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Relationships between stand dendrometric attributes and natural regeneration of "Juniper" in semi-arid North African ecosystems

Belkacem DAOUDI [1], Safia BELHADJ [2], Ahlame BENABDERRAHMANE [3], Mohamed Lamine BENABDERRAHMANE [4], Amar KHADOUMI [1], Abdelghafour DOGHBAGE [1], Abdallah BOUMAKHLEB [1], Hafidh ZEMOUR [5], Fathi Abdellatif BELHOUADJEB *[1]

[1] Centre de Recherche en Agropastoralisme - CRAPAST, Djelfa, Algeria.
[2] Faculty of Nature and Life Sciences, Ziane Achour University, Djelfa, Algeria.
[3] Research Laboratory: Exploration and Valorization of Steppe Ecosystems, SNV Faculty, Ziane Achour University, Djelfa, Algeria.
[4] Laboratory of English Language, Literature, Translation and Knowledge Production, University of Ouargla, Algeria.
[5] Institute of Applied Sciences and Technology (ISTA), University of Larbi Ben M'hidi, Oum El Bouaghi, Algeria.
*E-mail: b.daoudi17@gmail.com ; a.benabderrahmane@univ-djelfa.dz

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ABSTRACT: This study aims to examine the impact of dendrometric factors on the natural regeneration of red juniper (*Juniperus phoenicea* L.) in the semi-arid region, located in the central steppe area. Across ten selected homogeneous stations, a total of 100 temporary observation plots, of 400 m² each, were surveyed via a mixed sampling method (stratified and systematic). Within each plot, dendrometric variables were measured (total height, dominant height, density and cumulative canopy area). This process involved evaluating the natural regeneration of red juniper as well. Data analysis highlighted that the regeneration of red juniper decreases with the magnitude of stand attributes, particularly stand density, dominant height, and canopy projection area. Nonetheless, it is proportional to the average total height and the dominant canopy projection area. The maximum regeneration density of red juniper was observed in stands where canopy cover is moderate (between 16% and 20%), and the density of adult trees ranges between 100 and 115 trees/ha.
Keywords: *Juniperus phoenicea* L. *sensu lato*; natural regeneration; plant density; dendrometric parameters; steppe area; African semi-arid; North Africa.

Relações entre atributos dendrométricos do povoamento e a regeneração natural de "zimbro-vermelho" em ecossistemas semiáridos do norte da África

RESUMO: Este estudo tem como objetivo analisar o impacto de fatores dendrométricos na regeneração natural do zimbro-vermelho (*Juniperus phoenicea* L.) em uma região semiárida na área central da estepa. Em dez estações selecionadas como homogêneas, foram instaladas 100 parcelas temporárias de observação, com 400 m² cada, utilizando-se um método de amostragem misto (estratificado e sistemático). Em cada parcela, foram mensuradas as variáveis dendrométricas: altura total, altura dominante, densidade e área da copa cumulativa. Esse procedimento também incluiu a avaliação da regeneração natural do zimbro-vermelho. A análise dos dados revelou que a regeneração do zimbrio-vermelho diminui à medida que aumentam os atributos da povoação, em especial a densidade, a altura dominante e a área projetada da copa. Entretanto, apresenta relação proporcional à altura média total e à área projetada da copa dominante. A densidade máxima de regeneração do zimbrio-vermelho foi observada em povoamentos com cobertura da copa moderada (entre 16% e 20%) e densidade de árvores produtoras de sementes entre 100 e 115 árvores/ha.
Palavras-chave: *Juniperus phoenicea* L. *sensu lato*; regeneração natural; densidade de plantas; parâmetros dendrométricos; área de estepe; semiárido africano; norte da África.

1. INTRODUCTION

Juniperus phoenicea Linnaeus (1753) *sensu lato*, a heliophilous species, typically forms open forests in Algeria, colonizing various types of substrates ranging from coastal dunes to the Saharan boundaries. It is almost omnipresent in the forested landscapes of the Saharan Atlas. It replaces both *Pinus halepensis* and *Tetraclinis articulata* in continental areas (Boudy, 1950) and Quercus ilex when precipitation becomes insufficient for these species (ROL; JACAMON, 1968; BENABID, 1985).

In 1950, Boudy (1950) estimated that the area occupied by *J. phoenicea* in North Africa covered 450,000 hectares, of which 290,000 hectares were in Algeria (LOUNI, 1994). It is found in regions with arid and semi-arid bioclimates, particularly under a more continental regime in areas where precipitation most commonly ranges from 200 to 400 mm per year (QUÉZEL; GAST, 1998).

Djebaili (1984) stated that *J. phoenicea* forms low matorrals and wooded steppes. This results from forest degradation (KADIK, 2005). Such forests are often degraded and

regenerate very poorly. Nevertheless, they are of great interest as they represent the last forest element capable of persisting under such precarious conditions (BOUDY, 1950).

J. phoenicea thrives in extreme ecological conditions (El-BANA et al., 2010). It is resistant to drought, soil degradation, and anthropogenic pressures, particularly in the most arid regions (RIOU-NIVERT, 2001). It plays a pivotal role in the dynamics of pre-forest communities (QUÉZEL; GAST, 1998).

Despite its ecological importance, *J. phoenicea* matorrals have been at high risk of decline since the 1970s (Kabiel et al., 2016) due to the combined effects of several factors: 1) periodic drought crises (Gazol et al., 2017; Farahat, 2020; Dakhil et al., 2022); 2) intrinsic characteristics of the species (shallow root system) (Pausas, 1999); 3) poor soil properties and low water balance (El-Bana et al., 2010; Sahib et al., 2022; Benabderrahmane et al., 2025); 4) human pressures: overgrazing, exploitation for fuel or medicinal purposes (Hafsi et al., 2017; Pavon et al., 2020); and 5) deficient natural regeneration (EL-BANA et al., 2010; KABIEL et al., 2016; DAKHIL et al., 2022; BENABDERRAHMANE et al., 2025; ZINE EL ABIDINE et al., 1996; MOUSTAFA et al., 2016). These factors may have led to severe changes comprising the dramatic regression of the species' distribution area, reduction in its dispersal capacity, and weakened regeneration.

However, the mountains of the Saharan Atlas in Algeria represent the southernmost refuge of the distribution range of *J. phoenicea*, which encourages us to undertake a focused study of this forest genetic resource.

To better comprehend the structure and dynamics of this type of ecosystem, the study of certain dendrometric parameters such as stand density, height and crown projection area appears necessary to characterize these formations and establish an assessment that will subsequently allow us to determine the potential of these formations in the central Saharan Atlas.

Our objective is to determine, within a natural forest process, the influence of stand dendrometric parameters on the natural regeneration of *J. phoenicea* in the central steppe area.

2. MATERIALS AND METHODS

2.1. Study area

The study area is part of the Ouled Nail Mountains. This part constitutes the central portion of the Saharan Atlas and is located in the Djelfa province (300 km south of Algiers). The area encompasses the five (05) main massifs of the Ouled Nail Mountains, namely the remarkable and forested massifs of Senalba Chergui (1489 m), Senalba Gharbi (1613 m), Sahary Guebli (1484 m), Sahary Dahry (1190 m), and Djebel Djellel Chergui (1478 m) (Figure 1). The regional bioclimate is of the semi-arid Mediterranean type with a cold winter (EMBERGER, 1971).

Precipitation averages around 310 mm, and temperatures range between 26°C in July and 5.4°C in January. The precipitation regime follows the A.S.W.S. type (autumn, spring, winter, summer) (DAOUDI, 2024). Two types of soil are noted: rendzinas and brown limestone (KADIK, 2005).

2.2. Sampling

In this study, conducted over three months in 2023 (from April to June), a mixed sampling method (stratified and systematic) was adopted. For the stratified sampling, the study area was divided into ten (10) stations based on the massif, slope aspect, and soil type (Table 1). Within each station, we set up ten (10) temporary observation plots (a total of 100 plots) based on systematic sampling with fixed intervals of 100 m. These plots are circular in shape, covering an area of 400 m², with a radius of 11.28 m. They were marked using a tape measure stretched horizontally and identified by the geographical coordinates of their centers (EMBERGER, 1971).

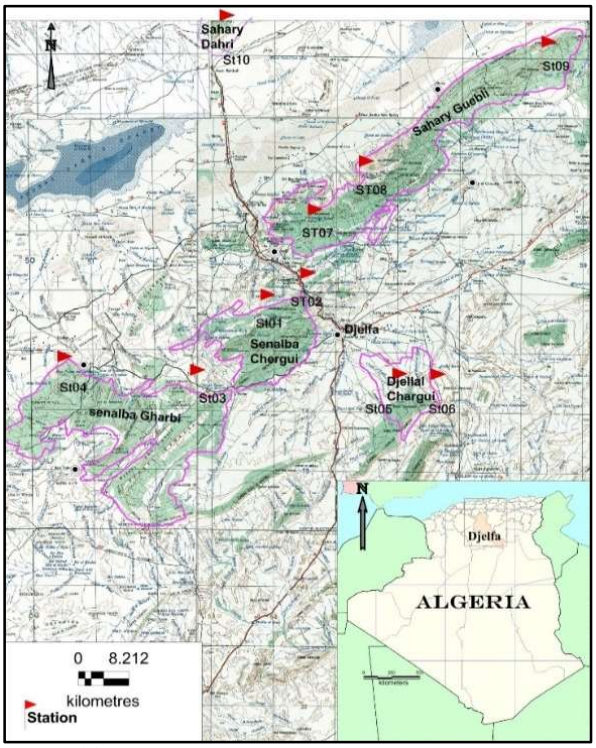


Figure 1. The location of the study area: central steppe area, in Algeria

Figura 1. Localização da área de estudo: região central da estepe na Argélia.

Since the regeneration of the red juniper in semi-arid zones is episodic, within each plot, all individuals with a height of less than 1.3 m and non-reproductive were considered juvenile (MILIOS et al., 2007; MACLAREN, 2016).

The regeneration index (RI) was used as a descriptor to quantify the regeneration phenomenon of the red juniper. It is an index determined by the ratio of the number of juveniles to adult trees (J/AT) (DOUAIHY et al., 2013). An index of (1) indicates a stable population size, while values below or above indicate, respectively, a decrease or increase in population size; nonetheless, it can be useful for population comparisons in terms of regeneration (DOUAIHY et al., 2013).

In each of the plots, a dendrometric inventory was established to characterize the stand (total average height; dominant height; total crown projection area per 400 m²; density per hectare; contribution of *J. phoenicea* to canopy cover (%); dominant crown projection area). Field surveys were conducted using a Garmin GPS receiver for station georeferencing, a Blume-Leiss for tree-height measurements, a measuring tape for dendrometric measurements, and stakes for plot delimitation and marking.

Table 1. Presentation of Geographical Characteristics for each Study Station
Tabela 1. Apresentação das características geográficas de cada estação de estudo.

Station	Massif	Slope aspect	Place called	Substratum	Geographic Coordinates
ST01	Senalba Chergui	Northern	Haoues	Marl- limestone	Alt: 1188 m; 34.69482°; 3.12971° E
ST02		Northern - South	Nakazia	Sandstone	Alt: 1208 m; 34.69986°; 3.16989° E
ST03	Senalba Gharbi	Northern-South	Zabache	limestone	Alt :1342 m; 34.56916°; 3.05063° E
ST04		Northern - South	Gouttaia	Marl- limestone	Alt :1550 m; 34.54608°; 2.80802° E
ST05	Djellal Chargui	Northern	SaboaMokrane	limestone	Alt :1390 m; 34.56335°; 3.38414°E
ST06		South	SboaMokrane	Marl- limestone	Alt :1346 m; 34.57794°; 3.40316°E
ST07	Sahari Guebli	South	Chebeika	Sandstone	Alt :1120 m; 34.72367°; 3.24712° E
ST08		Northern	Dreoua	limestone	Alt :1120 m; 34.85981°; 3.21014° E
ST09	Sahari Dahri	Northern - South	Medjedel	Marl- limestone	Alt :1055 m; 35.06835°; 3.64907° E
ST10		Northern - South	Gueltet Stell	Sandstone	Alt :1195 m; 34.14209°; 3.03567° E

2.3. Statistical analysis

Basic statistics were calculated at the intra- and inter-plot sampling scale. Fisher's F-test at $\alpha = 5\%$ was used to analyze variance with a single factor of variation, and the Tukey test was then used to determine which groups are homogeneous. A multivariate analysis, including principal component analysis (PCA) and hierarchical cluster analysis (HCA), was used to identify homogeneous groups of plots with respect to regeneration. All of these statistical analyses were carried out using Statistica 8.0 software, and the geographical data were mapped using MapInfo 11.0 software.

3. RESULTS

3.1. Natural regeneration of *Juniperus phoenicea*

The natural regeneration of *J. phoenicea* in the Djelfa region (central steppe area) is characterized by remarkable heterogeneity both between different stations and within each station. A highly significant difference in the distribution of the average density of natural regeneration of *J. phoenicea* across the studied stations was recorded (ANOVA: $F(9; 90) = 49.119$, $p < 0.001$) (Figure 2).

The highest average regeneration densities are observed in stations St08, St05, and St03 with 417.5 ± 292.04; 290 ± 190.1; and 322 ± 232.57 seedlings/ha, respectively. In contrast, the lowest average regeneration densities correspond to the juniper stands of stations St04, St07, St06, and St10 with 20 ± 15.8; 80 ± 46.85; 87.5 ± 44.49; and 97.5 ± 77.68 seedlings/ha, respectively. Meanwhile, the juniper stands of stations St09, St02, and St01 are notable for their intermediate average regeneration densities with 190 ± 94.43; 162.5 ± 212.28; and 225 ± 161.16 seedlings/ha, respectively.

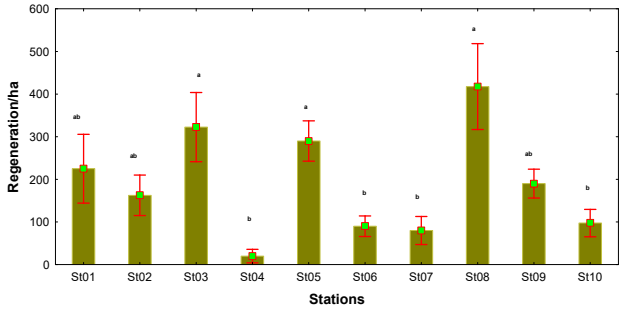


Figure 2. Distribution of the Average Natural Regeneration Density of *Juniperus phoenicea* stands in the Djelfa Region (Central Saharan Atlas).
Figura 2. Distribuição da densidade média de regeneração natural de *Juniperus phoenicea* na região de Djelfa (Atlas Sahariano Central).

The bars represent the mean ± standard deviation, and the different letters above the bars indicate a highly significant difference ($p < 0.05$) according to the Tukey test. (ANOVA results: $F(9; 90) = 49.119$, $p<0.001$).

3.2. Regeneration Index

The regeneration index highlights a different trend depending on the stations (Table 2), where the lowest values are observed for stations St4, St10, and St7, which exhibited measurements of 0.30, 0.52, and 0.58 juveniles/adult, respectively. The aforementioned distribution is characterized by a large proportion of older individuals compared to younger ones, indicating a limited regeneration capacity. Such a bottleneck in regeneration may be imposed by several factors that are not mutually exclusive. The limited regeneration in stations St02, St07, and St10 may result from these stations reaching their maximum capacity, a scenario likely to occur due to junipers occupying small gaps in sandstone fissures where the rock is heavily covered by parent outcrop material, sometimes up to 70% in certain plots, particularly in St10.

Table 2. Characteristics of Natural Regeneration of the Studied *J. phoenicea* stands.
Tabela 2. Características da regeneração natural dos povoamentos de *Juniperus phoenicea* estudados.

Station	Regeneration density/ha	Density (adults/ha)	regeneration index (RI)
Haoues (St01)	225	102.5 ± 27.51	2.2
Nakazia (St02)	162.5	165 ± 35.75	0.98
Zabache (St03)	322	115 ± 33.75	2.8
Gouttaia (St04)	20	65 ± 17.48	0.31
Saboa Mokrane Nord (St05)	290	177.5 ± 51.97	1.63
Saboa Mokrane Sud (St06)	87.5	82.5 ± 26.87	1.06
Chebeika (St07)	80	137.5 ± 27	0.58
Dreoua (St08)	417.5	107.5 ± 31.29	3.88
Medjedel (St09)	190	117.5 ± 34.45	1.62
Gueltet Stell (St10)	97.5	187.5 ± 37.73	0.52

This low regeneration rate is also reported in regions such as Egypt and Libya (Farahat, 2020; Dakhil et al., 2022), as well as for *J. excelsa* in Greece, Pakistan, Oman, and Lebanon (AHMED et al., 1990; FISHER; GARDNER, 1995; MILIOS et al., 2007).

The highest regeneration rates are observed in stations St01, St03, and St08, featuring values of 2.19, 2.80, and 3.80

juveniles/adult, respectively. This high recruitment rate shows a pattern similar to that of *J. communis* populations in the Atlantic, Northern European, and Boreal regions (FALIŃSKI, 1980; ROSEN, 1988; AUSTAD; HAUGE, 1990; MARION; HOULE, 1996; GARCÍA et al., 1999). Intermediate regeneration rates are noted for stations St06, St02, St09, and St05 with data of 1.06, 0.98, 1.60, and 1.63 juveniles/adult, respectively.

The regeneration density of *J. phoenicea* in the central Saharan Atlas appears to be very low compared to its neighboring species, *J. excelsa*, as reported in Pakistan (Sarangzai et al., 2012), where a stand with an average density of 176 trees/ha had regeneration densities often exceeding 6400 juveniles/ha. Similarly, Matney; Hodges (1991) reported a density of approximately 2000 individuals/ha as the minimum required to consider regeneration successful.

3.3. Characteristics of Dendrometric Attributes

A notably significant difference in the distribution of the average stand density of *J. phoenicea* was measured between the studied stations (ANOVA: F (9; 90) = 14.344, p <0.001) (Figure 3).

The bars represent the mean ± standard deviation, and the different letters above the bars indicate a highly significant difference (p < 0.05) according to the Tukey test (ANOVA: F (9; 90) = 14.344, p <0.001).

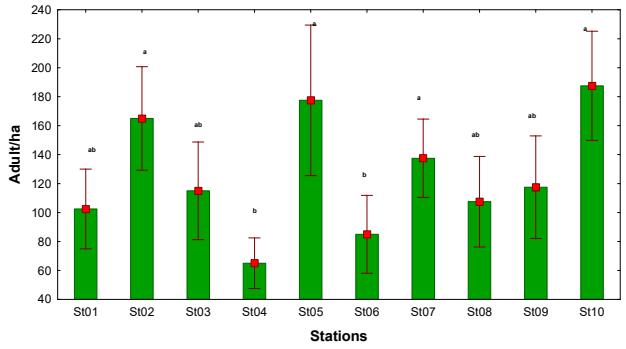


Figure 3. Distribution of the average stand density of *Juniperus phoenicea* in Djelfa Region.
Figura 3. Distribuição da densidade média dos povoamentos de *Juniperus phoenicea* na região de Djelfa.

The highest average stand density values correspond to stations St02, St05, St10, and St07, which exceed 130 trees/ha and feature values of 165, 177.5, 187.5, and 137.5 trees/ha, respectively. In contrast, in stations St04 and St06, the average density is low, with only 65 and 82.5 trees/ha. Stations St01, St03, St08, and St09 exhibit an intermediate average density ranging between 100 and 130 trees/ha.

In an arid climate, Farahat (2020) recorded species densities in northern Sinai ranging from 86.3 to 152.7 individuals per hectare. On the other hand, these values are lower than those reported in coastal and wetter stands. In Libya, in the Al-Akhdar mountains, the density of *J. phoenicea* stands varies from 2400 to 2600 trees/ha (KABIEL et al., 2016). In Greece, Tsiourlis (1992) reported a density of 554 trees/ha. Sarangzai et al. (2012) reported a density for *J. excelsa* varying from 29 to 268 trees/ha, with an average of 176 ± 77 trees/ha. Lower densities were detected in Lebanon for the same species (*J. excelsa*), ranging from 45 to 147 trees/ha (DOUAIHY et al., 2013). With values ranging from 100 to 292 trees/ha, Lefi et al. (2023) identified an average density for *J. thurifera* in Morocco reaching 201 trees/ha.

The average total height of the stands varies between 1.9 ± 0.26 m (station St06) and 3.12 ± 0.84 m (station St04) (Table 3). Conversely, the values for the dominant height follow the same trend as the average total height, ranging from 3 ± 0.3 m (station St06) to 5.8 ± 0.71 m (station St01). In fact, the pedological microsite located at the lower slope of station St03 hosts the tallest *J. phoenicea* observed, reaching a height of 6.4 m.

In 2024, Al-Sodany et al.(2024) reported that in the Sarrawat Mountains in Saudi Arabia, the maximum height of *J. phoenicea* reached 8.3 m. There is uniformity in the values of the average total height across these different types of formations, which can be interpreted as the significant frequency of tall trees. The low values recorded in station St06 could be attributed to climatic constraints induced by the southern exposure of Djebel Djellal Chergui (drier and warmer), combined with the marl-limestone soil, which is highly sensitive to desiccation and easily compacts during dehydration phases (RIPERT; VENNETIER, 2002).

Table 3. Characteristics of the Dendrometric Attributes of the Studied *J. phoenicea*
Tabela 3. Características dos atributos dendrométricos dos povoamentos de *Juniperus phoenicea* estudados.

	ATH	DH	CCP/400m²	CJCC %	DCPA
Haoues (St01)	2.9 ± 0.94	5.8 ± 0.71	87.43 ± 42.63	21.86	45.17 ± 17
Nakazia (St02)	2.71 ± 0.6	5.6 ± 0.27	87.98 ± 38.32	22	38.43 ± 9.50
Zabache (St03)	2.90 ± 0.79	4.8 ± 0.87	71.85 ± 33.28	18	48 ± 26.23
Goutaya (St04)	3.12 ± 0.84	5 ± 0.53	42.33 ± 14.5	10.6	25.70 ± 3.33
Djellel Chargui N (St05)	2.51 ± 0.51	4 ± 0.28	70.52 ± 21.5	17.63	24.85 ± 5.2
Djellel Chargui S (St06)	1.9 ± 0.26	3 ± 0.3	22.07 ± 8.44	5.52	12.60 ± 7.2
Chebeika (St07)	2.45 ± 0.69	4.25 ± 0.51	73.82 ± 22	18.45	23 ± 4.2
Dreoua (St08)	2.73 ± 0.57	4 ± 0.5	64.95 ± 30.75	16.24	39.41 ± 19.81
Mejedel (St09)	2.14 ± 0.42	4.85 ± 0.5	43.43 ± 20.17	10.86	26 ± 10.61
Gueltet Stel (St10)	2.48 ± 0.46	4.7 ± 0.12	81.93 ± 32.62	20.5	22.60 ± 3.5

ATH: Average total height; DH: Dominant height; CCP/400 m²: Cumulative canopy projection area per 400 m²; CJCC: Contribution of *J. phoenicea* to the canopy cover (%); DCPA: Dominant canopy projection area.
ATH: Altura total média; DH: Altura dominante; CCP/400 m²: Área de projeção da copa acumulada por 400 m²; CJCC: Contribuição de *J. phoenicea* para a cobertura de copa (%); DCPA: Área de projeção da copa dominante.

The canopy projection area (CPA) of the red juniper varies depending on the state of the stand. For example, it ranges from 22.07 ± 8.44 m² in station St06 to 87.98 ± 38.32 m² in station St02. The values for the dominant canopy

projection area (DCPA) fluctuate between 12.60 ± 7.2 m² in station St06 and 48 ± 26.23 m² in station St03. The largest specimen observed covers an area of 64 m² in station St01.

A clear discrepancy in the canopy projection area is noted among these different stands. This can be explained by the environmental conditions specific to each station, including soil type, exposure, slope, bedrock outcrops, interspecific competition, and anthropogenic pressures.

With contribution rates ranging from 5.52% (station St06) to 22% (station St02), the contribution of *J. phoenicea* to the vegetation cover in all studied stations appears sparse. These cover rates result from the specific environmental conditions of each station, influencing the form, appearance, and spatial distribution of individuals within populations. In the central Saharan Atlas, red juniper specimens adopt various forms based on adaptive behaviors that reflect both historical and current ecological conditions. Several authors have described a typology of forms for the same type of shrub (LATHUILLIÈRE, 1994; BLANCO et al., 1997; LEFI et al., 2023; ADAM et al., 2024).

In our study, all trees were grouped into four distinct categories (Figure 4).

- The Multiple Trunk form (Figure 4A): Predominant, generally thriving on mid- and lower slopes in sites compensating for multiple factors; includes trees with intense branching from the base of the trunk.
- The Tree form (Figure 4B): Rare; well-defined trunk topped by a continuous canopy, typically ovoid or elliptical (LEFI et al., 2023).
- The Conical form (Figure 4C): Cypress-like, with a canopy wider at the base; generally juvenile and considered a transitional stage toward adult forms (MONTES, 1999).
- The Ground-hugging Canopy form (Figure 4D): Common at summits and high slopes with wind exposure, producing a "cushion" shape (CARPITA et al., 1979).

3.4. Impact of Dendrometric Factors

The Principal Component Analysis (PCA) conducted on the matrix encompassing all dendrometric and orographic variables (altitude), including regeneration density per hectare, regeneration index (RI), canopy cover rate of adult trees (CJCC), dominant crown pro-jection area (DCPA), stand density per hectare (number of *J. phoenicea* adult individuals per hectare), dominant height (HD), and average total height (ATH) across the 10 studied sta-tions, identified three distinct groups of stations based on the regeneration of the red juni-per *(J. phoenicea*) (Figures 5 and 6).

On the F1 axis, with 45.86% of inertia, altitude on the positive side opposes all the dendrometric attributes of the stands represented by regeneration density per hectare, regeneration index (RI), canopy cover of adult trees, dominant canopy projection area, stand density per hectare, dominant height, and average total height.

On the F2 axis, with 22.06% of inertia, regeneration density per hectare, regeneration index (RI), canopy cover of adult trees, and average total height on the negative side oppose stand density per hectare, dominant height, and dominant canopy projection area on the positive side.

On the factorial plane (F1 × F2), the quality of representation exceeds 68% of inertia (45.86% + 22.06%), revealing three groups of stations in relation to the regeneration of red juniper: highly significant regeneration on the negative side (G1) and low regeneration on the positive side (G2) with respect to the F1 axis. Additionally, a third group (G3) exhibits moderate regeneration on the positive side of the F2 axis, opposing the other two groups (G1 and G2) on the same axis.

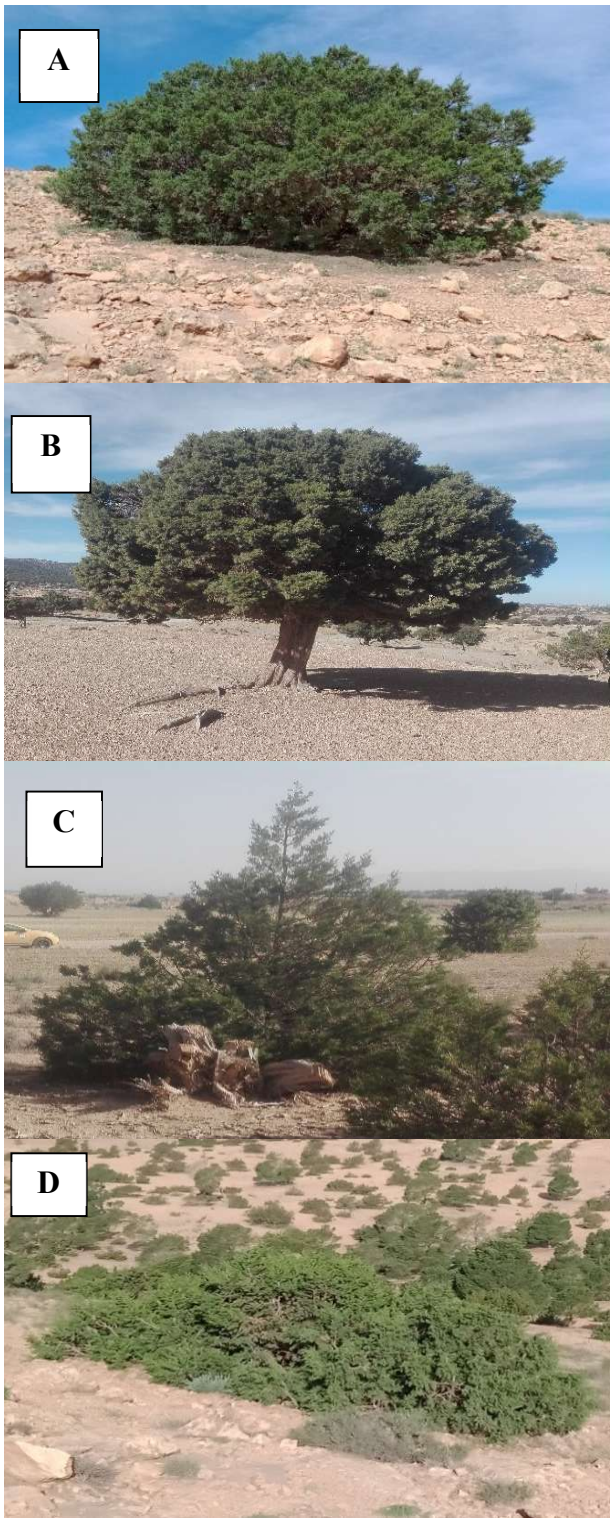


Figure 4. Different Forms of *Juniperus phoenicea* Observed in the Study Area:(A) Multi-ple Trunk; (B) Arboreal ; (C) Conical; (D) Ground-hugging Canopy

Figura 4. Diferentes formas de *Juniperus phoenicea* observadas na área de estudo: (A) tronco múltiplo; (B) arbórea; (C) cónica; (D) copa prostrada.

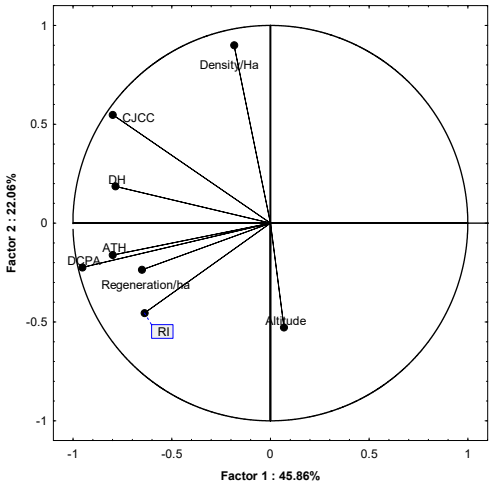


Figure 5. Results of the Principal Component Analysis (PCA), showing the projection of variables on the correlation circle.
Figura 5. Resultados da Análise de Componentes Principais (PCA), com a projeção das variáveis no círculo de correlação.

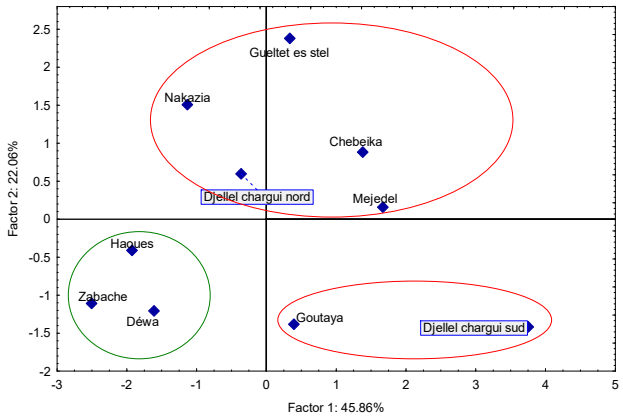


Figure 6. Results of the Principal Component Analysis (PCA), showing the projection of observations and the different groups of stations.
Figura 6. Resultados da Análise de Componentes Principais (PCA), com a projeção das observações e os diferentes grupos de estações.

The hierarchical ascending classification (HAC) (Figure 7) made it possible to identify and confirm the three groups resulting from the PCA.

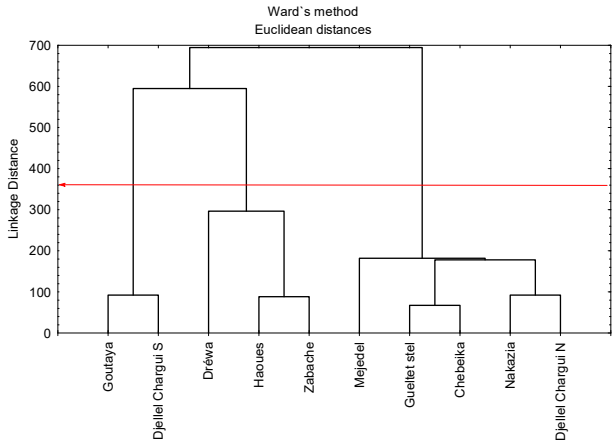


Figure 7. Results of the Hierarchical Ascending Classification (HAC).
Figura 7. Resultados da Classificação Hierárquica Ascendente (CHA).

4. DISCUSSION

The G1 group includes three (03) stations, namely St01 (Haoues), St03 (Zabache), and St08 (Dreoua), which are strongly correlated with the following variables: regeneration density, regeneration index (RI), dominant canopy projection area, and average total height (ATH). In these stations, the regeneration index is high, stretching from 2.2 to 3.88, with a very high regeneration density reaching 417.5 seedlings/ha. Moreover, these stations also show significant dendrometric values, particularly in terms of the dominant canopy projection area (between 40 m^2 and 48 m^2), average total height (ATH) (2.7 to 2.9m), and a moderate population density per hectare between 102 and 115 trees/ha. These estimable regeneration rate values could be attributed to the disturbance of the pine forests that are gradually deteriorating and giving way to the encroachment of red juniper.

The G2 group is composed of two stations, St04 (Goutaya) and St06 (Djellal Chargui Sud); These stations are strongly correlated with the altitude variable, being located at high altitudes (1390m - 1520m) for St04 and (1348m - 1482m) for St06. They exhibit a low canopy cover rate of adult trees, ranging from 5.52% to 10.6%, as well as the lowest population densities per hectare (82.5 trees/ha to 65 trees/ha). As a result, the regeneration of *J. phoenicea* is also very low in these stations.

These stations undergo stresses that affect the establishment and the growth of the red juniper. In the case of station St06 (Djellal Chargui Sud), the stress is abiotic, as the station is exposed to the harmful climatic fluctuation characteristics of south-facing slopes. For station St04 (Goutaya), the stress is biotic. Although it benefits from a cooler and more humid exposure to the north, the red juniper is gradually replaced due to interspecific competition by other species that are more mesic and better adapted to these altitudes. Examples of these are *Pistacia terebinthus, Bupleurum spinosum*, *Ephedra major*, *Quercus ilex*, *Rhamnus alaternus*, and *Prunus prostrata*.

Group G3 consists of five (05) stations: St02 (Nakazia), St05 (Djellel Chargui Nord), St07 (Chebeika), St09 (Medjedel), and St10 (GueltetStel); representing old stands, often composed of relatively pure juniper forests. The dendrometric attributes of these stands exhibit high values, with a density ranging from 140 to 187 trees/ha and a canopy projection surface coverage rate frequently oscillating between 18% and 22%. The regeneration density in these stations varies from 80 to 290 seedlings/ha and is dependent on the maximum capacity of the physical environment.

5. CONCLUSIONS

The regeneration of the red juniper in the central steppe area decreases with the extent of the stand attributes, particularly stand density, dominant height, and canopy projection area. It increases proportionally with the average total height, dominant canopy projection area, and the juvenile/adult ratio. These relationships reaffirm the heliophilic nature of red juniper. The maximum regeneration density of red juniper was observed in stands where the canopy cover is moderate, between 16% and 22%, and the seed tree density is between 100 and 115 trees/ha. Furthermore, juvenile density varied substantially among sites and was associated with stand structure, but environmental, spatial, and anthropogenic variables may also explain a significant portion of this variation.

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