+	+	+
	Anthemis arvensis L.	Therophyte	Ibero-Maur	+	+	+	-
	Hypochaeris glabra L.	Therophyte	End	+	-	+	+
	Hertia cheirifolia (L.) O.K.	Chamaephyte	Alg. Mar. End	+	+	+	+
	Crepis bursifolia L.	Therophyte	Eur. Med	-	+	-	-
	Pallenis spinosa (L.) Cass.	Therophyte	Eur. Med	-	+	+	-
	Scolymus hispanicus L.	Hemicryptophyte	Med	+	+	+	+
	Centaurea tougourensis B. et R.	Hemicryptophyte	End	+	+	+	-
	Centaurea melitensis L.	Hemicryptophyte	W. Med	-	-	-	+
	Onopordum macracanthum	Hemicryptophyte	W. Med	+	-	+	-
	Santolina rosmarinifolia L.	Chamaephyte	Med	-	-	+	-
	Carthamus carerulea L.	Hemicryptophyte	W. Med	+	-	-	-
	Matricaria camomilla L.	Therophyte	Med	+	-	+	-
	Centaurea tenuifolia Dufour	Hemicryptophyte	Med	+	-	-	+
	Artemisia herba-alba Asso.	Chamaephyte	Med	-	+	+	+
Berberidaceae	*Berberis hispanica* Boiss. et Reut.	Nanophanerophyte	Ibero-Maur	+	+	-	+
Boraginaceae	*Alkanna tinctoria Tausch subsp. tinctoria*	Hemicryptophyte	Med	+	+	-	+
	Echium arenarium Guss.	Hemicryptophyte	Euras. Med	-	+	-	+
Caryophylaceae	*Paronychia agrentea* Lam.	Therophyte	Med	-	+	-	-
	Dianthus caryophyllus (L.)	Hemicryptophyte	Med	-	+	+	+
Cistaceae	*Cistus salviifolius* L.	Chamaephyte	Med	+	-	+	-
	Helianthemum cinereum (Cav.) Pers.	Chamaephyte	Med	-	+	-	+
Convolvulaceae	*Convolvulus cantabrica* L.	Therophyte	Med	-	+	-	-
Crassulaceae	*Sedum acre* L.	Chamaephyte	Med	+	-	-	-
	Sedum sediforme (Jacq.) Pau.	Chamaephyte	Med		+	+	-
Cupressaceae	*Juniperus thurifera* L.	Phanerophyte	N.A. End	+	+	+	+

	Juniperus oxycedrus L.	Phanerophyte	Med	+	+	-	-
Dipsacaceae	*Sixalix atropurpurea subsp. maritima (L.) Greuter & Burdet*	Hemicryptophyte	Med	+	-	-	-
Ephedraceae	*Ephedra major* Host.	Phanerophyte	Mac. Med	-	+	-	+
Euphorbiaceae	*Euphorbia nicaeensis* All.	Chamaephyte	Euras	+	+	+	+
Fabaceae	*Astragalus armatus* Willd.	Chamaephyte	N.A. End	+	+	+	+
	Ononis natrix L.	Chamaephyte	Med	-	-	+	-
	Cytisus balansae (Boiss.) Ball	Chamaephyte	Med	+	-	-	-
	Anthyllis vulneraria L.	Hemicryptophyte	O.S. Eur	+	+	-	-
	Calicotome spinosa (L.) Link	Chamaephyte	W. Med	-	+	-	-
	Genista microcephala Coss. et Dur.	Chamaephyte	N.A. End	-	+	+	-
	Medicago luplina L.	Therophyte	Med	-	+	-	+
	Erinacea anthyllis Link	Chamaephyte	O.W. Med	+	+	-	+
	Lotus corniculatus L.	Hemicryptophyte	Euras	-	+	-	-
Globulariaceae	*Globularia alypum* L.	Chamaephyte	Med	+	+	-	+
Lamiaceae	*Thymus ciliatus* Desf.	Chamaephyte	N.A. End	+	-	+	+
	Teucrium polium L.	Chamaephyte	Eur. Med	+	+	+	+
	Salvia verbenaca L.	Hemicryptophyte	Med. Atl	+	+	-	-
	Marrubium vulgare L.	Hemicryptophyte	Med	+	+	+	+
	Teucrium chamaedrys L.	Chamaephyte	Eur. Med	-	-	-	+
	Rosmarinus officinalis L.	Chamaephyte	Med	-	+	-	-
Liliaceae	*Asphodelus microcarpus*	Geophyte	Can. Med	+	+	+	+
	Asphodeline lutea (L.) Rchb.	Geophyte	Can. Med	-	-	+	-
	Allium roseum L.	Geophyte	Med	-	+	-	-
Malvaceae	*Malope malachoides* L.	Therophyte	Med	+	+	-	-
Oleaceae	*Fraxinus dimorpha* Coss. & Durieu	Phanerophyte	Mac. Med	-	-	+	-
	Phillyrea angustifolia L.	Phanerophyte	Med	+	-	-	-
Pinaceae	*Cedrus atlantica* (Endl.) Carrière	Phanerophyte	O.Med	+	-	-	-
Plantagenaceae	*Plantago albicans* L.	Hemicryptophyte	Med	+	-	+	-
	Plantago lagopus L.	Therophyte	Med	-	+	-	-
Poaceae	*Stipa tenacissima* L.	Hemicryptophyte	Ibero-Maur	+	+	+	+
	Avena sterilis L.	Therophyte	Mac. Med	-	+	+	+
	Bromus rubens L.	Therophyte	Pal.Sub.Trop	+	+	-	-
	Ampelodesma mauritanicum (Poiret) Dur. et Sch.	Chamaephyte	W Med	-	+	-	+
	Hyparrhenia hirta (L.) Stapf	Hemicryptophyte	Sub.Trop	+	-	+	-
Primulaceae	*Anagallis monelli* L.	Hemicryptophyte	W.Med	-	+	-	+
	Anagallis arvensis L.	Therophyte	Med	+	-	-	-
Rhamnaceae	*Rhamnus alaternus* L.	Phanerophyte	W.Med	-	+	+	-
Ranunculaceae	*Ranunculus millefoliatus* Vahl.	Hemicryptophyte	E.Med	+	+	-	+
Rosaceae	*Rosa sempervirens* L.	Nanophanerophyte	Euras	-	+	-	+
	Rosa canina L.	Nanophanerophyte	Ibero-Maur	-	+	-	-
	Crataegus laciniata Ucria	Microphanerophyte	Euras. Med	-	-	+	-
Rubiaceae	*Galium setaceum Lamk.*	Therophyte	Sub.Med.Atl	+	+	-	+
	Galium tricornutum Dandy	Therophyte	Sub.Med.Atl	+	-	-	-
Selaginellaceae	*Selaginella denticulata*	Hemicryptophyte	Med	-	+	-	-
Thymelaeaceae	*Thymelaea virescens* Coss. et Dur.	Chamaephyte	Med	+	-	-	+
Zygophyllaceae	*Pegamum harmala* L.	Chamaephyte	Med	-	-	+	-

Examination of the floristic assemblage reveals a distinct heterogeneity in the distribution of genera and species among the families. Table 2 and Fig. 3 demonstrate a pronounced dominance of Asteraceae, constituting 22.9% (19 species) of the total, followed by Fabaceae at 10.8% (9 species), Lamiaceae with 7.23% (6 species), Poaceae at 6% (5 species), and Apiaceae making up 4.8% (4 species). The remaining families each represent less than 5% of the total species tally. MEDDOUR (2010) observed that anthropogenic pressure often promotes the proliferation of adventitious vegetation, predominantly consisting of Asteraceae and Fabaceae.

For his part, LE HOUEROU (1992) pointed out that the Asteraceae's adaptability to diverse environmental conditions enables their extensive territorial expansion. On the other hand, TRAORÉ ET AL. (2011) specify that anthropogenic pressure promotes the development of ruderal vegetation predominantly belonging to the Asteraceae and Fabaceae families. A comparison of the results obtained in this study, with those previously recorded in the Kabylie des Babors in northern Algeria (GHARZOULI & DJELLOULI, 2005) and (BEGHAMI, 2013) on the flora of the Aurès reveals that, for the majority of the plant families, the order remains consistent across both studies. The Asteraceae family is placed at the top of the classification, followed by the Fabaceae family and then the Lamiaceae and Poaceae families. These results are also in agreement with those obtained by DAOUDI ET AL. (2023) on the oak forests of Belezma Park in the Aurès, and are very close to those reported by MIARA ET AL. (2018) on forest and pre-forest environments in the western Tell Atlas of Tiaret, who noted a dominance of Asteraceae, Fabaceae, and Poaceae.

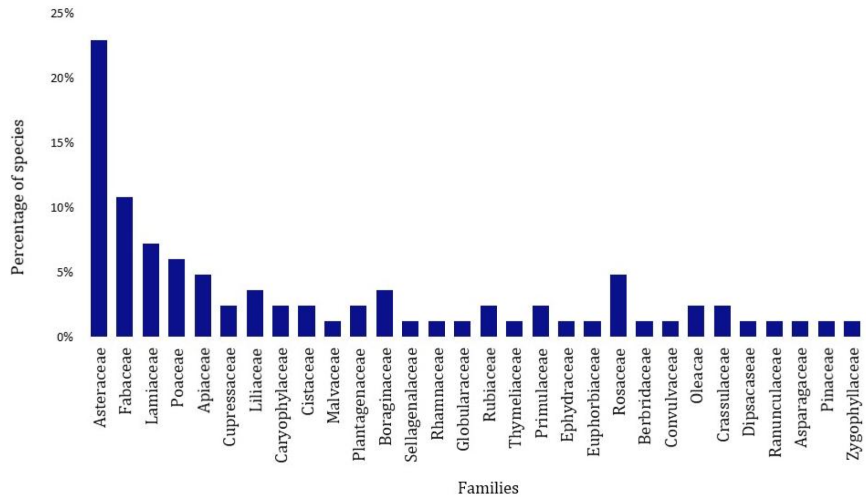

Fig. 3. Percentages of plant species recorded according to different families in the study area

3.2. Biological and biogeographical types

Across all surveyed stations, three plant life-forms: therophytes, hemicryptophytes, and chamaephytes, account for 88% of the total (Table 3). The Zana site, an easily reachable forest of *J. thurifera* at lower altitudes, exhibits a predominance of therophytes (31%). This pronounced abundance of therophytes, marked by an extensive incursion of annual species, benefits from a brief biological cycle and vigorous vegetative growth. BARBERO & QUÉZEL (1990) noted that the abundance of therophytes signals extensive openness and environmental degradation, typically due to overexploitation and grazing.

In contrast, the Chélia site, which resembles a forest environment with a well-preserved *Cedrus atlantica* - *J. thurifera* forest, located at higher altitudes, is mainly characterised by hemicryptophytes (33%). BARBERO & QUÉZEL (1989) linked the prevalence of hemicryptophytes in the Maghreb to the increase in organic matter and altitude in the forest land. Chamaephytes and therophytes are also very present there.

The Tkout and Ain Alwast sites, two high-altitude formations, are primarily characterised by the presence of chamaephytes (36% and 34%, respectively), while juniper incense plays a subsidiary role due to its low density. DANIN & ORSHAN (1990) indicated that chamaephytes are typical of scrubby shrublands. Furthermore, MEDAIL & DIADEMA (2006) mentioned that chamaephytes, which are usually toxic to herbivorous animals and therefore avoided by them, have increased in number, perhaps due to this deterrent property. DAGET (1980) emphasised the predominance of chamaephytes in matorral environments, underscoring their optimal adaptation to arid conditions. These species have been observed to be associated with high-altitude formations due to their capacity to adapt to the challenging climatic conditions that are characteristic of these environments. They have developed morphological and physiological strategies for survival (QUÉZEL & SANTA, 1962-1963; QUÉZEL, 1957).

Table 3. Distribution of Raunkiaer plant life forms in the Aurès thuriferae

Plant life-forms	Sites							
	Chélia		Zana		Tkout		Ain Alwast	
	Number of species	%	Number of Species	%	Number of species	%	Number of species	%
Therophytes	9	20	18	31	6	15	9	24
Hemicryptophytes	14	31	13	24	10	26	10	26
Chamephytes	13	29	15	26	14	36	13	34
Phanerophytes	6	11	5	11	5	13	4	11
Geophytes	3	7	4	7	4	10	2	5

Phanerophytes are found in second-to-last position across all sites. This regression of phanerophytes is indicative of a transition from forest-type vegetation to matorral. This phenomenon is indicative of a impending demographic shift within the composition of the vegetation, with the presence of old trees becoming increasingly prevalent.However, DAHMANI (1997) stated that, although geophytes show reduced diversity in degraded environments, they can predominate in specific scenarios such as overgrazing or frequent fires. The proportions of biological types recorded are in agreement with the results of several studies conducted in the Mediterranean area and the Aurès (AIDOUD, 1983; FLORET ET AL., 1990; BEGHAMI, 2013; MENASRI, 2014).

An evaluation of the documented flora reveals a transition from forest stands of incense juniper (*J. thurifera*) to a xerophytic vegetation, where species are becoming increasingly scarce. This, when considered in combination with the prevalence of spiny cushioned chamaephytes, suggests the onset of steppe formation and a regressive trend in incense juniper stands. This poses significant challenges for the conservation and renewal of the incense juniper. QUÉZEL (1999) stresses the importance of phyto-geographic studies in the conservation of biodiversity. QUÉZEL & MÉDAIL (2003) assert that the presence of remnants in the environment indicates that a climatic shift in this region has resulted in the migration of tropical and extratropical flora since the Miocene, underscoring the significance of biogeographical diversity in Mediterranean Africa.

The biogeographical examination of flora in the Aurès incense juniper stands reveals a chorological spectrum (Fig. 4), primarily composed of taxa of Mediterranean origin, representing 66%, followed by those with a widespread distribution at 18%. North African endemics, encompassing North African and Algero-Moroccan species, rank third, constituting 10% of the total flora. Nordic species have lowest participation, of about 6%. This analysis is in concordance with the studies conducted by QUÉZEL (1957), SCHOENENBERGER (1970), ABDESSEMED (1981), BEGHAMI (2013), GHARZOULI ET AL. (2000), and DAOUDI ET AL. (2023) in the Aurès region, mirroring the general flora trends in Algeria. BEGHAMI (2013) highlighted the predominance of the Mediterranean component, reflecting the mainly Mediterranean and less continental climate conditions at the northern edge of the Sahara, the world's vast desert. QUÉZEL (1999) pointed out that the regional scarcity of endemic elements is attributable to the extinction of several species following extensive environmental degradation.

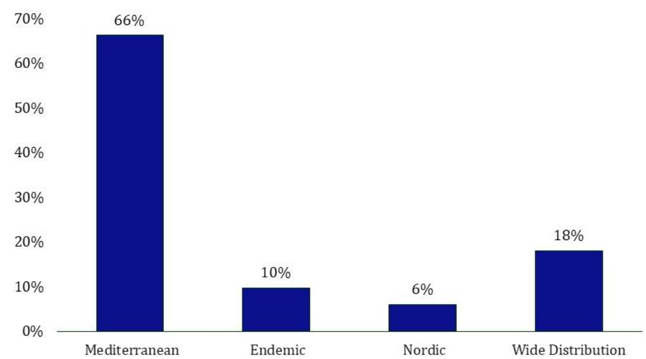

Fig. 4. Overall chorological types of species recorded in the study area

3.3. Diversity and equidistribution

3.3.1. Frequency of abundance

The classification of rare species, as indicated by low abundance and limited distribution, is predominant in the Zana, Tkout, and Ain Alwast region (Fig. 5), suggesting a preference for open and highly clear habitats (QUÉZEL & MÉDAIL, 2003). Consequently, the decline of these species in the region may be indicative of land-use conflicts, given their location in areas of intense human activity (GEGOUT, 1995).

In contrast, the Chélia site, a less disturbed cedar-thurifer stand, is home to predominantly constant species. This group includes species that are consistently found in all surveys throughout the year, although coverage rates vary, which indicates ecological stability and a strong adaptation of plant species to this environment. The under-representation of very rare species is suggestive of severe ecological selection or limiting environmental conditions. The observed variability between the sites can be attributed to environmental factors, including climate, soil type and altitude, as well as anthropogenic disturbances such as grazing and deforestation.

The predominance of rare species emphasises the necessity for targeted conservation strategies to protect this distinctive floral diversity. These observations are consistent with previous studies (Lemoine, 1965; Montès, 1999) that highlighted the floristic originality of thuriferous forests, particularly due to the high rate of regional endemism and the specific richness of these ecosystems.

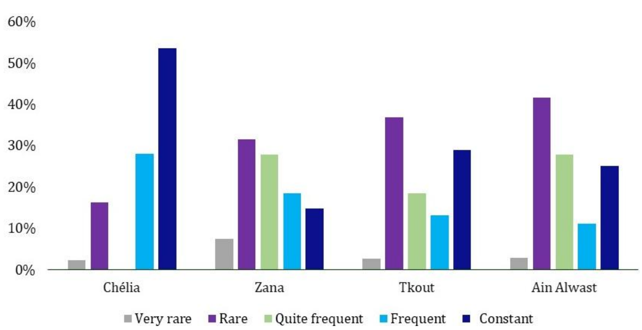

Fig. 5. Distribution of plant species in the ecosystems of *J. thurifera* in the Aurès, classified according to their frequency of abundance

3.3.2. Diversity and disturbance indexes

The Shannon index (H) and Pielou's evenness values (E) were found to be elevated at all of the studied sites (Table 4), thus indicating elevated diversity and a strong regularity in the distribution of individuals across species.

The results obtained for Zana demonstrate a species richness (St) of 55 species, indicating a high diversity (H' = 5.63), which approaches the theoretical maximum value (H'max = 5.75). The equitability value (E) is recorded as 98%, suggesting a balanced distribution of species within the ecosystem. This finding suggests that biodiversity is well-balanced and evenly distributed among species within this environment, providing favourable conditions for the coexistence of numerous species. This ecosystem is therefore deemed to be relatively stable and diverse. In contrast, the Tkout (89%) and Ain Alwast (90%) sites exhibit a slightly less balanced distribution.

Slimani et al. (2010) and Benabderrahmane et al. (2017) conducted studies on *J. thurifera* formations, identifying elevated diversity metrics within balanced plant communities. However, a comparative study conducted by Menasri (2014) on pine, oak, and incense juniper stands in the Aurès Mountains revealed that the pine and oak stands exhibited the highest diversity indices, while the incense juniper stand demonstrated the lowest diversity.

As posited by Akpo et al. (1999), an increase in diversity is indicative of an increase in the equality of individual contributions. Conversely, a decrease in diversity signifies a decrease in the regularity of individual distribution.

The disturbance indices calculated for each site (48% to 57%) indicate a moderately disturbed environment in the different studied areas (Table 4). A high index (like Zana with DI=57%) suggests a dominance of therophytes. This shows that the sites are subjected to regular disturbances (natural or human-induced), which influence the floristic composition and favour certain disturbance-resistant species with a short period of full development.

Table 4. Values of Total Specific Richness (St), Maximum Diversity (H'max), Shannon Diversity Index (H'), Equitability (E) and Disturbance Index (DI) of the Vegetation Inventoried in the Incense juniper stands of the Aurès Massif

Sites / Parameters	Chélia	Zana	Tkout	Ain Alwast
St	45	55	38	39
H' (bits)	5.06	5.63	4.72	4.82
H'max (bits)	5.42	5.75	5.24	5.28
E (%)	0.93	0.98	0.89	0.90
Disturbance index DI (%)	48	57	50	56

The importance of the disturbance index is proportional to the dominance of therophytes that find the environment favourable for their development, which also reflects a more open environment. Calculation of the disturbance index for each site makes it possible to quantify the therophytisation of an environment. The value of the disturbance index is significantly influenced by the prevalence of therophytes, which correlates directly with the openness of plant formations (Loisel & Gamila, 1993).

These results are consistent with those of Beghami (2013), who also explored incense juniper ecosystems in the Aurès region. Conversely, Larbi et al. (2021) demonstrated a low disturbance index (27%) for the Djurdjura cedar forest in Algeria. By contrast, Benabdellah (2011) documented a higher disturbance index (67%) for the Thuja and holm oak group in the Tlemcen mountains.

The disturbance index is a reliable indicator of the ongoing therophytisation and development of the steppe in the region under study. According to Barbero et al. (1981), therophytisation is interpreted as the final phase of ecosystem degeneration, characterised by the emergence of sub-nitrophilous species often associated with overgrazing. These disturbances are primarily the result of human pressures, deeply rooted in historical and social contexts (Abdessemed, 1984).

3.4. Hierarchical ascending classification (HAC)

HAC of the floristic surveys enabled the differentiation of the various groups of species most characteristic of the *Juniperus thurifera* association. It should be observed that HAC accentuates the presence of well-defined clusters or groups, within which individuals present high levels of similarity. The minimum level of variance is reduced under these conditions (Escofier & Pages, 1998). A study of the plant communities distinguished by *J. thurifera* identified four groups, as illustrated in Figure 6.

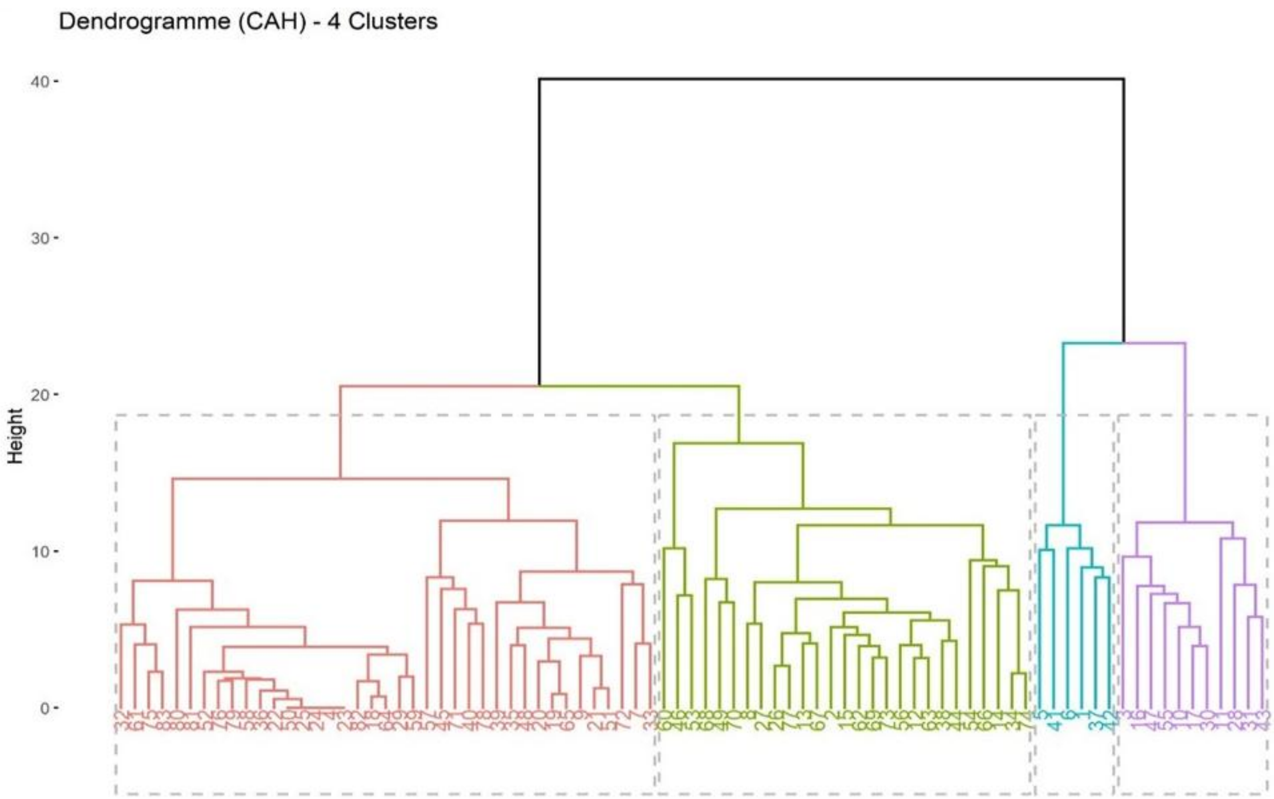

Fig. 6. Hierarchical ascending classification (HAC) dendrogram with 83 species classified by similarity, performed in the *J. thurifera* population of Aurès (study area)

Group1:

This group is constituted by a community of *Cedrus atlantica*, comprising three strata. The first stratum is represented by a cedar stand, which exhibits a cover exceeding 75% in this formation. The shrub layer is composed of *Fraxinus dimorpha, Phillyrea angustifolia* L.*, Berberis hispanica, Crataegus laciniata, with a herbaceous layer of variable importance comprising Cytisus aklansae, Sedum acre, Eryngium campestre* L., *Carduncellus pinatus, Anthemis arvensis* L.*, Cistus salviifolius* L., *Hyparrhenia hirta, Anagallis monelli*.

These species enhance the rather humid atmosphere of the cedar forest. They are found on very rugged rocky terrain, on north and west-facing slopes, at high altitudes (1930-1939 m) (BEGHAMI ET AL. 2007).

Phanerophytes are of particular interest in this regard, as they occupy a significant position within this ecological spectrum. They are indicative of environments that are less influenced by human activity due to their remote location, and they also represent environments that benefit from favourable climatic conditions. The phanaerophytes are primarily represented by rupicolous non-phanerophytes on fissured rock (BEGHAMI, 2013).

The phytosociological study by ABDESSEMED (1981) demonstrates that the cedar exhibits a high degree of versatility in its ability to thrive within a broad spectrum of groupings. These groupings encompass a wide range of ecological conditions, spanning from semi-arid to humid climates, and encompass different substrate types.

Group 2:

The second group is distinguished by the prevalence of therophytes and the infiltration of steppe species that demonstrate a tendency to reclaim space. The most prevalent species in these studies are: *Stipa tenacissima* L., *Avena sterilis* L., *Ampelodesma mauritanicus, Thymus ciliatus, Artemisia campestris* L., *Erinacea anthyllis, Globularia alypum, Thapsia gałganica* L., *Eryngium triquetrum* Vahl*, Atractylis humilis* L., *Asphodelus microcarpus, Plantago lagopus* L., *Avena sterilis* L. These species have been observed to be associated with high mountain formations, whether sylvan or rocky, and with mountain pastures (QUÉZEL, 1957; QUÉZEL & SANTA, 1962-1963), indicating the transition from forest-type vegetation to maquis due to the regression of phanerophytes in favour of the herbaceous component (RIVAS MARTINEZ ET AL., 1975). The presence of these species is indicative of a calcareous parent rock and a warm thermal environment, as they prefer dry, warm places on limestone (BAYER ET AL., 1990).

In this respect, BARBERO ET AL. (1981) propose the concept of therophytisation as the final stage in the degradation of ecosystems with sub-nitrophilic species linked to overgrazing. This disturbance is primarily attributable to anthropogenic pressure, which is both historical and social in origin (ABDESSEMED, 1984).

Group 3:

This grouping is characterised by the presence of thuriferous matorrals with thorny xerophytes, and is frequently accompanied by species that accompany *J. thurIfera*. In the field of phytosociology, these species are recognised as diagnostic species (GUINOCHET, 1973). The following species have been identified as the main 'companion' species of *Juniperus thurifera*: *Buplerum spinosum, Hertia cheirifolia, Artemisia compestris, Astragalus armatus, Euphorbea nicaeensis*. This predominance can be attributed primarily to the inhospitable climatic conditions characteristic of high-altitude mountainous regions, where *J. thurifera* is indigenous (OUHAMMOU, 1992; MONTÈS, 1999). These formations represent a transition zone characterised by sparse thuriferous vegetation, with a notable proliferation of spiny xerophytes. These species increasingly occupy the extensive interstitial spaces amongst the tree cover.

As BEGHAMI (2013) observes, there has been a substantial increase in chamaephytes within the high-altitude degraded thurifer group. These species are of particular interest in the landscape, and the thurifer plays a secondary role due to its density.

Group 4:

This community is distinguished by the complete absence of trees and shrubs, which are substituted by a layer comprised predominantly of hemicrypto-phytes. This phenomenon can be attributed to the high level of illumination, which is a consequence of the absence of phanerophytes (DANIN & ORSHAN, 1990; FLORET ET AL., 1990).

These formations are very open and exhibit a high degree of degradation characteristic of the high Asylvatic mountains. At the pedological level, in the majority of cases, the soil is absent or very skeletal, resulting from very intense erosion. Among these species, we menton *Eryngium campestre* L., *Carduus nutans* L.*, Scolymus hispanicus* L.*, Paronychia argentea, Dianthus caryophyllus, Ononis natrix* L., *Teucrium polium* L. These species are considered as the ultimate stages of forest degradation and highlight the importance of the degree of openness and degradation of the environment, as well as the phenomenon of aridification (Berbero et al., 2001).

4. Conclusion and perspectives

This study has enabled us to gain a better understanding of the floristic characteristics and plant groupings that distinguish the thurifer junipers of the Aurès, which remain relatively little studied.

The study of the degradation of *J. thurifera* stands using a biological approach confirmed a regression in the plant cover. This regression is characterised by the gradual disappearance of phanerophytes and the invasion of the environment by chamaephytes and therophytes. These phenomena indicate an advanced stage of degradation and the onset of steppisation.

It is imperative that researchers and managers closely monitor the evolution of the population in the coming years, and that the most appropriate conservation measures for its survival are considered in consultation with the local population.

It is vital that this fragile ecosystem is preserved at all costs. In all cases, it is imperative to establish protected plots of land. The absence of measures to conserve this invaluable heritage will inevitably lead to the transformation of the region into a completely asylvanic environment.

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