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Distribution and Dendrometry Evolution of Gall Oak (*Quercus faginea* Lam.) Forest Stands in the Region of Murcia (Southeastern Spain)

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Abstract: The southeast of Spain is one of the most arid and desertification-prone areas in continental Europe, with climate change contributing to this situation. Climatic conditions affect the availability of water in the plant structures of wild species, facilitating the onset and/or spread of forest fires and increasing aridity. The Region of Murcia, in southeastern Spain, has small forest stands of gall oak (*Quercus faginea*) with relict value. It is of interest to investigate the situation of these stands, allowing us to know about their distribution and their evolution in the face of climate change. For this purpose, previous dasometric, available from a specific stand, studies are considered to be contrasted with current data, individual trees were geolocated, and distribution maps of contrasting environmental conditions were created. In general, gall oak has been observed to be distributed up to 1200 m altitude, especially in shady areas and embedded valleys and north-northeast orientations. Importantly, there was a positive evolution of the vegetative development, with increments in the number of trees during the study period, despite some negative affections in specific areas due to climate change.

Keywords: dendrometry; desertification; barrenness; Región of Murcia; *Quercus fagínea*

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1. Introduction

The gall oak (*Quercus fagínea* Lam.) [1] displays a global distribution that is limited to the Mediterranean region (Figure 1a) [2]. Furthermore, this species' global distribution is centered primarily in Spain, with smaller occurrences in the rest of Europe and more significant ones in northern Africa [3]. However, the sketch in Figure 1b does not depict the presence of the species in countries such as France and Italy [1].

Figure 1. Distribution of *Quercur faginea*: (a) Worldwide distribution. (b) Distribution in the Mediterranean area [1,2]. (Yacine Kouba, 2014 & Sánchez Gómez et al., 2002).

In Spain, among the regions of origin of gall oak, the Region of Murcia, in the southeastern Iberian Peninsula (Figure 2a) is one of the most important areas (Figure 2b) [3–5].

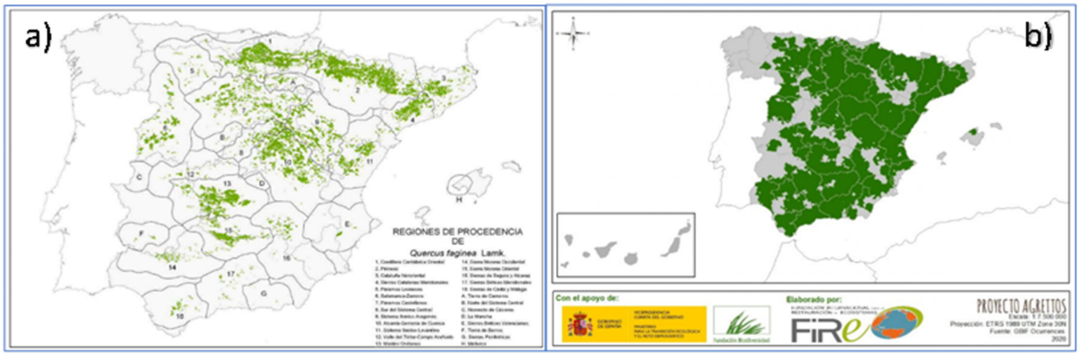

Figure 2. *Quercus faginea* in Spain: (a) regions of origin and (b) areas of distribution [3–5]. (MITECO, 2003; Jiménez et al., 1997 & AAVV, 2023).

Despite the southeastern area of the Iberian Peninsula being considered a potential distribution área of gall oak (Figure 2b), we are dealing with a species with very limited presence in the provinces of Murcia and Almería (southeastern Spain), representing a small remnant of its broader historical distribution. The areas under study can be classified within the so-called Spanish region of dry and warm origin, considered as areas with uniform ecological conditions where similar phenotypic or genetic characteristics can be found, depending on the species in question. One of the study áreas of this region, Salinas in Yecla [4], is characterized by an average annual precipitation not exceeding 450 mm, with a nearly four-month period of summer drought and average temperatures close to 14°C. The extreme moisture conditions make the species seek refuge in deep places with shaded orientations [6].

In moderately warm semiarid Mediterranean climates with precipitation ranging between 300 and 600 mm per year, when precipitation reach 300 mm, it is usually found on slopes and moister areas [6]. Other studies calculated the species' habitat taking into account that the maximum and minimum values, in this case, of rainfall, defining the upper and lower limits, respectively. They also defined the optimal or central habitat, where the species thrives without issues. The optimal rainfall level is 665.6 mm per year, with the lower limit being 486 mm and the upper limit at 796.6 mm. It should be considered that most of the territory in the Region of Murcia provides a marginal habitat for *Quercus faginea*, as its rainfall is less than 486 mm per year [7]. Other authors mention annual rainfall near 600-700 mm per year, which are found in territories located in the northwestern part of the region [8,9].

On the other hand, global warming has led to the expansion of arid climate zones, resulting in changes in the seasonal activities and abundance of some plant species. Climate change entails an increase in the frequency and intensity of certain extreme meteorological and climatic events as a result of global warming, and they will continue to increase. Consequently, some of these extreme events, such as heatwaves, are expected to increase in frequency, intensity, and duration. Similarly, the frequency and intensity of droughts are also projected to increase in the future, as they already are in some regions that are prone to drought, predominantly in the Mediterranean basin [10]. Indeed, since 1975 the region has experienced 57 heat waves [11].

The terrestrial areas threatened by desertification make up 40% of the Earth's surface. In Spain, the Canary Islands and the Mediterranean region are the areas at the highest risk of desertification [12]. The Region of Murcia, in the southeastern part of the Iberian Peninsula, is one of the driest areas in peninsular Spain, and a significant portion of it is at moderate to very high risk of desertification [13].

Desertification will have an impact on natural systems under climate change. Growing aridity increases the risk of extinction for some plant species, especially those already threatened due to small populations or restricted habitats [10]. Deforestation and forest degradation remain significant global threats. Forests are one of the Earth's largest carbon and biodiversity reservoirs, crucial for mitigating climate change [14]. Assessing the well-being of terrestrial ecosystems is a complex task, and the use of indicators can facilitate this work. By analyzing parameters that respond to changes, such as dendrometric parameters related to plant species, desired information can be obtained [15].

Quercus faginea populations in the Region of Murcia consist of small populations confined to areas that promote the isolation of small stands or scattered specimens throughout the regional territory. Additionally, this species is listed as a vulnerable species in the Regional Catalog of Protected Wild Flora of the Region of Murcia [16]. It should also be emphasized that in projections regarding the presence of this species, it is estimated to have disappeared from the Region of Murcia by 2071 [17].

Regarding its distribution on the Iberian Peninsula, a sketch of its distribution in the Spanish province of Guadalajara was already made in 1985 [18]. In the Region of Murcia, the gall oak, due to its water requirements, can be found in places where soil moisture or precipitation is higher than in the rest of the region, such as riverbeds and wetter mountain areas [19].

In light of all this, we hypothesized that the distribution and dendrometry of *Quercus faginea* can be used as an indicator of climate change and increased aridity in the Region of Murcia. Therefore, the objective of this work was to study the regional distribution of gall oak by comparing previous and actual dendrometric data from a relictic tree mass located in Barranco del Horcajo, Region de Murcia, Spain.

2. Material and Methods

2.1. Study área

From a chorological perspective, the Region of Murcia in the southeast of Spain (Figure 3) [20] was selected as the study area with the aim of roughly determining the territorial distribution of *Quercus faginea* stands, as well as significant trees of the species.

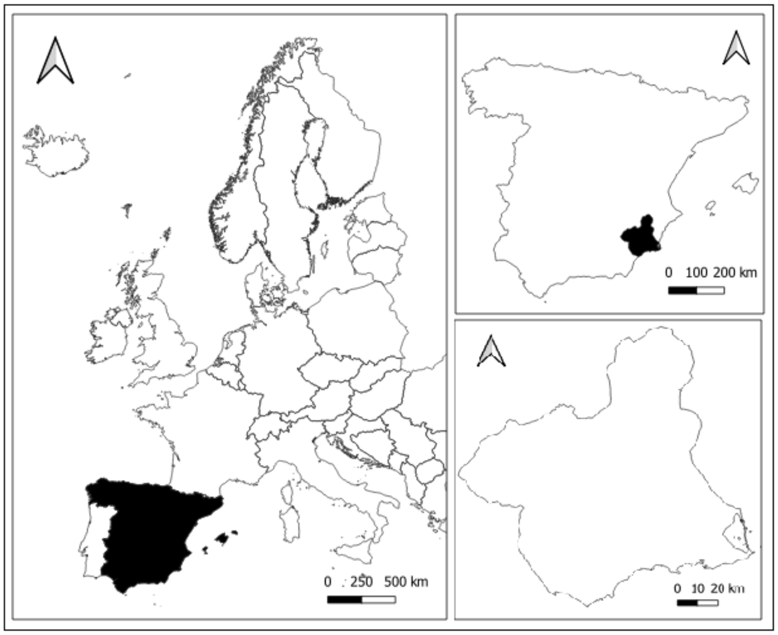

Figure 3. Location of the study area. Source: National Geographic Information Center of Spain [20] (CNIG-Spain, 2023).

2.2. Methodology

Utilizing existing literature on the location of *Quercus faginea* in the Region of Murcia [1] (Figure 4), information gathered from informal interviews with the Environmental Agents in the Region of Murcia, and taking into account the necessary climatic conditions for the species' survival, a survey was conducted in the areas of the Region of Murcia where the existence of these trees was most abudant.

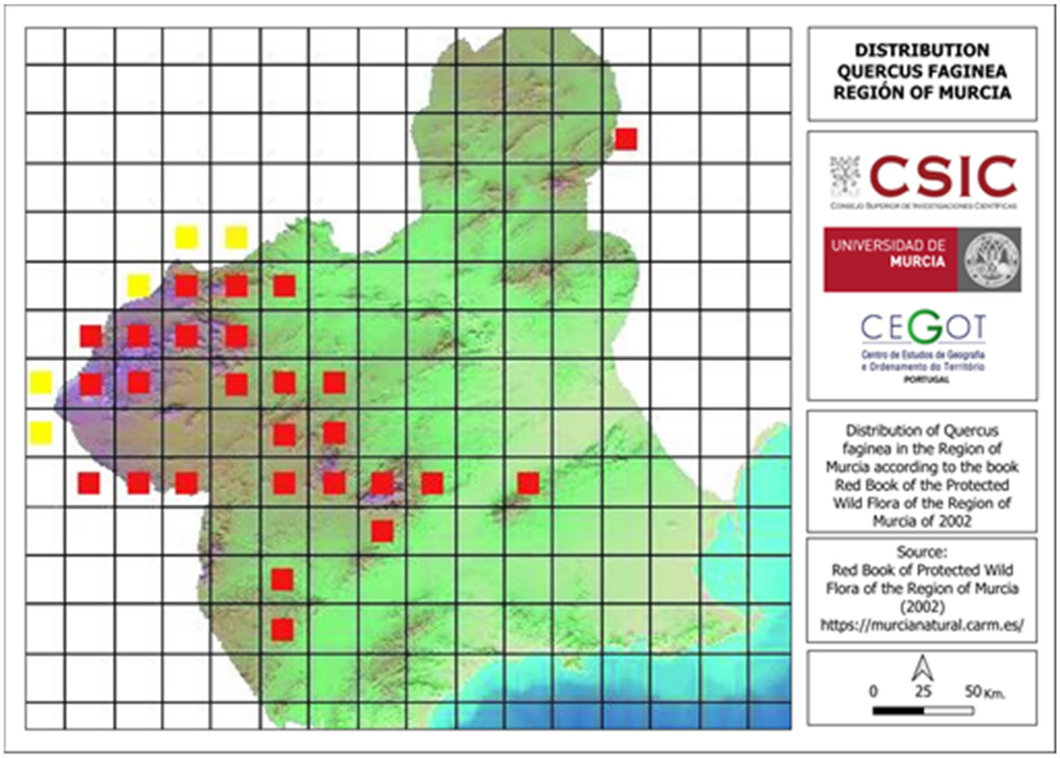

Figure 4. Accurate distribution (in red) and probable distribution (in yellow) in tiles of *Quercus faginea* in the Region of Murcia. Source: [1] Sánchez Gómez, et al. (2002).

Once the stands and significant trees were located, their geolocation was carried out using a GPS. New distribution maps and territorial location of the trees were created using the geolocation points.

Given that data on certain dendrometric, lithological-edaphological, floral assemblages, etc. parameters were collected in 2006 for the stand located in the Barranco de El Horcajo (Sierra de Pedro Ponce) [21,22] (Figure 5), some of which were published in 2012 [23], and considering that the most important indicator for studying the well-being of natural systems is related to the growth and vegetation production capacity of the plant components of the system, data on parameters related to the species under study were collected [15]. Additionally, it is of interest to collect data on these characteristics again to detect their evolution with respect to vegetative growth and other aspects.

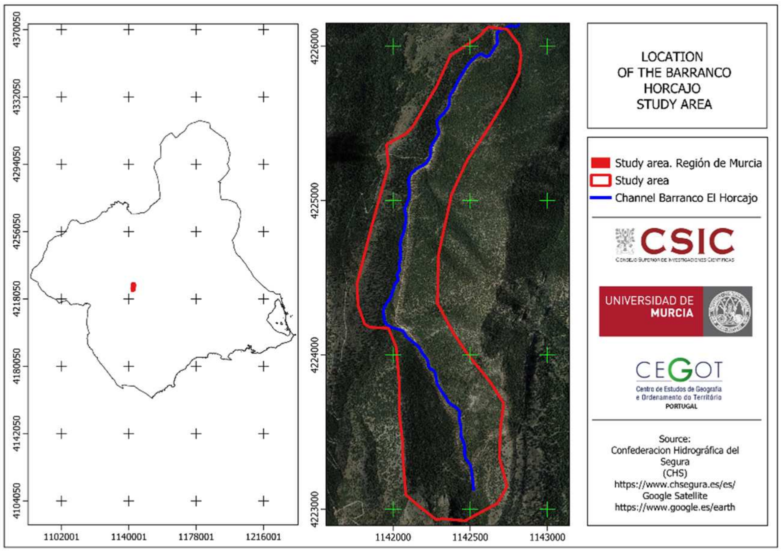

Figure 5. Location of the Barranco El Horcajo. Source: [21,22] Confederación Hidrográfica del Segura (CHS) (2023) y Google Terrain (2023).

The Barranco El Horcajo is formed by a discontinuous-flow riverbed located in a mountainous area. In the study area, it is flanked by slopes with gradients approaching 40%, altitude ranging between 1000 m and 1400 m, and a northeast orientation. This gives this small area climatic conditions that are colder and more humid than the surrounding areas.

Several pedestrian transects were carried out along the Barranco El Horcajo, covering both banks at intervals of 25 meters, measured from the thalweg, transversely to the riverbed. The trees were randomly selected from those present in the study area in 2012 [23]. Once selected, they were geolocated, various measurements of the tree were taken, the species comprising the floral assemblage were noted, and the types of lithological-edaphological materials were recorded.

The variables measured for each tree were: a) circumference of the trunk at a height of 1.30 meters, by using a tape measure, b) distance from the base to the first green whorl, with a laser-type hypsometer, c) distance between the first green whorl to the top, and d) crown width north-south and east-west orientation [24]. Data on the floral assemblage were collected by identifying as many plants as possible in two concentric circles with radius of 5 and 10 meters, respectively, with the tree's axis serving as the central point. Regarding lithological-edaphological characteristics, three concentric circles with radius of 1, 3, and 5 m were established, taking as central reference point the axis of the trunk using a tape measure. Three classes of materials were considered: 1) clays and sands, 2) mixed (where 1 and 3 were present), and 3 rocky.

The data collected in the field related to the trees were used to measure the volume of the standing trees through cubic calculation. A quick method, when high precision is not required, is to use the formula devised for hardwoods in normal thickness designed by Auvergne, which was used for this work:

$$V=0.55 \cdot d^2 \cdot 1.30 \cdot h, \quad (1)$$

where V (volume), d (diameter), and h (total height) at 1.3 m from the ground, with the latter measure being of great interest as it reflects the quality of a given site [24].

Quantifying the crown of the trees is important, as it allows the productive capacity to be assessed through biomass production. The volume of the crown of the different trees was calculated using the following formula:

$$V_{crown}=P_{crown} \; x \; S_{crown}, \quad (2)$$

where V (volume of the crown), P (depth of the crown), and S (surface of the crown). To calculate the independent variables, P was obtained by the difference between the total height of the tree (h) and the height at which the crown begins at the whorl, where at least 50% of the branches are alive, and S was calculated as $S_{crown}=(\pi/4)\ d^{2}_{crown}$. To determine the crown diameter, the two measurements taken based on the previously mentioned orientation were used through the application of the formula: $d_{crown}= (d1+d2)/2$ [24]. Where $d1$ is the diameter of the crown taken in the north-south direction and $d2$ in the east-west direction.

3. Results and Discussion

The regional distribution of *Quercus faginea* (Figure 6) shows some similarities and differences compared to what was described by Sánchez Gómez, et al. (2002) [23], as can be observed in Figure 4. Globally, the similarities are found in the mountains Las Salinas (Yecla), Villafuertes (Moratalla), Pedro Ponce (Mula), Sierra Espuña (Alhama de Murcia and Totana), and the municipality of Bullas. On the contrary, specimens were not found in certain areas of the northwestern and southwestern areas of the Region of Murcia. Its presence was also not detected in the mountain El Carche (Jumilla and Yecla) or in the the mountain La Zarza (Caravaca de la Cruz), although in the latter location, informal interviews with locals provided knowledge of the existence of some specimens [25].

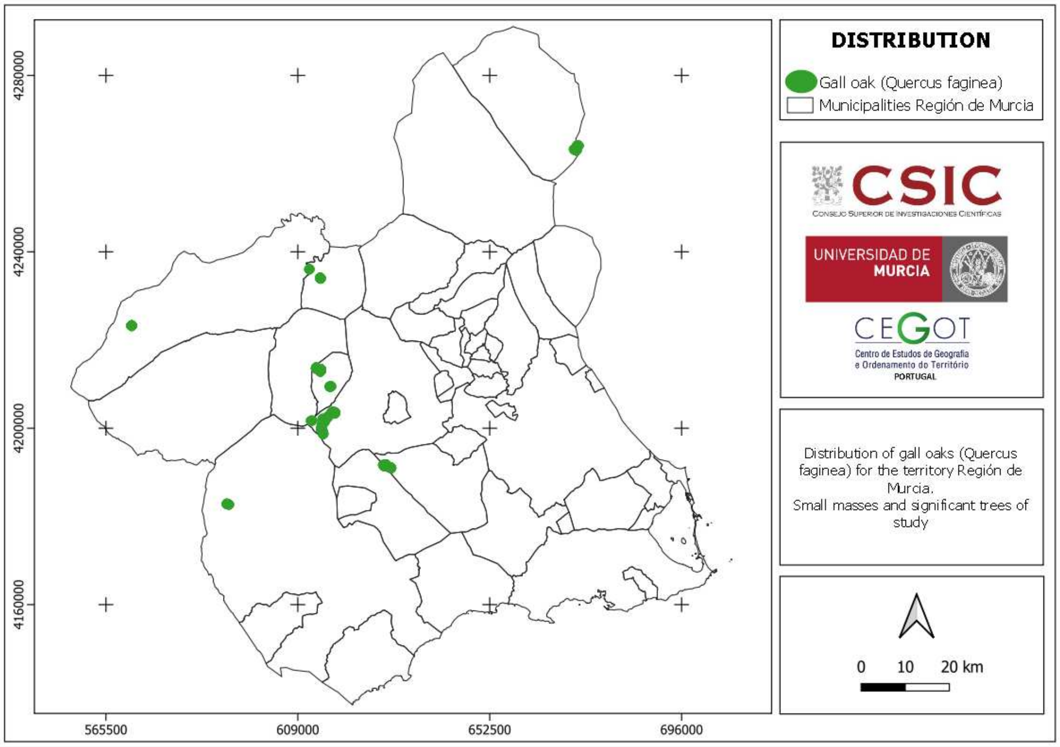

Figure 6. Distribution of *Quercus faginea* in the Región de Murcia.

In relation to the climate, rainfall has been considered as the most limiting factor for vegetative growth. It has been observed that the presence of small stands or groves of oak is focused in the rainiest areas of the Region of Murcia, where annual average precipitation exceeds 400 mm, and even surpass 600 mm in certain locations [8,26], according to data collected by the authors on dates preceding their publication in 2007 and 2013. The pattern of annual mean precipitation distribution is consistent in both figures. The northwest, along with certain mountainous enclaves, is identified as the area with the highest precipitation (Figure 7).

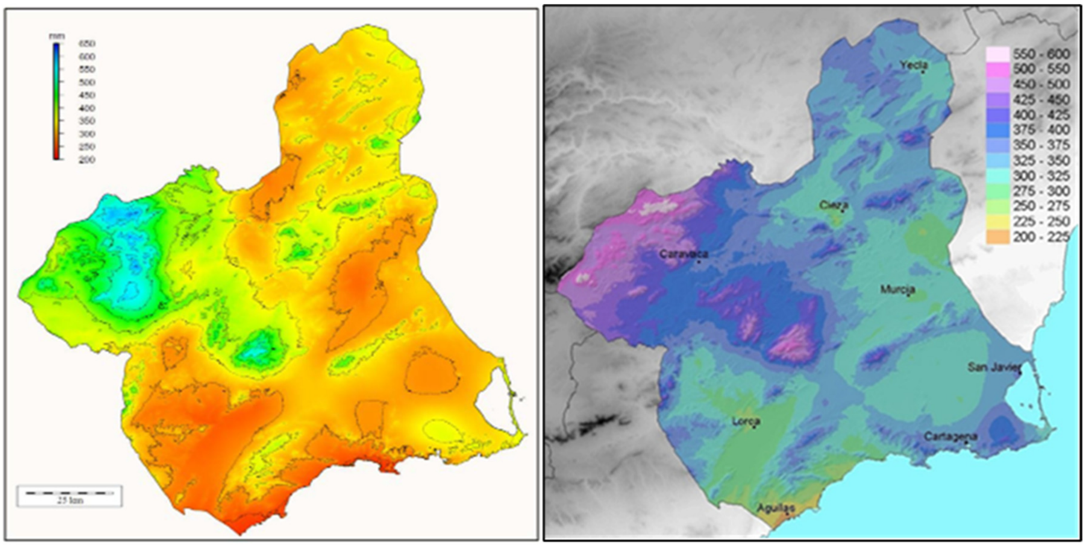

Figure 7. Annual rainfall distributionin the Region of Murcia. Source: [8,26] Alonso Sarría (2007) (left); Garrido Abenza, et al. (right) (2013).

Precipitation stands out as the most limiting factor for vegetative development. It has been observed that the presence of small masses or groves of gall oak occurs in the rainier areas of the Region of Murcia, where average annual precipitation exceeds 400 mm and can surpass 600 mm in specific locations [8,26] (Figure 7).

Regarding the Barranco El Horcajo, the information obtained about the oaks present in the Barranco El Horcajo shows an average annual rainfall that exceeds 500 mm (Figures 7 and 8).

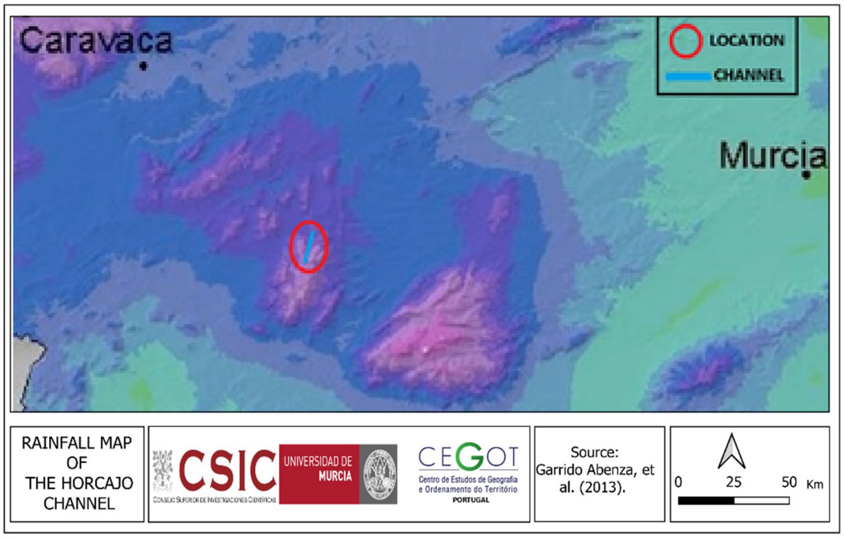

Figure 8. The Barranco El Horcajo location [26]. Garrido Abenza, et al. (2013).

The dendrometric information previously collected on part of the oak forest present in the Barranco El Horjaco allows for a partial evolutionary insight based on specific dendrometric parameters, which are not available for the rest of the regional trees. Hence, the interest in focusing attention on this territory.

The data collected in the field were obtained for a total of 33 trees (Figure 9), compared to 155 in 2006, which represents approximately 21.30%. Considering the margins, data for 16 trees on the right margin were collected, compared to 79 in 2006, which respereents around 21%. On the left margin, 17 trees were surveyed out of 76, resulting in 22.36%.

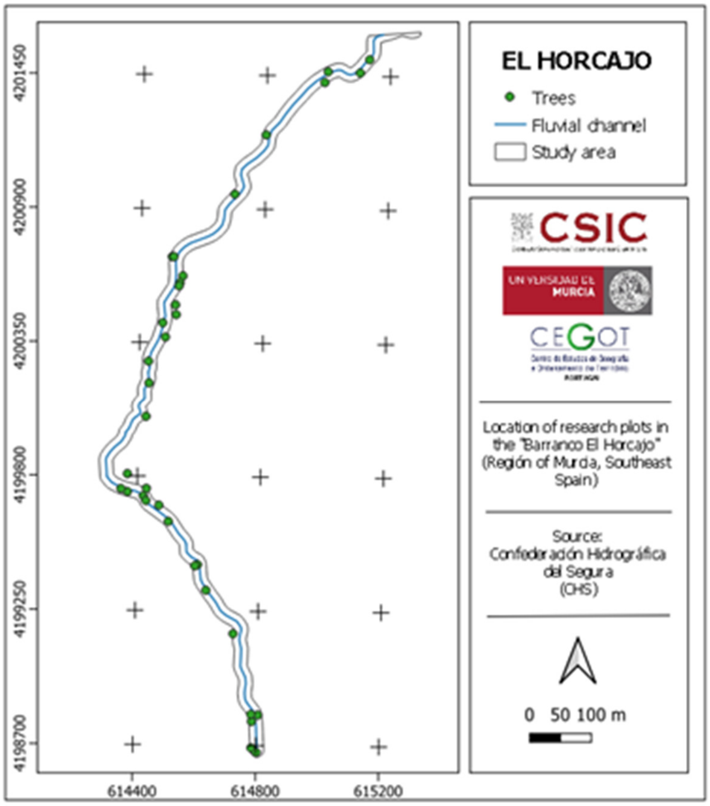

Figure 9. Distribution of the studied trees in the Barranco El Horcajo.

Regarding the dimensions of the different trees measured in 2006, the average total height was 4.70 meters for those located on the right margin of the ravine and 4.53 meters for those on the left margin, resulting in an overall average of 4.65 meters [23]. The results obtained in 2022 show a percentage increase on both sides compared to the 2006 data, with a higher increase on the left margin. Regarding trunk volume, the cubic measurement reveals a remarkably higher percentage increase on the left side, as is also the case for the height increments. The calculation was done using the formula: (final volume - initial volume/initial volume) x 100 (Tables 1 and 2).

Table 1. Total height (in m) and trunk volume (in m^3) of *Quercus faginea* selected trees in the Barranco El Horcajo.

Tree	2006			2022		
	Margin		Mean	Margin		Mean
	Right	Left		Right	Left	
Total height	4.70	4.53	4.65	6.35	7.61	6.83
Volume	0.042	0.041	0.0415	0.131	0.249	0.181

Table 2. Increments of total height and volumen (in percentage) between years 2022 and 2006 of the *Quercus faginea* selected trees in the Barranco El Horcajo.

Tree	Margin		Mean
	Right	Left	
Total height	35.10	67.99	46.88
Volume	169	507	336

In the case of the canopy, in 2006 only data regarding its surface area were collected, allowing us to determine the fraction of canopy cover (FCC). Comparisons have been established between the FCC of 2006 and 2022, revealing an increase in the average surface area, which amounts to an increase of 4.40 m^2. Considering the margins, the growth has been greater on the left margin, surpassing the right one by 2.63 m^2. In percentage terms, between 2006 and 2022, the average canopy surface area increased by 6.34%, with an increase of 5.62% for the right marginand 7.06% for the left margin (Table 3).

Table 3. Dendrometric values of the canopy of *Quercus faginea* selected trees in the Barranco El Horcajo.

Canopy	2006			2022		
	Margin		Mean	Margin		Mean
	Right	Left		Right	Left	
Surface (m)	3.06	2.87	2.94	6.62	8.06	7.34
Depth (m)	---	---	---	4.21	4.91	4.56
Volume (m^3)	---	---	---	27.87	39.55	33.70

The basic floral assemblage identified comprises 18 species of wild flora, including herbaceous, shrubby, and arboreal species, with an important proportion of them being protected species. Some of them were present in both 2006 and 2022, as well as on both margins and in both canopies, such as *Brachypodium retusum* (Pers.) P. Beauv, *Juniperus communis* L., and *Pinus halepensis* Mill. On the other hand, the least frequently present species include *Acer monspessulanum* L. and *Allium triquetrum* L. The rest exhibit varying degrees of presence (Table 4).

Table 4. Basic floral assemblage of *Quercus faginea* selected trees in the Barranco El Horcajo.

SPECIES	2006				2022			
	Margin				Margin			
	Right		Left		Right		Left	
	5	10	5	10	5	10	5	10
Acer monspessulanum L.		■				■		
Allium triquetrum L.				■				
Brachypodium retusum (Pers.) P.Beauv	■	■	■	■	■	■	■	■
Dephne gnidium L.					■	■		
Erinacea anthyllis Link.	■	■	■	■	■		■	■
Genista scorpius L.	■	■	■					
Helictotrichon filifolium Lag.					■	■	■	■
Juniperus communis L.	■	■	■	■	■	■	■	■
Lavandula latifolia Medicus	■	■	■	■				
Pinus halepensis Mill.	■	■	■	■	■	■	■	■
Pinus nigra Arnold		■			■	■		
Quercus coccifera L.	■		■	■	■		■	■
Quercus faginea Lam.	■	■	■	■	■	■		
Quercus rotundifolia Lam.	■		■	■	■	■	■	■
Rhamnus lycioides L.			■	■				
Rosmarinus officinalis L.	■	■	■	■		■		
Stipa tenacissima L.	■	■	■	■				
Thymus spp.	■	■	■	■				

The presence of one or another type of lithology-soil (substrate) displays varying values, ranging from 61% of occurrences of rocky terrain within a 5-meter radius canopy on the left margin in 2006 to only 3% of occurrences on the right margin for the same year and canopy (Table 5).

Table 5. Percentage of lithology-soil in crowns of 1, 3, and 5 m associated to *Quercus faginea* selected trees in the Barranco El Horcajo.

	2006						**2022**					
	Margin						Margin					
	Right			Left			Right			Left		
Lythology	*1m*	*3m*	*5m*	*1m*	*3m*	*5m*	*1m*	*3m*	*5m*	*1m*	*3m*	*5m*
Clay-Sand	16	11	3	16	14	11	38	44	44	12	24	24
Mixture	47	51	51	36	36	29	44	44	44	35	29	18
Rocky	37	38	47	50	50	61	19	13	13	53	47	59

If we compare the left margin of the two years, the predominance of rocky terrain stands out, with the clay-sandy type generally being the least common. In the case of the right margin, the predominance is of the clay-sandy type in 2006, and this substrate is fairly evenly matched with the one defined as mixed (Figure 10).

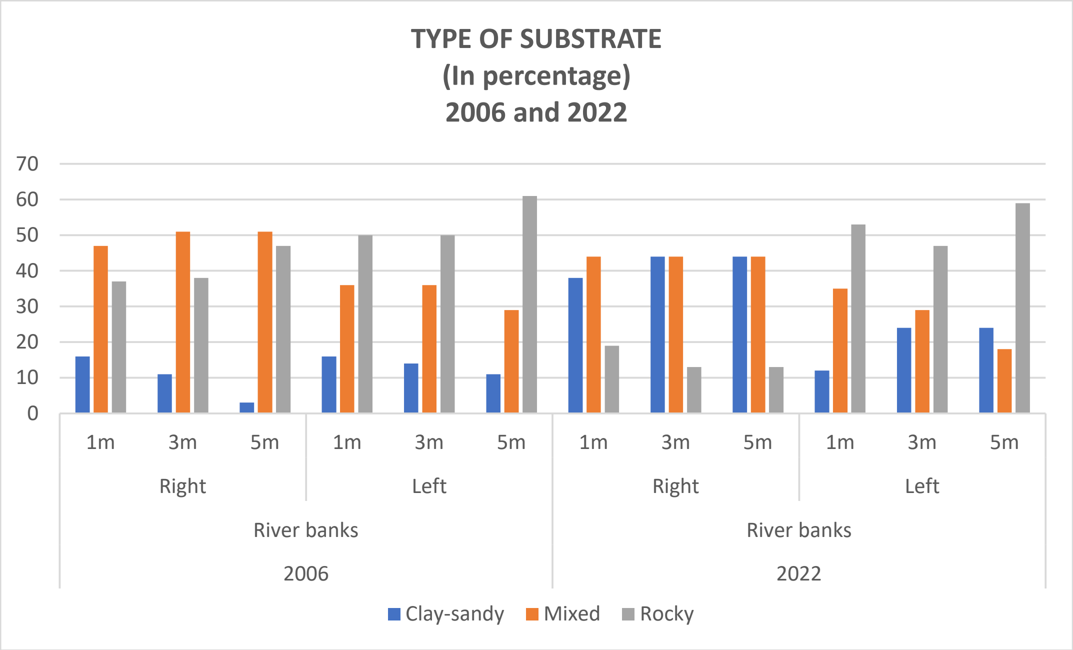

Figure 10. Distribution of lythology in percentage in crowns of 1, 3, and 5 m associated to *Quercus faginea* selected trees in the Barranco El Horcajo.

It is important to hightlight the location of small tree masses from 600 m of altitude up to 1300 m. All the small stands are located in riverbeds, sometimes ephemeral and at other times with continuous water flow (river), extending from the riverbed itself to the nearby slopes (Table 6). This circumstance coincides with what has been described for the warmer and drier areas of Spain (Alicante, Murcia, Almería, etc.), where oaks are primarily found in mountainous areas at the bottom of small valleys or ravines, where the best thermal and hydrological conditions create suitable microclimatic environments for their existence [18]. The terrains they grow on are predominantly oriented to the north. They all occupy the shady sides of the large mountains in the Region of Murcia. In agreement with Alcaraz Ariza et al. [19], it has been observed that the species inhabits soils that naturally have higher edaphic moisture.

Table 6. Geographic traits of different áreas where *Quercus faginea* tres can be found in the Región de Murcia.

Location	Altitude (m)	Orientation	Relief
Sierra de Salinas (Yecla)	1000-1100	Northeast	Ravine/Slope
Sierra de Villafuertes (Moratalla)	1250	North and East	Ravine/Slope
Río Mula (Bullas)	630	North	River/Slope
Carrascalejo (Bullas)	600	North	Ravine
Bco. Horcajo (Mula)	900-1300	North	Ravine/Slope
Sierra Espuña (Alhama de Murcia and yTotana)	800-1000	East	Ravine/Slope

It is important to note the structural drought that has been affecting the Region of Murcia for years, leading to the progression of desertification. This is exacerbated by the adverse effects of climate change that the region is experiencing, such as water scarcity and rising temperatures [27]. Arid climates in the Region of Murcia have been on the rise, with an increase in the average annual temperature of approximately 0.88°C between 1941 and 2019, both minimum and maximum temperatures affected by this rise. Regarding rainfall, no significant changes were observed, within the framework of variability typical of the Mediterranean region [28].

4. Conclusions

The Region of Murcia is facing a future scenario in which climate change will lead to rising temperatures and increased aridity. Precipitation is not expected to undergo significant variations in the near future. Extreme events, a higher number of heatwaves, longer summers, prolonged periods of drought, and torrential rains will become the norm in the future climate of the Region of Murcia [28]. In response to this situation, plant species undergo physiological changes as they continually adapt to the new conditions. Some wild plant species can serve as indicators of certain environmental changes. In the face of water scarcity and increased transpiration demands due to rising temperatures, some of these species experience water stress, which can severely reduce plant productivity [29].

Although the Region of Murcia is one of the driest regions in the Iberian Peninsula, with very low precipitation levels, there are small areas where soil moisture exceeds the general norm. This is the case in certain riverbeds or areas where rainfall exceeds the regional annual average of 300 mm, such as some inland mountains. These are the places where the located oak trees take refuge, exhibiting higher density in clearly mountainous enclaves like Sierra Espuña and Sierra de Pedro Ponce or in the vicinity of rivers, such as the Mula River in Bullas. Similar to other areas in Spain such as Catalonia, gall oak is associated with pine forests and some specimens of holm oaks (*Quercus rotundifolia*). Likewise, they can be found in shady areas, ravines, and sheltered valleys, and in the case of the Region of Murcia, on north and northwest-facing slopes [30]. The species, also described in North Africa (Morocco, Algeria, and Tunisia), shows interest due to similar conditions to those in the Region of Murcia, including tree distribution, the climate, mountainous areas with higher precipitation, and a terrain formed by a dense hydrographic network with notable elevation changes, likely serving as a refuge for North African specimens [31].

It has been observed through the evaluation of dendrometric parameters in the small stand located in the El Horcajo Ravine (Sierra de Pedro Ponce) that between 2006 and 2022, with increases in all parameters of *Quercus faginea*. There were no significant effects of climate change, as observed in the *Quercus* genera worldwide [32]. This suggests that the mountainous areas are less influenced by aridity.

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