Journal of Biological Research-Thessaloniki **16**: 296 – 303, 2011
J. Biol. Res.-Thessalon. is available online at http://www.jbr.gr
Indexed in: WoS (Web of Science, ISI Thomson), SCOPUS, CAS (Chemical Abstracts Service) and DOAJ (Directory of Open Access Journals)

Is facilitation the dominant process in the regeneration of the *Juniperus excelsa* M. Bieb. stands in Cyprus?

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Received: 16 December 2010 Accepted after revision: 13 May 2011

The present study was conducted in four locations in Cyprus. These areas are included in a broad study area of approximately 6200 ha. The majority of this area belongs to the Natura 2000 Network and a small part of this area is a designated Nature Reserve. In order to determine whether facilitation is the dominant process in the regeneration of the *Juniperus excelsa* M. Bieb. stands in Cyprus, 120 plots of 100 m^2 (10 m × 10 m) were established in eight site types. In each plot the regeneration plants were graded in categories, according to their location in relation to *J. excelsa* trees. In four of the eight site types, that were distinguished, the density of the *J. excelsa* seedlings in open areas was higher than the density of the regeneration plants that have been established under the facilitation of adult trees of the species. In the remaining site types, a statistically significant difference was not recorded. In Cyprus facilitation is not the dominant process in the regeneration of *J. excelsa*. On the contrary, it seems that in many cases competition is the dominant force that determines the regeneration process of the species. The *J. excelsa* formations exhibit adequate recruitment, but in the future, the presence of *J. excelsa* in Cyprus will gradually be reduced in better sites, since it will be replaced by more competitive species having greater site sensitivity.

Key words: negative interactions; positive interactions; Natura 2000 Network; recruitment.

INTRODUCTION

Juniperus excelsa M. Bieb. is a site-insensitive species which can endure shade for many decades, even though it has the ability to germinate and grow under full light (Milios *et al.*, 2007, 2009). According to Milios *et al*. (2009), *J. excelsa* growth plasticity may contribute efficiently to its maintenance in severe and intensely disturbed environments.

Juniperus excelsa is a species of central and southwest Asia, although it is also found in the central and southern Balkans, Anatolia, Crimea and east Africa (Athanasiadis, 1986; Boratynski *et al.*, 1992; Christensen, 1997). It is reported that nurse plant facilitation plays an important role in the regeneration of *J. excelsa* in many regions of the species expansion such as the valley of Hayl Juwari of Oman, Balouchistan of Pakistan and the central part of the Nestos valley in Greece (Ahmed *et al*., 1989, 1990; Fisher & Gardner, 1995; Milios *et al*., 2007). According to Hall (1984), in Africa in areas with a precipitation of between 1000 and 1250 mm, *J. excelsa* behaves as a light-demanding species, thus needing a major disturbance (for example a forest fire) in order to be established in full light.

Negative (competition) and positive (facilitation) interactions among plants influence and regulate distribution and abundance of plant species, as well as the dynamics of plant communities (Armas & Pugnaire, 2005; Gómez-Aparicio *et al*., 2005; Bartelheimer *et al*., 2006; Gómez-Aparicio, 2009; Maestre *et*

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al., 2009). According to some theoretical models, the significance of facilitation in plant communities rises with abiotic stress while there is a decrease in the relative significance of competition (Bertness & Callaway, 1994; Callaway & Walker, 1997; Brooker & Callaghan, 1998). These models have been questioned in arid and semi-arid ecosystems (Maestre *et al*., 2005, 2006). According to another approach, competition will be predominant at the extremes of the abiotic gradient and facilitation will prevail at medium environmental stress (Maestre & Cortina, 2004; Cheng *et al*., 2006; Maestre *et al*., 2009).

Facilitation among plants may be related to the a) protection from sunlight through shading (Smit *et al*., 2008), b) rise of soil moisture (Zou *et al*., 2005), c) improvement of soil fertility (Callaway *et al*., 1991), d) reduction of temperatures in soil surface (Franco & Nobel, 1989; Petrou & Milios, 2011) and e) protection of tissues from frost damage (Gómez-Aparicio *et al*., 2008). Moreover, facilitation may be related to the protection from grazing (Garsia & Obeso, 2003). In some cases, facilitation is related to a combination of two of the above procedures (Milios *et al*., 2007; Gómez-Aparicio *et al*., 2008).

In Cyprus, *J. excelsa* appears as scattered individual trees or as very small stands or groups of trees in an area that belongs to the Natura 2000 Network (Papachristophorou *et al.*, 2000). The understanding of the species regeneration behaviour will contribute to the conservation of the *J. excelsa* groups and stands in the island, while increasing the understanding of the species ecology in diverse regions of the planet.

In the present study, the main objectives were: a) to analyse the regeneration patterns of the *J. excelsa* stands and b) to determine whether facilitation is the dominant process in the regeneration of *J. excelsa* in Cyprus.

MATERIALS AND METHODS

Study sites

*Juniperus excels*a formations and individual trees are found scattered in four locations in Cyprus. These are Papoutsa, Madari, Lagoudera, and Saranti-Kannavia (information from Cyprus Department of Forests). According to an inventory of Cyprus Department of Forests, in Madari there are 5138 *J. excelsa* plants, in Lagoudera 430 and in Saranti-Kannavia 1301 plants of the species, while there are no data for Papoutsa (Cyprus Department of Forests, 2011). In Papoutsa, *J. excelsa* appears at elevations from 1080 to 1520 m in an area of 861 ha (Cyprus Department of Forests, 2011). The corresponding values for the other locations are: Madari – 1190 to 1600 m and 512 ha, Lagoudera – 1052 to 1368 m and 90 ha, Saranti-Kannavia – 1121 to 1324 and 41 ha (Cyprus Department of Forests, 2011). These areas are included in a broad study area of approximately 6200 ha. The majority of this area belongs to the Natura 2000 Network and a small part of this area is a designated Nature Reserve (Papachristophorou *et al*., 2000; see also Cyprus Department of Forests, 2011). The studied area is very important for the conservation of biodiversity of the island since many endemic species and subspecies of Cyprus have been found there (Papachristophorou *et al*., 2000; Tsintides *et al*., 2007). Also, *J. excelsa* was evaluated as a "Near Threatened" plant for Cyprus, according to the IUCN criteria (Tsintides *et al*., 2007). The terrain in this area is dominated by steep slopes. The geological substratum is variable and it is constituted of plutonic and volcanic rocks, as well as diabase rocks with characteristic dikes (Geological Survey Department of Cyprus, 1995; Papachristophorou *et al*., 2000). The soils are shallow and rocky. In many cases, surface appearances of parent material are observed. The soil texture is sandy loam, loam and sandy clay loam. In order to determine the soil particle size distribution, soil profiles were carried out and soil samples were taken in the study area. Moreover, data from the Cyprus Department of Forests were used. The determination of soil particle size distribution, using the Pipette Method (Alifragis & Papamihos, 1995), was carried out at the Laboratory of Silviculture at the Faculty of Forestry and Natural Environment at Aristotle University of Thessaloniki. The annual sum of precipitation averages 666.9 mm and the mean annual air temperature is 15.8°C (data from the Meteorological Service of Cyprus).

Small, pure and mainly mixed groups and stands of *J. excelsa* and species such as *Quercus alnifolia*, *Pistacia terebinthus*, *Acer obtusifolium*, *Pinus brutia*, *J. oxycedrus* etc. exist in the study area. Moreover, *Rosa chionistrae*, *R. canina*, *Berberis cretica*, *Cistus creticus* and other species are also found in the same area.

In Papoutsa, three site types, where the groups and small *J. excelsa* stands appear, were distinguished: a) north to east facing slopes = PNE, b) south facing slopes = PSO and c) narrow ridges = PNR. In Madari, three site types were also distinguished: a) northeast to east facing slopes = MNEE, b) northwest to west facing slopes = MNWW and c) south to southwest facing slopes = MSSW. In Lagoudera, as well as Saranti-Kannavia, groups and small *J. excelsa* stands appear only in one site type (Lagoudera: west to north facing slopes = LWN, Saranti-Kannavia: west to north facing slopes = SWN).

Many scattered, small, pure and mainly mixed *J. excelsa* stands and groups surrounded by areas with bare ground or other species are found in each site type. In the site type PNR mineral soil is almost absent (lithosol). In the past, the grazing in the study area was excessive until the 1940's, when all domestic livestock were excluded from state forests (Thirgood, 1987).

Regeneration

During the summer of 2006, 15 sample plots of 100 m^2 (10 m × 10 m) were established in each site type using the simple random sampling method in areas where the groups and small *J. excelsa* stands appear. In total, 120 sample plots were established covering all site types. In some areas where the plots were established, *J. excelsa* was the only appearing woody species while in the majority of cases it was the dominant or one of the dominant woody species (in a few plots) regarding the height and diameter of trees.

In each plot, all *J. excelsa* trees with a diameter above 0.5 mm at ground level and height up to 1.3 m were considered to be regeneration plants (seedlings) and were graded in 3 categories according to their location in relation to *J. excelsa* trees (plants with a height of over 1.3 m): S plants = "seedlings under closed canopy (under a single tree or a group of *J. excelsa* trees)" and P plants = "seedlings under (or near) the edge of the canopy of a single tree or a group of *J. excelsa* trees" (see also Milios *et al*., 2007). These two categories belong to the F plants (seedlings that have been established under the facilitation of other plants of the same species). The last category is G plants; seedlings growing in open areas (a canopy gap without significant side shade).

Moreover, in each sample plot, all plants of all species with a height of over 1.3 m were counted, their species was recorded and the percentage of the area that was covered by trees-shrubs and phrygana was estimated. In all site types, observations of the existence of plant litter (and its amount) under and around *J. excelsa* trees as well as of the substrate in which the regeneration plants of all location categories grow (rocky soil, existence of plant litter, etc.) were made.

Statistical analysis

The comparisons between the distributions of F and G seedlings and between the S and P seedlings in each site type were performed by means of the Wilcoxon test (Mehta & Patel, 1996). In each case the observed significance level (*p*-value) of the test was calculated by the exact method (Mehta & Patel, 1996). All statistical analyses were carried out using SPSS (SPSS, Inc., USA).

RESULTS

The average cover percentage of trees-shrubs and phrygana of the plots in all site types of Madari is at least 50% (MNEE total = 54.0%, trees-shrubs = 41.0% and phrygana = 13.0%, MNWW total = 50.0%, trees-shrubs = 48.3% and phrygana = 1.7%, MSSW total = 65.7%, trees-shrubs = 20.4% and phrygana = 45.3%). On the other hand, all the other site types except for the PNE have an average cover percentage below 50% (Papoutsa: PNE total = 54.7%, trees-shrubs = 48.3% and phrygana = 6.4%, PSO total = 36.7%, trees-shrubs = 25.3% and phrygana = 11.4%, PNR total = 16.0%, trees-shrubs = 10.0% and phrygana = 6.0%, Lagoudera: LWN total = 43.7%, trees-shrubs = 30.7% and phrygana = 13.0%, Saranti-Kannavia: SWN total = 19.7%, trees-shrubs = 12.7% and phrygana = 7.0%).

Three seedlings found under the edge of the canopy of other tree species, in the MNWW site type, were graded in the P category, while a seedling that was found under the canopy of an individual of an other species in the MNEE site type was graded in the S category.

In all site types of Madari as well as in the site type PNE, there is no statistically significant difference in density between the F and G seedlings ($p > 0.05$) (Table 1). In the other site types in Papoutsa, Lagoudera, and Saranti-Kannavia, the density of G plants is greater than that of F seedlings ($p < 0.05$). In all site types of all areas, there is not a statistically significant difference between the density of S and P plants ($p > 0.05$) (Table 1).

Apart from *J. excelsa* and *Q. alnifolia*, which are the most abundant species in the *J. excelsa* small stands and groups of all site types (Table 2), the following species were also found (reported proportionally with their abundance in the sample plots): in PNE: *A. obtusifolium*, *P. terebinthus* and *P. brutia*, in PSO and PNR: *P. terebinthus* and *A. obtusifolium*, in MNEE: *A. obtusifolium*, *P. terebinthus* and *Styrax officinalis*, in MNWW: *Sorbus aria*, *P. brutia* and *A. ob-*

TABLE 1. Regeneration characteristics in the *J. excelsa* groups and small stands in Cyprus

Site type	Categories of regeneration plants N ha^{-1}				F vs G plants Wilcoxon test with exact test outputs		S vs P plants Wilcoxon test with exact test outputs	
	S plants	P plants	F plants	G plants				
				Papoutsa				
PNE	7	20	27	33	z = –0.333,	p = 1.000	z = –1.000,	p = 0.625
PSO	0	7	7	73	z = –2.226,	p = 0.039	z = –1.000,	p = 1.000
PNR	0	0	0	73	z = –2.887,	p = 0.004	z = 0.000,	p = 1.000
				Madari				
MNEE	7	26	33	27	z = –0.378,	p = 1.000	z = –1.342,	p = 0.375
MNWW	7	86	93	73	z = –0.045,	p = 0.992	z = –1.826,	p = 0.125
MSSW	20	20	40	93	z = –1.999,	p = 0.072	z = –0.378,	p = 1.000
				Lagoudera				
LWN	20	40	60	187	z = –2.219,	p = 0.026	z = –0.647,	p = 0.656
				Saranti-Kannavia				
SWN	0	27	27	127	z = –2.830,	p = 0.004	z = –1.633,	p = 0.250

S plants = seedlings under closed canopy
P plants = seedlings under (or near) the edge of the canopy
F plants = S + P plants = seedlings that have been established under the facilitation of other plants of the same species
G plants = seedlings growing in open areas
Papoutsa: PNE = north to east facing slopes, PSO = south facing slopes, PNR = narrow ridges
Madari: MNEE = northeast to east facing slopes, MNWW = northwest to west facing slopes, MSSW = south to southwest facing slopes
Lagoudera: LWN = west to north facing slopes
Saranti-Kannavia: SWN = west to north facing slopes

TABLE 2. Density of *J. excelsa, Quercus alnifolia* and other species plants with a height of over 1.3 m in *J. excelsa* formations in Cyprus

Site types	Density, N ha^{-1}		
	J. excelsa	*Q. alnifolia*	Other species
		Papoutsa	
PNE	293	633	160
PSO	253	420	140
PNR	200	200	73
		Madari	
MNEE	213	607	40
MNWW	247	93	27
MSSW	320	20	13
		Lagoudera	
LWN	287	100	87
		Saranti-Kannavia	
SWN	220	100	93

Papoutsa: PNE = north to east facing slopes, PSO = south facing slopes, PNR = narrow ridges
Madari: MNEE = northeast to east facing slopes, MNWW = northwest to west facing slopes, MSSW = south to southwest facing slopes
Lagoudera: LWN = west to north facing slopes
Saranti-Kannavia: SWN = west to north facing slopes

tusifolium, in MSSW: *P. terebinthus*, in LWN: *P. terebinthus*, *A. obtusifolium*, *Olea europaea*, *J. oxicedrus* and *Crataegus azarolus* and in SWN: *P. terebinthus*, *A. obtusifolium*, and *P. brutia*.

DISCUSSION

The *J. excelsa* small stands and groups in Cyprus exhibit a higher density of *J. excelsa* plants (trees and seedlings) than the stands of the species in Balouchistan and the *J. excelsa* formations in the valley of Hayl Juwary in Oman (Ahmed *et al*., 1989, 1990; Fisher & Gardner, 1995). On the other hand, the *J. excelsa* small stands in the central part of the Nestos valley in Greece have a higher density of *J. excelsa* trees and regeneration plants compared to those of Cyprus (Milios *et al*., 2007). However, in Cyprus, the small stands and groups of *J. excelsa* usually occupy very small areas, in many cases, lower than 0.05 ha per formation. Especially, in site type LWN in Lagoudera, even though the small stands and groups of the species are rather dense (Tables 1 and 2), each group appears in a small area and the total area that small stands and groups of the *J. excelsa* occupy is very restricted (possibly lower than 1 ha). This is the reason why the Cyprus Department of Forests (2011) reports a small total number of *J. excelsa* trees (430) in Lagoudera.

In contrast to Balouchistan, the valley of Hayl Juwary in Oman and the central part of the Nestos valley in Greece (Ahmed *et al*., 1989, 1990; Fisher & Gardner, 1995; Milios *et al*., 2007), facilitation in Cyprus is not the dominant process in the regeneration of *J. excelsa*. On the contrary, it seems that in many cases competition is the dominant force that determines the regeneration process of the species. In four of the eight site types that were distinguished, the density of the seedlings in open areas was higher than the density of the regeneration plants that have been established under the facilitation of adult trees of the species (Table 1). The majority of G plants grows in rocky substrates. Ozkan *et al*. (2010) report that in the forests of southwest Anatolia (Turkey), *J. excelsa*, in many cases appears at sites where the surface stoniness is very high. These results are compatible with the ecology of the species which can both germinate and grow under full light, as well as under shade (Milios *et al.*, 2007, 2009).

The underlying mechanism of facilitation of *J. excelsa* regeneration by nurse plants in the valley of Hayl Juwary in Oman is probably the amelioration of harsh, abiotic conditions by partial shade (Fisher & Gardner, 1995; see also Weltzin & McPherson, 1999; Smit *et al*., 2008). According to Fisher & Gardner (1995), topography, hydrology and microclimate are important for *J. excelsa* growth.

In Balouchistan, *J. excelsa* seedlings occur frequently under a canopy cover of dense shrubs (Ahmed *et al.*, 1989), in the vicinity of groups of parent trees as well as near dense shrubby patches (Ahmed *et al.*, 1990). Ahmed *et al.* (1989) report that *J. excelsa* seedlings could be damaged or killed by trampling as a result of grazing. Moreover, they refer that the most likely reason for the absence of regeneration in some stands for a period of time, was cutting and overgrazing. According to Ahmed *et al.* (1990) in Balouchistan the *J. excelsa* seedlings will not be established in overgrazed and open areas, since they demand shade and undisturbed soil conditions (see also Ahmed *et al.*, 1989). However, the establishment of seedlings under shade or near parent trees and shrubby patches is possibly related to protection from intense grazing in the area. According to Gómez (2005), the habitat distribution and niche structure of plants are affected by herbivory. Also, in the central part of the Nestos valley in Greece, grazing is by far the most stressful biotic factor, which determines "the species regeneration patterns through the nurse plants' facilitation process" (Milios *et al*., 2007). In this case, plant litter under the nurse plants (individuals and groups) seems to be another factor that, while affecting soil fertility, constitutes a facilitation mechanism of *J. excelsa* regeneration plants (Milios *et al.*, 2007). According to Moro *et al*. (1997), in semi-arid environments of southeast Spain biomass production under the canopy of *Retama sphaerocarpa* was affected by litter decomposition.

The above-mentioned stressful factors that led to the dominance of facilitation in the regeneration process of *J. excelsa* do not exist in our study area in Cyprus. The climate in the areas where the species appear in Cyprus is not extreme for *J. excelsa* as in the case of Oman (see Fisher & Gardner, 1995). As a result, the microclimate amelioration is not a crucial factor for the establishment of seedlings. According to Gómez-Aparicio (2009), "the further a site is from the fundamental niche optimum, the more likely facilitation will be". Moreover, grazing and trampling by herbivores are absent from the area and there is no need for seedling protection.

On the other hand, in almost all site types there is plant litter under and around adult *J. excelsa* trees.

However, the amount of plant litter is by far lower than in the case of the central part of the Nestos valley (personal observation). This is expected since in Cyprus, *J. excelsa* does not create groups (aggregations) of trees as dense as in the central part of the Nestos valley (personal observation). Thus, improved soil conditions (soil rich in humus and nutrients), as a result of the organic matter produced by the canopy, are not sufficiently created under and around the *J. excelsa* trees.

This plant litter is more abundant under the crown of nurse plants than under the edge of their canopy. It seems that this is not a factor that strongly determines the establishment of seedlings under facilitation in Cyprus, since in all site types, there is not a statistically significant difference between the density of S and P plants (Table 1). Moreover, in the four site types where there is not a statistically significant difference in density between the F and G seedlings, the average cover percentage of trees-shrubs and phrygana is at least 50%, while in the remaining site types it is lower than 44%. It is possible that, in these site types, one of the reasons that the G plants (seedlings growing in open areas) are not dominant is the lower portion of open areas that is available for their establishment.

An interesting point is that in the most extreme abiotic conditions where the soil is almost absent, in site type PNR, not even one seedling was found under facilitation (Table 1). This seems to agree with the theory that competition predominates at the extremes of the abiotic gradient (Maestre & Cortina, 2004; Cheng *et al*., 2006; Maestre *et al*., 2009). In the site type PNR, apart from the absence of soil, there is almost no plant litter under and around nurse plants. This could be the result of strong winds that characterize the narrow ridges in Papoutsa. According to Maestre & Cortina (2004), competition under high abiotic stress is likely to dominate "when the levels of the most limiting resource are so low that the benefits provided by the facilitator can not overcome its own resource uptake". Moreover, Maestre *et al*. (2009) reported that "the effect of neighbors can be negative at both ends of the stress gradient when both interacting species have similar competitive or stress tolerant life histories and the abiotic stress gradient is driven by a resource (e.g. water)".

The *J. excelsa* formations in Cyprus exhibit adequate recruitment, since the percentage of seedlings (height up to 1.3 m) in relation to the total number of *J. excelsa* plants (seedlings + trees with a height of over 1.3 m) ranges from 17.0% in the PNE site type to 46.3% in LWN site type.

The present density and species composition of *J. excelsa* formations is probably the result of past anthropogenic disturbances. These disturbances, especially grazing, were severe (see Thirgood, 1987). According to Milios *et al*. (2007), in the central part of Nestos valley, "grazing and illegal cuttings gave *J. excelsa* the ability to dominate even in better sites as a result of low competition". In the future, the presence of *J. excelsa* in Cyprus will gradually be reduced in better sites and only scattered individuals or very small *J. excelsa* groups will be found, since it will be replaced by more competitive species having greater site sensitivity (see also Milios *et al*., 2007). The *J. excelsa* trees will dominate mostly in stony places or where the soil is almost absent. In order to preserve *J. excelsa* formations in better sites in Cyprus, the individuals of other species that compete with *J. excelsa* regeneration plants or trees have to be suppressed through frequently repeated cuttings. Additionally, to increase the participation of *J. excelsa* trees in better sites, the Cyprus Department of Forests must raise planting stock in nurseries from seeds collected from the study area. These seedlings must be planted either in open areas, beneath the shade of or near individuals of other species. Afterwards, these plants will be released from competition through the gradual cutting of their competitors (see also Milios *et al.*, 2006).

ACKNOWLEDGEMENTS

We would like to thank Professor Paulos Smiris, director of the Laboratory of Silviculture in the Faculty of Forestry and Natural Environment at Aristotle University of Thessaloniki, who permitted the usage of the laboratory for the determination of soil particle size distribution. Moreover, we want to thank the Forest Department of Cyprus for their cooperation.

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