Research Article

Range extension of the endangered Mexican cycad *Ceratozamia fuscoviridis* Moore (teosintle): implications for conservation

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Abstract

Ceratozamia fuscoviridis, or teosintle in nahuatl, is a recently rediscovered endangered cycad species previously known from only one population (Molango) in Sierra Madre Oriental of the State of Hidalgo, Mexico. Recent botanical explorations have found new but scattered populations, increasing its known geographical range. Ecological studies were conducted on six of the 29 populations found. Parameters such as size, density, population structure, and static life table are presented. This is the first study of its kind conducted to prompt the Mexican authorities to establish natural protected areas for this species and the associated biodiversity, because deforestation is rapidly diminishing the populations. The population structure in general showed a Deevey-III curve, while two populations showed Deevey-I curves. A 400 m^2 area had a population size from 143 to 378 individuals. Population density varied from 0.358 individuals/m^2 to 0.945 individuals/m^2. Population structure was statistically different among populations. The large amount of seedlings in all sites was distinctive and indicated the specie's reproductive success even in small forest fragments. This research provides the most complete information available to date regarding populations of *C. fuscoviridis*. Future protected areas established in the better conserved populations could enable the populations' rapid recovery. This study shows that *C. fuscoviridis* is not as restricted in area as previously believed. We suggest the IUCN Red listing category of the species be amended from Critically Endangered (CR) to Endangered (EN) in view of newly discovered populations, high population size, and successful recruitment.

Keywords: *Ceratozamia molango,* endemic plant species, life table, Sierra Madre Oriental, Zamiaceae

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Introduction

Cycads are among the most threatened plants in the world [1]. Of an ancient lineage [2, 3], the Order Cycadales have survived massive extinctions, and today's living species are of recent evolution [4, 5] but are clearly declining in the "anthropocene" sensu Crutzen [6]. These primitive gymnosperms are the oldest living seed plants, currently threatened by habitat loss, poaching, slow growth rates [7], species-specific reproductive system (pollination by beetles) [8]-[10], and slow germination rates [11]. These charismatic plants are also under pressure on a worldwide level because of their ornamental horticultural appeal [1], and according to the IUCN Red List, almost all cycad species are under threat [1].

We need to formulate and implement adequate conservation strategies for threatened species that are represented by unique and small populations on a narrow geographic range [1]. In many countries the conservation portfolio includes: natural protected areas (NPA), community-based conservation (CBC), and *ex situ* conservation [12]. However, the question remains, where to apply which conservation strategies, and why. The answers require information on the biological, social, economic and political dimensions.

Analyzing the biological dimension, for cycads in particular, conservation decisions are generally based on geographical area and population sizes (especially adult plants), whilst ecological studies and demography are scarce [7, 13 - 17] due to the lengthy observation time-span for obtaining meaningful results on these long-lived plants.

Mexico ranks second worldwide in cycad diversity [18]) with over 22% of its cycad flora listed by IUCN [1] as "critically endangered" (CR), including *Ceratozamia fuscoviridis* (teosintle in nahuatl). Osborne et al. [19] and Donaldson [1] estimated a population size of only 250 reproductive individuals, with only one known population endemic to the Molango region in the State of Hidalgo [19]. *Ceratozamia fuscoviridis* is not yet included in the Mexican official list of threatened and endangered native species NOM-059-SEMARNAT-2010 [20], because some basic aspects of its populations are still unknown.

Ceratozamia fuscoviridis was named provisionally (*sic*) in 1878 by Moore from specimens thought to be acquired from Cuba [21]. Osborne et al. [19] revised and validated the epithet citing Moore´s holotype (Hort Glasnevin 1881 D. Moore s.n. HOLOTYPE: K - 3 sheets!). *Ceratozamia fuscoviridis* has been regularly confused with *C. mexicana* Brongn., but, studies show cytological and biochemical differences between these two species [22], apart from the characteristic reddish brown color of the veins of new leaves in the former [19] (hence the epithet "fuscoviridis") which does not occur in *C. mexicana*. The species is mostly used for traditional purposes, such as food and for ritual [23]. The challenge is how to conserve this critically endangered species when only fragmentary historic information exists on its taxonomy and nothing on its ecology [19, 21, 22].

For future conservation strategies of *C. fuscoviridis,* we evaluated some population properties (size, density, structure, and static life tables), and carried out intensive fieldwork to determine its geographical range by looking for new populations. Both objectives helped to reach our goal of designing conservation strategies. These strategies involve new NPAs and the creation of sustainable management nurseries within or associated with these areas, called rural sustainable management nurseries (Spanish acronym UMAs for unidades de manejo y aprovechamiento de vida silvestre) licensed under the Mexican environment secretariat (SEMARNAT). This scheme, ongoing since 1990, permits rural farmers who have natural cycad populations on their lands to become important stakeholders, and they are encouraged to propagate cycads (seed harvest, sowing and cultivation in rural nurseries). This creates an incentive to conserve the cycad and native habitats through plant sales benefiting the farmers directly. Some individuals produced in the nursery are reintroduced back into the habitat to compensate seed removal [12, 24]. More details on the philosophy and working of these cycad UMAs in Veracruz and Chiapas and a summary of problems and successes can be found in [24, 25]. The discovery of new populations of *C. fuscoviridis* will helps identify which populations to include in the new NPA proposals, as well as their suitability for management under the UMA scheme. The conservation strategies proposed here could be applied to species with similar conservation problems.

Methods

Geographic range of the species

Between December 2007 and June 2011, field excursions were made in 22 municipalities of the Sierra Madre Oriental (SMO) in Mexico (covering the states of Hidalgo, Veracruz and Querétaro) in order to collect plant material and record information on the species´ geographic range. Collections are supported by collection permits: SGPA/DGVS/05612/09 and SGPA/DGVS/10163/10 by SEMARNAT. A total of 59 herbarium vouchers (Appendix 1) was deposited at HGOM (Universidad Autónoma del Estado de Hidalgo) and XAL (Instituto de Ecología, A.C.) and determined by A.P. Vovides, authority on Mexican cycads.

At each locality we contacted the local authority, explained the project, and obtained at least oral consent to proceed (permission was not issued in writing). At five localities, local authorities accompanied us in the fieldwork.
Our study required special permission because we worked with a protected species. The specific location of our study area is not published because of the risk of poaching, but can only be provided to the Journal privately.

Collections in Querétaro and Veracruz were infertile or had very immature reproductive structures and were determined as *Ceratozamia* affinis *fuscoviridis.* Although further taxonomic study of these populations could increase the species' range, we decided to limit the present population studies to Hidalgo as the populations appear to be restricted to this state.

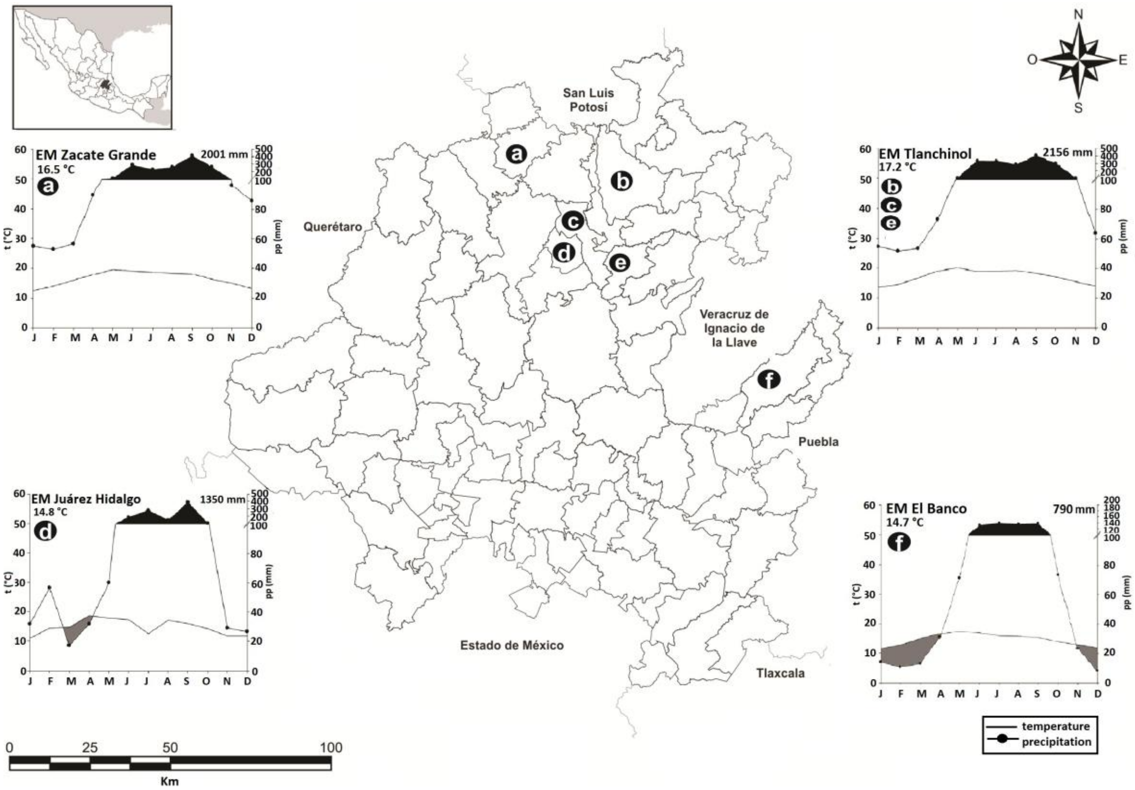

Fig. 1. Municipalities in which the demographic study of *Ceratozamia fuscoviridis* took place. Places: a= Chapulhuacán, b= Tlanchinol, c=Xochicoatlán, d=Juárez Hidalgo, e=Molango, f= San Bartolo Tutotepec. Climate diagrams correspond to the Meteorological Stations (MS) closest to the populations sampled. Climatic data taken from [47].

Study Plots

With the aid of native guides, we visited all the 29 accessible populations found throughout the species' range. Inaccessible populations on extremely steep canyon faces, which could be accessed only with rappel equipment, were not sampled. Six populations of *Ceratozamia fuscoviridis* were selected within its range in Hidalgo. We selected the populations at extremes in latitude, longitude and elevation in order to capture the broadest variation, enabling us to evaluate the species' conservation status. In each area we selected the largest, best-conserved populations and avoided isolated individual plants. Sampling took place from 2008 to 2010 (Xochicoatlán in June 2008, Molango in July 2008, Juárez Hidalgo in April 2009, Tlanchinol in December 2009, Chapulhuacán in April 2010, and San Bartolo Tutotepec in October 2010, Fig. 1).

A 400 m^2 (20 x 20 m) plot was measured out for each population, and then subdivided into four 10 x 10 m sub-quadrats with ropes and with wooden stakes at each corner. GPS coordinates, slope, altitude, and percentage tree cover were recorded in all sub-quadrats in every plot. Vegetation type, visible disturbance in the plots and surrounding area (garbage, fences, wood extraction, exotic plants, plantations, and/or roads) were also noted. Local guides provided information on current and historical land uses in the area (timber extraction, fires, agriculture, grazing, etc.). Records from the closest meteorological station were used to obtain climatic data.

Population size and density

Population size and density were calculated per plot; population size was the sum of individuals per plot, while density was the number of individuals per m^2, recording each individual found in the six plots. Additionally, the following data were recorded per individual: number of leaves, number of leaflets found on the longest leaf, length of longest leaf, and sex whenever there was a cone or cone remnants. The correlations among number of leaves, number of leaflets found on the longest leaf, and leaf length were used as an indicator of plant size to classify the individuals (see below).

Population structure

Size distribution in cycads has used diverse criteria such as number of leaflets [13, 26], trunk height classes [16], leaf number per individual [27], plant height [7], or leaf length and stem diameter [15]. In order to register differences within and between populations we used the number of leaflets on the longest leaf as a criterion (Appendix 2) to classify individuals in eight size categories: Seedling, Infant 1, Infant 2, Juvenile 1, Juvenile 2, Adult 1, Adult 2 and Adult 3 (Table 1). In general, breaks between categories were set by both number of leaflets and biological criteria to define smaller individuals and adults. We considered it more informative to divide smaller individuals into seedling and Infant 1 rather than pooling data in only one category. Seedlings were defined as plants with the seed still attached, while infants had no seed attached and had ≤ 29 leaflets on the longest leaf. Juvenile had among 30 to 49 leaflets. A plant was classified as adult if it had ≥ 70 leaflets on the longest leaf, based on our field observations that individuals with 69 or fewer leaflets are never reproductive.

Table 1. Size categories used to describe the population structure of *Ceratozamia fuscoviridis*. X: present **-**: absent.

Category	Symbol	Number of leaflets	Reproductive Structure	Aerial stem
Seedling	SL	1-4	-	-
Infant 1	I1	5-11	-	-
Infant 2	I2	12-29	-	-
Juvenile 1	J1	30-49	-	X
Juvenile 2	J2	50-69	-	X
Adult 1	A1	70-89	X	X
Adult 2	A2	90-109	X	X
Adult 3	A3	≥ 110	X	X

Life Table

We constructed a static life table [28, 29] using the total number of individuals per class for the six populations in order to assess mortality and survival rates for a population. Resulting data are treated as if a cohort was followed through time (*i.e.,* the number of organisms decreases in every class). Even though this is static information, it can be indicative of population change through time, particularly in long-lived organisms.

Data analysis

Data from the field were analyzed with basic statistics to determine frequency and proportion of individuals for each size category. Population size, population density, population size structure, and spatial distribution were estimated for each plot. ANOVA and correlations between population size (total and adults) and elevation, tree cover, slope, annual precipitation and number of disturbance causes were explored.

The population structure among plots was compared using X^2 statistics. An *a posteriori* test (adjusted residual analysis described by Haberman [30]) to identify these differences was also carried out; the Haberman test enabled us to identify the categories with excess (marked with +) or missing (marked with -) individuals. The number of individuals in each category was used for X^2 and Haberman tests. Because the number of individuals in the adult category was often less than five (a limitation for Haberman test), we decided to merge the three categories of adults. Additionally, skew and kurtosis analyses were applied to compare the shape of the size distribution curve.

Finally, a static life table according to Begon et al. [29] and Krebs [28] was calculated using the sum of individuals in the six populations and estimate of the total population structure. I1 and I2 individuals were merged into one category for the sake of the analysis.

Results

Geographical range

Twenty-nine populations of *Ceratozamia fuscoviridis* were found in twelve municipalities in the state of Hidalgo, occurring in Cloud Forests, Oak Forest, and Montane Rainforests, on pronounced slopes (34º to 44º), between 900 and 1,880 masl. All showed some level of human disturbance (Table 2).

Population size and density

Population size varied among populations: a 400 m^2 area had between 143 to 378 individuals, and the most dense population was three times that of the least dense. Populations at San Bartolo and Tlanchinol were the densest, with 0.945 and 0.938 individuals/m^2 respectively; Chapulhuacán was the least dense, with the remaining populations having intermediate densities (Table 3). There was a negative relationship between population size per plot and slope ($F_{1, 4}$ = 39.8, P<0.001); the equation is Y = - 28.8 * slope + 1142.045.

Population structure

Population structure was statistically different among populations (χ^2 = 480.7, P < 0.05, d.f. = 25, Fig. 2); seedlings were proportionally more abundant in Tlanchinol, Juárez, and Xochicoatlán, and scarcer in Chapulhuacán, San Bartolo, and Molango (Fig. 2); and adults were proportionally more abundant in Tlanchinol and Molango and less abundant in Chapulhuacán, San Bartolo, and Juárez (Fig. 2).

Table 2. General characterization of the study plots. MR: Montane Rainforest. CF: Cloud Forest. Data on rainfall, temperature and climate from [47 - 49] and type of soil from [50].
***Ejido system, put in place in Mexico in the 1920s during the agrarian reform following the revolution, assigns lands to local communities as common property. n.a. non available

Municipality	Xochicoatlán	Molango	Juárez Hidalgo	San Bartolo Tutotepec	Tlanchinol	Chapulhuacán
Altitude (masl)	1880	1530	1540	1560	1550	990
Tree cover (%)	86.7 ± 2.8	88 ± 2.2	91.4 ± 1.1	97 ± 0.5	91.6 ± 1.7	93 ± 1.2
Vegetation	CF	CF	CF	CF	CF	MR
Slope (°)	41	36	38	35	34	44
Dominant soil	Leptosol	Leptosol	Leptosol	Regosol	Leptosol	Leptosol
Climate	Humid temperate	Humid temperate	Sub-humid temperate	Temperate	Humid temperate	Humid temperate
Yearly average temp. (°C)	19	17	14.8	14.7	17.2	16.5
Yearly average rainfall (mm)	1890	1438	1541.9	790.7	2156.2	2001.1
Disturbance	Patch of forest surrounded by grasslands and agricultural land	Patch of fenced forest, surrounded by wasteland	Had cattle	Had garbage	Patch of fenced forest, surrounded by wasteland	Had garbage and cattle grazing nearby
History	Damaged by wood extraction	Found on the margins of the Contzintla river	Wood was extracted 50 years ago as well as cycad leaves for roofing purposes	Wood from dead trees is extracted	It became waste land 30 years ago and 10 years ago there was timber extraction.	n.a.
Land Ownership	Ejido*	Private property	Ejido	Private property	Private property.	n.a.

Table 3. Density and abundance of *C. fuscoviridis* individuals by size category in the sampled plots (400 m^2). Categories: SL= Seedlings, I1= infant 1, I2= infant 2, J1= juvenile 1, J2= juvenile 2, A1= adult 1, A2= adult 2 and A3= adult 3.

	Density (number of individuals / m^2)					
Category	Chapulhuacán	San Bartolo	Tlanchinol	Juárez Hidalgo	Xochicoatlán	Molango
SL	0.098	0.245	0.568	0.325	0.340	0.210
I1	0.068	0.053	0.035	0.085	0.028	0.040
I2	0.100	0.153	0.038	0.105	0.038	0.093
J1	0.085	0.253	0.028	0.055	0.023	0.100
J2	0.005	0.220	0.103	0.030	0.030	0.080
A1	0.003	0.023	0.135	0.013	0.035	0.068
A2	0.000	0.000	0.030	0.018	0.025	0.050
A3	0.000	0.000	0.003	0.018	0.005	0.040
Total	0.358	0.945	0.938	0.648	0.523	0.681
Number of individuals	143	378	375	259	209	272

The six populations studied presented a left-skewed frequency distribution. The degree of skew and kurtosis differed among populations. Ranked by decreasing degree of skew and kurtosis are: Xochicoatlán, Tlanchinol, Juárez, Molango, San Bartolo, Chapulhuacán (Table 4). The size structure showed two groups: 1) similar to an inverted *J* - Juárez, Xochicoatlán, Tlanchinol and Molango (Fig. 2). The populations at these sites had abundant seedlings with numbers decreasing in subsequent categories; the distribution was leptokurtic and displayed a skew around 2 units (Table 4); and 2) San Bartolo and Chapulhuacán displayed high numbers in infants 2 and juvenile 1 but fewer adults, suggesting a Deevey-I curve [31] (Fig. 2); they exhibited a platykurtic distribution and no skew (Table 4).

In general, seedlings dominated. Infants and juveniles were less frequent and adults even more scarce (Fig. 2). No samples of A2 and/or A3 categories were found in San Bartolo and Chapulhuacán (Fig. 2). Seedlings represented 26% to 65% of the populations, although in some cases they were not the most abundant category; juveniles dominated in San Bartolo (50%), and infants in Chapulhuacán (47%). There were a large percentage of adults in three populations (23%, 18% and 12.5% in Molango, Tlanchinol, and Xochicoatlán respectively), while in the remaining populations there were fewer adults (1% in Chapulhuacán, 2% in San Bartolo and 7% in Juárez). The average number of fertile individuals sampled was 1.66 ± 0.49 in all populations.

Life Table

The life expectancy for the six populations of *Ceratozamia fuscoviridis*, from the sum of individuals observed per category, is indicated by l_x, the surviving proportion, and has a value of 0.036 in A3. This shows that only 3% of individuals passed on to the oldest category. The death rate, q_x, fluctuated between 0.138 in J1 to 0.555 in A1, and was higher in seedlings and adults (Table 5).

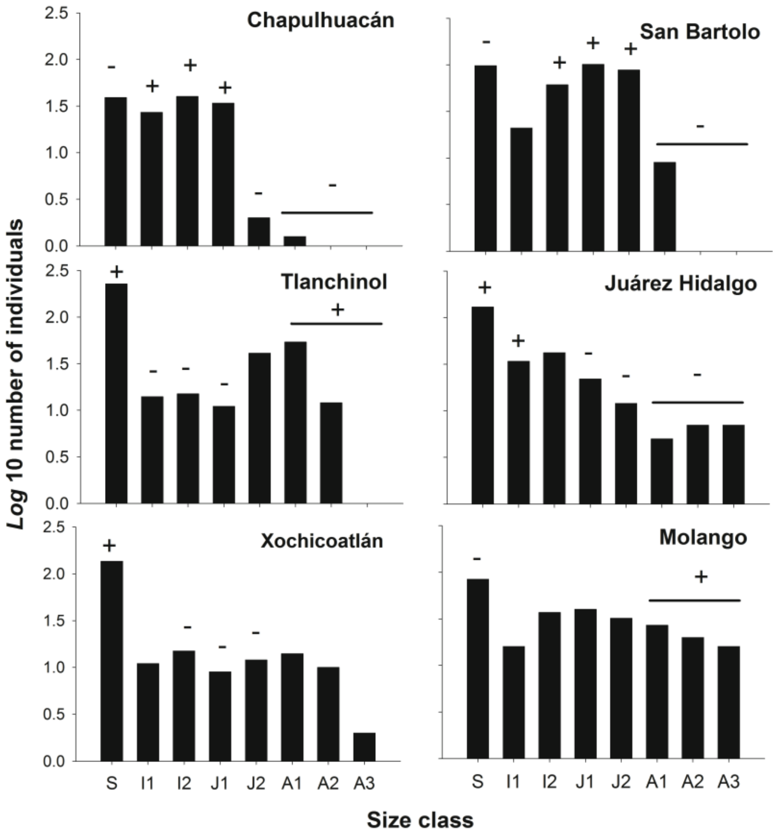

Fig. 2. Population structure (*log* 10 of the number of individuals) of *Ceratozamia fuscoviridis*, in the six 400 m^2 plots. Categories: S= seedling, I1= infant one, I2= infant two, J1= juvenile one, J2= juvenile two, A1= adult one, A2= adult two and A3= adult three.

Table 4. Kurtosis and skewness values for the six populations of *Ceratozamia fuscoviridis* studied.

	Kurtosis	Skewness
Xochicoatlán	7.814	2.783
Tlanchinol	6.695	2.538
Juárez Hidalgo	5.556	2.278
Molango	4.320	1.930
San Bartolo	-2.272	0.153
Chapulhuacán	-2.497	0.144

Table 5. Life table for *Ceratozamia fuscoviridis* calculated from the sum of the six populations studied at Hidalgo.

Category	n_x Observed number	l_x Proportion surviving n_x / n_0	d_x Proportion dying $l_x - l_{x+1}$	q_x Finite rate of mortality $(n_x - n_{x+1}) / n_x$	k_x Killing power $log_{10}\, n_x - log_{10}\, n_{x+1}$
S	714	1.000	0.534	0.534	0.331
I1+I2	333	0.466	0.162	0.348	0.186
J1	217	0.304	0.042	0.138	0.065
J2	187	0.262	0.108	0.412	0.230
A1	110	0.154	0.085	0.555	0.351
A2	49	0.069	0.032	0.469	0.275
A3	26	0.036			

Discussion

Geographic range

Ceratozamia fuscoviridis was found to have a larger geographic range than just the Molango area, as previously thought [19]. The new populations found within Hidalgo possibly extend into the neighboring states of Veracruz and Querétaro, and further explorations may confirm this. However, this species still has a restricted overall geographical distribution, as it is known only from small populations in the cloud forests, oak, and montane rainforests of Hidalgo, all these being threatened, patchy ecosystems that are rapidly disappearing due to human activities.

Population size and density

The six populations varied in population size, apparently related to slope, while the population structure was not related to environmental or disturbance factors. The status of the present populations of *Ceratozamia fuscoviridis*, a long-lived species, is probably the result of historic multiple events such as deforestation and fragmentation. The life cycle of *Ceratozamia* typically extends about 30 years [32], although individual specimens can live for centuries.

The high density of *C. fuscoviridis* populations (0.358 ind/m^2 to 0.945 ind/m^2) is unusual in comparison to other Mexican cycads. For example, *Ceratozamia mexicana* has densities of 0.28 individuals/m^2 [33] to 0.78 ind./m^2 in well-preserved sites, and up to 0.26 ind./m^2 in altered ones [34]; *C. matudae* has 0.10 ind./m^2 to 0.33 ind./m^2 [27]; *Dioon edule* or chamal has from 0.21 ind./m^2 to 0.44 ind./m^2 [35]; *D. purpusii* has 0.0037 ind./m^2 [36]; *D. caputoi* De Luca, Sabato & Vázq.Torres has 0.002 ind./m^2 and *D. merolae* De Luca, Sabato & Vázq.Torres 0.01 ind./m^2 [37]. Cycads are generally capable of producing a large amount of seedlings [38]. Such recruiting indicates viable populations even in very small areas, and suggests that reproduction is probably not a limiting factor under moderate habitat disturbance. Nevertheless, life cycles and population dynamics must be taken into account in making management decisions, even under good recruitment. Being very long-lived, cycads should be considered analogous to long-lived trees [17].

Although populations of *Ceratozamia fuscoviridis* have high densities, they occur only within a vegetation mosaic as small fragmented patches of approximately 0.1 ha. They were never seen in populations of a large area (>10 ha). We believe that the current geographic range could reflect a time when this species belonged to larger continuous populations; gene flow studies in the future may confirm or refute this.
Differences in population densities could be related to the conservation status of the habitat, as observed for *C. mirandae* [16] and *Zamia melanorrhachis* D.W. Stev. [26], where there were higher densities in well-preserved forests than in disturbed ones. However, the evaluation of the relationship between population characteristics and disturbance (particularly disturbance index, not only number of disturbances) needs to be measured.

Population structure

The six populations studied resulted in two groups. The first, in Juarez, Molango, Tlanchinol and Xochicatlán, was leptokurtic. These four populations had an inverted *J* static population structure corresponding to a Deevey-III [31] or Bongers et al. [39] type I distribution, common for shade-tolerant plants that maintain a more or less constant recruiting rate but higher mortality in the earlier life stages. This structure is the one most often seen in cycads such as *Zamia debilis* L.f. [40], *Ceratozamia matudae* Lundell [27], *C. mirandae* Vovides, Pérez-Farr. & Iglesias [16], *Dioon edule* [7], *D. purpusii* Rose [36] and *D. spinulosum* Dyer ex Eichler [41]; it was observed in four of the six populations of *C. fuscoviridis* studied. In contrast, the second group, the Chapulhuacán and San Bartolo populations showed a Deevey-I or Bongers-III distribution pattern. In part this is due to the absence of A2 and A3 individuals, possibly caused by disturbance or illegal extraction of the larger individuals, although direct evidence for this is lacking.

Population structure is extremely dynamic and very sensitive to environmental changes, so distribution Bongers-I can easily change to a Bongers-II if recruitment rates drop or are interrupted, or changed to a type III if there are other obstacles to regeneration, such as severe drought or fire [7], [42].

Life table

The analysis of six populations of *Ceratozamia fuscoviridis* as a whole showed that the proportion of surviving plants, (l_x), greatly decreases in the infants category, whilst the decrease is almost constant in the remaining categories. Therefore, l_x (log) has a tendency towards Deevey type II. This is a predictable result because it represents the pooling of the six populations, some of them with a Deevey I feature and others exhibiting a Deevey III. In general, the remarkable change occurred in the transition from seedlings to infants, while the other changes were of minor magnitude. While these data represent a static life table, they provide some information about population dynamics. In species with long life cycles, the population structure reflects multiple events occurring over long time periods. Therefore, this life table analysis gives only limited population dynamics, needing studies over several years to calculate elasticity matrix and lambda values for a better resolution of events.

Conservation status

We recommend an update of the species IUCN Red List category from “critically endangered” (CR) to “endangered” (EN). The extent of occurrence of *Ceratozamia fuscoviridis* is approximately 2,075 Km^2 and the area of occupancy is about 500 Km^2 (Fig. 3). According to IUCN criteria B [47] the species can be considered as “endangered” (EN).

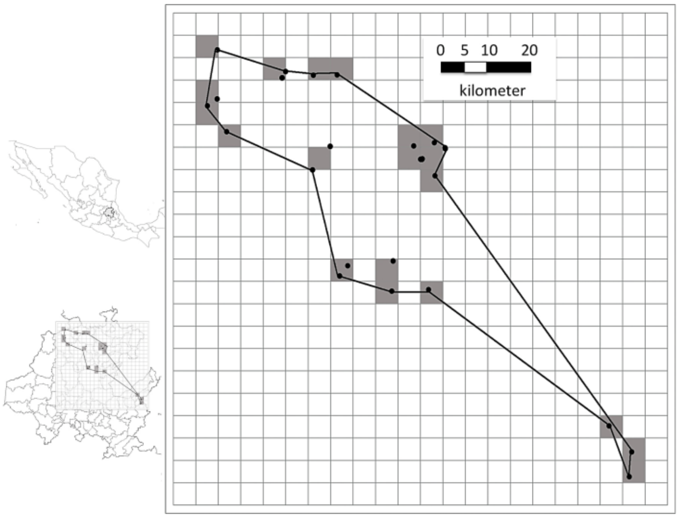

Fig. 3. Quantification of "extent of occurrence" (polygon) and "area of occupancy" (shaded squares), according to IUCN terminology [51] for the species *Ceratozamia fuscoviridis*. Each square represents 25 Km^2.

Fig. 4. *Ceratozamia fuscoviridis* and its habitat. Photo credits: María Teresa Pulido Silva. Except botton left by Jonathan Silva Chavez.

Implications for conservation

Additional efforts are needed to increase the seedling-infants transition in natural populations. This could be facilitated by nursery reintroduction (UMAs) or by establishing NPAs as key long-term conservation strategies. It is therefore urgent to include the species in the NOM-059-SEMARNAT-2010.

The UMA system [12] can be promoted in some of these populations, particularly in Tlanchinol, Molango, Juárez, and Xochicoatlán, as it is easier to conserve small areas through the UMA scheme than through NPAs; smaller areas attached to homesteads are better controlled by a few family members than the larger NPAs, where patroling is inefficient or non-existent. However, a new NPA is required at least in Northwestern Hidalgo due to the presence of important populations of *C. fuscoviridis* (Fig. 4) and other cycads, as well as high levels of biological diversity [23] in this region. A combination of conservation strategies, including NPAs, UMAs, and areas of community-based conservation is highly recommended for conservation of the species.

The main threat to survival is change in land use, where high risks of deforestation still exist, particularly in the northwest region of Hidalgo (http://www.inecc.gob.mx/imgs/dgipea/irdef_hgo.jpg). Although not directly studied for *C. fuscoviridis*, this is implicit, since Mexico is being deforested at a rate of 500,000 ha/year [43]. We observed habitat destruction by both road construction and pasture expansion on repeated field expeditions to forests with cycad populations. Therefore, we highly recommend the establishment of NPAs and sanctuaries to conserve the populations, particularly in the northwest region. Environmental education of the local inhabitants, who could combine management and conservation of this species through Community-Based Conservation, sustainable management in UMAs, as well as a regional botanic garden, should be also be implemented.

We emphasize key practical aspects of conservation efforts: a) it is very important to involve local people as active conservation participants by means of nurseries and other activities without transferring the conservation cost to local human populations [44]; b) it is also very important to conduct extensive field work to locate new populations based on local experience; c) long-term demographic studies should be done on the conserved populations; d) participants must recognize that conservation issues involve complex-systems [45] requiring multi-stakeholder processes, cross-scale institutional linkages, and multiple institutions and actors, among others [46].

Finally, long term population dynamic studies are needed to fully understand the conservation status of *Ceratozamia fuscoviridis.* Determining elasticity and lambda (λ) values to ascertain whether the populations are stable, increasing or decreasing will enable more effective conservation strategies. Genetic population studies are already underway.

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Appendix 1. Herbarium vouchers collected for this study. These are deposited in the herbarium of Universidad Autónoma del Estado de Hidalgo (HGOM) and Herbario del Instituto de Ecología A.C. (XAL).

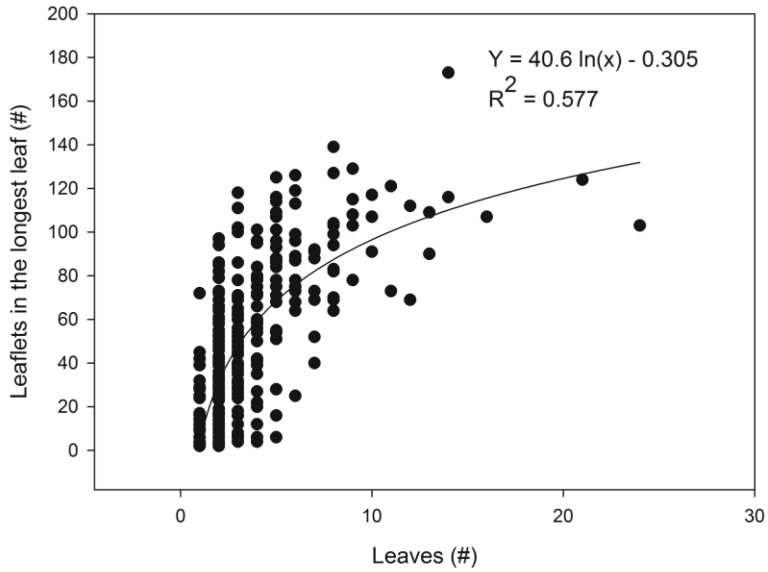
MÉXICO: HIDALGO, Chapulhuacán, *A. Vite-Reyes 25* (HGOM), *26* (HGOM), *33* (HGOM), *M. Vargas-Zenteno 27* (HGOM), *28* (HGOM), *29* (HGOM), *M.T. Pulido-Silva 147* (HGOM), *148* (HGOM), *149* (HGOM); Juárez Hidalgo, *A. Vite-Reyes 40* (HGOM), *41* (HGOM), *M. Vargas-Zenteno 7* (HGOM), *8* (HGOM), *9* (HGOM); La Misión, *A. Vite-Reyes 12* (HGOM), *13* (HGOM), *14* (HGOM), *15* (HGOM), *16* (HGOM), *17* (HGOM), *18* (HGOM), *19* (HGOM), *20* (HGOM, XAL), *21* (HGOM), *M. Vargas-Zenteno 30* (HGOM); Molango, *A. Vite-Reyes 3* (HGOM), *5* (HGOM), *6* (HGOM, XAL); Pisaflores, *M. Vargas-Zenteno 26* (HGOM); Tenango de Doria, *M. Vargas-Zenteno 34* (HGOM); Tianguistengo, *M. Vargas-Zenteno 1* (HGOM), *2* (HGOM), *3* (HGOM); Tlanchinol, *A. Vite-Reyes 1* (HGOM), *M. Vargas-Zenteno 10* (HGOM), *11* (HGOM), *12* (HGOM), *13* (HGOM), *14* (HGOM), *15* (HGOM), *16* (HGOM); Xochicoatlán, *M. Vargas-Zenteno 17* (HGOM).

MÉXICO: QUERÉTARO, Landa de Matamoros, *M. Vargas-Zenteno 18* (HGOM), *19* (HGOM), *20* (HGOM), *21* (HGOM), *22* (HGOM), *23* (HGOM), *24* (HGOM), *25* (HGOM), *M.T. Pulido-Silva 134* (HGOM), *137* (HGOM), *143* (HGOM).

MÉXICO: VERACRUZ, Huayacocotla, *M. Vargas-Zenteno 4* (HGOM), *5* (HGOM), *6* (HGOM), *31* (HGOM), *32* (HGOM), *33* (HGOM).

Appendix 2. Correlations between the number of leaflets on the longest leaf and two variables: a) leaf number and b) leaf length. The population stage distributions were generated using the number of leaflets on the longest leaf.

a)



b)