Revue Agrobiologia
www.agrobiologia.net
ISSN (Print): 2170-1652
e-ISSN (Online): 2507-7627

AgroBiologia

REGENERATION IN GAPS OF ATLAS CEDAR (*CEDRUS ATLANTICA* ENDL.) CARRIÈRE IN THE DJURDJURA NATIONAL PARK, NORTHERN ALGERIA

ALILECHE Ahmed[1*], HIMRANE Hocine[2], SLIMANI Said[1] and DERRIDJ Arezki[1]

1. Mouloud Mammeri University of Tizi Ouzou. Faculty of Biological and Agronomic Sciences, Department of Biology, Laboratory of Plant Ecology, B.P.17 RP, Tizi Ouzou, 15000, Algeria.
2. National Forest Institute Research (NFIR) of Bainem. BP 37 Chéraga, Algiers, Algeria.

Reçu le 26/12/2020, Révisé le 27/05/2021, Accepté le 07/06/2021

Abstract

Description of the subject: This study deals with the natural regeneration in gap of the mountain forests of Atlas cedar (*Cedrus atlantica* Endl.) Carrière in the Djurdjura National Park, northern Algeria.

Objectives: This study aims to highlight the effects of light transmittance on regeneration dynamics of this tree species, with a focus on their establishment.

Methods: We recorded the light transmittance, soil depth and topographic variables; we counted the number of established seedlings and measured the dimensions of all the inventoried adult stems, over 39 nine plots. A one-way analysis of variance, a principal component analysis and a multiple linear regression were run to highlight the effect of the considered variables on seedling establishment.

Results: Our findings revealed that the natural regeneration of Atlas cedar occurs under a combined effect of multiple parameters, which are the stand structure, topography and soil properties.

Conclusion: The results obtained make it possible to orient the conduct of silvicultural practices; this is the first step in facilitating the emergence and establishment of seedlings in the Atlas cedar forests.

Keywords: Gap regeneration; stand structure, seedling establishment; Atlas cedar; light transmittance.

RÉGÉNÉRATION PAR TROUÉES DU CÈDRE DE L'ATLAS (*CEDRUS ATLANTICA* ENDL.) CARRIÈRE DANS LE PARC NATIONAL DE DJURDJURA, NORD DE L'ALGÉRIE

Résumé

Description du sujet : Cette étude porte sur la régénération naturelle par trouées des forêts de montagnes du cèdre de l'Atlas (*Cedrus atlantica* Endl.) Carrière dans le parc national du Djurdjura, au nord de l'Algérie.

Objectifs : Cette étude vise à mettre en évidence les effets de la transmission de la lumière sur la dynamique de régénération de cette espèce d'arbre, en mettant l'accent sur l'établissement des semis.

Méthodes : Nous avons relevé l'éclairement lumineux, profondeur du sol, variables topographiques, et dénombré le nombre de semis établis et mesuré les dimensions des tiges adultes inventoriées, à travers 39 placettes. Une analyse de variance à un seul facteur, une analyse en composantes principales et une régression linéaire multiple ont été effectuées pour mettre en évidence l'effet des variables considérées sur l'établissement des semis.

Résultats : Nos résultats ont révélé que la régénération naturelle du cèdre de l'Atlas se produit sous l'effet combiné de plusieurs paramètres, qui sont la structure du peuplement, la topographie et les propriétés du sol.

Conclusion : Les résultats obtenus permettent d'orienter la conduite des pratiques sylvicoles ; ce qui est la première étape pour faciliter la levée et l'établissement des semis dans les forêts de cèdre de l'Atlas.

Mots clés : Régénération par trouées ; structure du peuplement ; établissement de semis ; cèdre de l'Atlas ; transmittance de la lumière.

*Corresponding author: ALILECHE Ahmed, E-mail: alileche_scout@yahoo.fr

INTRODUCTION

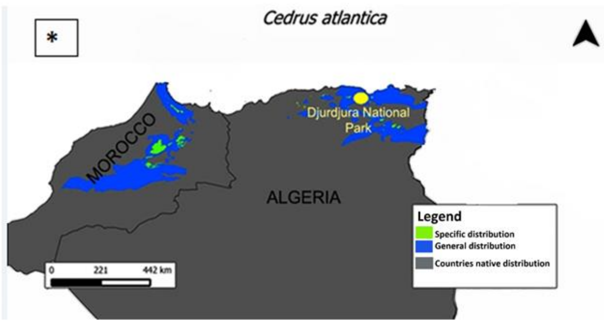
Atlas cedar *(Cedrus atlantica* Endl.) Carrière is an endemic species to the North African mountains (Algeria and Morocco). In addition to its adaptation to extreme conditions, it is a fire-resistant tree species; it produces a high-quality wood [1] and has ecological and productive potentials which put it in a privileged place in reforestation and rehabilitation programs [2]. In Algeria, northern cedar forests of the Tellian Atlas and those southern of the Aures and Belezma are still under strong natural and anthropic pressures : recurrent droughts, fires, illegal logging of trees overgrazing, which have been causing regression of the natural range of Atlas cedar [3]. Many studies have been carried out on the natural regeneration of this tree species and the findings reported the importance of a combined effect of environmental factors on this process [4 - 10]. Seedling establishment and growth are only possible under favorable ecological conditions for the entire cycle of seed production and plant recruitment[8]Forest dynamics and its corollary, the natural regeneration are marked by the existence of gaps [11]. Disturbances due to low-intensity fires, lightning, wind and snow causing windthrows may locally destroy the aerial stand structure leading to liberating space in the canopy. If the biological potential of the soil is not affected, Atlas cedar seedling recruitment can be observed in the created bare-ground area [12]. Many studies reported that disturbances modify species distribution [13]. Derridj [6], suggests that Atlas cedar trees become established in dense cohorts within large forest gaps after improvement of edaphoclimatic conditions. However, the gap characteristics and the availability of an appropriate substratum in addition to anthropogenic disturbances (grazing, fires, tourism, etc.) substantially affect seedling establishment [6, 14]. Therefore, the level of disturbance necessary to the regeneration of *C. atlantica* raises many debates [9]. The natural regeneration of the Djurdjura Atlas cedar forest is difficult, especially in senescent stands and in those characterised by a closed canopy. To the best of our knowledge, this is the first investigation on forest regeneration via gap dynamics in Algeria. Many authors highlighted the factors affecting establishing and maintaining of the seedlings. The most important ones are the pluviothermal conditions [5], the summer drought and the beginning period of germination [4], the stand structure (density and degree of canopy openness) and the substrate type [7], the elevation, the stand canopy cover and soil tillage [8], the microclimate conditions and plant facilitation [3] and the stand disturbances [9]. In the current study, we focused on the combined effect of a set of considered parameters on the regeneration of Atlas cedar. The main objective was, first, to demonstrate the effect of light transmittance on Atlas cedar establishment thought natural regeneration. The assumption is that light transmittance is the determinant factor, which is determined by a combination of several other parameters, such as the stand density and the canopy openness, their impact on the light transmittance to the soil surface, and the topography (elevation, aspect and slope). The edaphic characteristics (soil depth and thickness of humus layer) and their influence on the establishment of the seedlings were also examined. Then, statistical analyses were performed in order to highlight the main parameters which could be involved in modeling Atlas cedar regeneration. The findings will complement previous studies, carried out on the dynamics and the regeneration of this species.

MATERIAL AND METHODS

1. Characteristics of the Study area

The current study was carried out within the Djurdjura National Park, located in the north of Algeria, 40 km as the crow flies from the Mediterranean Sea (Fig. 1). This protected area covers 18 550 ha. The sampled area is comprised between the latitudes 36°31’02’’and 36°25’42’’N and the longitudes 3°57’23’’and 4°19’43’’E. The elevation varies from 700 to 2308m and the slope rages between 10% to over than 50%. The metamorphic massif of Djurdjura is composed of sedimentary soils, highly pleated and fractured, part of which is formed during the Paleozoic, but mainly belonging to the Mesozoic and the Cenozoic [15]. They are slightly developed, of the type A/C and generally calcimagnesic on the northern slope and acidic forest soils of the type A (B) C on the southern slope [16]. The climate is Mediterranean and varies from the cool and sub-humid to the cold and humid.

The total annual precipitation ranges from 850 to 1500 mm on the northern side, exceeding 1800 mm at the mountain top, and exhibit a deficit of 200-350 mm on the southern side [15]. The annual mean temperature varies from 10 to 12°C [6, 10]. The vegetation belongs to the supra-Mediterranean stage [17].



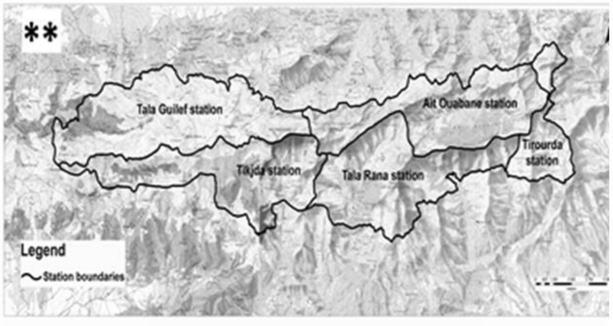


Figure 1: (*) Natural distribution of *Cedrus atlantica* [18].
The circle corresponds to the sampled area within the Djurdjura National Park.
(**) sampled area location within the Djurdjura National Park [19].

2. Brief description of the studied stations

The five (5) study stations have relatively distinct ecological characteristics. The Tala Guilef and Ait Ouabane stations located on the northern flank of the Djurdjura karst chain are wetter and cooler than the Tikjda and Tala Rana stations which are located on the southern flank of the Djurdjura and exposed to the hot south wind (sirocco). The fifth station (Tirourda) is located higher in the south-east of Djurdjura. Geologically, the nature of the substrate is essentially sandstone and limestone, except for the resort of Ait Ouabane where we meet marl and marl limestone. The cedar trees that were the subject of our study are relatively different between the five stations. On the northern exposure, the cedar stands are irregular and almost pure at Tala Guilef, while at Ait Ouabane, the cedar stands are a mixture of holm oak and maple. These two cedar forests are ecologically stable (dense and with closed canopy). On the other hand, the cedar stands on the southern exposure (Tikjda and Tala Rana) are ecologically close but strongly disturbed by the frequency of fires and overcrowding, particularly in Tikjda. Finally, for the Tirourda cedar stand, located on shallow soils, it is sparse with loose stands.

3. Selection of sample plots and field procedures

The stratified sampling method, as described by Ezzahiri and coll. [20], for the Atlas cedar forests of the Middle Atlas (Morocco) and Madjour [10], for the Atlas cedar forests of Tala Guilef (Djurdjura), was adopted.

This procedure is well-adapted to heterogeneous environments [21], which is the case in the Djurdjura massif. The sampling procedure was applied taking into consideration the three following stratificators: *(i)* Topographic gradient: the sampled plots were placed along an altitudinal gradient with an elevation ranging from 1224 to 1832 m, representing all the aspects (north, south, east, west and intermediary) and with a slope range of 10-65 %; *(ii)* Edaphic gradient (soil depth and humus layer thickness); *(iii)* Wide range of openings (gaps) or canopy discontinuity where seedlings are established;

Covering about 2000 ha, the studied plots were spread over the five sectors of the Djurdjura National Park, which are: Tala Guilef (430 ha), Ait Ouabane (420 ha), Tikjda (400 ha), Tala Rana (460 ha) and Tirourda (290 ha) (Fig. 1). We opted for circular plots with a minimum radius of 10m, which corresponds to a sampling surface per plot of 314 m^2. The plot surface (S) is calculated according to the following formula: $S= \Pi \times R^2$, Where Π =3.14 and R is the radius of the plot. However, as the radius varies with the slope, a corrective term allowing determining directly the length of the radius was added: $S_{pm}= \Pi \times R^2 \cos \alpha$. S_{pm} is the sampling plot surface, R the radius of the plot and α: the slope angle.

The sampled circular plots were placed within stand openings and positioned according to a wide range of the canopy openness degree [22] as follows (Fig. 2): Plots in circular openings within the canopy;

Plots in semi-circular openings, with a horseshoe shape, at the forest limit and Plots in canopy discontinuity at the forest edge where seedling are established along a uniform limit.

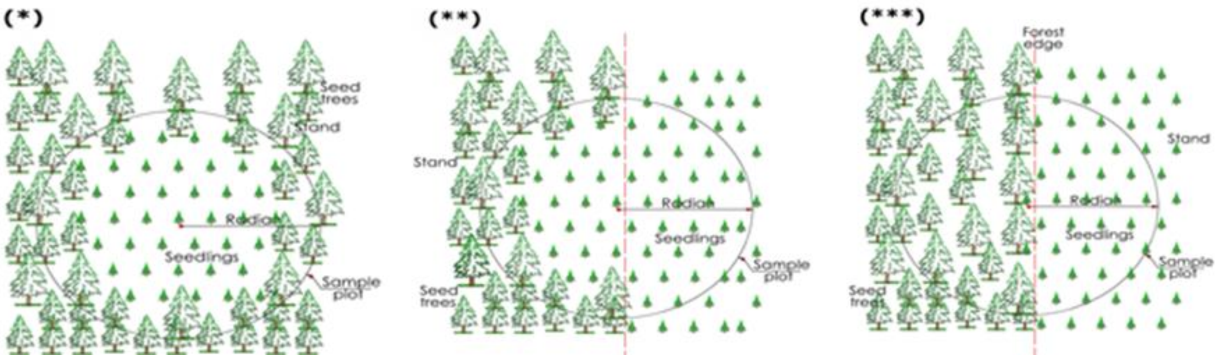


Figure 2: Gap shapes of the studied plots:
(*) Circular gap (O), (**) Semi-circular gap (C), (***) Uniform forest edge.

Thirty-nine (39) circular sampling plots were identified. They were proportionally allocated according to the stratum surface, the human impact level and the access constraints, which are related to rugged terrain conditions: 12 plots for both stations of Tala Guilef and Tikjda, six plots for Ait Ouabane and Tala Rana and three plots for Tirourda. The following parameters were measured at the center of each plot:

3.1. Abiotic parameters

- *Illumination (I):* The light transmittance (lux) was measured at the soil surface using a lux meter.

- *Soil depth (SD) and humus layer thickness (HLT):* Soil sampling was carried out on the layer presenting presence of seedlings roots (15 to 30 cm). In addition, the humus layer was measured.

- *Topographic parameters:* Three topographic parameters were considered: the slope (S) in %, the elevation (E) in m and the aspect (A).

3.2. Biotic parameters

The biological material was divided into two categories:

- *Established natural regeneration:* contrary to Madjour [10], who considered different kind of seedlings, including non-established ones, in this study, only established seedlings, were counted. This category consisted of relatively lignified individuals between 6-10 years old [20], with a diameter at the breast height (DBH) between 2.5 and 7.5 cm at a height lower than 1.50 cm [23].

In order to assess the regeneration density, the number of seedlings (NS) was considered through three regeneration classes as follows: $NS \leq 20$, $20 < NS \leq 30$ and $NS > 30$.

- *Sub-mature and mature population* [23]:

(i) Sub-mature population, representing the understory, composed of non-pre-countable stems with a DBH ranging from 7.5 to 17.5 cm;

(ii) Mature population, representing the upper most layer of the forest, which is composed of stems with a DBH > 17.5 cm.

Within each plot, we counted the number of stems (NSt) and for the sub-mature and mature population; we measured the tree total height (TH), the tree diameter and circumference at the breast height (DBH and C1.30). Moreover, for this category, the mean crown diameter (CD), which often presents an asymmetric shape, was measured in two perpendicular directions according to the following equation: $CD = (L+l)/2$. Where L is the length (m) and l is the width (m). In addition, TH and DBH were used to calculate the tree slenderness coefficient (TSC) according to the following formula: $TSC = TH/DBH$

3. Statistical analyses

The R software program (version 3.4.3) was used to compute descriptive and multivariate statistics. A one-way analysis of variance (one-way ANOVA) was used to check if there are any differences between the plots for the studied variables considering the significant level $\alpha=0.05$ and the Newman-Keuls post-hoc (SNK) test were performed to point out the effect of the position of the sampling plot on the variability of the considered parameters.

In addition, a boxplot chart was used to show the effect of the aspect on the number of seedlings. A principal component analysis (PCA) involved stand dendrometric and structural parameters associated to site conditions in order to show the combined effect of the set of the considered factors on Atlas cedar regeneration. In addition, a multiple linear regression (MLR) was used to establish a statistical model in order to explain the dependent variable (number of seedlings) as function of the considered four independent variables.

3. RESULTS

1. Repartition of sampled plots

Out of the 39 sampled plots, 23 plots were installed in gaps with a circular shape (O), 10 plots installed in gaps presented a horseshoe shape (C) and only 6 plots were installed at the opening of the forest edge.

The gaps created within the studied forest are likely to be generated after single or grouped trees disappearance (according to the gap size) due to senescence, windfall or insect outbreaks.

2. Variability of number of seedlings (NS) as function of the aspect

The boxplot chart (Fig. 3) revealed a high variability in number of seedlings according to the different aspects. The maximum median value was recorded within plots with south-facing aspect, which exhibited positive skew. However, while considering all the plots, the highest NS was noted at both north-west and south facing aspects, in the sampled plots from Tikjda and Tala Rana, which are located in the southern side of the Djurdjura massif, while the lowest was recorded in Ait Ouabane, which is located in the northern side. These results are consistent with those reported in Tala Guilef by Madjour [10], who noticed a higher mean NS in the south-facing slopes.

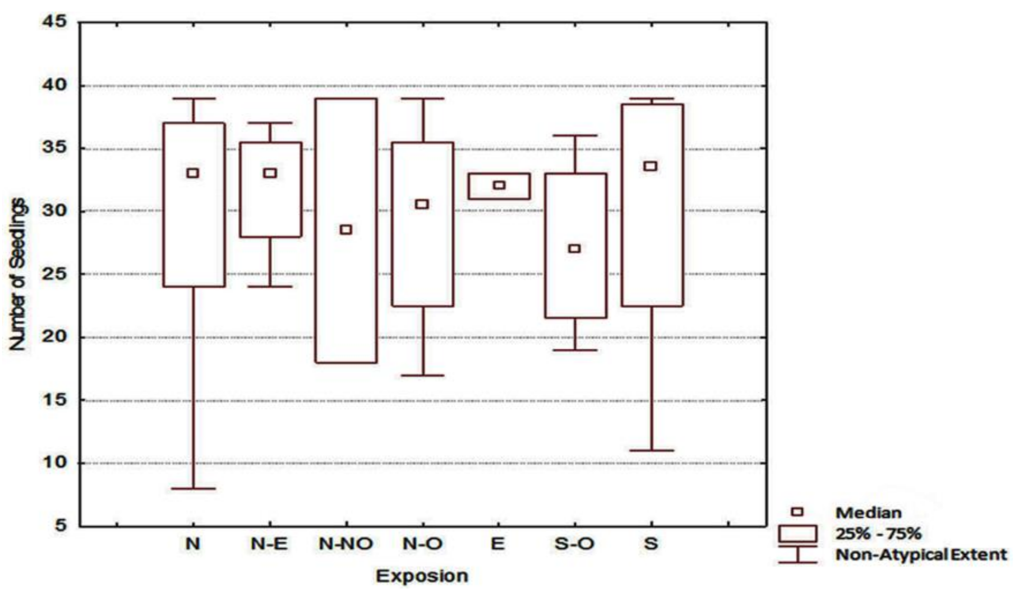


Figure 3: Boxplot of number of seedlings (NS) as function of the aspect.
The variability in regeneration rate according to the direction show that a slope faces reflects the impact of this topographical factor on the germination and the establishment of the seedlings.

3. Descriptive statistics of dendrometric data mean values

A total of 1153 seedling individuals (NS) were recorded in the 39 sample plots. The number of stems (NSt) composed by pre-countable and non-pre-countable stand, registered 395 individuals (Table 1). The results of descriptive statistics revealed an interplot heterogeneity for all measured variables. The number of seedlings (NS) per plot varied from 8 (P13) to 39 (P21, P29, P35, P22 and P9). The total NS reached 1153 with a regeneration density/plot of 29.56. For the regeneration, eight out of the 39 plots (21%) belonged to the class NS $\leq$ 20 with a mean regeneration per plot of 15.75 (126 seedlings). The class 20 < NS$\leq$ 30 included nine plots (23%) with a mean regeneration of 26.78(241 seedlings). The rest of the 22 plots (56%) belonged to the class NS >30, with a mean regeneration of 35.73 (786 seedlings).

Table 1: Descriptive statistics of dendrometric data mean values. F and p values were computed from the one-way ANOVA. *** corresponds to a highly significance level. The capital letters A, B, C and D are used to show homogenous groups determined from the SNK post-hoc test.

Station	Plot	NS	C1.30*** F=7.41 p<0.001		TH*** F=8.56 p<0.001		TSC*** F=12.031 p<0.001		CD*** F=7.761 p<0.001	
			Mean	SNK	Mean	SNK	Mean	SNK	Mean	SNK
Tala Guilef	P1	31.00	1.66	BC	15.80	AB	41.80	AB	3.41	A
	P2	36.00	1.00	D	10.41	BC	34.34	AB	2.38	BC
	P3	37.00	1.08	D	11.41	B	35.86	AB	2.97	AB
	P4	25.00	3.33	AB	11.60	B	17.11	C	4.76	A
	P5	35.00	2.65	AB	10.21	BC	13.26	C	4.05	A
	P6	24.00	3.53	AB	11.89	B	11.25	C	6.00	A
	P7	29.00	1.58	BC	12.23	B	34.28	AB	2.49	B
	P8	29.00	1.92	AB	13.75	AB	23.97	B	3.13	AB
	P9	15.00	1.68	BC	16.10	AB	31.95	AB	3.01	AB
	P10	34.00	1.23	C	13.24	AB	34.06	AB	3.85	A
	P11	32.00	1.62	BC	12.66	AB	37.12	AB	3.13	A
	P12	36.00	2.54	AB	16.08	AB	22.17	B	6.62	A
Ait Ouabane	P13	8.00	1.69	BC	16.79	A	31.69	AB	2.49	B
	P14	18.00	1.65	BC	11.63	B	23.88	B	2.07	C
	P15	33.00	1.55	BC	15.25	AB	32.45	AB	2.17	C
	P16	18.00	1.06	D	9.35	BC	30.40	B	1.45	D
	P17	24.00	0.97	D	10.92	B	35.83	AB	2.32	BC
	P18	17.00	1.13	CD	10.20	BC	29.04	B	2.35	BC
Tikjda	P19	38.00	2.36	AB	15.47	AB	21.11	B	2.41	B
	P20	24.00	1.74	BC	10.95	B	21.85	B	3.90	A
	P21	39.00	0.88	D	9.16	BC	34.92	AB	2.22	C
	P22	39.00	1.99	AB	15.70	AB	36.61	AB	5.16	A
	P23	38.00	1.85	AB	11.99	B	22.38	B	4.43	A
	P24	27.00	1.20	CD	16.70	A	51.37	A	2.50	B
	P25	32.00	0.94	D	10.28	BC	37.57	AB	2.39	BC
	P26	36.00	1.36	C	12.26	B	35.89	AB	2.83	AB
	P27	33.00	1.12	D	10.21	BC	30.77	B	2.27	C
	P28	29.00	1.18	CD	9.68	BC	27.00	B	2.76	B
	P29	39.00	1.24	C	11.86	B	35.86	AB	3.11	AB
	P30	36.00	1.31	C	8.84	BC	23.63	B	1.87	CD
Tala Rana	P31	39.00	3.17	AB	12.87	AB	13.72	C	4.06	A
	P32	35.00	2.57	AB	11.80	B	15.64	C	2.52	B
	P33	32.00	1.48	C	9.91	BC	27.19	B	1.70	CD
	P34	30.00	3.57	A	12.38	B	10.81	D	2.97	AB
	P35	39.00	1.74	BC	11.48	B	21.16	B	1.92	CD
	P36	11.00	1.60	BC	9.17	BC	18.82	C	1.98	CD
Tirourda	P37	20.00	1.49	C	8.16	BC	21.49	B	3.02	AB
	P38	19.00	1.13	D	7.78	C	24.73	B	2.25	C
	P39	37.00	1.84	B	8.04	BC	15.95	C	4.08	A

PN) **NS**: number of seedlings, **C.1.30**: circumference at 1.30m above ground, **TH**: total height**, TSC**: tree slenderness coefficient and **CD**: crown diameter.

The mean circumference at breast height (C1.30) reached 1.73 m. Only 14 plots (36%) registered a C1.30 higher than this average. The lower C1.30 (0.88 m) was recorded in Tikjda (P21), while the highest (3.57 m) was registered in Tala Guilef (P6). The mean total height (TH) was 11.91 m. sixteen plots (41%) registered TH values higher than the average. The minimum value (7.78 m) was recorded in Tirourda (P38) and the maximum (16.79 m) was obtained in Ait Ouabane (P13). The mean crown diameter (CD) was found as 3.05 m. This average was exceeded in 14 plots (36%). Minimum CD (1.45 m) was recorded in Ait Ouabane (P16) and the maximum (6.26m) was reached in Tala Guilef (P12).

The tree slenderness coefficient (TSC), which is the total height /diameter at the breast height ratio, registered high values in plots (P1,P3, P9, P10, P17, P22, P24, P25) and low values in plots (P4, P5, P6, P31, P32, P34, P36). The TSC registered a mean value of 27.19, which was exceeded in almost a half of the sampled plots (49%). The lowest TSC (10.81) was recorded in Tala Rana (P34), while the highest (51.37) was noted in Tikjda (P24). The one-way ANOVA detected interplot significant differences for C1.30, TH, CD and TSC. Calculated F-values were higher than the theoretical ($p < 0.001$).The SNK post-hoc test showed that these differences are highly significant and revealed homogenous groups (Table 1). Four main homogenous groups and three intermediate groups were determined for the variables C1.30 and CD. For TH, three main homogenous groups and two intermediates were identified. Three main homogenous groups and one intermediate group were noticed for the variable TSC.

4. Correlation matrix

The correlation matrix (not reported) highlighted the relationships between the considered variables, which the majority were not significant. The significant relationships registered a correlation coefficient (critical value of r) higher than 0.30 (α =0.05). C1.30 was negatively correlated to TSC, to SD and to I, and positively correlated to CD. In addition, CD was positively correlated to HLT and negatively correlated to I. TH was correlated positively to TSC and CD, but the relation is negative with E, which presented a positive correlation with the S and a negative relation with HLT.

5. Bivariate correlations between NS and NSt, CD, I and SD

No significant linear relationships were found between NS and other parameters. However, some of them registered r values close to the significance level. Negative correlation coefficients were registered between NS and the NSt (- 0.26), I (-0.26) and SD (- 0.28) and a low positive r value was recorded with CD (0.23) (Fig. 4). However, the non-linear relationships registered better correlations.

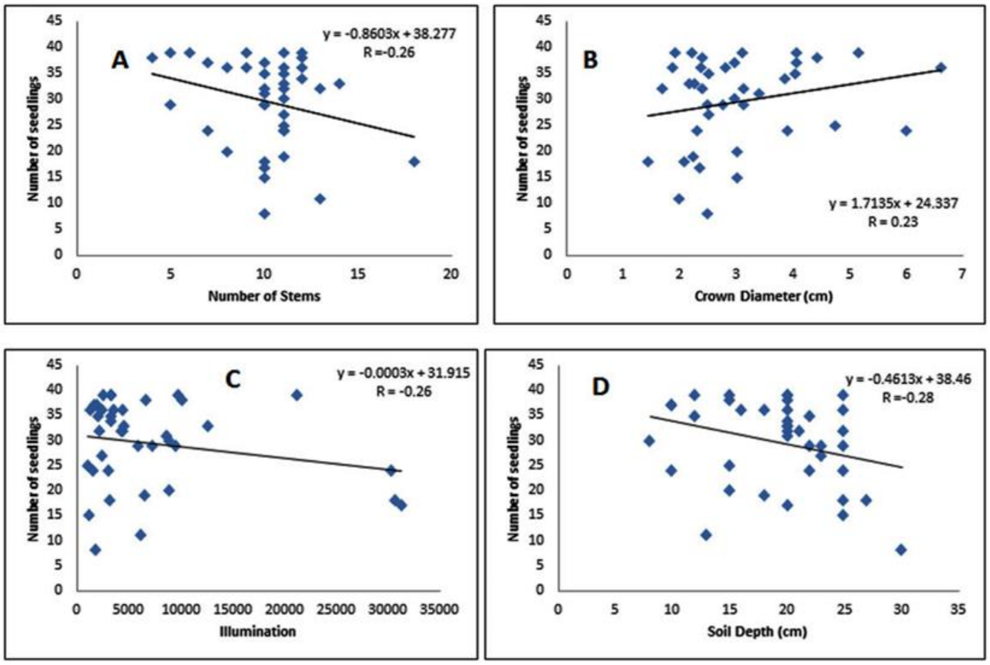


Figure 4: Relationships between the number of seedlings and (a) the number of stems, (b) the crown diameter, (c) the illumination and (d) the soil depth. Bivariate correlations between NS and the set of variables composed by NSt, CD, I and SD being low, and given the dispersion of the points along the adjusted line, the relationships are assessed better with the non-linear (or polynomial) trend, which generates low residues.

6. Multiple linear regression

The multiple linear regression, performed between the dependant variable NS and the combination of the independent variables SD, NSt, I and CD generated a significant correlation coefficient (r = 0.40). The multiple linear regression model generated a F value of 1.65 ($p < 0.005$). It is developed according to the following equation: NS= 0.06 CD -0.24 SD -0.19NSt -0.12 I +0.42. This model did not reveal any statistically significant result.

7. Principal component analysis

A PCA was performed to show the combined effect of multiple factors on Atlas cedar regeneration. The analysis involved dendrometric and structural parameters as well as site conditions. The first eigen value accounts for 25.63 of the total variance. The second and the third components registered 18.78% and 13.58% of the total variance respectively. The axes 1 and 2 cumulate only 44.41% of the total variance. These suggests that plots discrimination in not enough explained by the variables that contribute to form only these two axes. The total inertia exceeds 77% from the fifth component. This reflects also the need to explain these five axes.

The PCA showed the influence of the considered parameters on the regeneration of Atlas cedar. Compared to the work carried out by Madjour [10] and Ezzahiri and coll. [20] which highlighted the dependence of the natural regeneration of the Atlas cedar on certain parameters linked to the site (altitude, topography, depth of the soil) and the stand (density of stems), in our study, in addition to these parameters indicated, we have highlighted the determining role of light transmittance on regeneration dynamics of this tree species. Many gradients, which can explain the contribution of each variable, were distinguished:

Axis 1 is defined by three variables: C1.30 and CD are positively correlated with the abscissa, with the contributions of 0.26 and 0.22 respectively, while I is negatively correlated, with a contribution of -0.14. This axis reflects a gradient of illumination (I).

Axis 2 is also determined by three variables: E is positively correlated with the abscissa (0.20), whereas TH (-0.25) and SD (-0.28) are negatively correlated. This axis corresponds to an elevation gradient (E).

Axis 3 is defined by two variables: NSt is positively correlated with the abscissa (0.31) and NS is negatively correlated (-0.31).This axis represents a gradient of stand density, where the two variables are negatively correlated. These results showed an inverse relationship between the stand density and the regeneration rate.

Axis 4 is also defined by two variables: S is positively correlated with the abscissa (0.50) and HLT is negatively correlated (-0.30). This axis defines a topographic gradient. It reflects the decrease of HLT with S.

Finally, axis 5, which presents only 8.10% of the eigenvalues, is formed by only the negative contribution of TSC. TSC is opposed to NS and its contribution is not marked in the formation of the four first axes. Indeed, the contribution of this parameter in plot discrimination is low. This corresponds to a dendrometric gradient.

Figure 5 reveals nine plot groups (G1 to G9). They are organized according to the plot similarities in dendrometric measurements, stand structure and pedological and sites characteristics, which present moderate to high heterogeneity. Individuals (plots) repartition, according to their coordinates on the five first axes, allows characterizing each group on the basis of the contribution of the involved parameters to the formation of these axes. In this study, only the bi-plot results for the axes 1 and 2 is presented (Fig.3).

Axis 1 opposes the group G4, which is composed by the plots p16, p17, p18, p38, p27, p35, p36 and p37, located in its negative area and characterized by high values of illumination, to G9, constituted by the plots p32, p6, p4 and p34, located in its positive side and characterized by trees with high dendrometric values (C1.30 and CD), corresponding to well-developed mature stands.

Axis 2 opposes G3, formed by P28, P2, P3, P29 and P30, which are located at high elevations, positioned in its positive side, to G2 (P15, P13, P7 and P14) and G7 (P12, P11, P8, P9, P20 and P19), which are composed of high trees growing on deep soils and concentrated in the negative part of this axis.

Axis 3 opposes plots of G1 (P21, P25, P24, P1, p33, P26 and P10), placed on its negative part and characterized by an important mature stand density,

to those of G8 (P23, P39 and P5) presented in the positive side of the axis and marked with a high values of NS.
Axis 4 opposes G5, represented only by P22, which is plotted on the negative part of the axis and characterized by a thick humus layer, to plots with steep slope and a rather thin humus layer, which are presented on the positive side of this axis.
Axis 5 highlights the group G6, which is composed only by one single plot (p31), marked by a low tree slenderness coefficient. This plot is distinguished by a stand composed by trees with moderate height growing on shallow soils.

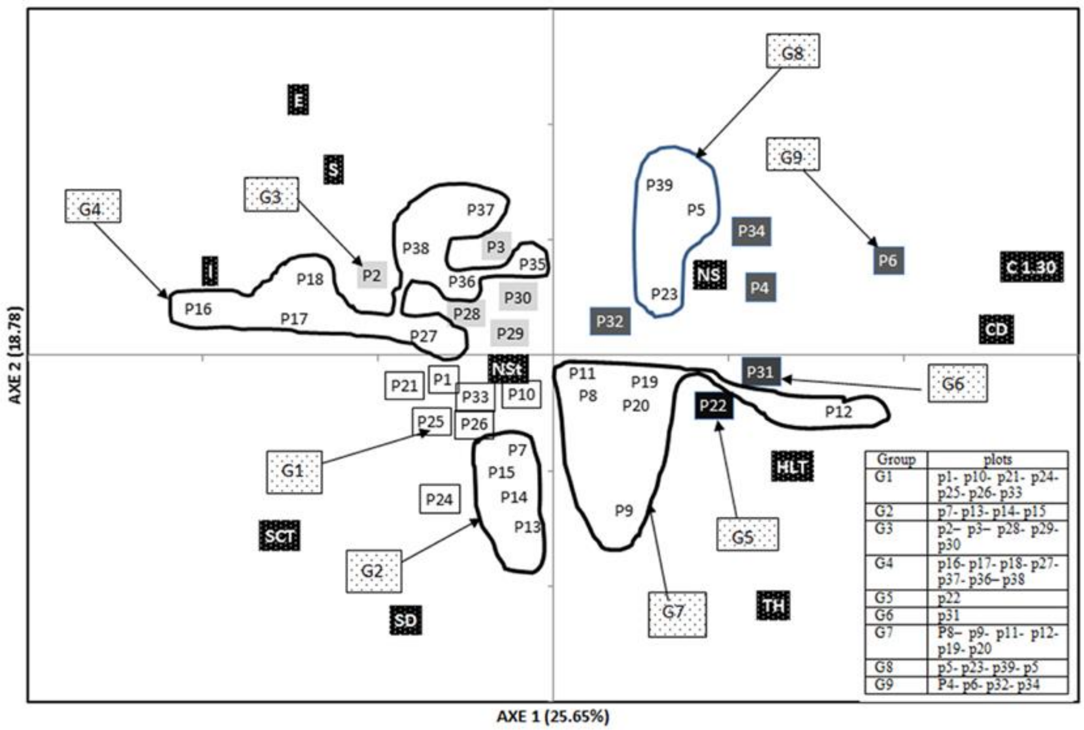


Figure 5: Bi-plot results of principal component analysis of plots (P) and considered parameters distribution for axes 1-2. Plots of the same color belong to the same group. E is the elevation, S the slope, I the illumination, NS the number of seedlings, C1.30 the circumference at breast height, CD the crown diameter, NSt the number of stems, HLT the humus layer thickness, SCT the slenderness coefficient of a tree, SD the soil depth and H the total height.

DISCUSSION

The dominance of circular gaps than other shapes noted in our study area is due to the sampling procedure applied where regeneration was observed. This can be explained by the development of seedlings thanks to the edaphic (seed bank in the soil) and adjective (seed rain) seminal potentials of the surrounding seed trees [24].
According to the box-plot (Fig. 3), the north-west and south facing aspects registered higher means of number of stems due to more exposure to sunlight than in the north-facings slopes, especially within plots with dense canopy cover [10].
Indeed, the effects of the aspect, the slope and the gap size determine the light transmittance to the soil surface and influence the regeneration dynamics [25].
For the variability in regeneration rate according to the direction of the aspect (slope faces), Prevost and Raymond [25], noted that this topographical factors (slope and aspects) and the size of the gap determine the light transmittance to the soil surface and influence the regeneration dynamics. When the topography is irregular, the effect of the aspect of the slope is superimposed on that of the altitude. Then, the light available in the gaps depends largely on the topographical features of the site [25]

According to the results of the one-way ANOVA (Table1), north-facing slopes, dense forest cover (low illumination) and adverse site conditions (shallow soil, steep slope, low number of seed trees) generate poor regeneration, preventing Atlas cedar seeds germination and seedling establishment. These results are consistent with those reported by [6, 7]. In contrast, high regeneration was observed within burned plots with a deep soil and south and west aspects: wildfires promote seed germination and abundance of natural regeneration of Atlas cedar [26] and the sunlight reaching the soil from the openings in the forest canopy support seedling establishment and forest stand renewal [6, 27]. This suggests that regeneration is a complex process depending on a combination of multiple factors, especially the degree of the canopy cover, the aspect and the presence of seed trees.

The C1.30 is high in mature stands plots, especially in the called “Millennium forest” of Tala Guilef and in Tala Rana, where trees achieved their height growth and invest heavily in radial growth. On the contrary, C1.30 is low in young and in dense stands. Mason-Euan [28], reported that high forest density affects radial growth.

The TH recorded high values in Atlas cedar stands with a north-facing slope and with high density (competition for light) and within mature stands, which reached their upper growth limit. In contrast, TH is low in young stands, in which trees have not yet reached their vertical growth limit, or in those located within upland degraded forest. Several authors reported that this parameter is influenced by many environmental factors, such as elevation, slope and illumination [29].

For the tree slenderness coefficient (TSC), the high values characterize dense stand which are located on the northern aspect (competition for light), in contrary, the low values are registered in plots located on the southern aspect (hot) with clear stand. This can be explained by the fact that dense stands promote vertical structure development [30].

The CD registered its lowest values in young stand where illumination is very limited and associated to lateral competition. This stimulates young trees height growth at the expense of the radial growth. Consequently, the number and size of the branches are reduced. Similar results were reported by Rasse [31]. However, in relatively open mature stands, where space is enough between trees to allow them deploying laterally their branches, the crown diameter is well developed. Our findings are consistent with those reported by Derridj [6], who noted that this structure is also linked to the biogenic character of Atlas cedar, which slender when the tree is young and takes a tabular shape when mature.

In the matrix correlation, the negative relationship between NS and NSt reflects the effects of the density of the stand (NSt per ha) and its canopy cover degree on the germination and establishment of the seedlings. That is why, Forest ecologists and silviculturalists have emphasized the importance of creating canopy gaps to promote tree regeneration, because light is a resource that limits tree seedling recruitment in many forest understoreys [32].

The relationships (bivariate correlation) between NS and the parameters NSt, CD and I show that Atlas cedar regeneration do not support a strong illumination and a dense canopy (generated by trees with high C130 and CD). High illumination triggers strong evapotranspiration and the development of interfering vegetation [33]. Nonetheless, a moderate cover provides an appropriate microclimate, reducing evapotranspiration and maintaining favorable moisture for the seedlings development [31]. Likewise, it allows litter transformation by the decomposing organisms to a form that plants are able to absorb, which is vital for forest trees development [34].

The result obtained in the multiple linear regression confirms the complexity of estimating NS directly from a small number of parameters. Anyway, many authors who tried to model forest regeneration reported that the models are difficult to establish because of lack of both available data and knowledge allowing integration of all the processes involved in forest regeneration, or at least the most important ones [35].

The illumination gradient (Axe 1.) means that sunlight (I) reaching the soil surface depends strongly on the tree measurements (C1.30, CD), on the elevation, and possibly on other parameters, such as the shape and the size of the gaps, as well as the site topography [25].

The negative correlation between I and the two parameters C1.30 and CD reflects the effect of these variables on the light transmittance to the soil surface [36]. The elevation gradient (Axe 2.) can be explained as noted by Nardin [37], who suggested that trees of many coniferous present generally a lower growth (TH) at high elevations. Likewise, Akay an coll. [38] reported that soil depth (SD) decreases along an altitudinal gradient. The gradient of stand density (Axe 3.) indicates that in dense stands, regeneration is low because of poor seed production and low light availability, which are limiting to growth and decreasing the chances of seedlings survival [6, 33]. On the contrary, light availability promotes regeneration, especially for species that are very demanding as regard light, which is the case of Atlas cedar [39]. The topographic gradient (Axe 4.) reflects the decrease of HLT with S as reported by Akgul and Hasdemir [39], who noticed that organic debris are easily moved down and the humic horizon is maintained in thin layer. At last, the negative correlation between NS and TSC (Axe 5.) means that when TSC increases (case of stands with high density of stems, where competition for light is pronounced), the density of regeneration decreases, because of the low light transmission to the soil surface. This highlights the role of light as a limiting factor in the regeneration under the canopy Çoban and coll. [32], as reported in the correlation matrix.

Overall, our results are consistent with those reported in Algeria, for the Tala Guilef, by Madjour [10] and by Ezzahiri and coll. [20], for the Moroccan Atlas cedar forests of the Mid-Atlas Mountains.

CONCLUSION

The current study on gap regeneration in the Atlas cedar forests of the Djurdjura massif produced a number of interesting findings and observations on the behaviour of this species towards stand structural parameters and conditions (environmental and dendrometric factors). The results revealed that the natural regeneration of Atlas cedar depends greatly on a combination of multiple parameters, especially the topography (slope, aspect and elevation) and the stand structure (canopy closure and stem density), which control the illumination at the soil surface and, consequently, the microclimatic conditions required for seed germination and seedling establishment. Our results showed that forest management operations consisting of a thinning grade, taking into account the elevation, the topography and the stand structure, could be applied to improve Atlas cedar regeneration. At low and moderate elevations, in cool slopes (north, northeast and northwest), where the favourable temperature for germination is late, we recommend a strong thinning, especially within dense stands. On the contrary, in hot slopes (south and southwest), characterized by an earlier germination, it is recommended to keep moderate forest covers, which will protect seedling from the very high summer temperatures. At high elevation, in cool sides, the thinning degree from the top should be strong, because Atlas cedar regeneration occurs when seeds are completely subjected to light; in the southern slope, however, stand clearing should be very low. Seedlings are established earlier at lower elevations. At higher elevations, a large rate of seedling roots does not have enough time to go deep in the soil to avoid the summer soil surface drying out, which begins from July. Hence, high rate of root growth is a key factor for the survival of the seedlings. These findings confirm the sciaphilous behaviour of Atlas cedar at low elevation, while it adopts a heliophilous character at high elevation, which affect regeneration. Further studies at a larger scale, and involving much more parameters, such as other shapes and sizes of the gaps, the tree age, the position of the seed trees and also edaphic potentials, would complete our findings for a better understanding of the natural regeneration and dynamics of Atlas cedar forests in Algeria.

REFERENCES

[1]. Messaoudene, M., Loukkas, A., Janin, G.,Tafere, M.; Dilem, A., Gonçalez, J. (2004). Propriétés physiques du bois d'éclaircie des cèdres (*Cedrus atlantica*), contenant du bois de compression, provenant de l'Atlas du Djurdjura (Algérie). *Annal of Forest Science*, 61: 589-595. https://doi.org/10.1051/forest.

[2]. Rabhi, K. , Akli, A. , Djouhri, A. , Yahi, N. , Boudedja, S. , Messaoudene, M. (2018). Bilan et croissance des reboisements de cèdre de l'Atlas, Cedrus atlantica (Endl.) Carrière, en Algérie: cas du Djurdjura et de l'Atlas blidéen. *Bois et Forêts des Tropiques*, 337 : 3-15. Doi : https://doi.org/10.19182/ bft.

[3]. Yahi N. (2007). Les cédraies d'Algérie: Phytoécologie, phytosociologie, dynamique et conservation des peuplements. Thèse de doctorat d'Etat en écologie végétale, Université des Sciences et de la Technologie Houari Boumediéne (USTHB), Alger. P.276.

[4]. Lepoutre B. and Pujos A. (1963). Facteurs climatiques déterminant les conditions de germination et l'installation des plantules de cèdre. *Annales de la recherche forestière au Maroc*. Tome 6. Fasc2.211 p.

[5]. Lepoutre B. (1964). Suite d'observations sur la régénération du cèdre par taches. *Ann. Rech. For. Maroc*, 7: 1-20.

[6]. Derridj A. (1990). Etude des populations de *Cedrus atlantica*. Manetti en Algérie. Thèse de doctorat d'Etat en écologie, Université Paul Sabatier- Toulouse - France. p. 282.

[7]. Ezzahiri M. and Belghazi B.(2000). Synthèse de quelques résultats sur la régénération naturelle du cèdre dans l'Atlas au Moyen Atlas, Maroc. S*écheresse* 11(2): 78-84.

[8]. Khanfouci M.S. (2005). Contribution à l'étude de la fructification et de la régénération du cèdre de l'Atlas (*Cedrus atlantica* Manetti) dans le massif du Belezma. Mémoire Magist., Univ. Batna, Département Agronomie, 236 p + annexe.

[9]. Navarro-Cerrillo Rafael M., Manzanedo R., Bohorque J., Sánchez R., Sánchez J., De Miguel S., Solano D., Qarro M., Griffith D., Palacios G. (2013). Structure and spatio-temporal dynamics of cedar forests along a management gradient in the Middle Atlas, Morocco. *Forest Ecology and Management*, 289: 341–353.

[10]. Madjour K. (2015). Régénération naturelle du cèdre de l'Atlas (*Cedrus atlantica*, Manetti) au niveau du Parc National du Djurdjura (Secteur de Tala-Guilef). Thèse de Magister. UMMTO, Algérie. 82 p. + annexes.

[11]. Ngueguim J.R., Zapfack L., Youmbi E., Riera B., Onana J., Foahom B., Makombu J.G. (2010). Diversité floristique sous canopée en plantation forestière de Mangombe-Edea (Cameroun). *Biotechnol. Agron. Soc. Environ*. 14(1) : 167-176.

[12]. Mediouni K., Yahi N. (1989). Etude structurale de la série du cèdre à Aït-Ouabane (Djurdjura). *Forêt méditerranéenne*, XI, 2 :103-1120.

[13]. Tabet S., Belhemra M., Francois L., Arar A. (2018). Evaluation by prediction of the natural range shrinkage of *Quercus ilex* L. in eastern Algeria. *Forestist* 68(1): 7-15. DOI: 10.5152

[14]. Muscolo A., Settineri G., Bagnato S., Mercurio R., Sidari M. (2017). Use of canopy gap openings to restore coniferous stands in Mediterranean environment. *Forest* 10: 322-327. – doi: 10.3832/ifor1983-009.

[15]. Meddour R. (2010). Bioclimatologie, phytogéographie et phytosociologie en Algérie. Exemple des groupements forestiers et pré forestiers de la Kabylie Djurdjuréenne. Thèse de doctorat d'Etat en écologie, université Mouloud Mammeri de Tizi Ouzou. P.461.

[16]. Benmouffok A. (1995). Note de recherche: description de formations à *Cedrus atlantica* Manetti du massif central du Djurdjura. *Cahiers Agricultures*; (4): 383-7.

[17]. Yahi N. (1988). Contribution à l'étude des formations à Cèdre (*Cedrus atlantica,* Manetti) d'Aït Ouabane. Mem. DES. Université des Sciences et de la Technologie Houari Boumediéne (USTHB), Alger, 90 p.

[18]. Wazen N., Fady B., 2015. Geographic distribution of 24 major tree species in the Mediterraean and their genetic resources. Final report Project GCP/GLO/440/FRA.FAO 41p.

[19]. PND., 2014. Plan de gestion quinquennal (2014-2019).

[20]. Ezzahiri M., Belghazi B., Bahmad M. (1994). Bilan de la régénération naturelle de la cédraie des parcelles clôturées du Moyen Atlas (Maroc). *Ann. Rec. For. Mar*. Numéro spécial (27) :259-268.

[21]. Daget P., Godron M. (1982). *Analyse fréquentielle de l'écologie des espèces dans les communautés*. Masson, Paris, 163 p.

[22]. Van Counwenberghe R. (2011). Effets des facteurs environnementaux sur la distribution et l'abondance des espèces végétales forestières aux échelles locales et régionales. Ecosystèmes. Agro ParisTech.

[23]. CRPF (Centre Régional de la Propriété Forestière). (2011). Fiche technique : Analyse prospective de la ressource forestière et des disponibilités en bois de la région Aquitaine à l'horizon 2025. Etat des lieux des forêts aquitaines à l'automne 2011.

[24]. Douh C., Daïnou K., Loumeto J. J., Fayolle A., Doucet J.L. (2014). Explorer la banque de graines du sol pour mieux comprendre la dynamique de régénération des forêts tropicales africaines (Synthèse bibliographique). *Biotechnologie, Agronomie, Société et Environnement*, 18: 558-65. http://hdl.handle. net/2268/174538.

[25]. Prévost M., Raymond P. (2012). Effects of gape size, aspect and slope on available light and soil temperature after patch-selection cutting in yellow bird-conifer Stands, Québec, Canada. *For.Ecol.Manage*.274: 210-221.

[26]. Toth J. (1987). Effets des facteurs d'environnement sur l'accroissement du cèdre de l'Atlas. *Bull. Soc. Et Nat. Vaucluse*.: 71-76.

[27]. Lamhamedi M. and Chbouki N. (1994). Les principaux facteurs influençant la régénération naturelle du cèdre de l'atlas (*Cedrus atlantica* Manetti). *Ann. Rech. For. Maroc*, T (27) : 243-257.

[28]. Mason, Euan G., 2004. A brief review of the impact of stand density on variables *affecting Radiata pine* stand value.

[29]. Alves L.F., Vieira S.A., Scaranello M.A., Camargo P.B., Santos F.A.M., Joly C.A. Martinelli L.A. (2010). Forest structure and live aboveground biomass variation along an elevational gradient of tropical Atlantic moist forest (Brazil). *Forest Ecology and Management*, 260 :679–691. doi:10.1016/j.foreco.

[30]. Blanchard E. (2016). Diversité structurale des forêts denses humides de la Province Nord de Nouvelle-Calédonie: de l'arbre au paysage. Sciences de l'environnement. Ecole Doctorale GAIA, Thè. Doc. Univ. Montpellier. France. 304p.

[31]. Rasse N. (2012). Le traitement irrégulier appliqué aux peuplements de douglas ou de pins purs et mélangés en Bourgogne. Bilan de la convention 2010 – 2012. CRPF de Bourgogne.

[32]. Çoban S., Çolak A., Rotherham I., Özalp G., Çalıskan A. (2018). Effects of canopy gap size on the regeneration of Scots pine (*Pinus sylvestris* L.) in Eskisehir –Çatacik region of Turkey. *Austrian Journal of Forest Science*. 183-212. http://shura.shu.ac.uk/23258/.

[33]. Ligot G., Balandier P., Courbaud B., Jonard M., Kneeshaw D., Claessens H. (2015). Dosage de la lumière pour maintenir la coexistence d'espèces d'ombre et de demi-ombre dans la régénération de la futaie irrégulière. *Rev. For. Fr*. LXVII - 3-2015: 195-211.

[34]. Çakır M. and Akburak S. (2017). Litterfall and nutrients return to soil in pure and mixed stands of oak and beech. *Journal of the Faculty of Forestry Istanbul University* 67(2): 185-200. DOI: 10.17099/jffiu.301602.

[35]. Gaudio N. (2010). Interactions pour la lumière entre les arbres adultes, les jeunes arbres et la végétation du sous-bois au sein d'un écosystème forestier: application à la régénération du pin sylvestre en peuplement mélangé chêne sessile-pin sylvestre. Sciences de la Terre. Université d'Orléans. France.

[36]. Balandier P., Marquier A., Perret S., Collet C., Courbaud B. (2010). Comment estimer la lumière dans le sous-bois forestier à partir des caractéristiques dendrométriques des peuplements. Rendez-vous Techniques ONF n° 27-28, pp. 52- 58. https://hal.archives-ouvertes.fr/hal-00504405.

[37]. Nardin M. (2013). Ajustement biologique du mélèze aux variations environnementales le long d'un gradient altitudinal: approche microdensitométrique de la réponse au climat. Sciences agricoles. Université d'Orléans. Français. NNT.https://tel.archives-ouvertes.fr.

[38]. Akay A.E., Taş İ., Gencal B. (2019). Variation of Tree Diameters along Road Edges: The Case of Karacabey Linden Forest in Bursa, *Turkey*. *Forestist* 69(2): 81-86.

[39]. Akgul M. and Hasdemir M. (2018). Investigation on slope and canopy closure effects to minimize sediment movement in riparian buffer zone. *Forestist*, 68(1): 70-77. İstanbul University, Faculty of Forestry, İstanbul, Turkey.