Criteria to set conservation priorities for natural areas in the Sinaloa region, Mexico

Criterios para establecer áreas prioritarias para la conservación en la región de Sinaloa, México

Francisco Amador-Cruz [a,b]*, Bruno G Bordenave [c,d]

[a] Universidad de Guadalajara, Centro Universitario de la Costa Sur, Departamento de Ecología y Recursos Naturales, Autlán de Navarro, Jalisco, México.

* Corresponding author: [b] FAC Consultoría Ambiental, División de Investigación, México. tel: +52 5539693696, francisco.amador@alumnos.udg.mx

[c] Université de Bretagne Occidentale, Département de Biologie, Brest, France.

[d] BGB Consultance -Tropical Botany, Trégunc, France.

SUMMARY

The study aimed to identify Conservation Priority Sites (CPS) in the southern Sinaloa region, Mexico, using the Determination Index (DET) method. This method utilizes criteria such as Specific Diversity Index, Ratio of Species of Concern, Relative Scarcity Index, and Habitat Fragility Index to assess conservation stakes over wild plant species and habitats. In 2017 eight sampling sites were evaluated, two in mangroves, three in dry forests and three in semi-deciduous forests, each plot/area covers 0.12 hectares. Species-area curves were analyzed to quantify species diversity. A Floristic Originality Index determined the ratio of species of concern. A relative scarcity index was calculated from each type of vegetation surface area. Fragility of habitats was estimated over five levels of resilience. The results identified semi-deciduous forest sites as the highest conservation priorities due to their higher species diversity, number of species of concern, and scarce surface area. The DET method facilitated the ranking of CPS in the study area and is recommended as a valuable tool for landscape planning and conservation efforts.

Keywords: plant diversity, tropical forest, mangroves, ecological value.

RESUMEN

Para identificar los Sitios Prioritarios para la Conservación (CPS), actualmente se dispone de varios modelos, por ejemplo, utilizando sistemas de información geográfica, algoritmos matemáticos o métodos de campo más tradicionales entre los que se destacan el método del Índice de Determinación (DET), el cual utiliza un conjunto de criterios: Índice de Diversidad Específica, Relación de Especies de Preocupación, Índice de Escasez Relativa e Índice de Fragilidad del Hábitat, para evaluar los intereses de conservación sobre las especies de plantas silvestres y los patrones de hábitats. El objetivo de este estudio es establecer CPS en la región sur de Sinaloa, México utilizando el método DET. En 2017 se evaluaron ocho sitios de muestreo, dos en manglares, tres en bosque seco y tres en bosque semicaducifolio, cada uno de 0,12 ha de superficie. Se analizaron curvas de especies-área para cuantificar la diversidad de especies. La proporción de especies de interés se calculó utilizando un índice de originalidad florística. A partir de cada tipo de superficie vegetal se calculó un índice de escasez relativa. La fragilidad de los hábitats se estimó en cinco niveles de resiliencia. El DET evidencia que los sitios con bosque semicaducifolio son las prioritarios para conservación, debido a valores más altos de diversidad de especies, número de especies de interés y escasa superficie. El método DET permitió la clasificación de CPS en el área de estudio, además, se recomienda como una herramienta útil para la planificación del paisaje natural y antrópico y para proponer medidas de conservación.

Palabras clave: diversidad vegetal, bosque tropical, manglares, valor ecológico.

INTRODUCTION

Since 2000, when Mexico was designated as one of the world's megadiverse countries listed as a Biodiversity hotspot for conservation priorities (Myers *et al.* 2000), the country has maintained its recognition as the fifth country with the highest global biodiversity index as of 2022 (Nash 2022). Furthermore, Mexico ranks second among megadiverse countries, meeting more commitments of the Convention on Biological Diversity - Aichi Biodiversity Target 11 (Bacon *et al.* 2019).

Similarly, on a global scale, actions have not yet been sufficient to stop the biodiversity crisis in Mexico (Williams *et al.* 2022). However, several projects of Natural Protected Areas are highly likely to be implemented (Bacon *et al.* 2019). This underscores the importance of methodological tools designed to define Conservation Priority Sites (CPS) to include high ecological value areas within the Natural Protected Areas are essential to address global biodiversity stakes (Verniest *et al.* 2022).

An important application of Conservation Biology science is the establishment of protected areas. Various techniques and methods can be used to characterize patterns of species populations, communities or ecosystems, such as interaction, connectivity, landscapes permeability, or the impacts of global warming on biodiversity (Meine 2010), in order to define CPS.

The local Ecological Footprinting Tool (Long *et al.* 2018), the Determination Index (Bordenave *et al.* 2000), and Key Biodiversity Areas (Verniest *et al.* 2022) are available tools to identify CPS. These methods have been proposed for several taxonomic groups, at different scales, and with several assessment criteria. For instance, researchers may focus on sites with high suitability for birds (Pérez-Arteaga *et al.* 2005), mammals (Frick *et al.* 2019), or plants (Darbyshire *et al.* 2017). Some include the vulnerability associated with globally threatened species as a critical-essential criterion. Nevertheless, the evaluation of species diversity is the only aspect shared among them (Amador-Cruz *et al.* 2021).

In this sense, from the plethora of frameworks to establish CPS, determining the most plausible one is a complex operation. Factors such as potential operators, fieldwork data availability, site accessibility, weather assessment in a terrestrial or marine environment, and existing remote sensing data, should be considered to select the most suitable tools.

The Determination Index model emerges as an interpretive index allowing interpolation from samplings made over remote or extensive areas, where vegetation is characterized through classical methods such as floristic composition, species distribution, rarity, diversity and population structure (Bordenave *et al.* 2011).

The current research aims to identify CPS in various habitats in Mexico by applying a set of distinct criteria, including considerations of biodiversity, endangered species, habitat scarcity, and fragility. The goal is to provide guidance for conservation planning in Mexico.

METHODS

Study area. The Palmito de Verde Region covers an area of 320 km^2 in the southern part of the Sinaloa State (municipalities of Escuinapa and Rosario), Mexico (figure 1A). It is included within the polygons of "Priority Areas for Conservation" established by national institutions such as the National Commission for the Knowledge and Use of Biodiversity (CONABIO) and the National Commission of Protected Natural Areas (CONANP), as well as international organizations like the Ramsar Convention (Ramsar 2001), Hemispheric Network for the Conservation of Shorebirds (RHCAP), among others (Blanco y-Correa Magallanes 2011). However, the Palmito de Verde Region is excluded from the definitive polygons of the Marismas Nacionales Sinaloa Biosphere Reserve (CONANP 2008).

The Palmito de Verde Region is considered an old geological system with functional isolation, which was formed during the Holocene Quaternary Cenozoic era, approximately 7,000 years ago. This region receives a constant supply

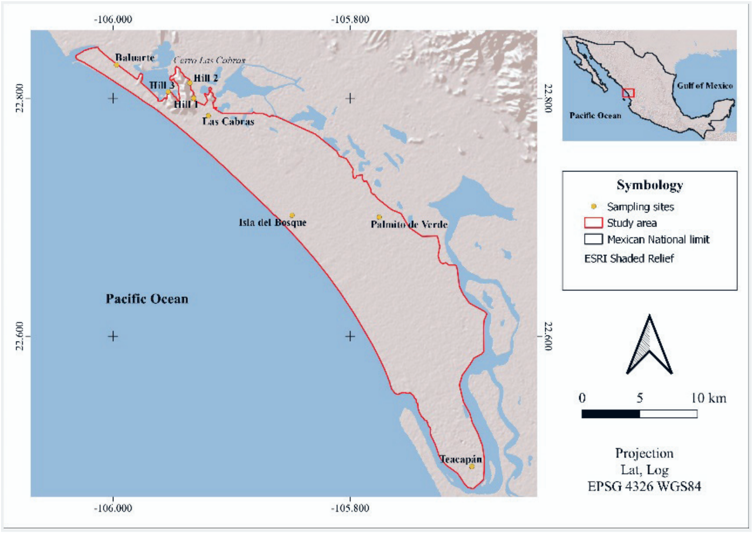

Figure 1. Palmito de Verde Region (red polygon), situated in Sinaloa in western Mexico. Names of sampling sites are mentioned. Background map INEGI (2016).

Región Palmito de Verde (polígono rojo), situada en Sinaloa al occidente de México. Nombre de sitios de muestreo son mencionados. Mapa base de INEGI (2016).

of sediments forming deltas, floodplains, marshes, and lagoons. These processes, along with progradation processes have facilitated the development of a frontal dune plain with strong water infiltration (Scott and Foster 2000). The most prominent elevation in the area is "Cerro las Cabras", which has an igneous origin with rhyolite and basaltic tuff.

The area is characterized by four main soil types (i) Solonchak, (ii) Cambisol, (iii) Phaeozem and (iv) Arenosol / Regosol, the latter one being most common in the Palmito de Verde Region (INEGI 2013; IUSS Working Group WRB 2022). The climate is classified as Awo: tropical with summer rains (Köppen 1918, García 2004).

Currently, more than 80 % of the area is covered with livestock and agriculture,the remaining parts consist of a patchwork of natural and anthropogenic ecosystems. The region harbors over 250 vascular plant species (Amador-Cruz *et al.* 2019). The major types of vegetation include mangrove (6.05 %) (figure 2A), dry forest (2.4 %) (figure 2B), and semi-deciduous forest, which is the scarcest type of vegetation (0.38 %) (figure 2C).

These three types of vegetation in the Palmito de Verde Region can be described as follows:

Mangroves (figure 2A) are the most extensive vegetation found on temporary or permanently inundated soil in the Palmito de Verde Region, characterized by high salts concentration. The influence of human activities on mangroves is limited, primarily associated with aquatic farms. Typical woody species include *Rhizophora mangle* L., often referred to as "Red mangle" and *Laguncularia racemosa* (L.) C.F.Gaertn., known as "White mangle" (Amador-Cruz 2018).

Dry forests (figure 2B) are prevalent in the area around "Cerro las Cabras", located in the northern part of the of Palmito de Verde Region. Human activities, particularly logging, the lower portions of these forests, mainly logging. The dominant tree species include *Lysiloma divaricatum* (Jacq.) J.F.Macbr. and *Albizia occidentalis* Brandegee (Amador-Cruz 2018).

Semi-deciduous forest (figure 2C) are present in several patches across the frontal dune plain. However, these forests are hightly fragmented, and no large patches exist to efficiently enable dispersal. Common woody species found in semi-deciduous forests include *Guazuma ulmifolia* Lam. and *Pithecellobium lanceolatum* (Humb. & Bonpl. *ex* Willd.) Benth. (Amador-Cruz 2018).

Field surveys and study sites. In 2017, eight sampling sites were randomly selected (table 1): two in mangroves, three in the semi-deciduous forest, and the three in dry forest (figure 1A). Each sampling sites covered an area of 0.12 ha (Phillips *et al.* 2003), evaluated using three 400 m^2 rectangles as replicates (CONAFOR 2014).

Botanical records. The data recording was limited to species rooted only inside transects, even if their aerial parts exceeded the area. This process includes all woody lianas with $D_{130} \geq 0.6$ cm (diameter at 1.3 m from the ground), all trees with $D_{130} \geq 0.5$ cm, and all adult shrubs with a diameter measured at mid main axis. Seedlings, juvenile plants and grasses were not sampled. For species with stilt roots, the trunk diameter was measured above.

For each individual plant the following data were recorded:

- Identification to species level; when unknown, an herbarium specimen was taken to be determined in the lab,
- Occurrence (presence of the species in a given transect),
- Density (number of individuals of the species within the transect), and
- Height (m).

Duplicate botanical specimens were collected, dried and conditioned. They were determined at the species levels (Tropicos 2019) and deposited in the Herbarium Jesús

Table 1. Name, type of vegetation and geo-coordinates of the sampling sites.
Nombre, tipo de vegetación y geo-coordenadas de los sitios de muestreo de altura.

Sampling site	Kind of vegetation	Latitude	Longitude
Teacapán	Mangroves	22.587190°	-105.679203°
Baluarte	Mangroves	22.810134°	-105.973429°
Hill 1	Dry forest	22.788340°	-105.931138°
Hill 2	Dry forest	22.792890°	-105.931627°
Hill 3	Dry forest	22.796806°	-105.957214°
Las Cabras	Semi-deciduous forest	22.779090°	-105.911600°
Isla del Bosque	Semi-deciduous forest	22.692866°	-105.845737°
Palmito de Verde	Semi-deciduous forest	22.706310°	-105.802721°

Figure 2. Types of vegetation in Palmito de Verde Region: A) mangroves, B) dry forest, C) semi-deciduous forest.

Tipos de vegetación en Región Palmito de Verde: A) manglares, B) bosque seco, C) bosque semicaducifolio.

González Ortega (UAS), in Culiacán, Sinaloa and the Herbarium of the Centro de Investigación en Alimentación y Desarrollo, A.C. (HCIAD), in Mazatlán, Sinaloa.

Determination index. To determine which sampling sites in the Palmito de Verde Region should be considered as conservation priorities, we have defined a Determination Index based on ecological criteria proposed by Bordenave *et al.* (2011). This index incorporates ecological properties and structural as well as functional features of landscapes, which are essential aspects for defining CPS (Willis *et al.* 2012). However, out of the five criteria in the Determination Index, we have retained only four, as the behavior of the Habitat Heterogeneity Index seems not appear to be suitable for homogeneous vegetations such as mangroves. These criteria were:

- Specific Diversity Index: This index references the species richness calculated from the slope (λ) of the species-area curve using a natural logarithm model [$y = \lambda \ln(x) + \gamma$] with y as the species number, x the surface area and ɣ the intercept (Marcon 2013). The slope (λ) of the species-area curve depicts the SDI value. A relative value (SDIr) was obtained through equation [1].

$$SDI_r = \frac{SDI_{foreachsamplingsite}}{\sum_{i=k}^{n} SDI} x100 \qquad [1]$$

- Ratio of Species of Concern: This criterion refers to species of particular conservation concern, in relation to restricted range endemism, habitat specificity, local population size, and vulnerability. We used the Floristic Originality Index, developed by Rabinowitz (1981) and modified by Amador-Cruz *et al*. (2019) to determine it. This index provides the proportion of conservation priority species. First, we obtained the RSC through equation [2].

$$RSC = \frac{No. species\ in\ the\ Floristic\ Originality\ Index_{for\ each\ sampling\ site}}{No. total\ of\ species\ in\ the\ sampling\ site} \qquad [2]$$

Posteriorly, a relative value (RSC_r) was determined using equation [3].

$$RSC_r = \frac{RSC_{foreachsamplingsite}}{\sum_{i=k}^{n} RSC} x100 \qquad [3]$$

- Relative Scarcity Index: This index had been used for different applications, such as evaluating natural resources (Liang *et al.* 2013) or measuring the water availability. Although there are complex methods as proposed by Barnett and Morse (1963), the index designed by Bordenave *et al.* (2011) uses the relative surface area of each type of vegetation, under the premise that the most restricted habitats determine a priority for conservation.

To determine the scarcity value, the extension of each area of mangrove was based on the proposal made by Blanco y-Correa Magallanes (2011). In the case of dry forest, we determined the size of the "Cerro las Cabras" (figure 1A) and the value was divided in three, since we recorded three sampling sites. For the semi-deciduous forest, we measured the surface area for each sampled patch. The above, using QGIS 3.4.5 Madeira software.

First, we estimated a scarcity value by habitat with the equation [4].

$$\text{Scarcity} = \frac{No.hectares_{associates\ with\ each\ vegetation\ types}}{No.\ hectares\ for\ all\ vegetation\ types} \qquad [4]$$

The inverse of scarcity value depicted our RSI, it was estimated through equation [5].

$$RSI = \frac{1}{Scarcity} \qquad [5]$$

Finally, a relative value (RSIr) was determined with the equation [6].

$$RSI_r = \frac{RSI_{foreachsamplingsite}}{\sum_{i=k}^{n} RSI} x100 \qquad [6]$$

- Habitat Fragility Index: The ability of vegetation to recover after disturbance is referred to as 'resilience' (Holling 2010) and can be quantified through a semiquantitative Habitat fragility index (Bordenave *et al.* 2011). A value from 1 to 5 is hence given to each habitat from the lowest level of fragility to the most fragile one (Bordenave *et al.* 2011): (1) very favourable forest regeneration potential; (2) favourable forest regeneration potential; (3) uncertain forest regeneration potential, significant risks of organic soil erosion; (4) low forest regeneration potential with significant risks of organic soil erosion; (5) very poor forest regeneration potential with obvious risks of soil erosion and desertification.

After assigning the value of fragility each sampling site, the relative value (HFIr) was estimated using the equation [7].

$$HFI_r = \frac{HFI_{foreachsamplingsite}}{\sum_{i=k}^{n} HFI} x100 \qquad [7]$$

- Determination index: The data obtained with each index was relativized, so each one provided a maximum value of 100 %. Subsequently, each relative value per sampling site was divide by 4 (number of criteria) to obtained a maximum overall Determination Index value of 100. The results of the 4 indexes were used for the DET equation [8].

$$DET_{samplingsite} = \frac{SDI_r}{4} + \frac{RSC_r}{4} + \frac{RSI_r}{4} + \frac{IFH_r}{4} \quad [8]$$

RESULTS

The Palmito de Verde Region is an area with complex habitats and several types of vegetation, which were sensitive to the indices used in this research (table 2). Therefore, the Determination Index is a plausible tool to define CPS in this part of Mexico.

In the following section, description of outcomes by criterion are presented.

Specific Diversity Index. The species-area curve for mangroves in "Teacapán" remained constant at a value of 3, as this was the consistent number of species recorded in each replicate (mangroves). In contast, the sampling site "Baluarte" which exhibited semi-deciduous forest, showed an estimated 27 species/ha, with a $R^2 = 0.99$ (figure 3A). For the dry forest, the curves for all three sampling site displayed a similar pattern, with "Hill 1" showing the highest species/ha value, estimated at 63 sp./ha, with $R^2 = 0.99$ (figure 3B). Lastly, although all sampling sites with semi-deciduous forest showed an $R^2 > 0.96$, "El Paraiso" had an estimated 74 species/ha, while extrapolation to 1 ha for "Las Cabras" was only 29 species/ha (figure 3C).

Using λ from the species-area curves, the Specific Diversity Index values were defined for each sampling site. The highest relative Specific Diversity Index value was observed in the sampling site "Isla del Bosque", with a relative value of 23.06 %. Conversely, the lowest relative Specific Diversity Index relative was found at the sampling site of "Teacapán" (0.46 %), representing mangrove vegetation (table 2).

Ratio of species of concern. The Ratio of Species of Concern results are shown in table 2.

Twenty-seven species were identified as conservation priorities, and their Floristic Originality Index was estimated (appendix 1). The sampling site "Isla del Bosque" exhibited a notable number (12) of species with a significant Floristic Originality Index values; resulting in the highest Ratio of Species of Concern relative value. Among these species, *Sideroxylon persimile* subsp. *subsessiliflorum* (Hemsl.) T. D. Penn. stands out due to its small local populations and threatened status (*sensu* NOM-059-SEMARNAT-2010); although it has a broad geographical range, its habitat specificity is narrow ("eco-endemic"). Similarly, the Dry forest exhibited a significant number of species with high Floristic Originality Index values, with *A. occidentalis* being the most prominent, which displays the highest Floristic Originality Index value. *A. occidentalis* is considered a restricted range endemic and threatened species (*sensu* NOM-059-SEMARNAT-2010), with very limited local populations. Lastly, the "Teacapán" sampling site lacked species with high Floristic Originality Index values.

Relative Scarcity Index. The Palmito de Verde Region spans 320 km^2 nevertheless the majority of this area is utilized for human activities (livestock, agriculture or human settlements). Only 8.8 % (28.28 km^2) of the region maintain natural habitats. Among these natural habitats, mangroves dominate, comprising the largest proportion. Consequently, mangroves exhibit the lowest Relative Scarcity

Table 2. Outcomes of the criteria to set conservation priorities. sp. – species, sp./ha – species for hectare, SDI – Specific Diversity Index, FOI sp.– number of species in Floristic Originality Index, RSC – Ratio of Species of Concern, RSI – Relative Scarcity Index, HFI – Habitat Fragility Index. Letter "r" after each index represents the relative value.

Resultados de los criterios para establecer prioridades de conservación. sp. – especies, sp./ha – especies por hectárea, SDI – Índice de Diversidad Específica, FOI sp.– número de especies en el Índice de Originalidad Florística, RSC – Relación de Especies de Preocupación, RSI – Índice de Escasez Relativa, HFI – Índice de Fragilidad del Hábitat. La letra "r" después de cada índice representa el valor relativo.

Sampling site	sp.	sp./ha	SDI	SDIr (%)	FOI sp.	RSC (%)	RSCr	Surface (ha)	Relative area (%)	RSI	RSIr (%)	HFI	HFIr (%)
Teacapán	3	3	0.35	**0.46**	0	0	**0.00**	1,598.5	38.5	1.77	**0.57**	2	**9.09**
Baluarte	13	27	6.82	**8.20**	1	7.69	**4.88**	340.4	11.8	8.31	**2.67**	2	**9.09**
Hill 1	33	63	14.39	**18.86**	8	24.24	**15.39**	256.33	8.8	11.03	**3.55**	4	**18.18**
Hill 2	21	39	8.68	**11.37**	7	33.33	**21.17**	256.33	8.8	11.03	**3.55**	4	**18.18**
Hill 3	33	56	11.19	**14.66**	7	21.21	**13.47**	256.33	8.8	11.03	**3.55**	4	**18.18**
Las Cabras	21	29	4.36	**5.71**	3	14.29	**9.07**	18.11	1	156.18	**50.24**	2	**9.09**
Isla del Bosque	34	73	17.65	**23.06**	12	35.29	**22.41**	46.3	2	61.09	**19.65**	2	**9.09**
Palmito de Verde	28	56	13.48	**17.66**	6	21.43	**13.61**	56.1	2	50.42	**16.22**	2	**9.09**

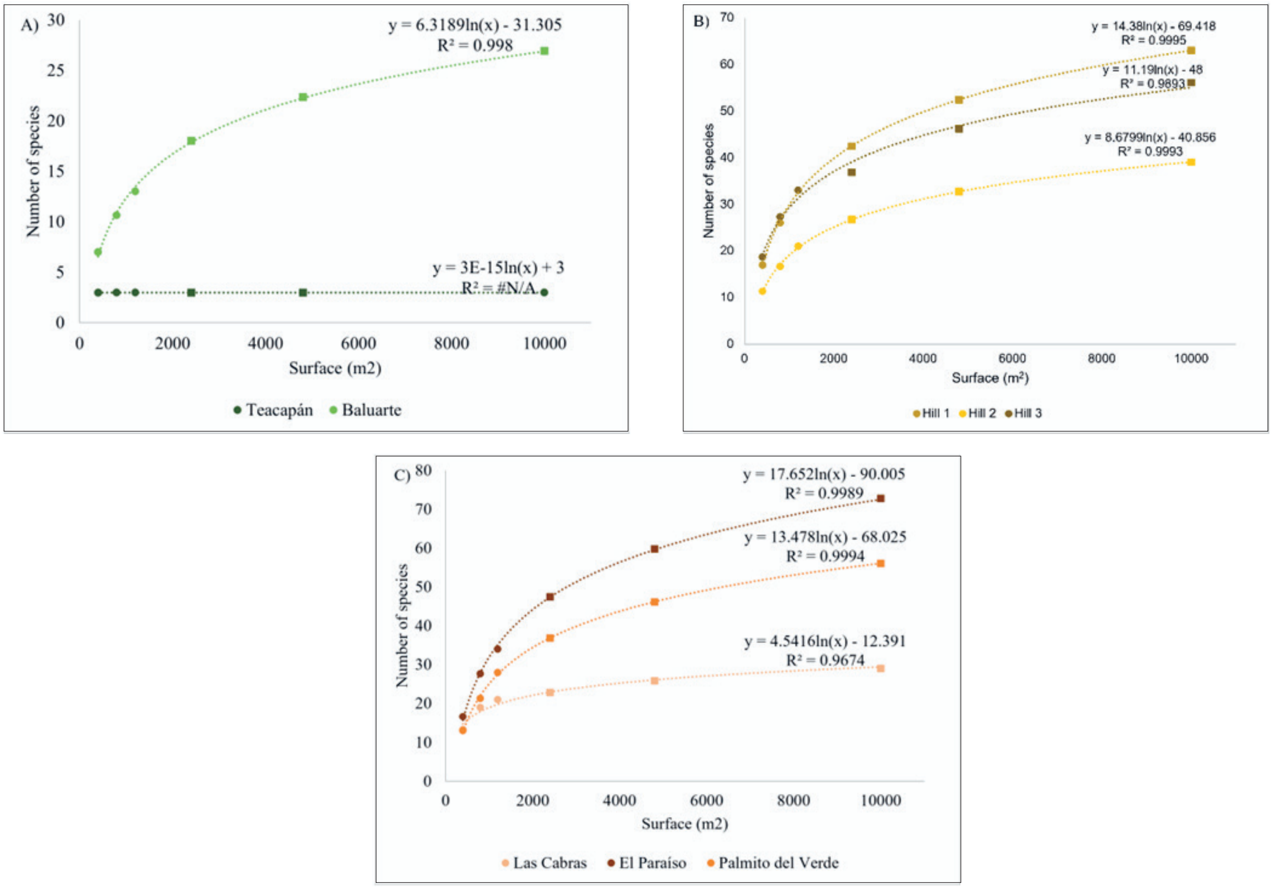

Figure 3. Species-area curves. Figures: circles-sampling surface, square- extrapolation. A) mangroves, B) dry forest, C) semi-deciduous forest.

Curvas especie-área. Figuras: círculos-superficie de muestreo, cuadrados-extrapolación. A) manglares, B) bosque seco, C) bosque semicaducifolio.

Index values across both sampling sites, followed by the three dry forest sites. Conversely, the semi-deciduous forest, particularly the sampling site "Las Cabras", demostrates the highest Relative Scarcity Index value (50.24 %). Despite the combined surface area of the three semi-deciduous forest sampling sites being close to 1.2 km^2 they remain scarce in comparison (table 2).

Habitat Fragility Index. Due to their location in flatland areas where slope increases the risk of topsoil erosion,) the mangroves and semi-deciduous forest sampling sites possess relatively favorable forest regeneration potential without anthropic interventions. Consequently, these sampling sites obtained a low Habitat Fragility Index relative value (9.09 %). Conversely, the dry forest replicates sampling sites exhibit steep declivities of up to 45°, indicating high risks of topsoil erosion and low forest regeneration potential (table 2).

Determination index. Based on the calculated Determination Index values, both the "Isla del Bosque" and "Las Cabras" sampling sites exhibited the same and highest values at 18.5 % (figure 4A). Despite the former displaying much higher species richness and a greater number of species of concern, the latter represents a restricted and isolated area (figure 4B). Therefore, both sites can be considered as first rank CPS. The "Palmito de Verde" sampling site displayed Determination Index values (14,2 %) quite similar to those of "Hill 1" (14 %), "Hill 2" (13.6 %) and "Hill 3" (12.5 %), with the former being scarcer than the dry forest sampling sites, while the three dry forest sites are considered as most fragile (figure 4B). They can be considered as CPS ranked after the natural semi-deciduous forest vegetation. Finally, the lowest Determination Index values for this study were found in both mangroves sampling sites (figure 4A), and therefore, these can be considered as third-rank CPS with the current method.

DISCUSSION

Determination Index in the general context. Even though numerous useful tools are available to determine CPS at region scale, those targeting specific vegetation types are scarce due to the lack of accessible data in consistent formats for decision-making (Darbyshire *et al*. 2017). Furthermore, establishing the most plausible assessment criteria is a challenge. This explains why a single tool can hardly elucidate the complexity of the landscape to identify sites with higher conservation priority. To address this gap, we develop a multi-criteria Determination Index, which incorporates both ecological properties of the plant population - such as species diversity and ratio of vulnerable species - and functional features - such as relative scarcity and habitat fragility. Therefore, the Determination Index serves as a tool based on the intrinsic values of the ecosystem (Cordell *et al*. 2005) that can be applied to both anthropized and natural environments (Willis *et al*. 2012). Moreover, this recording criteriadata offers a cost-effective and convenient means of monitoring and provides reliable ecological information.

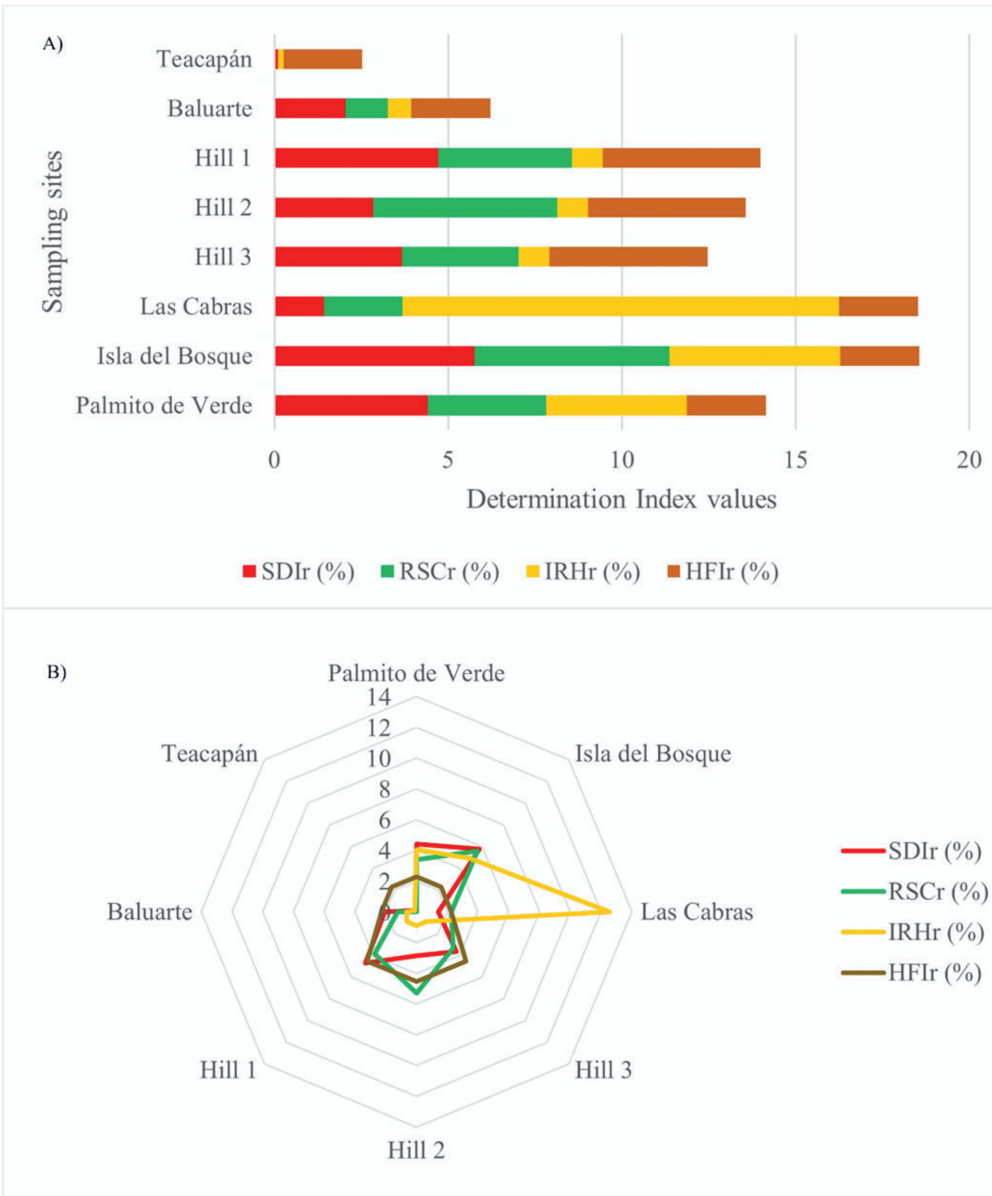

Figure 4. A) Determination Index for Palmito de Verde Region. B) Distinctive index values contribute to each sampling site's overall Determination Index value. SDIr – Relative Specific Diversity Index; RSCr – Relative Ratio of Species of Concern; RSIr – Relative Scarcity Index; HFIr – Relative Habitat Fragility Index.

A) Índice de Determinación para la Región Palmito de Verde. B) Contribución de los valores de índice de criterios al valor del índice de determinación general en cada sitio de muestreo. SDIr – Índice de Diversidad Específica Relativa; RSCr: proporción relativa de especies de interés; RSIr – Índice de Escasez Relativa; HFIr – Índice de Fragilidad Relativa del Hábitat.

Determination Index in the context of Palmito de Verde Region. In the state of Sinaloa, particularly in the Palmito de Verde Region, among all types of vegetation, semi-deciduous forest is deemed the most diverse according to Mexico's National Forest Committee (CONAFOR 2014). However, aside from the species richness, no other evidence was provided regarding its diversity. In this research, we found that semi-deciduous forest not only have the highest woody plant diversity value (Specific Diversity Index relative), but also high proportion of species of significant conservation value (Ratio of Species of Concern relative), limited surface area (Relative Scarcity Index) mainly due to land use, and noticeable soil fragility (Habitat Fragility Index relative), contributing to its classification as the natural vegetation type that need priority protection at region scale.

Dry forest vegetation is more widely distributed in Sinaloa State (Prieto-Torres *et al*. 2015), but is nevertheless restricted to the northern portion of the Palmito de Verde Region, characterized by isolated mountain ecosystems. This mountainous terrain, combined with the presence of fragile soils in the absence of vegetation cover (INEGI 2013), can compromise natural forest regeneration and increase the risk of topsoil erosion. Lastly, the variation observed in Specific Diversity Index relative and Ratio of Species of Concern relative between the sampling sites indicates that this vegetation type is highly heterogenous, even among nearby areas (CONAFOR 2014).

Regarding mangroves, we recorded the three mangle species that dominate the brackish wetland in Mexico: R. mangle, L. racemosa and Avicennia germinans (L) Stearn. The abundance of each species depends to a great extent on the hydroperiod. In the case of the "Teacapán" site, this environmental variable presents ideal conditions for the presence of all three species, as it is flooded year-round, favouring mangroves succession (Monroy-Torres *et al*. 2015). Conversely, the Determination Index value observed in the "Baluarte" site can be linked to a six-month flood period (Blanco y-Correa Magallanes 2011), allowing semi-deciduous forest species to establish in the mangroves system, explaining the increase in Specific Diversity Index relative and Ratio of Species of Concern relative values.

Implications. The progress in the knowledge of local plant species and the development of ecological restoration project should enable feedback and update to the Ratio of Species of Concern relative and Relative Scarcity Index matrix, refining the Determination Index values. For example, a project aimed at restoring semi-deciduous forest could increase its surface area, leading to a decrease in Relative Scarcity Index value. Additionally, some species may be added or removed from the threatened species list, resulting in a change in the Ratio of Species of Concern relative. In this sense, the Determination Index can be used for long-term ecological assessment and monitoring, similar to others tools used to define CPS, such as the Local Ecological Footprinting Tool (Long *et al.* 2018).

Although the Determination Index can prioritize conservation priorities between types of vegetation or sampling sites, it only considers few available criteria to define these CPS. For instance, if additional criteria associated with ecosystem services were included, the "conservation priority values" for mangroves could increase. Tools such as NaturEtrade have been proposed for this purpose, but currently only use remote sensing data (Willis 2018). In that sense, the Determination Index can evolve and be adapted to aid decision-making regarding particular environmental feature.

Lastly, considering the efficiency of this tool, it can provide additional and relevant ecological information to establish Natural Protected Areas. For instance, the current polygon of the, "Marismas Nacionales Sinaloa Biosphere Reserve" (CONANP 2008) excludes part of the semi-deciduous forest surface. However, if Determination Index is included as land conservation planning tool, the functional connectivity between Marismas Nacionales Nayarit and Marismas Nacionales Sinaloa could be established not only through its mangrove vegetation, but also with most diverse and susceptible type of vegetation, especially semi-deciduous forests.

CONCLUSIONS

The ecological criteria used in this study (Specific Diversity Index, Ratio of Species of Concern, Relative Scarcity Index, Habitat Fragility Index) enabled the determination of conservation priorities among sampling sites in the Southern Sinaloa, Mexico. Specifically, in the Palmito de Verde Region, the results highlight the sampling sites associated to the semi-deciduous forest as conservation priorities, as they exhibit the highest Determination Index value. The application of this methodology could be encouraged in other regions of Mexico. Further studies could consider a broader range of habitats, such as mesic forest and xeric vegetation.

Additionally, this practical index can be implemented in ecosystem characterization within the context of environmental impact assessments.

ACKNOWLEDGMENTS

The first author wishes to express his gratitude to the Master's degree program team at the Autonomous University of Sinaloa's, as well as to team of UNAM-FONATUR's Program of Integral Management of Vegetation. He also wants to thank cordially D.E. Serrano-Hernández, D. Benítez-Pardo, M.J. Ochoa-Izaguirre, M.L. Rico-Arce, Stephanie and A.L. Torres-Díaz for their valuable comments.

AUTHORS CONTRIBUTIONS

FAC and BB conceived the idea. FAC prepared the first draft. FAC and BB reviewed and wrote the manuscript.

FUNDING

This study was supported by the Consejo Nacional de Ciencia y Tecnología CONACyT (769304), by the PROgrama de Fomento y Apoyo a Proyectos de Investigación of Universidad Autónoma de Sinaloa (PROFAPI2015/039), by Azteca Lighting, by FAC Consultoría Ambiental and by the Tultepec municipality, State of Mexico.

REFERENCES

Amador-Cruz F. 2018. Composición florística y estructura de la vegetación del sur de Sinaloa, con fines de manejo y conservación. Master in Science Thesis. Sinaloa, Mexico. Sea Science Faculty, Universidad de Sinaloa. 211 p.

Amador-Cruz F, BG Bordenave, D Benítez-Pardo. 2019. Applying a floristic originality index in tropical forests of south Sinaloa, Mexico. *Neotropical biology and conservation* 14(4): 539-557. DOI: https://doi.org/10.3897/neotropical.14.e49166

Amador-Cruz F, BL Figueroa-Rangel, M Olvera-Vargas, ME Mendoza. 2021. A systematic review on the definition, criteria, indicators, methods and applications behind the Ecological Value term. *Ecological Indicators* 129: 107856. DOI: https://doi.org/10.1016/j.ecolind.2021.107856

Bacon E, P Gannon, S Stephen, E Seyoum-Edjigu, M Schmidt, B Lang, T Sandwith, J Xin, S Arora, KN Adham, AJ Rhodes-Espinoza, M Qwathekana, AP Leite-Prates, A Shestakov, D Cooper, J Ervin, BF de Souza-Dias, B Leles, M Attallah, J Mulongoy, SB Gidda. 2019. Aichi biodiversity target 11 in the like-minded megadiverse countries. *Journal for Nature Conservation* 51: 125723. DOI: https://doi.org/10.1016/j.jnc.2019.125723

Barnett HJ, C Morse. 1963. Scarcity and growth: the economics of natural resource availability. Baltimore, U.S.A. Johns Hopkins University Press. 309 p.

Blanco y Correa JM. 2011. Diagnóstico funcional de Marismas Nacionales. Guadalajara, Mexico. Universidad Autónoma de Nayarit-Comisión Nacional Forestal. 74 p.

Bordenave BG, N Raes, JJ De Granville. 2000. Etat initial de la végétation forestière de la Montagne de Kaw 2. Cayenne, French Guiana. IRD Rapport de Mission ASARCO.

Bordenave BG, JJ De Granville, K Steyn. 2011. Quantitative botanical diversity descriptors to set conservation priorities in Bakhuis Mountains rainforest, Suriname. *Botanical Journal of the Linnean Society* 167(1): 94-130. DOI: https://doi.org/10.1111/j.1095-8339.2011.01163.x

CONAFOR (Comisión Nacional Forestal, MX). 2014. Inventario Estatal Forestal y de Suelo-Sinaloa 2013-2014. Mexico City, Mexico. Comisión Nacional Forestal-Secretaría de Medio Ambiente y Recursos Naturales. 190 p.

CONANP (Comisión Nacional Forestal, MX). 2008. Estudio previo justificativo para el establecimiento del Área Natural Protegida "Reserva de la Biósfera Marismas Nacionales Sinaloa". Comisión Nacional de Áreas Naturales Protegidas. Accessed 13 dec. 2021. Available in http://www.cofemersimir.gob.mx/expediente/17892/mir/38241/anexo/1319275

Cordell HK, D Murphy, KH Riitters, JE Harvard. 2005. The natural ecological value of wilderness. *In* Cordell HK, JC Bergstrom, JM Bowker eds. The natural ecological value of wilderness. Alberta, Canada. Venture Publishing Inc. p. 205-249.

Darbyshire I, S Anderson, A Asatryan, A Byfield, M Cheek, C Clubbe, Z Ghrabi, T Harris, CD Heatubun, J Kalema, S Magassouba, B McCarthy, W Milliken, B de Montmollin, EN Lughadha, JM Onana, D Saïdou, A Sârbu, K Shrestha, EA Radford. 2017. Important plant areas: revised selection criteria for a global approach to plant conservation. *Biodiversity and Conservation* 26: 1767-1800. DOI: https://doi.org/10.1007/s10531-017-1336-6

Frick WF, T Kingston, J Flanders. 2019. A review of the major threats and challenges to global bat conservation. *Annals of the New York Academy of Sciences* 1469: 5-25. DOI: https://doi.org/10.1111/nyas.14045

García E. 2004. Modificaciones al sistema de clasificación climática de Köppen. Mexico City, Mexico. Instituto de Geografía-Universidad Nacional Autónoma de México. 98 p.

Holling CS. 2010. Resilience and stability of ecological systems. *In* Gunderson LH, CR Allen, CS Holling eds. Foundations of ecological resilience. Washington, DC, U.S.A. Island Press. p. 19-50.

INEGI (Instituto Nacional de Estadística y Geografía, MX). 2013. Conjunto de datos vectoriales edafológico, escala 1:250000, Serie II. Instituto Nacional de Estadística y Geografía. Accessed 21 dec. 2021. Available in http://www.conabio.gob.mx/informacion/gis/

INEGI (Instituto Nacional de Estadística y Geografía, MX). 2016. División política estatal, escala 1:250000. Instituto Nacional de Estadística y Geografía. Accessed 21 dec. 2021. Available in http://www.conabio.gob.mx/informacion/gis/

IUSS Working Group WRB. 2022. World Reference Base for Soil Resources. Accessed 02 oct. 2023. Available in https://wrb.isric.org/files/WRB_fourth_edition_2022-12-18.pdf

Köppen W. 1918. Klassifikation der Klimate nach Temperatur, Niederschlag und Jahresablauf. *Petermanns Geographische Mitteilungen* 64: 193-203.

Liang J, H Wang, T Song. 2013. Resource bottlenecks and environment constraints in green development. *In* Li X, J. Pan eds. China Green Development Index Report 2011. Beijing, China. Beijing Normal University Press-Springer. p. 169-187.

Long PR, D Benz, AC Martin, PW Holland, M Macias-Fauria, AWR Seddon, R Hagemann, TK Frost, A Simpson, DJ Power, MA Slaymaker, KJ Willis. 2018. LEFT—a web-based tool for the remote measurement and estimation of ecological value across global landscapes. *Methods in Ecology and Evolution* 9: 571-579. DOI: https://doi.org/10.1111/2041-210X.12924

Marcon E. 2013. Mesures de la biodiversité. Paris, France. Centre de Coopération Internationale en Recherche Agronomique pour le Développement. 275 p.

Meine C. 2010. Conservation biology: past and present. *In* Sodhi NS, PR Ehrlich eds. Conservation biology for all. Oxford, U.K. Oxford University Press. p. 7-22.

Monroy-Torres M, F Flores-Verdugo, F Flores-de-Santiago. 2015. Growth of three subtropical mangrove species in response to varying hydroperiod in an experimental tank. *Ciencias Marinas* 40(4): 263-275. DOI: https://doi.org/10.7773/cm.v40i4.2455

Myers N, RA Mittermeier, CG Mittermeier, GAB da Fonseca, J Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* 403: 853-858. DOI: https://doi.org/10.1038/35002501

Nash MH 2022. The 201 Most (& Least) Biodiverse Countries in 2022. The Swiftest. Accessed 21 nov. 2022. Available in https://theswiftest.com/biodiversity-index/

Pérez-Arteaga A, SF Jackson, E Carrera, KJ Gaston. 2005. Priority sites for wildfowl conservation in Mexico. *Animal Conservation* 8: 41-50. DOI: https://doi.org/10.1017/S1367943004001817

Phillips OL, R Vásquez Martínez, P Nuñez-Vargas, A Lorenzo-Monteagudo, ME Chuspe-Zans, W Galiano-Sánchez, A Peña-Cruz, M Timaná, M Yli-Halla, S Rose. 2003. Efficient plot-based floristic assessment of tropical forests. *Journal of Tropical Ecology* 19(6): 629-645. DOI: https://doi.org/10.1017/s0266467403006035

Prieto-Torres DA, AG Navarro-Sigüenza, D Santiago-Alarcon, OR Rojas-Soto. 2015. Response of the endangered tropical dry forests to climate change and the role of Mexican Protected Areas for their conservation. *Global Change Biology* 22: 364-379. DOI: https://doi.org/10.1111/gcb.13090

Rabinowitz D. 1981. Seven forms of rarity. *In* Synge H. ed. The biological aspects of rare plant conservation. Chichester, U.K. John Wiley. p. 205-217.

Ramsar. 2001. Ficha Informativa de los Humedales de Ramsar. Ramsar. Accessed 21 nov. 2022. Available in https://www.ramsar.org/es/recursos/fichas-informativas-de-ramsar

Scott SD, MS Foster. 2000. The prehistory of Mexico's northwest coast. A view from the Marismas Nacionales of Sinaloa and Nayarit. *In* Gorenstein S ed. Greater Mesoamerica: The archaeology of west and northwest Mexico. Salt Lake City, U.S.A. University of Utah Press. p. 107-135.

Tropicos. 2019. Tropicos. Missouri Botanical Garden. Accessed 21 nov. 2022. Available in http://www.tropicos.org/

Verniest F, T Galewski, R Julliard, A Guelmami, I Le Viol. 2022. Coupling future climate and land-use projections reveals where to strengthen the protection of Mediterranean Key Biodiversity Areas. *Conservation Science and Practice* 4(11): e12807. DOI: https://doi.org/10.1111/csp2.12807

Williams DR, C Rondinini, D Tilman. 2022. Global protected areas seem insufficient to safeguard half of the world's mammals from human-induced extinction. *Proceedings of the National Academy of Sciences* 119(24): e2200118119. DOI: https://doi.org/10.1073/pnas.2200118119

Willis KJ, ES Jeffers, C Tovar, PR Long, N Caithness, MGD Smit, R Hagemann, C Collin-Hansen, J Weissenberger. 2012. Determining the ecological value of landscapes beyond protected areas. *Biological Conservation* 147: 3-12. DOI: https://doi.org/10.1016/j.biocon.2011.11.001

Willis KJ. 2018. NaturEtrade: creating a marketplace for ecosystem services. Accessed 21 dec. 2022. Available in https://webgate.ec.europa.eu/life/publicWebsite/index.cfm?fuseaction=search.dspPage&n_proj_id=4753

Recibido: 16.07.23
Aceptado: 11.11.23

Appendix 1. Priority species for conservation with an estimated Floristic Originality Index (**FOI**) value and sampling sites where were present (with an "X" mark). **TN** – Teacapán, **BA** – Baluarte, **H1** – Hill 1, **H2** – Hill 2, **H3** – Hill 3, **LC** – Las Cabras, **IB** – Isla del Bosque, **PV** – Palmito de Verde.

Specie	FOI	TN	BA	H1	H2	H3	LC	IB	PV
Albizia occidentalis Britton & Rose	128			X	X	X			
Attalea guacuyule (Liebm. *ex* Mart.) Zona	128						X		
Sideroxylon persimile subsp. *subsessiliflorum* (Hemsl.) T. D. Penn.	64			X				X	
Acanthocereus occidentalis Britton & Rose	8							X	X
Pilosocereus purpusii (Britton & Rose) Byles & G. D. Rowley	8				X				
Stenocereus alamosensis alamosensis (J. M. Coult.) A. C. Gibson & K. E. Horak	8			X					
Diospyros sphaerantha Standl.	8							X	
Enriquebeltrania disjuncta De-Nova & V. Sosa	8							X	
Jatropha sympetala S. F. Blake & Standl.	8							X	
Lonchocarpus mutans M. Sousa	7			X		X			
Annona glabra L.	6		X						
Agonandra racemosa (DC.) Standl.	6							X	
Bursera simaruba (L.) Sarg.	5			X	X	X		X	X
Bursera palmeri S. Watson	5					X			
Rourea glabra Kunth	5					X		X	X
Diospyros salicifolia Humb. & Bonpl. *ex* Willd.	5							X	
Erythroxylum havanense Jacq.	5							X	
Enterolobium cyclocarpum (Jacq.) Griseb.	5								X
Senna fruticosa (Mill.) H.S. Irwin & Barneby	5						X		
Ceiba aesculifolia (Kunth) Britten & Baker f.	5					X			
Ficus padifolia Kunth	5							X	X
Ficus petiolaris Kunth subsp. *petiolaris*	5				X				
Exostema mexicanum A. Gray	5			X	X				
Zanthoxylum caribaeum Lam.	5							X	
Zanthoxylum fagara (L.) Sarg.	5			X					X
Cupania dentata DC.	5				X				
Thouinidium decandrum (Bonpl.) Radlk.	5			X	X	X	X		
Total		**0**	**1**	**6**	**8**	**7**			**3**