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Original Article

Spatial Patterns and Facilitating Role of Holm Oak (*Quercus ilex*) in the Regrowth of Atlas Cedar (*Cedrus atlantica* (Endl.) Carrière) in Chelia, Aurès, Algeria

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ABSTRACT

The process of natural forest rejuvenation, which refers to the self-renewal of forest ecosystems, encompasses the substitution of mature trees with the succeeding generation and is subject to the influence of environmental factors. The characteristics of the stands themselves both impact and determine the spatial organization of tree regeneration. The natural regeneration of the Atlas cedar follows a complex set of eco-physiological processes involving several environmental factors during the different phases of its establishment and development. Thus, it is noteworthy that the cedar always remains closely associated with the holm oak, forming well-stable mixed associations. Therefore, this study investigates the cedar stand of Chelia, affected by dieback where regeneration seems inconstant. Accordingly, the study describes the stand's spatial structure to understand spatial patterns' mechanisms the areas of forest that contain a variety of different tree speciem in the north-east of Algeria .Using data from four rectangular plots (60 m × 40 m) temporarily established in the mountain of Chelia, all the seedlings were charted, measured, and located through their (xi, yi) coordinates In addition, two vertical measurements of holm oak crown diameter were recorded for each tree, along with other structural variables. Then, the pair correlation functions were used to investigate uni- and bivariate spatial point patterns to assess the spatial relationship between the cedar seedlings and the holm oak undergrowth. We found that the univariate pair correlation function showed a spatial aggregation of seedlings, concerning the holm oak pattern, which was regular only at small scales but was predominantly random. The bivariate pair correlation function revealed that regeneration was found to be clumped and the spatial association between holm oak and Atlas cedar seedlings.

Keywords: Aggregation, Atlas cedar, Chelia, holm oak, natural regeneration, spatial distribution

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Introduction

The Atlas cedar is a North African mountain endemic (Algeria and Morocco). In Algeria, the northern cedar forests of the Tellian Atlas, as well as those in the southern Aures and Belezma, are still subject to significant natural and anthropogenic stresses, including recurring droughts, fires, illicit tree cutting, and overgrazing, all of which have caused a regression of the Atlas cedar's natural range (Yahi, 2007). The first studies on the natural regeneration of the cedar forest of North Africa made it possible to underline the difficulties of maintaining seedlings, in particular during the first years of development, and to highlight some determining factors. Thus, the early germination of young seedlings appears to be an asset increasing its chances of resistance to summer drought and therefore its survival. This parameter would be modulated by altitude, slope effect, water balance, undergrowth, herbaceous vegetation, litter, and soil (Marion, 1955; Lepoutre, 1961; Lepoutre & Pujos, 1964; Zine El Abidine et al., 2013). However, it is accepted that it is the interaction between the different factors that controls the level of regeneration of a species. Those who act first would be decisive, hence the interest of studying the processes that take place during the first phases of regeneration (Tan & Bruckert, 1992). In addition, an increasing stream of studies has confirmed that most species are not randomly distributed. Indeed, either they are clustered, random, or regular (Condit et al., 2000; Watt, 1949; Wiegand et al., 2007). This observation has led many researchers to investigate the relevance of spatial patterns regarding species coexistence and biodiversity conservation (Hurtt, 1995; Murrell et al., 2001; Szmyt & Tarasiuk, 2018).

Research on species associations plays an important role in understanding the interactions and ecological relationships between species and also provides information on the dynamics of constituent species. The spatial association between species was the result of species interaction and species adaptation to the environment.

Spatial patterns and tree species associations would change with the different growth stages of tree species. Several studies have shown that most species tend to be aggregated at the seedling stage, whereas they tend to be regular or random at the adult stage (Gu et al., 2019; Ledo, 2015).

The spatial structure mainly defines the local environment surrounding each tree (in terms of the number of its neighbors), thus its growth conditions. This local environment modifies the manifestation of natural processes such as growth and mortality (Goreaud, 2000) and influences the seed development, thereby affecting the stand regeneration. Inversely, these natural processes modify the spatial structure of the stand in a feedback cycle (Goreaud, 1999).

In most mixed forest systems, regeneration is a crucial step for tree survival and species coexistence. The latter is governed by the species' small-scale spatial structure and competitive abilities (Collet et al., 2017; Shen et al., 2009; Wang et al., 2010). The regeneration of Atlas cedar in Chelia, Aurès, Algeria, is a complex process that depends on various biotic and abiotic factors. Understanding the spatial structure of cedar populations and the potential facilitating effect of other plant species such as holm oak can provide insights into the ecological dynamics of cedar forests and inform management strategies for their conservation and restoration (Derridj, 1990). However, the regeneration of natural stands is problematic, particularly because of the gradual disappearance of seedlings during the first dry summer period (Derridj, 1985). The environment where the seedlings grow, the undergrowth protects the seedlings against the herds' access owing to its density. Overall, the average cover is favorable to the establishment of regeneration and the maintenance of young plants compared to the shallow and high cover (M'hirit & Benzyane, 2006).

The aim of this study is to assess the regeneration and spatial patterns of an endemic North African conifer (*Cedrus atlantica*) in Algeria in relation with (*Quercus ilex*), an important species associated with Atlas cedar. Moreover, African forests were the subject of very few researches on spatial point pattern analysis (SPPA). Currently, this analysis type becomes an important tool worldwide aiming to describe, interpret, and forecast spatial structure and interaction among/between points.

Thus, we believe that the spatial distribution of Atlas cedar seedlings in the Chelia mixed forest would be aggregated, and the regeneration would be facilitated by holm oak's undergrowth. Specifically, we sought to

i. Characterizing the spatial distribution of young individuals of Atlas cedar (diameter at breast height (DBH < 10 cm)),
ii. Evaluating the influence of undergrowth on seedling spatial distribution and to determine the spatial structure of the DHP, the crown size of the holm oak
iii. Defining the undergrowth's role in facilitating Atlas cedar regeneration, survival, and maintenance
iv. Facilitating effect of holm oak on natural regeneration of Atlas cedar

Material and Methods

Species and Study Area

The study considers the Chélia massif (Figure 1) in northeastern Algeria. The Atlas cedar, indigenous to Algeria and Morocco's high mountains, occupies a very fragmented area of distribution. Its surface area is more important in Morocco, where it occupies nearly 120,000 ha and is located in four blocks: the Rif, the central and eastern Middle Atlas, and the High Atlas (M'hirit, 1994). In contrast, the Atlas cedar area in

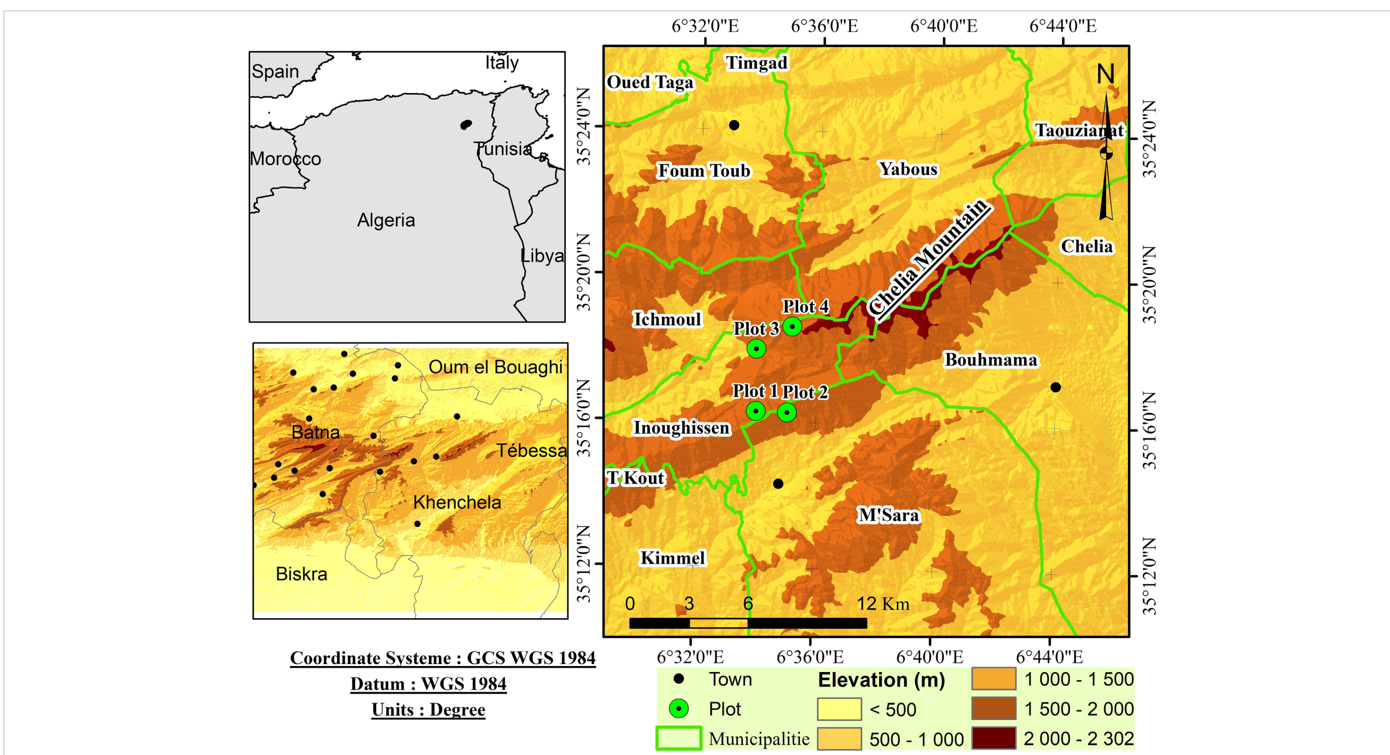

Figure 1.
Geographical location of the four study sites randomly distributed on two slopes.

Algeria is about 27,000 ha, comprising the Aurès mountains, Djurdjura, Blideen Atlas, the Ouarsenis, and the Babors. It develops in the colder variants of the subhumid, humid, and perhumid climatic environments, as its bioclimatic optimum lies in the supra-Mediterranean and the Mediterranean mountain between 1600 m and 2000 m. Conversely, on the southern facies, the cedar supports a semi-arid bioclimate (Benabid, 2000). In medium altitude, it is often associated with sparse vegetation that is organized in a mixed forest comprising many wood species, such as (*Pinus halepensis*), (*Quercus ilex*), (*Fraximus dimorphe*), and (*Juniperus oxycedrus*). The high mountain cedar stand whose altitude level ranges from "1800" to "2000" m appears on slopes on either side, occurs in mixed forest, and is present in a mixed forest. The latter is the predominant forest figure, increasingly enriched with holm oak, which develops at the same altitude depending on the local topographical conditions.

The Chelia mountain is abundant in cedar and coniferous trees due to its altitude. Depending on the year, snow covers its summit from November to February and the beginning of March. The environment develops in a Mediterranean semi-arid climate, with temperatures ranging from −1°C in January to +35°C in July. At low and medium altitudes, the average annual rainfall is 431 mm, occurring mainly in spring with 136 mm. This amount of precipitation is relatively uniform in autumn and winter, with 120 mm and 112 mm, respectively, and about 64 mm in summer, representing the driest season. At high altitudes, the annual rainfall can reach 800 mm (Abdessemed, 1981). The soil is derived from sandstone and limestone

Data Collection

Data were collected on both sides of the Chelia mountain. The Chelia cedar forest faces southwest and northeast orientations. The latter broadens over 6.5 km on the summit of Jebel Chelia and extends over 12 km, meeting in a space between two slopes that are aligned in opposite directions (north-south). This area extends as an anticline, with a strongly uneven relief established in the lower Cretaceous hard limestone and dolomite, whose slopes exceed 25% of declination and altitudes ranging from "1200 m" to "2300 m." In terms of altitude, the natural pattern of the cedar increases on a northern slope across a wide altitudinal range as rainfall increases.

In terms of exposure, the northern slopes offer a more humid environment, well exposed to the cold and rainy winds full of humidity, weakened temperature extremes, reduced luminosity, and intense snow cover. These conditions constitute an ideal environment for the cedar to adapt to, followed by typical vegetation associations such as the holm oak. In contrast, the southern slopes are often uncovered and subject to a microclimate close to the northern slopes of the Saharan Atlas mountains. Consequently, the environment is less humid and very exposed to the rising winds from the south that cause more frequent heating, allowing locally, in parallel to the cedar, the development of the scrub, mainly prickly juniper (Bentouati, 2008).

The study sites were chosen primarily for their accessibility and ecological conditions, compatible with the existence of the cedar and holm oak associations. Two temporary rectangular plots of (60 m × 40 m) were set up on each slope. Moreover, the orientation of the mountain slope was defined using a compass, with plots placed on each slope to obtain different exposures (north and south side).

The measurements taken in each plot relate to the distance between the center of the plot and all the oaks as well as the cedars (saplings and seedlings) (Figure 2) in polar coordinates. The position of point A is defined by the distance *d* and the angle ***α***. The radial coordinate (noted *d* and called the radius) expresses the distance of the point from a central point called the pole (equivalent to the origin in Cartesian coordinates). The angular coordinate (also called the polar angle or azimuth and often noted ***α***) expresses the measurement, in the trigonometric direction (positive direction), of the angle between the point and the half-line of angle 0°, called the polar axis (equivalent to the abscissa axis in Cartesian coordinates). This distance is measured parallel to the ground with a tape measure. Then their coordinates (xi, yi) were calculated according to the magnetic azimuth from the plot center. In addition, we measured the circumference of all the saplings (trees of height ≥ 1.3 m) and seedlings (2 ≤ DBH ≤ 10 cm) as well as the crown shapes of the holm oak, which was measured using a meter tape in two directions: parallel and perpendicular to the slope and represented by ellipses. Due to the very uneven topography, as well as the presence of rocky areas and empty areas, we noticed that some plots were heterogeneous (Getzin et al., 2006).

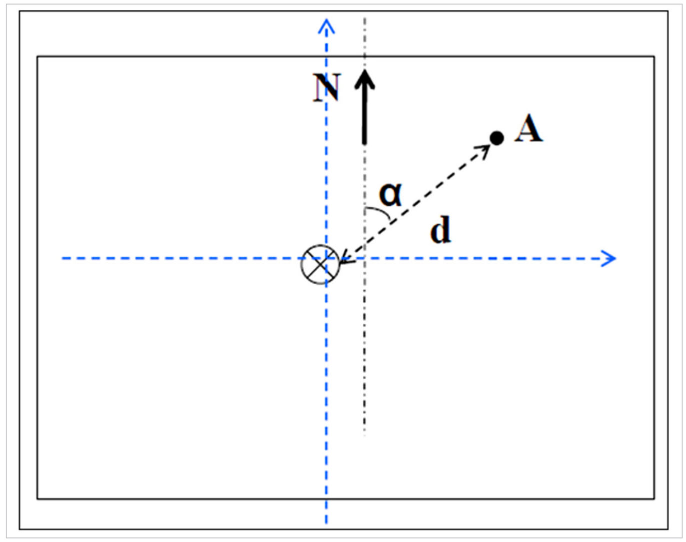

Figure 2.
Simplified diagram to explain the method of data collection.

Point Pattern Model

A SPPA is used to assess the spatial distribution and intra- and interspecific interaction among and between the understory holm oak and the Atlas cedar seedlings. A point model represents the spatial model (e.g., trees) that consists of a map of the point locations in a given study area (Wiegand & Moloney, 2004).Therefore, SPPA studies the spatial pattern of points. The sample plot is commonly referred to as the observation window, which is usually a rectangular or circular area. The latter is selected to provide representative data for the broad community studied (Pommerening et al., 2011). The properties of the point process define the structure of the point pattern (Ripley, 1977). Accordingly, there are three main types of point structure: random, regular, or aggregated. In addition, the observed structures are governed by ecological processes such as competition or facilitation; for example, a regular distribution could reflect a competitive interaction (Wiegand & Moloney, 2004).

The study applies two analyses:

- An unmarked analysis where only the locations of the points (*x*, *y*) are considered.
- In marked point pattern analysis, two patterns are examined, including two species, two size classes (adult vs. seedlings, such as in our

study), and two life phases (understory vs. overstory). The understory is the layer of vegetation that grows beneath the forest canopy but above the forest floor. It typically includes smaller trees, shrubs, and herbaceous plants.

Analysis 1: Univariate Analysis
The pair correlation function is related to the derivative of the K-function (Ripley, 1977; Stoyan & Stoyan, 1994), given by the following equation:

$$g(r) = k'(r)/2\pi r \quad (1)$$

The univariate pair correlation function g(r) (Stoyan & Stoyan, 1994; Wiegand & Moloney, 2004) was used to evaluate the single-point pattern distribution space. Thus, the g(r) was calculated separately for all Atlas cedar seedlings, saplings, and holm oak trees.

Along with Ripley's K-function, g(r) is the spatial function describing spatial patterns commonly used by ecologists (Velázquez et al., 2016).

Estimating g(r) requires overall tree-to-tree distances in a mapped area. This gives the expected number of trees at a distance r from an arbitrary tree in a specific pattern. Therefore, dividing the g(r) by the intensity λ of the pattern (Stoyan & Stoyan, 1994; Wiegand & Moloney, 2004) enables defining whether a pattern is random, aggregated, or regular (Wiegand & Moloney, 2004). Consequently, if $g(r) > 1$, there are, on average more nearby trees at smaller distances *r* than would be expected by a random distribution, indicating a tendency toward aggregation (Stoyan & Penttinen, 2000; Wiegand & Moloney, 2014). In contrast, if the values of $g(r) < 1$, there are, on average, fewer nearby trees at smaller distances *r* than expected by a random distribution assumption, suggesting that the model tends toward regularity. According to Wiegand and Moloney (2004), we employed the heterogeneous Poisson null model in our situation, which assumes that the pattern intensity λ varies slightly with location (*x*, *y*) (Stoyan & Stoyan, 1994; Wiegand & Moloney, 2014) and to take into account the heterogeneity within plots.

Analyse 2: Bivariate Analysis
The study also uses a bivariate version of the pairwise correlation function $g_{12}(r)$ to assess the relationship between green oak adults and Atlas cedar seedlings ($2 \le DBH \le 10$ cm). The $g_{12}(r)$ analyzes the association between two patterns of points. First, $g_{12}(r)$ is the density of the point pattern 2 (the seedlings in our case) at a distance *r* from a typical point of pattern of 1 (holm oak in our case) divided by the intensity λ_2 of the point pattern 2 (Raventós et al., 2011). For this analysis, the antecedent condition assumption (Wiegand & Moloney, 2004) was used by randomizing the seedling positions (pattern 2) and keeping the adults' positions (pattern 1) fixed. This model is widely used in young-adult associations (Velázquez et al., 2016), as it addresses situations where two types of points are not created simultaneously but in sequence (Szmyt, 2014), which is the case for seedling-adult relationships.

Analysis of Holm Oak Crown Projection
The spatial distribution of tree crowns affects many variables of the understorey, including light distribution and shrub cover. In order to adapt standard point pattern analysis and take into account surfaces rather than just points, as suggested by Wiegand et al. (2006), The mark correlation function takes into account quantitative parameters (such as crown radii, which are connected with sapling placements) and then determines the spatial correlation of these markings in the observed point pattern (Wiegand & Moloney, 2014). The mark correlation function is a frequently used scale-dependent analytic approach for clarifying competitive interactions between trees and understanding likely changes in stands (Getzin et al., 2008; Pommerening, 2002). Mark's correlation functions for holm oaks were tested in four plots to study the bivariate pattern of all holm oaks to saplings and seedlings. In order to generate simulation envelopes for the summary statistics, we employed the Monte Carlo method. This involved simulating a large number of instances under the null hypothesis, and at each time, calculating g(r) values for various distances r (Goreaud, 2000). In our investigation, we evaluated the deviation from the null models using a two-sided test based on the fifth largest and fifth smallest simulated values derived from the Monte Carlo simulations. These simulations produced approximately 200% simulation envelopes, with a significance level $\alpha = .05$ (Baddeley et al., 2014; Stoyan and Stoyan, 1994; Wiegand & Moloney, 2014).

Software
The R software's "spatstat" package was used for all univariate and bivariate point pattern analyses (Baddeley et al., 2015).

Results

Forest Stand Structure
Stationary data are reported for each plot in (Table 1). These data include:

Topographic data: altitude (m), geographic coordinates (NE), slope (%), and exposure.

Regeneration status: Atlas cedar was the dominant species in all plots with a significantly higher seedling density. The mean diameters of Atlas cedar seedlings ranged from 2 to 5 cm indicating good regeneration, and large diameters were rare almost in all four plots. In addition to the presence of holm oaks, with varying densities from one plot to another, other tree species were also present. The histogram illustrating the distribution of cedar trees by diameter categories (Figure 3) indicates that the four plots have a high proportion of seedlings (2–10 cm), which do not exceed this stage in the evolution of the forest, and a limited presence of large-diameter trees. Conversely, there is a notable abundance of trees with small.

Unmarked Spatial Analysis
The results of the spatial pattern analysis of all oak trees and cedar seedlings using univariate correlation functions are shown in (Figure 4). Distances are given in meters (m), the solid black curve represents the value of g(r). The shaded area is the confidence intervals of g(r) at each distance. Ripley's g(r) function value for both point seedlings (a) appears to have an aggregative structure.

Cedrus atlantica
According to the results, an aggregated distribution is observed for the four plots. Moreover, g(r) is greater than 1 at all distances, which explains why the young seedlings are grouped in the most favorable places. Moreover, there can be various causes, among which is an aggregate pattern. This indicates that the Atlas cedar is an aggregated species at the juvenile stage.

Quercus ilex
The distribution appears entirely random, much like the bivariate analysis illustrated in Figure 5. The resulting curve is given in a black solid line. Moreover, the red dashed curve represents the middle of the confidence interval, and the two bounds of the envelope are given as well

Table 1.
Main geographical, orographic, and structural characteristics of Chelia Mountain sample plots

Plots: 2400 m	Geographical Coordinates	Altitude (m)	Exposition	Slope (Degree) (%)	Atlas Cedar Numbers	Holm Oak Number	Number of Seedlings	Average Radius	Observation (Soil and Vegetation)
Pl1	35°18′22″N 6°36′05″E	1743	South-east	27%	303	41	252	3.5	Poorly developed soils, presence of mosses, and herbaceous plants
Pl2	35°18′27″N 6°38′42″E	1748	South-east	30%	354	141	299	2.9	Poorly developed soils, lithic soil type, presence of mosses + herbaceous
Pl3	35° 19′ 41″N 6° 36′ 51″E	1803	North-east	40%	806	79	700	2	Uneven relief, rocky formations, bare soil + humus layer, presence of mosses; herbaceous plants
Pl4	35°19′46″N 6°36′43″E	1810	North-east	38%	316	66	245	2.7	Uneven relief, rocky formations, bare soil + humus layer, presence of mosses; herbaceous

as the gray curves and envelope using the g12(r) function, which examines the arrangement of atlas cedar seedlings concerning oak trees. This analysis aligns with the notion that an attractive mechanism operates between these two species resulting in the observed clustered pattern over short distances, up to 5 meters, and to a slightly greater extent for plots 3 and 4. This implies the existence of an attractive force between the two species, leading to the observed clustering pattern.

Marked Spatial Analysis
Ripley's bivariate form provided the most interesting analyses. Indeed, the relationship between crowns and seedlings in the four plots (Figure 6) showed a significant positive association. Moreover, the attraction between seedlings and holm oak crowns was observed at distances up to 10 m for plots 1, 2, 4, and very noticeable for plot 3 this could be related to the position of the slope. Analysis of the points between the saplings and the crowns shows a small effect of repulsion at distances, and therefore the influence of the crowns on the seedlings was more obvious.

The four plots are shown in (Figure 7), which describe the location of the Atlas cedar, the undergrowth holm oaks, and their crown shapes. The 4 plots are represented in (Figure 6) showing the location of the

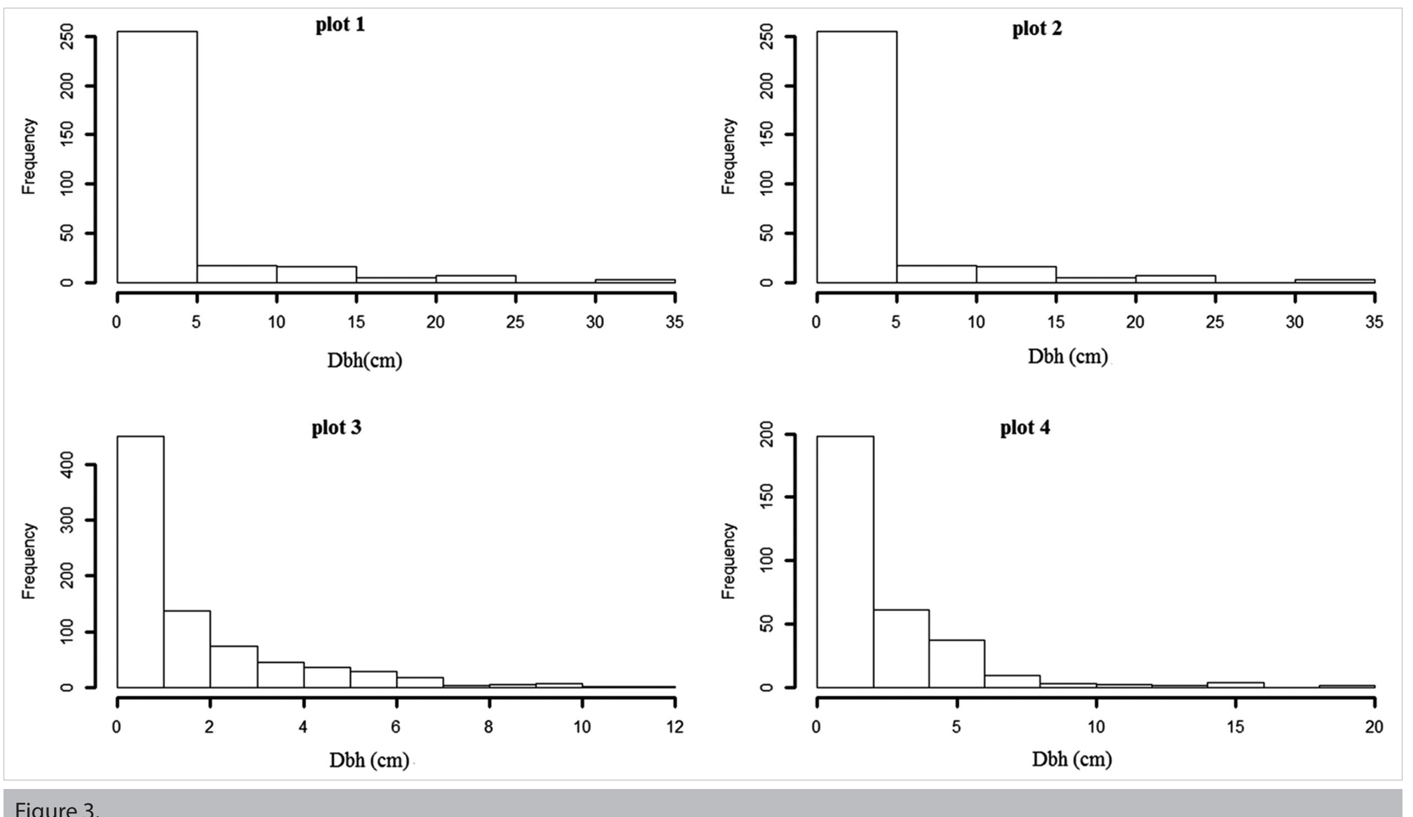

Figure 3.
Histogram graph showing the diameter distribution of saplings and seedling at each study plot.

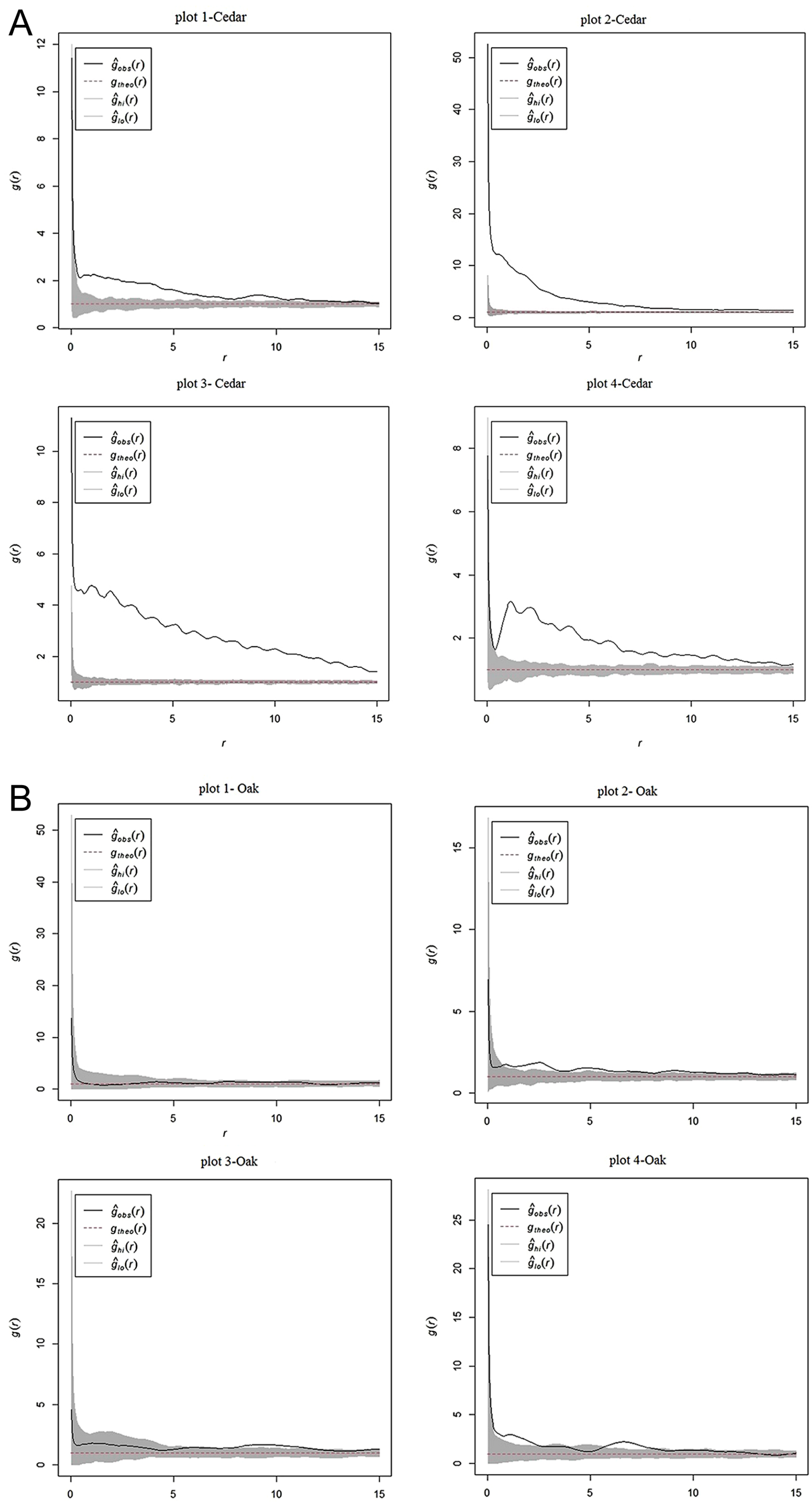

Figure 4.
Univariate analysis of all individuals of (A) Cedrus atlantica (dot plot) and (B) Quercus ilex in the four plots using the univariate pair correlation function g(r).

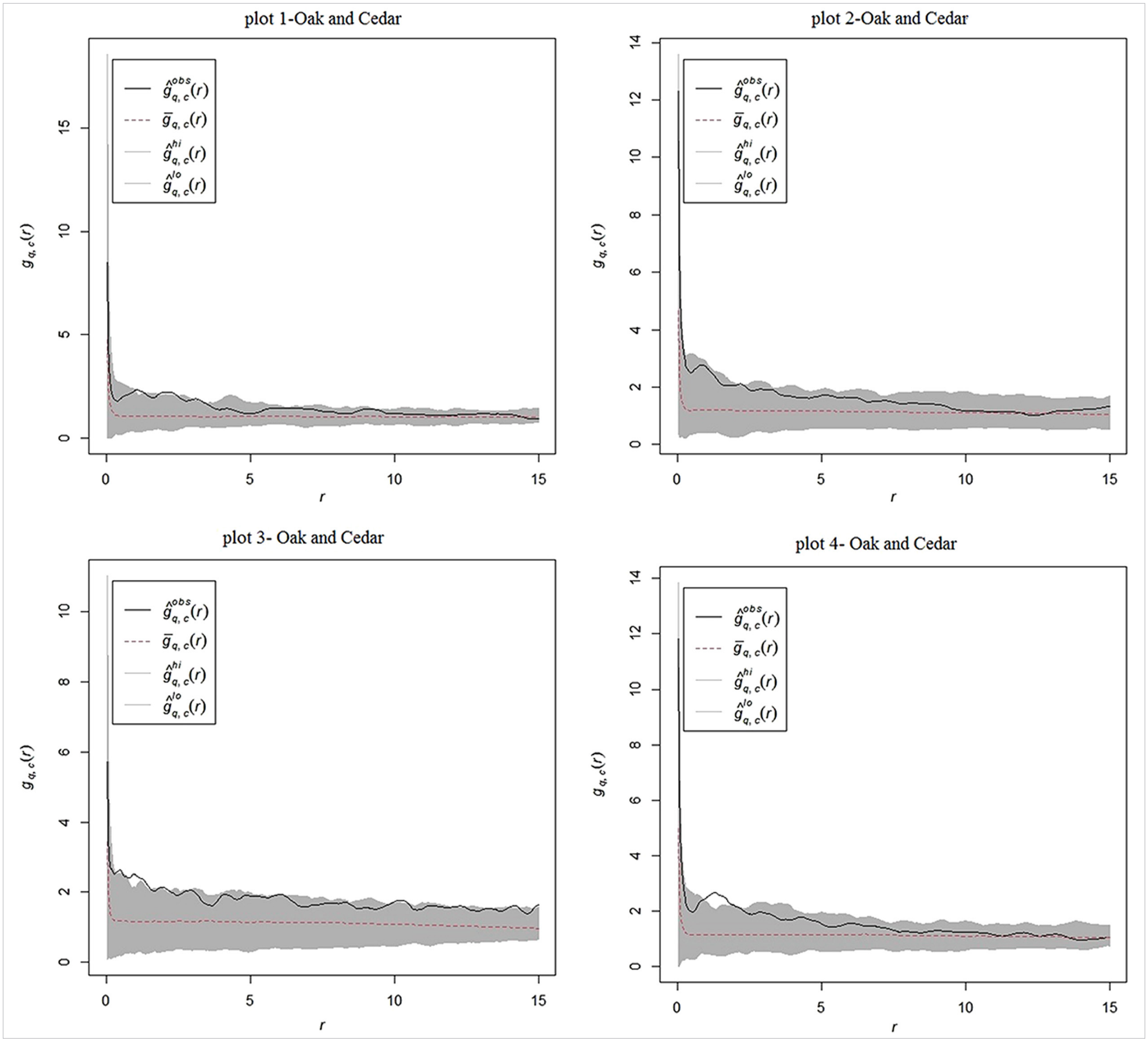

Figure 5.
Univariate analysis of the set of Atlas cedar seedlings vs. holm oak in the four plots using the bivariate pair correlation function g12(r).

Atlas cedar and the undergrowth holm oaks, as well as their crown shapes defined by the two perpendicular diameter measurements and represented in the form of ellipses. Bivariate analysis of holm oak stands using the grid approximation, in which tree crowns are considered instead of simple points, revealed a positive relationship between holm oak crowns and seedlings with a clear pattern of attraction forming clumps around the crowns for most of the plot area.

Discussion and Conclusion

Several factors are essential in defining the spatial patterns of trees in a plant community. The spatial distribution of tree species can result from many biotic and abiotic processes such as regeneration, competition, dispersal limitation, habitat heterogeneity, disturbance, and other stochastic events (Collet et al., 2017).

Field observations indicated abundant cedar regeneration on both slopes. In addition, classes with large diameters are rare and evenly distributed, while small diameters (2–10 cm) are abundant (Figure 3) (Table 1), reflecting good regeneration capacity. However, seedlings have difficulty surviving the summer due to drought. Only the young seedlings under the holm oak canopy can resist (Ezzahiri, 2000).

In our Chelia study site, the pattern of Atlas cedar regeneration exhibited clustering and expansion across different scales of 5–10 m in plot 1 (Figure 4). However, only plot 3 showed strong aggregation up to 15 m. Aggregation is generally attributed to a positive interaction between

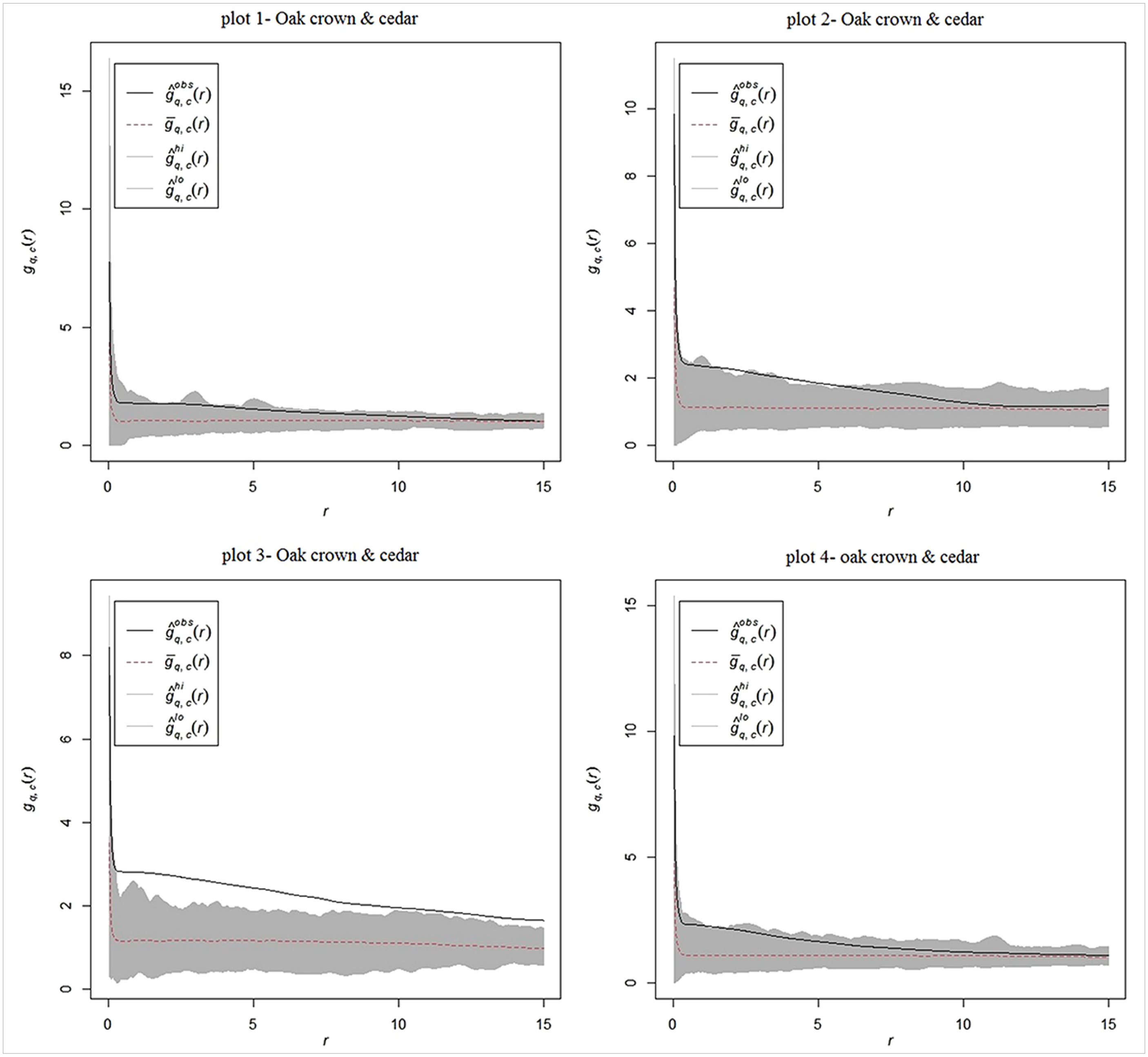

Figure 6.
Analysis of the crown pattern (thick solid black line) between the undergrowth holm oak and the Atlas cedar seedlings with the 95% quintile bounds corresponding to the toroidal offset null pattern (dotted lines).

points; aggregation indicates that points in the model are on average closer together than expected (Wiegand & Moloney 2014). Furthermore, stations with northeast exposures provide favorable conditions for cedar germination, facilitating germination and allowing young seedlings to survive during the summer. Conversely, southern exposures are generally the warmest, and seed germination is early (Benabid, 2002).

The results obtained in Figure 4B confirm the intuitions we had on the spatial distribution of holm oak. The tendency for concentration as well as for dispersion is not obvious, since the curve g(r) remains located within the confidence interval below a radius of 5 m. Beyond this radius, the observed distribution of holm oaks does not seem to deviate significantly from a random distribution. Holm oak is a flexible and sturdy species that can adapt to varied climatic conditions. This ability allows it to cover several zones with different bioclimatic levels. It is a species with a wide geographical distribution (Barbero & Loisel, 1980).

It is easy to see that the spatial distributions are observable for all the distances studied between the natural regeneration of the Atlas cedar and the holm oak (Figure 5). We can consider that the highest levels of aggregation appear at fine scales (5–10 m**)**. In the very first study radii, the proportion of seedlings around holm oaks is approximately twice as high. The structure of vegetation influences regeneration. Indeed, enough cover creates a wetter forest microclimate, especially

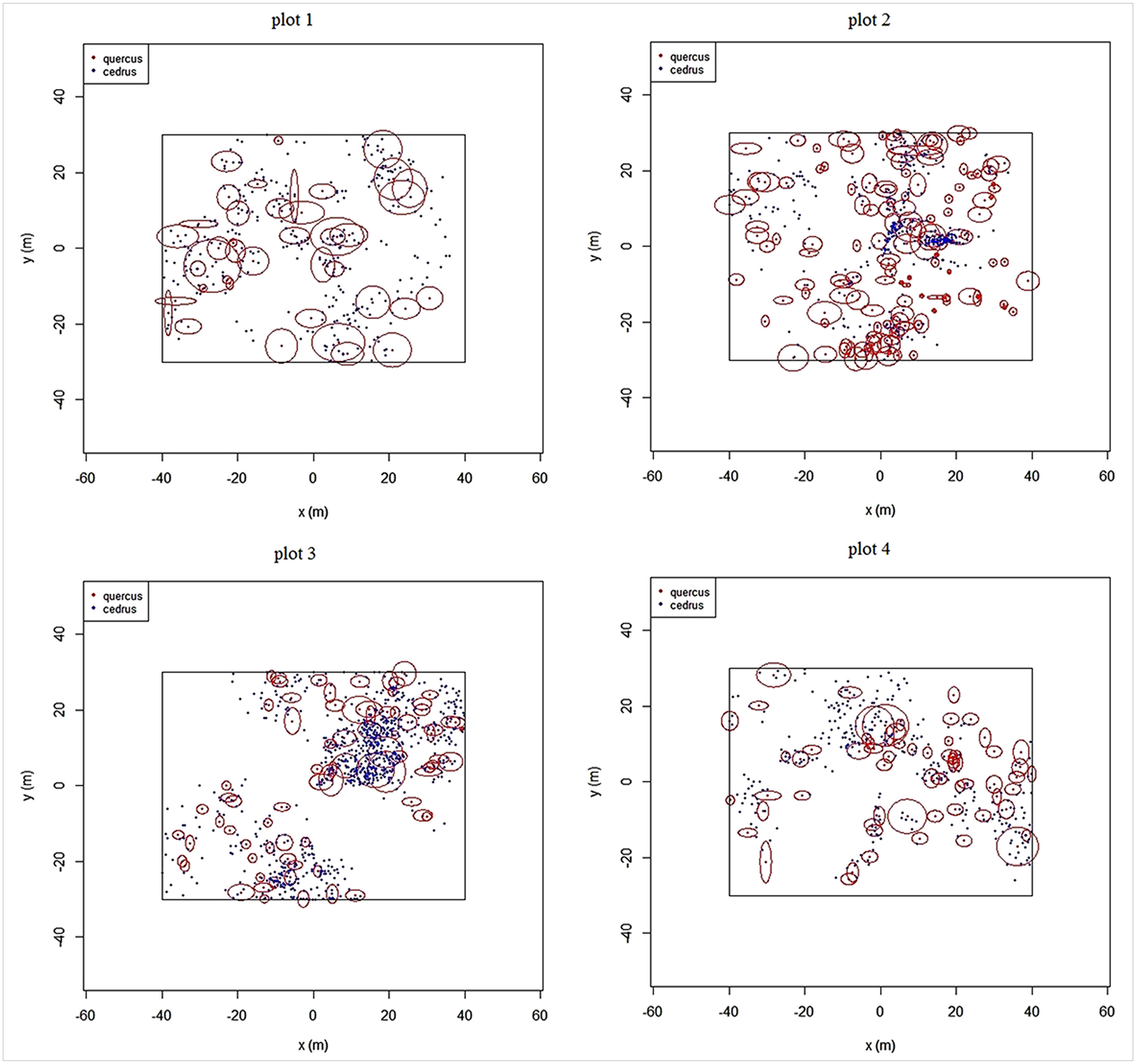

Figure 7.
Projection maps of the crown in the four sized plots (60 m × 40 m). Seedlings are represented by blue dots and holm oak by red dots.

in a Mediterranean context, favoring seedling survival in dry areas (Benabid, 2002). The facilitating effect of undergrowth provides small plants mechanical protection against animals (grazing, trampling) and protects them from climatic hazards (torrential rains, exceptional cold). On the other hand, it provides a microclimate improving the availability of water and nutrients in the soil, which would constitute an excellent host structure for cedar seedlings. However, the facilitating effect would only be effective during the early stages of establishment. The improving effect of tree cover would be linked to its role in the filtration and availability of light. The cover, by lowering the levels of radiation, would maintain microclimatic conditions of temperature, air humidity, and soil water balance favorable to germination and the establishment of seedlings (Benabid, 2002).

The bivariate analysis with g_{12} (r) supports the hypothesis that the facilitation process results in the observed patterns (indicative of attraction). As illustrated in (Figure 6), there is an appealing relationship between holm oak crowns and cedar seedlings (in the surroundings of holm oak, the density of seedlings is higher). Furthermore, spatial attraction between species with similar growth requirements has been observed (Martínez et al., 2010). Consequently, the holm oak facilitates the establishment of cedar's young seedlings, resulting in aggregations of both species during the regeneration phase. Therefore, a species' shade tolerance is expected to significantly impact its distribution pattern, which explains why seedlings are more aggregated than large trees. Thus shade-tolerant species should be more aggregated than moderately tolerant species; so this is the distribution spatial pattern of a species may stem from a strong habitat preference (Zhang et al., 2010).

According to Ledo et al. (2014), aggregation patterns are common in early life, as recruits may establish where seeds fall on seedbeds. However, on dry sites, seedling survival may be enhanced by shade from the undergrowth (holm oak) (Fajardo et al., 2006).

Lecompte (1986) observed that cedar regeneration would occur under holm oaks, where the canopy's root desiccation of young seedlings is countered by the canopy that limits evaporation. However, it is essential to mention that the conditions favorable to regeneration vary from location to location. For instance, the limiting factor may be temperature or humidity, depending on the altitude and exposure. Thus, at a high altitude and on a well-watered slope, an accentuated opening of the stands will be beneficial to raise the temperature sufficiently, allowing the germination of the seeds and promoting the photosynthesis of the seedlings (Dubé, 2007). Conversely, at a lower altitude and on a less-watered slope, a more closed canopy will favor the conservation of a higher degree of humidity. It will thus favor cedar regeneration (M'hirit & Benzyane, 2006).

Atlas cedar seeds are dispersed through a combination of mechanisms, including wind dispersal and animal dispersal. The dispersal ability of Atlas cedar seeds may explain aggregation in or near the area influenced by the crown. Moreover, several studies have shown that dispersal limitation is often considered one of the major mechanisms to explain species aggregation (Figure 7) (Plotkin et al. 2000; Seidler & Plotkin 2006). Therefore, crown size and position could be the main factors influencing regeneration in Mediterranean forests (Barbeito et al., 2008; Ledo et al., 2014).

The influence of vegetation cover on regeneration is essential. For example, in low cedar forests, holm oaks play a positive role in reducing the amount of evaporation and protecting young seedlings. In contrast, its role and associated species at high altitudes are secondary or adverse if they are not harmful because their shade delays seed germination (Marion, 1954). Generally speaking, about 50% of the cover is almost always favorable to regeneration, unlike the outer cover (M'Hirit, 1999). Although cedar seedlings need light and grow very well on edges and in small clearings and gaps interspersed with the forest, this species must have sufficient protection from an undergrowth that is almost always holm oak (Boudy, 1950). Indeed, it seems that regeneration is largely linked to the undergrowth of holm oak that shelters the plants until they are cut back. Moreover, the development of undergrowth protects the young subjects against the access of the herds due to its density.

The favorable association between seedlings of holm oak and Atlas cedar has substantial conservation significance. Maintaining this beneficial relationship between the two species in the environment requires their preservation and management. Planting or maintaining holm oak beside Atlas cedar can help with restoration and reforestation efforts in the region, increasing the success of regrowth attempts.

Spatial distribution provides information on the occupation of space, and therefore on the social pattern of a species or plant population; natural regeneration provides information on the probability of renewal without human intervention. The spatial structure and facilitative role of the holm oak in the natural regeneration of the Atlas cedar are crucial aspects to comprehend in order to appreciate their interaction within the Mediterranean ecosystem. Holm oak is a tree species that is notably present in Mediterranean forests and, by means of its spatial distribution and facilitative mechanisms, assumes a crucial role in the regeneration of the Atlas cedar, while the Atlas cedar is an iconic tree of the North African mountain regions. These two species are closely connected in their natural environment, and their interaction has significant implications for the natural regeneration of the Atlas cedar. Understanding the contribution of holm oak in the regrowth of Atlas cedar has profound implications for conservation efforts in Chelia, Aurès. Recognizing the facilitative role of holm oak in Atlas cedar regrowth highlights the importance of preserving and managing these ecosystems. Strategies should aim to conserve both holm oak and Atlas cedar to maintain the symbiotic relationship that benefits Atlas cedar regrowth.

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