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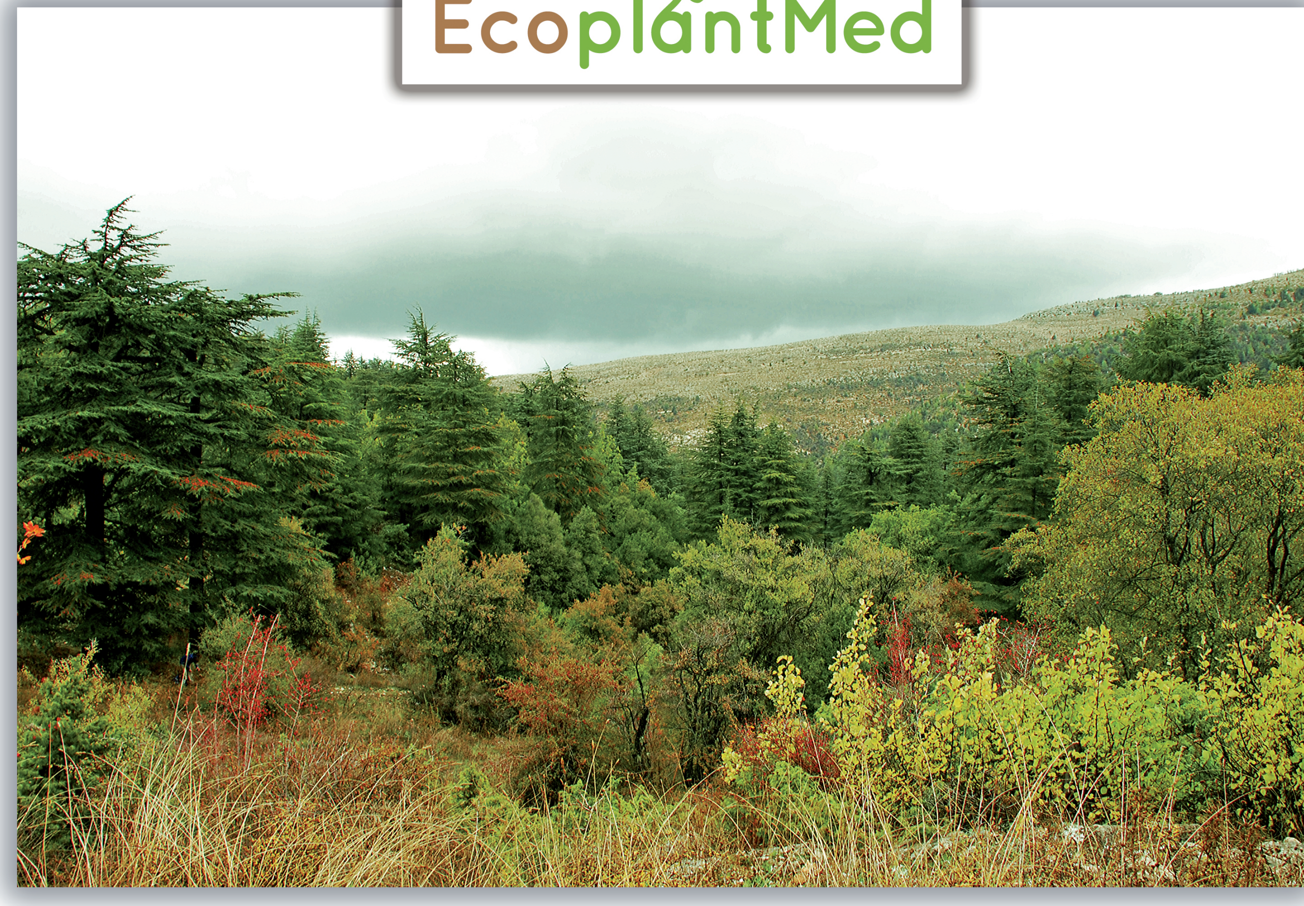

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Juniperus drupacea Labill. stands in Jabal Moussa Biosphere Reserve, a pilot study for management guidelines

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Abstract
The Syrian juniper, *Juniperus drupacea* Labill has a very limited distribution and is facing severe fragmentation and dieback in Lebanon. The present investigation is a pilot study conducted in Jabal Moussa Biosphere Reserve in order to develop a plan for conservation and sustainable management of this species. A total of 106 individuals were studied from five areas. The correlations between environmental factors (altitude, exposition, and slope) as well as canopy density with the trees distribution, size and vitality were investigated. The most remarkable individuals were mainly found in Aarbi, the central karstic area in association with *Quercus calliprinos* Webb., *Q. infectoria* Oliv. and *Pistacia palaestina* Boiss. The statistical analysis showed that the *optimum* conditions for *Juniperus drupacea* growth is at middle altitudes, at western expositions with low slope and in relatively open forest. In short term, to manage and conserve this unique species, we can perform a selective cutting to i) eliminate infested trees and branches, ii) reduce the number of trees per unit area – reducing therefore the density of the canopy and distance between trees – in order to preserve the remarkable vitality of trees.

Key words: eco-geography, forest management, *Juniperus drupacea* Labill., Lebanon, phytoecology.

Introduction

The Syrian juniper (*Juniperus drupacea* Labill., *Arceuthos drupacea* (Labill.) Antoine & Kotschy) a conifer tree from the cypress family is the only representative of the Section *Caryocedrus* (Endlicher, 1847) of the *Juniperus* L. genus. It is a dioecious tree reaching up to 20 m high and sometimes 40 m high. The crown of the young trees is conical while in the older individuals it becomes more irregular. The fleshy seed cones contain 1 to 3 seeds that are almost entirely fused into an ovoid "hard nut". This species is native of the Eastern Mediterranean region. It is found in Greece (Peloponnese), southern Turkey, Lebanon, and Syria. It is rare in Lebanon and Greece but widespread and common in Turkey and Syria (Mouterde, 1966; Farjon, 2010).

This species grows under Mediterranean climates between 600 and 1800 m with cold winter conditions and summer drought, and is indifferent to soil type as it can grow on calcareous or granitic soil (Abi Saleh *et al*., 1996; Farjon, 2010). In Lebanon, its altitudinal range is between 1000 and 1700 m, corresponding to the Supramediterranean and Mountain Mediterranean vegetation levels (Mouterde, 1966; Abi Saleh *et al*., 1996).

Juniperus trees in general do not constitute a dense canopy, and more precisely *J. drupacea* do not constitute pure stands. In the Supramediterranean it is found as an accompanying species to *Quercus calliprinos* Webb. with *Pistacia palaestina* Boiss., *Styrax officinalis* L. and *Cercis siliquastrum* L. at the lower limits, and to *Quercus infectoria* Oliv. and *Q. cerris* L. in the middle sector. In the Mountain Mediterranean it can be found associated to *Cedrus libani* and to *J. excelsa* M. Bied with *J. oxycedrus* L. (Abi Saleh *et al*., 1996).

J. drupacea is a very interesting ornamental tree because of its columnar shape, good growth rate and resistance to frost (Farjon, 2010). In Turkey the fleshy cones are used to produce molasses. In Lebanon this species has no specific use by the local populations. Reforestation activities in Lebanon are in constant growth with higher awareness for the use of native tree species and the preservation of the forests biodiversity. The Syrian juniper can be used to enhance the biodiversity in oak and cedar forests restoration.

Until today no extensive ecological studies were made on *Juniperus drupacea* populations in the Mediterranean. The limited past investigations focused on the elaboration of *ex situ* germination protocols in Turkey (Alpacar, 1988; Gultekin & Ozturk, 2003), or assessed its ecological status in Greece (Boratynski *et al*., 1982; Tan *et al*., 1999; Maerki & Frankis, 2005).

In order to insure successful management and reforestation activities of *Juniperus drupacea* in Lebanon, it is necessary to undertake *in situ* investigations in its different habitats. These studies can allow a better understanding of this species dynamics in relation with different environmental factors related to climate, topography, soil as well as to accompanying and compe-

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ting species.

The present work is a pilot study conducted in Jabal Moussa Biosphere Reserve, Mount-Lebanon. It aims to address the actual distribution of the Syrian juniper in accordance with environmental factors prevailing in this mountain. The results will help better understand the optimum conditions and factors that determine its distribution and its vitality in order to develop a sustainable management and conservation plan of this species.

Materials and methods

The study was undertaken in Jabal Moussa located in Keserwan, Mount-Lebanon. This protected area is dominated by deciduous and evergreen oak trees and was declared Biosphere Reserve in 2009.

The mountain was divided into five zones where this species is present (Fig. 1, Tab. 1): i) Jabal Mar Jerjes (Z1) in the north-west at 1200 m a.s.l. dominated by *Quercus infectoria* and *Ostrya carpinifolia* associated with *Styrax officinalis*, *Fraxinus ornus* and *Q. cerris*, ii) Mcheteh-Ain el Delbeh (Z2) is the western zone at 1200 m a.s.l. dominated by evergreen vegetation of *Q. calliprinos* associated with deciduous species like *Q. infectoria* and *Pistacia palaestina*, iii) Broqta (Z3) to the north-east at 1300m a.s.l. dominated by deciduous species mainly *Q. cerris* and *Q. infectoria* associated with *Cercis siliquastrum* and *Sorbus torminalis*, iv) Qahmez and Daraj el Mcheteh (Z4) is the south and south-east area at 1400 m a.s.l. with a vegetation similar to the one found in Z2, and finally (v) Aabri (Z5) is the central plateau at 1500 m a.s.l. where an open deciduous forest of *Quercus infectoria* associated with *Ostrya carpinifolia* and *Pistacia palaestina* dominates. This subdivision is based on the vegetation

Tab. 1 - The environmental characteristics of the five studied zones in Jabal Moussa Biosphere Reserve.

Zone	Localization	Geographic position	Altitude range (m)	Exposition	Slope (%)	Landform	Canopy density range (%)	Mean annual rainfall (mm)*
Z1	Jabal Mar Jerjes	34.062°N 35.753°E	1215-1285	north-west	110	Mountain slope	>70	1200-1300
Z2	Mcheteh-Ain el Delbeh	34.033°N 35.766°E	1184-1272	western zone	45-120	Mountain slope	>70	>1400
Z3	Broqta	34.069°N 35.787°E	1326-1348	north north-east	0-60	Mountain slope	>70	>1400
Z4	Qahmez - Daraj el Mcheteh	34.056°N 35.775°E	1396-1499	south south-east	40-90	Mountain slope	10-70	>1400
Z5	Aabri	34.060°N 35.772°E	1485-1575	central plateau	0-85	Plateau	<10 - ≤ 70	1300-1400

**based on the mean annual precipitation map of Lebanon by Plassard (1972).*

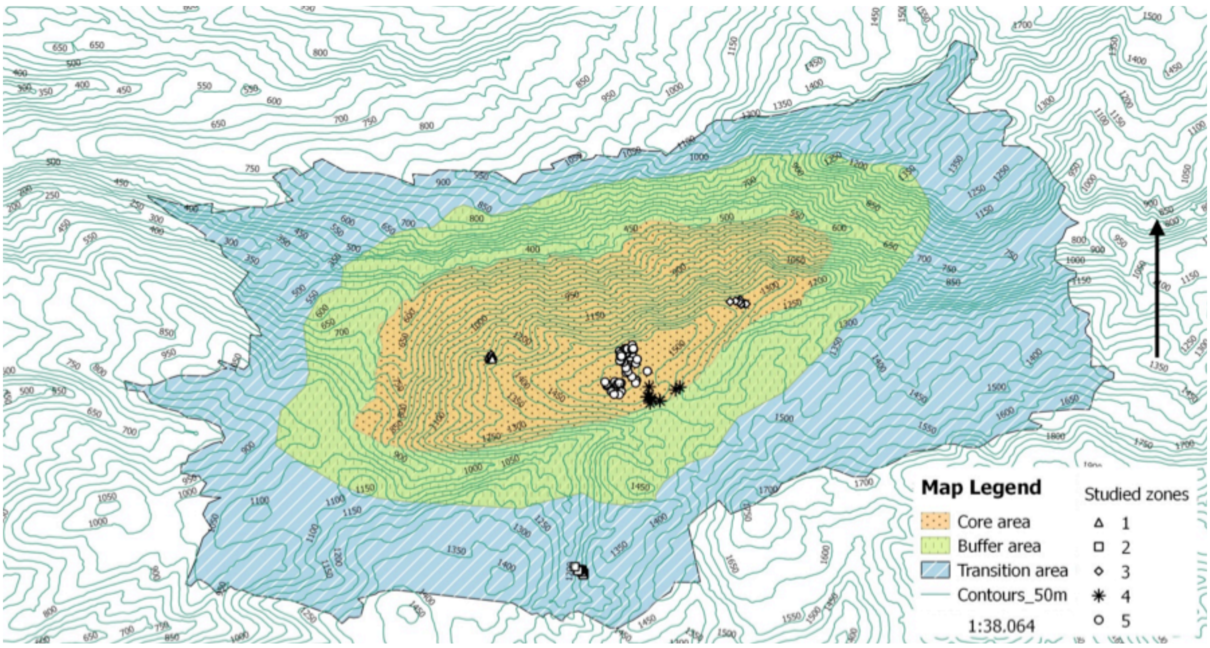

Fig. 1 - Jabal Moussa Biosphere Reserve map showing the distribution of the recorded trees in each of the five studied zones. The zones codes as in Table 1. This figure was obtained by QGIS.

and landforms maps developed by Safi (1999). This sampling methodology allowed us to cover most of the *Juniperus drupacea* trees in Jabal Moussa, with all the possible variability of the prevailing environmental factors (topography, altitude, slope, exposition and canopy density).

The position of the adult trees was recorded by GPS, and for each tree the following parameters were recorded: sex, tree height (in meters), diameter of the trunk at breast height (DBH in centimeters), and tree vitality. We considered the tree as adult when its height is higher than 4 m. The environmental characteristics of each site were also recorded for the type of landform, altitude range, slope, exposition and canopy density (Tab. 1).

In order to study the natural regeneration, we defined circle areas of 50 m^2 with a radius of 4 m in the seedling establishment points. The regeneration was then evaluated as the number of seedling/m^2.

For the statistical analysis we considered three altitudinal ranges: (1) < 1300 m, 1300 m < (2) ≤ 1500 m and (3) > 1500 m; four slope classes: 0% ≤ (1) < 25%, 25% < (2) ≤ 50%, 50% < (3) ≤ 75% and (4) > 75%. The canopy density was divided in four classes: (1) < 10%, 10% < (2) ≤ 40%, 40% < (3) ≤ 70% and (4) > 70%; as well as the exposition: Northern (N), eastern (E), western (W) and southern (S).

We used the software R for statistical analysis. Tests of analysis of variance (ANOVA) followed by the Tukey test were used to study the effect of each factor on the trees size and regeneration levels. The deviation from unity of the sex ratio was tested using the G-test.

We analyzed the spatial structure using the linearized function L(r) of the Ripley's function K(r), implemented in the SpatStat R package (1.25) (Ripley 1977; Baddeley & Turner 2005; R Core Team 2013).

Results

A total of 106 adult trees were recorded unevenly in the five studied zones of Jabal Moussa Biosphere Reserve. The majority of the studied trees (55.6%, 59 trees) were found in Z5, the central karstic area of dolines (sinkholes), while 9 to 15 trees were recorded in each of the other four zones (Table 2).

The altitudinal distribution of *J. drupacea* varied between 1200 and 1575 m a.s.l.. The lowest altitude recorded was 1180 m a.s.l for one tree in Z2. 50% of the trees were found between 1500 and 1575 m a.s.l. located in Z5, while 24.5% were recorded between 1200-1300 m a.s.l located in Z1 and Z2 and the rest (25.5%) between 1300 and 1500 m a.s.l. located in Z2, Z3, Z4 and Z5 (Tab. 2).

Most of the trees (53.7%) tend to be on western expositions (west, northwest and southwest) in Z1, Z2, Z4 and Z5; while 31.3% of the trees were found on eastern expositions (east, northeast and southeast) in Z3, Z4 and Z5. The rest were found on north (4.7%), south (5.6%) and on the plateau (4.7%) (Tab. 2). In total four dead trees were found in southern exposure in Z4.

We found a total of 48 female (F), 54 male (M) and 4 trees with no reproductive organs (U) (Tab. 3). The sex ratio (M/F) of the total population did not deviate significantly from unity (G= 0.35, P=0.55).

The diameters measured at breast height varied between 13 and 102 cm with a mean value of 50.45 cm (±1.94 cm), while tree height varied between 4 and 17 m with a mean value of 10.68 m (±0.25 m). The trees DBH and height classes' followed a normal centered distribution (Fig. 2) with the DBH showing two close peaks at 30 and 50 cm and the height showed a single peak at 11 m.

The tree DBH varied significantly with altitude (F = 32.14, P=1.29x10-7), exposition (F=7.483, P= 1.47 x10-4), slope (F = 17.97, P= 4.87x10-5) and canopy density (F= 12.5, P= 5.02x10-7) (Fig. 3).

The mean tree diameter was significantly higher at high altitude (58.66 ± 2.45 cm) then at low and medium altitude (35.09 ± 3.17 cm and 49.31 ± 3.61 cm respectively). Moreover, the mean trees DBH at the northern exposure (39.31 ± 3.63 cm) was significantly lower than trees DBH distributed across the rest of the expositions. In addition, the trees located in areas with strong slopes (>75%), had significantly lower mean DBH (37.33 ± 3.09 cm) (Fig. 3). We found 35% of the studied trees in a very dense forest structure (canopy

Tab. 2 - The distribution of *Juniperus drupacea* adult trees in each studied zone according to different environmental factors.

	Altitude (m)					Exposition									Slope (%)				Canopy density (%)				
Zone	**<1200**	**1200-1300**	**1300-1400**	**1400-1500**	**>1500**	**Plateau**	**E**	**N**	**NE**	**NW**	**S**	**SE**	**SW**	**W**	**0-25**	**25-50**	**50-75**	**> 75**	**<10**	**ott-40**	**40-70**	**>70**	**Total adult trees**
Z1	0	15	0	0	0	0	0	14	1	0	0	0	0	0	0	0	0	15	0	0	0	15	**15**
Z2	1	11	0	0	0	0	8	0	0	0	0	4	0	0	0	1		11	0	1	0	11	**12**
Z3	0	0	9	0	0	0	0	9	0	0	0	0	0	0	3	4	2	0	0	0	0	9	**9**
Z4	0	0	2	9	0	0	0	0	2	0	3	1	1	4	0	5	3	3	1	5	4	1	**11**
Z5	0	0	0	6	53	5	7	3	5	2	6	11	8	12	27	19	12	1	4	35	19	1	**59**
Total	**1**	**26**	**11**	**15**	**53**	**5**	**15**	**26**	**8**	**2**	**9**	**16**	**9**	**16**	**30**	**29**	**17**	**30**	**5**	**41**	**23**	**37**	**106**

density > 70%) but with slender trunks and poor vital status especially in Z1 (Table 2). The Tukey test showed a significantly lower DBH mean at canopy density > 70% (36.50 ± 2.64 cm) (Fig. 3).

On the other hand, the tree height varied significantly only with the altitude (F=4.22, P=0.0173). The results showed mean tree heights at low altitude (9.48 ± 0.49 cm) significantly lower comparing with the medium and high altitudes (Fig. 4).

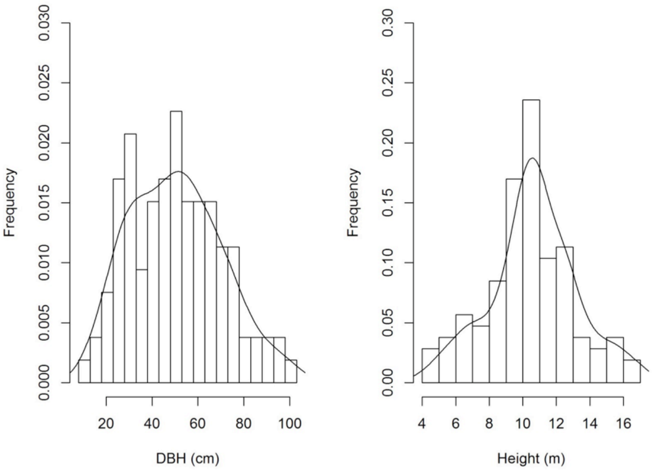

Fig. 2 - Size structure of *Juniperus drupacea* population in Jabal Moussa Biosphere Reserve showing the distribution of the diameter size classes' distribution (left) and the height classes' distribution (right) of 106 adult trees.

The spatial distribution of seedlings, and adult trees (male and female) were analyzed through Ripley test only in Z5, being the larger zone, where all trees were practically inventoried. The results showed a high level of aggregation of male and female trees (Fig. 5). Seedlings also showed high level of aggregation with the adult trees. In fact, seedling establishment were only found near the adult trees in 34 establishment points distributed in in the five zones. The regeneration level varied between 0.05 and 12 seedlings/m^2 across the 5 zones with a mean global value of 3.11 ± 0.50 seedlings/m^2 (Tab. 3). The regeneration level did not vary significantly with the environmental factors or across the studied zones. Moreover, the tree DBH did not significantly affect the regeneration observed under it.

Discussion

The results showed that *Juniperus drupacea* optimal altitude is between 1500 and 1600 m a.s.l. where we found the majority of the trees as well as the biggest ones. This species seems to require a certain level of humidity in order to thrive, as most trees tend to be on low western slopes and in the sinkholes. Moreover this species do not tolerate strong competition, it is a heliophilous tree with a better growth observed in relatively open forest.

These *optimum* conditions were all found in the central area (Z5) where the topography of sinkholes, the low slope, the variation of exposition and canopy density tend to positively affect the trees growth. In

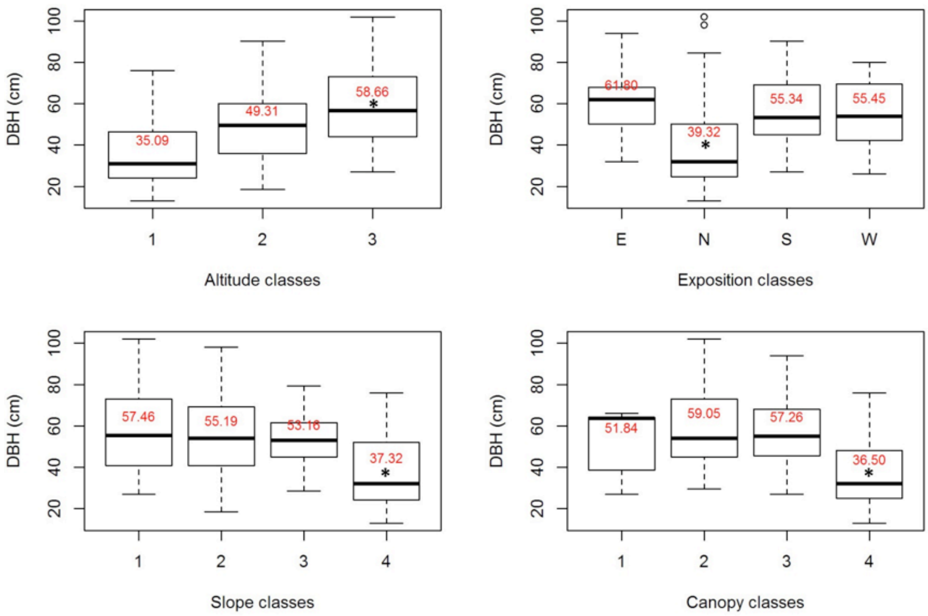

Fig. 3 - Tree diametres (DBH) boxplots according to the altitudinal range, slope, exposition and canopy density of *Juniperus drupacea* population in Jabal Moussa Biosphere Reserve. Means with (*) are significantly different according to Tukey test for a threshold of 5%.

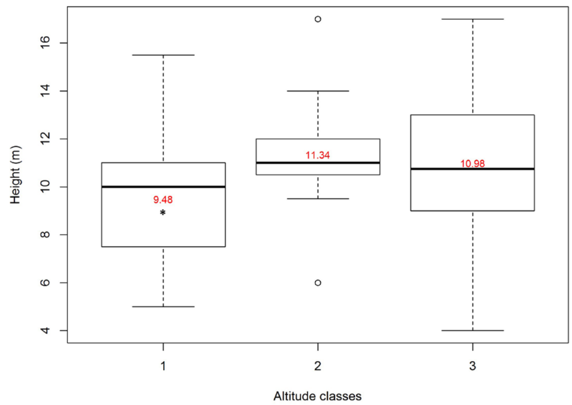

Fig. 4 - Tree height boxplots according to the altitudinal range. Means with (*) are significantly different according to Tukey test for a threshold of 5%.

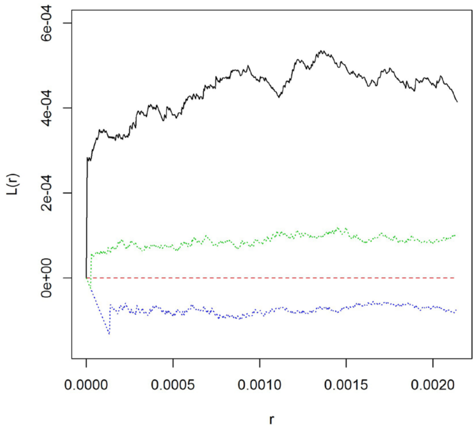

Fig. 5 - Spatial structure of *J. drupacea* in Zone 5. The observed L(r) values (straight line) show a high level of aggregation of the adults. The pointed lines correspond to 95% confidence interval of L(r) under a random distribution assumption.

this zone the trees are sheltered from wind and benefit from cooler temperatures and lower evapotranspiration, higher snow coverage and persistence allowing a slow snowmelt in the dolines. These conditions ensure the necessary moisture for trees growth during the dry summer season and without competition from other species.

In the dense forest of the Mar Jerjes zone (Z1) the frequent past trimming allowed the regeneration and growth of the trees found today. However, between 1993 and 2004, the ministry of agriculture suspended cutting and wood exploitation licenses of hardwood species (e.g. *Ostrya carpinifolia* Scop., *Styrax officinalis* L.), followed by the process of protecting Jabal Moussa before its designation as a biosphere reserve in 2009. The resulting dense canopy has hindered the growth of the newly established population of *J. drupacea*, a sun-loving species. The effect of canopy density on diameter is directed by competition for light and forest dynamics. For instance in Z2, the Syrian juniper dominates *Quercus calliprinos* coppice in height, and is codominant in height with deciduous oaks in Z3; oaks are generally late serial species and are established after conifer species, which allowed *J. drupacea* to develop before any competition.

The average trunk diameters at the northern exposure were found significantly lower than at the rest of the expositions. So we can initially assume that individuals of *J. drupacea* show weak growth in the Northern aspect. In Z1, the Northern exposure provides a minimum of sunlight and insures freshness and a stable water balance due to the presence of the Nahr Ibrahim River. As for Z2, the proximity of the Nahr El Dahab valley provides a short duration of sunshine and high humidity which can compensate the loss of freshness caused by the low altitude.

The four dead trees found in Z4, were found in sou-

Tab. 3 - The trees sex distribution (Male, Female or undetermined) and the number of regeneration points and regeneration density in each studied zone.

		Sex			Regeneration	
Zone	**Total adult trees**	**F**	**M**	**U**	**Seedlings/m^2**	**number of regeneration points**
Z1	**15**	4	11	0	1 to 3	4
Z2	**12**	5	7	0	1 to 3	2
Z3	**9**	3	6	0	0.5 to 10	5
Z4	**11**	5	2	4	0.05 to 3	2
Z5	**59**	31	28	0	1 to 12	21
Total	**106**	**48**	**54**	**4**	**3.11 ± 0.50**	**34**

thern exposure with an average slope of 50 % , within a moderately dense canopy and an average altitude of 1440 m. Here, not one factor can offset the negative effect exerted by the southern aspect, but rather contributes to amplify it. Trees are exposed to the sun and water-stressed. The steep slope hinders infiltration, and the canopy density is not high enough to provide more shade and a humid organic litter. Would these dead trees with remarkable diameters be witnessing the beginnings of climate change effect? The decline of some species on the southern slopes has been widely observed by foresters and researchers (Touchan *et al*., 2005). And since the Lebanese Syrian Juniper populations are living at the low latitude edge of its global natural distribution, the evaluation of the current vitality of *Juniperus drupacea*e populations in Lebanon and their conservation are of high priority (Hampe & Petit 2005; Aitken, 2008).

J. drupacea has a great tendency to cluster in bunches as showed the Ripley test results. This clustering can be explained by the short seed dissemination distances for this species as all the dissemination points were observed near the mother trees. In fact the seed cones are the biggest in the *Juniperus* genus; they fall near the mother tree and are then decorticated by small rodents that are attracted by the rich in sugar fleshy seed cones. More studies are needed to be done on the potential seed disseminators to elucidate the pattern of seed dissemination for this species.

The low regeneration level of *J. drupacea* in Jabal Moussa was not surprising. In fact, several studies showed the same results for other Juniper species. The limited natural regeneration in junipers can be caused by high rates of empty seeds due to pollen limitation and environmental stress (Knight *et al*., 2005; Wesche, *et al*. 2005; Douaihy *et al*., 2013a); complex seed dormancy (Cregg *et al*., 1994), seed predation (García, 2000; El Alaoui El Fels & Roques, 2006; Douaihy *et al*., 2013b) and juvenile death due to summer drought and grazing (Fisher & Gardner, 1995; Garcia *et al*., 1999). The successful pollination depends on the population sex structure determined by the reproductive effort of both sexes (Ortiz *et al*., 2002). Our results showed that the population did not deviate from the unity of sex ratio and there were no significant difference in size between male and female trees.

Conclusion

In short term, to manage and conserve this unique species within the Biosphere Reserve of Jabal Moussa: (1) a selective cutting should be performed to have a canopy density around 50% in order to preserve the remarkable vitality of trees; (2) plant new seedlings in the Z5 area which is the optimal area in the reserve for this species.

Further studies should investigate the reproduction effort for each sex and include bigger number of trees to study the spatial distribution of both male and female according to environmental factors. Moreover an investigation of the seed viability and the quality of pollination could elucidate the reproductive capacity of the *J. drupacea* populations in Lebanon. We also need to identify the best germination protocol for this species and make it available for the local nurseries because; because *ex situ* propagation is a vital solution for the long term conservation of this rare species.

On the other hand, *J. drupacea* is currently facing massive diebacks in other populations in Lebanon due to the parasitic aerial plant, *Arceuthobium oxycedri*. There is an urgent need to determine the current and potential infection rate of this parasitic plant in several populations in Lebanon. The Ehmej population was recently chosen by the Ministry of Agriculture in collaboration with Ehmej Municipality and Lebanon Mountain Trail NGO as a pilot site to proceed with an intervention to limit the propagation of the mistletoe by pruning or cutting infected trees.

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