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Relict oak forest of *Quercus greggii* (A. DC.) Trel. in the Potosino Plateau, Mexico

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ABSTRACT

Objective: *Quercus greggii* (A. DC.) Trel. is a representative species of the shrubby oak forest, ecologically important and poorly studied. Its presence was identified, characterized, quantified, and its distribution area was determined on Peñón Blanco Hill, Salinas, San Luis Potosí, Mexico.

Design/methodology/approach: Samples of *Quercus* specimens were collected and identified using dichotomous keys. Representative anatomical structures of the leaves were revealed through clearing techniques, venation was studied, and the stomatal index of each individual was calculated. The distribution of *Q. greggii* (n=25) was estimated by georeferencing each individual, projected onto orthophotos, and limited to 2.44 hectares.

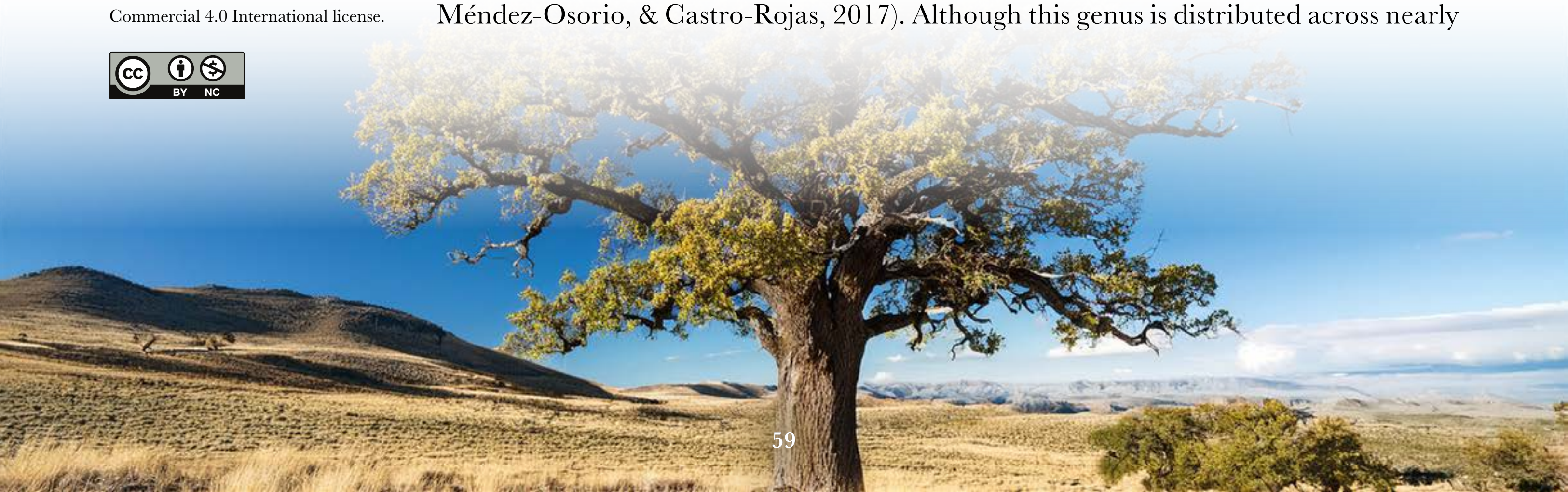
Results: The sampled trees were adults, with an average height of 7.5±1.8 m, a diameter at breast height (DBH) of 4.6 ± 1.8 m and 5.0±2.7 m in canopy coverage (CC). The canopy area was 85.30±67.6 m^2, and the breast height area was 397.5±0.027 cm^2. The average stomatal index was 4.8±1.3.

Findings/conclusions: The described population of *Q. greggii* is isolated, and the low rate of regeneration along with overgrazing in the area could pose a threat to its survival. Therefore, it is necessary to enhance knowledge about this species at the site to establish a management plan that ensures its long-term persistence.

Keywords: Arid zones; distribution of species; shrublands oak; vegetation relict, diversity.

INTRODUCTION

Globally, Mexico holds the greatest diversity of the genus *Quercus* in the Western Hemisphere (Scareli-Santos, Sánchez-Mondragón, González-Rodríguez, & Oyama, 2013), being home to approximately 150 species (Scareli-Santos *et al.*, 2013) and a significant number of endemic ones (Villaseñor, 2016; Mora-Donjuán, Burbano-Vargas, Méndez-Osorio, & Castro-Rojas, 2017). Although this genus is distributed across nearly



the entire country —except Quintana Roo— at altitudes ranging from 0 to 3,500 m.a.s.l. and in temperate, tropical, semi-humid, or semi-arid climates (Valencia, 2004; Rodríguez & Romero, 2007; Sabás-Rosales *et al.*, 2016), its diversity is mainly concentrated in areas with semi-dry temperate climates at altitudes between 1,201 and 2,700 m (Sabás-Rosales *et al.*, 2015). San Luis Potosí is considered one of the states with the highest diversity of oak species, hosting at least 45 species, including endemics such as *Quercus potosina* and *Q. ariifolia* (Badano *et al.*, 2019). Beyond its species richness, the Potosino-Zacatecano Plateau region contains relict forests with high genetic, ecological, scenic, and recreational value (García-Arévalo, 2008). These forests, evolutionary remnants of the original woodlands, represent a critical resource for the restoration of current ecosystems (CONAFOR, 2019). While some relict species, such as *Picea chihuahuana* (Pinedo-Álvarez *et al.*, 2019; García-Arévalo, 2008; González-Elizondo *et al.*, 2007; Gordon, 1968; Martínez, 2018), *Abies* spp. (Requena-Lara *et al.*, 2020), and *Quercus* spp. (Flores, 2007; Ignacio-Ruiz *et al.*, 2014; Ramos, 2014), have been studied, further research is required to enhance our understanding of their current status, biodiversity, ecology, and threats. This knowledge is essential for establishing management plans to ensure their future persistence, particularly because these ecosystems are isolated, fragile, and highly vulnerable to climate change (Pineda *et al.*, 2013; Requena-Lara *et al.*, 2020).

Quercus greggii (A. DC.) Trel. is a significant species within chaparral or shrub oak forests, where it plays a fundamental ecological role (Rzedowski, 1965). Its contributions to ecosystem functioning include carbon sequestration and storage, regulation of water and oxygen cycles, climate stabilization, and the maintenance of soil fertility (CONAFOR, 2019). These functions highlight the importance of this species in sustaining the ecological balance of the regions it inhabits.

The natural distribution of *Q. greggii* is primarily associated with shallow soils located on summits and convex slopes, where it thrives in specific environmental conditions (Giménez & González, 2011). It is particularly prevalent in mixed forest areas across Charcas, Catorce, Guadalcázar, and Zaragoza (Rzedowski, 1965; Giménez & González, 2011; Sabás-Rosales *et al.*, 2015). Despite its wide distribution and ecological importance, this species has received limited scientific attention, leaving significant knowledge gaps regarding its populations, particularly those found in relict forests within the Potosino-Zacatecano Plateau (Cabrera-Rodríguez *et al.*, 2019). To address these gaps, this study focused on identifying, characterizing, quantifying, and mapping the distribution of *Q. greggii* in the region of El Peñón Blanco Hill, San Luis Potosí, Mexico. This research aims to provide a comprehensive understanding of this species and contribute to the development of conservation and management strategies.

MATERIALS AND METHODS

Area of study. The study area is situated in the region of El Peñón Blanco Hill, San Luis Potosí, Mexico (Figure 1), covering a total of 604 hectares. The vegetation in this area is primarily characterized by shrub oak forests, dominated by *Quercus greggii*, *Q. eduardii*, *Q. tinkhamii* and *Q. potosina* (Rzedowski, 1998; Cabrera *et al.*, 2019). Additional vegetation

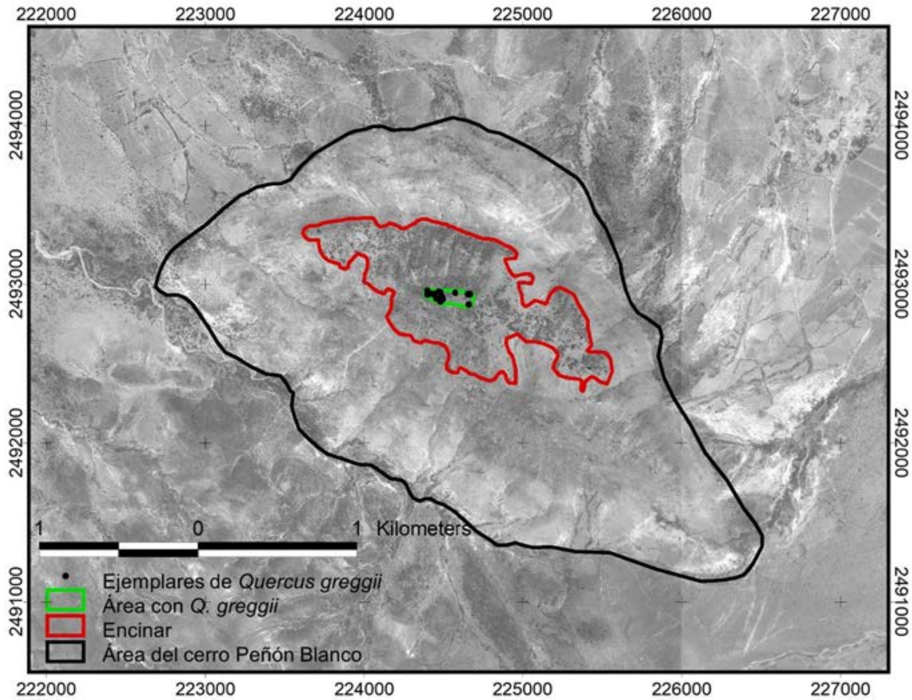


Figure 1. Distribution of *Quercus greggii* on El Peñón Blanco Hill, Salinas, San Luis Potosí. Based on orthophoto F14A61F provided by INEGI (2015). Coordinates in UTM WGS84, Zone 14Q.

types include thornless-crassifoliate shrubland, crassicaulous-thornless shrubland, and natural grassland (CETENAL, 1971; INEGI, 2016). The region's climate is classified as dry desert (BS1kw) with summer rains, an average annual temperature of 16 °C, and mean annual precipitation of 335 mm (CONAGUA, 2018). The elevation ranges from 460 to 2,765 m.a.s.l. (INEGI, 2017), and the geological composition reflects acidic igneous rocks from the Tertiary period in the higher altitudes, transitioning to limestone-shale and shale-sandstone formations in the lower regions. The soil is predominantly thin and classified as Leptosols, with smaller areas of Phaeozem (CETENAL, 1971). This combination of diverse vegetation, climate conditions, and geological features makes El Peñón Blanco Hill an ecologically significant and unique site for studying the distribution and characteristics of local plant species.

Identification and characterization. In February 2015, a field visit was conducted to the study area, during which 12 individuals of the genus *Quercus* were randomly selected for analysis. Morphological variables were recorded for each specimen, including total height (m), two aerial diameters (measured using a Qualitäts–bandmaß measuring tape), diameter at breast height (DBH, 1.30 m), and altitude (measured with a Garmin Etrex GPS). Aerial and basal coverage were subsequently calculated using the formulas for the area of an ellipse and a circle, respectively.

Based on the identified *Q. greggii* individuals and the surface area where they were located, the population density of the species was estimated. Descriptive statistics, including mean, standard deviation, maximum, and minimum values for each morphological variable, were calculated and are presented in Table 1. To ensure accurate species identification,

Table 1. Mean and standard deviation of altitude, total height, DBH, canopy coverage (CC) and circumference at breast geight (CBH) of relict white oaks (*Quercus greggii*, n=12) located on El Peñón Blanco Hill, San Luis Potosí, Mexico.

Variable	Average	Standard Deviation	Minimum Value	Maximum Value
Altitude (msnm)	2733.8	5.95	2724	2739
Height (m)	4.6	1.81	0.93	7.50
DBH, cm	20.9	8.6	1.2	34.00
CC, m^2	85.3	67.64	0.5	252.30
CBH, cm^2	397.50	907.9	1.13	266.02

flowers and fruits were collected from each specimen (Figure 2). Identification as *Quercus greggii* was confirmed through the use of dichotomous keys proposed by Zavala (1989) and cross-referenced with records from the Herbarium of the Autonomous University of Aguascalientes (HUAA; record 29455). This comprehensive approach allowed for precise characterization of the selected *Quercus* specimens and provided a foundation for further ecological analysis. In this regard, each leaf was cleared based on the method suggested by Castellano *et al*. (2007), replacing the immersion in 5% chloral hydrate of the leaf's adaxial surface with dissection. The cleared structures were observed under a microscope (40x, VELAB, model VE-B2) and described according to the criteria proposed by González and Améndola (2010), where:

$$SI = \left(\frac{NS}{(NS + NE)}\right) \times 100$$

Where: *SI*=Stomatal Index, *NS*=Number of stomata per field, and *NE*=Number of epidermal cells per field (40x). To determine the venation levels, microphotographs (Canon EOS, model Rebel T3i) of the veins, cells, and stomata were taken, following the guidelines established by Rodríguez and Romero (2007).

Quantification: The *Q. greggii* specimens were quantified through exhaustive sampling across the entire study area, locating all individuals of this species.

Figure 2. Specimens of *Quercus greggii* (A. DC.) Trel. on El Peñón Blanco Hill, Salinas, San Luis Potosí, Mexico.

Determine the distribution: Based on the geographic coordinates recorded with a Garmin GPS for each specimen, a polygon was drawn considering the peripheral individuals. This was done using Google Earth, saved in KMZ format, and later converted to Shapefile format to obtain the area with the presence of *Q. greggii*.

RESULTS AND DISCUSSION

A total of 25 white oaks (*Quercus greggii* (A. DC.) Trel.) were identified within the El Peñón Blanco Hill area, San Luis Potosí, Mexico. The morphological variables of these specimens, including altitude, total height, diameter at breast height (DBH, measured at 1.3 m), canopy coverage (CC), and circumference at breast geight (CBH), are summarized in Table 1.

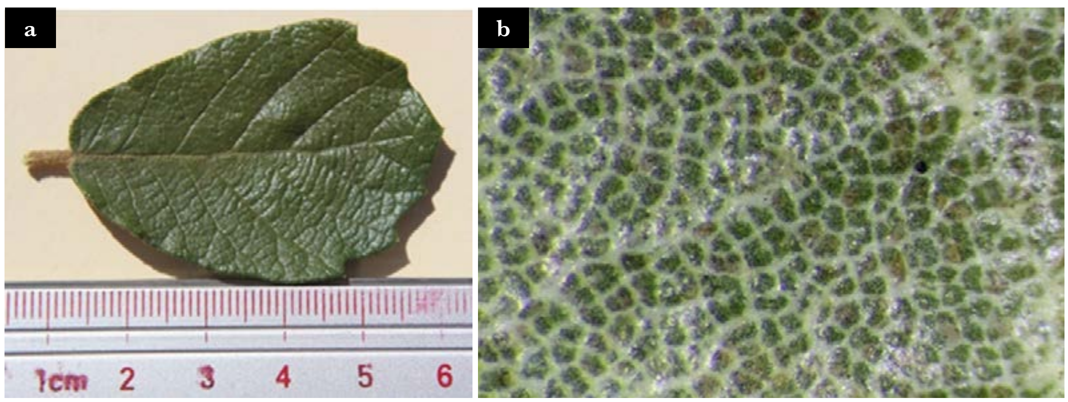
Based on the data collected from the 12 randomly selected *Quercus greggii* specimens, the recorded height ranged from 0.93 to 7.5 m, with a mean of 4.6 m. The width of the specimens varied between 0.17 and 11.0 m, with an average of 5.0 m. The diameter at breast height (measured at 1.3 m above ground level) ranged from 1.2 to 34 cm. The mean canopy coverage was calculated as 85.3 m^2, while the average circumference at breast height was 397.5 cm.

These specimens were located at an average altitude of 2733.8 m, with a standard deviation of 6 m (Table 1). This comprehensive morphological dataset provides critical baseline information for understanding the ecological characteristics of this relict population.

In the study area, the oak forest extends over 97.7 ha, with the specific area occupied by the species under study covering 2.44 ha. A total of 38 individuals of *Quercus greggii* were identified, yielding a population density of 15.6 individuals per hectare. This area is also shared with *Q. potosina*, which was not included in the scope of this study; therefore, no data are available for this species within the area.

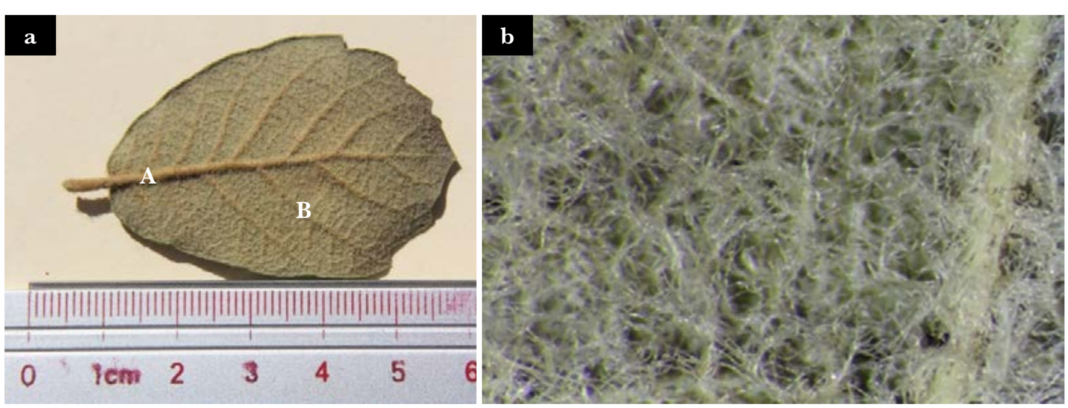
Figure 3. Herbarium specimen of *Quercus greggii* (A. DC.) Trel. housed at the Herbarium of the Autonomous University of Aguascalientes.

The *Quercus greggii* specimens exhibited twigs measuring 2 to 4 mm in diameter, ranging from pubescent to glabrescent. The buds were ovoid, with rounded to obtuse apices, brown to reddish-brown in color, and measured 2 to 3 mm in length. They were accompanied by subulate stipules 5 to 6 mm long, which were pubescent on both surfaces. The mature leaves (Figures 4 and 5) had petioles that were brown to dark reddish, measuring 5 to 9 mm in length. The leathery leaf blades were obovate, oblong-obovate, or oblong-elliptic, with thickened, revolute, entire margins featuring 1 to 5 mucronate teeth on each side. The adaxial surface was olive green, slightly dark, rough in texture, and slightly glossy, while



a) Complete leaf (adaxial surface). Photograph taken with a Nikon D3400 camera in macro position.
b) Close-up of the adaxial surface. Photograph taken using a Leica M60 KL 200 LED microscope, with 4.0x magnification, and a Canon EOS Rebel T3i camera with an 18-55mm lens in macro position, viewed through the eyepiece.

Figure 4. *Quercus greggii* (A. DC.) Trel. leaf: complete leaf (a) and close-up of the adaxial surface (b), El Peñón Blanco Hill, Salinas, San Luis Potosí.

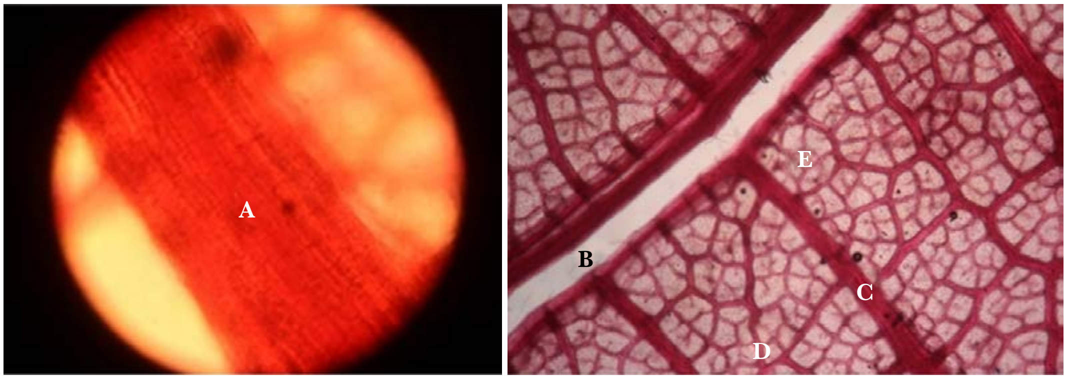


a) Primary vein (A) and secondary vein (B). Complete leaf (abaxial surface). Photograph taken with a Nikon® D3400 camera in macro position.
b) Close-up of the abaxial surface. Photograph taken using a Leica M60 KL 200 LED microscope, with 4.0x magnification, and a Canon EOS Rebel T3i camera with an 18-55mm lens in macro position, viewed through the eyepiece.

Figure 5. *Quercus greggii* (A. DC.) Trel. leaf: complete leaf (abaxial surface) (a) and close-up of the abaxial surface (b), El Peñón Blanco Hill, Salinas, San Luis Potosí.

the abaxial surface (Figure 5) was slightly glaucous and reticulated, with an epidermis that appeared slightly to highly blistered. The fruits matured annually, producing 1 to 2 nuts per season. The nuts were ovate-elliptic, measuring up to 17 mm in length and 9 to 11 mm in diameter. The cupule was hemispherical with a straight edge, and the scales on the lower half were thickened at the base, occasionally obtuse to rounded, and densely pubescent to puberulent at the apex.

According to Rodríguez and Romero (2007), the venation pattern observed in the *Quercus greggii* specimens corresponds to a mixed craspedodromous-camptodromous type (Figures 4 to 6). The number of stomata per field of view at 40x magnification ranged from 153 to 166, while the number of epidermal cells varied between 459 and 512, with averages of 159.7 and 483.8, respectively (Figure 7, Table 2). These values exceed those reported by Rodríguez and Romero (2007), which ranged from 17 to 22 stomata and 20 to 30 epidermal cells. The stomatal index observed ranged from 23.0 to 26.5, with an average of 24.8. While these values fall within the range (19-42) reported by Rodríguez



Primary vein (A), secondary vein (B), tertiary vein (C), quaternary vein (D), and quinquenary vein (E).

Figure 6. Venation of *Quercus greggii* leaves, photographed with a Canon EOS Rebel T3i camera, 18-55mm lens in macro position and observed through the 4x lens (primary vein) and other veins at 10x magnification using a VELAB® VE-B2 microscope.

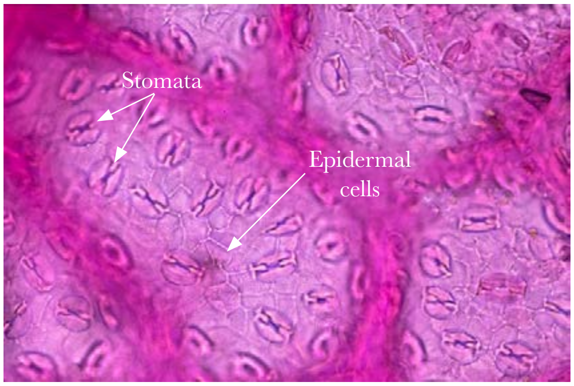


Figure 7. Stomata and epidermal cells on the adaxial surface of *Quercus greggii* leaves. Photograph taken with a Canon® EOS Rebel T3i camera, 18-55mm lens in macro position, viewed through the 40x lens of a VELAB® VE-B2 microscope.

Table 2. Number of stomata, epidermal cells, and stomatal index (SI) of *Quercus greggii* leaves on El Peñón Blanco hill, Salinas, San Luis Potosí.

Observation repetition at 40x	Stomata	Cells	SI
1	161	496	24.5
2	153	512	23.0
3	164	487	25.2
4	166	459	26.6
5	156	474	24.8
Minimum	153	459	23.0
Maximum	166	512	26.5
Average	159.7	483.8	24.8
Standard deviation	5.4	20.3	1.3

and Romero (2007) for the Lobatae section, they are lower than the values of 36-47 previously reported for this species by the same authors. In comparison, Arambarri *et al.* (2009) documented an average stomatal index of 4.62-24.03 for 25 tree species. Regarding venation, the secondary veins emerged at angles of 45-65° from the primary vein. Tertiary veins typically branched off at angles of 90° from the secondary veins, while the quaternary veins formed a reticulate pattern, originating at angles of 90-100° from the tertiary veins and branching at angles of 45-140°. Similarly, the quinary veins also displayed a reticulate pattern, branching at angles of 50-160° (Figure 6). These results align with those previously reported by Rodríguez and Romero (2007) for *Q. greggii* specimens from San Luis Potosí. For comparison, Borri, Wagner, and Varela (2017) described the venation in *Scutia buxifolia*, where the primary vein was equivalent to the tertiary vein in this study, the secondary vein represented the second-order vein, and the ultimate marginal vein corresponded to the quinary vein.

Specimens of *Q. greggii* were identified on El Peñón Blanco hill, located in the physiographic subprovince of the Potosino-Zacatecano Plains and Sierras, extending its distribution southward in the Potosino Plateau (Cabrera *et al.*, 2019). The nearest previously recorded location of this species (150 km in a straight line) is reported in Sierra Catorce (González *et al.*, 2007), which is situated in the physiographic subprovince of the Western Sierras and Plains. According to information published on www.naturalista.mx, the closest locations where *Q. greggii* has been reported are 150 km away in Sierra Catorce, 290 km in Cadereyta, Querétaro, and 325 km in the Zapalinamé Sierra, Coahuila. Zavala (1998) mentions the presence of *Q. greggii* in the central region of the country, which includes San Luis Potosí, but without specifying the exact location, something similar to what Pérez and Valencia (2017) state. Similarly, Sabas *et al.* (2015) include Salinas among the municipalities with the presence of one or two species, and Uribe-Salas *et al.* (2019) note that *Q. greggii* is present in the state of San Luis Potosí, but without providing a specific location. Among the localities mentioned by Villaseñor (2016) as having the presence of *Q. greggii*, neither El Peñón Blanco nor the municipality of Salinas is included. Rodríguez and Romero (2007) mention specimens of *Q. greggii* in the municipalities of Cerro de San Pedro and Catorce (Sierra Catorce) but do not specify the exact locations.

On El Peñón Blanco Hill, the density of *Quercus greggii* was recorded at 15.6 individuals ha^{-1}, with a sapling density of 44.6 individuals ha^{-1}. This sapling density is lower than the 57 individuals ha^{-1} reported for the Zapalinamé Sierra by Encinas *et al.* (2009). The average height of *Q. greggii* specimens was 4.6 m, with a variance of 1.8 m, which is also lower than the height range reported for the Zapalinamé Sierra (8-10 m; Encinas *et al.*, 2009). Similarly, the observed height is below the growth habit range described on the "Oaks of the World" website (http://oaks.of.the.world.free.fr/quercus_greggii.htm), which indicates an average height of 5-7 m, though several specimens from El Peñón Blanco exceeded this range (Table 1). The average canopy coverage of the sampled trees was 85.3 m^2, with a variance of 67.6 m^2. The average diameter at breast height (1.3 m above ground) was 20.9 cm, with a variance of 8.6 cm. Notably, the trunks of these trees were thicker than those reported in the Zapalinamé Sierra, Coahuila, where trunk diameters ranged from 5 to 10 cm (Encinas *et al.*, 2009). The altitude of the study site ranged from 2,724 to 2,739 m, a narrow interval that falls within the altitudinal ranges documented by other authors: 2,000-2,900 m (Valencia, 2004), 2,280-2,600 m (Encinas *et al.*, 2009), and 2,600-3,200 m (Giménez & González, 2011). These results indicate that the population of *Q. greggii* on El Peñón Blanco exhibits unique characteristics within the broader ecological context of this species.

Shrub oak forests in the Potosino-Zacatecano Plateau region are rare and locally distributed as relict ecosystems on isolated hills and mountain ranges (Rzedowski, 1965). The presence of *Quercus greggii* within these areas can be attributed to the high variability of the genus *Quercus*, as highlighted by Valencia (2004), among other environmental factors. On El Peñón Blanco Hill, *Q. greggii* is primarily associated with *Q. potosina*. The distribution of these species appears to be influenced by altitude, physiography, and climate, similar to the case of *Picea chihuahuana*, whose presence has been linked to factors such as aspect, slope, and proximity to water flows (Aguilar-Soto *et al.*, 2015). At El Peñón Blanco, *Q. greggii* occurs on granitic porphyry rocks (SGM, 2007), consistent with findings by Sabás-Rosales *et al.* (2015), who reported the species growing on lower cretaceous limestone sedimentary rocks, quaternary sandstones, and tertiary igneous rocks such as granite. The soil at this site is classified as lithosol with a lithic phase (CETENAL, 1971). Based on the profile specifically analyzed for this study, the soil corresponds to epipetric leptosols (WRB, 2014) and lithic torriorthents (SSS, 2014). In Sierra Catorce, *Q. greggii* has been documented on a variety of soil types, including phaeozems, lithosols, and rendzinas (Sabás-Rosales *et al.*, 2015), as well as regosols and leptosols (Giménez & González, 2011). These findings underscore the species' ability to adapt to diverse geological and edaphic conditions, reflecting its ecological resilience and significance within relict oak forests.

The discrepancies between our results and those reported by Rodríguez and Romero (2007) regarding the number of stomata, epidermal cells, and potentially the stomatal index may stem from methodological differences. Specifically, our study was limited to a maximum magnification of 40x due to the unavailability of a higher-powered microscope. In contrast, Rodríguez and Romero (2007) conducted their analysis at 100x magnification, which provided a smaller field of view and likely allowed for more precise counting and differentiation of these structures compared to the broader field of view at 40x.

Relict vegetation areas, though typically small, hold considerable ecological significance as they serve as vital genetic reservoirs for the preservation of species adapted to these fragile ecosystems (García-Arévalo, 2008). These ecosystems are highly isolated and vulnerable to changes in climate and land management practices (Pineda *et al.*, 2013; Requena-Lara *et al.*, 2020). Ramos (2014) highlights that forests are significantly impacted by land-use changes, such as conversion for agricultural or mining purposes, which disrupt soil properties, reduce water infiltration, and adversely affect forest species. Consequently, relict oak forests, such as those found on Peñón Blanco Hill, are often surrounded by degraded landscapes. A relict ecosystem is considered "disabled" when it loses its ability to regenerate naturally (Ramos, 2014), a condition often resulting from inadequate self-regeneration or competition with other species (Carlos-Arévalo, 2014). This appears to be the situation on Peñón Blanco Hill to some extent. The relict oak forests of the Potosino-Zacatecano Plateau are typically located on isolated hills and sierras (Rzedowski, 1961; Cabrera-Rodríguez *et al.*, 2019), which contributes to their ecological fragility. Despite these challenges, Peñón Blanco Hill functions as a phyto-refuge for at least four oak species, providing them with the necessary ecological conditions to persist. However, the presence of domestic livestock, including sheep and goats (with observed herds exceeding 100 individuals), horses, and cattle, poses a significant threat to the regeneration of this isolated forest. Similar issues have been reported in the Sierra de Álvarez, San Luis Potosí (Ramos, 2014), where factors such as low production of viable acorns, acorn predation by parasites or livestock, and seedling mortality due to grazing and unfavorable climatic conditions hinder the natural regeneration of oak forests.

Climax species within relict forests are increasingly confined to smaller and more isolated areas, as observed in the Sierra Madre Oriental and Occidental (Flores-Cano, 2007). The oak forests of Peñón Blanco Hill face comparable pressures, particularly from domestic livestock, which exacerbates their vulnerability and threatens their ecological sustainability. These findings underscore the urgent need for effective conservation strategies to mitigate anthropogenic impacts and promote the long-term preservation of these relictual ecosystems.

Borrell *et al.* (2019) mention that species refuges have been suggested as priority sites for conserving global biodiversity under climate change due to their ability to facilitate species survival in adverse conditions (Meister *et al.*, 2005) and to help build future evolutionary resilience (Sgrò *et al.*, 2010). Anthropogenic pressure on steep terrains induces erosion, with a globally estimated loss of 50-200 Pg of soil each year. Additionally, there is growing evidence that Neolithic populations had already fundamentally altered landscapes worldwide and that today only completely inaccessible ecosystems remain without a direct human footprint (Steven *et al.*, 2017). The oak forest on El Peñón Blanco hill and in the Potosino-Zacatecano Plateau may be affected by some of the factors mentioned by Gordon (1968), which threaten *Picea chihuahuana* with extinction. These factors include having a very specific ecological niche, the lack of a continuous corridor, regeneration issues, and a long time to reach sexual maturity, among others. This further justifies the need to establish a management plan for these oak forests and to conserve them by declaring them protected natural areas, at least at the municipal level.

CONCLUSIONS

The *Quercus greggii* oak forest on El Peñón Blanco Hill holds considerable biodiversity significance. This forest is isolated, exhibits low repopulation rates, and is subject to intense anthropogenic pressure and overgrazing, rendering it highly vulnerable. These factors collectively cast doubt on its long-term survival. Nevertheless, El Peñón Blanco Hill can be regarded as a phyto-refuge or biodiversity hotspot at the state level and within the Potosino-Zacatecano Plateau, as it provides the specific ecological conditions necessary for the persistence of the oak species it supports. To ensure the long-term survival of this oak forest, it is crucial to develop and implement a comprehensive management plan. Such a plan should prioritize the mitigation of overgrazing, the protection of acorns from consumption, and the promotion of natural repopulation processes. These measures are essential to preserve the ecological integrity and biodiversity of this relictual oak forest.

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