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Phytoecology of *Pinus Halepensis* Mill. stands in the Semi-Arid Region of Saida (Western Algeria)

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ABSTRACT: We conducted 166 floristic surveys in four Aleppo pine (*Pinus halepensis* Mill.) stands in the semi-arid region of Saïda, western Algeria, to investigate the relationships between plant community composition and selected climatic and edaphic variables. The study area is characterized by a cool-winter, semi-arid climate, with mean annual precipitation ranging from 300 to 400 mm. The soils beneath the surveyed stands contained 0.40–2.99% organic matter and had pH values ranging from 6.2 to 8.1, indicating slightly acidic to moderately alkaline conditions. Electrical conductivity ranged from 0.10 to 0.98 mS cm⁻¹, and the sampled soils were predominantly non-saline and calcareous, with CaCO₃ contents reaching up to 30.95%.

A total of 228 plant species belonging to 158 genera and 46 families were recorded. The most species-rich families were Asteraceae (49 species; 21.5%), Fabaceae (21; 9.2%), Poaceae (14; 6.1%), Lamiaceae (14; 6.1%), and Brassicaceae (13; 5.7%). The biological spectrum followed the order TH > HE > CH > PH > GE. Therophytes were the dominant life form (44%), followed by hemicryptophytes (21%), chamaephytes (20%), phanerophytes (8%), and geophytes (6%). The predominance of therophytes is consistent with arid conditions and disturbance; however, the respective contributions of climatic conditions and human activities were not quantified in this study. These stands warrant targeted protection and monitoring to support natural regeneration and reduce avoidable anthropogenic pressures.

1. INTRODUCTION

Pinus halepensis Mill. is a drought-tolerant conifer widely distributed across the Mediterranean Basin (Grioui *et al.*, 2020). It occupies approximately 3.5 million hectares, particularly in North Africa and southern Europe, from Spain to Greece (Fady *et al.*, 2020). It is widespread in semi-arid areas (Cherifi and Medjahdi, 2024). Indeed, it is a drought-tolerant conifer species (Mauri *et al.*, 2016; Zeoli, 2022). It is capable of surviving in unfavorable conditions (Vennetier, 2020).

In Algeria, the Aleppo pine is the most abundant forest species (Kherchouche *et al.*, 2023). It covers 40% of the country's forest area, with a surface area of 800,000 ha (Daoui, 2007). This species is found in most of Algeria's Mediterranean bioclimatic variants, even populating the most hostile areas on the edge of the Sahara (Rabhi *et al.*, 2023). Due to its high ecological plasticity and xerophilic nature (Khouja, 2020), *P. halepensis* is widely used in reforestation programs (Moutchou *et al.*, 2024). This conifer species is also distinguished by its relatively rapid growth (Mauri *et al.*, 2016).

In the Saïda region, Aleppo pine stands cover an area of 54.740 ha (D.G.F., 2018). Unfortunately, these Aleppo pine stands in the semi-arid region of western Algeria are undergoing continuous decline, mainly due to the combined effects of anthropogenic

and natural pressures. The study aims to carry out an ecological assessment of Aleppo pine forest in the semi-arid region of Saïda (western Algeria), examining their current state and identifying the factors that affect them. Specifically, the study evaluates floristic composition and selected climatic and edaphic attributes to inform the management of these stands.

2. MATERIALS AND METHODS

2.1 Study Material

The wilaya of Saïda is located in northwestern Algeria, between latitude 34°50' N and longitude 00°09' E (Figure 1). The province forms a geographical transition between the southern steppe and the northern Tell region. Due to its fairly large territory, two distinct natural areas can be distinguished: to the north, the Atlas Tell area and to the south, the high steppe plains (**Labani, 2005**). It covers a total area of 6,765 km² and is bordered to the north by the province of Mascara, to the south by the province of El-Bayadh, to the east by the province of Tiaret, and to the west by the province of Sidi Bel Abbès. The region is characterized by a large forest area covering approximately 174,361 ha, representing 26.17% of its total area. More than 59.67% of this forest area is located in six municipalities in the Daïa and the Saïda mountains. The region's soils are divided into three main groups: calcareous soils (brown calcareous soils, humic calcareous soils), red soils (non-calcareous fersiallitic soils, slightly calcareous fersiallitic soils, and red rendzinas) and lihosols (**Satec, 1976; Pietracarprina, 1988; Halitim, 1988; Benabdeli, 1996, BNEDER, 2008**). The vegetation in the study area is dominated *Pinus halepensis* Mill. and *Tetraclinis articulata* (Vahl) Masters, along with *Quercus coccifera* L. and *Quercus ilex* L., *Pistacia lentiscus* L., *Phillyrea angustifolia* L., *Genista tricuspidata* Desf. and *Genista ericoides* (Lam.) de Candolle, *Rosmarinus tournefortii* Spenn. and other species forming the understorey (**Terras, 2011**). The Saïda region is characterized by a wide range of elevations, ranging from 500 to 1,100 m (Kefifa, 2013).

Choice of study sites

Four representative sites were selected based on the presence of *Pinus halepensis* Mill. stands within the Wilaya of Saïda.

Table 1. Characteristics of study stations

Station	Youb	Sidi Boubker	Ouled Brahim	Aïn El Hadjar
Municipality	Youb	Sidi Boubker	Baloul	Aïn El Hadjar
Area (ha)	1,44	1,40	1,36	2,44
Altitude (m)	688 à 830	820 m à 1100 m	900 m à 1150 m	840 m à 1200 m
Exposure	South	Northwest	Northeast	Northwest
Coordinates	34°59'49.51"N	34°57'38.33" N	35° 1'34.03" N	34°44'25.63"N
	0°13'28.78"O	0° 3'28.89" E	0°31'57.86" E	0° 0'5.71"E
Numberof readings	36	35	34	61

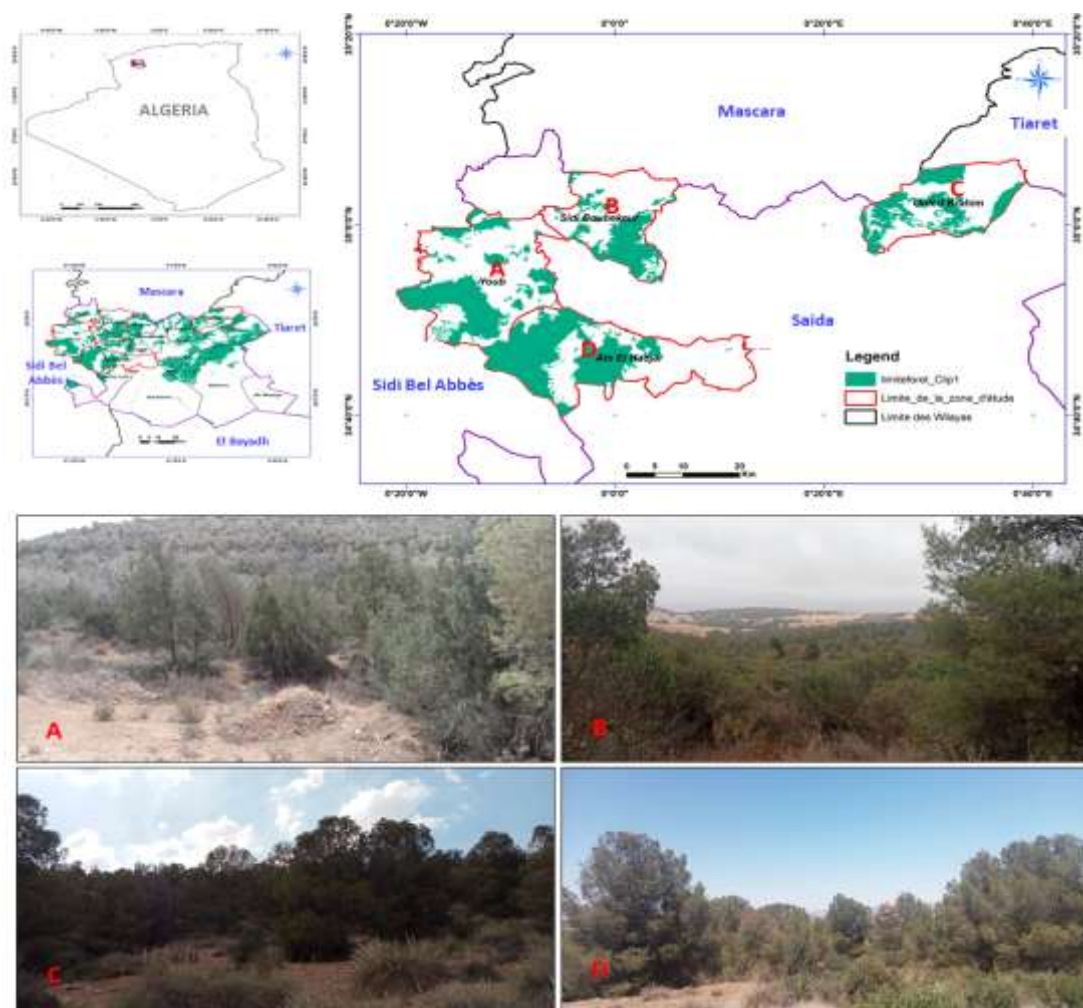


Figure 1. Map showing the location of the study area.

Description of study stations

- **Station 01 (A) « Youb »** It is characterized by a vegetation typical of semi-arid environments. (Bazan *et al.*, 2015), The vegetation is structured into three distinct strata. The tree layer is relatively sparse and is dominated by *Pinus halepensis* Mill. The shrub layer is relatively well developed and is mainly composed of *Pistacia lentiscus* L. and species of the genus *Cistus*. The herbaceous layer is sparse and is dominated by *Macrochloa tenacissima* (L.) Kunth. The soil has an average organic matter content of $2.88 \pm 1.02\%$, with values ranging from 1.53% to 6.05%. The pH ranges from 6.55 to 8.20, with an average of 7.23 ± 0.35 , indicating a slightly alkaline soil. The CaCO_3 content ranges from 2.61 to 16.50%, with an average of $10.19 \pm 3.41\%$, corresponding to a moderately calcareous soil. Electrical conductivity (EC) ranges from 0.125 to 0.950 mS/cm, with an average of 0.35 ± 0.23 mS/cm, indicating a non-saline soil. This mosaic reflects a fragile balance between natural factors (drought), human pressure (especially overgrazing in these areas), and the resilience of local species.

- **Station 02 (B) « Sidi Boubker »**: It is characterized by a vegetation dominated by *Pinus halepensis* Mill. And Mediterranean shrubs like *Pistacia lentiscus* L., *Phillyrea angustifolia* ... The soil is characterized by an organic matter content ranging from 0.40 to 4.36%, with an average of $2.30 \pm 0.87\%$. The pH ranges from 6.63 to 8.20, with an average of 7.30 ± 0.38 , indicating a slightly alkaline soil. The CaCO_3 content ranges from 0.71 to 25.23%, with an average of $9.16 \pm 5.72\%$, corresponding to a moderately calcareous soil. Electrical conductivity (EC) ranges from 0.10 to 0.99 mS cm^{-1} , with an average of 0.23 ± 0.18 mS cm^{-1} , indicating a non-saline soil. Taken together, these findings reflect ecological dynamics influenced by semi-arid climatic conditions, wildfires, and human activities.

- **Station 03 (C) « Ouled Brahim »:** The vegetation is degraded and structured into three distinct layers. The tree layer is dominated by *Pinus halepensis* Mill. The shrub layer consists mainly of *Pistacia lentiscus* L. and *Phillyrea angustifolia* L. Finally, the herbaceous layer is relatively sparse and is composed mainly of xerophytic species, such as *Macrochloa tenacissima* (L.) Kunth. The soil has an organic matter content ranging from 0.69 to 6.65 percent, with an average of 2.90 ± 1.39 percent, corresponding to an average organic matter content. The soil pH ranged from 6.58 to 8.30, with a mean of 7.52 ± 0.43 , indicating that the soil is slightly alkaline. The CaCO_3 content ranged from 1.19 to 19.20%, with a mean of $10.43 \pm 5.80\%$, corresponding to a moderately calcareous soil. Electrical conductivity (EC) ranged from 0.12 to 0.25 mS cm^{-1} , with an average of $0.17 \pm 0.03 \text{ mS cm}^{-1}$, indicating a non-saline soil. Soil conditions contribute to shaping floristic diversity.

- **Station 04 (D) « Aïn El Hadjar »:** It is characterized by an open forest formation, with a sparse tree layer dominated by *Pinus halepensis* Mill., a well-developed shrub layer composed mainly of *Pistacia lentiscus* L., *Phillyrea latifolia* L., and *Phillyrea angustifolia* L., as well as a dense herbaceous layer dominated by *Ampelodesmos mauritanicus* (Poir.) Durand & Schinz and *Macrochloa tenacissima* (L.) Kunth. The soil has an organic matter content ranging from 1.02 to 6.12 percent, with an average of 2.32 ± 1.01 percent, indicating a moderate organic matter content. The soil pH ranged from 6.00 to 8.20, with an average of 7.20 ± 0.39 , indicating that the soil was slightly alkaline. The CaCO_3 content ranged from 1.90 to 30.95%, with an average of $8.06 \pm 5.41\%$, indicating that the soil was moderately calcareous. Electrical conductivity (EC) ranged from 0.10 to 0.206 mS cm^{-1} , with an average of $0.142 \pm 0.021 \text{ mS cm}^{-1}$, indicating that the soil was non-saline. These characteristics, combined with semi-arid conditions, contribute to the fragility of the environment and may increase its susceptibility to erosion.

2.2 Climate study:

Climate data for Saïda were obtained from the National Meteorological Office (ONM) for the reference period (1991–2020). Monthly and annual precipitation (P), the average maximum temperature (M), and the average minimum temperature of the coldest month (m) were used to characterize the climate regime. The bioclimatic classification is based on the Emberger pluviothermal quotient (Q_2), while the duration of the dry season was determined from the monthly precipitation and temperature patterns.

2-3- Edaphic analysis

Between April and May in 2022 and 2023, 166 soil samples were collected beneath mature *P. halepensis* trees selected according to predefined health and site-representation criteria. The objective of this sampling was to analyze the main edaphic properties that are likely to influence the floristic diversity and dynamics of this species. In order to obtain an accurate picture of soil composition, the analysis focused on parameters widely recognized as indicators of soil quality: organic matter (OM), total calcium carbonate (CaCO_3) content, pH and electrical conductivity (EC) (Maharjan *et al.*, 2017).

2.4. Floristic analysis

The floristic inventory was based on 166 vegetation surveys conducted in the four selected sites between March and June in 2022 and 2023. This period is optimal, as it generally occurs in a rainy context that allows the establishment of annuals (Achir, 2016; Arjdal *et al.*, 2023; Wu *et al.*, 2024; Denton *et al.*, 2024). Plots were selected purposively within apparently homogeneous vegetation; the criteria and potential selection bias should be stated explicitly. This is the simplest and most intuitive form, which consists of selecting areas that appear particularly homogeneous and representative as samples (Gounot, 1969). For the study area, the minimum area is 400 m^2 to 500 m^2 , depending on the vegetation type (Gounot, 1969; Ozenda, 1982).

To identify the flora, we consulted the flora of Algeria and the southern desert regions of (Quézel and Santa 1962, 1963). The botanical nomenclature adopted follows the Synonymic Index of North Africa (Dobignard and Chatelain, 2010-2013).

2.5 Analytical Methods

To characterize the edaphic properties of the study sites, several physicochemical soil parameters were analyzed, including organic matter, pH, electrical conductivity, and CaCO_3 content. The organic matter content was determined using the Walkley and Black method, as described by Konkobo *et al.* (2025). One gram of soil was used for each analysis, which was performed in duplicate. The method involves the cold oxidation of organic carbon using a potassium dichromate solution ($\text{K}_2\text{Cr}_2\text{O}_7$, 1 N) in concentrated sulfuric acid (H_2SO_4). The unreacted dichromate is then titrated using a standard solution of ferrous sulfate

(FeSO₄), in the presence of diphenylamine as a redox indicator. The color change from dark blue to blue-green marks the equivalence point. The amount of oxidized carbon is calculated based on the volume of reagent consumed and then converted to a percentage of organic matter according to the formula used:

$$\%OC_x = \frac{C \cdot 4.0,3}{g} \cdot 100$$

g

$$\%OM = \%OC_x \cdot 1,724$$

C: volume of potassium dichromate added, in ml

4: conversion to 0.1 N.

g: test sample in mg.

% Cox: percentage of carbon oxidized.

The pH was determined using 40 g of air-dried fine soil suspended in 100 mL of distilled water. The suspension was stirred for 15 minutes, then filtered through filter paper. The pH was then measured in the filtrate using a pH meter. Electrical conductivity (EC) was measured using a conductivity meter by immersing the electrode in the filtered solution prepared from 40 g of soil in 100 mL of distilled water. The values obtained were expressed in mS/cm and interpreted according to salinity classes.

The total limestone content (CaCO₃) was determined using Bernard's calcimeter. This method involves measuring the volume of CO₂ released during the reaction of the calcium carbonate contained in the soil sample with hydrochloric acid, and then comparing it to the volume of CO₂ produced under the same conditions from a known quantity of pure CaCO₃. The CaCO₃ content is then calculated based on this comparison.

$$CaCO_3 \% = \frac{V \cdot U}{P \cdot V_0} \cdot 100$$

P.V₀

V: volume of CO₂ released

U: Weight of pure CaCO₃

V₀: volume of pure CaCO₃

P: Weight of the sample.

2.6 Statistical Analysis

Using the statistical software XLSTAT (version 2024), an Ascending Hierarchical Classification (AHC) was performed, followed by a Principal Component Analysis (PCA).

This statistical approach allowed us to highlight the relationships between the variables studied. This mixed-methods approach offers the advantage of homogeneity and stability in the classes (Husson *et al.*, 2017). PCA allows the different boroughs to be grouped according to their coordinates on the various factor axes, while HCA creates classes that are homogeneous in terms of their temporal profiles (Matsaguim *et al.*, 2020).

3. RESULTS AND DISCUSSION

3.1 Climate study

The Saida region is located in the upper semi-arid bioclimatic zone with cool winters, where rainfall ranges from 300 to 400 mm per year. January is the coldest month, with an average minimum temperature of 2.7°C, while August, the hottest month, has an average temperature of around 31.5°C. The seasonal rainfall pattern is HAPE. The dry season lasts for up to six months. The region has a semi-arid bioclimate with cool winters according to the EMBERGER classification. Despite these difficult climatic conditions, *P. halepensis* is able to tolerate aridity, even though its flora, particularly annual herbaceous plants, are degraded.

Therefore, the semi-arid climate of the Saïda region is generally favorable for the *Pinus halepensis* Mill. This species is well adapted to semi-arid conditions, where it finds its optimum growth, particularly in areas where annual rainfall is between 300 and 600 mm.

3.2 Edaphic study

The results of the soil analysis are presented in Figure 2. Soil pH values ranged from 6.2 to 8.1, indicating conditions ranging from slightly acidic to moderately alkaline. Electrical conductivity is similar in the soils of our study area, ranging from 0.1 mS/cm to 0.98 mS/cm, indicating that the soils are not saline to slightly saline in some areas. The organic matter content varies from 0.4% (low) to 2.99% (average), with the exception of one reading with a significantly higher value (6.65%), recorded in a

soil with a slightly acidic pH (6.95). Analysis of the limestone (CaCO_3) reveals that all samples are slightly to moderately calcareous, with the exception of two readings that show particularly high limestone levels (30.95% and 29.52%).

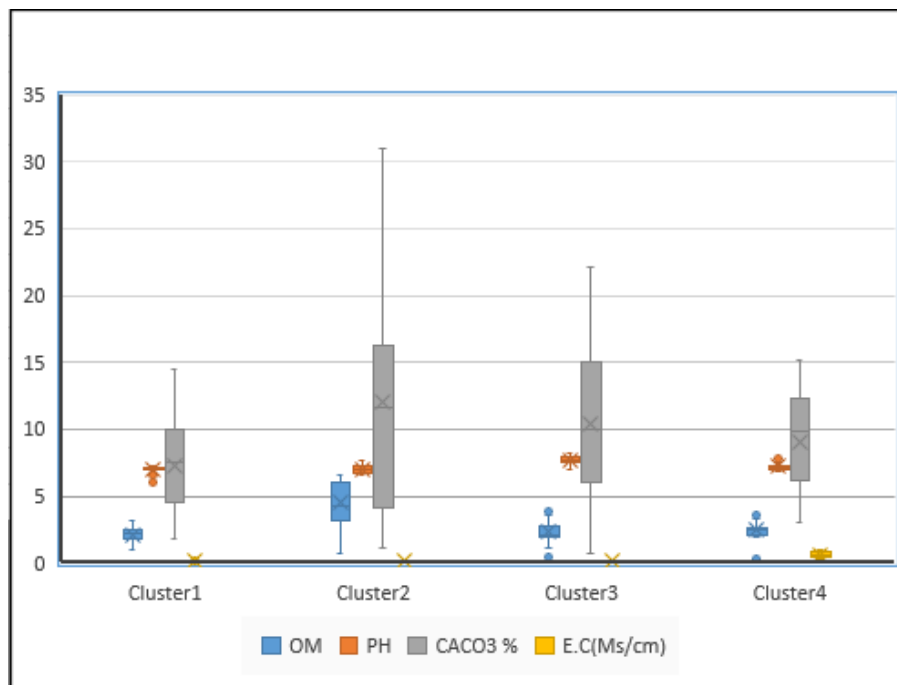


Figure 2. Characterization of edaphic parameters in *Pinus halepensis* forest formations at the study sites

Each cluster groups together soils with similar characteristics, and the graph compares their distributions in OM (%), pH, CaCO_3 (%) and electrical conductivity (EC). Soil properties vary between clusters. Organic matter is low and stable in C1, average but highly variable in C2, and moderate to low with similar variability in C3 and C4. pH is fairly constant, neutral to alkaline in C1 and C2, and more alkaline in C3 and C4. The limestone content varies greatly: low in C1, very heterogeneous in C2, and moderate to high with extreme values in C3. Electrical conductivity indicates relatively low salinity: stable and low in C1, more variable in C2 and C3, and slightly higher in C4. Cluster 2 is characterized by highly heterogeneous soils, particularly in terms of organic matter and calcium carbonate. Cluster 1 is the most homogeneous, with low OM and CaCO_3 contents. Clusters 3 and 4 have intermediate profiles, with moderate and fairly consistent values.

3.3 Floristic diversity

The floristic diversity of our study area is 228 species divided into 46 botanical families and 158 genera. The main families are Asteraceae (49 species), Fabaceae (21 species), Poaceae (14 species), Lamiaceae (14 species) and Brassicaceae (13 species) (Figure. 3).

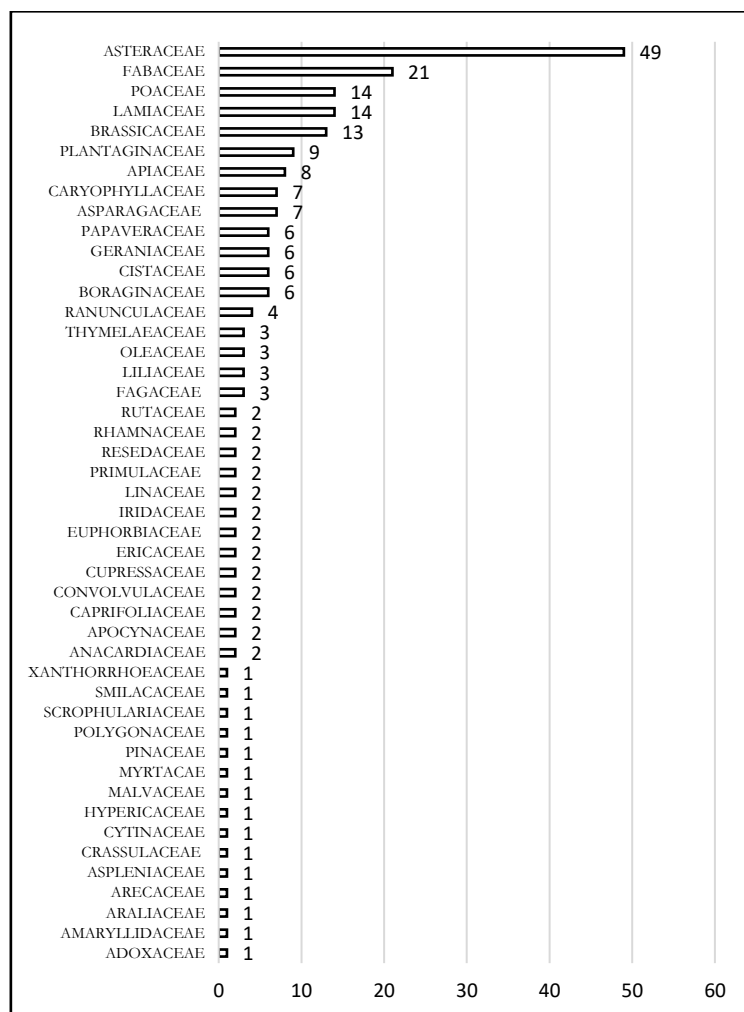


Figure 3. Distribution of botanical families within the study sites.

Biological spectrum

In our study area, the biological spectrum follows the order: TH > HE > CH > PH > GE. Therophytes are by far the most common (44%), followed by hemicryptophytes (21%), chamaephytes (20%), phanerophytes (8%) and geophytes, which are the least represented with only 6% of the total (Figure 4).

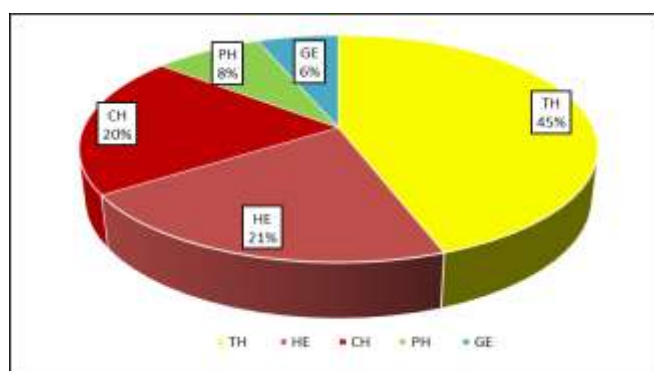


Figure 4. Type of biome in the study area

Biogeographical types

The flora in our study area is mainly Mediterranean in origin (37.72%) (Figure 5), followed by Western Mediterranean and Iberian-Mauritanian types, confirming the biogeographical roots in the western Mediterranean region. The presence of widely distributed types (Eurasian, cosmopolitan) shows ecological diversity, while the significant proportion of endemic species (around 10%) highlights the rich heritage of the local flora.

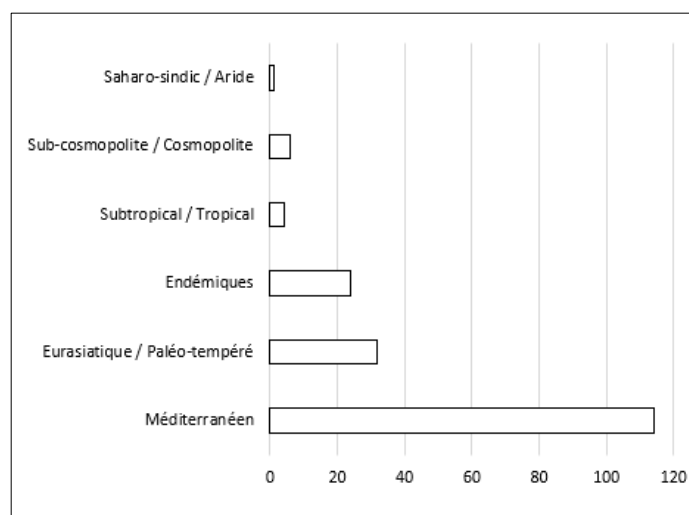


Figure 5. Biogeographical types in the study area

Endemism

The flora of the study area includes 22 regional endemic species (Table 2), representing 9.64% of all species recorded. Of the 46 botanical families present, 10 include these endemic species. The most frequently recorded families are, in descending order: Brassicaceae (5 species), followed by Asteraceae and Lamiaceae (4 species each), then Fabaceae and Boraginaceae (2 species each). Among these 22 taxa, 11 belong to the Algerian-Moroccan endemic group, which constitutes 4.91% of the 224 species in this group identified at the regional level, according to (Vela and Benhouhou, 2007).

Table 2. List of endemic species

Species	Endemism
<i>Centaurea phaeolepis</i> Coss.	End. Alg.
<i>Otocarpus virgatus</i> Durieu	End. Alg.
<i>Thymus lanceolatus</i> Desf.	End. Alg.
<i>Astragalus incanus</i> subsp. <i>incurvus</i> (Desf.) Maire	End. Alg.-Mar
<i>Borago trabutii</i> Maire	End. Alg.-Mar
<i>Carlina macrophylla</i> (Desf.) DC.	End. Alg.-Mar
<i>Centaurea involucrata</i> Desf.	End. Alg.-Mar
<i>Cordylolobus muricatus</i> Desf.	End. Alg.-Mar
<i>ErUCA vesicaria</i> (L.) Cav. subsp. <i>Vesicaria</i>	End. Alg.-Mar
<i>Genista quadriflora</i> Munby	End. Alg.-Mar
<i>Iris tingitana</i> Boiss. & Reut.	End. Alg.-Mar

<i>Pardoglossum lanatum</i> (L.) Barbier & Mathez	End. Alg.-Mar
<i>Thymus munbyanus</i> subsp. <i>ciliatus</i> (Desf.) Greuter & Burdet	End. Alg.-Mar
<i>Thymus pallescens</i> de Noé	End. Alg.-Mar
<i>Bupleurum balansae</i> Boiss. & Reut.	End. Alg.-Mar-Tun
<i>Psychine stylosa</i> Desf.	End. Alg.-Mar-Tun
<i>Ebenus pinnata</i> Aiton	End. Alg.-Mar-Tun-Lib
<i>Enartbrocarpus clavatus</i> Delile ex Godr.	End. Alg.-Mar-Tun-Lib
<i>Helianthemum helianthemoides</i> (Desf.) Grosser	End. Alg.-Mar-Tun-Lib
<i>Onopordum arenarium</i> (Desf.) Pomel	End. Alg.-Mar-Tun-Lib
<i>Thymus algeriensis</i> Boiss. & Reut	End. Alg.-Mar-Tun-Lib
<i>Linum tenue</i> Desf. subsp. <i>Tenue</i>	End. Alg.-Mar-Esp

Rarity and protection status of plant species

The study of the species recorded shows that 7.98% of the recorded flora, or 18 taxa, are classified as rare (Table 3). Of these, 6 are considered fairly rare (FR), 10 rare (R) and 2 very rare (RR). In addition, nine taxa identified in the study area have legal protection status (Table 4), in accordance with Executive Decree No. 12-03 of January 4, 2012, relating to protected non-cultivated plant species in Algeria. Among these nine protected taxa, two are also included in the IUCN Red List (2022). The floristic analysis shows vulnerable biodiversity, marked by a remarkable rate of rare and protected species. This ecological vulnerability highlights the urgency of implementing conservation measures and sustainable management to safeguard this threatened ecosystem.

Table 3. List of rare plants

Taxon	Endemic	Protected	Rarity
<i>Eryngium campestre</i> L.	/	/	FR
<i>Achillea santolinoides</i> Lag	/	/	FR
<i>Alyssum serpyllifolium</i> Desf.	/	/	FR
<i>Genista hirsuta</i> subsp. <i>eriolada</i> (Spach) Raynaud	End	P	FR
<i>Genista quadriflora</i> Munby	End. Alg.-Mar	/	FR
<i>Thymelaea argentata</i> (Lam.) Pau	/	/	FR
<i>Daucus carota</i> L. subsp. <i>Carota</i>	/	/	R
<i>Euphorbia squamigera</i> Loisel.	/	/	R
<i>Centaurea phaeolepis</i> Coss	End	P	R
<i>Marrubium supinum</i> L.	/	P	R
<i>Platycapnos spicata</i> (L.) Bernh.	/	/	R
<i>Teucrium fruticans</i> L.	/	/	R
<i>Thymus lanceolatus</i> Desf	End	P	R

<i>Rosmarinus eriocalyx</i>	/	/	R
<i>Linum tenue</i> Desf. subsp. <i>Tenne</i>	End. Alg.Mar.Esp.	/	R
<i>Phillyrea angustifolia</i> L.	/	/	R
<i>Carlina macrophylla</i> (Desf.) DC	End. Alg.-Mar	/	RR
<i>Otocarpus virgatus</i> Durieu	End	P	RR

FR: Quite rare – infrequent species, scattered presence R: Rare – very infrequent species, limited distribution RR: Very rare – extremely localized species, exceptional presence P: Species protected by national legislation (Executive Decree No. 12-03 of January 4, 2012)

Table 4. List of protected plants in Algeria

Taxon	Endemic	D.E.	UICN	Rarity
<i>Genista hirsuta</i> subsp. <i>erioclada</i> (Spach) Raynaud	End	P		FR
<i>Centaurea phaeolepis</i> Coss	End	P	R	R
<i>Marrubium supinum</i> L.	/	P		R
<i>Thymus lanceolatus</i> Desf	End	P		R
<i>Otocarpus virgatus</i> Durieu	End	P	E	RR
<i>Pistacia atlantica</i> Desf.	/	P		FC
<i>Helianthemum helianthemoides</i> (Desf.) Grosser	End. Alg.-Mar-Tun	P		CC
<i>Juniperus oxycedrus</i> L. subsp. <i>Oxycedrus</i>	/	P		CC
<i>Tetraclinis articulata</i> (Vahl) Mast.	/	P		CC

P: Species protected by national legislation (Executive Decree No. 12-03 of January 4, 2012). **E:** Endangered, species facing a very high risk of extinction in the medium term, according to the IUCN (2022). **R (Rare):** Term used to designate species with a restricted range or low abundance, in the former pre-2001 IUCN categories. **FC:** Fairly common. The species is regularly present, without being abundant. **CC:** Very common. The species is abundant and widespread.

3.4 Data analysis

Analysis of factorial designs and dendrograms (C.A.H.) identified four types of clusters characteristic of *Pinus halepensis* formations. The PCA interpretation was only performed on the first three factor axes that were most strongly correlated with each other. The first three axes explain 81.76% of the information (Table 5).

Table 5. Eigenvalues and percentage of inertia of the PCA.

	F1	F2	F3
Eigenvalue	1,266	1,007	0,998
Variability (%)	31,655	25,173	24,941
Cumulative %	31,655	56,828	81,769

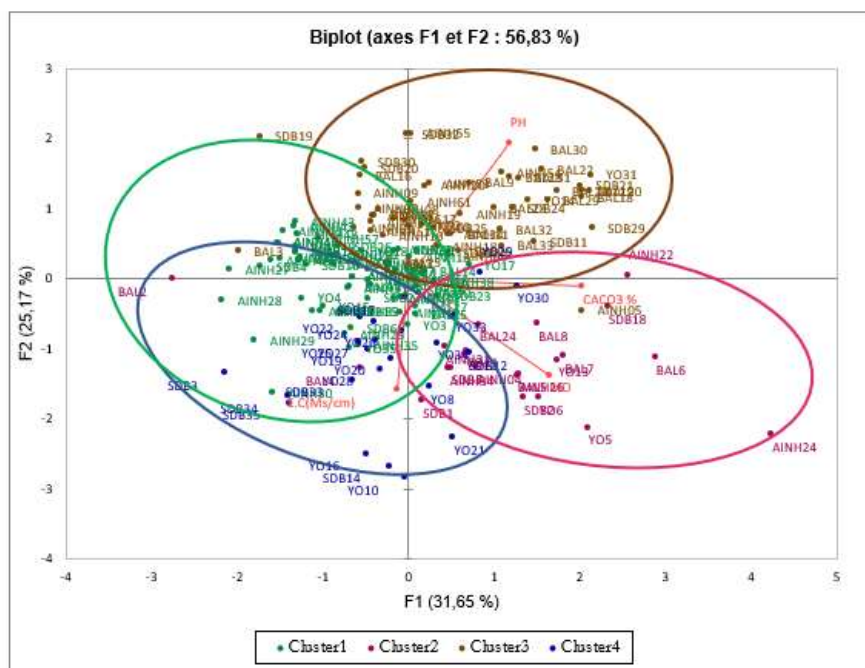


Figure 6. Projection of variables on factor axes 1-2.

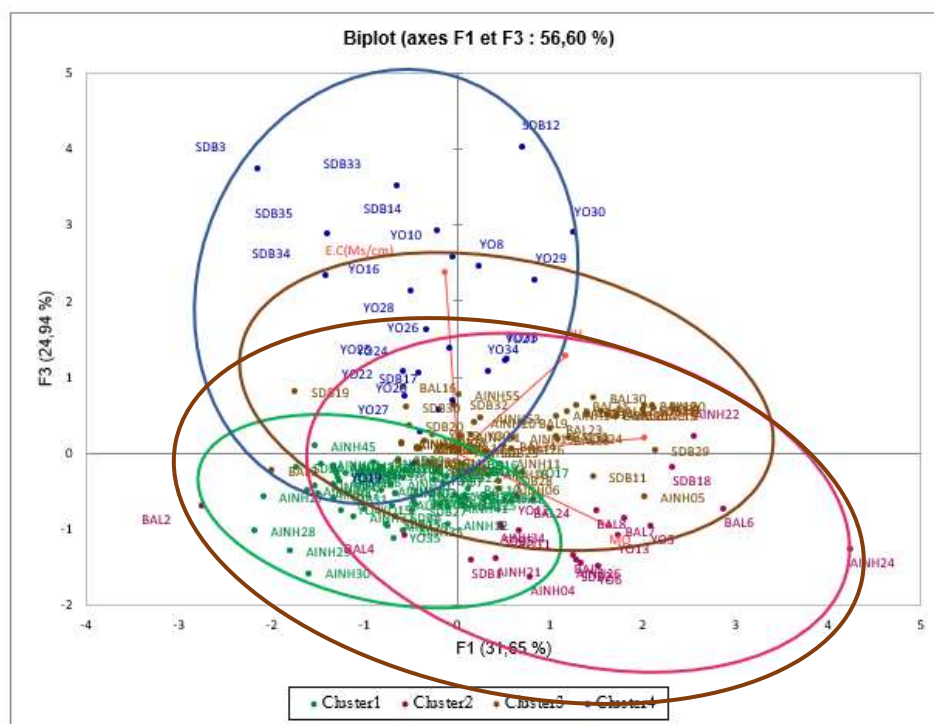


Figure 7. Projection of variables on factor axes 1-3.

Correspondence factor analysis (CFA) applied to floristic data often reveals classification structures within the data, which allowing species and surveys to be grouped into distinct classes or groups.

Four groups were visually distinguished in the ordination, although their statistical separation and stability require validation.

Subgroup 1 (Cluster 1): The areas recorded in this cluster have unfavorable environmental conditions, as shown by the strong negative correlation (F01). This is reflected in poor soils with lower organic matter content.

Subgroup 2 (Cluster 2): Analysis of the surveys shows that cluster 02 is associated with areas with soils rich in organic matter and calcium carbonate (F01).

Subgroup 3 (Cluster 03): The Cluster 03 readings indicate the positive characteristics that sustain plant growth in certain environments.

Subgroup 4 (Cluster 4): This subgroup presents conditions that are unfavorable to plant growth, characterized by low organic matter and poor soil that limit nutrient availability.

4. DISCUSSION

From an edaphic perspective, the pH of the soils in most of our study area is neutral to basic. Similar results have been reported in various studies. In the Fenouane forest (Saïda Mountains, western Algeria), the average pH is 7.24 (Borsali *et al.*, 2014). According to Zouidi *et al.* (2020), a pH of 8.20 was recorded for coniferous forest soils in two forest areas (arid and semi-arid) in western Algeria. According to Allam *et al.* (2020), the measured pH of forest soils in western Algeria was 7.64. In the Lanzarote region (Spain), the pH of 7.9 indicates slightly alkaline soil (Perdomo-Gonzalez *et al.*, 2023).

Electrical conductivity was consistently low across the study area, in agreement with values previously reported for soils in the Saïda region (Borsali *et al.*, 2014) found 0.47 mS/cm, (Zouidi *et al.*, 2019) 0.30 mS/cm, (Zouidi *et al.*, 2020) 0.42 mS/cm, (Allam *et al.*, 2020) 0.22 mS/cm, and (Allam *et al.*, 2020) 0.19 mS/cm. These values indicate that the sampled soils were predominantly non-saline. In the Djelfa region, Zehraoui and Kadik (2021) reported values ranging from 0.115 to 0.134 mS/cm, indicating unsalted soil.

Concerning soil organic matter, Overall, soil organic matter was low to moderate, except for one sample with a high value (6.65%). which can be explained by several mechanisms. On the one hand, although a higher pH generally promotes the solubilization of organic matter, a decrease in pH can induce the destabilization of organo-metallic complexes, leading to the release of organic compounds into the soil solution (Kalbitz *et al.*, 2000). On the other hand, pH also has an indirect influence on organic matter dynamics, particularly through the structure and activity of microbial communities, which are major players in the transformation and mineralization of organic carbon (Quideau *et al.*, 2021). This value of 6.65% is consistent with observations made in our study area. Indeed, (Zouidi *et al.*, 2019) reported a higher organic matter content (7.84%) in the soils of the pine forests of the Djebel Sid Ahmed Zeggai forest massif in the wilaya of Saïda. Similarly, (Allam *et al.*, 2020) noted an even higher content (8.58%) in the soils of pine forests in the same region. Most of the soils analyzed have a low to medium organic matter content. These results are comparable to those reported in the Djelfa region, notably by (Guit and Nedjimi, 2019), who found values ranging from 0.4% to 2.74%, and by (Zehraoui, 2021), with contents ranging from 1.54% to 2.93%. Meanwhile, in the Al Jabal Al-Akhdar region (Libya), (Eldiabani *et al.*, 2018) report contents ranging from 1.12% to 1.51%. In Beni Sohane (Morocco), (Benarchid *et al.*, 2022) recorded values ranging from 1.51% to 2.24%. In Castile-La Mancha (Spain), (Plaza-Álvarez *et al.*, 2021) noted a value of 2.44%.

Analysis of the limestone (CaCO₃) reveals that all samples are slightly to moderately calcareous, with the exception of two readings that show particularly high limestone levels (30.95% and 29.52%). In the comparative study by (Zouidi *et al.*, 2019), a limestone content of 27.03% was recorded in the semi-arid pine forest area of Saïda. The high limestone and calcium content is due to the presence of a limestone crust in the soil. According to (Ruellan 1999), the presence of coarse limestone in the form of concretions or crusts in the soil profile is a characteristic frequently observed in soils in arid and semi-arid regions, particularly when the underlying bedrock is mainly composed of limestone formations. Soils with limestone crusts are mainly found in arid and semi-arid areas, where they support the development of forest formations dominated by *Pinus halepensis* Mill. and *Quercus ilex* L. According to Lamouroux's observations (1968), the CaCO₃ content varies, with a general tendency to increase with depth in the profile, resulting in the accumulation of small friable clusters, nodules, and crusts. Decarbonation is more intense in humid and cold climates, often at high altitudes with hard, permeable rocks. In contrast, soils are more calcareous in hot, dry climates, at lower altitudes, and on softer rocks. Thus, the total limestone gradient is influenced by climatic and edaphic factors (Kadik, 2005).

From a Floristic perspective, the Asteraceae family is the most dominant. According to (Waheed and Arshad, 2024), this family is the most diverse, mainly present in semi-arid areas and exhibits adaptive convergences to stress, which is reflected in the aridity of these areas and the degradation of vegetation cover.

The Asteraceae and the Poaceae families are well adapted to arid and semi-arid areas and are widespread throughout the steppe and the Saharan Atlas (Ozenda, 1977; Benaradj *et al.*, 2011; Benaissa *et al.*, 2019; Ghafoul *et al.*, 2019; Hadjadj *et al.*, 2020; Hadjadj *et al.*, 2021; Gerine *et al.*, 2022, Rahmoune *et al.*, 2024, Khader *et al.*, 2025).

The biological spectrum reveals that these stations are characterized by a strong presence of therophytes, which dominate the vegetation. This abundance of therophytes is characteristic of arid Mediterranean areas, where water stress is higher (Daget, 1980). Most authors who have worked in the Mediterranean region assert that therophytization is linked to climate aridification (Barbero *et al.*, 1990, Barbero *et al.*, 1995, Dahmani, 1997, Henni and Mehdadi, 2012). This trend towards therophytization is mainly due to site characteristics, particularly drought, as well as excessive exploitation of forest resources (overgrazing, felling and removal of tree branches) (Guit and Nedjimi, 2021).

(El Zerey *et al.*, 2009) clarify that harsh climatic conditions and structural instability of the soil favor the development of species with short life cycles, especially therophytes. According to (Kadik 2005), the dominance of therophytes is evidence of significant anthropogenic action. These harmful actions disrupt the regeneration of phanerophytes, particularly Aleppo pine and destroy perennial species to the detriment of annuals (Guit and Nedjimi, 2021).

Hemikryptophytes account for 21% of the flora, which can be explained by the soil's lower organic matter content (Barbero *et al.*, 1989). Chamaephytes, representing 20% of the floristic list in our study area, are well adapted to soil aridification because they have various forms of adaptation to drought (Floret *et al.*, 1990). According to Daget, (1980), these biological types show a strong ability to adapt to summer drought conditions and high light intensity.

The proportion of phanerophytes is relatively low in the study area. This type is represented by 18 species, or 8% of the total. Examples include *Pinus halepensis* Mill, *Quercus coccifera* L., *Q. Ilex* L., *Phillyrea angustifolia* L., *P. Latifolia* L., etc. Geophytes are represented by a lower rate of 6% in the study area. (Dahmani, 1996) notes that geophytes are less diverse in degraded environments.

For Biogeographical types, the wide variety of poorly represented types reveals biogeographical complexity and a transitional floristic character. Our biogeographical results are consistent with those (El Bouhissi *et al.*, 2021) concerning the Zegla forest, located in the semi-arid zone of the Dhaya mountains, between the Saïda mountains to the east and the Tlemcen mountains to the west. The dominance of Mediterranean-affinity elements, which include 133 species representing 58.33% of the total flora, reflects the adaptation of the local vegetation to Mediterranean climatic conditions, characterized by dry summers and mild winters (Ramirez-Valiente *et al.*, 2022). Our findings confirm the results reported by Saidi & Keifa (2024).

The proportion of regional endemic taxa recorded in the present study is comparable to that reported by Miara *et al.* (2017) in the Western Tell Atlas (Tiaret region). Seven North African endemic taxa, present in at least three Maghreb countries (Algeria, Morocco, Tunisia, or Libya), were found in the study area. This figure is close to that observed by (Darrab *et al.*, 2023) in the Saïda region.

In addition, three strictly endemic species were identified: *Thymus lanceolatus* Desf., *Otocarpus virgatus* Durieu and *Centaurea phaeolepis* Coss. & Durieu ex Batt. These data are consistent with the results of (Djebbouri and Terras, 2019) in the forests of Saïda.

From a multivariate analysis perspective In Subgroup 1 (Cluster 1), the positive relationship with pH (factorial plans F02 and F03) suggests that the soils are predominantly alkaline. The lower organic matter content of Aleppo pine soil could explain the elevated pH (Hedjam, 2010).

These areas are characterized by sparse vegetation dominated by *Pinus halepensis* Mill., *Quercus coccifera* L., and *Phillyrea angustifolia* L. The understorey consists mainly of *Pistacia lentiscus* L., and, occasionally, *Quercus ilex* L. The herbaceous layer is dominated by *Macrochloa tenacissima* (L.) Kunth, *Salvia rosmarinus* Spenn., and *Ampelodesmos mauritanicus* (Poir.) Durand & Schinz

According to Alcaraz (1982), *Macrochloa tenacissima* (L.) Kunth is a highly competitive species, particularly common in open forests and degraded matorral-type formations. Although it tolerates a wide variety of substrates (sand, marl, gypsum crusts,

clay soils, etc.), it shows a clear preference for very calcareous and shallow soils (10 to 20 cm), which coincides with the edaphic characteristics observed in some of our stations. Human activities influence these forests and favor the presence of *Stipa parviflora* Desf., which **Celles (1975)** considered a steppe species. It adapts to dry, infertile soils. In addition, a few individuals of *Asparagus acutifolius* and *Astragalus tenuifoliosus* are found in arid pastures. According to **Quezel and Santa (1962)** and **Djebaili (1978)**, this species is associated with sandy soils and a lower organic matter content, estimated at 0.5%. **Pouget (1980)** considers this species to belong to arid climatic steppes with cold to cool variants on slopes and more or less encrusted surfaces, on soils tolerant of different lithologies.

In Subgroup 2 (Cluster 2), The presence of CaCO_3 contributes to soil alkalinity, which can influence microbial activity and organic matter dynamics. However, in semi-arid areas, low humidity and high temperatures remain the main factors limiting the decomposition of organic matter (**Oudart, 2013**). The neutral to alkaline pH of the soil under Aleppo pine is due to the presence of calcium carbonates (**Hedjam, 2010**). These parameters (presence of limestone, pH), therefore play only a very limited role in soil differentiation, but also as ecological factors responsible for certain ecological determinisms (**Pouget, 1980; Lahouel, 2022**).

However, the negative relationship between cluster 02 and salinity (F02) suggests that fairly high levels of salinity negatively affect the species present. This means that plants in this cluster may encounter constraints in developing in saline conditions, leading to a decline in plant diversity.

In the studied sites, the forests are sparse, grow on limestone substrates, and are dominated by *Pinus halepensis* Mill and *Pistacia lentiscus* L. Frequent species include *Ampelodesma mauritanicum* (Poir.) T. Durand & Schinz, *Genista quadriflora* Münby, *Marrubium vulgare* L., *Rosmarinus eriocalyx* Jord. & Fourr., as well as *Cistus clusii* Dunal and *Cistus ladanifer* L. *Daucus carota* L., *Erica arborea* L., *Lonicera implexa* Aiton and *Ziziphora hispanica* L.

Ampelodesma mauritanicum (Poir.) T. Durand & Schinz is linked to xeric conditions in the sub-humid bioclimatic zone, but its ecological status changes in the semi-arid zone. In fact, in these environments where survival conditions are difficult, this taxon becomes an indicator of humid environments, on cool exposures and valley floors. In other words, in the xeric environments of the semi-arid zone, this species is replaced by *Macrochloa tenacissima* (L.) Kunth (**Kadik, 2017**).

According to **Julve (2021)**, based on the Baseflor index, *Marrubium vulgare* L. is a xerophilous species, adapted to nutrient-rich carbonate mull soils. *Daucus carota* L. is mesotrophic, preferring moderately rich soils of the same type. *Erica arborea* L. is meso-oligotrophic, typical of active mull soils that are often poor in nutrients. In contrast, *Lonicera implexa* Aiton is classified as mesotrophic and adapted to carbonate mulls. According to **Kadik (2005)**, this species is particularly dominant in humid forests, which highlights a certain ecological amplitude. In general, plant diversity is enhanced by soils rich in organic matter and calcium. According to **Pouget (1980)**, soils become increasingly calcareous when the climate is warmer, less humid, and at low altitudes, especially when the bedrock is soft. These edaphic conditions favor the establishment of xerophytic species, which are well adapted to drought. Furthermore, the presence of halophilic species such as *Hordeum marinum* Huds. may indicate high salinity in certain locations. Several authors: **Garthwaite et al., (2005)**; **Hmidi et al., (2019)** and **Isayenkov et al., (2020)**, have highlighted the high tolerance of this species to saline environments, making it a good ecological indicator of saline soils. **Pouget (1980)** indicates the relative salinity of certain soils, highlighting the complexity of the environmental conditions of these ecosystems.

In Subgroup 3 (Cluster 3), the alkaline soil pH may favor the growth of certain plant species. This positive relationship reflects the adaptations of these species to alkaline conditions, enhancing their ability to exploit the nutrients available in this type of soil. Soil pH is very important for plant nutrition, as nutrient availability depends on it, as cited by **Bates (1973)**.

In terms of flora, *Quercus coccifera* L., *Phillyrea angustifolia* L., *Tetraclinis articulata* (Vahl) Mast., and *Juniperus oxycedrus* L. are present. *Macrochloa tenacissima* (L.) Kunth and *Rosmarinus eriocalyx* Jord. & Fourr. dominate, accompanied by *Atractylis caespitosa* (Desf.) DC. and *Centaurea pullata* L. *Hordeum murinum* L. *Phagnalon saxatile* (L.) Cass. and *Echinaria capitata* (L.) Desf. as well as *Stipa parviflora* Desf. with a coverage of approximately (40%). *Echinaria capitata* (L.) Desf., *Atractylis caespitosa* (Desf.) DC., *Hordeum murinum* L. and *Phagnalon saxatile* (L.) Cass. are typically xerophilic, basophilic, and often oligotrophic species, characteristic of dry, nutrient-poor, alkaline environments.

They grow preferentially on calcareous soils, often rich in calcium carbonate and poorly developed, such as lithosols and regosols, which are frequently found in arid to semi-arid areas (Julve, 2021). *Atractylis caespitosa* (Desf.) is a xerophytic species, typical of arid to hyperarid areas. *Phagnalon saxatile* (L.) Cass. is a very common plant, endemic to the Mediterranean region and found in sunny, dry, rocky locations (Rivas-Martinez *et al.*, 2001; Haddouchi *et al.*, 2021). *Centaurea pullata* L. is a basophilic, xerophilic and meso-oligotrophic species that grows on calcareous, dry and fairly nutrient-poor soils (Julve, 2021). The soil pH is neutral to alkaline, which is often characteristic of steppe soils (Amara et Bouazza, 2013) explaining the dominance of xerophilous and steppe species.

In Subgroup 4 (Cluster 4), low organic matter content and poor soils limit nutrient availability. According to (Pouget, 1980), the total organic matter content of surface horizons decreases with climate aridity. High salinity also limits the ability of plants to capture water and nutrients. These combined factors mean that these areas contain plants that have great difficulty growing and adapting to these unfavorable conditions.

According to Hadjadj *et al.* (2015), Azzaoui *et al.* (2017), Hadjadj (2017) soils colonized by *Tetraclinis articulata* (Vahl) Mast., are characterized by an alkaline reaction and a high total carbonate content, classifying them as highly calcareous soils. These substrates also have moderate organic matter content. The species thus adapts to basic, dry, calcium-rich soils, reflecting its xerophilic and calcicolous ecology.

According to Boudy (1952), Hadjadj-Aoul (1995), and Hadjadj & Letreuch-Belarouci (2017), *Tetraclinis articulata* (Vahl) Mast., has an affinity for calcareous soils, which are known to be more aerated and warmer, favoring its development. It is also important to note the xerophytic tendency of these sites, illustrated by taxa such *Atractylis caespitosa* (Desf.) DC., *Bromus hordeaceus* L., *Filagospatulata* Presland, *Plantago albicans* L. According to Julve (2024), *Atractylis caespitosa* (Desf.) DC. is a xerophilic steppe species adapted to arid climates. It preferentially colonizes poorly developed, basic, carbonate-rich soils, such as lithosols and regosols.

Plantago albicans L. is a steppe species with psammophilic characteristics (Alcaraz, 1982; Benhamada-Driouèche *et al.*, 2021). Pouget (1980) associates *Plantago albicans* L. with steppes, both climatic and edaphic, developing on thick soils with a very coarse and sandy texture. This species is also characteristic of hydromorphic environments, halomorphic soils, deep saline soils, and edaphic steppes on gypsum soils. *Atractylis caespitosa* is a xerophilous steppe species adapted to arid climates. It mainly colonizes poorly developed, basic, carbonate-rich soils, such as lithosols and regosols (Julve, 2024).

According to Julve (2021), the presence of the species *Plantago albicans* L. is due to its adaptation to basic, very dry, nutrient-poor soils. It also grows on poorly developed substrates such as lithosols and regosols, which are often found in rocky and arid environments. The presence of the basophilic and the xerophilic species *Eruca vesicaria* L., which prefers calcareous, dry, and moderately nutrient-rich soils with high calcium content (carbonate mull soils).

4. CONCLUSION

This study assessed the composition of Aleppo pine stands in the Saïda region and examined their associations with selected climatic and edaphic variables. In terms of bioclimate, the Saïda region has a semi-arid climate. Despite these climatic constraints, *Pinus halepensis* Mill. can thrive and tolerate low rainfall and fairly pronounced periods of drought.

Soil analysis shows that *Pinus halepensis* Mill. forest formations grow on thin, silty-sandy and sandy-silty soils. The total carbonate content is high (30.95% and 29.52% respectively), which is linked to the nature of the bedrock, which is often limestone, and the recorded organic matter values are low (0.3% and 1.7%). These formations tolerate limestone and develop on non-saline soils (electrical conductivity 0.1 and 0.2 mS/cm).

The floristic study at the four study sites enabled us to identify 228 species divided into 46 botanical families under the Aleppo pine tree layer, with a predominance of therophytes and Mediterranean species. The comparative approach allowed us to note that the study sites have been invaded by steppe species that characterize the original vegetation. Once again, these results show remarkable diversity despite aggressive anthropogenic action (overgrazing). The flora studied is herbaceous and/or more or less shrubby in nature, represented mainly by the Asteraceae family, which accounts for 21%, followed by the Poaceae family with 9%. These are the most important families. These climatic and edaphic conditions reveal their influence on the growth of *Pinus halepensis* Mill. stands in the Saïda region (western Algeria).

The observed vegetation is consistent with degradation associated with aridity and human pressure; however, temporal deterioration and its causes cannot be demonstrated without direct disturbance measurements or longitudinal data. The results of the assessment will enable the proposal of appropriate silvicultural and conservation management measures to ensure the sustainability of these pine forests in the face of threats such as fires, diseases, and climate change.

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AUTHOR CONTRIBUTIONS

Guendouz F. Conceptualization, Investigation, Methodology, Analysis.

Guit B. Methodology, Analysis, Supervision, Review & Editing.

Hadjadj K. Data Curation, Supervision, Review & Editing.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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