Current Status of Magnolia vovidesii (Magnoliaceae, Magnoniales): New Data on Population Trends, Spatial Structure, and Disturbance Threats

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Abstract

Magnolia vovidesii has been found in a few small patches in central Veracruz, Mexico. Previous ecological studies have suggested high reproductive potential and stable population growth; however, in the last 20 years, there have been severe anthropogenic environmental impacts on the species. The main objectives of this study were (a) to document the current trend of the population, (b) to determine its spatial structure, and (c) to identify the main threats to the species in order to propose conservation and management strategies. Our results show a population in decline, caused by high mortality during early establishment stages (seeds and seedlings) and the removal of young sick trees during the reproductive stage. We found a strong spatial dependence between seedlings and reproductive individuals (young and old adults) and a weak spatial association between reproductive stages, suggesting a nursing effect, inbreeding, and pollen dependence. The main threats to the population are frequent plant removal, trails used by people, land-use change, and parasitism. These data show the urgent need to carry out prompt conservation action for the species, with special emphasis on ex situ propagation. The results of this study suggest that *M. vovidesii* should be transferred to the International Union for Conservation of Nature Red List category for critically endangered species.

Introduction

The Magnoliaceae family is widely distributed in the New World in temperate and tropical zones of the Neotropics. In this geographical range, the family is represented by a single genus, *Magnolia*, with about 170 species, which represent 95% of the genus in the continent and 40% worldwide, with high levels of endemism. Within this range, Mexico is one of the three most diverse countries, along with Colombia and Ecuador (Vázquez-García, 2019; Vázquez-García et al., 2013). Most species are characterized by growing in particular environments such as mountain cloud forests (Gutiérrez & Vovides, 1997). However, this is one of the most fragmented ecosystems and is undergoing continuous reduction in area, land-use conversion, and susceptibility to

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global climate change (García-Hernández & Toledo-Aceves, 2020). As a result, endemic species of this vegetation type are the most affected, placing several of them under a single category of risk according to the International Union for Conservation of Nature (IUCN) Red List (Vázquez-García et al., 2013).

The first ecological analysis of *Magnolia vovidesii* A. Vázquez, Domínguez-Yesca & L. Carvajal was done by Gutiérrez and Vovides (1997), who described the conservation state of four putative populations of *M. dealbata* Zucc. These authors conducted an exhaustive survey of two populations from Oaxaca (southern Mexico), one in Hidalgo (northeastern Mexico) and a rare, unique isolated population in central Veracruz (central Gulf of Mexico). For decades, the name *Magnolia dealbata* has been applied indiscriminately to any deciduous Mexican magnolia with large flowers and leaves with glaucous (light bluish green) undersides. In this context, only a large population in San Juan Juquila in northern Oaxaca corresponds to the original description of *M. dealbata* (Zuccarini, 1836), although we now know that these reports are actually of isolated populations of unknown size (Domínguez-Yescas, 2012; Martínez-Velasco, 2018). Most of the bibliographical references to *Magnolia dealbata* (Azuma et al., 2001; Callaway, 1994; Figlar, 1997; Johnson, 1989; Kim et al., 2001; Nie et al., 2008; Pattinson, 1986; Qiu et al., 1995a, 1995b; Russell, 1984; Sánchez-Velázquez & Pineda-López, 2006, 2010) correspond to *M. vovidesii*, while a few others (Dodd, 1980; Pfaffman, 1975; Vázquez-García et al., 2015) correspond to the recently described *M. rzedowskiana* (A. Vázquez, R. Domínguez-Yescas & R. Pedraza), a further more recent two (Velazco-Macías et al., 2008) are from the recently described *M. nuevoleonensis* A. Vázquez & R. Domínguez-Yescas (Vázquez-García et al., 2013, 2015, 2016), and material from Tamaulipas corresponds to *M. alejandrae* García-Mor. & Iamonico (García-Morales et al., 2017). In 2013, *Magnolia vovidesii* was separated from the *M. dealbata* complex based on an exhaustive morphological characterization by Vázquez-García et al. (2013).

Magnolia vovidesii is endemic to Central Veracruz, with confirmed herbarium records in Xico (G. Pattison V083077, XAL), Ixhuacán de los Reyes (Gutiérrez Carvajal XAL0114618, XAL), Totutla (October 1941, Liebman 1975, K), Huatusco (1841–1843, Liebmann 1983, K), Los Reyes (Rincón 1413, XAL), Cosautlán (IBUG), and Tequila (Herbario de Zongolica), all of which have an estimated range of less than $85\,km^2$ (Rivers, 2016). However, this information differs from that of the Gutiérrez and Vovides (1997) report, who located only two patchy sites, with different disturbance degree, in an area of $4,800\,m^2$, the two patches are approximately 450 m apart. The species is listed as Endangered by the IUCN Red List category B1ab (iii, v) (Rivers, 2016). According to assessment information, its habitat is severely fragmented and the species continues to decline due to land-use change—particularly clearing for pastures, coffee plantations, and human settlements—and cutting for firewood (Muñoz-Villers & López-Blanco, 2008). Most of the population studies have been carried out based on the location of Gutiérrez and Vovides (1997). However, up-to-date information and quantification of actual disturbance threats are necessary in order to reevaluate the populations and their conservation status.

The main obstacle to *M. vovidesii* management programs is the low germination rate and short viability of seeds. A primary description of the controlled propagation of *M. vovidesii* showed a low seed germination rate (40%) after approximately 10 months (Vovides & Iglesias, 1996). Recent studies have shown a germination success of $90.8 \pm 1.1\%$, but with an artificial supplement of organic matter after six months (Toledo-Aceves, 2017). In addition, during tissue culture, genetic instability of somatic embryos was reported (Mata-Rosas et al., 2006). Rural propagation in the field in collaboration with local communities has been unsuccessful, with only four trees surviving out of more than 10,000 seeds sown in natural conditions over a period of 5 years (2013–2018; Galván-Hernández, personal communication, 31 August, 2019). Similar results were obtained in a previous study with less than 0.1% survival in the transition from seeds to seedlings over 3 years. Seedling mortality for this species was found to be high in the first year (84.21%) by Sánchez-Velásquez and Pineda-López (2010). Recently, a study of the potential for field propagation has been described (García-Hernández & Toledo-Aceves, 2020), where a survival of 53% to 97% was estimated. The survival rate increased with elevation; this result has potential as a conservation strategy to mitigate global climate change effects.

It has been shown that cutting the stems will cause a reduction in the effectiveness of the reproductive component of the populations. Furthermore, a classification of adult individuals without clear criteria with respect to reproductive events suggests that adult permanence in the populations is overestimated by Sánchez-Velásquez and Pineda-López (2010). The population studied by Sánchez-Velásquez and Pineda-López (2006) had approximately 300 individuals per hectare (ind/ha) in 2001. A contagious spatial distribution was recorded, but with contrast between patch sizes being dependent on a secondary succession stage, which suggests a non-quantified disturbance effect on the population (Gutiérrez & Vovides, 1997).

Based on these previous results, the aims of this study were to document the current status of the *M. vovidesii* population, analyze its spatial structure, and identify the principal threats. This study therefore proposes to mitigate the lack of information for the continuous updating of the IUCN Red List and NOM-059, whose purposes

are focused on classifying high-risk species, as well as to provide the specifications for inclusion, exclusion, or criteria change within these lists.

Methods

Study Site

This research was conducted in 2018 in the major population of *Magnolia vovidesii* at Coyopolan, Ixhuacán de los Reyes, Veracruz, Mexico (19°22′0.60″ N, 97°04′3.22″ W). The population was chosen in order to compare previous data reported about population size and to calculate rates of change. This area is located within an altitude range of 1,520 to 1,550 masl. The climate is subtropical and average annual temperature of 19.5°C (Gutiérrez & Vovides, 1997; Sánchez-Velásquez & Pineda-López, 2006). The population is located on a slope of $32.8° \pm 11.74°$. In terms of plant associations, tree species of the genera *Carpinus*, *Clethra*, *Liquidambar*, *Quercus*, *Miconia*, *Litsea*, and *Senecio*, among others, coexist with *M. vovidesii* (Gutiérez & Vovides, 1997).

A complete census of the population was registered in April 2018. The XY coordinate position of each individual in an 80×130 m rectangular plot ($10,400$ m^2) was registered. Our plot size was larger than that used by Gutiérrez (1993; 6×5 m, $4,200$ m^2) and Sánchez-Velázquez and Pineda-López (2006; 10×10 m, $1,600$ m^2), in order to include the largest number possible of previously reported individuals from the two patches. Diameter at breast height (cm) and height (m) were measured for each tree, and number of cones per individual (registered and collected in September 2018). Fifty cones (Figure 1) were collected to estimate the variability of seed number by reproductive category (young adults and to adults) and to calculate the reproductive component by category (average number of seeds per cone multiplied by the average number of cones per individual). The reproductive component was compared between fertile categories using a Mann–Whitney test (paired contrast for nonparametric data) with the STATISTICA v.10 program (StatSoft, 2011).

Current Population Trend

Plants were classified by a cluster analysis of the mentioned morphological traits listed in the previous section using Ward's agglomeration method with Euclidean distances, a measure specific to the grouping method, which allows an analytical-parametric contrast. The groups were established by a bootstrap resampling with 10,000 iterations and corroborated by an amalgamation diagram, using the STATISTICA v.10 program (StatSoft, 2011). The resulting categories and the reproductive

component were used to construct a static life table (SLT). The main demographic traits in the SLT were (a) l_x; survival rate in class x, and (b) m_x; fecundity of reproductive individuals, calculated as the average number of seeds per cone and the quantity of fruits per individual (Castillo-Lara et al., 2017). Using values of R_0 (reproductive rate: $\sum l_x m_x$) and T_G (generation time: $\frac{\sum x l_x m_x}{\sum l_x m_x}$) population growth rate per capita (r) was calculated as $r\approx$, representing an unweighted approximate value for the increase in a population from one generation to the next (Castillo-Lara, et al., 2017; Rubio-Méndez et al., 2018; Valverde et al., 2005). Based on these data, the intrinsic population growth rate ($\lambda = exp^r$) was calculated, where $\lambda = 1$ means that the population remains stable, $\lambda > 1$ means it grows, and $\lambda < 1$ means it decreases.

Spatial Distribution

Spatial distribution and association among categories were determined by the K_{12} and K_t functions according to Ripley (1981), with the *Spatial Analysis* program (Duncan, 1990). In the case of *Magnolia vovidesii*, 99 simulations in ascending distances increasing by 1 m were run until a radius of 25 m was reached. This is the limit proposed by De la Cruz (2006) that corresponds to less than a third of the rectangular plot lengths in order to diminish border effects. If the data do not match the expected values generated by the functions, then an aggregated pattern (K_t) and dependency between groups (K_{12}) are presented (Peter, 1995).

Disturbance Analysis

Fourteen traits (Table 1) related to disturbance (modified according to Martorell & Peters, 2009) were evaluated in 16 transects of 50×1 m (800 m^2), randomly distributed on the total censored population area. In addition, parasitism by *Convolvulus arvensis* was considered as a specific disturbance trait, because it is one of the main causes of plant mortality, and local villagers cut back infected trees to promote vegetative regeneration, reducing the reproductive component (Figure 1H and I). The sum of 1 m^2 quadrats on the affected transect by each indicator was divided by the total number of quadrats per transect (50 m^2) and multiplied by 100 to convert it to a percentage.

These data enable us to describe the percentage of effect per disturbance trait in the population, as well as to establish transect groups using Ward's agglomeration method with Euclidean distances and grouping by a bootstrap resampling (10,000; StatSoft, 2011). Finally, a contrast evaluation (analysis of variance) between transect groups was made for each disturbance trait.
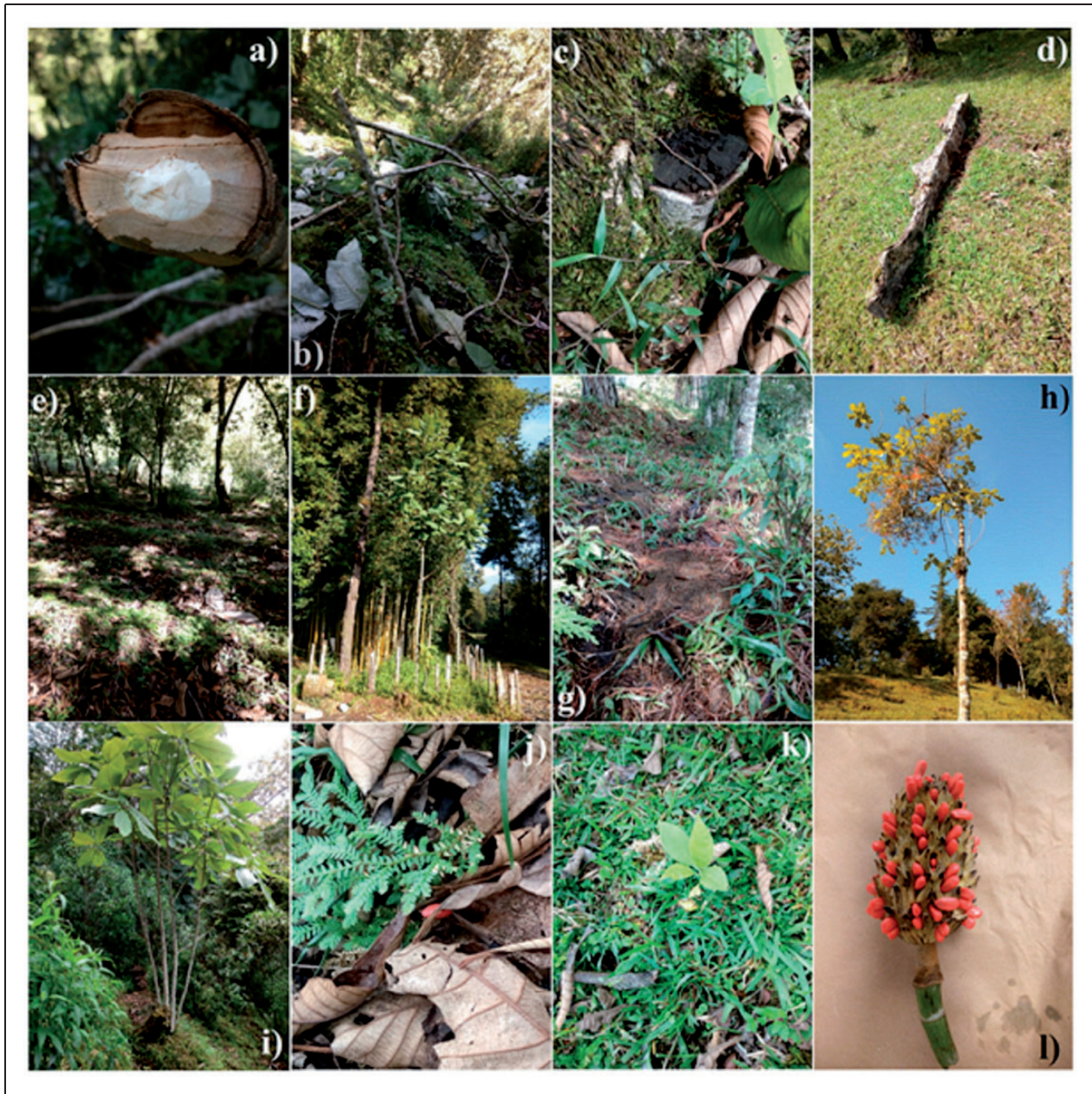
Figure 1. Evidence of Disturbance and Regeneration Indicator in the Studied Population of *Magnolia vovidesii*. A: cutting; B: massive cutting; C: evidence of fire; D: wood extraction; E: trails used by people; F: fences and roads; G: cattle dung; H: parasitism; I: vegetative regeneration; J: seed in field; K: 1 year seedling; and L: dehiscent cone.

Conservation Status

Conservation status was summarized by consulting Mexican regulations (NOM-059-SEMARNAT-2010) and the IUCN Red List (2000). In addition, we calculated the amount of risk using the extinction risk assessment method (MER) in plants (Annex II, NOM-059), which is based on four criteria: (A) characteristics of geographical distribution of the species; (B) habitat characteristics; (C) intrinsic biological vulnerability, which includes demographic and genetic aspects; and (D) impact of human activities. Each of these criteria is broken down into particular characteristics that sum to one, and all of them combined have a maximum possible value of four. Risk has a positive relationship with the calculated value of the index (DOF (Diario Oficial), 2010).

For the purpose of re-categorization, we used the criteria of the IUCN Red List: (A) reduction of population size; (B) restriction of geographical distribution, B1

Table 1. Evaluated Disturbance Measures Modified From Martorell and Peters (2009).

Type	Key	Measure
Human activity	PC	Fraction of plant cut: affected 1 m^2 segments on transect divided by total length of transect.
	FE	Evidence of fire: carbonized areas on trunks or soil on affected 1 m^2 segments on transect divided by total length of transect.
	WE	Fuel wood extraction: evidence of harvesting on affected 1 m^2 segments on transect divided by total length of transect.
	TUP	Cover of trails used by people: proportion of transect covered by trails.
	UD	Urban distance: average (five points per transect) distance (km) to nearest town.
	HD	Distance to nuclei of human activity: average (five points per transect) distance (km) to crops, grassland, fences, etc.
Livestock activity	HR	Evidence of herbivory: proportion of transects covered by evidence of grazing.
	TUC	Cover of trails used by cattle: proportion of transect covered by livestock trails.
	CD	Cattle or horse dung: proportion of transects with bovine or equine dung.
	GD	Goat dung: proportion of transects with caprine dung.
	SC	Soil compaction: average (five points per transect) absorption time of 250 ml of water on native soil divided by absorption time on trail.
Environmental degradation	ESS	Percentage of eroded-soil surface: proportion of transect with material removed by water.
	STM	Cover of surface totally modified: proportion of paved roads, houses, artificial waterways or ancient cultures within the transect.
Ecological associations	P	Parasitism: proportion of parasitized plants within the transect.

Table 2. Morphological Description of the Defined Categories by a Cluster Analysis of *Magnolia vovidesii*.

Life-cycle condition	N	Height (m $\pm$ SD)	Diameter (cm $\pm$ SD)	Reproductive structures (average $\pm$ SD)	Seeds by cone (average $\pm$ SD)
Seedlings	93	0.12 $\pm$ 0.06	1.05 $\pm$ 0.27	0	0
Juveniles	9	1.21 $\pm$ 0.73	2.39 $\pm$ 0.94	0	0
Young Adults	38	4.94 $\pm$ 1.3	8.01 $\pm$ 4.1	9.57 $\pm$ 4.03[a]	65 $\pm$ 29.7[a]
Adults	40	7.9 $\pm$ 1.6 m	19.5 $\pm$ 8.4	29.5 $\pm$ 4.14[b]	137.33 $\pm$ 34.02[b]

N = individuals by class; SD = standard deviation.
[a,b]Significant differences between average reproductive structures by individual and average seed by cone of young adults and adults. $p < .001$, Mann–Whitney test.

(presence area) or B2 (occupation area) or both; (C) and (D) are related to the size of the estimated population and the number of mature individuals, and (E) corresponds to the analysis of the probability of extinction under natural conditions (IUCN, 2012).

Results

Current Population Trend

The cluster analysis of morphological traits defined four size categories, each named according to its life-cycle stage: seedlings, juveniles, young adults, and adults. The average number of seeds per cone was 108.4 $\pm$ 48.67, with a mean cone production per individual of 25.93 $\pm$ 4.03. Only five young adults and eight adults had fruits; the latter category had significantly more cones and seeds than young adults (Mann–Whitney $U = 53$, $p < .001$; Table 2).

Estimated seed production was 3,110.25 $\pm$ 598.5 for young adults and 32,409.88 $\pm$ 1,126.74 for adults. The reproductive rate (R_0) of *M. vovidesii* was 0.012 and the generation time (T_G) was 3.57 years, resulting in a negative growth rate ($r = -0.24$, $\lambda = 0.787$). The maximum life expectancy was 3.5 years, with 99.77% seed mortality and 96.77% mortality in the transition from seedlings (Figure 1K) to juveniles in the field, as expected for a type III curve according to Deevey's (1947) criteria.

Spatial Distribution

The 180 counted individuals were distributed on a 10,400 m^2 landscape with a slope of 32.8° $\pm$ 11.74°.
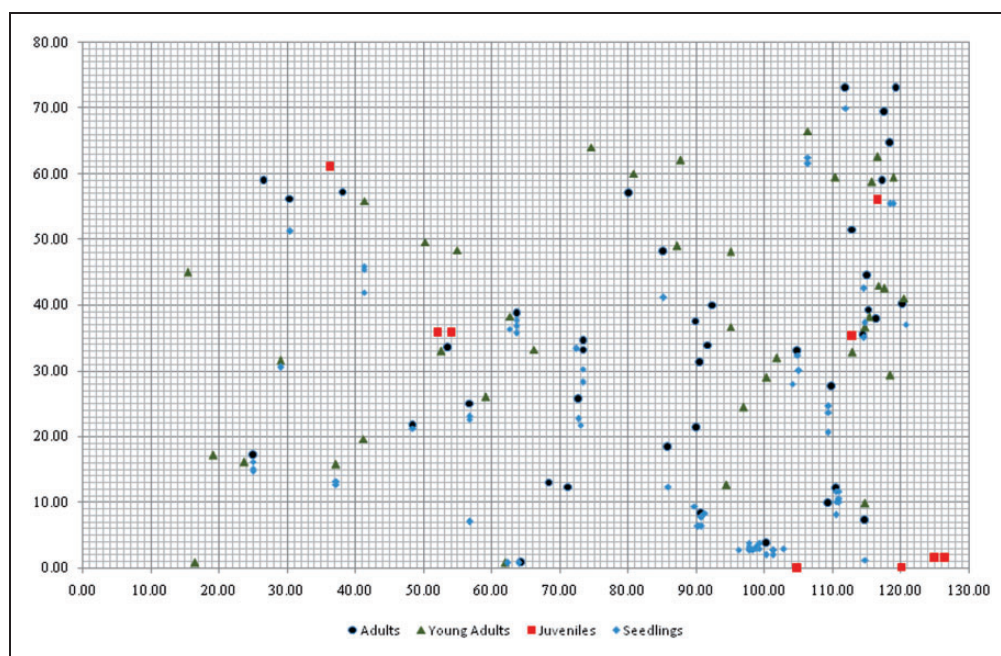
Figure 2. Spatial Distribution in Main Core of *Magnolia vovidesii* Population With a Census of All Individuals.

The average density of *Magnolia vovidesii* was 173.07 ind/ha within the rectangular plot, but several prospecting routes were only able to register five individuals outside of the plot in an area of 2 ha, resulting in an overall average density of 0.00925 ind/ha.

In general, plants were clumped together in a radius of less than 12 m; seedlings were spatially clustered in a radius of less than 3 m, and young adults and adults were clustered within a radius of 5 to 12 m or larger (Figure 2). There was spatial dependency (Ripley's K_{12} function) of seedlings with young adults and adults in a radius of 1 to 7 m; young adults and adults showed spatial dependency in a 6 to 7 m radius, and juveniles were always randomly and independently distributed (Table 3).

Disturbance Analysis

All transects showed some level of disturbance, most notably (more than $100/800 \, \text{m}^2$ of effect) the fraction of cut plants (PC), cover of trails used by people (TUP) and cattle (TUC), cover of totally modified surface (STM), and parasitism (P) (Figure 1A, E, F, and H, respectively). The average probability of finding a square meter affected by some indicator of disturbance in the population was 0.128 ± 0.028. However, the cluster analysis showed that not all transects were equal in terms of this probability (Figure 3), with two transect types identified: transects with high probability of disturbance (average probability of effect 0.166 ± 0.01) and transects with low probability of disturbance (average probability

of effect 0.12 ± 0.23; Table 4). It should be noted that transects with the highest average probability of disturbance were found at the edges of the population. The major significant divergence values between clusters were STM, $F(1,14)$: 78.88, $p < .001$, TUC, $F(1,14)$: 6.35, $p = .024$, and P, $F(1,14)$: 5.38, $p = .035$ (Table 4).

Conservation Status

The MER evaluation based on Mexican legislation (NOM-059) results in a score of 2.09 for *Magnolia vovidesii*. This value is greater than 2, which correspond to the danger of extinction (P) category (criteria values: A = 0.9, B = 0.44, C = 0.35, and D = 0.4). The components of this index are (i) its distribution area is less than or equal to $1 \, \text{km}^2$, (ii) the total number of individuals is between 5,001 and 50,000, (iii) the impact of human activities on the taxon's habitat does not allow viability of existing populations, and (iv) the species has hyper-dispersed populations with a population density of 1 individual or fewer per 5 ha.

The IUCN criteria for critically endangered (CR) species state that a species can be incorporated if it meets any of criteria A to E. Considering our ecological and demographic data, and following the guidelines, we propose that *M. vovidesii* meets the criteria B1 (presence-area), subsection a (severely fragmented), b-iii and V (continuous decrease of the population due to habitat quality depletion and reduction in the number of mature individuals), and c-iv (fluctuations in the number of mature individuals). It also meets criterion

Table 3. Ripley's Functions K_t and K_{12} for *Magnolia vovidesii* Population Using a 95% Confidence Interval (99 Simulations) With a 1-m Step.

Class	No.	Distance (m)											
		1	2	3	4	5	6	7	8	9	10	11	12
Seedlings	91	+	+	+									
Juveniles	9												
Young Adults	40					+	+	+	+	+	+	+	+
Adults	38					+	+	+	+	+			
Total		+	+	+	+	+	+	+	+				
Seedlings—Adults		+	+	+	+	+	+	+					
Seedlings—Young Adults		+	+	+	+	+	+	+					
Seedlings—Juveniles													
Juveniles—Young Adults													
Juveniles—Adults													
Young Adults—Adults							+	+					

Note. The plus symbol indicates a clumped distribution, and empty cell indicates a random distribution.
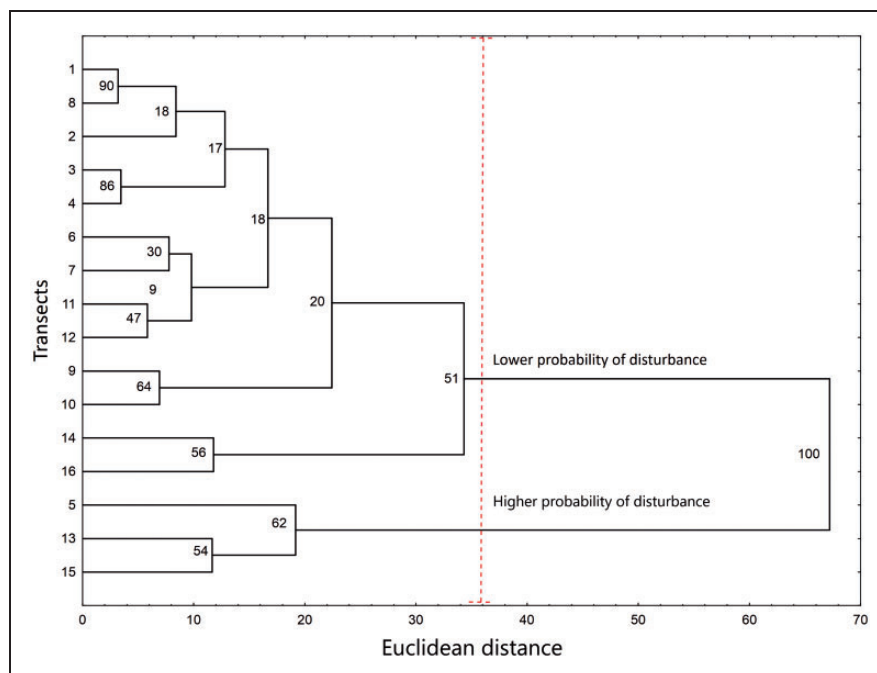
Figure 3. Cluster Analysis to Classify Transects According to the Degree of Disturbance Within the Studied Population of *Magnolia vovidesii*. Branches show bootstrap estimates.

C with estimated population size fewer than 250 mature individuals, and a 25% population reduction (we calculated 35%) due to fluctuations of mature individuals. Therefore, it meets the criteria to be considered CR species.

Discussion

The present study was conducted at exactly the same location as the previous studies, which allowed precise quantification of population size reduction. Gutiérrez

and Vovides (1997) reported 338 ind/ha in 1995 and Sánchez-Velásquez and Pineda-López (2006) reported 300 ind/ha in 2001. This study found only 173.07 ind/ha. The 2001 evaluation suggested a population decrease of 1% annual loss, but the current evaluation shows an accelerated reduction of 15.4% annual loss and a total reduction of 38.33% of the population size in 17 years (2001–2018). If this trend applies to all populations of the species, it is clear that the degree of threat has increased. Furthermore, considering the measured density (173.07 ind/ha), the previously reported area of the

Table 4. Description of Disturbance Traits on the *Magnolia vovidesii* Population (Mean $\pm$ Standard Deviation).

Type	Affected area (m²)	Coverage (%)	Distance (m)	Compaction index	Mean frequency by transect	Lower probability of disturbance transects	Highest probability of disturbance
PC	*146*	18.25			9.13 ± 3.36	9 ± 3.53	9.67 ± 3.06
FE	2	0.25			0.13 ± 0.34	0	0.15 ± 0.37
WE	82	10.5			5.13 ± 2.75	4.69 ± 2.49	7 ± 3.61
TUP	*129*	16.13			8.06 ± 3.88	8.23 ± 4.16	7.33 ± 2.89
UD			650 ± 60		650 ± 60	660 ± 4	620 ± 13
HD			2 ± 0.2		2 ± 0.2	0	2 ± 0.3
HR	58	7.25			3.62 ± 2.39	3.38 ± 2.6	4.67 ± 0.58
TUC	53	6.63			3.31 ± 2.38	*2.69 ± 1.18**	*6 ± 4.58**
CD	29	3.63			1.81 ± 2.19	1.46 ± 1.61	3.33 ± 4.04
SC				1.23 ± 0.02	1.23 ± 0.02	1.24 ± 0.22	1.21 ± 0.02
ESS	4	0.5			0.25 ± 0.57	0.23 ± 0.6	0.33 ± 0.58
STM	*114*	14.25			6.38 ± 8.76	*2.62 ± 3.5**	*22.67 ± 3.51**
P	*115*	14.38			7.18 ± 7.38	*0.08 ± 0.28**	*10 ± 1**

Note. PC = fraction of plant cut; FE = fire evidence; WE = fuel wood extraction; TUP = cover of trails used by people; UD = urban distance; HD = distance to nuclei of human activities; HR = herbivore evidence; TUC = cover of trails used by cattle; CD = cattle dung; GD = goats dung; SC = soil compaction; ESS = percentage of eroded-soil surface; STM = cover of surface totally modified; P = parasitism.
**Significant differences between grouping transects, *p<0.05.

patches that include populations distributed both in cloud forest and pastureland, and an extrapolation to the other registered populations in central Veracruz, we could estimate 7,355.86 individuals per species, but with the current observed density (0.00925 ind/ha), this number should be reexamined.

The previous studies reported size structure similar to our size groups, obtained by a multivariate approach, with the advantage that suckers emerging from cut bases (Figure 1I) were grouped with young adults by the assignation model, and seedlings and juveniles correspond to younger plants. This allowed us to determine survival in the early stages with greater precision, which is troubling in terms of the current annual percentage of recruitment.

Batista and Platt (2003) found that *Magnolia grandifolia* exhibited a susceptible syndrome in response to a massive disturbance, Hurricane Kate, in 1985 in Florida. They noted a large reduction in growth and survival and no detected recruitment after the hurricane. The magnitude of disturbance and limitation of recruitment are similar to our results. Some studies suggest that a reduction in aggregation radius is related to a restricted optimal environmental condition for establishment of seedlings, particularly for rare and restricted species (Octavio-Aguilar et al., 2019). In the case of *M. vovidesii*, the reduction in spatial aggregation radius was stronger in seedlings, potentially increasing the extinction risk of this population via competition for soil resources. In sum, both results (limited recruitment and reduction of aggregation radius) were responses to the modification of environment quality by disturbance. A similar situation has been noted in *Beucarnea inermis*, a threatened

plant that shows a significant population decrease between protected (280 ind/ha) and unprotected sites (186 ind/ha) in response to disturbance intensity (Rubio-Méndez et al., 2018).

An accumulation of adults and low population recruitment is notable because most of the young and older adults were not in a reproductive state. They persisted through vegetative growth, yet they produced a large number of seeds. This elevated production suggests high inbreeding in early life stages and may be related to massive mortality, similar to the case of *M. obovata* (Ishida, 2006). An inferred pollen movement distance from 3.2 to 540 m was recorded for *M. obovata*, with strong inbreeding within limited dispersion populations (Isagi et al., 2000). This pollen movement may be related to our results, which slow spatial dependence between young and older adults in a 6–7 m radius, suggesting pollen source dependence and a potentiated importance of insect pollination success in contrast to the inbreeding effect on seedling and juvenile survival (Matsuki et al., 2008).

Unfortunately, the proximity to grassland and crops (STM) exposes pollinator species to pesticides (Blacquiere et al., 2012) and increases the edge effect of parasitism (Esseen & Renhorn, 1998) and consequently promotes an increase in the cutting of diseased parasitized trees (PC). This in turn increases the coverage of trails on the landscape (TUP). Sánchez-Velásquez and Pineda-López (2010) pointed out that cattle exclusion experiments do not show significant effects on the demographic dynamics of *M. vovidesii* (previously identified as *M. dealbata*), but they report a reproductive stage contribution to population growth rate affected by

cattle inclusion. We found limited area coverage affected by this type of disturbance (CD: 3.63%; Figure 1G), but a low reproductive rate (R_0) of 0.012, indicating limited contribution of the reproductive stage to the calculated population growth rate.

The contrast in the importance of CD suggests that anthropogenic disturbances are the principal activities explaining the persistence and risk to *M. vovidesii*, and that susceptibility of the reproductive stages is principally due to environmental modifications, not only cattle, but any alteration that increases the edge effect. This result is different from the report of Vásquez-Morales et al. (2017) for *M. schiedeana*, who state that moderate anthropogenic activities do not affect population growth. However, they argue that it is necessary to reconsider the contribution of trees with resprouting to the λ value, because more die after cutting. In *M. vovidesii*, cut trees were classified as being in a vegetative stage and their contribution to population was evaluated, as they proposed.

Implications for Conservation

The main conservation problem for *Magnolia vovidesii* is that the majority of the population is on privately held grasslands. This puts anthropogenic pressure on the wild population and makes translocation of adult plants unviable.

The second principal problem is recruitment, owing to early seed and seedling mortality, and taking into account that field propagation has been unsuccessful. However, recent experiments have shown a high radiation potential, conditioned by an elevation gradient, but the seedlings used were grown under controlled conditions from the seed stage up to 18 months old. These previous acclimations guarantee increased survival even when some plants would die under natural conditions (García-Hernández & Toledo-Aceves, 2020).

Results of propagation in closed areas with similar environmental conditions suggest unexplored edaphic requirements, including organic matter, biological interactions (bacteria and fungi), or specific nutrient concentrations. The next and necessary approach is to guarantee in vitro propagation of germinated embryos (to prevent the genetic instability of somatic embryos), taking advantage of the large number of seeds that are produced in the wild population.

The third principal problem is disturbance pressure, associated with land-use conditions. The response to this problem is an ex situ conservation program in protected areas of cloud forest, botanical collections, and backyards of potential producers interested in conservation, with follow-up environmental education programs on the importance of germplasm preservation. Importantly, the preservation of natural environments

is not only aimed at conserving only a single species. An integrated management program for the cloud forest is necessary to preserve all possible natural interactions within the ecosystem.

Finally, the current population trend of *Magnolia vovidesii*, according to our data and compared with previous studies, suggests that this species is in decline. The main cause of this decline is mortality in the early stages (seeds and seedlings) and the cutting of diseased young reproductive trees. The spatial structure showed a strong spatial dependence of seedlings on reproductive individuals (young and older adults) and a weak spatial association between reproductive stages, suggesting a nursing effect, inbreeding, and pollen dependence. The main threats to the population were the PC; TUP; STM in particular fences, grassland, and crops; and the proportion of individuals with parasitism (P). These threats had a greater effect at the edges, increasing the spatial aggregation in conserved areas, which has displaced plants to an even smaller patch. All these data show the urgent need to carry out prompt conservation action for the species, with special emphasis on in situ and ex situ propagation but also using new technologies that guarantee controlled propagation; the protection of wild populations with the highest densities and control of anthropogenic disturbance.

Conservation Status

The risk assessment studies for endangered species constitute a guide to reevaluating the conservation status of the species or considering species that are not yet covered by Mexican regulations. *Magnolia vovidesii* is a species with a restricted distribution area, endemic to mountain cloud forest, which is continuously shrinking. The species has a total population of fewer than 10,000 individuals, with recruitment problems in its natural environment, and a patchy and disconnected distribution. Data are lacking on its genetic variation, and the effects of human activities and phytoparasites are evident. In summary, we request inclusion of *M. vovidesii* into the NOM-059-SEMARNAT-2010 standard in the category in danger of extinction (P). We also suggest the modification of the IUCN Red List risk category of *M. vovidesii* to critically endangered species.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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