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Distribution and conservation status of *Dioon vovidesii* (Zamiaceae), a cycad from Sonora, Mexico

Distribución y estado de conservación de Dioon vovidesii *(Zamiaceae), una cícada de Sonora, México*

Karen Yoselin Jiménez-Cedillo [a], Karla Fabiola Yescas-Romo [b, c], José F. Martínez [b], Francisco Molina-Freaner [b, *]

[a] *Universidad Nacional Autónoma de México, Instituto de Ecología, Posgrado en Ciencias Biológicas, Circuito exterior s/n anexo al Jardín Botánico, Ciudad Universitaria, 04510 Mexico City, Mexico*

[b] *Universidad Nacional Autónoma de México, Instituto de Ecología, Departamento de Ecología de la Biodiversidad, Avenida Colosio S/N, Colonia Los Arcos, 83250 Hermosillo, Sonora, Mexico*

[c] *Secretaría de Ciencia, Humanidades, Tecnología e Innovación, Insurgentes Sur 1582, Col. Crédito Constructor, Alcaldía Benito Juárez, 03940 Mexico City, Mexico*

*Corresponding author: freaner@unam.mx (F. Molina-Freaner)

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Abstract

Extinction is not a random process; certain traits make some species more vulnerable. Cycads face a high risk of extinction due to threats such as habitat loss, illegal trade, and invasive species. *Dioon vovidesii*, a recently described cycad species, has limited information available regarding its conservation status. To address this gap, we evaluated its vulnerability using IUCN Red List criteria and Mexico's Extinction Risk Assessment Method (MER). Information on species distribution, habitat, life history, population size, demographic trends, and anthropogenic threats was obtained from fieldwork in Sierra de Mazatán and specialized sources. Eight populations were identified in Sonora, Mexico, with small sizes ranging from 2 to 120 individuals. Although demographic analyses suggested near-equilibrium population dynamics, low seedling survival and poor recruitment were observed. All populations were exposed to anthropogenic threats within a 5 km radius. Based on both assessments, *D. vovidesii* is proposed to be classified under a risk category. These results highlight the need for continuous monitoring, further research on life history and ecology, and the effects of land-use change and buffelgrass invasion. Effective conservation and management strategies require collaboration among local communities, academic institutions, and government agencies to ensure the long-term survival of the species.

Keywords: Cycadales; Endemic species; Endangered; Extinction risk; IUCN Red List; MER method; Mexican flora; Threatened plant

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Resumen

La extinción no es un proceso aleatorio; ciertos rasgos hacen que algunas especies sean más vulnerables. Las cícadas enfrentan un alto riesgo de extinción debido a amenazas como la pérdida de hábitat, el comercio ilegal y las especies invasoras. *Dioon vovidesii*, una especie descrita recientemente, cuenta con información limitada sobre su estado de conservación. En este estudio evaluamos su vulnerabilidad utilizando los criterios de la Lista Roja de la UICN y el método de evaluación del riesgo de extinción (MER) de México. Se recopiló información sobre su distribución, hábitat, ciclo biológico, tamaño poblacional, tendencias demográficas y amenazas antropogénicas mediante trabajo de campo en la sierra de Mazatán y fuentes especializadas. Se identificaron 8 poblaciones en Sonora, con tamaños entre 2 y 120 individuos. Aunque las poblaciones mostraron una dinámica cercana al equilibrio, se observó baja supervivencia y escaso reclutamiento. Todas las poblaciones presentaron amenazas antropogénicas en un radio de 5 km. Con base en ambos métodos, se propone clasificar a *D. vovidesii* dentro de una categoría de riesgo. Estos resultados subrayan la necesidad de monitoreo continuo, mayor investigación biológica y la implementación de estrategias de conservación con participación comunitaria, académica e institucional.

Palabras clave: Cycadales; Especie endémica; Peligro de extinción; Riesgo de extinción; Lista Roja UICN; Método MER; Flora mexicana; Planta amenazada

Introduction

Extinction does not occur randomly among species; instead, certain traits or features, such as habitat specificity, generation time, or the size of the geographic range, predispose certain species to a higher vulnerability to extinction (Chichorro et al., 2022; Zhong et al., 2021). In plants, empirical evidence indicates that low population size, high habitat specificity (i.e., restricted to microhabitats) and small geographical distribution is associated with greater extinction risk (Fischer & Stocklin, 1997; Guevara-Andino et al., 2024). From a theoretical perspective, small populations are especially vulnerable to demographic and environmental stochasticity, which can increase the probability of extinction even in the absence of deterministic decline (Lande, 1993; Shaffer, 1981). Species occurring in few localities and showing habitat specialization may therefore exhibit reduced resilience to habitat alteration and environmental change. Thus, implementing effective conservation actions for endangered species requires identifying the intrinsic traits that make them vulnerable to extinction and the threats they face (Lacher et al., 2025).

Cycads, in particular, have been singled out as a group with a high susceptibility to extinction (Mankga & Yessoufou, 2017). The order Cycadales is considered as one of the most primitive groups of seed plants that exist nowadays (Liu et al., 2022). This plant group faces a notable risk of extinction due to various threats, including habitat loss through land-use changes, over-collection for illegal trade, and the introduction of invasive species, among other factors (IUCN/SCC Cycad Specialist Group, 2003; Mankga & Yessoufou, 2017).

Currently, 380 cycad species have been globally described, with Australia, Mexico, and South Africa exhibiting the greatest species diversity (Calonje et al., 2026). Mexico has a total of 77 species of cycads, making it the second most diverse country in the world for cycad species (Calonje et al., 2026). Exceptional cycad conservation efforts have been identified in Mexico, including the establishment of live collections in botanical gardens and nurseries for commercial production and plant re-introduction into natural populations (Segalla et al., 2019; Vovides et al., 2010). Unfortunately, despite these conservation efforts, 81.8% of Mexican cycad species are under a category of extinction risk (IUCN, 2025; Semarnat, 2019). The primary threats to Mexican cycad species include habitat destruction resulting from forest exploitation and the expansion of agricultural activities (IUCN/SCC Cycad Specialist Group, 2003).

Over the last 2 decades, a great number of new species of cycads have been described in Mexico, as is the case of *Dioon vovidesii* (Gutiérrez-Ortega, Jiménez-Cedillo, Pérez-Farrera, Martínez et al., 2018; Martínez-Domínguez et al., 2023). Distributed in northwestern Mexico, *D. vovidesii* is an arborescent cycad (Fig. 1) inhabiting rocky granitic outcrops in oak forests, desert scrub, tropical deciduous forests, and transitional vegetation among them (Fig. 2a, b) (Gutiérrez-Ortega, Jiménez-Cedillo, Pérez-Farrera, Martínez et al., 2018). This species showcases anatomical adaptations to aridity, allowing it to occupy areas with greater seasonality than its sister species, *D. sonorense*, and granting it the status of the cycad species with the world's northernmost distribution (Gutiérrez-Ortega, Jiménez-Cedillo, Pérez-Farrera, Vovides et al., 2018; Gutiérrez-Ortega et al., 2021). Despite these

unique features, *D. vovidesii* is confronted with potential threats such as illegal collection and land-use change and consequently has been suggested as a threatened species (Gutiérrez-Ortega et al., 2014; Gutiérrez-Ortega, Jiménez-Cedillo, Pérez-Farrera, Martínez et al., 2018). However, due to the limited information available, no formal studies currently exist on the actual conservation status of *D. vovidesii* (Gutiérrez-Ortega, Jiménez-Cedillo, Pérez-Farrera, Martínez et al., 2018).

In order to fill the gap about the conservation status of *D. vovidesii*, its vulnerability to extinction was evaluated using criteria from the IUCN Red List and the Extinction Risk Assessment Method for wild species in Mexico (MER). We aimed to: *1)* describe its distribution range through field visits and search of records in herbarium databases, *2)* evaluate whether plants show habitat specificity, *3)* measure the size and population trends of representative populations of the species, *4)* identify anthropogenic threats surrounding populations, and *5)* assign a risk category to this species. By integrating distributional, demographic, ecological, and threat information, this study provides the first comprehensive evaluation of the extinction risk of *D. vovidesii* and establishes a baseline for its conservation planning.

Materials and methods

The state of Sonora, located in northwestern Mexico, shows a great diversity of climates and vegetation types due to factors such as an elevational gradient and its geographic position, among others (Brito-Castillo et al., 2010). The study area was in central Sonora, where *D. vovidesii* is distributed and 7 populations have been described (Gutiérrez-Ortega et al., 2021). The study focused on the Sierra de Mazatán (Fig. 3), which is considered as the southernmost sky island of the Madrean Archipelago, with an extension of 191 km^2 and an elevation ranging from 700 to 1,545 m asl (Arriaga et al., 2000; Conanp, 2012). This region has a semiarid climate of the temperate subtype (BS1k(x´)/(BS1h(x´)) and major vegetation types include desert scrub, oak forest, and aquatic and subaquatic vegetation (Rzedowski, 1978; Sánchez-Escalante et al., 2017). The Sierra de Mazatán has been recognized as a priority region for conservation as it functions as a biological corridor between biotas of the Sonoran Desert and the Sierra Madre Occidental (Arriaga, 2000).

Data collection

The distribution range of *D. vovidesii* was determined compiling evidence from specialized literature (i.e., Gutiérrez-Ortega, Jiménez-Cedillo, Pérez-Farrera, Martínez et al., 2018), Herbarium collections (Supplementary material: Table 1), consulting experts on the Flora of the Sonoran Desert, the genus *Dioon*, and regular field work during the period 2020-2021 through the Sierra de Mazatán, Sonora.

Habitat specificity was studied in the 3 populations from Sierra de Mazatán: Cañada de la Leona, Peñón de las Iglesias, and Rancho de la Cueva. Preliminary field observations suggested that individuals of *D. vovidesii* in populations from this area are mainly distributed in rock crevices. Therefore, to determine whether there is any type of microhabitat preference, the observed distribution of the location of plants on the ground in each population was compared with the distribution expected under the hypothesis of no preference. For each plant recorded in the field, data were collected on the substrate where it was found, using the substrate categories of rock, soil, or crevice, with crevice defined as small gaps or cracks between rocks. Using the linear transect method of Brower et al. (1997), 5 lines —50 m long— were established with a random starting point and direction within the area occupied by the population. The length intercepted by each substrate category was measured in each transect. Subsequently, the percentage represented by each category was calculated, and the values between transects were averaged. Using the above information, a goodness-of-fit test was performed to evaluate whether the observed distribution was consistent with the expected distribution if they were randomly distributed according to the frequency of each substrate.

Population size was determined through direct counting and conducting a census in the 3 known populations from the Sierra Mazatán. All plants in each population were tagged, georeferenced, and monitored over 1 year (2020-2021). The lengths of all the stems of each individual were summed, and plants were classified in 7 size categories, following the method of Lázaro-Zermeño et al. (2011). Size categories were: *a)* seedlings, plants without basal stem with 1-2 leaves of less than 30 cm in length (Fig. 2d); *b)* I, plants without basal stem with 2 or more leaves longer than 30 cm; *c-f)* 4 classes of 40-cm intervals in plants with basal stem length from 1 to 160 cm; and *g)* one class of plants whose total length was more than 160 cm. Census or field visits were not conducted in the rest of the populations from central Sonora due to difficult access or regional security problems. However, evidence about population size from those populations was obtained from Gutiérrez-Ortega et al. (2014), Gutiérrez-Ortega, Jiménez-Cedillo, Pérez-Farrera, Vovides et al. (2018).

Anthropogenic threats were identified by locating human constructions or settlements, water bodies, roads,



Figure 1. Individual of *Dioon vovidesii* showing 3 stems with associated leaf crowns.

and trails in proximity to *D. vovidesii* populations. A search and selection of geographic information layers was carried out, covering the geographic location of all populations (Supplementary material: Table 2). Once layers were obtained, they were imported to ArcMap v 10.5 for further analysis (ESRI, 2016). In addition, to obtain evidence of the illegal collection of plants, we searched for websites selling *D. vovidesii*, following the protocols suggested by Stringham et al. (2021). For evidence of invasive species, we searched SEINET (https://swbiodiversity.org/seinet/index.php), a database of herbarium records, for specimens of the invasive buffelgrass (*Cenchrus ciliaris*) close (< 5 km) to each population to identify populations potentially threatened by this species known to be affecting native plant species (Marshall et al., 2012).

Data analysis

Based on the information gathered about field localities, a map of the geographic range of *D. vovidesii* was generated using QGIS v 3.34.3-Prizren (QGIS, 2024). Additionally, the extent of occurrence (EOO) and area of occupancy (AOO) were estimated for *D. vovidesii*, following the methods dictated by IUCN (2024), using the geospatial conservation assessment tool GeoCAT (Backman et al., 2011).

Census data derived from the populations in Sierra de Mazatán were used to generate a histogram depicting population structure using the package ggplot2 v 3.4.4 (Wickham et al., 2016). To analyze differences in population structure among *D. vovidesii* populations in the Sierra de Mazatán, a chi-square test was performed. For this analysis, a contingency table was created with the frequencies of individuals in each size category for each population. Then, the R stats v 4.3.1 package (R Core Team, 2023) was used to perform the chi-square test.

Additionally, the demographic dynamics were analyzed through a Lefkovitch (*L*) transition matrix that was created using data from the 3 populations (Supplementary material: Table 3). This matrix contains the average probability of transition between size classes, stasis, and fertility categories from the data observed during the monitoring period (2020-2021). In this matrix, stasis values appear on the diagonal and correspond to

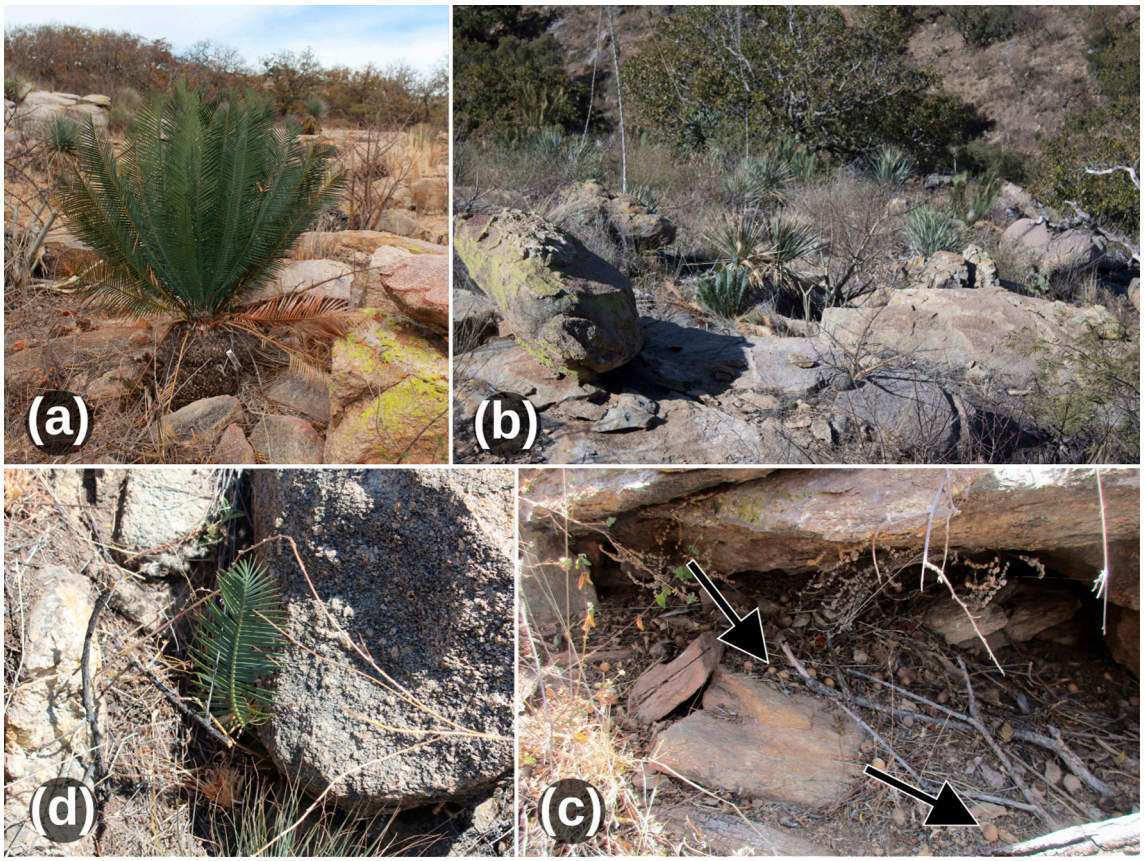


Figure 2. *Dioon vovidesii*: a) individual in size class III; b) natural habitat in Cañada de la Leona; c) group of seeds in a rock crevice (arrows indicate 2 seeds); and d) seedling established in a rock crevice.

individuals that survived and remained in the same size category after 1 year. Values below the diagonal refer to individuals that changed from one size class to the next in the same time period (Supplementary material: Table 3). Fertility values (Supplementary material 1), i.e., the production of new individuals, appear in the top row of the matrix. The population size after 1 year was determined by the equation $Nt+1 = L * Nt$, where Nt+1 is the population size in the following year, L is the Lefkovitch matrix, and Nt is the vector containing the initial number of individuals per size category. This process was repeated until the proportion of individuals per size category remained stable, represented by the right vector (w). The finite growth rate (λ) was obtained from the matrix model: (Nt+1/Nt), where Nt+1 is the total number of individuals at time t+1 and Nt is the number of individuals at time t (Caswell, 2001). Using the R package popbio (Stubben & Milligan, 2007), the finite population growth rate (λ) was estimated from the transition matrix, as well as the 95% confidence interval for this value (100,000 bootstrap samples) (Álvarez-Buylla & Slatkin, 1994; Caswell, 2001).

Anthropogenic threats near populations of *D. vovidesii* were identified using the 'Generate Near Table' tool in ArcMap v 10.5 (ESRI, 2016). A search radius of 5 km was applied for each population, with a maximum of 200 coincidences using the geodesic method. Anthropogenic threats were grouped according to the classification of direct threats of the IUCN v 4.0 (Salafsky et al., 2025).

Using life history and ecological data from specialized literature, layers of geographic information (Supplementary material: Table 2), alongside information on population size and structure, geographic range, and threats, the extinction risk of *D. vovidesii* was assessed. This evaluation employed criterion B from the Red List of IUCN (2024) and the method for evaluating extinction risk in wild species in Mexico (MER) (Sánchez et al., 2007; SEMARNAT, 2010).

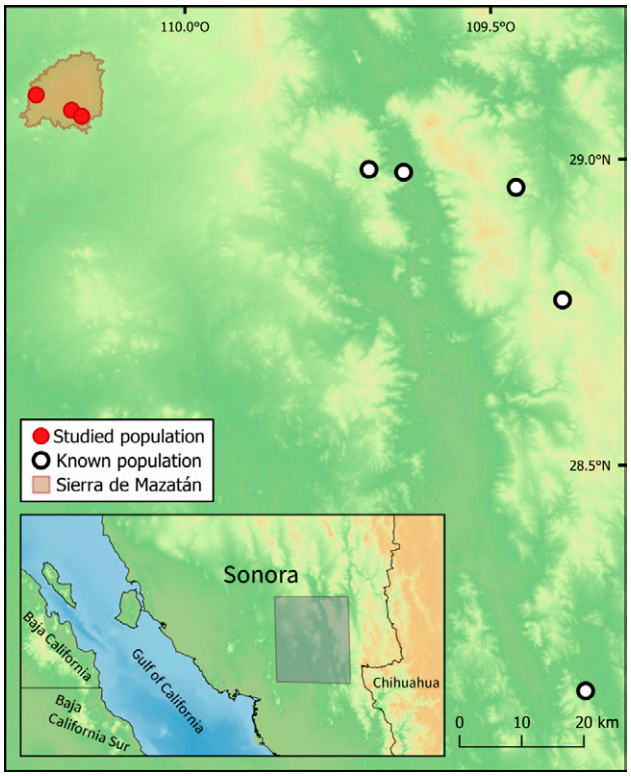


Figure 3. Geographic location of the 8 known populations of *Dioon vovidesii* in central Sonora. Red circles indicate populations within the Sierra de Mazatán; white circles indicate the remaining populations.

Results

A total of 103 records of the genus *Dioon* were identified in the state of Sonora, sourced from 10 herbaria (Supplementary material: Table 1). These records were refined to select those specifically attributed to *D. vovidesii*, in accordance with the distribution proposed in the species description (Gutiérrez-Ortega, Jiménez-Cedillo, Pérez-Farrera, Martínez et al. 2018). Subsequently, a total of 47 records were classified as belonging to *D. vovidesii*. Finally, after elimination of entries with errors, duplications, or deficiencies in geographic references, a total of 8 populations of *D. vovidesii* were identified in Sonora, Mexico (Fig. 3). Using the population records as a basis, we estimated an extent of occurrence of 3,642 km^2 and an area of occupancy of 32 km^2.

To evaluate whether individuals of *D. vovidesii* in Sierra de Mazatán show a microhabitat preference, the observed distribution of the location of plants was compared with the distribution expected if no preference existed. The null hypothesis of expected distribution according to the frequency of substrate types was rejected in Cañada de la Leona (χ^2 = 1534.01, p < 0.0001), Peñón de las Iglesias (χ^2 = 1163.18, p < 0.0001), and Rancho de la Cueva (χ^2 = 710.10, p < 0.0001). Between 60% and 100% of plants in each population were established in rock crevices, despite their relatively limited availability within the sampled area (Fig. 4). However, in the Cañada de la Leona, the expected and observed distributions in the 'soil' category are similar, suggesting that plants establish according to the frequency of this type of substrate. In contrast, in Peñón de las Iglesias, no plants were recorded growing on soil.

The population sizes found in the censuses conducted in the Sierra de Mazatán were 120, 34, and 35 individuals for Cañada de la Leona, Peñón de las Iglesias, and Rancho de la Cueva, respectively. Conversely, the sizes reported for the rest of the populations of the species vary in a range between 2 and 30 individuals (Fig. 5a). There are no reports of the number of individuals in the population known as 'Soyopa'. Regarding the structure of the surveyed populations, both Cañada de la Leona and Peñón de las Iglesias exhibited a greater number of individuals in smaller size categories. In contrast, the Rancho de la Cueva population has a more balanced distribution, with a greater number of individuals in larger size categories (Fig. 6). However, the population structures do not differ significantly from each other (χ^2 = 14.516, p = 0.269).

For the demographic study, 189 individuals were used to construct a population matrix. A finite population growth rate slightly below equilibrium was estimated (λ = 0.94), with a 95% confidence interval ranging from 0.89 to 1.00. Although the point estimate suggests a modest population decline, the confidence interval includes unity, indicating that the available data do not provide conclusive evidence of either population decline or population equilibrium. Reproductive structures were observed across all size categories except seedlings. Recruitment was observed (2020-2021) (Fig. 2c), identifying 17 female cones in 2020 and 7 seedlings in 2021 (Fig. 2d). However, a low seedling survival rate and an effective recruitment were found (0.005).

All populations of *D. vovidesii* had evidence of anthropogenic threats within a 5 km radius, which were classified into 7 categories (Fig. 5b). Populations face different types of threats: Bacanora and Cañada de la Leona had the fewest number of threat types, whereas Rancho de la Cueva, Soyopa, and Bacanora - El Novillo had the most (Fig. 5b). Regarding distance to threats, Peñón de las Iglesias was the population with the greatest distance to a threat, while Bacanora-El Novillo and Nuri had the shortest distance (Fig. 5c). In general, populations of central Sonora are exposed to a greater number and

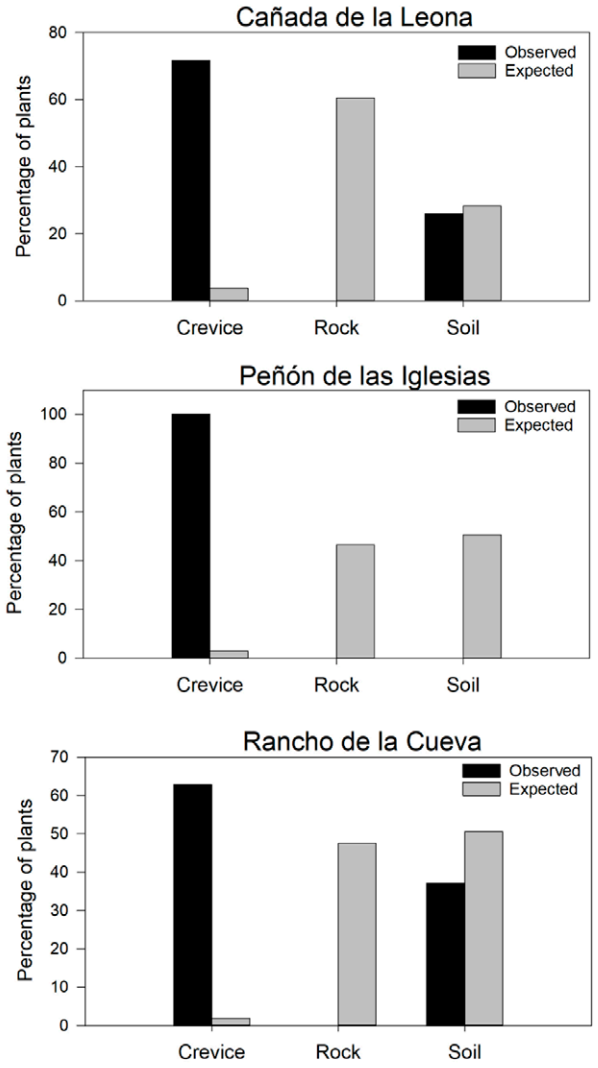


Figure 4. Percentage of observed and expected individuals in 3 substrate categories in populations of *Dioon vovidesii* in the Sierra de Mazatán. Values represent the percentage of individuals relative to the total population size in each substrate category.

types of anthropogenic threats than those located in the Sierra de Mazatán (excepting Rancho de la Cueva).

In the evaluation of the conservation status using both the IUCN Red List and the MER method of Mexico, *D. vovidesii* was assigned to a risk category. Considering the values obtained for extent of occurrence (3,642 km^2) and area of occupancy (32 km^2) and meeting the conditions of severely fragmented and a continuing decline of (i) area of occupancy and (v) number of mature individuals, *D. vovidesii* is within the Endangered category under criterion B (B1 and B2) of the IUCN Red List (2024). On the other hand, the assessment using the MER method resulted in a score of 0.73 for criterion A (Geographic distribution), 0.11 for criterion B (Habitat features), 0.48 for criterion C (Biological vulnerability), and 0.40 for criterion D (Impact of human activities), corresponding to the Threatened category for a total of 1.72 points (Supplementary material 2).

Discussion

This study provides the first comprehensive assessment of the conservation status of *Dioon vovidesii*, integrating distributional, demographic, ecological, and threat data. The evidence indicates that the species has a restricted geographic range, small and spatially isolated populations, marked habitat specialization, and widespread exposure to anthropogenic threats. Together, these factors place the species at high risk of extinction and support its classification as Endangered following IUCN criterion B and as Threatened following the MER framework.

The estimated extent of occurrence (3,642 km²) and area of occupancy (32 km²) are low relative to many other cycad species and fall within thresholds associated with elevated extinction risk (Carvajal-Hernández et al., 2020; Montalvo-Fernández et al., 2020). The species is known from only 8 confirmed populations, several of which contain fewer than 30 individuals. Small population size increases susceptibility to demographic stochasticity, environmental variability, and localized disturbance events (Lande, 1993; Shaffer, 1981). In addition, the spatial isolation of populations suggests limited connectivity, which may further reduce resilience to disturbance. Although the current number of documented populations is limited, the possibility that additional, undiscovered populations exist cannot be excluded. Nevertheless, given the rugged terrain and prior botanical exploration in the region, the likelihood of numerous large, unrecorded populations appears low. Therefore, the available evidence supports the conclusion that the species has a genuinely restricted distribution.

In Sierra de Mazatán, plants of *D. vovidesii* show clear evidence of habitat specificity as more than 60% of individuals in the 3 populations recruit in rock crevices (Fig. 4). This type of habitat specificity has been documented in other rare or endangered plant species (Laguna et al., 2016; Yates & Ladd, 2004). These microhabitats can be considered as safe sites for seedling recruitment as usually they offer a favorable microclimate with less thermal amplitude than in exposed conditions (García et al., 2020), greater soil nutrients and moisture (Zhao et al., 2023), and likely protection against disturbance. As seedlings

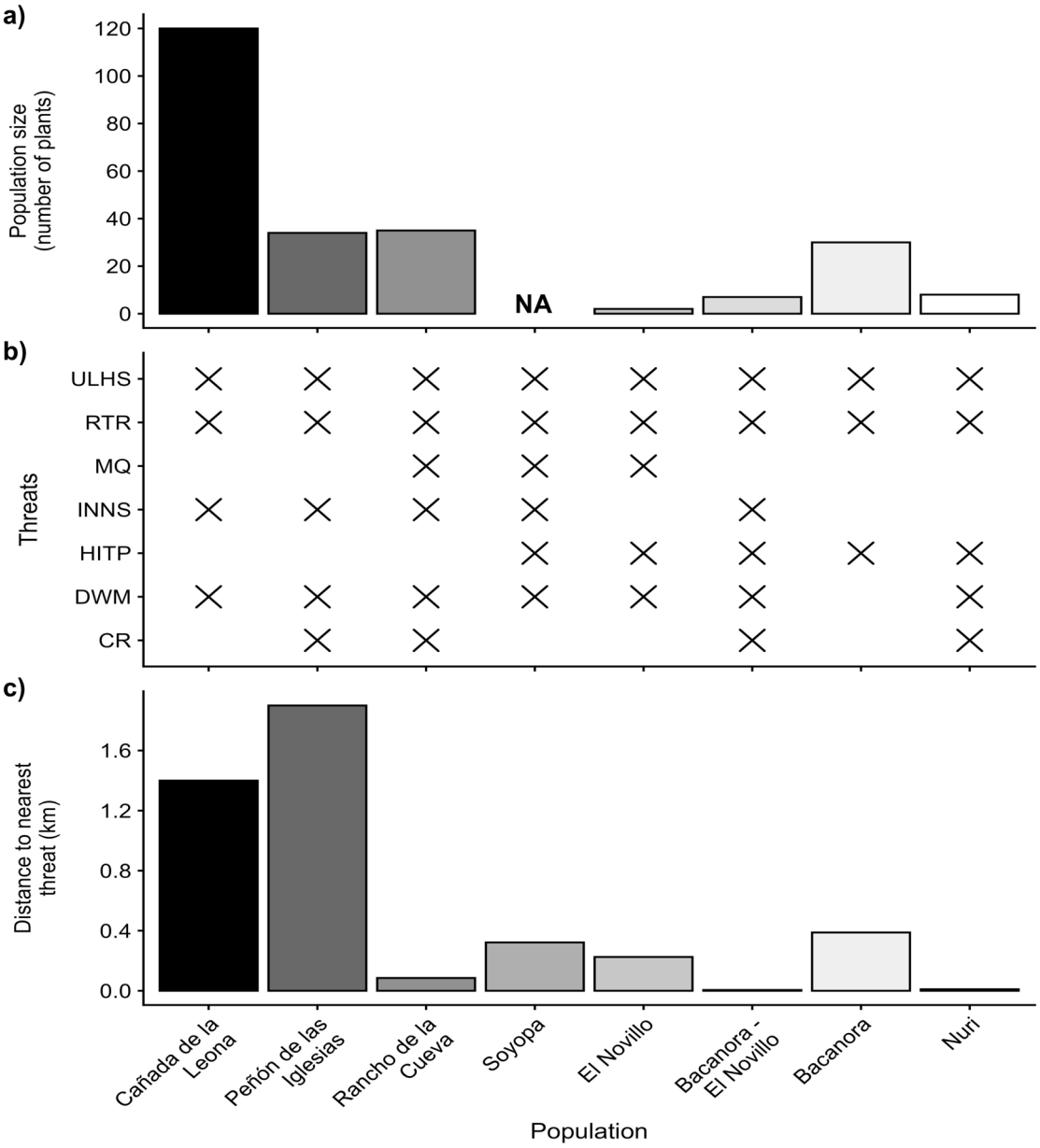


Figure 5. Population size (a), type of threats (b), and distance to the nearest threat (c, km) for each of the 8 known populations of *Dioon vovidesii*. Threat categories follow the IUCN Classification of Direct Threats (Salafsky et al., 2025): use of land and human settlements (ULHS; 1.1); roads, trails, and railroads (RTR; 4.1); mining and quarrying (MQ; 3.2); invasive non-native species (INNS; 8.1); illegal harvesting of terrestrial plants (HITP; 5.2); dams and water management (DWM; 7.2); and crops (CR; 2.1).

of cycad species have greater survival under shade than under the sun (Álvarez-Yépiz et al., 2014), rock crevices may play a crucial role in the regeneration of *D. vovidesii*.

The population size of *D. vovidesii* in Sierra de Mazatán was smaller than previously reported and compared with other cycad species (Gutiérrez-Ortega et al., 2014; Octavio-Aguilar et al., 2017). However, the demographic analysis yielded a finite population growth rate slightly below equilibrium ($\lambda = 0.94$). Although the point estimate suggests a modest population decline, the associated confidence interval (0.89-1.00) includes unity, preventing a clear inference regarding whether the

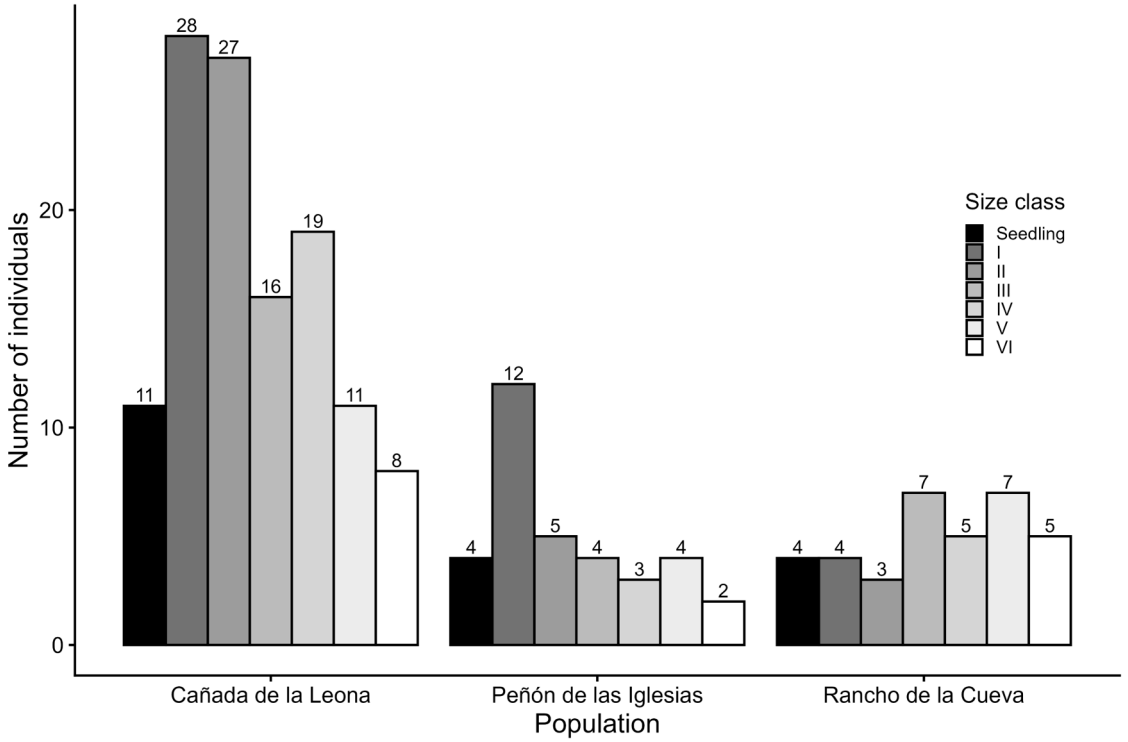


Figure 6. Distribution of size classes among populations of *Dioon vovidesii* in the Sierra de Mazatán. Numbers indicate the number of individuals in each size class. Seedlings were defined as individuals without a stem and with 1 or 2 leaves < 30 cm in length. Size class I included individuals without a stem and with 2 or more leaves > 30 cm. Size classes II-VI were defined based on total stem length (sum of all stems per individual) in 40-cm intervals: 1-40, 41-80, 81-120, 121-160, and > 160 cm.

population is declining or remaining stable. Consequently, the available demographic evidence should be interpreted as indicating near-equilibrium dynamics with substantial uncertainty. Regardless of whether populations are currently stable or slowly declining, high seedling mortality and low effective recruitment (0.005) were observed. The population is primarily composed of individuals in smaller size categories, reflecting a Bongers type III population structure (Bongers et al., 1988; Supplementary material 1). Prioritizing the protection of larger individuals has been suggested in other cycad species (Álvarez-Yépiz et al., 2011; Lázaro-Zermeño et al. 2011) where stasis was the demographic process of greatest influence on the finite growth rate and the category of greatest influence. However, seedling production and protection are essential for ensuring the species' long-term survival (Cabrera-Toledo et al., 2019). These findings should be interpreted with caution due to the uncertainty caused by the fact that we only have 1 year of study, as the population could be declining despite finding a trend to equilibrium in population size (Supplementary material 1, Raimondo & Donaldson, 2003).

All populations of *D. vovidesii* are located within 5 km of some form of human activity. The evidence of nearby human activity is similar to the main threats facing other Mexican cycad species, such as habitat fragmentation and land use changes driven by agricultural and livestock activities (IUCN/SCC Cycad Specialist Group, 2003; Velasco-García et al., 2016). For cycads, low habitat quality, reduced area extent, and smaller population sizes have been related to greater anthropogenic impact in the vicinity of populations (López-Gallego, 2008; Velasco-García et al., 2016). As a result, *D. vovidesii* populations may be highly vulnerable to extinction due to these nearby human activities. Gutiérrez-Ortega et al. (2014) reported declining numbers of individuals in the populations of El Novillo, Bacanora - El Novillo, and Nuri, which they attributed to illegal collection and proximity to human settlements, findings that are consistent with our results (Fig. 5b). On the other hand, although the populations in Sierra de Mazatán are generally farther from human activity compared to those in central Sonora, the process of designating this mountain range as a natural protected area would provide greater protection against

habitat destruction and illegal poaching for *D. vovidesii* populations (Conanp, 2012; Gutiérrez-Ortega et al., 2014). The presence of buffelgrass (*Cenchrus ciliaris*) near several populations is of particular concern. This invasive species alters fire regimes and dynamics in arid and semi-arid ecosystems, potentially increasing mortality and reducing recruitment in native species (Marshall et al., 2012). Given the low effective recruitment already observed in *D. vovidesii*, additional stressors could shift populations from near equilibrium to decline.

In conclusion, *D. vovidesii* combines several traits associated with elevated extinction risk: restricted range, habitat specialization, small and fragmented populations, and ongoing anthropogenic pressure. Although current demographic estimates suggest near-equilibrium dynamics, low effective recruitment and widespread disturbance indicate limited buffering capacity against future environmental or anthropogenic change.

Dioon vovidesii requires systematic and continuous monitoring, along with studies on its life history traits, ecology, and the impact of land use changes to design an effective management and conservation plan. To better understand long-term population trajectories and the role of demographic processes and environmental stochasticity, multi-year monitoring of populations is needed. Such monitoring would allow more robust estimation of population growth rates and determine whether the slight departure from equilibrium observed here reflects a true population decline or short-term demographic variation (Octavio-Aguilar et al., 2017; Raimondo & Donaldson 2003). Additionally, listing *D. vovidesii* as a threatened species at national and international levels could encourage its protection and further study. Systematic and continuous monitoring and collaboration between local communities, government, and academia is essential to ensure the long-term survival of *D. vovidesii*.

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