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Article

Reassessment of the extinction risk status of the ponytail palm *Beaucarnea inermis*

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Abstract: *Beaucarnea inermis* is an endemic species from Northeast Mexico, in the states of San Luis Potosí and Tamaulipas. It is appreciated as an ornamental plant, so its populations are subject to the poaching of individuals for illegal trade. Previous studies determined that their populations have been affected due to the disturbance since the incidence of anthropogenic activities affects the viability of the species. Here we determine the current conservation status of *B. inermis* and identify their main risk factor by performing an extinction risk assessment based on the Annex II "Method for Evaluation of Risk of Extinction of Plants in Mexico". We studied 10 populations of *B. inermis* from protected and non-protected areas in San Luis Potosí and Tamaulipas. We considered the MER criteria: A) geographical distribution characteristics, B) habitat characteristics, C) intrinsic biological vulnerability, and D) impact of human activity. Using field and analyzed data, the MER assessment gives 1.91 points that confirm *B. inermis* is correctly classified as an Endangered species. The natural protected areas where the species occurs represent cores for its protection; however, the surface of these areas may not be sufficient without biological corridors that connect them.
Keywords*: Endangered species; endemism; Mexico; natural protected areas; seasonally dry tropical forests; Sierra Madre Oriental.*

Reevaluación del riesgo de extinción de la pata de elefante *Beaucarnea inermis*

Resumen: *Beaucarnea inermis* es una especie endémica del Noroeste de México distribuida en los estados de San Luis Potosí y Tamaulipas. Es apreciada como planta ornamental, por lo que sus poblaciones están sujetas al saqueo de individuos para su comercialización ilegal. En trabajos anteriores se determinó que sus poblaciones han sido afectadas debido al disturbio por la incidencia de actividades antrópicas que afectan su viabilidad. En la presente contribución se determina el nivel de riesgo de *B. inermis* con base en el Anexo Normativo II "Método de Evaluación de Riesgo de Extinción de Plantas en México". Se estudiaron 10 poblaciones de *B. inermis* en San Luis Potosí y Tamaulipas, tanto en áreas naturales protegidas como en sitios no protegidos. Los criterios MER considerados fueron: A) características de la distribución geográfica, B) características del hábitat, C) vulnerabilidad biológica intrínseca y D) impacto de la actividad humana. El análisis MER arroja un valor de 1.91 que, confirma a *B. inermis* dentro de la categoría de Amenazada. Las áreas naturales protegidas donde se distribuye la especie funcionan como núcleos de protección, sin embargo, su superficie puede no ser suficiente sin la presencia de corredores biológicos que las conecten.
Palabras-clave: *Especie amenazada; endemismo; México; áreas naturales protegidas; bosque tropical estacionalmente seco; Sierra Madre Oriental.*

Introduction

Beaucarnea inermis (S. Watson) Rose (Asparagaceae) is an endemic species to the seasonal tropical forests of northwestern Mexico. It is distributed in the biocultural region of Huasteca, in the northeast of San Luis Potosí and the south of Tamaulipas. It is an arborescent and massive species, dominant within its natural habitat, where it can reach up to 18 m in height and 3 m in base diameter (Castillo-Gómez 2011, Hernández-Sandoval et al. 2012, Rubio-Méndez et al. 2018a, 2018b; Figure 1). Although *B. inermis* has been considered a synonym of *B. recurvata* Lem., some authors separate them by morphological differences in the habit, the bases of the branches, rosettes, and inflorescences (Hernández-Sandoval et al. 2012, Rojas-Piña et al. 2014). Due to its striking morphology, with massive bulbous trunk, the species has a relevant ornamental use at regional, national, and international levels, so illegal poaching of natural populations threatens its long-term conservation (Rubio-Méndez et al. 2018a, 2018b). In addition, their habitat has been subject to changes in land use for agricultural production, so the size of their populations, sex proportions, and establishment of new individuals have been altered (Hernández-Sandoval et al. 2012), which could negatively affect the genetic diversity of the species. For this reason, *B. inermis* is in the category of Threatened (A) within the Mexican norm NOM-059-SEMARNAT-2010 (SEMARNAT 2010) and in Appendix II of CITES (2022). One of its main populations is located within the Sierra del Abra Tanchipa Biosphere Reserve (SATBR), a protected natural area that stands out as an important refuge for the conservation of the species in terms of its demography and population structure (Rubio-Méndez et al. 2018a, 2018b). Other protected populations are located in the El Cielo Biosphere Reserve (ECBR) and the Sierra de Tamaulipas Biosphere Reserve (STBR) (Castillo-Gómez, 2011). They all belong to the national category of Biosphere Reserves in Mexico, which includes ecosystems that have not been significantly altered and are home to endemic or threatened species. The SATBR and STBR are recognized in the category VI "Protected area with sustainable use of natural resources" of the IUCN World Commission on Protected Areas (WCPA), which conserve ecosystems and habitats, together with associated cultural values and traditional natural resource management systems and where conservation and sustainable use can be mutually beneficial (Dudley 2008). However, the populations of *B. inermis* have yet to be properly evaluated just as some other *Beaucarnea* species considered endangered: *B. gracilis* (Fuentes et al. 2020a) *B. guatemalensis* (Coronado et al. 2022), *B hiriartieae* (Fuentes et al. 2020b), *B. olsonii* (Fuentes et al. 2020c), *B. purpusii* (Martínez Salas et al. 2020a), *B. recurvata* (Martínez Salas et al. 2020b), and *B. sanctomariana* (Fuentes et al. 2020d).

Figure 1. Adult specimen of *Beaucarnea inermis* at the RBSAT, San Luis Potosí.

As a way of promoting objectivity and thus being able to offer greater relevance, credibility, and legitimacy in the assignment of categories of risk of extinction of wild species, a Wild Species Extinction Risk Assessment Method, included in the NOM-059-ECOL-1994 updated in 2001, was developed in Mexico, to identify and weigh the factors that affect and threat a species (Tambutti et al. 2001, Sánchez et al. 2007, Castillo-Gómez 2011, *Pérez-Paredes 2013*, *Sánchez-Salas* et al. 2013). In the update of the NOM-059 in 2010, the Normative Annex II "Method of Evaluation of Risk of Extinction of Plants in Mexico" (MER-Plants) is included, which considers intrinsic attributes of the plants such as geographical distribution, specificity of habitat, and demographic issues that require to be evaluated differently from animals (Sánchez-Salas et al. 2013, SEMARNAT 2010). The MER-Plants is based on two indices, the Rarity Index (IR) and the Anthropogenic Impact Index (IIA) both encompassing four independent decision criteria. The IR includes: Criterion A) Characteristics of geographic distribution; Criterion B) Characteristics of the habitat with respect to the natural development of the taxon; Criterion C) Intrinsic biological vulnerability. And the IIA includes Criterion D) Impact of human activity. Considering this, our aim was to reassess the extinction risk status of *Beaucarnea inermis* and identify the main threatening factors by evaluating the criteria of the MER-Plants, based on published and new information about the species.

Materials and Methods

To obtain MER-Plants indexes, we used information regarding distribution, demographics, genetic diversity, and habitat degradation of 10 representative populations of the natural distribution of *Beaucarnea inermis* in the states of San Luis Potosí and Tamaulipas (El Abra, El Sabinito, Estación Micos, Grutas de Quintero, La Chaca, Ocampo, RBSAT, San Dieguito, San Gerónimo and Sótano del Arroyo). The risk category for the species is determined by summing all criterion' values, which weight the same and are normalized between 0 and 1 (SEMARNAT 2010, Ruiz-Jiménez et al. 2018).

1. Rarity index

Criterion A) Characteristics of geographical distribution. We included presence-only data of 82 species records of previously studied populations from 10 localities of San Luis Potosí and Tamaulipas, geographical records from herbaria specimens from collections SLPM, MEXU, and QMEX, as well as the databases of the Naturalista portal (CONABIO 2020) and the Global Biodiversity Information Facility (GBIF), all of them validated in the field during the year 2020 (Figure 2). To reduce spatial autocorrelation, we previously eliminated the duplicate records and used the rest to delimit the extension of the occupied area (Solano & Feria 2007). For these records, we used a non-spatial partition by selecting two random k-fold, dividing the presence records for *B. inermis* into two independent data sets. For the delimitation of the calibration area –referred to as the accessibility area *sensu* Soberon and Peterson (2005)– we use the intersection of the biogeographic provinces proposed by Morrone et al. (2017) with the ecoregions proposed by Dinerstein et al. (2017), and physical factors that may have meant a barrier to the dispersal of species (Soberon & Peterson 2005, Barve et al. 2011). Since the resulting surface greatly exceeded the area with a concentration of species records, we considered a 100 km buffer to determine the extreme limits.

According to Hijmans et al. (2005) and Fick & Hijmans (2017) we used 19 climate variables from WorldClim Global Climate Data V.1.4 (http://www.worldclim.org), with a resolution of 30 arcsec (1 km^2), from which we selected only a set of 15 climate variables excluding four layers (i.e., Bio 8, Bio 9, Bio 18, and Bio 19), as these present spatial anomalies in the form of odd discontinuities between neighboring pixels (Escobar et al. 2014, Booth, 2022). Then, in order to minimize the repeated information from layers, we performed a normality test and as 13 of the 15 remanent variables had a non-normal distribution, we conducted a non-parametric Spearman correlation analysis using the variable values corresponding to the species' records and selected only seven variables (i.e. Bio 1, Bio 2, Bio 3, Bio 4, Bio 12, Bio 15, Bio 17) with a correlation coefficient < 0.7.

To obtain the geographic distribution of the species we used MaxEnt v.3.4.1 (Phillips et al. 2006) via Wallace, a shiny application for modeling species distributions (Muscarella et al. 2014, Kass et al. 2022). The Maxent parametrization was performed considering the feature clases: linear (*l*), linear and quadratic (*lq*) and linear, quadratic and hinge (*lqh*), as well as the regularization in a sequence from 0.5 to 3.5 in intervals of 0.5. The background sampling (representing potentially suitable but unsampled locations) was 20,000 points out of a total of 74,000 available in the calibration area extent. From this

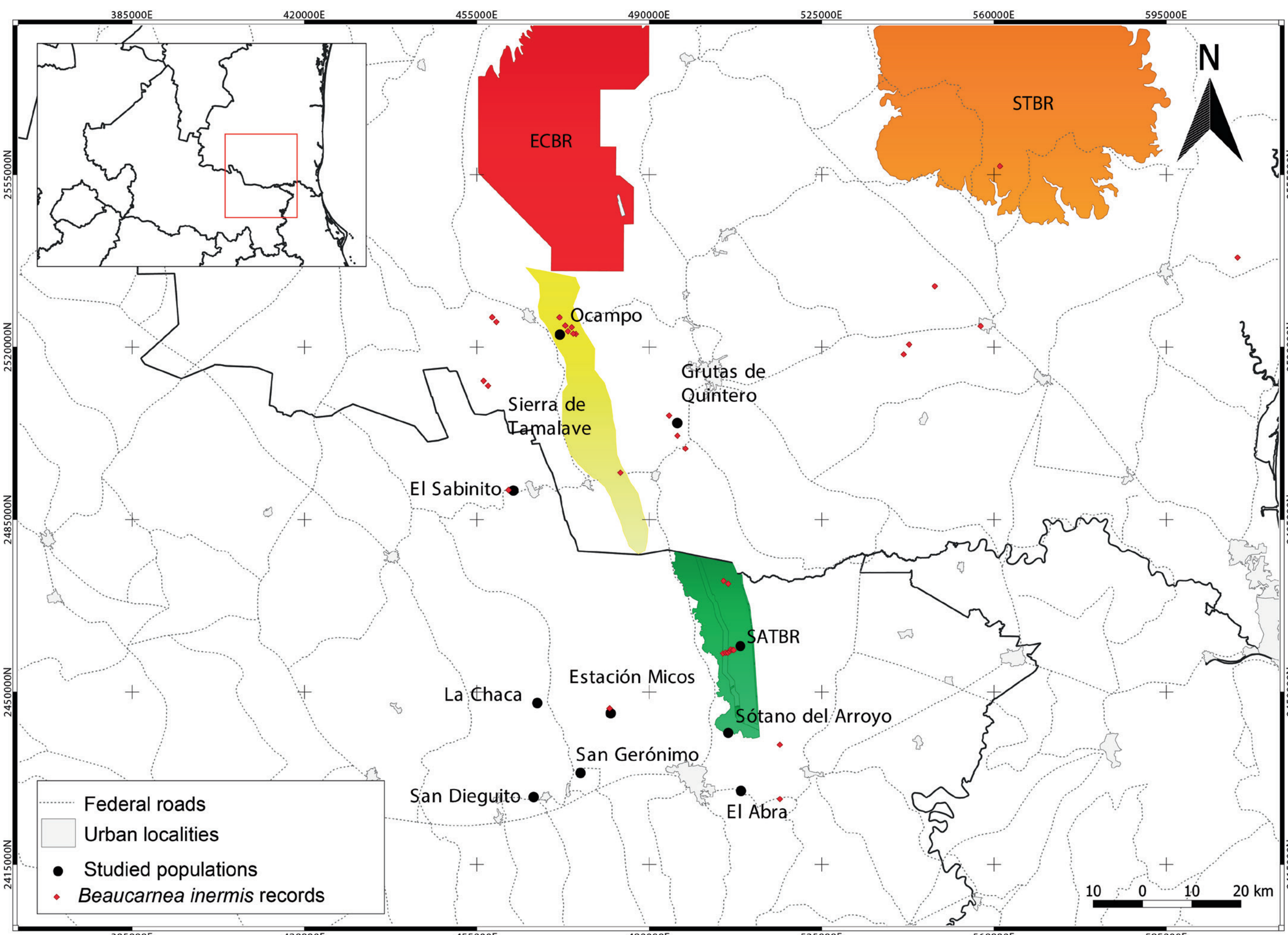

Figure 2. Locations of analyzed records and populations of *Beaucarnea inermis* for this study.

parametrization, we obtained 21 different models and the best model selection was conducted by favoring the omission rates as the first filter, followed by the higher values of the Continuous Boyce Index, and as the last the AIC.

Criterion B) Characteristics of the habitat. The current state of the habitat and the requirements for the establishment of *Beaucarnea inermis* were determined according to the characteristics of the sites, mainly regarding the level of disturbance, types of vegetation, and associations presented, which have been indicated in previous studies (Castillo-Gómez 2011, Hernández-Sandoval et al. 2012, Rubio-Méndez et al. 2018a).

Criterion C) Intrinsic biological vulnerability. Six components were considered. 1) Demography: The demographic information and conservation status of the species have been previously analyzed by Rubio-Méndez et al. (2018a, 2018b). All individuals found within plots of 100 m × 10 m (0.1 ha) at each site were counted and classified by age, as proposed by Castillo-Gómez (2011). With the frequencies of each age, static life tables were generated for each population group to describe survival and mortality in each age class based on different attributes: l_x, the proportion of surviving individuals entering class x, with respect to the initial number of individuals; q_x, mortality rate as the proportion of dead individuals during the time interval from class x to x + 1, with respect to the original number of individuals; E_x, life expectancy as the expected life time of an individual of class x; R_0, net reproductive rate of each generation. The intrinsic population growth rate was calculated as $\lambda = e^r$, where e = Avogadro's constant of 2.71828 and r = population growth rate per capita. When $\lambda = 1$, population size is constant; $\lambda > 1$ indicates increase in population size per generation, while $\lambda \leq 1$ indicates a decrease (Caswell 2001, Castillo-Lara et al. 2017, Rubio-Méndez et al. 2018a). 2) Population structure: the population structure was estimated from the Gini asymmetry coefficient ($g1$) with the measurements of the base diameter, neck diameter (where the base narrows), and total plant height (Bendel et al. 1989, Palacios-Wassenaar et al. 2016), as described in Rubio-Méndez et al. (2018a); we used base diameter and neck diameter because they are suitable to describe size in this genus. 3) Sex ratio: the sex of adult individuals was recorded based on the presence of reproductive structures (Castillo-Gómez 2011, Hernández-Sandoval et al. 2012). 4) Phenology: two phenophases, flowering and fruiting, were identified. The periods in which each phase occurs were established based on the review of herbarium specimens and collections during field visits. 5) Seed germination: the previously disinfected seeds were placed on moist filter paper in Petri dishes covered with newspaper. 240 seeds collected in six sites (n = 40) were used (Cardel et al. 1997, Castillo-Gómez 2011). 6) Genetics: To estimate genetic diversity, seven populations were analyzed using microsatellite-type molecular markers (SSR: Short Sequence Repeat) as described below. Genetic diversity was evaluated with a sample of 74 individuals from seven populations (El Sabinito, Estación Micos, Grutas de Quintero, La Chaca, RBSAT, San Geronimo, and Sótano del Arroyo).

Genomic DNA was extracted from *Beaucarnea inermis* leaf tissue by the modified CTAB method, adding 1% polyvinyl pyrrolidone (PVP) and 0.1% sodium metabisulfite. PCR reactions were performed by cross-amplification using six previously designed SSR molecular marker primers for species of the phylogenetically close genera *Dracaena cambodiana* and *Asparagus conchinchinensis* (Table 1), 2.5 µl of 10x Taq Buffer + $(NH_4)_2SO_4$ (Thermo Fisher Scientific, Waltham, Massachusetts, USA), 0.4 µl of 100 mM DNTP's (Thermo Fisher Scientific, Waltham, Massachusetts, USA), 2/1.5 µl of 25 mM MgCl2, 0.5 µl of each primer (Fwd and Rev) 10 mM, 0.1 µl of Taq 500 u (Thermo Fisher Scientific, Waltham, Massachusetts, USA), 50 ng of DNA and ultrapure water (Laboratorio PiSA, México) up to a volume of 25 µl, in a thermocycler T100 Thermal Cycler (Bio Rad, Hercules, California, USA) under the following program: 94 °C for 5' followed by 40 cycles of 94 °C for 30 mins., Ta for 30 mins., 72 °C for 1 min. and a final extension at 72 °C for 8 mins. The PCR products were separated on a 12% polyacrylamide gel stained with EtBr and visualized in a Benchtop 2uv Biodoc-It Imaging System photodocumenter (UVP Laboratory System, Upland, California, USA), using a 50 bp molecular weight marker (ThermoFisher Scientific, Waltham, Massachusetts,

Table 1. Microsatellite molecular markers (SSR: Short Sequence Repeat) used to evaluate the genetic diversity of *Beaucarnea inermis*.

Locus	Primer sequence	Annealing temperature (ºC)	Species	Reference of primer
DC003	F: AGAAAGGGAGGTGACAGG	54	Dracaena cambodiana	Zhang & Li (2010)
DC003	R: GTCAAAGAGCCCAAACAA	54	Dracaena cambodiana	Zhang & Li (2010)
DC006	F: GTTTCTAGTTCAAGAACCCAA	54	Dracaena cambodiana	Zhang & Li (2010)
DC006	R: TTCCTCCTCTTTCTCATCCT	54	Dracaena cambodiana	Zhang & Li (2010)
DC465	F: TCCCATAAATGCTCCTCA	48	Dracaena cambodiana	Zhang & Li (2010)
DC465	R: TCAAGCTATGCATCCAAC	48	Dracaena cambodiana	Zhang & Li (2010)
DC522	F: GTAAGAAGAAAAGAGGAAGA	52	Dracaena cambodiana	Zhang & Li (2010)
DC522	R: AGGGAATCTGTCACTTGT	52	Dracaena cambodiana	Zhang & Li (2010)
AC011	F: TGTGCGGTCGACTGAATTGA	55	Asparagus cochinchinensis	Kim et al. (2017)
AC011	R: GAGGCTACACACTCCCAAGG	55	Asparagus cochinchinensis	Kim et al. (2017)
AC079	F: GCTTTCGGAGGGGGAAGAAA	55	Asparagus cochinchinensis	Kim et al. (2017)
AC079	R: GAAGCGGCGAGAGAGAGTAC	55	Asparagus cochinchinensis	Kim et al. (2017)

USA). Genotyping was performed using Gel Analyzer V. 2010a software (http://www.gelanalyzer.com/index.html). The number of different alleles, the expected heterozygosity, the observed heterozygosity, the F_{IS} fixation index (Peakall & Smouse 2012), and the *S* self-fertilization index were estimated. Data analyzes were performed using Arlequin V.3.5.2.2 (Excoffier & Lischer 2010) and GenAlex V.6.5 (Peakall & Smouse 2012).

2. *Anthropogenic impact index*

Criterion D) Impact of human activity. Potential risk factors of anthropogenic origin for *Beaucarnea inermis* were identified in the study sites, using the Chronic Disturbance Index (CDI) developed by Martorell and Peters (2005, 2009), which combined 14 parameters grouped into three disturbance agents: livestock raising, human activities, and habitat degradation (Martorell & Peters 2005, 2009). This index was previously applied to *B. inermis* by Rubio-Méndez et al. (2018a). For the calculation of the CDI, values were assigned to 14 variables clustered in three disturbance categories (livestock raising, human activities, and land degradation) at the sites during the field sampling according to the magnitude of the impact considered for each one (Rubio-Méndez et al. 2018a). Data were standardized and combined through a principal component analysis (PCA), discarding those variables with no variation for the sites as recommended by Hernández-Oria et al. (2006) and as it is described in Rubio-Méndez et al. (2018a). Additionally, information on confiscations of *B. inermis* specimens in the state of San Luis Potosí was requested from the Federal Environmental Protection Agency in Mexico (PROFEPA).

Results

1. *Rarity index*

Criterion A) Characteristics of geographical distribution. The known populations of *Beaucarnea inermis* occur in three regions with geomorphologically distinct characteristics: the Sierra Madre Oriental, the Sierra de Tamaulipas, and the Gulf Coastal Plain semi-flat lands, with a discontinuous distribution in isolated patches, although in some cases it is distributed in relatively large areas such as in the SATBR and the Sierra de Tamalave. The potential distribution generated (Figure 3) showed high values of CBI (0.85) and a high probability of prevalence (>75%) coinciding with the current known distribution and some nearby areas with an approximate surface of 102 531.42 ha in San Luis Potosí, which represents only 1.6% of the state territory, while for Tamaulipas the approximate area is 55 338.48 ha, 0.68% of the state territory. The total area that *Beaucarnea inermis* could potentially occupy is 157 869.90 ha, barely 0.08% of the national territory. Of this potential area, only 22.3% is located within some protected natural area, which includes the ECBR, the SATBR, and the STBR, representing 0.01% of the national territory.

Criterion B) Characteristics of the habitat. The habitat of the analyzed populations presents a high percentage of limestone outcrops and shallow soil, from semi-flat terrain to slight slopes. These sites present semi-warm humid and warm sub-humid tropical climates according to the modified Köepen classification (García 2004), with two well-defined climatic seasons, a rainy season between June and September and a dry season between November and April. The populations in the localities of San Gerónimo and Ocampo present the most humid climates with annual precipitation greater than 1 500 mm, while the populations in the localities of El Abra, Grutas de Quintero, San Dieguito, SATBR, and Sótano del Arroyo, present drier conditions, with annual precipitation ranging between 900 mm and 1 000 mm. The types of vegetation present in the study sites correspond to variants of seasonally dry tropical forests, which have been recognized by Rzedowski (1978) as tropical deciduous forest (TDC) and tropical semi-deciduous forest (TSC). In all sites *Beaucarnea inermis* was found in association with *Bursera simaruba* (L.) Sgt. and *Pseudobombax ellipticum* (Kunth) Dugand, as well as *Bromelia pinguin* L. and *Dioon edule* Lindl. The population within the SATBR presents the widest and most continuous distribution for the species. The highest canopy is found in San Gerónimo, with trees up to 18 m tall. In San Dieguito there is secondary vegetation with an abundance of *B. pinguin* and *Sabal mexicana* Mart. and, in both places, the undergrowth is very closed. Ocampo is located near an active mining bank. The populations of El Abra and Sótano del Arroyo have a more open shrub layer and an herbaceous layer with an abundance of *B. pinguin* and *Hechtia* spp. In Grutas de Quintero, the shrubby and herbaceous strata are more open.

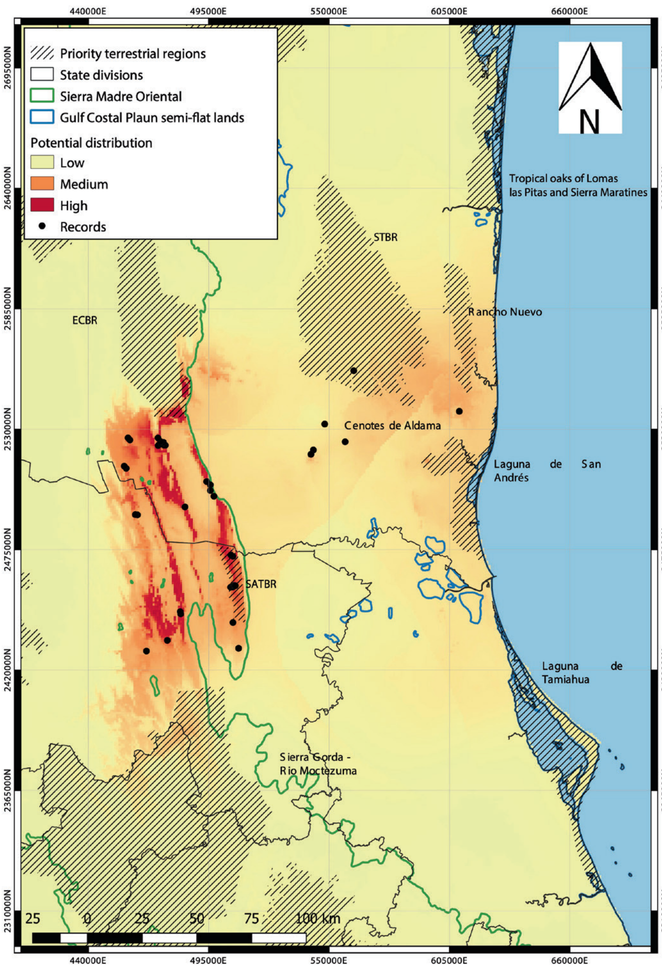

Figure 3. Niche-based distribution model of *Beaucarnea inermis*.

Criterion C) Intrinsic biological vulnerability. The average population density of *Beaucarnea inermis* is 236.9 ind/ha (Rubio-Méndez et al. 2018a), with higher values within the SATBR (280 ind/ha).

The asymmetry index *g1*, previously reported by Rubio-Méndez et al. (2018a), indicates that the populations are dominated by large-sized adult individuals (average *g1* of –0.61 within the SATBR and –0.75 for the other populations). According to the life tables previously reported by Rubio-Méndez et al. (2018a) two mortality events are detected: the transition from seed to seedling, which occurs inside and outside the SATBR, and the transition from seedling to juvenile present in all populations except the SATBR (Table 2). Adult individuals show the highest survival rate in all populations except in El Abra where the dominance corresponds to seedlings. The net reproductive rate (R_0) is less than 1 in all populations, however, the life expectancy for seedlings and juveniles within the SATBR is greater than for the other populations. The proportion of individuals in the reproductive phase during the samplings carried out was approximately 50%. The sex ratio (m:f) was 0.93:1 within the SATBR and 0.76:1 for the other populations. Flowering occurs from February to August and fruiting occurs from June to April of the following year and has two peaks, one in August and the other in January. The percentage of germination in the laboratory is up to 92.5% (Castillo-Gómez 2011), in the field the same probably occurs in favorable times of humidity and temperature, however, only a small proportion manages to establish itself as juvenile; once the adult stage is reached, the populations seem to remain stable. The genetic diversity evaluated with the six SSR markers indicates that the observed heterozygosity for all analyzed populations was lower than expected, indicating a significant heterozygous deficit (average Ho = 0.39, average He = 0.74, Table 3) according to the Hardy-Weinberg balance test (χ^2 = 111.53, $p < 0.0002$). Likewise, the populations present high inbreeding F_{IS} = 0.56, with an index S = 0.71, which indicates that 71% of the progeny of the species might be produced by self-fertilization.

2. *Anthropogenic impact index*

Criterion D) Impact of human activity. According to the CDI values (Table 4), the main risk factors identified were human activities, mainly the incidence of fires and the proximity to towns and centers of human activity. These activities mainly affect survival and mortality in the seedling and juvenile stages, which affects the establishment of new individuals and alters the sex ratio, resulting in a decrease in the reproductive rate. According to PROFEPA, in San Luis Potosí there is a record of confiscation of illegal *Beaucarnea inermis* specimens in the last decade; one of the most numerous was recorded in 2012, where 346 plants were confiscated in the municipality of Huehuetlán and 29 in Tancanhuitz (Rubio-Méndez et al. 2018b).

3. *MER results*

The summing results of the MER ratings for each of the evaluated criteria (Appendix I) were A = 0.45 (width of distribution), B = 0.33 (habitat status), C = 0.43 (intrinsic biological vulnerability), and D = 0.7 (impact of human activity), which in total add up to a value of 1.91.

Table 2. Life table for *Beaucarnea inermis* at each disturbance level.

Stage	Level of disturbance	lx	qx	ex
Seedling	Low	9,40E-07	–3	65,83
	Medium	5,48E-05	0,89	1,82
	High	5,04E-05	0,68	1,54
	Mean (SD)f	3.54E-05 (1.73E-05)	–0.47 (1.265)	23.06 (21.38)
Juvenile	Low	3,76E-06	–14,33	15,83
	Medium	5,60E-06	–11	12,5
	High	1,56E-05	–1,35	2,85
	Mean (SD)f	8.35E-06 (3.71E-06)	–8.89 (3.89)	10.39 (3.89)
Adult	Low	5,76E-05	1	0,5
	Medium	6,72E-05	1	0,5
	High	3,69E-05	1	0,5
	Mean (SD)f	5.39E-05 (8.93E-06)	–	–
R0	Low	3,06E-04		
	Medium	2,11E-02		
	High	1,10E-02		
	Mean (SD)f	3.19E-02 (1.43E-02)		
λe	Low	0,66		
	Medium	0,82		
	High	0,79		
	Mean (SD)f	0.83 (2.31E-02)		

Table 3. Genetic diversity for seven populations of *Beaucarnea inermis*. N: Sample Size, Na: Number of alleles, Ne: Number of effective alleles; Ho: Observed heterozygosity, He: Expected heterozygosity, F_{IS}: Fixation index, S: Self-fertilization index, D: Index of chronic disturbance.

Population	N	Na	Ne	Ho	He	F_{IS}	S	D
SATBR	22,83	19,83	14,81	0,4	0,93	0,58	0,74	Low
El Sabinito	4,5	4,66	3,95	0,42	0,61	0,44	0,61	Medium
Estación Micos	3,5	4,5	4,14	0,32	0,74	0,68	0,81	Medium
Sotano del Arroyo	5,67	6,33	5,62	0,33	0,81	0,65	0,79	Medium
Grutas de Quintero	3,17	4	3,61	0,36	0,67	0,61	0,76	Medium
San Gerónimo	3,67	5,16	4,45	0,49	0,66	0,37	0,54	High
La Chaca	5,17	5,5	4,59	0,38	0,77	0,59	0,74	–
Mean	6,93	7,14	5,88	0,39	0,74	0,56	0,71	–

Table 4. Values of the CDI for nine populations of *Beaucarnea inermis* and their disturbance level.

Population	Livestock raising	Human activities	Land degradation	CDI	Level
SATBR	1	0,45	0	0,3	Low
El Abra	1	1,59	0	0,69	Medium
Grutas de Quintero	1	1,71	0,1	0,7	Medium
Sótano del Arroyo	1	2,08	0	0,73	Medium
Estación Micos	1	2	0	0,75	Medium
El Sabinito	1,4	2,4	0	0,81	Medium
Ocampo	1	2,64	0,1	1,33	High
San Dieguito	1,3	2,76	0	1,36	High
San Gerónimo	1,48	2,75	0	1,37	High

According to Normative Annex II of NOM-059-SEMARNAT-2010, *Beaucarnea inermis* remains in the Threatened (A) category.

Discussion

Since its first publication in 1994, NOM-059-SEMARNAT has been used to assess the conservation status of the different biological groups distributed in Mexico for the development and application of conservation policies (García-Aguilar et al. 2017). Despite being questioned due to the apparent lack of objective and scientific criteria in the classification system and the use of subjective terms in the risk categories (De Grammont & Cuarón 2006, Cuarón & De Grammont 2007, Soberón & Medellín 2007, García-Aguilar et al. 2017) this Norm represents the only legal normative instrument in Mexico for the protection of biodiversity and it has been modified over the years in order to constitute a coherent and dynamic element of regulatory consultation with the participation of experts in the different taxonomic groups of Mexico (Tambutti et al. 2001, Sánchez-Salas et al. 2013). It has been highlighted that extinction is a demographic and evolutionary process in which the populations of a species have difficulties replacing their generations until they lose all their individuals (Lacy 1988, Lande 1988, Allendorf & Luikart 2007). In this sense, having a protocol such as the MER, which estimates the risk of extinction of a species based on rigorously weighted and systematized available information, can allow the long-term conservation of some species, at least on the legal normative plane (Tambutti et al. 2001, SEMARNAT 2010, Castillo-Gómez 2011).

The application of the MER for the case of *Beaucarnea inermis*, with updated information, indicates that the species should be kept in the Threatened (A) category, as a species that could become endangered in the short and medium term if the factors that negatively affect its viability continue, particularly the deterioration or modification of its habitat and the direct reduction of the effective population size. Fragmentation and habitat loss, caused by anthropic disturbance, are the main causes of species extinction due to their negative effects on effective population sizes and genetic diversity (Gurrutxaga-San Vicente & Lozano-Valencia 2006). It has been previously indicated that the main threat faced by *B. inermis*, in addition to the individual's illegal extraction, is the loss of habitat caused by anthropic disturbance that affects its demographic dynamics, particularly the mortality of seedlings and juveniles (Rubio-Méndez et al. 2018a, 2018b). The most vulnerable stages are from seedling to juvenile because the pressures of disturbance mainly affect the recruitment. The high mortality at the seedling stage may act as a strong selective filter on seed traits and seedling traits like in other plant species (Kitajima & Fenner 2000), where traits can be interpreted as ''gap-detection mechanisms'' in seeds restrict germination in time and space, enhancing the likelihood of seedling survival and growth (Rubio-Méndez et al. 2018a). In general, disturbance also affects the sex ratio, which decreases the net reproductive rate of a population in the long term (Pérez-Farrera et al. 2006, Octavio-Aguilar et al. 2018).

Regarding the intrinsic vulnerability of the taxon, the average density recorded for *Beaucarnea inermis* (236.9 ind/ha) is higher than that reported for other species such as *B. gracilis* (16.9 ind/ha) and *B. recurvata* (130 ind/ha; 20.1 ind/ha; Cardel et al. 1997, Hernández-Sandoval et al. 2012, Rubio-Méndez et al. 2018a, Espinoza-Cruz 2019). Although populations of *B. inermis* outside protected natural areas show a higher density of seedlings, they have a higher mortality rate than juveniles and adults (Rubio-Méndez et al. 2018a). Apparently, the disturbance favors the germination and establishment of new individuals for the species, but the microclimate generated by the decrease in canopy cover, with higher temperature and direct incidence of sunlight and lower soil moisture, has a negative effect on the seedlings avoiding they join the population as reproductive individuals (Augspurger 1984, Augspurger & Kelly 1984, Kitajima & Fenner 2000, Flores 2003, Flores et al. 2004). The protected area category in which populations of the species occur allows some of their territories to be under sustainable natural resource management, and juveniles are affected by illegal poaching, threatening their long-term conservation (Rubio-Méndez et al. 2018a, 2018b). The heterozygosity deficit in the analyzed populations of *B. inermis* could imply an interruption in the genetic flow as the result of the disturbance and fragmentation of the habitat that the populations of the species present. In recent decades, the fragmentation of the habitat in the Huasteca region has reached such a magnitude that in some areas with little inclination, the forests and jungles have been eliminated, and only relicts remain on hills with limestone outcrops that are difficult for humans to access (Errejón-Gómez et al. 2018). For genetic diversity in the long term, such fragmentation can lead to alleles being fixed or lost in *B. inermis* populations, leading to possible extinction. However, additional information on genetic diversity and structure is needed to assess the levels of gene flow between populations and their structure to have a better overview of the conservation status of *B. inermis* populations.

Conclusions

The main risk factor of extinction for *Beaucarnea inermis* is anthropogenic activities, such as changes in land use and extractive activities, so we propose to apply management plans and conservation programs focused on awareness, sustainable use, and assisted legal propagation of the species, which allow reducing the effects of anthropic disturbance on the populations and thus achieve their long-term conservation. The protected natural areas ECBR, SATBR, and STBR represent the core zones for *B. inermis* habitat since they buffer the effects of anthropic disturbance by allowing individuals to reach reproductive age. However, the area occupied by *B. inermis* within these reserves may not be sufficient to ensure the protection and quality of the species' habitat in long term. Without the presence of biological corridors that connect them, these areas would remain isolated, favoring the loss of genetic diversity and the local extinction of populations. According to our results, the status of *Beaucarnea inermis* as a Threatened species is confirmed according to the criteria of the MER-Plants, however, this could change for the worse if the intensity of the impacts detected does not decrease, putting *B. inermis* in critical danger of extinction.

Supplementary Material

The following online material is available for this article:

Appendix I - Ratings for each of the evaluated criteria MER-Plantas for Beaucarnea inermis according to Normative Annex II of NOM-059-SEMARNAT-2010.

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Conflicts of Interest

The authors declare that they have no conflict of interest related to the publication of this manuscript.

Data Availability

Supporting data are available at <https://doi.org/10.48331/scielodata.TTBDRB>

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