Ixtlán de Juárez, Oaxaca 30 of January of 2025

To: International Oak Society (IOS)

First, I want to express my immense gratitude for the grant of the project, which has allowed us to expand a lot our knowledge about the amazing species ***Quercus macdougalli*** Martínez. This wonderful species has occupied 10 years of our research, and we will continue studying it in the coming years. It is in the 12th most biodiverse region in the world, according to WWF, in the most conserved and incredible forests of Mexico, in the Sierra Juárez, home to over 20 species of oaks. This place has been my home for 18 years, where, from a small university "Universidad de la Sierra Juárez" in Oaxaca state located in the region, this team began to study this species.

I would like to clarify that this report details that I will outline below. As I mentioned in the partial report sent in December, there were still some details missing in the final report:

1.- We corrected errors in the database and added more individuals from a census conducted at the end of last year in San Pedro Yólox (Attachment 1). The altitude in each individual is not precise, this is how the GPS works because the variations of terrain are meters between points to point of tree to tree.

2.- The article sent to Maderas y Bosques Journal is attached; (Attachment 4). Supporting documents demonstrating that it was sent are also included.

3.- Videos made in the two communities are included. Although they are simple, they will be uploaded to the social media of the communities and the University. The videos are in English and Spanish, and we have translators for both languages (Zapotec and Chinantec). However, the communities have pointed out that the script needs revision, as there are nonexistent words. They will work with us in the coming months to correct it. Zapotec, spoken by very few people in Ixtlán de Juárez, and Chinantec, which is not written, will take several months to translate. We hope you can be patient, as we will add these translations to the video. We did not anticipate that these languages would be so different from Spanish and English (Attachment 6)

3.- A photographic record and videos of the two exhibitions and material used in the UNSIJ communities, and the adult workshops are presented, along with a list of participants (Attachment 2).

4.- The authorities of administration provided me the financial report from the Universidad de la Sierra Juárez and I'm sending with this report. (Attachment 5). As I mentioned earlier, there were leftover funds many times. With prior information to Amy, the surplus money was used to print photos and exhibition materials, both other GPS and satellite photograph were bought. A big part of the funds was also used to cover food and fuel expenses during the workshops in December, as well as during field trips for the 30% populations census in the last year in the three communities. I want to report that there was a remaining balance; I decided not to return it and to convert it into gas vouchers. It was invoiced in December, but it was used for a field trip to collect more data in San Pedro Yólox and to visit the communities where the workshops and photographic exhibitions were held in January. I hope this is not a problem, as the school went on vacation on December 19. According to the agreement, the funds had to be spent before the 31st.Finally, we believe we have fulfilled all our commitments, and we hope that the final report meets your satisfaction. **Please**, **Lastly, the photos and video of the children (is prohibited by law in Mexico to show the face of the children) and for this reason, cannot be published or disclosed, as it is prohibited by law in Mexico; they were sent as supporting material only, sorry for this by is the law in Mexico**. Additionally, we added more Photo of Yólox in Attachment 3.

What follows:

Although they committed to conducting two workshops, these will take place in March or April probably in the community of San Pedro Yólox. While these are not part of the original project (only two were committed), we will provide you with the results for children again of this community.

In 2025, we will send an article for publication regarding the workshops and the evaluations of the children. We will also share this information with you as part of the work of the biology students (704 group), who supported the workshops as part of their training, as the students are also from the region.

In February, there will be a presentation in a webinar of IOS about the population structure and regeneration of ***Quercus macdougal*****lii** throughout its distribution range in Sierra Juárez, Oaxaca. A project titled "Working with local communities to conserve ***Quercus macdougallii***, a biocultural heritage of Sierra Juárez, Oaxaca, Mexico. What have we done?" has been proposed to the Global Conservation Consortium for April probably. The following talks are intended to be proposed for presentation at the IOS congress, which will be held in October of next year here in Oaxaca:

1. Nelly Pacheco Cruz: Initial exploration of genomic variation, association with environmental factors, and potential distribution of ***Quercus macdougallii*** Martínez in Sierra Juárez, Oaxaca.
2. Jorge Campos Contreras: Diversity of mycorrhizae associated with the endemic oak ***Quercus macdougallii*** in Oaxaca, Mexico.
3. Juan José Von Thaden Ugalde: ***Quercus macdougallii***: Exploring habitat potential, land-use dynamics, and climate change challenges.
4. Tania Martínez León: Population genomics and land-use change of the most threatened oak in Mexico: ***Quercus mulleri***.

5. Discovering the Wild cats' lives in *Quercus macdougalli* forest. Itaí Moreno Arellano.

In October, the master's thesis of student Paola Montserrat de los Angeles Rodríguez, will be ready, as well as an new article that will also be submitted."

We will continue studying genetics simultaneously, as we are the same work group.

During my sabbatical next year, I plan to develop the tissue culture technique for the development of potential seedlings. I am seeking financial resources for a genetic study to determine whether the sprouts are sexual or clonal origin and explore more the genetic diversity using GBS and SNPs.

Finally, we will continue working to ensure that people, especially children, take ownership of this species. We have selected the community of Ixtlán to establish a nursery in the future. Next year, we will want to work on a project to continue fieldwork in the middle zone, but above all, to work in Ixtlán de Juárez with children and authorities so that the species is firmly established as part of their biocultural heritage and is key to its conservation in the next decades. We will seek funding for this, as it requires resources.

All information will be shared with IOS in the future because for me is important to keep in touch and again my immense gratitude for the grant *Quercus macdougalii* is an amazing species that deserve to continue existing and is the heritage from this place, Mexico and all of us.

Greeting

Cecilia Liana Alfonso Corrado
Prosessor
Universidad de la Sierra Juarez

" FINAL REPORT (2023-2024) OF THE PROJECT"

" FINAL REPORT (2023-2024) OF THE PROJECT"

“Conservation of micro-endemic *Quercus macdougalli* Martínez, in Sierra Norte, Oaxaca, México

Cecilia Liana Alfonso Corrado

Introduction

With about 500 species distributed in Eurasia, Africa, and the Americas, mainly in the temperate and subtropical regions of the Northern Hemisphere, the oaks, members of the genus *Quercus* L. (Fagaceae), are the largest genus of this family (Nixon, 1998). The genus diversified primarily in two centers: China and Mexico. Mexico was in the first position, accounting for 32.8% of the total oak species, with about 165 species, among which 110 are endemic (Nixon, 1998; Valencia, 2004; Romero-Rangel et al., 2015; de la Luna-Bonilla et al., 2024). Mexico's top species richness is due to Mexican speciation, which results from the local orographic, climatological, and edaphic conditions (Nixon, 1998). Taxonomically, Mexican oaks are grouped into three sections, namely, Sections I. Lobatae (the red oaks); II. Protobalanus (golden or intermediate oaks); and III. Quercus (white oaks); the Quercus Section has the highest diversity (Romero-Rangel et al., 2015; Cavender-Bares, 2018). Towards the north end of this section traces endemism, especially the microendemic varieties, are found in this section, many confined to very limited geographic space as in the case of *Quercus macdougalli*.

Quercus macdougalli Martínez was described in 1963 by the well-known botanist Maximino Martínez (1888-1953) in honor of Thomas Macdougall, a Scottish botanist who visited Oaxaca and collected specimens of this oak (Pacheco-Cruz, 2019). This species, which is highly endemic and vulnerable, is primarily found in the Sierra Norte de Oaxaca and, specifically, Ixtlán de Juárez (*Yaa dua yu* in Zapotec), Santiago Comaltepec (*Ma kue* in Chinantec), and San Pedro Yólox Communities). In this area, its geographical and altitudinal distribution are limited from 2,600 to 3,100 meters above sea level (Clark-Tapia et al., 2018; Pacheco-Cruz, 2019).

Recent research (Clark-Tapia et al., 2018; Pacheco-Cruz, 2019) has highlighted major pressures on the long-term persistence of this species. For example, studies using single nucleotide polymorphisms (SNPs) and next-generation sequencing technology indicated low genetic diversity (*H_e* = 0.2) and tentative population structuring. The studies also showed an extremely low effective population size and low regeneration rates. In both last two years (2023-2024), no acorn o very low productions have been reported due to the abortion of acorns from parent trees. (Personal Observation) *Q. macdougalli* hasn't been producing viable acorns for five to ten years, likely a result of climate change, as it ranges in altitude from 2,600 to 3,100 meters above sea level and its former range is too high to migrate upward to avoid rising temperatures.

Additionally, individual extraction and wildfires have hit the species hard in the Santiago Comaltepec area in the past few decades, negatively impacting its populations in 1982 and 1998 (Clark et al. 2018; Pacheco-Cruz, 2019). Recently the study in the field, rediscovering past fires in Ixtlán de Juárez and San Pedro Yólox. Additionally, raising cattle and the appropriate management of forests in focus in pines industries seem to aggravate the decrease in Santiago Comaltepec oaks.

In the other hand, *Quercus macdougalli* is a keystone species in three locations (Ixtlán de Juárez, Santiago Comaltepec, and San Pedro Yólox) and provides sources of associated biodiversity, water, and soil (Clark-Tapia et al., 2018; Pacheco-Cruz, 2019). Its economic value lies in carbon payment schemes in Santiago Comaltepec and ecotourism in Ixtlán de Juárez, while its biocultural significance is particularly high in Ixtlán de Juárez. Elements of both *in-situ* conservation and the biocultural heritage of the communities where *Q. macdougalii* occurs were the focus of this project, which sought to understand important aspects of the species' biology.

The original proposal for the project consisted of establishing different objectives focused on the biology of the species. These were: 1) knowing its current total distribution, 2) assessing the impact of climate change on its populations, 3) analyzing the population structure, 4) identifying the variables that affect its abundance and distribution, 5) understanding its regeneration from fructification to the establishment and growth of seedlings, since it has not produced seeds in the last five years, and 6) training and raising awareness among the local population about the importance of this oak, not only ecologically but also as a process of biocultural inclusion of the species.

However, considering the issue of acorn production failure, the following objectives were redefined: In 2023, after many years, the species produced acorns in low quantities. After identifying the acorn-producing trees, the process was initiated, but massive abortion of the acorns prevented further progress and hindered the achievement of goal 5. The cause of the acorn loss is unknown, and this issue also occurred with many species in the Sierra Juárez, such as *Q. castanea* and *Q. crassifolia*. However, one suspicion is that climate warming and anthropogenic processes in the study area may be contributing factors. This year, the production was very low, and to date, acorns are still being aborted again.

Therefore, the new objectives have been proposed and accepted.1)Knowing its Current Distribution; 2) The impact of Climate Change on its population, 3) The population structure, 4) Identifying the variables that affects its abundance and distribution, 5) Analysis of Forest Cover Change between 1972-2022 in *Q. macdougalli* habitat zones, 6)Population Dynamic Analysis and Passive restoration 25 years after a *Quercus macdougallii* (Fagaceae) fire in Santiago Comaltepec, 7) Two theoretical and practical workshops will be held where the importance of the biological tree is explained to children, youth, and adults, as authorities in which the following points will be addressed: involving constant care of the populations with a vision to the future of inserting the tree as a biocultural heritage and in the future have a nursery of seedling.

Knowing its Current Distribution, and the impact of Climate Change in *Q. macdougalli* habitat zones. Objective 1 and 2.

Methodes

During multiple field outings, the coordinates of 91 individuals of *Q. macdougallii* were recorded. These records were supplemented with data from international databases such as the Global Biodiversity Information Facility (GBIF) (https://www.gbif.org), adding 10 additional records, resulting in a total of 101 presence records. It is important to note that the distribution analysis under current and future climate change scenarios was conducted only for the Sierra Juárez, Oaxaca, Mexico, once the endemism of the species for this region was validated in the field. To ensure data quality, software ENMTools was used to eliminate duplicate records. Additionally, we applied a 10 km distance filter on the presence points with the aim of mitigating spatial autocorrelation and model overfitting (spThin package in R 4.10. This allowed us to reduce biases due to oversampling in specific regions, ensuring a better representation of the environmental combinations of the species' ecological niche. Only the occurrence records of *Q. macdougallii* were used for model construction.

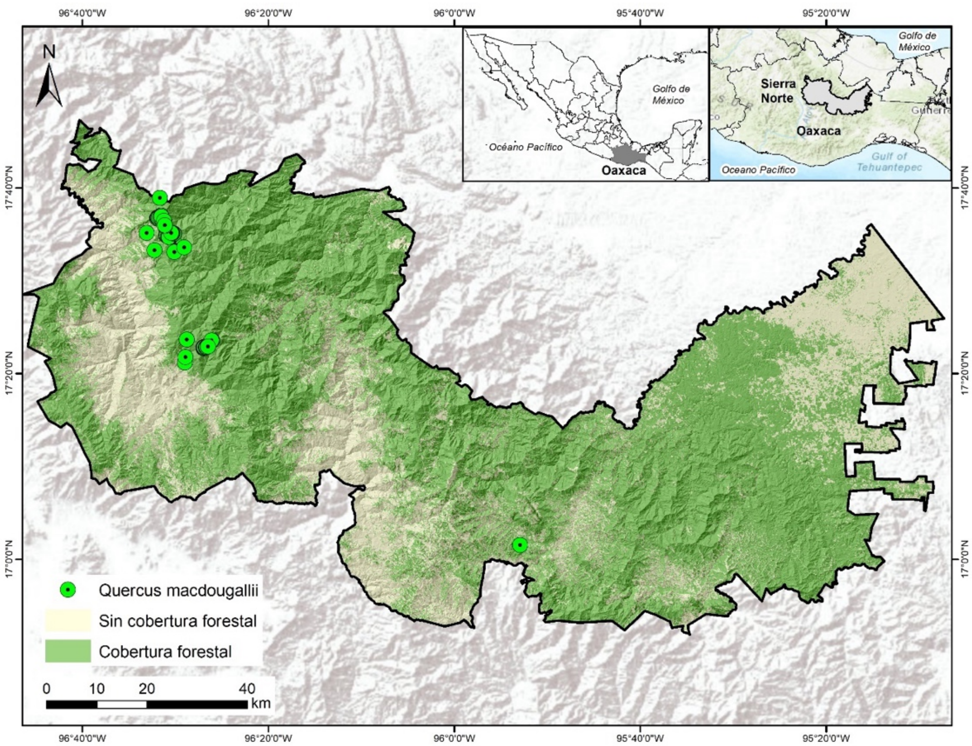

Figure 1.- Records of *Q. macdougallii* in the Sierra Juárez, Oaxaca.

Modeling Suitable Habitat and Climate Scenario

For the modeling of the current suitable habitat and evaluation of future climate change in *Q. macdougallii*, a set of 19 bioclimatic layers obtained from WorldClim v.2 (https://www.worldclim.org/) with a spatial resolution of 30 seconds (~1 km² per cell; Hijmans et al. 2005) was used. Additionally, key geographic variables such as latitude, longitude, and altitude (2600-3200 m above sea level) were considered, as they are relevant to the abundance and distribution of the species. To select the predictive environmental variables, a multicollinearity analysis was performed to identify those with the highest explanatory power and minimal redundancy (Graham and Glaister 2003).

The Variance Inflation Factor (VIF) was used to assess multicollinearity among the initial predictor variables, following a sequential approach and excluding those variables with a VIF greater than 5, which allowed for the reduction of collinearity and improved the robustness of the model (James et al. 2013). This analysis was carried out in R software (version 3.0.3; R Core Team 2014) using the car (Fox et al., 2007), sp (Pebesma et al., 2012), and corrplot (Wei et al., 2017) packages. As a result, the selected variables were BIO1, BIO4, BIO7, BIO10, BIO13, altitude, and latitude, which proved to be the most relevant for modeling due to their lower collinearity and their relationship with the key ecological factors (Table1).

Table 2. Set of bioclimatic environmental layers obtained from WorldClim

Abbreviation	Description
Bio1	Average annual temperature*
Bio2	Average monthly average maximum and minimum temperature
Bio3	Index of variability of temperature
Bio4	Seasonality of temperature*
Bio5	Maximum temperature of the warmest month
Bio6	Minimum temperature of the driest month
Bio7	Annual temperature range*
Bio8	Average temperature of the month with
Bio9	Average temperature of the driest month
Bio10	Average temperature of the warmest quarter*
Bio11	Average temperature of the oldest quarter
Bio12	Annual precipitation
Bio13	Precipitation of the wettest month*
Bio14	Precipitation of the driest month

Bio15	Seasonality of precipitation
Bio16	Precipitation of the wettest quarter
Bio17	Precipitation of the driest quarter
Bio18	Precipitation of warmest quarter
Bio19	Precipitation of coldest quarter

The resulting habitat suitability model provides maps where higher values indicate areas with better conditions for the species. These maps allow for the identification of potential areas of expansion and contraction under different climate scenarios, which is essential for conservation planning. Additionally, the SDMtoolbox (http://www.sdmtoolbox.org/) was used to calculate the areas in km² of contraction and expansion of the species' distribution area. The potential distribution model was validated using presence data collected in the field, where the species showed a potential distribution. For the models under future climate conditions, the same variables were projected for the years 2041-2060 using the CMCC-ESM2 climate model (downloaded from www.worldclim.org) (IPCC, 2013; Hijmans, 2017). The Representative Concentration Pathways (RCPs) of 4.5°C and 8.5°C were used, known as the optimistic (intermediate) and pessimistic scenarios, respectively. Maxent models were employed to generate species distribution projections under these scenarios. Maxent, a software for ecological niche modeling based on the maximum entropy principle, produces predictive models from incomplete or partial data (Phillips et al., 2006). A total of xxx replicates and xxx iterations were performed using the Bootstrap method, and duplicate presence records were removed. Additionally, a different random sampling was implemented for each replicate to improve the robustness of the model.

Results

Modeling Suitable Habitat and Climate Scenario

The AUC values for assessing model performance were 0.998 with a standard deviation of ± 0.001. The suitable habitat maps suggest an endemic restricted distribution to the state of Oaxaca, particularly in the mountainous area that spans the biogeographic provinces of the Sierra Madre del Sur and the Province of Oaxaca, with low probabilities of species occurrence outside its distribution area in Sierra Juárez. The model's potential projections indicate a distribution of 230.87 km²; however, field records suggest that this may be less than 50 km², restricted to an altitudinal range of 2600 to 3150 m above sea level.

On the other hand, the future projections of the species' potential distribution for 2050 and 2070, under both scenarios (RCP4.5 and RCP8.5), show that the maximum probability of occurrence for the species in Sierra Juárez will gradually decrease the area of its suitable habitats for establishment, from the current (0.94) to those of 2050 (RCP4.5= 0.82; RCP8.5= 0.78), and down to those of 2070 (RCP4.5= 0.31; RCP8.5=0.22). Similarly, a significant decrease in area (km²) is expected, from the currently estimated potential distribution (230.87) to the year 2050 (RCP4.5=13.09 and RCP8.5=96.23). This decrease continues in the projections for 2070, where a considerable reduction was observed (RCP4.5=2.45 and RCP8.5=0.82). This implies a reduction of suitable habitat by 58% to 94% for 2050, with a considerable reduction for 2070 exceeding 98% (Table 2, Fig. 2).

Table 2.- Areas of suitable habitat in km². Current, with WorldClim models. Future projections, with models under climate change scenarios RCP4.5 and RCP8.5, for the years 2050 and 2070. The probability of occurrence is indicated; the minimum was set at 0.2 for each model, and the maximum was the highest value reported for each model.

	Scenario	Min	Máx.	Area (km^2)	Decrease (%)
	Actual	0.2	0.94	230.87	100%
2050	RCP4.5	0.2	0.82	13.09	94.30%
	RCP8.5	0.2	0.78	96.23	58.20%
2070	RCP4.5	0.2	0.31	2.45	98.90%

RCP8.5	0.2	0.22	0.82	99.60%

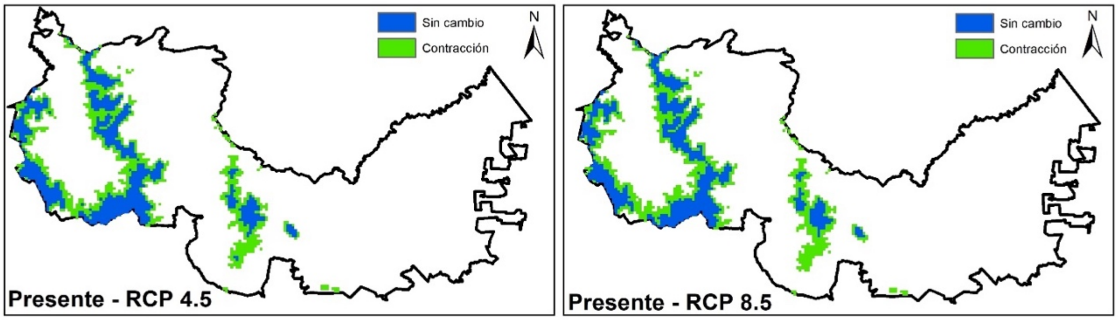

Figure 2. Potential distribution that persists and contracts in the future under different climate scenarios.

The actual versus potential distribution found is centered on three municipalities in the Sierra Juárez (Figure 2), with the most abundant population located in Santiago Comaltepec, Ixtlán de Juárez, and San Pedro Yólox. These areas are characterized by a low-density occurrence (1-50 individuals/ha) compared to *Q. laurina*, its associated species (50-200 individuals/ha). It was recorded that in the presence of other oak species (Q. *crassifolia* and Q. *glabrecens*), or when these species become dominant, *Q. macdougallii* is not present.

Discussion

Quercus macdougallii Martínez has been studied by our research group for over 10 years, covering various aspects from genetics to some ecological aspects (Anacleto-Carmona, 2015; Clark-Tapia et al., 2018; Pacheco Cruz, 2019). However, this project has expanded our knowledge of the species; for the first time, we explored its actual distribution starting in 2023, with different field outings, and in 2024, we committed to surveying 30% to 50% of the population. The censuses conducted this year have not been without problems, particularly due to the change of municipal authorities that occurs every year and a half, which forces us to renegotiate access to the sites. For instance, in Santiago Comaltepec, we were unable to work for almost four months in 2024; during a census in July, we were forced to abandon the site due to the new authorities not being able to meet with us because of their activities. Nonetheless, in Attachment 1, we provide the complete database for the three sites, including coordinates, diameter at breast height (DBH), height of individuals, and coverage. We believe we reached 30% coverage in each site, with the largest population in Santiago Comaltepec, followed by Ixtlán de Juárez, and lastly Yólox. The population is much larger than we initially thought and is stable right now.

Furthermore, the analysis of the potential distribution of *Q. macdougallii* suggests an endemic restricted distribution. This potential distribution coincides with what has been described in previous studies (Anacleto-Carmona, 2015; Pacheco-Cruz, 2019) and field monitoring conducted, where its presence was ruled out in reported sites in the Mixe region (Cerro Zempoatpel) and suitable habitats in intermediate distribution areas located in the municipalities of San Juan Atepec, Santa María Jaltianguis, and Macuiltianguis, where oak species such as Q. laurina, *Q. crassifolia*, *Q. glabrecens*, and *Q. rugosa*, which compete with *Q. macdougallii*, predominate.

The potential and observed distribution in the field regionalizes the distribution of *Q. macdougallii* into two separated areas or zones within the Sierra Juárez, which coincides with reports by Anacleto-Carmona (2015) and Pacheco- Cruz (2019). However, there are still areas in the intermediate region that need to be explored. The genetic differentiation values (F_{ST}) obtained for the species suggest the presence of two genetic areas: the first located on the slopes of Cerro Humo Chico and Cerro Zacate (San Pedro Yólox and Santiago Comaltepec), which promotes differences among individuals at different geographic altitudes in that area; and the second located on the slopes of Cerro Pozuelos (Ixtlán de Juárez), which tends to isolate the species as a single population. This is generated by the orographic and altitudinal gradients present in the Sierra Juárez.

For example, *Q. macdougallii* showed a strongly restricted distribution to high areas, being found from 2,600 to 3,150 meters above sea level. Altitude, which has been reported as an important factor in the establishment of oaks (Firmat et al., 2017), likely contributes to this specificity. The high specificity of the species may be associated with the formation of specific microhabitats given the great variety of environments generated by the orography present in Sierra Juárez (Clark-Tapia et al., 2018a), where climatic elements such as precipitation and temperature can significantly affect species distribution. Antúnez et al. (2017), using simple generalized additive models, suggest that the average temperature of the coldest month is a variable that can considerably influence the abundance of the species. One of the variables that showed a significant influence in the potential distribution model, highlighting part of the ecological requirements of the species, was the precipitation of the warmest quarter (BIO 18), which suggests that prolonged drought events and alterations in the temporal distribution of precipitation during the summer could significantly affect the species, as reported for *Q. oleoides* (Ramírez-Valiente et al., 2018).

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Population Structure and Identifying the variables that affects its abundance and distribution. **Objective 3 and 4.**

Methods

Size Structure and 3D Spatial Structure

The data collected on individual tree sizes by census in the tree sites, including diameters and heights, were analyzed to evaluate the population structure. This study chose trunk diameter (DBH) as the primary size indicator. DBH is a reliable metric for classifying tree size, particularly in areas affected by fire, where canopies and heights may be compromised. Unlike height, diameter reflects a tree's historical growth and biomass more accurately, as it is less affected by disturbances. Additionally, measuring DBH is practical and precise under irregular conditions, offering a stable representation of the population structure.

Initially, individual diameters were classified into five predefined categories: 0–1, 1–5, 5–20, 20–50, and >50 m. This classification was performed using the cut ( ) function in RStudio, dividing the data into representative ranges of structural variation. The diameter categories were plotted for each study site (Santiago Comaltepec, San Pedro Yólox, and Ixtlán de Juárez), to facilitate visual differentiation and identify patterns among the categories. The frequency of individuals in each diameter category was calculated and graphically represented using bar plots. Utilizing the ggplot2 package in R, bar plots were generated to display the frequency of individuals in each diameter category, with differentiation by study site (Comaltepec, Yólox, and Ixtlán de Juárez) and error bars indicating standard deviation to highlight variations among categories.

A spatial analysis was also conducted to classify trees by diameter category in a 3D plot. The previously established diameter categories were used to create the 3D plot with the scatter3D function from the plot3D library, where geographic coordinates (longitude and latitude) were combined with tree diameter as the z-axis (vertical axis). A color legend was included, with adjustments to its size and placement to enhance the interpretation of diameter categories within the spatial context of the study areas.

Spatial Distribution and Ecological Patterns

The spatial distribution of individuals was analyzed using two main methods. First, the Clark-Evans index was applied, a statistical tool used to assess whether points in a dataset exhibit random, uniform, or clustered distribution. This index compared the observed average distance between points with the expected distance under a completely random distribution. The results were interpreted as follows: a value close to 1 indicated a random distribution; values greater than 1 suggested a uniform distribution, while values less than 1 indicated clustering or aggregation of points.

The second approach involved analyzing spatial patterns using Ripley's K-function, which evaluates point density within increasing radii, allowing the identification of aggregation or dispersion trends at different scales. This analysis produced four key curves: Kiso (representing the observed pattern without corrections), Ktrans (adjusting for transitions between scales), Korda (correcting for edge effects), and Kpois (a reference pattern based on a random Poisson distribution).

Geographic coordinates (latitude and longitude) and the diameter of individuals were used as variables for the analysis. The data were processed in R using the spatstat and sp libraries. Initially, a ppp object (points in a plane) was created with the ppp ( ) function, delimiting the geographic area through an owing object (a type of data structure used in spatial analysis within the R package spatstat), based on latitude and longitude ranges. The Clark-Evans index was calculated using the clarkevans() function, while Ripley's K-function analysis was performed using Kest ().

The statistical significance of the observed patterns was assessed using Monte Carlo simulations (999 iterations). The simulate () function generated random point configurations under a Poisson distribution. The indices obtained from the simulations were compared to observed values to determine whether the actual patterns differed significantly from those expected under a random model.

Finally, spatial patterns and potential aggregations were visualized using plots and maps created with the plot() function in spatstat. This analysis provided a robust framework for understanding population spatial dynamics and their relationship with environmental factors and associated ecological processes.

Interpretation of Ripley's K-Function Curves:

• Kpois: This curve represented the expected pattern under a completely random distribution of points.

- If K(r) from the observed data (e.g., Kiso, Ktrans) was above Kpois, it indicated a clustering pattern.
- If K(r) was below Kpois, it suggested a uniform or dispersed pattern.

• Kiso (Isotropy): This curve represented the K(r) function corrected for edge effects, assuming patterns were homogeneous in all directions.

- If Kiso was significantly above Kpois, it indicated that points were more clustered than expected by chance. Possible explanations included:
  a) Preference for specific microhabitats.
  b) Clonal reproduction or social processes.

• Separation Between Kiso, Ktrans, and Kbord:

- Ktrans (Transformed): Included an additional mathematical correction. If Ktrans was closer to Kpois than Kiso, it suggested a less homogeneous distribution model.

• Kbord (Edge): Represented a more basic approximation and could differ from Kiso in heterogeneous landscapes.

- Distinct Separation Between Kiso and Kpois:
- If Kiso was consistently higher than Kpois, it indicated a strong aggregation pattern, where individuals tended to occur in groups or clusters.
- Ecological factors such as indirect competition, patchy reproduction, or heterogeneous resources might have influenced this pattern.
- If Kiso was below Kpois, it revealed a dispersal pattern, potentially linked to resource competition or negative interactions between individuals.

• Differences Across Spatial Scales: Wide separations between the curves were more noticeable at smaller spatial scales (low K(r) values). These likely reflected ecological processes acting at short distances, such as neighbor competition or colony formation.

Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was used as a complementary approach to the mixed model to explore the underlying structure of environmental variables prior to their inclusion in the model. PCA reduces the dimensionality of the dataset and groups correlated variables, facilitating the interpretation of relationships between environmental variables and the diameter of individuals. This approach was justified as some environmental variables exhibited high correlation, potentially causing multicollinearity issues in the mixed model.

Using PCA, the principal components that explained most of the variance in the dataset were identified, enabling efficient integration of relevant information into the analysis while improving the robustness and interpretability of the final model. The PCA was conducted using the FactoMineR and factoextra libraries in R software after selecting relevant environmental variables (latitude, bio01, bio04, bio12, and Srad). Variables were standardized to ensure comparability.

The proportion of variance explained by each principal component was visualized through a scree plot of eigenvalues, which highlighted the primary sources of variability in the dataset. Variable loadings on each principal component were extracted to assess their relative contributions to the total variability, providing insights into how environmental variables influenced the structure of the analyzed sites.

Analysis of the Effect of Environmental Variables on Individual Diameter

To evaluate the influence of environmental variables on individual diameters, a multiple linear regression model was fitted using the lm function in R. The model included the following environmental variables: annual mean temperature (bio01), temperature seasonality (bio04), annual precipitation (bio12), and average solar radiation (Srad).

The variance explained by the model was assessed using marginal and conditional R2R^2R2 indices calculated with the MuMIn package, offering a more detailed evaluation of model fit. These analyses comprehensively understood how climatic variables influenced individual diameters across the selected sites.

```
model_mixto <- lm(Diameter ~ bio01 + bio04 + bio12 + Srad, data = datos)
```

Analysis of the Effect of Environmental Variables on Individual Diameter Using a Bayesian Mixed-Effects Model

A Bayesian multivariate mixed-effects model was fitted to analyze the relationship between environmental variables and the diameter of individuals using the brms library in R. The model included the environmental predictors: annual mean temperature (bio01), temperature seasonality (bio04), annual precipitation (bio12), and average solar radiation (Srad). Random effects were modeled for each site (Sites) to account for spatial variability. The general model formula was as follows:

```
model_bayes <- brm(Diameter ~ bio01 + bio04 + bio12 + Srad + (1 | Sites), data = datos)
```

Results and Conclusion

The size structure of individuals, classified into diameter categories, revealed clear differences in frequency distributions across size classes (0–1, 1–5, 5–20, 20–50, and >50 meters) among the three study sites (Santiago Comaltepec, Yólox, and Ixtlán de Juárez). A consistent pattern of clustering was observed as individuals transitioned from smaller to larger categories, indicating significant differences between size classes (Fig. 1).

The size structure of individuals, classified into diameter categories, revealed clear differences in frequency distributions across size classes (0–1, 1–5, 5–20, 20–50, and >50 m), among the three study sites (Santiago Comaltepec, Yólox, and Ixtlán de Juárez). A consistent clustering pattern was observed as individuals transitioned from smaller to larger categories, indicating significant differences between size classes (Fig. 1). The differences observed among sites indicated variability in local ecological conditions that impact individual growth and survival, potentially influenced by factors such as habitat type, management practices, or recent disturbances, such as individual extraction and wildfires have hit the species hard specially in the Santiago Comaltepec area in the past few decades, negatively impacting its populations in 1982 and 1998 (Clark et al., 2018; Pacheco-Cruz, 2019).

In the frequency distribution of individuals by diameter category across the three sites (Fig. 2), Santiago Comaltepec showed the highest number of individuals in the 1–5, 5–20, and 20–50 m categories but had fewer individuals in the >50-meter category, where Ixtlán de Juárez displayed the highest abundance. Yólox, in contrast, exhibited significantly lower frequencies across all categories.

Notably, there was a high predominance of adult individuals in the 20–50 meter and >50 m categories, suggesting a population with a substantial proportion of larger individuals. In Ixtlán de Juárez and San Pedro Yólox, a lower frequency of small individuals was recorded in the 0–1 and 1–5 m categories. Additionally, a large proportion (80%) of individuals in the smallest categories (0–1 and 1–5 m) originated from resprouting, attributed to prior disturbances.

This pattern reflected a regeneration process characterized by a strong presence of larger individuals, with recovery in the smaller categories predominantly driven by resprouting.

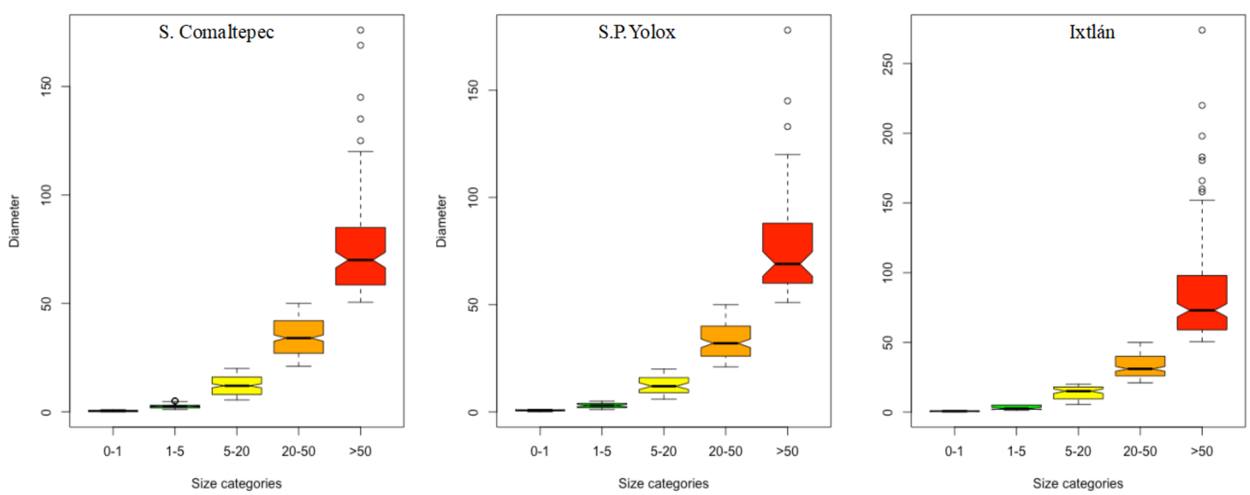

Figure 1.- Individual size structure classified by diameter categories.

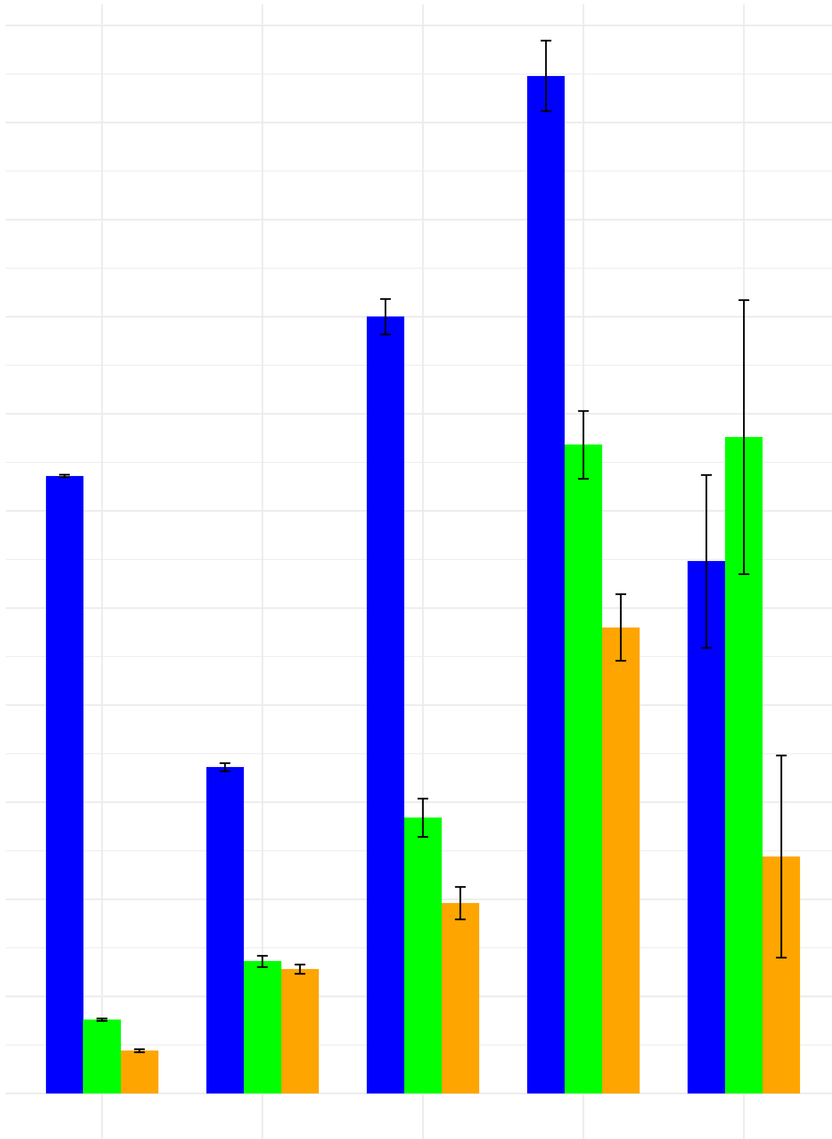

Figure 2. Frequency distribution of individuals by diameter category across the study sites.

Spatial Distribution and Ecological Patterns

The Clark-Evans index values for *Quercus macdougallii* populations in Santiago Comaltepec, San Pedro Yólox, and Ixtlán de Juárez were 0.27, 0.36, and 0.44, respectively, suggesting a significantly aggregated distribution of individuals ($p < 0.001$). This indicates that individuals (*e.g.*, trees or species) were located closer to one another than would be expected under a random distribution.

The Ripley's K-function plots for the populations in Santiago Comaltepec, San Pedro Yólox, and Ixtlán de Juárez (Fig. 3) also showed an aggregated distribution of *Q. macdougallii*, consistent with the Clark-Evans results. The Kiso, Ktrans, and Kbord curves were nearly identical, indicating that the boundaries of the study area did not significantly affect the observed patterns. This suggests that the individuals tended to cluster at specific distances.

In Yólox, more significant environmental heterogeneity was evident based on the larger separation between the K-functions in the Ripley's K plot. Compared to a random pattern (Kpois), the results confirmed a significantly non-random distribution of individuals. This result could indicate biological or ecological processes driving aggregation, such as environmental factors, competition, or life history traits (*e.g.*, short-distance dispersal or clonality).

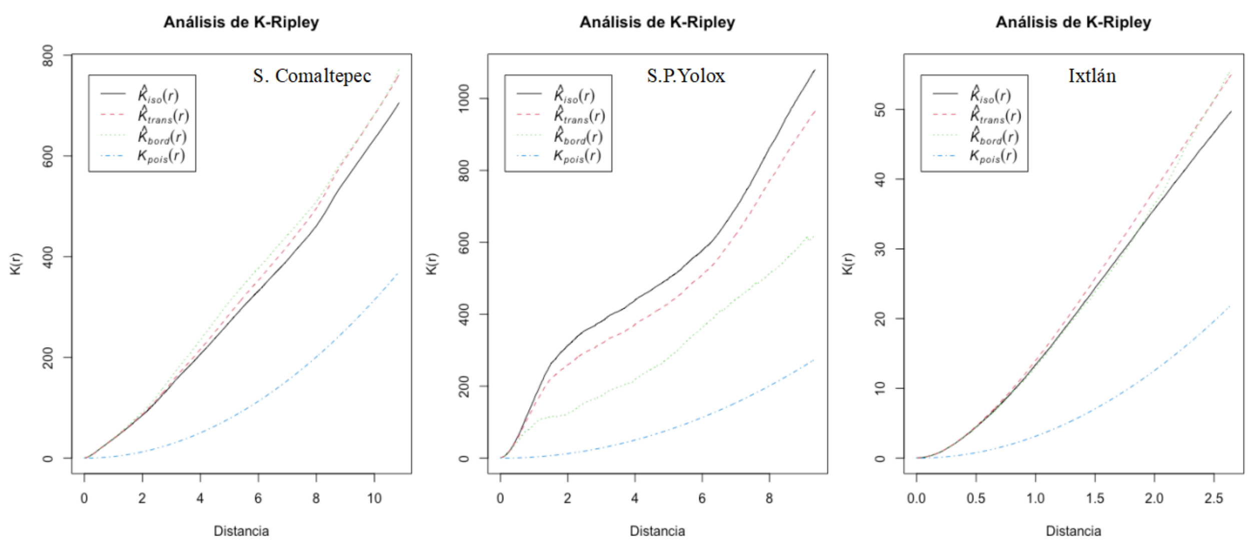

Figure 3. Ripley's K(r) function with edge Corrections.

This figure illustrates Ripley's K-function curves for *Quercus macdougallii* populations, incorporating various edge corrections to account for boundary effects and compare with a completely random distribution (CSR):

- K*iso*: Isotropic edge correction assumes a uniform pattern in all directions.
- K*trans*: Translation edge correction minimizes biases in areas near study area boundaries.
- K*bord*: Edge correction adjusts for boundary effects using weights based on proximity to the area's limits.
- K*pois*: Theoretical curve under the CSR hypothesis.

The 3D plots (Figs. 4-6) reveal distinct aggregation patterns of *Q. macdougallii* individuals within specific geographic zones. These patterns suggest the existence of preferential growth areas or potential genetically related family clusters, that which we are trying to address in a future genetic study. Clustering individuals across size categories indicates a population structure favoring accumulation in environmentally favorable conditions. Additionally, the limited frequency of smaller size categories reflects a low rate of sexual regeneration, implying a dependence on vegetative resprouting as the primary mechanism for regeneration.

Key observations include:

- Up to 80% of smaller individuals have regenerated from vegetative resprouting after disturbance, underscoring the species' survival strategy through resprouting rather than seed germination probably to the non-production of acorns due to climate change
- This reliance on resprouting highlights potential deficiencies in seed production or germination success, contributing to the observed patterns.

Recommendations for Future Research

1. Dynamic Studies on Resprouting: Investigate the relationship between resprouting and disturbance events to understand how disturbance regimes shape population dynamics.
2. Regeneration Constraints: Explore limitations to sexual regeneration, including seed dispersal challenges, competition, and habitat conditions.

3. Genetic analyses should be conducted to investigate population structure and the mechanisms underlying spatial clustering, focusing on evaluating the role of genetic relationships in the observed patterns. These studies should determine precisely whether current individuals exhibit greater genetic variability compared to past populations and assess the presence of family groups identified through ecological observations.
4. Habitat Fragmentation: Assess the impact of habitat fragmentation on regeneration processes and the long-term viability of *Q. macdougallii* populations under varying environmental conditions.

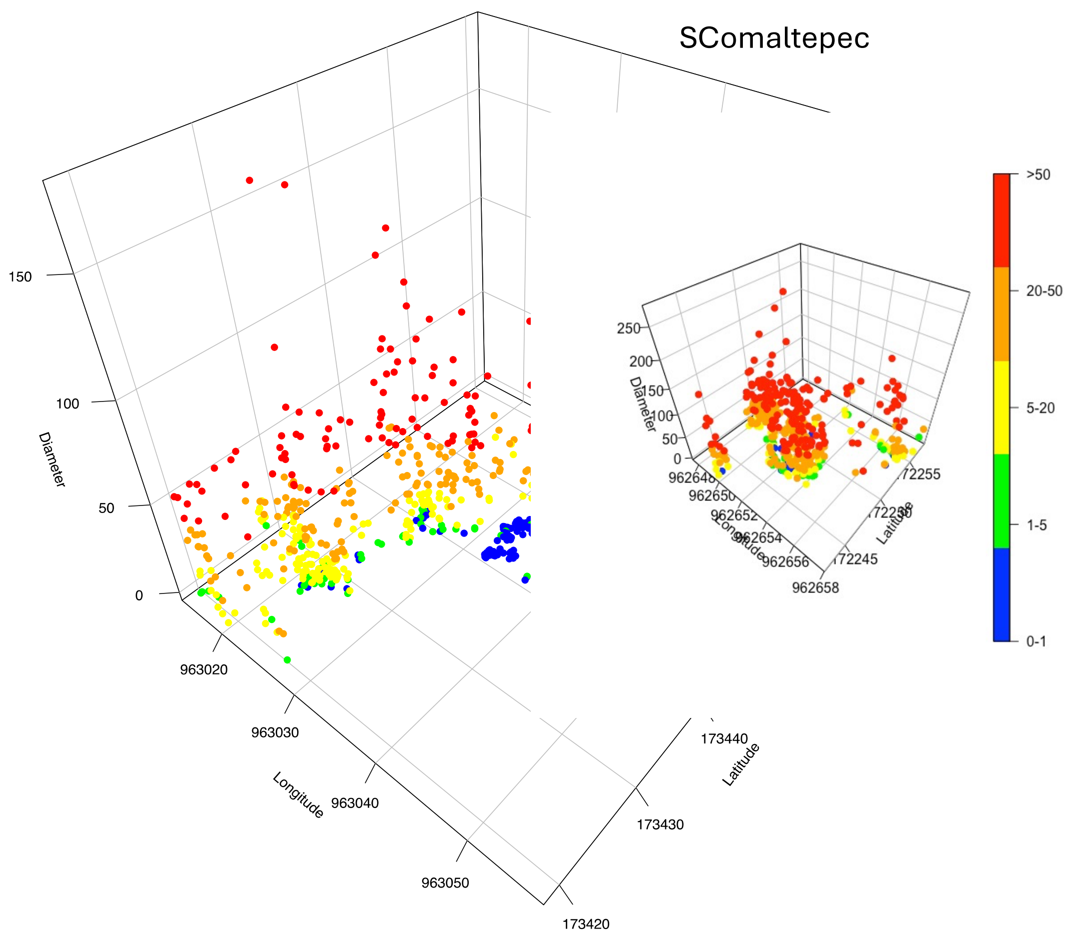

Figure 4.- Spatial Distribution and Size Structure of *Quercus macdougallii* Individuals Based on Latitude, Longitude, and Diameter in Santiago Comaltepec.

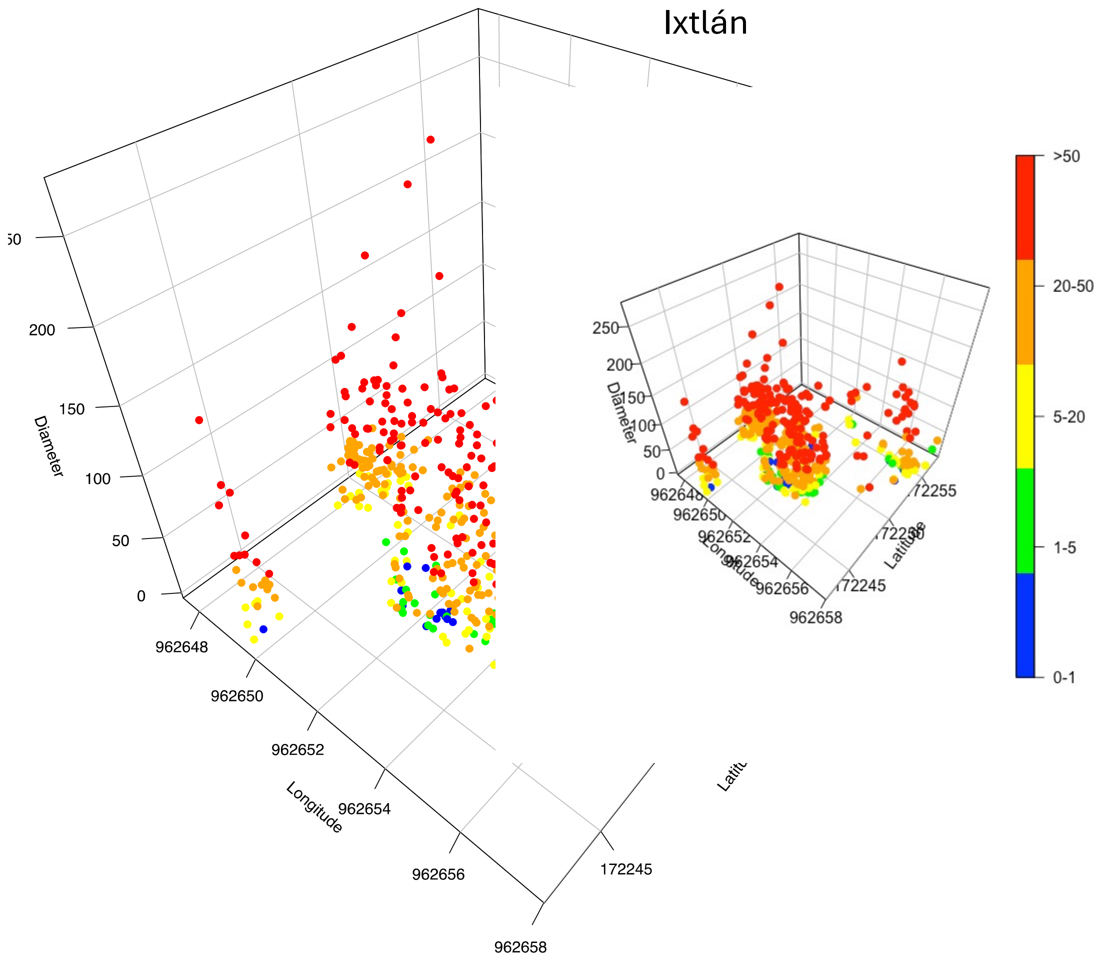

Figure 5.- Spatial Distribution and Size Structure of *Quercus macdougallii* Individuals Based on Latitude, Longitude, and Diameter in San Pedro Yólox.

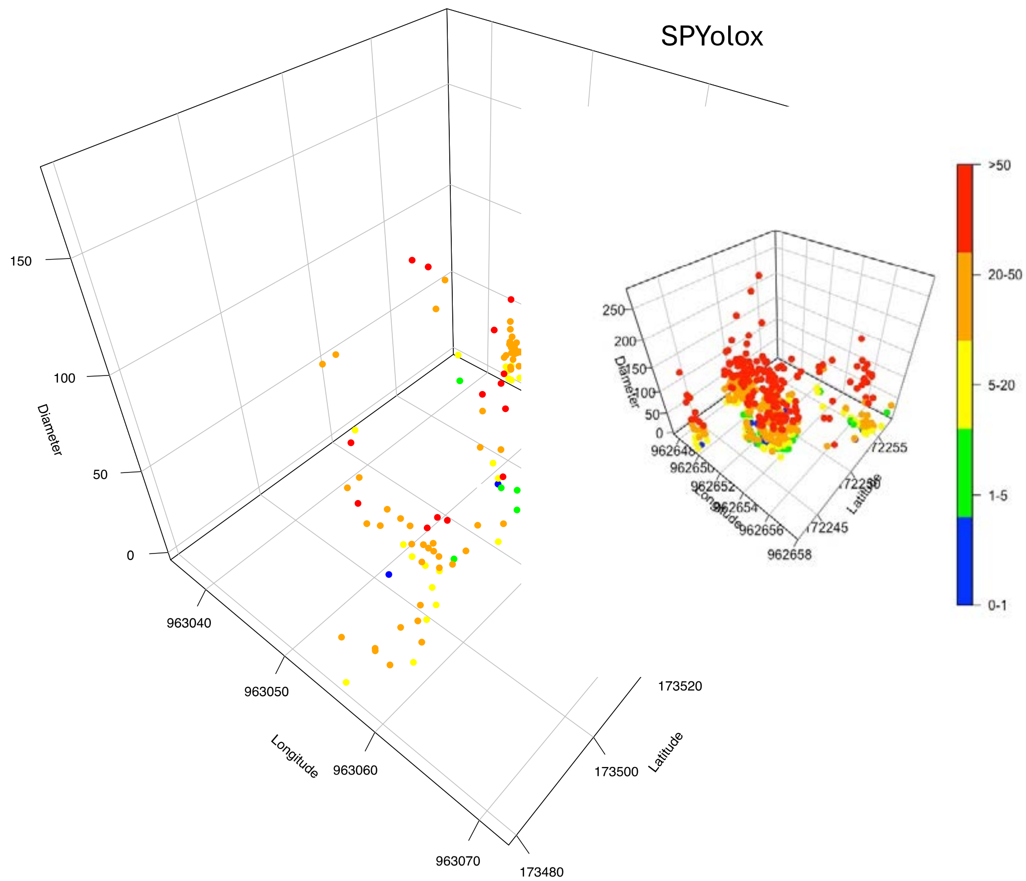

Figure 6. Spatial Distribution and Size Structure of *Quercus macdougallii* Individuals Based on Latitude, Longitude, and Diameter in Ixtlán de Juárez

Principal Component Analysis (PCA)

By utilizing all environmental variables in the analysis, differences were identified between the habitats of *Q. macdougallii*. Specifically, the PCA revealed significant differences between the conditions at Ixtlán de Juárez and those recorded at Comaltepec and Yólox. While displaying some differences, the latter two sites were more like each other (Figure 7). The two principal components explained over 99% of the total variance, indicating that most of the data variability was captured within these two components. This finding was consistent with genetic studies by Pacheco Cruz (2019)

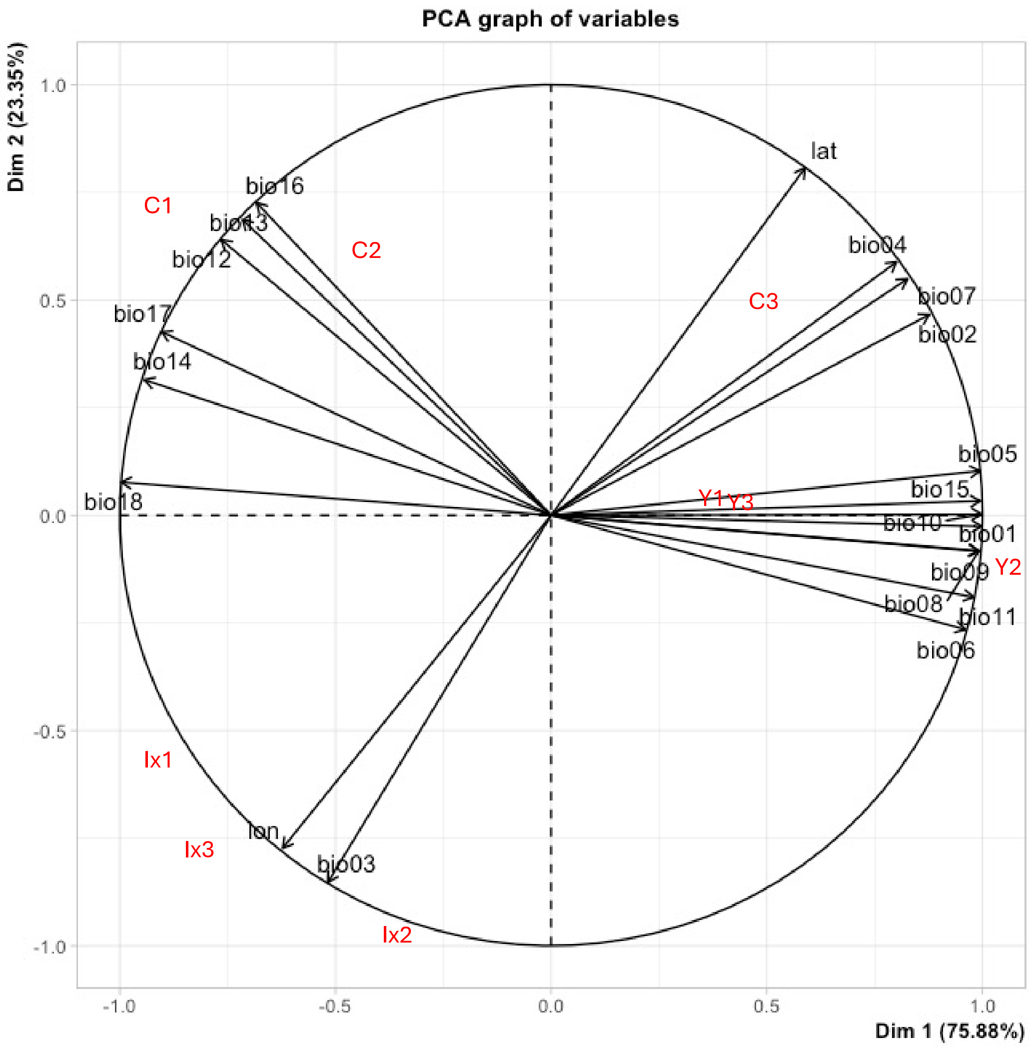

Figure 7. PCA analysis of environmental variables influencing the species distribution in the study region.

The PCA analysis conducted with four variables showed no multicollinearity and examined their effect on individual size. It was observed that the first principal component (PC1) explained 68.42% of the total variance, while the second principal component (PC2) explained 19.93%. Together, these two components accounted for 88.35% of the total variance, indicating that most data variability was concentrated in these two components. The variable loadings revealed that bio01 (0.974), bio04 (0.980), and latitude (0.748) contributed strongly to PC1, suggesting that this component primarily reflected patterns related to these three variables. In contrast, PC2 was mainly associated with Srad (0.971), indicating that solar radiation was the most influential variable in this component. When plotting the sites based on the first two principal components, it became evident that geographically closer sites shared similar environmental characteristics, particularly in latitude, bioclimate, and solar radiation.

These results confirmed that latitude and bioclimatic variables were the most relevant environmental factors driving the observed variability among sites, while solar radiation contributed significantly to an additional environmental pattern. These results indicated that latitude and bioclimatic factors were the most relevant environmental drivers of the observed site variability. Additionally, solar radiation contributed significantly to an additional environmental pattern influencing the distribution and size of *Q. macdougallii* individuals.

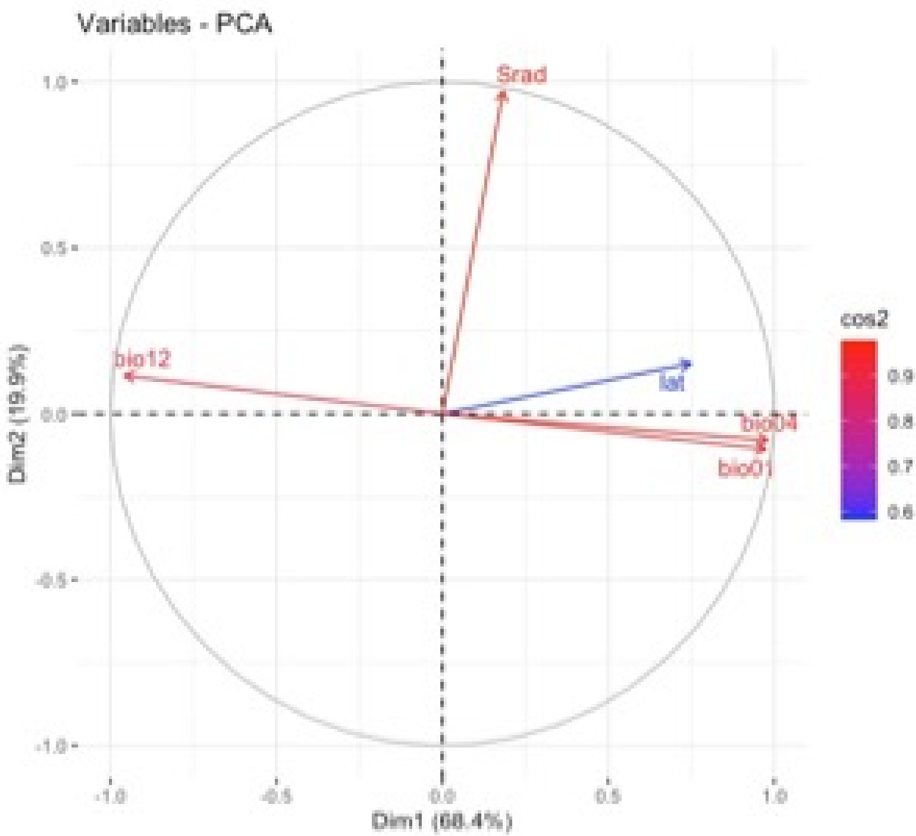

Figure 8.- PCA analysis of key environmental variables affecting the diameter of individuals in the study region.

Results of the Linear Models

The linear mixed-effects model exhibited a multiple determination coefficient (R^2) of 0.0476, with an adjusted R^2 of 0.0332, indicating that only 3.3% of the variability in diameter was explained by the included variables. Additionally, when calculating the marginal and conditional R^2 using the r.squaredGLMM() function from the MuMIn package, both the marginal and conditional R^2 were found to be 0.0470. This suggested that the environmental variables considered explained a small proportion of the variance in diameter relative to the global model (including random effects, if applicable).

Variable	Coefficient	Standard Error	t-value	p-value
(Intercept)	-1162.4	445.5	-2.61	0.00961 **
bio01	2.785	3.168	0.88	0.38023
bio04	0.5139	0.2056	2.5	0.01306 *
bio12	0.1166	0.0532	2.19	0.02920 *
Srad	0.000673	0.00195	0.35	0.72971

The estimated coefficient for bio04 (0.5139, p = 0.01306) showed that an increase in temperature seasonality was significantly associated with larger individual diameters, possibly reflecting greater access to resources during specific periods of the year. Similarly, bio12, representing annual precipitation, exhibited a positive effect (0.1166, $p = 0.02920$), suggesting that higher precipitation levels might be linked to larger diameters in this region. In contrast, bio01 and Srad were not statistically significant ($p > 0.05$), indicating that mean annual temperature and solar radiation were not major determinants of diameter growth in this analysis.

Analysis of Environmental Variables' Effects on Diameter Using a Bayesian Mixed-Effects Model

The Bayesian model produced the following results for regression coefficients and residual distribution parameters:

Parameter	Estimate	Standard Error	95% CI	Rhat	Bulk_ESS	Tail_ESS
Intercept	-1132.43	447.93	[-2010.36, -270.19]	1.01	1062	1390
bio01	2.64	3.21	[-3.42, 8.87]	1.00	926	2012
bio04	0.51	0.21	[0.11, 0.91]	1.00	1830	2444

Parameter	Estimate	Standard Error	95% CI	Rhat	Bulk_ESS	Tail_ESS
bio12	0.11	0.05	[0.01, 0.22]	1.01	989	1625
Srad	0.00	0.00	[-0.00, 0.00]	1.00	2334	2952
sigma (residual)	20.33	4.92	[10.02, 26.91]	1.09	27	44

The intercept was estimated at -1132.43, with a 95% confidence interval ranging from -2010.36 to -270.19. Like the linear mixed-effects model, the Bayesian model provided a more detailed understanding of the effects of environmental variables on individual diameter, accounting for random site effects. Results indicated that temperature seasonality (bio04) and annual precipitation (bio12) significantly influenced diameter growth. However, the lack of significance for bio01 and Srad suggested that these variables did not have a direct impact on diameter or that their effects were more complex than could be captured by the current model.

The results from the linear mixed-effects and Bayesian models, combined with the principal component analysis (PCA), reveal that environmental variables have a differentiated impact on the diameter growth of individuals in the studied species. Although the variance explained by the models is low, key factors such as temperature seasonality (bio04) and annual precipitation (bio12) were identified as significant contributors to individual diameter growth. The PCA supports these findings by showing that these environmental variables are principal determinants structuring the variability of sites within the study region. The identified patterns suggest that differences in local environmental conditions, such as specific periods of increased resource availability due to temperature seasonality and total annual precipitation, may be linked to the ability of individuals to achieve larger sizes.

Ecologically, this indicates that the distribution and development of individuals are influenced by local environmental characteristics, emphasizing the importance of climatic variation as a key driver of population structure. The lack of significance for other variables, such as solar radiation (Srad) and mean annual temperature (bio01), suggests that individual growth depends not on constant or average factors but on dynamic and seasonal factors that affect resource availability throughout the year.

Therefore, climatic variability, particularly the interaction between seasonality and water availability, is critical in the species' ecology, affecting its growth and distribution in the study region. This knowledge can inform conservation strategies that consider microclimatic differences and local dynamics that support population development.

Literature

Clark-Tapia, R., Mendoza-Ochoa, A., Aguirre-Hidalgo, V., Antúnez, P., Campos-Contreras, J.E., Valencia-A., S., Luna-Krauletz, M.D. y Alfonso-Corrado, C. (2018).Sexual reproduction of *Quercus macdougallii*, an endemic oak of Sierra Juárez, Oaxaca. Maderas y Bosques, 24: (2)e2421617. doi: 10.21829/myb.2018.242161

Pacheco-Cruz, N. J., (2019). Variación genómica y distribución potencial de *Quercus macdougallii* Martínez, especie endémica de Oaxaca. Tesis de Maestría no publicada. Universidad Nacional Autónoma de México, México

Analysis of Forest Cover Change between 1972-2022 in *Q. macdougalli* habitat zones

Introduction

Land use change refers to the alteration or modification of existing vegetation cover to convert it into different uses, with the purpose of being exploited for economic benefit. This is a phenomenon that profoundly affects biodiversity and the ecosystem services that sustain life on the planet (Lambin et al., 2003). In regions like Oaxaca, Mexico, the transformation of natural ecosystems into agricultural areas, livestock farming, forest use, or urban development (such as road construction and urban sprawl) has caused a significant decrease in the extent and quality of natural habitats (Murguía et al., 2014). This trend not only compromises the survival of numerous species but also alters hydrological cycles, reduces carbon sequestration capacity, and increases ecosystem vulnerability to climate change.

Quercus macdougallii, an endemic oak species of the state of Oaxaca, serves as a flagship case to study the impacts of land use change (Clark-Tapia et al., 2018). Being a species with a limited geographical distribution that inhabits areas susceptible to human activities, *Quercus macdougallii* faces significant pressures threatening its existence. The conversion of oak forests into agricultural lands or forest utilization zones has contributed to habitat fragmentation and loss, putting this species at risk of extinction (Clark-Tapia et al., 2018). Considering this scenario, it is crucial to understand the relationship between land use change and the conservation of *Quercus macdougallii*. Analyzing how land management practices influence the survival and distribution of this species can provide valuable data for its preservation. Likewise, studying *Quercus macdougallii* and its interaction with the environment can indicate the current situation faced by individuals of the *Quercus macdougallii* species.

Methods

Study Area

Based on several field outings, 91 individuals of *Quercus macdougallii* (Appendix 1) have been identified distributed across three municipalities: Ixtlán de Juárez, San Pedro Yólox, and Santiago Comaltepec (Figure 1). From the location of these individuals, six influence areas were established with radii of 500m, 1km, 2km, 3km, 4km, and 5km. The objective of defining these areas was to analyze and understand the dynamics of forest cover change in the vicinity of the *Quercus macdougallii* habitat, allowing for an evaluation of whether they are undergoing deforestation or forest recovery processes.

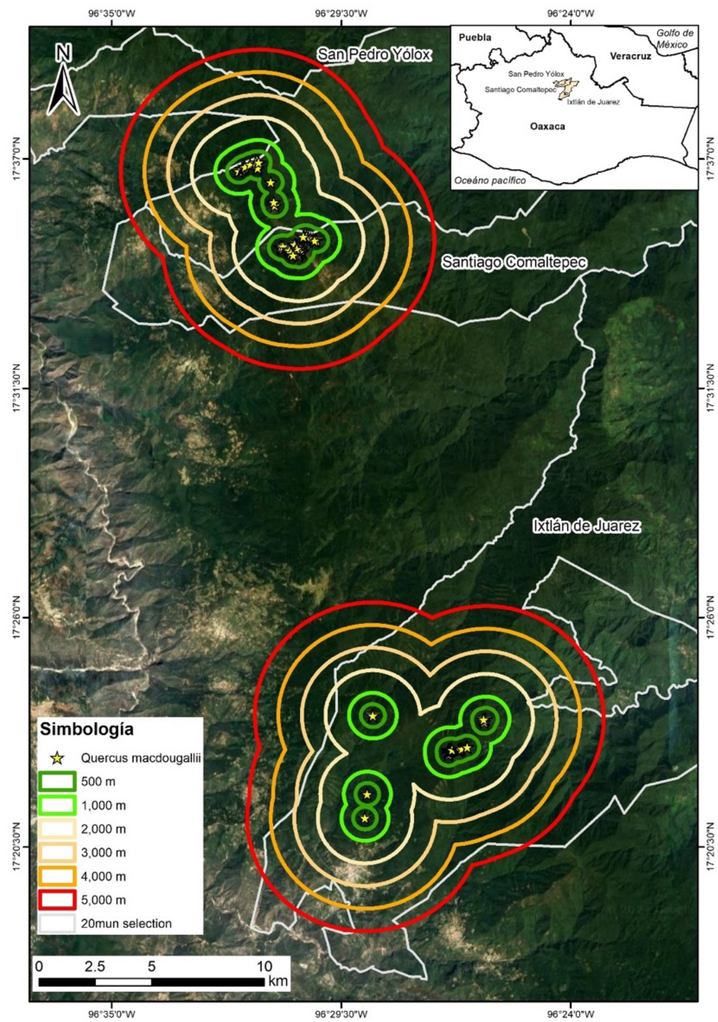

Figure 1 - Delimitation of the Study Area

Forest Cover Maps

The analysis of forest cover change was conducted for the period from 1979 to 2022, covering the last 43 years. For the analysis of the year 1979, aerial photographs provided by the National Institute of Statistics and Geography (INEGI; https://www.inegi.org.mx/app/geo2/siiv/) were used. For the year 1995, INEGI orthophotos (https://www.inegi.org.mx/temas/imagenes/ortoimagenes/) were utilized, and for the year 2022, Sentinel satellite images (https://dataspace.copernicus.eu/) were employed. Given the low spectral radiation of aerial photographs and orthophotos (being single band; panchromatic), they were classified using the unsupervised classification method through the Iso Cluster algorithm. On the other hand, the Sentinel satellite image, being multispectral, allowed for the application of supervised classification using the Maximum Likelihood algorithm. In both cases, two categories have been classified: forest (which includes any type of forest vegetation) and non-forest (including categories such as roads, urban areas, forest utilization zones, and agricultural activities).

Results

For the influence areas from 500 meters to 2 km, there is a trend of increasing forest cover between 1995 and 2022. In the case of the 3 km influence area, an increase in surface area is observed from 1979 to 1995, from 13,380.4 ha to 13,962.7 ha, but for 2022, there was only an increase of 4.34 ha. Conversely, for the influence areas of 4 and 5 km, an increase in forest cover is observed between 1979 and 1995, but in both cases, there is a decrease in forest area from 1995 to 2022 (Table 1).

Table 1 - Forest and non-forest areas for different influence areas between 1979-2022

	500 m		1 km		2 km		3 km		4 km		5 km	
Year	Forestry	No Forestry	Forestry	No Forestry	Forestry	No Forestry	Forestry	No Forestry	Forestry	No Forestry	Forestry	No Forestry
19	1,090	82.3	3,029	199.3	8,164	622.4	13,83	1,144	20,26	1,96	27,62	3,064

79	.2		.6		.9		0.4	.9	7.1	6.4	0.1	.6
1995	1,116.5	55.9	3,080.9	147.9	8,290.8	496.5	13,962.7	1,012.56	20,565.9	1,667.5	28,852.5	2,744.8
2022	1,136.3	36.2	3,139.4	89.5	8,383.9	403.3	13,967.0	1,008.2	20,454.9	1,778.6	27,787.9	2,896.9

As shown in Figure 2, in 1979, road construction represented the main threat to *Quercus macdougallii* in the three municipalities, primarily due to the activities of Fapatux, a paper company that obtained concessions in various forests of the Sierra Norte. By 1995, a general recovery of forest cover was observed, although in specific areas, such as in Santiago Comaltepec, an increase in agricultural activities was recorded. Towards the year 2022, a notable recovery of forest cover has been observed in Yólox and Santiago Comaltepec. However, in Ixtlán de Juárez, forest extraction emerges as the predominant threat at present.

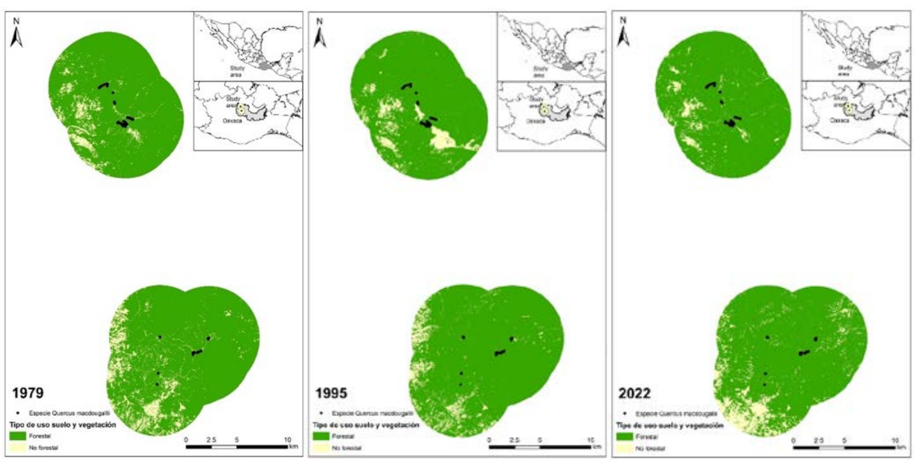

Figure 2 - Forest Cover Maps for the Years 1979, 1995, and 2022.

In Figure 3, examples of aerial photographs, orthophotos, and satellite images are shown, illustrating this phenomenon of threat change, which shifted from road construction to urban expansion and forest utilization.

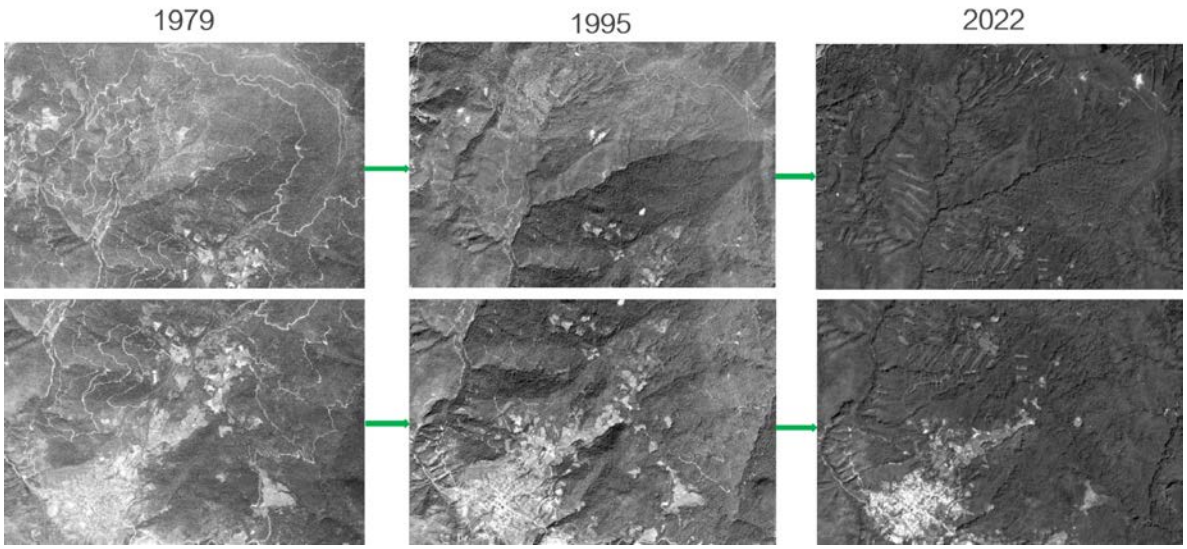

Figure 3.- Examples of forest cover change transitions.

Conclusions

The forest cover in areas adjacent to *Quercus macdougallii* habitats has shown signs of recovery from 1979 to 2022. It is important to note that the absence of forest cover loss does not necessarily imply that there is no degradation in the *Quercus macdougallii* habitat, due to selective logging or the effects of climate change. A notable aspect of the recovery has been observed on roads, where the forest canopy has begun to spread, covering a significant portion of them. Between 1979 and 1995, there was a recovery in forest cover; however, from 1995 to 2022, a slight decrease was perceived. Nevertheless, considering that this area is designated for forest utilization, further degradation can be expected.

It is crucial to understand that sustainable forest management can coexist with the conservation of habitats for species such as *Quercus macdougallii*, if practices are implemented to minimize negative impacts on the *Quercus macdougallii* habitat.

Literature

Clark-Tapia, R., Mendoza-Ochoa, A., Aguirre-Hidalgo, V., Antúnez, P., Campos-Contreras, J.E., Valencia-A., S., Luna-Krauletz, M.D. y Alfonso-Corrado, C. (2018).Sexual reproduction of *Quercus macdougallii*, an endemic oak of Sierra Juárez, Oaxaca. Maderas y Bosques, 24: (2)e2421617. doi: 10.21829/myb.2018.242161

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Annex 1.- Coordinates of individuals identified in the field

Ixtlán de Juárez					
Id	**Latitude**	**Longitude**	**Id**	**Latitude**	**Longitude**
1	17.39158	-96.43457	18	17.3804	-96.4481
2	17.39283	-96.43394	19	17.3805	-96.4479
3	17.3926	-96.4344	20	17.3804	-96.4477
4	17.39265	-96.43481	21	17.3805	-96.4474
5	17.3787	-96.4488	22	17.3802	-96.4448
6	17.3794	-96.4487	23	17.3804	-96.4444
7	17.3796	-96.4485	24	17.38056	-96.44397
8	17.3805	-96.4485	25	17.38093	-96.44348
9	17.3802	-96.4489	26	17.3817	-96.4415
10	17.3802	-96.4488	27	17.3815	-96.4415
11	17.38	-96.4489	28	17.38158	-96.44134
12	17.3803	-96.4488	29	17.3943	-96.4792

13	17.3802	-96.4483	30	17.3942	-96.4791
14	17.3801	-96.4481	31	17.39418	-96.47895
15	17.38	-96.448	32	17.39411	-96.47903
16	17.3802	-96.448	33	17.353221	-96.482218
17	17.3804	-96.4484	34	17.362821	-96.481281

Santiago Comaltepec

Id	Latitude	Longitude	Id	Latitude	Longitude
35	17.5795	-96.5072	57	17.5812	-96.5159
36	17.5795	-96.5073	58	17.5811	-96.5157
37	17.5799	-96.5074	59	17.5809	-96.515
38	17.5799	-96.5075	60	17.5809	-96.5151
39	17.5805	-96.5079	61	17.5808	-96.5151
40	17.581	-96.5081	62	17.5815	-96.5156
41	17.5815	-96.509	63	17.5816	-96.5149
42	17.5818	-96.5095	64	17.5805	-96.5127
43	17.5823	-96.5099	65	17.5801	-96.5123
44	17.5824	-96.5103	66	17.57901	-96.51167
45	17.5799	-96.5096	67	17.57816	-96.51088
46	17.5798	-96.5098	68	17.5847	-96.5038
47	17.5796	-96.5101	69	17.5845	-96.5029
48	17.5793	-96.51	70	17.5842	-96.502
49	17.5779	-96.5086	71	17.5842	-96.5018
50	17.5785	-96.5082	72	17.584	-96.5016
51	17.5787	-96.5088	73	17.584	-96.5023
52	17.5789	-96.5091	74	17.5851	-96.5047
53	17.57936	-96.50868	75	17.58538	-96.50559
54	17.5794	-96.5084	76	17.5856	-96.5055
55	17.57993	-96.50907	77	17.5856	-96.5064
56	17.58067	-96.50937	78	17.5855	-96.5068

San Pedro Yólox

Id	Latitude	Longitude	Id	Latitude	Longitude

75	17.6117	-96.5326	82	17.6145	-96.5248
76	17.6127	-96.5313	83	17.613	-96.525
77	17.6131	-96.5308	84	17.6152	-96.5246
78	17.6131	-96.5304	85	17.60731	-96.519791
79	17.6135	-96.5301	86	17.597979	-96.518175
80	17.6144	-96.528	87	17.599293	-96.518607
81	17.6151	-96.5259			

Population Dynamics Analysis and Passive Restoration 25 Years After a *Quercus macdougallii* (Fagaceae) Fire in Santiago Comaltepec, Oaxaca

Introduction

Note: This objective and number two are part of the thesis of master's student in Conservation of Forest Resources in the Universidad de la Sierra Juárez, Biol. Paola Montserrat de los Angeles Rodríguez, who will graduate in October or November of 2025. The thesis and the publication that will be sent to us in this date.

The species *Quercus macdougallii* also has a history of significant anthropogenic disturbances in recent decades, including the extraction of individuals and fires occurring in the region of Santiago Comaltepec in 1982 and 1998 (Pacheco-Cruz, 2019). Regeneration of a species is defined as the process by which new individuals are incorporated into the reproducing population while others disappear due to mortality. Additionally, in oaks, population regeneration is a sensitive and highly complex process, where the establishment of new individuals depends on intrinsic and environmental factors such as (1) limited acorn production, which can be annual or vary between years, (2) acorn mortality, primarily caused by desiccation and parasitism, and (3) failure in seedling establishment due to not finding favorable sites where light, nutrients, and association with other species such as mycorrhizae are fundamental (Clark-Tapia et al., 2018). Since *Quercus macdougallii* is in the status of microendemic and belongs to the Sierra Juárez region in Oaxaca, it can be considered a very important species for this region. It has great biological importance and can be considered a flagship species. Its presence in the area supports associated biodiversity, being considered a keystone species. Its high vulnerability to anthropogenic disturbances (e.g., fires; Pacheco-Cruz, 2019), its low population number and effectiveness, as well as its limited regeneration, necessitate a profound analysis of this species. Therefore, this study aims to understand changes in individual abundance over the years (1998-2024) following a fire, using high-resolution satellite imagery and field visits to understand its spatial distribution and size changes and to comprehend the species' regeneration processes in the study area.

Between April 11 and 27, 1998, 172 hectares were burned on Cerro Pelón (elevation 2518 to 2977 meters above sea level; Figure 1), the highest part of the Sierra Norte, Oaxaca, where the *Quercus macdougallii* oak was located. To delimit and assess the extent of the area affected by this fire, a Landsat satellite image from April 27, 1998, was used, applying the Normalized Burn Ratio (NBR) technique. This index is widely used in remote sensing to identify burned areas and assess the severity of forest fires. The NBR is calculated from the bands of the near-infrared (NIR) and shortwave infrared (SWIR) spectra present in satellite images, such as those provided by Landsat.

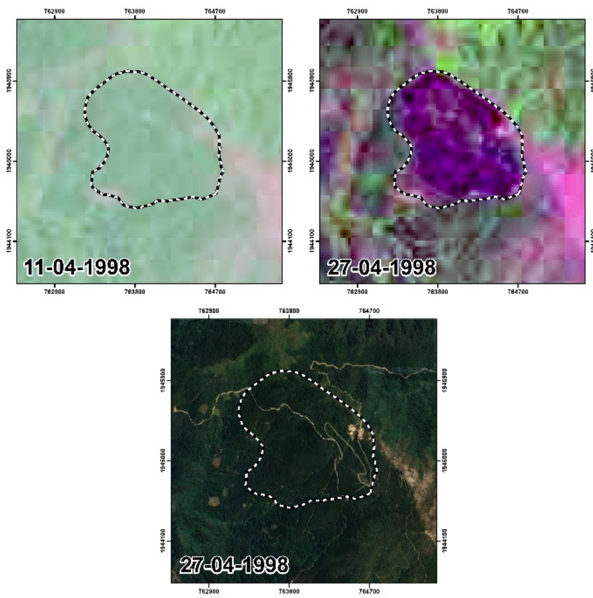

Figure 1: Study Area of the Fire in Cerro Pelón.

To monitor and assess the regeneration of *Quercus macdougallii*, this study will employ the Normalized Difference Vegetation Index (NDVI) to analyze vegetation recovery in the burned areas. NDVI, a widely used remote sensing index, provides valuable insights into vegetation health by measuring the density and vigor of green vegetation. By tracking NDVI changes over time, this study aims to quantify the regeneration progress of Quercus macdougallii populations in Cerro Pelón after the 1998 fire. Understanding vegetation recovery through NDVI analysis is crucial, as it highlights the conditions necessary for the regeneration of this microendemic oak species, offering insight into its resilience to environmental stressors and its role as a keystone species within the Sierra Juárez region.

Methods

Study Area

The study area is in the Sierra Norte of Oaxaca, specifically near the community of Santiago Comaltepec, at approximately 17°34'36.68"N and 96°30'31.02"W. This region features a mountainous landscape with elevations ranging from around 2,518 to 2,977 meters above sea level, with Cerro Pelón as one of the prominent peaks. The area is dominated by temperate forests, primarily cloud forests and mixed pine-oak forests, which provide critical habitats for a diverse array of flora and fauna, including the microendemic oak species *Quercus macdougallii*. This area has been subject to significant anthropogenic pressures, such as selective logging, forest fires, and land use changes, which have impacted local biodiversity. The study area is also influenced by a subtropical highland climate, with distinct wet and dry seasons, providing conditions that affect species regeneration and distribution. The unique environmental characteristics and ecological importance of this region make it an ideal location for studying post-disturbance regeneration processes and the impact of habitat conditions on endemic species like *Quercus macdougallii.*

Calculation of Burned Areas and Fire Intensity

The NBR is effective for detecting burned areas because healthy plants have high reflectance in NIR and low reflectance in SWIR, while the opposite occurs in burned areas: reflectance in NIR decreases and in SWIR increases. This results in significantly lower NBR values in burned areas compared to unaffected vegetation or bare soil.

The formula for calculating the NBR is:

NBR = (NIR + SWIR) / (NIR - SWIR)

Where: NIR represents reflectance in the near-infrared band.; SWIR represents reflectance in the shortwave infrared band.

The difference between the pre-fire NBR (Prefire) and the post-fire NBR (Postfire) obtained from images is used to calculate the differential NBR (dNBR or ΔNBR), which can then be used to estimate the fire severity. A higher dNBR value indicates more severe damage, while areas with negative dNBR values may indicate new growth after a fire. The formula used to calculate dNBR is shown below:

dNBR or ΔNBR = PrefireNBR - PostfireNBR

dNBR values can vary from case to case, so, if possible, interpretation in specific cases should also be carried out through a field evaluation to achieve the best results. However, the United States Geological Survey (USGS) proposed a classification table to interpret burn severity, which can be seen below (Table 1).

Table 1. Severity levels in fires obtained from dNBR, proposed by USGS.

Severity Level	**dNBR Range (scaled by 10^3)**	**dNBR Range (not scaled)**
Enhanced Regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
Enhanced Regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
Unburned	-100 to +99	-0.100 to +0.099
Low Severity	+100 to +269	+0.100 to +0.269
Moderate-low Severity	+270 to +439	+0.270 to +0.439
Moderate-high Severity	+440 to +659	+0.440 to +0.659
High Severity	+660 to +1300	+0.660 to +1.300

Fire severity data and maps can assist in the development of post-fire rehabilitation and emergency restoration plans. They can be used to estimate not only fire severity on the ground but also the likelihood of future downstream impacts, such as flooding, landslides, and soil erosion.

Analysis to evaluate the recovery of the *Quercus macdougallii* population over a 35-year period before and after a fire.

To evaluate the recovery of the *Quercus macdougallii* population before and after the fire event, we analyzed a time from 1988 to 2023. Assessments were conducted every five years, specifically in 1988, 1993, 1998, 2002, 2014, 2019, and 2023, using Landsat satellite imagery. For each of these years, we calculated the

Normalized Difference Vegetation Index (NDVI) to monitor changes in vegetation cover and health over time.

NDVI is a widely used remote sensing index that quantifies vegetation by measuring the difference between near-infrared (NIR) and red light reflected by vegetation. The formula for NDVI is as follows:

NDVI=(NIR−RED) (NIR+RED)NDVI = \frac{(NIR - RED)}{(NIR + RED)}NDVI=(NIR+RED)(NIR−RED)

where NIR represents the near-infrared band, and RED represents the red band. NDVI values range from -1 to +1, with higher values indicating healthier and denser vegetation, while lower values suggest sparse or damaged vegetation.

The selected imagery was primarily from the month of December, which follows the rainy season, allowing for optimal vegetation assessment as plants are likely at their peak health and density. The only exception was the image for 1998, which was acquired in January due to the lack of available December data. This timing ensured that we captured vegetation in its best possible condition post-rainy season for a more accurate assessment of *Quercus macdougallii* recovery.

Results

Burned Areas and Fire Intensity

Based on the NBR analysis, an affected area of 171.72 hectares was identified (Figure 1). This area was categorized according to fire severity levels, which provided insights into the extent of damage across the landscape. The distribution of fire severity within this area (Figure 2) revealed that a small portion, 4.86 hectares, experienced high severity, indicating significant vegetation loss and ecosystem impact. In contrast, low severity areas covered a substantial 50.49 hectares, suggesting minimal fire effects and a likelihood of rapid recovery. Moderate to high severity areas occupied 27.54 hectares, while moderate to low severity extended over 44.37 hectares, each showing varying degrees of fire impact that could influence vegetation recovery differently. Additionally, very low severity areas accounted for 44.46 hectares, where the effects of the fire were minimal, allowing for higher resilience and potential natural regeneration. This classification of severity levels provides a baseline for understanding post-fire recovery and guides restoration efforts for the impacted *Quercus macdougallii* population in the study area.

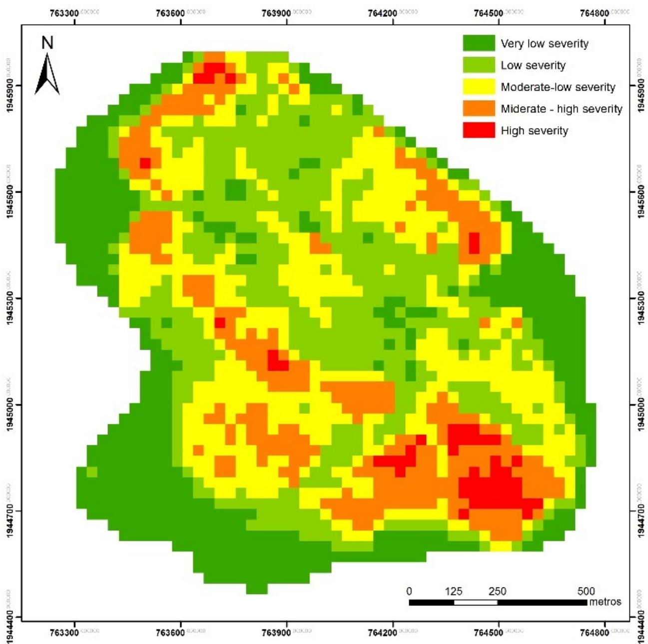

Figure 2.- Fire intensity near Cerro Pelón.

Analysis to evaluate the recovery of the *Quercus macdougallii* population over a 35-year period before and after a fire.

The average NDVI values for the study area were calculated for each selected year to assess vegetation changes before and after the fire event in 1998, which occurred in April. The NDVI value for January 1998, prior to the fire, was 0.348, indicating relatively healthy vegetation cover at that time. Historical data shows a peak NDVI value of 0.466 in 1993, suggesting favorable vegetation conditions before the disturbance. However, following the fire, there was a significant decline in NDVI, with the lowest value recorded in 2002 at 0.178, highlighting the immediate impact of the fire on vegetation health and cover (Table 1).

Table 1. NDVI over the Years

Year	NDVI
1988	0.396
1993	0.466
1998	0.348
2002	0.178
2014	0.288
2019	0.306
2023	0.273

Subsequent years show gradual recovery, with NDVI values increasing to 0.288 in 2014 and reaching 0.306 in 2019, indicating some regrowth and stabilization in vegetation. However, by 2023, the NDVI decreased slightly to 0.273, suggesting variability in recovery rates or potential ongoing challenges in vegetation regeneration for *Quercus macdougallii*. This trend in NDVI values over time provides insights into the resilience of the ecosystem and helps to assess the long-term recovery dynamics following significant fire disturbance (Figure 3).

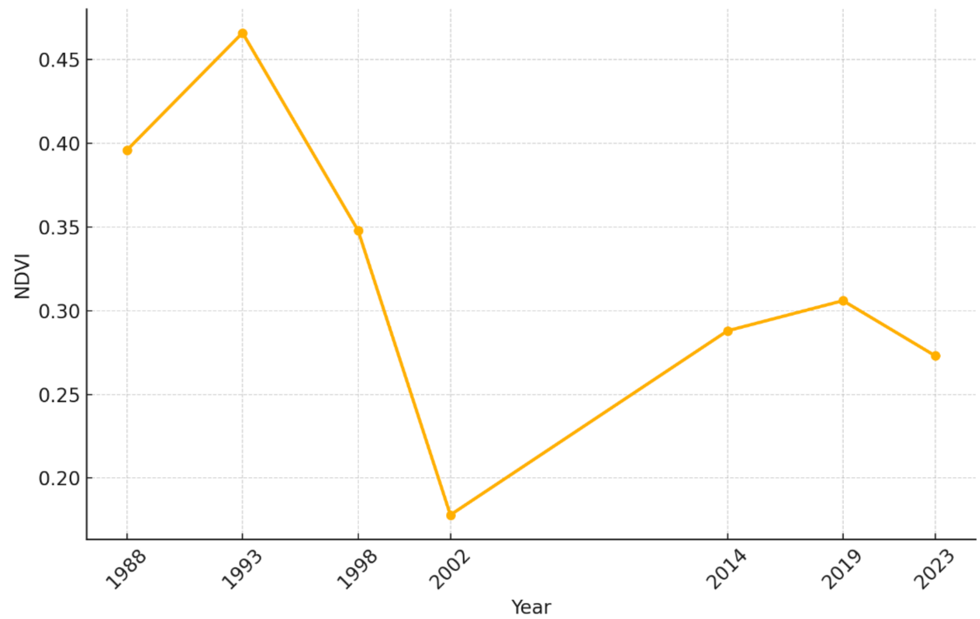

Figure 3: NDVI Trends Over the Years (1988-2023)

The analysis of NDVI values across different fire severity levels (Table 2) from 1988 to 2023 reveals distinct trends in vegetation recovery and degradation following the 1998 fire. Each severity level displays unique changes in NDVI, with a general trend of recovery observable in less severely affected areas over time, while high-severity zones show slower or more limited recovery (Figure 4).

Table 1. NDVI values across different fire severity levels

1988						
Severity	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**
High severity	0.27	0.45	0.18	0.37	0.04	19.98
Low severity	0.22	0.64	0.42	0.44	0.08	248.85
Miderate - high severity	0.22	0.54	0.32	0.35	0.06	107.80
Moderate-low severity	0.13	0.61	0.48	0.40	0.08	198.20
Very low severity	0.03	0.57	0.55	0.37	0.10	180.80
1993						
Severity	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**

High severity	0.37	0.61	0.24	0.49	0.04	26.33
Low severity	0.16	0.62	0.46	0.47	0.06	264.81
Miderate - high severity	0.30	0.61	0.31	0.47	0.06	142.47
Moderate-low severity	0.23	0.61	0.38	0.48	0.06	235.37
Very low severity	0.11	0.60	0.49	0.44	0.08	219.73
1998						
Severity	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**
High severity	0.14	0.48	0.34	0.30	0.10	15.97
Low severity	0.10	0.62	0.52	0.36	0.08	202.83
Miderate - high severity	0.04	0.46	0.43	0.24	0.07	73.91
Moderate-low severity	0.08	0.49	0.41	0.28	0.07	136.93
Very low severity	0.13	0.64	0.51	0.47	0.09	234.62
2002						
Severity	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**
High severity	0.01	0.25	0.23	0.11	0.05	6.13
Low severity	-0.01	0.35	0.36	0.19	0.06	108.70
Miderate - high severity	-0.03	0.26	0.29	0.12	0.05	35.31
Moderate-low severity	-0.02	0.33	0.35	0.16	0.06	77.80
Very low severity	-0.23	0.42	0.65	0.23	0.09	112.02
2014						
Severity	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**
High severity	0.23	0.34	0.11	0.30	0.02	16.28
Low severity	0.09	0.38	0.29	0.29	0.04	161.27
Miderate - high severity	0.19	0.38	0.19	0.30	0.04	91.28
Moderate-low severity	0.16	0.39	0.23	0.30	0.04	147.69
Very low severity	0.04	0.41	0.37	0.27	0.05	133.12
2019						

Severity	MIN	MAX	RANGE	MEAN	STD	SUM
High severity	0.27	0.37	0.10	0.31	0.02	16.64
Low severity	0.10	0.40	0.29	0.31	0.04	172.11
Miderate - high severity	0.19	0.40	0.21	0.31	0.04	94.61
Moderate-low severity	0.20	0.41	0.21	0.32	0.04	155.89
Very low severity	0.08	0.45	0.37	0.29	0.05	144.32
2023						
Severity	**MIN**	**MAX**	**RANGE**	**MEAN**	**STD**	**SUM**
High severity	0.19	0.34	0.14	0.24	0.03	12.95
Low severity	0.11	0.42	0.31	0.29	0.04	162.55
Miderate - high severity	0.14	0.35	0.20	0.25	0.03	77.20
Moderate-low severity	0.18	0.41	0.23	0.28	0.04	136.79
Very low severity	0.08	0.38	0.30	0.27	0.05	131.05

In **1988** and **1993**, prior to the fire, NDVI values were relatively stable across all severity categories. Low severity areas had the highest mean NDVI values, with moderate and very low severity areas showing similar trends, indicating healthy vegetation cover across the study area.

In **1998**, the year of the fire, there was a noticeable decline in NDVI values, especially in the high-severity areas. The mean NDVI for high-severity zones dropped to approximately 0.295, while other severity levels also experienced reductions, indicating a significant impact on vegetation health.

Post-fire analysis shows that by **2002**, high-severity areas had the lowest mean NDVI (approximately 0.114), reflecting the limited recovery in these zones. Conversely, very low severity areas had a higher mean NDVI of about 0.365, suggesting a quicker recovery in less impacted regions.

In **2014**, gradual recovery is evident in the moderate and low-severity areas, with mean NDVI values around 0.310 and 0.231, respectively. High-severity zones, however, continued to show lower values, around 0.301, indicating a slower recovery pace.

By **2019**, there was further improvement in low and very low severity zones, with mean NDVI values reaching approximately 0.359 and 0.292, respectively. High-severity areas remained low in NDVI, highlighting persistent impacts from the fire.

In **2023**, while moderate and low-severity areas approached pre-fire NDVI levels, high-severity areas maintained a lower mean NDVI, around 0.239, demonstrating that the most severely affected zones continue to struggle with full vegetation recovery.

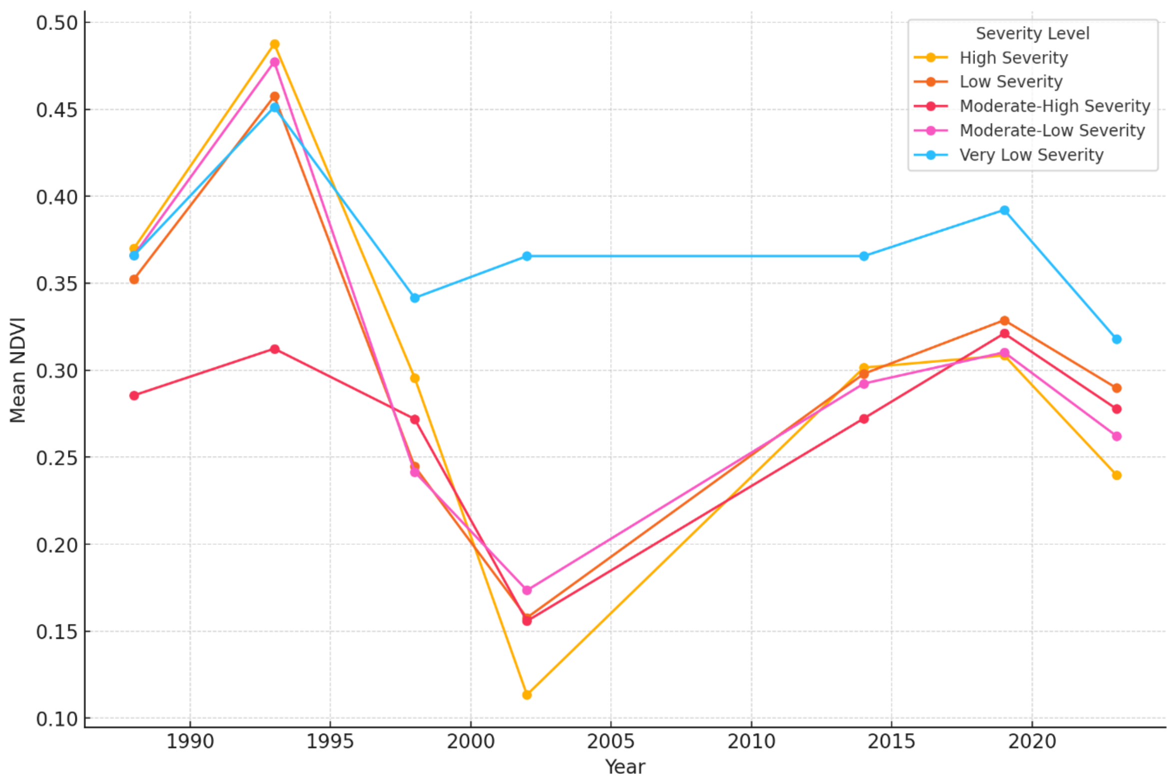

Figure 4. NDVI Trends by Fire Severity Level Over Time (1988-2023)

Conclusion

The analysis of *Quercus macdougallii* recovery over the 35-year period from 1988 to 2023 highlights the complex dynamics of post-fire regeneration in temperate forest ecosystems. NDVI trends indicate that areas with low to very low fire severity have shown higher rates of recovery, likely due to less initial damage, which allowed for a more rapid re-establishment of vegetation. In contrast, high-severity zones have experienced slower and more inconsistent recovery, emphasizing the challenges of natural regeneration in severely impacted areas. The gradual increase in NDVI values over time demonstrates the ecosystem's resilience and the potential for passive regeneration, where vegetation regrows without human intervention. This passive regeneration is crucial in supporting biodiversity and ecosystem function over time, even though it may not entirely restore the original pre-fire plant composition.

It is important to note, however, that the passive regeneration observed does not necessarily imply that the original species, such as *Quercus macdougallii*, are returning in the same abundance or health as before the fire. Instead, the NDVI data suggest a general greening of the area, which may include a mix of native and potentially opportunistic species that thrive under post-disturbance conditions. This shift could alter the ecosystem's structure and function, impacting associated biodiversity and ecosystem services. The findings underscore the need for ongoing monitoring to assess whether the recovery process supports the return of native species or leads to a different vegetative composition. Understanding these dynamics is essential for making informed decisions about conservation and management strategies to support the resilience of endemic and keystone species in the face of future disturbances.

Literature

Clark-Tapia, R., Mendoza-Ochoa, A., Aguirre-Hidalgo, V., Antúnez, P., Campos-Contreras, J.E., Valencia-A., S., Luna-Krauletz, M.D. y Alfonso-Corrado, C. (2018).Sexual reproduction of *Quercus macdougallii*, an endemic oak of Sierra Juárez, Oaxaca. Maderas y Bosques, 24: (2)e2421617. doi: 10.21829/myb.2018.242161

Pacheco-Cruz, N. J., (2019). Variación genómica y distribución potencial de *Quercus macdougallii* Martínez, especie endémica de Oaxaca. Tesis de Maestría no publicada. Universidad Nacional Autónoma de México, México

Two theoretical and practical workshops will be held where the importance of the biological tree is explained to children, youth, and adults, as authorities in which the following points will be addressed: Involving constant care of the populations with a vision to the future of inserting the tree as a biocultural heritage and in the future have a nursery. Additionally, activities for the dissemination of the species are presented.

This report outlines the educational workshops conducted in two of the three communities where the target species is found, namely Ixtlán de Juárez, a Zapotec community, and Santiago Comaltepec, a Chinantec community. These workshops aimed to educate local students about the significance of the species, its ecological role, and conservation.

Workshop Details

Two workshops were organized: one in Ixtlán de Juárez and another in Santiago Comaltepec. The primary school in Ixtlán de Juárez hosted fifth-grade students (four groups, aged 10) on November 19 and sixth-grade students (three groups, aged 11) on November 21. In Santiago Comaltepec, workshops were conducted for third grade (8 years), fourth grade (9 years), fifth grade (10 years), and sixth grade (11 years) students on December 9. A total of 107 children participated in the workshops in Ixtlán de Juárez, while 64 children participated in Santiago Comaltepec. The selection of age groups was made by the directors of both primary schools, with Santiago Comaltepec accommodating only one group per grade due to its smaller community size. Lists of participants' names are attached in **Attachments 3**

Workshop Content in Elementary School

The workshop began with a 15-minute presentation titled "Let’s Learn About a Treasure in Your Community." This presentation covered the following topics:

- Definition and significance of forests in the communities
- Explanation of biocultural and endemic species
- Description of the target tree species and its biological role in the forest
- Importance of the species as a keystone species
- Associated biodiversity and threats faced by the species
- Conservation efforts and community involvement

Following the presentation, the students engaged in interactive games such as “Memory” and “What’s in the Tree?” to reinforce their learning. The students were shown photographs depicting the associated biodiversity, highlighting the fauna present in the areas where the tree grows and its significance in local food webs and biocultural importance.

The primary school in Santiago Comaltepec did not allow us to take many photos, unlike the one in Ixtlán de Juárez, so the photographic memory is smaller.

Evaluation of Knowledge

To assess the knowledge acquired during the workshops, questionnaires were administered before and after each session. These questionnaires were part of the Ethics course projects for Group 704 in the bachelor’s degree in biology, led by MC. Montserrat Gorgonio Ramírez, with a conclusion date set for February. Although this initiative was not part of the original project, it provided an invaluable opportunity for students from the Universidad de la Sierra Juárez, many of whom hail from Sierra communities. This experience is essential for their training as future biologists, with additional participation from students in the master's program in Conservation of Forest Resources.

Practical Workshop in Ixtlán de Juárez of children to elementary school

On November 28, a practical workshop was conducted for two grade groups in Ixtlán de Juárez, facilitated by the community's provision of transportation for 40 individuals, including one fifth grade and one sixth-grade class along with their teachers and parents. Fuel and meals for participants, selected by the primary school director, were also provided with the budget to the grant. During this practical workshop, students learned about the species in a hands-on environment, enhancing their understanding of its ecological importance. However, similar practical workshops were not feasible in Santiago Comaltepec due to unsuitable terrain conditions. In **Attachments 2**, there are videos and photos of this beautiful activity; however, they cannot be published on social media or disseminated. They are provided only as proof material, just like the other photos. **According to the law in Mexico, this is prohibited, and I could face imprisonment if they are published. It was only authorized to send them under the promise that they will not be published.**

High School Workshops

Workshops for High School students were held in both communities for third-year students on November 26 (48 students in Ixtlán de Juárez) and (49 students in Santiago Comaltepec) on December 10. The content mirrored that of the primary school workshops, encompassing a 30-minute talk on biocultural and endemic species, followed by interactive games to reinforce the knowledge gained. Educational materials were donated to both primary and secondary schools for future use. Documentation of materials, presentations, and participation lists are included in Attachments 3**. It is crucial to note that the photographs cannot be publicly disclosed or shared on social media due to legal restrictions aimed at protecting minors by Mexican law.**

Adult workshops

The adult workshops were held on January 26 in the community of Santiago Comaltepec and on January 29 in Ixtlán de Juárez (https://www.facebook.com/photo/?fbid=1007503068077162&set=pb.100064524349372.-2207520000), aimed at the public and at the University in 28 (https://www.facebook.com/photo/?fbid=1082053093934120&set=a.497057879100314&__cft__[0]=AZWPY8I7amA-CoFGBo_qBQOTkWes7T8Y-NyDdyY-PHuB13aP3UfYn4m4YUJa1yxjTUBianJQ_5KXWlZi3oW_yD4wbrAtrxTe7oIH_5uClPrOBushqiJf0EcGkzv2aBm_hOLHhoOTN-Pm5SbGK2W4VJjwZs4RWnUPdNG9HNIpjkCMLN7odxtmblwlNkVzyCQZgXHCCk8p45WBrtpN9XUNhf4av17nuz7IO9zIg4ZXLMdSvPMYqDkNNoe795I9nMBti-M&__tn__=EH-y-R). (https://www.facebook.com/profile.php?id=100064524349372) Alongside these workshops, a photographic exhibition was organized, as well as the presentation of the video. It was frustrating for the team in Santiago Comaltepec that both the photographic exhibition and the workshop, as well as the authorities who had been insisting for more than two months, only attracted 12 attendees, as included in the list. Moreover, they did not publish the poster, I sent them on their social media. There is total apathy regarding their resources; although the authorities say they are interested, the reality is different. We have already experienced this with a previous project ten years ago. The changes in government every year and a half do not provide continuity to anything, and the material delivered gets lost. When one wants to return and continue, other authorities change the rules of the game and show no interest. As happened to us in July, it took three months to back to field work, and with the difficult negotiation of wanting to charge us as scientific tourism. The video was delivered, and we mentioned the possibility of translating it into their language, I am in shock and very worried, but I will try my best to continue working with us because I have hope.

In Ixtlán, it not different with adults but not with the authorities; although it is more organized, and the tree is in a tourism area that is biocultural important. Unlike the previous situation, we see no interest from the adults people; only 7 people attended, along with the authorities. In this communities, they value the tree and are concerned about its biocultural integration. One of the attendees mentioned that people are often apathetic and only attend when there are village assemblies. He suggested asking for a space; in fact, I had been doing that for more than two months with the communal land authorities, but they denied it, not because they didn't want to, but because they have matters to address and their time is valuable. Perhaps my mistake was not starting the workshops in January, but I didn't have results. Additionally, three months were lost without being able to work in Comaltepec due to the change of authorities. I wanted all the data to be complete; I tried to schedule an assembly, but I can't give a date because here the villages are governed by their own times and customs. However, despite everything, it was enriching for those who attended. For me, the most significant moment was when a little girl saw me and said, "You went to school, and I learned, and I want to hug you." I couldn't take a photo, but that means a lot to me; reaching someone, especially a child, is wonderful and motivates me to keep working with the species and people.

We want to engage in long-term work with them so that the tree becomes biocultural part of their established heritage, which is part of what follows. The community even sought a person to translate the video into Zapotec, with whom we are working, and she herself sent us the final part of the script that we will include in the video. Once it is finished, it will be sent to you. It is a difficult language, and there are words that need to be changed or do not exist.

For the reasons mentioned, if one day we have a nursery in the communities where the species can survive, from my very particular point of view, it is here in Ixtlán de Juárez. A photographic exhibition was also held at the university, along with the workshop and the presentation of the videos, as I mentioned, even though it was not included in the original project. Students from the area and from the central valleys of Oaxaca, studying Biology and a Master’s in Forest Resource Conservation, participated; without them, it would have been almost impossible to conduct the survey. We consider it important for the university, being the region's institution, to play a significant role in their academic training. All supporting information is in Attachment 2 and videos are in Attachment 6.

The workshop in the two communities for adults began with a 30-minute presentation titled "View through the window a *Quercus macdougalii*." This presentation covered the following topics:

- Definition and significance of forests in the communities.
- Explanation of biocultural and endemic species.
- Description of the target tree species and its biological role in the forest.

- Importance of the species as a keystone species.
- Associated biodiversity and threats faced by the species.
- Conservation efforts and community involvement.

Documentation of materials, presentations, and participation lists is included in Attachment 2.

We wanted to conduct workshops with the authorities, and although they are interested, they have mentioned that they cannot do so this month due to their commitments. Despite my efforts over more than two months include this January of insistence, I was unable to finalize anything before the project deadline. Therefore, I will leave this matter pending for their timing and consideration, as it is beyond my control. I hope they understand this situation.

The remaining community, San Pedro Yólox, is set to conduct its workshops in March or April. Although only two workshops were initially promised, additional sessions will be conducted as required.

Also, attendance was also recorded at a dissemination congress held in the city of Oaxaca for citizens, promoting the species as biocultural heritage in Oaxaca state and at the University of Sierra Juárez for students and professors. Documentation of this event is attached, and it was broadcast on a local radio program, "La Voz de la Sierra Juárez."

Printed outreach materials were also provided to the three communities for dissemination, along with information about the tree. Receipts for these materials are included. And Video and photographic was made for the two communities.

Conclusion

The workshops conducted in Ixtlán de Juárez and Santiago Comaltepec have significantly contributed to the education of local students regarding the ecological importance of the target species. The involvement of university students has further enriched the experience, fostering a sense of community engagement and conservation awareness. The results of the questionnaires will be analyzed at the end of the semester, with plans for publication in 2025 There needs to be long-term work with the adults, as they do not show interest in the species, unlike the children. For adults' workshop we need to work for a long time to include the species in theirs minds.

Conclusions

1. **Endemic Distribution and Climate Change Threats**: ***Quercus macdougallii*** has an endemic and restricted distribution in the Sierra Juárez, Oaxaca, Mexico, which is significantly threatened by climate change. Future distribution models predict a drastic reduction in its suitable habitat, with expected decreases range from 58% by the years 2050 and 2070, depending on greenhouse gas concentration scenarios (RCP4.5 and RCP8.5). This underscores the urgent need for conservation strategies to protect this species and its habitats in the face of climate change.
2. **Population.** The population is currently larger than previously believed and remains stable, although its limited regeneration occurs probably primarily through resprouting right now. This survival strategy may be necessary due to the lack of acorn production observed in other oak species in the Forest.
3. **Impact of Environmental Variables**: Environmental variables, particularly temperature seasonality and annual precipitation, significantly influence the growth of the diameter of ***Quercus macdougallii*** individuals. Although only a small proportion of the variability in diameter can be attributed to these variables, they are critical factors affecting the population structure and development of the species. Local environmental conditions, such as seasonal resource availability, play a vital role in determining tree size and distribution, emphasizing the importance of considering climatic variability in conservation strategies for this species.

4. **Forest Cover Recovery**: Between 1979 and 2022, forest areas adjacent to the habitats of ***Quercus macdougallii*** have shown signs of recovery. However, the absence of forest cover loss does not guarantee that there is no habitat degradation due to selective logging or climate change effects. While there was a general recovery from 1979 to 1995, a slight decrease in forest cover was noted from 1995 to 2022. This indicates that sustainable forest management practices are essential for coexistence with the conservation of habitats for ***Quercus macdougallii*** and must be implemented to minimize negative impacts on its habitat.
5. **Post-Fire Recovery Dynamics**: Analysis of ***Quercus macdougallii*** recovery over a 35-year period from 1988 to 2023 reveals that areas with low to very low fire severity have shown higher recovery rates, while high-severity zones have experienced slower and more inconsistent recovery. Although passive regeneration indicates ecosystem resilience, it does not ensure that original species, such as ***Quercus macdougallii***, will return in the same abundance or health as before the fire. This highlights the importance of ongoing monitoring to assess vegetative composition and its impact on biodiversity and ecosystem services.
6. **Microendemic Distribution**: For the first time, this study explored the actual distribution of ***Quercus macdougallii***, a microendemic species, based on potential distribution models and field outputs across three communities: Ixtlán de Juárez, Santiago Comaltepec, and San Pedro Yólox in the Sierra Norte de Oaxaca. The species was not found in areas suggested by potential distribution models, indicating a need for further exploration in the central part of its distribution.
7. **Size Structure and Regeneration**: The size structure of the population shows a scarcity of small individuals, primarily resulting from vegetative propagation. Population right now is stable and bigger than expected.
8. **Community Engagement**: Workshops with children and teenagers and adults should continue to foster a connection between the species and its

biocultural heritage. We the adults people we are needing to work with them for a long time.

9. **Integration with Genetic Research**: The findings of this study complement and support the genetic research being developed by the working group, presenting new challenges for ongoing conservation efforts.

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SUPLEMENTARY MATERIALS

Attachments 1. A complete database of the three locations was added, including more individuals from an outing made on December 30 to San Pedro Yólox. Many trees were cut down or burned in the past, so they sprouted from a trunk and therefore have multiple branches. At the San Pedro Yólox site, no coverings were taken, so they are not included in the data base.

Attachments 2. Include the list of participants from the workshops in Santiago Comaltepec and Ixtlán de Juárez, which involved children, adolescents, and adults. There should be photographic records of the workshops, as well as a photographic record of the exhibition. Materials used in the workshops were given to the authorities. A radio program was created to promote awareness of the species, along with promotional materials distributed to the three communities. Additionally, include the receipt for a conference in a congress held in Oaxaca City on biocultural heritage, as well as one conducted at the Universidad de la Sierra Juárez for students and professors."

Attachments 3

PHOTOGRAPHIC RECORD OF THE POPULATIONS AND SITES OF QUERCUS MACDOUGALLI MARTÍNEZ AND FIELDWORK (Attachments 3)

A photographic record of the fieldwork on *Quercus macdougalli* Martínez has been compiled, which is provided in Attachments 3. In this folder, you will find two subfolders: one containing photos of the *Q. macdougalli* forests at each of the three sites, and the other offering videos and photos from the fieldwork, which was quite challenging due to the high altitude ranging from 2,600 to 3,100 meters above sea level. The terrain is very steep, and the climate is extremely cold throughout the year.

I must mention that the students, as part of their master's program in Forest Resource Conservation, along with the mayor biology group 904, supported the workshops. Many of them are from the Sierra Juárez region, also known as the Sierra Norte, and we found it incredible that they asked us for assistance several times to learn more about the species. I should also note that we provided meals for the participants during the days to field work, especially for those in the biology group, as many come from low-income backgrounds.

Among the photos in the other folder, I took the liberty of including a picture of one of the Chinantec towns, which I consider the most beautiful, with its forest in the background where the trees are always associated with water springs in all three communities. In these final reports I added more photos of San Pedro Yólox.

Attachments 4

The article sent to Madera's y Bosques Journal

Attachments 5

Financial report was given to me for the University Administrations

Attachments 6

Video provided to both communities for dissemination in English and Spanish.