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Research article

Influencia de la perturbación en atributos morfológicos y estructura poblacional de *Dalbergia palo-escrito* Rzed. & Guridi-Gómez

Disturbance influence on morphological attributes and population structure of *Dalbergia palo-escrito* Rzed. & Guridi-Gómez

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Abstract

Palo escrito is considered a precious wood and is used in luthier woodworking; its uncontrolled harvesting puts its natural populations at risk. Fortunately, its adaptability to disturbed areas and secondary vegetation suggest that it is susceptible to management. Mensuration attributes were analyzed of this species in relation to the disturbance index (human activity, livestock and habitat deterioration) in four natural populations. The populations were morphologically described by organizing individuals by Euclidean distances. The population density and aggregation pattern were established using the Coefficient of variation in the distance between individuals. Results showed from which four morphological groups, Group 3 was formed with individuals with straight, non-bifurcated stems and complete dominance in the initial axis for timber production. All populations differed significantly ($p \leq 0.01$) in composition in all disturbance comparisons ($Chi^2 > 19.3$). The greatest disturbance was due to human activity, followed by livestock activity and finally habitat deterioration. Populations with an intermediate level of disturbance have the highest number of individuals best suited for timber production; however, extremes in the level of disturbance compromise recruitment and the homogeneity of desirable morphological attributes. Also, spatial distribution analysis showed that the species forms clusters of individuals in all populations. It is concluded that disturbance modifies the density and morphological conformation of individuals, but only to a point, which makes this species susceptible to agrosilvopastoral and conservation management.

Key words: Habitat deterioration, agrosilvopastoral management, *Palo escrito*, natural population, restoration, secondary vegetation.

Resumen

El palo escrito es una especie considerada madera preciosa que se ha empleado en laudería. Su aprovechamiento sin control pone en riesgo sus poblaciones naturales, pero afortunadamente su adaptabilidad a zonas perturbadas y vegetación secundaria sugiere ser susceptible al manejo. Se planteó el análisis de atributos dasométricos de palo escrito con relación al Índice de Perturbación (actividad humana, ganadera y deterioro del hábitat) en cuatro poblaciones naturales. Las poblaciones se describieron morfológicamente y se agruparon los individuos mediante distancias Euclidianas. Se estableció la densidad poblacional y el patrón de agregación mediante el Coeficiente de Variación en la distancia entre individuos. Los resultados mostraron cuatro grupos morfológicos; el Grupo 3 se integró con individuos de fuste recto, no bifurcado y dominancia completa en el eje inicial para la producción maderable. Las poblaciones difieren significativamente ($p \leq 0.01$) en su composición en todas las comparaciones de disturbio ($Chi^2 > 19.3$). La mayor afectación fue por actividad humana, seguida por la actividad ganadera y el deterioro del hábitat. Las poblaciones con nivel intermedio de perturbación presentaron la mayor cantidad de individuos mejor conformados para la producción maderable; sin embargo, los extremos en dicho nivel comprometen el reclutamiento y la homogeneidad de atributos morfológicos deseables. El análisis de distribución espacial indica que la especie forma agrupaciones de individuos en todas las poblaciones. Se concluye que el disturbio modifica la densidad y conformación morfológica de los individuos, pero solo parcialmente, lo que hace susceptible a esta especie para el manejo agrosilvopastoril y de conservación.

Palabras clave: Deterioro de hábitat, manejo agrosilvopastoril, palo escrito, población natural, restauración, vegetación secundaria.

Introduction

Several factors, both biotic and abiotic have an effect on vegetable populations, that influence and determine their regeneration processes (Funk et al., 2017). When a population undergoes some important change in its size, composition and disposition of resources, it results in specific alteration in its structure and dynamics that occurs in specific time and space. Scientific information shows the relationship between habitat loss, the drastic decrease in populations and the fragmentation of the vegetation that come from these specific changes in time and space (Rivera-Fernández et al., 2012). Disturbance alters the structure of ecosystems, changing the disposition of resources and the physical environment (De la Cruz-Cabrera & Contreras, 2019).

Fragmentation decreases size and connectivity between populations, promotes general deterioration (Silvério et al., 2019), and generates particular selection pressures on the least adapted categories. This induces demographic changes that increase the risk of extinction of local populations (Alfaro et al., 2014), which has been associated with the decrease in population size (Cohen et al., 2016), reduction in fertility (Zheng et al., 2017), alterations in the structure and demographic composition (McDowell et al., 2020), low density and loss of evolutionary potential (Budde et al., 2016).

On the other hand, disturbance directly impacts the diversity of communities and persistence of populations, including their demographic and genetic aspects. This is interesting to explain local adaptations to degraded habitats, modifications in their genetic diversity and short and medium term variation in the demographic structure (Octavio-Aguilar et al., 2017).

Dalbergia palo-escrito Rzed. & Guridi-Gómez, known as "Written stick", is a tree species up to 35 m high, with stems up to 80 cm in normal diameter, whose wood is considered fine and has been used in agroforestry management as shadow canopy for *Coffea arabica* L., and in *Musa* spp. plantations.

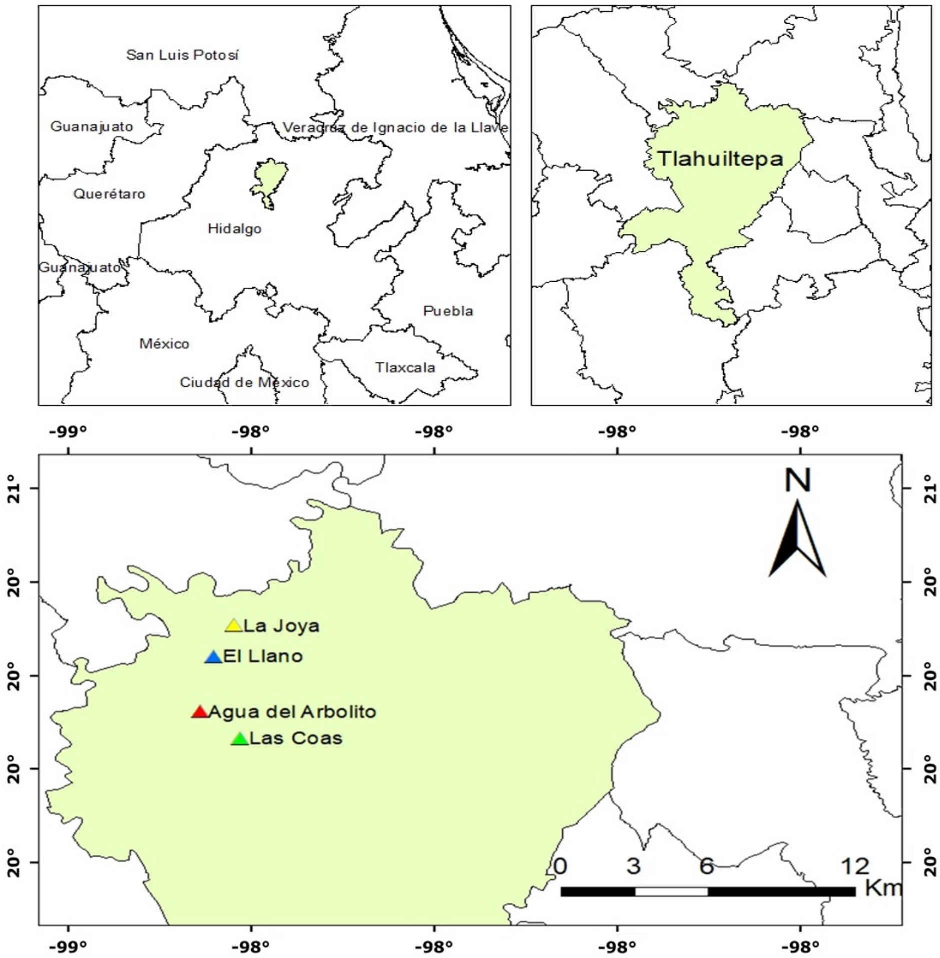
It grows with other tree species such as *Juglans pyriformis* Liebm., *Trema micranthum* (L.) Blume., *Bursera simaruba* (L.) Sarg., *Platanus mexicana* Moric. and *Cedrela odorata* L.; where it has been observed that the agroforestry association benefits the performance of morphological attributes for timber production in this species (Suárez-Islas et al., 2020).

On the other hand, Rzedowski and Guridi-Gómez (1988) said that *D. palo-escrito* is favored by certain types of disturbance and is presented with greater abundance in secondary forest, although it is unknown if the disturbance changes some morphological attribute of the tree of interest. Such information is necessary for decision -making and technical criteria for forest and agroforestry management for conservation and restoration. Therefore, this work aimed to determine the influence of the disturbance on the variation of morphological attributes and the population structure of *D. palo-escrito* in four locations in *Tlahuiltepa*, *Hidalgo* state, Mexico.

Materials and Methods

Study area

Tlahuiltepa municipality, state of *Hidalgo*, Mexico (Figure 1), it is located between 21°02' and 20°38' North, and 98°51 'and 99°07' West. Physiographically it is within the *Sierra Madre Oriental* in particular in the *Sierra Alta Hidalguense*. It has an irregular topography with cliffs ranging from 20 to 80 % slope in 90 % of the territory. The annual average temperature is 17 °C and the annual precipitation, 900 mm. The predominant climates in these sites are tempered (C) and subhumid temperate (C_W) (Instituto Nacional de Estadística y Geografía [INEGI], 2003). The predominant tree species are *Cupressus lusitanica* Mill., *Platanus mexicana*, *Myroxylon balsamum* (L.) Harms, *Dalbergia palo-escrito*, *Quercus* spp., *Pinus* spp., *Junglas* spp., among others (Sistema Integral de Información del Estado de Hidalgo [SIIEH], 2011).



San Luis Potosí = State of *San Luis Potosí*; *Veracruz de Ignacio de la Llave* = State of *Veracruz de Ignacio de la Llave*; *Guanajuato* = State of *Guanajuato*; *Querétaro* = State of *Querétaro*; *Hidalgo* = State of *Hidalgo*; *Puebla* = State of *Puebla*; *México* = State of Mexico; *Tlaxcala* = State of *Tlaxcala*; *Ciudad de México* = Mexico City; *Tlahuiltepa* = *Tlahuiltepa* municipality. *La Joya* = *La Joya* population; *El Llano* = *El Llano* population; *Agua del Arbolito* = *Agua del Arbolito* population; *Las Coas* = *Las Coas* population.

Figure 1. Geographic location of *Dalbergia palo-escrito* Rzed. & Guridi-Gómez natural populations in *Tlahuiltepa*, *Hidalgo* state, Mexico.

Sampling

Through field tours, four populations of *D. palo-escrito* in *Tlahuiltepa* municipality, *Hidalgo* state (Table 1) were identified. The study sites were selected based on the presence of human activity, grazing and disturbance by different agents; they were georeferenced with a model Montana 680 Garmin® GPS. In each one, a 50×50 m quadrant was established, with the representative characteristics of the trees (Galván-Hernández et al., 2020).

Table 1. Assessed *Dalbergia palo-escrito* Rzed. & Guridi-Gómez natural populations in *Tlahuiltepa* municipality, *Hidalgo* state, Mexico.

Population	Locality	Latitude	Longitude	Altitude (masl)	Slope (%)
Las Coas	*Demañi*	20°55’35.8”	98°59’51.4”	1 635	33
Agua del Arbolito	*El Duraznito*	20°56’19.8”	99°00’44.4”	1 443	65
El Llano	*El Llano*	20°57’49.8”	99°00’25.4”	1 611	48
La Joya	*Agua Tapada*	20°58’39.8”	98°59’59.4”	1 309	42

The trees were mapped in a Cartesian plane to locate them and then evaluate the spatial density of individuals (Aguirre-Salado et al., 2015). Each one was measured the total height, the bifurcation height (distance to the point where the main axis loses dominance and develops in two or more axes) and clean shaft (m) with a Vertex III Haglöf® hipsometer and its auxiliary transmitter (transponder). For the normal diameter (cm) a model 5M Forestry Suppliers Inc.® with mm precision diamethric tape was used. The shaft shape, the main axis dominance, the insertion angle of the first branch and the crown shape were evaluated according to the numerical scale developed by Acosta-Hernández et al. (2011) and da Cunha et al. (2013) (Table 2). In the quadrants, three transects of 50×1 m were drawn, where 14 disturbance indicators were assessed (Martorell & Peters, 2005).

Table 2. Classification of variables and descriptors for the morphological characterization of *Dalbergia palo-escrito* Rzed. & Guridi-Gómez.

Stem shape (*SS*)	Straight	6
	Slightly sinuous (slight curve in 1 or 2 planes)	4
	Sinuous (extreme curve in one plane)	2
	Very sinuous (extreme curve in more than one plane)	1
Bifurcation height (*BH*)	Not bifurcated	6
	Bifurcated in the upper 1/3	4
	Bifurcated in the middle 1/3	2
	Bifurcated in the lower 1/3	1
Main axis dominance (*MAD*)	Complete dominance in the initial axis	2
	Partial dominance of the initial axis over the lateral branches	1
	Complete dominance over the lateral branches	0
Branch insertion angle (*BIA*)	From 0° to 30°	1
	From 30° to 60°	2
	From 60° to 90°	3
Crown shape (*CS*)	Circular	6
	Irregular circular	5
	Half circle	4
	Less than half circle	3
	Few branches	2
	Mainly regrowth	1

Source: Modified from Acosta-Hernández et al. (2011).

Morphological analysis

Populations were morphologically described by grouping individuals with a cluster analysis using Ward's method based on Euclidean distances (Hidalgo, 2003). Groups were defined by a 1 000-step bootstrap, which consists of a resampling simulation method (Alonso et al., 2002). Group composition was contrasted between populations using the X^2 test (Castañeda-Garzón et al., 2021). For the analysis of diameter structure, histograms of normal diameter classes were created with 5 cm intervals. Statistical analyses were performed with the Statistica program 10.0 version (StatSoft, 2011).

Disturbance analysis

The methodology of Martorell and Peters (2005) was used to determine the disturbance of the populations. The data were analyzed using principal coordinates with Gower distances (Galindo-García et al., 2019; Gower, 2005) to establish the indicators with the greatest weight in the divergence of the populations. This distance measure allows the integration of continuous and discrete variables. The method measures 14 disturbance indicators that are added together to form the disturbance index, which results from the sum of the total proportion of affectation by each disturbance indicator in the transects.

In each population, a 50×50 m plot (2 500 m^2) was established and the disturbance indicators were measured along three 50×1 m transects and 20 points in each plot.

Both the transect and the points were placed randomly in each plot. Each of the 14 disturbance indicators was measured three times per transect.

Spatial structure analysis

The population density and spatial aggregation pattern of individuals were established using the Coefficient of variation (*CV*) in the distance between individuals. When the *CV* is equal to 1, the populations are randomly distributed; when the *CV* is significantly greater than 1, the populations are spatially ordered, and when the *CV* is significantly less than one, then the populations are distributed in an aggregated manner (Dale & Fortin, 2014; Octavio-Aguilar et al., 2017; Rivera-Fernández et al., 2012). To corroborate the relationship between the *CV* and the unit, *t* tests were used.

Basal area analysis and Shannon Index

To determine the dominance of *D. palo-escrito* over other species through density, the basal area per individual (g) was calculated with the formula:

$$g = \left(\frac{\pi}{4}\right) \times d^2 \qquad (1)$$

Where:

g = Basal area per individual

d^2 = Density of individuals per square meter in each population, obtained from the sum of all individuals at the sampling site

The basal area per hectare (*G*) was obtained by extrapolation (Shannon & Weaver, 1949). The Shannon Index was also established to determine species diversity and relative abundance of individuals per population, assuming that these two factors influence community heterogeneity (Pla, 2006; Shannon & Weaver, 1949). The following formula was used:

$$H' = -\Sigma pi \, log \, pi \qquad (2)$$

Where:

pi = Relative abundance of *i* species: $\frac{ni}{N}$

ni = Number of individuals of *i* species

N = Total number of species

Results and Discussion

Morphological structure

Four morphological groups were detected by cluster analysis, the main variation of which is due to mensuration characteristics (Table 3). The four populations differ significantly in terms of their composition of morphological groups (Xi^2>19.3 in all comparisons, $p \leq 0.01$). Individuals from Group 3 (*Agua del Arbolito*) presented better attributes (straight, non-bifurcated trunk and complete dominance in the initial axis) for wood production, followed by Group 4 (*El Llano*). The population of *La Joya* (Group 1) had the highest proportion of young individuals, while the population with the highest dominance of intermediate trees corresponds to *Las Coas* (Group 2). The differences in the morphological structure of the populations analyzed are shown by means of the normal diameter (Figure 2).

Table 3. Cluster analysis for morphological descriptors that indicate characteristics for timber activity.

	ND	***TH***	***CS***	***SS***	***BH***	***MAD***	***BIA***	***CS***	***N***
Group 1	3.6±2.1	3.5±2.0	2.5±1.7	4.0±1.9	5.0±1.7	0.7±0.8	2.0±0.5	1.6±0.9	48
Group 2	12.6±3.9	10.7±2.6	5.9±2.6	2.3±1.0	3.6±1.5	1.6±0.5	2.1±0.5	3.3±1.3	115
Group 3	15.9±3.7	20.4±2.7	9.9±4.9	2.8±1.1	3.5±1.2	1.8±0.4	2.0±0.5	3.6±1.2	75
Group 4	32.2±6.7	18.6±5.2	4.7±2.1	2.3±1.0	2.1±1.1	1.5±0.6	2.5±0.5	3.9±1.3	30

ND = Normal diameter (cm); *TH* = Total height (m); *CS* = Clean stem (m); *SS* = Stem shape; *BH* = Bifurcation height (m); *MAD* = Main axis dominance; *BIA* = Branch insertion angle; *CS* = Crown shape; *N* = Number of individuals. Source: Acosta-Hernández et al. (2011).

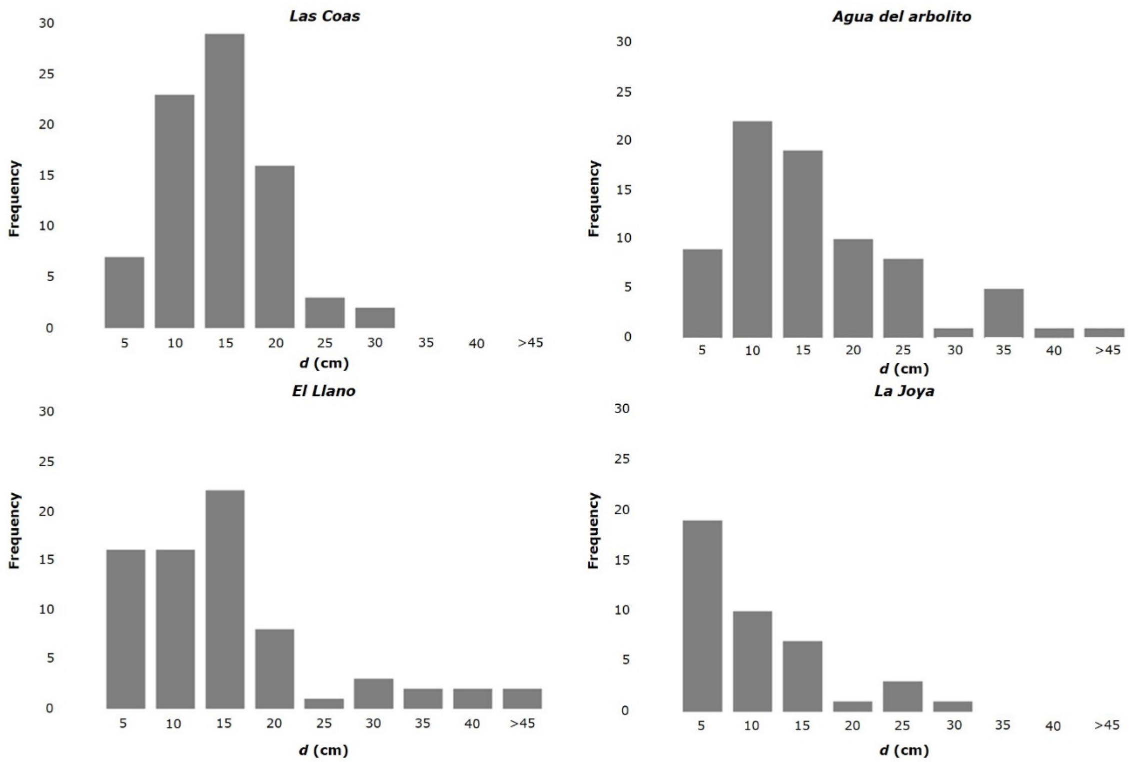


Figure 2. Diameter distribution in four *Dalbergia palo-escrito* Rzed. & Guridi-Gómez natural populations in *Tlahuiltepa* municipality, *Hidalgo* state, Mexico.

Disturbance analysis

The natural population of trees with the highest disturbance index was *La Joya* (7.6), while the group of trees under conservation conditions is located in the *Las Coas* population (4.1). Likewise, the latter is considered a secondary forest due to natural regeneration of around 20 years, the last five as a private reserve; this has limited the entry of cattle, loggers and hunters (Table 4). The *Agua del Arbolito* population received silvopastoral management by leaving *D. palo-escrito* as a shade species for the growth of forage. The trees in the group are around 18 years old, and are associated with livestock and wood extraction; the largest individuals in height and diameter of the evaluated populations were found there.

Table 4. Disturbance of *Dalbergia palo-escrito* Rzed. & Guridi-Gómez natural populations in *Tlahuiltepa* municipality, *Hidalgo* state, Mexico.

Agent	Indicator	*La Joya**	*Agua del Arbolito**	*El Llano**	*Las Coas**
Human activities	w	0.55	0.65	0.30	0.26
	a	1.00	1.00	1.00	1.00
	tb	0.61	0.34	0.36	0.61
	f	0.67	0.33	0.33	0.33
	p	1.00	1.00	1.00	0.00
	u	1.00	1.00	1.00	1.00
Livestock activity	b	0.61	0.47	0.06	0.07
	tt	0.34	0.12	0.06	0.02
	dc	0.60	0.40	0.30	0.20
	dg	0.00	0.00	0.00	0.00
	c	0.78	0.72	0.63	0.65
Habitat deterioration	e	0.25	0.15	0.10	0.05
	i	0.00	0.00	0.00	0.00
	m	0.00	0.00	0.00	0.00
Disturbance index		7.60	6.29	5.14	4.19

*Populations analyzed by Martirell and Peter's methodology (2005). The 14 indicators of disturbance (Martorell & Peters, 2005): w = Trees with cuts for firewood extraction; a = Proximity to agricultural fields; tb = Paths used by people; f = Evidence of fire in *D. palo-escrito* trees; p = Proximity to human settlements less than 1 km (p=1); u = Change in land use; b = Browsed plants; tt = Paths used by livestock; dc = Frequency of cattle droppings; dg = Frequency of goat droppings; c = Soil compaction caused by livestock; e = Soil erosion; i = Presence of erosion islands; m = Surface totally modified and not suitable for plant growth.

The trees of *El Llano* are under agroforestry management for agricultural activities (production of corn, beans, squash, striped chili, among other crops) and silvopastoral for cutting grass as fodder for cattle and sheep. The trees were remnants of selective cutting and are approximately 25 years old, which favors the development of crops and pastures. Finally, the trees of the *La Joya* population have been disturbed by slash-and-burn activities in order to form pastures, where the *D. palo-escrito* species protects the cattle with shade. The trees have about 10 years of natural regeneration, and it is confirmed that the species is heliophilous since vigorous juvenile individuals were found in open sites with full sun exposure. The highest disturbance index was determined at this site.

The results of the present study are similar to those reported by Cervantes (2016) and Gálvez (2009) because they show the same risk of disturbance of natural populations from the extraction of wood by rural communities for local use, coupled with the intrinsic threats to its biology such as its natural scarcity and slow growth, which have seriously impacted natural populations (Cervantes et al., 2019). This situation has led to all native Mexican timber species of *Dalbergia* L. f. being classified under some risk category, which are listed under protection by CITES and competent Mexican authorities (NOM-059-SEMARNAT-2010) (Cervantes et al., 2019).

Spatial structure analysis

Trees in the *Agua del Arbolito* natural population are on average 24.1±12.4 m apart from each other, with a Coefficient of variation significantly lower than one (CV=0.52, $p\leq0.01$), indicating a spatial aggregation pattern (patched); the population density was 300 individuals ha^{-1}. In the *El Llano* population, the average distance between individuals was 18.0±10.7 meters, with a Coefficient of Variation less than one (*CV*=0.59, *p*≤0.001), also corresponding to an aggregated pattern; the population density was 280 individuals ha^{-1}. The natural population *La Joya* had the lowest tree density with 160 ind ha^{-1}, with a distance between individuals of 27.4±15.1 m and a Coefficient of Variation less than one (*CV*=0.55, *p*≤0.01). Finally, the *Las Coas* tree population had an aggregated pattern (*CV*=0.61, *p*≤0.01) and distances between individuals of 22.8±13.8 m, with a density of 320 ind ha^{-1}. The species in natural environments had a clumped pattern (Figure 3), regardless of disturbance or light availability, which has been linked to deficiency in seed dispersal and habitat loss due to fragmentation (Arasa-Gisbert et al., 2021) or for conservation purposes (Fahrig et al., 2019).

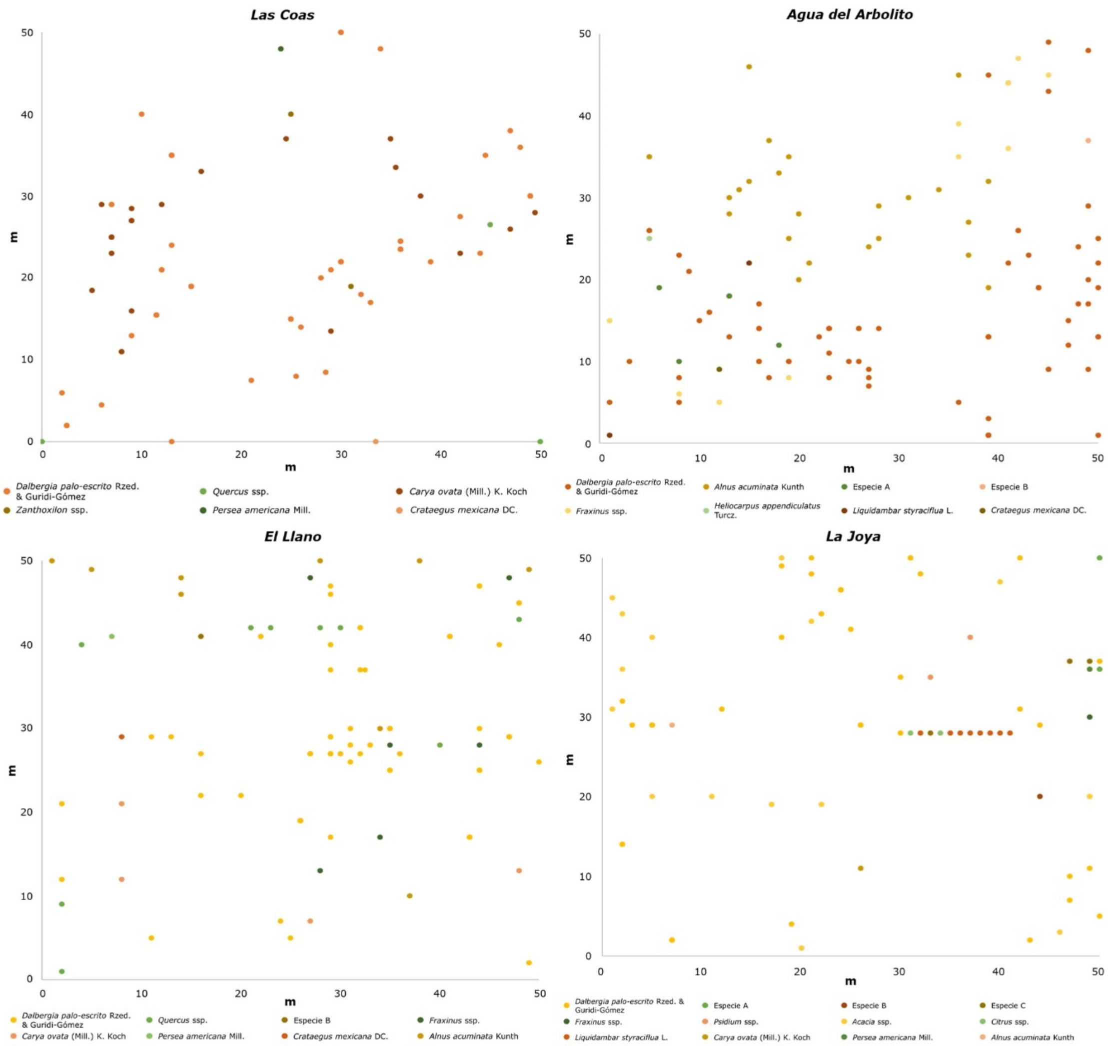


Figure 3. Spatial distribution of trees *Dalbergia palo-escrito* Rzed. & Guridi-Gómez in natural populations in *Tlahuiltepa* municipality, *Hidalgo* state, Mexico.

Basal area analysis and Shannon index

The natural population *Las Coas* presented less species diversity, and was also the least disturbed. In contrast, the *La Joya* population had the highest species diversity, low density, and highest disturbance. This suggests that species diversity in populations may be related to the intensity of disturbance. According to the Shannon index (*H'*: <2 low diversity and >3 high diversity), the natural populations of *D. palo-escrito* in *Tlahuiltep*a municipality, *Hidalgo* state, had lower values than two in the referred index (*Las Coas* 1.3, *Agua del Arbolito* 1.5, *El Llano* 1.6, and *La Joya* 1.8). This means low species diversity due to the current land use for agroforestry and silvopasture.

However, D. palo-escrito remains the predominant species in the region (Figure 4). The results of the present research are similar in the morphological traits to those that Onaindia et al. (2013) described for Quercus robur L. and Pinus radiata D. Don. in older tree populations. In the basal area variable for Pinus spp., gains were obtained in basimetric composition (Hernández-Salas et al., 2013) and modifying tree density promoted a greater abundance of individuals (Barefoot et al., 2019). In *Pinus hartwegii* Lindl. forests, morphological gains were recorded in height and normal diameter (Rojas-García et al., 2022).

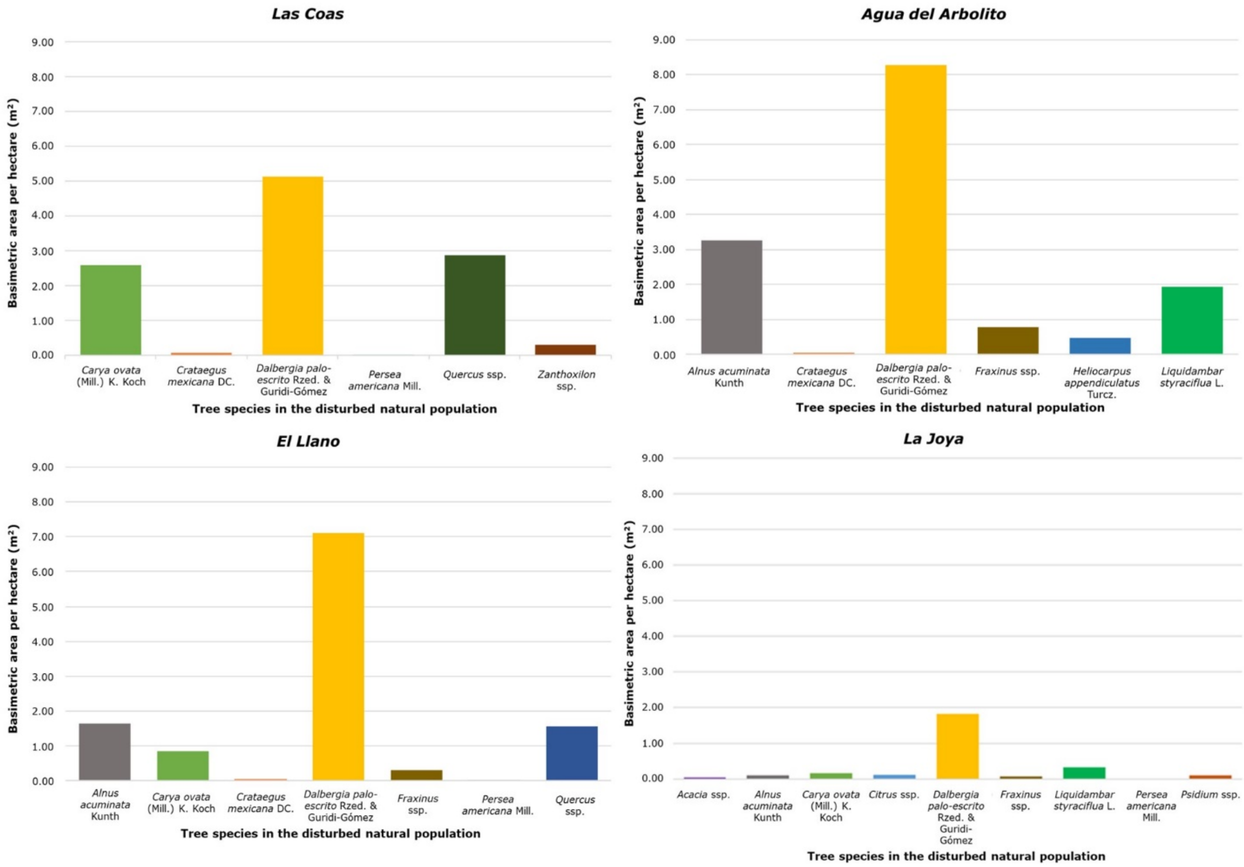


Figure 4. Basal area distribution of tree species in four *Dalbergia palo-escrito* Rzed. & Guridi-Gómez natural populations in *Tlahuiltepa* municipality, *Hidalgo* state, Mexico.

In another study, Douglas fir forests (*Pseudotsuga menziesii* (Mirb.) Franco) have been used as a model to evaluate the gain and loss of morphological traits under different levels of disturbance (Linares & Samain, 2019).

Conclusions

Moderate disturbance by cattle and loggers in natural populations of *Dalbergia palo-escrito* favors population density and morphological conformation of trees for sawmilling purposes. Its spatial distribution is aggregated and generates suitable conditions for the use of the species in agrosilvopastoral systems in the region. However, high levels of disturbance compromise the conservation of natural populations of *D. palo-escrito* in *Tlahuiltepa* municipality, *Hidalgo* state, Mexico.

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Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

Cuauhtémoc Alain Rubio Tobón: data collection in the field, interpretation of results, structure and writing of the manuscript; Rodrigo Rodríguez Laguna: design of the field format, review and correction of the manuscript; Alfonso Suárez Islas: review, design and interpretation of the results and review of the document; Pablo Octavio Aguilar: analysis of the field data, interpretation of results, review and writing of the manuscript; Juan Capulin Grande: correction and review of the document.

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