Revista Mexicana de Ciencias Forestales Vol. 17 (95)
Mayo - Junio (2026)

DOI: 10.29298/rmcf.v17i95.1621

Research article

Current status and threats of the endemic conifers in the *Sierra Madre Occidental* range, Mexico

Situación actual y amenaza de las coníferas endémicas de la Sierra Madre Occidental, México

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Fecha de recepción/Reception date: 3 de diciembre de 2025.
Fecha de aceptación/Acceptance date: 24 de marzo de 2026.

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Resumen

El problema de la pérdida de especies se ha posicionado como uno de los principales desafíos de la conservación de la biodiversidad. Este trabajo evalúa el nivel de riesgo al que se enfrentan 13 taxones de coníferas endémicas de la Sierra Madre Occidental (SMO), México. Se utilizaron tanto los criterios de la Lista Roja de la UICN como el Método de Evaluación del Riesgo de Extinción (MERE) de la NOM-059-SEMARNAT-2010. Además, se identificaron zonas prioritarias de conservación por medio de la superposición de las distribuciones de cada taxón y un análisis de complementariedad. Los resultados revelaron que hay al menos dos zonas de prioridad extrema que albergan una alta riqueza de coníferas endémicas, varias de las cuales enfrentan amenazas y no están consideradas en la legislación vigente. Se sugiere que varios taxones sean añadidos o reclasificados en categorías de mayor riesgo, como *Juniperus blancoi* var. *huehuentensis* y *Abies neodurangensis* a "En Peligro", destacando su fragilidad ante distintas amenazas. Aunque el manejo forestal sostenible ha contribuido para mantener la estabilidad de algunas especies comerciales como *Pinus cooperi*, la mayoría son altamente vulnerables a los efectos del cambio climático. Es fundamental ampliar el conocimiento existente sobre las especies por medio de estudios de sistemática, inventarios dasométricos, análisis genéticos y modelación climática. Es esencial que los actores sociales que manejan el bosque conozcan con precisión las especies que hay, con el fin de fomentar una cultura de conservación que priorice la gran diversidad de las coníferas endémicas de la SMO.

Palabras clave: *Abies*, conservación, *Juniperus*, Lista Roja UICN, NOM-059-SEMARNAT-2010, riesgo.

Abstract

The issue of species loss has emerged as one of the main challenges facing biodiversity conservation. This study evaluates the level of risk faced by 13 taxa of conifers native to the *Sierra Madre Occidental* (*SMO* for its acronym in Spanish), Mexico. Both the IUCN Red List criteria and the Extinction Risk Assessment Method (*MERE* for its acronym in Spanish) specified in NOM-059-SEMARNAT-2010 were used. In addition, priority conservation areas were identified by overlaying the distributions of each taxon and conducting a complementarity analysis. The results revealed that there are at least two areas of extreme priority that are home to a large diversity of endemic conifers, several of which face threats and are not covered by the current legislation. It is suggested that several taxa be added to or reclassified into higher-risk categories —*e. g.*, *Juniperus blancoi* var. *huehuentensis* and *Abies neodurangensis* to "At Risk"—, to highlight their vulnerability to various threats. Although sustainable forest management has helped maintain the stability of some commercial species, such as *Pinus cooperi*, most are highly vulnerable to the effects of climate change. It is essential to expand our current knowledge of species through systematic studies, dasometric surveys, genetic analyses, and climate modeling. An accurate understanding of these species by the stakeholders managing the forest is essential in order to promote a culture of conservation that prioritizes the rich diversity of conifers endemic to the *SMO*.

Keywords: *Abies*, conservation, *Juniperus*, IUCN Red List, NOM-059-SEMARNAT-2010, risk

Introduction

The global biodiversity crisis is evidenced by a rapid decline of species and the resulting deterioration of ecosystem services that are essential to the well-being of present and future generations (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES], 2019; Koleff & Urquiza-Hass, 2011). Among the many factors contributing to this situation are the ongoing loss of natural habitat, the unsustainable use of natural resources, the intensification of droughts linked to climate change, the increased vulnerability to pests and diseases, and the proliferation of invasive species (Pfenning-Butterworth et al., 2024).

Assessment and legal protection of endangered species are essential for biodiversity conservation. Classifying species based on their risk of extinction is a fundamental tool for taking better-informed decisions and developing effective conservation strategies to prioritize resource allocation toward the species at greatest risk (Cossios & Maffei, 2021). The conservation status of species serves as a key indicator of ecosystem health and as a basis for developing conservation policies (Pérez-Sarabia et al., 2020).

Globally, the Red List of Threatened Species of the International Union for Conservation of Nature (IUCN) is the leading authority on assessing the risk of extinction; it incorporates rigorous scientific criteria that have been adopted in international policies such as the Convention on Biological Diversity and the United Nations Sustainable Development Goals (Butchart et al., 2025; De Grammont & Cuarón, 2006). In Mexico, the Official Mexican Standard NOM-059-SEMARNAT-2010 is used to address similar situations; this standard employs the Extinction Risk Assessment Method (*MERE* by its Spanish acronym) (Secretaría de Medio Ambiente y Recursos Naturales [Semarnat], 2010, 2019).

Furthermore, consistency between the categories used in national lists and the IUCN Red List is essential, as unsubstantiated discrepancies could indicate the need for a reassessment in order to implement conservation measures (Brito et al., 2010; Esperon-Rodriguez et al., 2024). Despite the existence of these regulations, there are numerous taxa that have not yet been assessed under any conservation plan, suggesting that some of them may be at risk without this being recognized (Pimm et al., 2014). Endemic species should be a priority, as any threat within their limited range can have devastating consequences for their entire population (Myers, 1990).

It should be noted that, compared to other groups of organisms, plants have received less attention from a conservation perspective, which constitutes a neglect of their important ecological role (Caldwell et al., 2024). Within this trend, conifers stand out as a group that is particularly vulnerable to climate change; therefore, they face a high risk of extinction worldwide (Allen et al., 2010; Farjon & Page, 1999; Farjon et al., 2006; McDowell et al., 2016). This vulnerability stems from the fact that gymnosperms typically have relatively slow growth rates, late maturation periods, and, in many cases, a restricted geographic distribution, which limits their ability to adapt and disperse in the face of rapid changes in their environment.

Because of the combination of these intrinsic characteristics, along with several anthropogenic threats and climate change, conifers were one of the first groups to be assessed by the IUCN (Farjon & Page, 1999). Since then, there has been an increase in the number of species at risk (Workman, 2014); this underscores the importance

of monitoring them and periodically updating their conservation status in order to establish more effective protection strategies (Xie et al., 2022).

In Mexico, there are 39 conifer taxa (nearly 40 % of the total) classified in a risk category under NOM-059-SEMARNAT-2010, and 16 of them are included in the Red List (Gernandt & Pérez-de la Rosa, 2014). The *Sierra Madre Occidental* (Western *Sierra Madre*) is home to the largest number of conifers in Mexico, including 13 endemic species, of which only two are listed as threatened under NOM-059-SEMARNAT-2010: *Picea chihuahuana* Martínez and *Pinus maximartinezii* Rzed. (Endangered) (Semarnat, 2019, 2025). On the other hand, the IUCN recognizes seven taxa in this mountain range with threat categories ranging from Vulnerable to Endangered. These discrepancies between geographic scales and taxonomic lists highlight the need to compare the various tools and reassess the taxa in order to take appropriate measures for their protection.

Within this context, the objective of this study was to determine the level of vulnerability of the endemic conifers of the *Sierra Madre Occidental* to identify priority sites for their conservation. This assessment is a crucial step toward incorporating the studied taxa into forest management plans and effective conservation initiatives in the region.

Materials and Methods

Study area

The *Sierra Madre Occidental* (*SMO* for its acronym in Spanish) is the longest mountain range in Mexico, stretching, in a northwest-southeast direction, from northern states of *Chihuahua* and *Sonora* to northern state of *Jalisco* and southern state of *Zacatecas* (González-Elizondo et al., 2012).

Based on physiographic and ecological criteria, it is possible to identify three ecoregions in the temperate zone of the *SMO* (González-Elizondo et al., 2012): (1) The Madrean region in the strict sense, located in the highest-altitude area and characterized by cool-temperate climates; (2) Tropical Madrean, on the western slope, with warm-temperate and subhumid climates, and (3) Xerophytic Madrean, located in the foothills of the eastern slope, with dry climates and extreme continental-type temperatures.

Its physiographic characteristics and ecological complexity have made it a biological corridor of great importance for woody plants of boreal origin, with a remarkable diversity and concentration of endemic species (González-Elizondo et al., 2012).

Endemic conifers of the *Sierra Madre Occidental*

Based on a review of the literature (Adams, 2014; Debreczy & Rácz, 2011; Gernandt & Pérez-de la Rosa, 2014) and herbarium specimens, as well as fieldwork, the conifers endemic to the *Sierra Madre Occidental* were identified. Subsequently, a search was conducted for each taxon in the IUCN Red List (International Union for Conservation

of Nature [IUCN], 2023) and NOM-059-SEMARNAT-2010 (Semarnat, 2019, 2025) to determine their threat category.

Records were obtained from the databases of the *CIIDIR*, *UACH-HER*, and *UAZ* herbaria; the SEINet information portal (Regional Network of North American Herbaria); *SNIB* (National Biodiversity Information System of Mexico, which includes records from iNaturalist); and *Monafor* (National System of Forest and Soil Monitoring Sites: http://forestales.ujed.mx/monafor). For records that lacked coordinates or contained erroneous data, the coordinates were estimated based on the descriptions of the collection sites. The records in the consulted databases were cleaned up. To reduce spatial autocorrelation among taxa, records of the same taxon less than 2 km apart were excluded.

IUCN Red List criteria

The Red List uses five criteria to assess whether a species falls under a particular threat category (UICN, 2012).

Criterion A: Population decline. This is assessed through direct observation or abundance indices, and is determined by a decline or deterioration of the habitat due to actual or potential levels of exploitation; or as a result of introduced species, as well as contaminating pathogens or parasites.

Criterion B, regarding geographical distribution. Is represented by the area of occupancy (*AOO*) of each record within a 4 km^2 radius and the extent of occurrence (*EOO*), which denotes the area enclosed by a polygon where the recorded specimens stand. To fulfill this criterion, the number of locations (fragmentation), population decline, and extreme variations in aspects of Criterion A are also considered.

Criteria C and D refer to the limited number of populations and the decline in the number of mature individuals, as well as the projected range for the future (up to a maximum of 100 years).

Criterion E uses quantitative analysis to assess the likelihood of a species becoming extinct.

The IUCN notes that meeting one criterion is sufficient to classify a taxon into a particular threat category (UICN, 2012). However, it is also important to evaluate all criteria, to the extent that information is available; finally, the met criteria must be specified.

The georeferenced records provided the data needed to evaluate Criterion B. The *EOO* parameter was obtained using the open-source software GeoCAT (Bachman et al., 2011) and was plotted on distribution maps for each taxon. The *AOO* was dismissed because, due to the low number of records, all taxa were grouped into the "Endangered" category.

A review of the available literature on each taxon was conducted to assess the latter according to criteria B and D-E.

Method for assessing the risk of plant extinction

The Method for Assessing the Risk of Extinction of Plants (*MERE* for its acronym in Spanish; Normative Annex II of NOM-059-SEMARNAT-2010 [Semarnat, 2010]) addresses four criteria that determine the Rarity index and the Anthropogenic impact index on plant species.

The Rarity index is calculated using Criterion A, which corresponds to the characteristics of the species' geographic distribution; Criterion B describes habitat characteristics, and Criterion C assesses the species' intrinsic biological vulnerability (based on demographic and genetic factors, as well as specialized biotic interactions). The

Anthropogenic impact index is assessed under Criterion D, which measures the effect of human activities on the habitat or use of the taxon.

The four criteria of the *MERE* for Plants are considered to be equally important, and each has a maximum value of 1. To calculate the total score for each aspect, it must be normalized by dividing it by the maximum score for that aspect so that the maximum value is 1. Risk classifications are determined by the total sum of the four criteria (Semarnat, 2010).

Priority conservation sites

In order to identify priority areas for the conservation of endemic conifers, a grid of 256 km^2 hexagons was generated in ArcMap 10.8 (Environmental Systems Research Institute [ESRI], 2019), with an area similar to that of the Priority Terrestrial Sites for Biodiversity Conservation of National Commission for the Knowledge and Use of Biodiversity (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad [Conabio] et al., 2007), to which the records of all species were added. Once the hexagons containing the species had been identified, each record was assigned a conservation value based on the category resulting from the *MERE* assessment for each species: 1 for Endangered, 0.8 for Threatened, 0.6 for Special Protection, and 0.4 for those classified as of least concern. This categorization was used to optimize the value of the cells, based not only on the number of species present but also on the threat level of each species.

In addition, a complementarity analysis was conducted to identify sites of the highest priority. This process began by excluding taxa with records within any Protected Natural Area (PNA) (Conabio, 2020; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad & Comisión Nacional de Áreas Naturales Protegidas [Conabio &

Conanp], 2024). The analysis was then performed iteratively: the hexagon with the greatest species richness was selected, and the species contained in that cell were excluded from the next iteration.

Finally, the resulting conservation units were compared with the protected areas (PNAs) and with the Priority Terrestrial Sites for Biodiversity Conservation (Conabio et al., 2007).

Results and Discussion

Thirteen conifer taxa endemic to the *Sierra Madre Occidental* were identified: six from the family Cupressaceae and seven from Pinaceae (Table S1). A dataset comprising 658 georeferenced records was obtained. *Pinus cooperi* C. E. Blanco was the most frequently recorded taxon (*n*=291), followed by *Juniperus durangensis* var. *durangensis* Martínez (*n*=124). Taxa with a significantly lower frequency (73 %) had fewer than 25 records each.

The criteria outlined in each description, as well as the assessments from the IUCN Red List and the *MERE* of NOM-059-SEMARNAT-2010, are presented in the tables S2 to S14; Table 1 summarizes the proposed new categories.

Table 1. Distribution and proposed threat category for endemic conifers of the *Sierra Madre Occidental*, Mexico.

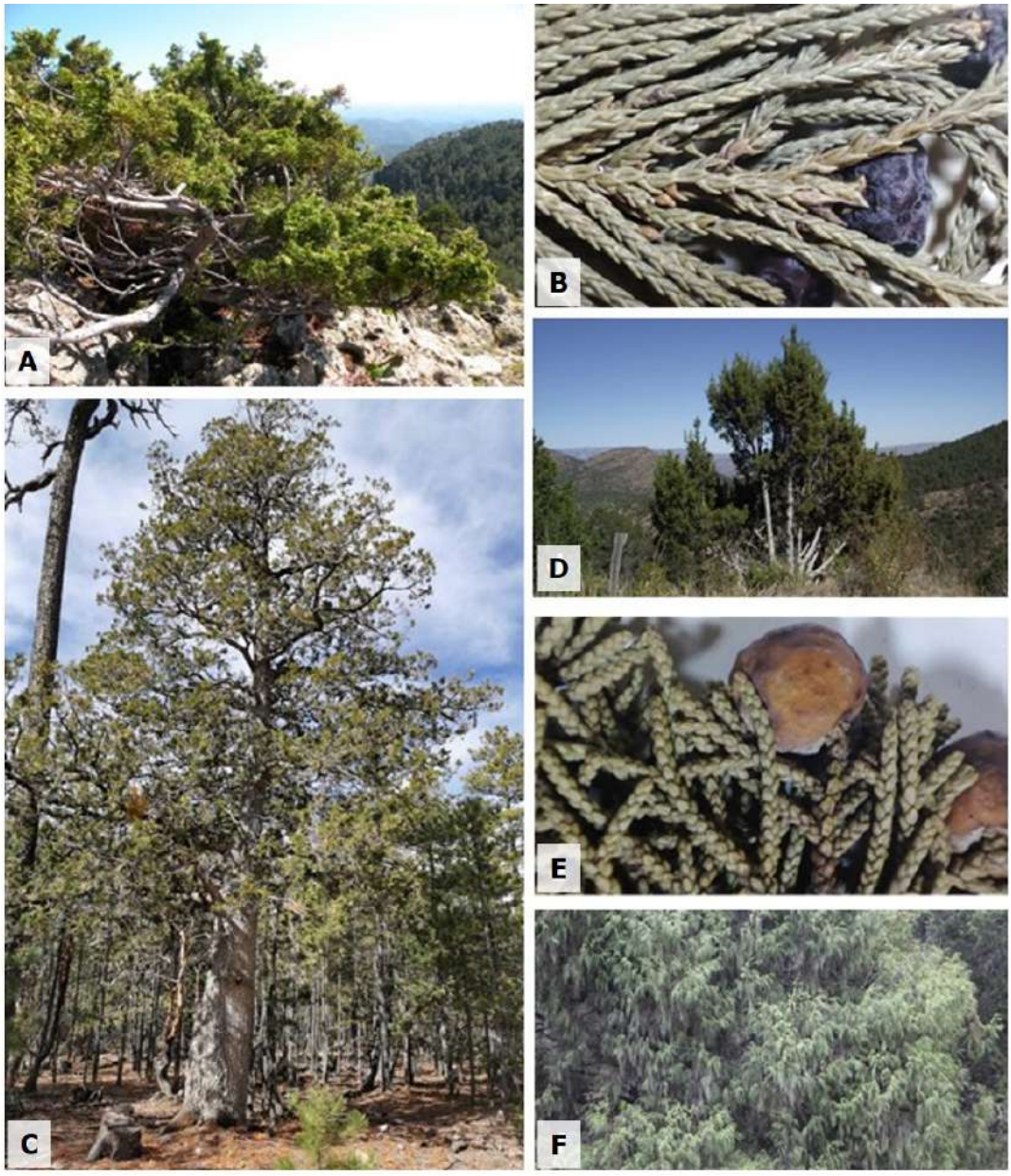
Taxon	Distribution		Proposed threat category	
	Altitude (m)	State	IUCN	NOM-059
Cupressaceae				
Juniperus blancoi var. *huehuentensis* R. P. Adams, S. González & M. González	3 150-3 350	Dgo., Chih.	EN	P
Juniperus blancoi var. *mucronata* (R. P. Adams) Farjon	1 300-2 200	Chih., Son.	VU*	A
Juniperus deppeana var. *robusta* Martínez	2 000-3 300	Dgo., Chih., Son., Zac.	VU*	--*
Juniperus durangensis var. *durangensis* Martínez	1 950-3 300	Dgo., Chih., Jal., Sin., Son., Zac.	LC*	--*
Juniperus durangensis var. *topiensis* R. P. Adams & S. González	1 700-2 200	Dgo., Chih.	EN	A
Juniperus poblana var. *decurrens* R. P. Adams	1 300-2 200	Dgo., Sin.	VU	Pr
Pinaceae				
Abies durangensis Martínez	1 800-3 300	Dgo., Chih., Son., Zac.	LC*	Pr
Abies neodurangensis Debreczy, I. Rácz & R. M. Salazar	1 900-2 500	Dgo., Sin.	EN	P
Picea chihuahuana Martínez	2 250-2 900	Dgo., Chih.	EN*	P*
Pinus cooperi C. E. Blanco	1 950-3 200	Dgo., Chih.	VU*	--*
Pinus gordoniana var. *sinaloensis* (Debreczy & I. Rácz) Frankis	1 200-1 800	Dgo., Sin.	EN	A
Pinus maximartinezii Rzed.	1 800-2 400	Dgo., Zac.	EN*	P*
Pinus yecorensis Debreczy & I. Rácz	900-2 300	Chih., Son.	LC	--*

IUCN = International Union for Conservation of Nature; NOM-059 = NOM-059-SEMARNAT-2010. EN = Endangered; VU = Vulnerable; LC = Least concern. P = Endangered; A = At risk; PR = Subject to special protection. -- = minor risk; *Retains its current status. Dgo. = State of *Durango*; Chih. = State of *Chihuahua*; Son. = State of *Sonora*; Zac. = State of *Zacatecas*; Jal. = State of J*alisco*; Sin. = State of *Sinaloa*.

Cupressaceae family

Juniperus blancoi var. *huehuentensis* R. P. Adams, S. González & M. González

This variety grows as a shrub on the highest peaks of the *SMO*, at altitudes above 3 150 m asl (Figure 1A). Its distribution is restricted to *Cerro Huehuento* in *San Dimas*, *Durango*; *Cerro Gordo* in *Pueblo Nuevo*, *Durango*, and *Cerro Mohinora* in *Guadalupe y Calvo*, *Chihuahua* (Figure S1).



A = *Juniperus blancoi* var. *huehuentensis*; B = *J. blancoi* var. *mucronata*, hojas y cono; C = *J. deppeana* var. *robusta*; D = *J. durangensis* var. *durangensis*; E = *J. durangensis* var. *topiensis*, hojas y cono; F = *J. poblana* var. *decurrens*. Photos: A and C: M. S González-Elizondo; B, D, E an F: L. Ruacho-González.

Figure 1. Conifers of the Cupressaceae family endemic to the *Sierra Madre Occidental*.

The total population is estimated at fewer than 300 individuals. Because of its location at the highest altitude in the *SMO*, a gradual decline in the population on each peak is expected due to warming, as the plants have nowhere to migrate to find the conditions they need (Mastretta-Yanes et al., 2012).

Furthermore, the population at *Cerro Mohinora* face an additional vulnerability due to the impact of human activity, as the site hosts telecommunications infrastructure that require maintenance, posing a direct threat (Comisión Nacional de Áreas Naturales Protegidas [Conanp], 2017); the other two populations do not have this problem.

Based on the Red List and *MERE* assessment criteria, the taxon is classified as "Endangered"; this entails the change of its IUCN category from "Vulnerable" and its inclusion in NOM-059-SEMARNAT-2010 to ensure its protection under the law (Table 1).

***Juniperus blancoi* var. *mucronata* (R. P. Adams) Farjon**

A tree and sometimes a shrub, it is distinguished by its leaves, which have a prominently acute or mucronate apex (Figure 1B). It is endemic to the northern part of the *SMO*, along the border between *Chihuahua* and *Sonora* (Figure S1), at altitudes ranging from 1 300 to 2 200 m asl.

It is one of the least studied taxa; therefore, little is known about its population and genetic dynamics. No records of damage caused by disturbances or biological agents were found either. Due to its growth characteristics, it has no documented commercial use.

The estimated range suggests that this variety could be classified as "Vulnerable" under IUCN criterion "B1" (11 311 km^2), thereby confirming its current status on the Red List. According to the *MERE*, its inclusion in the NOM-059-SEMARNAT-2010 under the category of "Subject to Special Protection" is recommended.

Juniperus deppeana var. *robusta* Martínez

It is characterized by an oblong crown and thick, quadrangular plates on its bark (Figure 1C). It is the taxon with the largest range among those studied, occurring at altitudes ranging from 2 000 to 3 300 m asl in areas of *Sonora*, *Chihuahua*, *Durango* and *Zacatecas.* (Figure S1). Based on its *EOO*, it should not be classified under any threat category; however, there is a lack of available information to support its current classification on the Red List (VU B2ab(ii,iii,v)).

In the *MERE* assessment, it received a score below 1.2, which is insufficient to place it in any risk category under NOM-059-SEMARNAT-2010. Among the factors contributing to its vulnerability, it was noted that, in some areas, these trees are harvested for their high-volume trunks (Martínez, 1946); in other areas, they have been used as fence posts, in housing construction, or for firewood (Farjon, 2019).

Given the above considerations, it is recommended that the current status be maintained for each assessment tool: "Vulnerable" on the IUCN Red List, and remains unlisted in NOM-059-SEMARNAT-2010 (Table 1).

Juniperus durangensis var. *durangensis* Martínez

Commonly known as *táscate* or *cedro chino* in the study area, it grows as a shrub or tree reaching a height of up to 6 m, with an irregular crown. It is distinguished by its fibrous bark, which peels off in longitudinal strips (Figure 1D). It is found throughout most of the *SMO*, at elevations ranging from 1 950 to 3 300 m (Figure S2).

Although it is valued locally as firewood, for making ornaments, or for charcoal, the greatest impact arises from land-clearing projects (Unidad de Conservación y Desarrollo Forestal Integral "Topia", 2020). Assessments based on the Red List criteria and the *MERE* do not classify it as a threatened taxon. However, there are gaps in our understanding of its ecology and genetic diversity; filling these gaps could provide further insight into its long-term vulnerability to pressures caused by human activities and environmental changes.

***Juniperus durangensis* var. *topiensis* R. P. Adams & S. González**

This variety is distinguished by having 5 to 9 seeds per cone, in contrast to the 1-3 (-4) seeds found in the typical variety of *J. durangensis* (Figure 1E); and by being a small shrub (1-1.5 m) with a greater number of branches, although less densely clustered, and forming dense colonies. It was described from the vicinity of *Topia*, *Durango*; however, a disjunct population exists in the *Cascada de Basaseachi* National Park, *Chihuahua* (Figure S2).

This *Juniperus* species is not currently listed in any conservation framework, even though its limited distribution and the small number of its locations suggest a high risk of extinction for this unique evolutionary lineage (Adams et al., 2012). For this reason, its inclusion in the "Endangered" category of the Red List and the "Threatened" category of NOM-059-SEMARNAT-2010 should be a priority.

Juniperus poblana var. *decurrens* R. P. Adams

It is particularly distinguished by its decurrent leaves, which have a divergent apex and fan-shaped, limp branches, giving it a drooping appearance (Figure 1F). It is found in the Tropical Madrean ecoregion in *Durango* and *Sinaloa*, at altitudes ranging from 1 300 to 2 200 m (Figure S2). Its limited geographic distribution and the potential for habitat disturbance (Adams & Schwarzbach, 2015) are factors that support its classification as "Vulnerable" on the Red List and "Subject to Special Protection" under NOM-059-SEMARNAT-2010.

The genetic study by Adams et al. (2018) shows that it is distinct from *J. poblana* var. *poblana* and *J. flaccida* due to several mutational events. This divergence in the evolutionary history of these species underscores its importance as a unique entity for genetic conservation.

Pinaceae family

Abies durangensis Martínez

It is a tree species that develops a well-defined conical-pyramidal crown. The young trees have a smooth, grayish trunk that becomes darker and scaly over the years. Its leaves are arranged in two rows along the twigs, which are glabrous or slightly hairy (García-Arévalo & González-Elizondo, 1998) (Figure 2A). It is found in cold, humid areas of the Madrean region, at elevations ranging from 1 800 to 3 300 m (Figure S3).



Twigs: A = *Abies durangensis*; B = *A. neodurangensis*; C = *Picea chihuahuana*. Detail of the shape of the leaves of: D = *Pinus cooperi* (rigid and curved); E = *P. arizonica* (straight). F = *P. gordoniana* var. *sinaloensis*; G = *P. maximartinezii*; H = *P. yecorensis*. Photos: A and E: M. S. González-Elizondo; B and H: C. O. Rodríguez-Lozano; C: R. M. Gutiérrez-Sánchez; D and G: L. Ruacho-González; F: H. Ávila-González.

Figure 2. Conifers of the Pinaceae family endemic to the *Sierra Madre Occidental*.

Given its widespread distribution in the *SMO* and the lack of demographic studies, it is recommended that the species remain in the "LC" category currently assigned to it on the Red List, as there is insufficient evidence to indicate an imminent risk of threat in the near future. On the other hand, dendrochronological studies have revealed that it is highly sensitive to climate, as evidenced by changes in its radial growth caused by physiological stress resulting from droughts (Pompa-García et al., 2020). Therefore, more detailed assessments are needed to properly estimate the risk to which the taxon is exposed.

The *MERE* assessment, which takes into account more vulnerability criteria than the Red List, classifies this species as a candidate for inclusion in the "Subject to Special Protection" category.

***Abies neodurangensis* Debreczy, I. Rácz & R. M. Salazar**

It is found in the Tropical Madrean region, at elevations between 1 900 and 2 500 m asl in *Durango* and *Sinaloa* (Figure S3). It is very similar to *Abies durangensis*, from which it differs in having larger (3.3-5.3 cm), flexible needles with a deep green upper surface, and densely pubescent twigs (García-Arévalo & González-Elizondo, 1998) (Figure 2B).

It exhibits a distinct phenology in cone maturation compared to *A. durangensis*. In *A. neodurangensis*, mature cones appear from May to June, whereas *A. durangensis* is in bloom during those same months (Debreczy & Rácz, 1995). This mismatch acts as a reproductive barrier that prevents gene flow between the two species and the potential formation of hybrids; therefore, the two lineages remain segregated.

Assessments using both evaluation tools classify the species as "Endangered". Its limited range and its few known locations make it highly vulnerable to habitat fragmentation and the effects of climate change. Its inclusion on both the Red List and NOM-059-SEMARNAT-2010 should be a priority.

Picea chihuahuana Martínez

It is one of the three species of *Picea* native to Mexico and is considered one of the flagship taxa in the field of conservation due to its ecological and scientific value, particularly because of its relict distribution. It is also one of the taxa for which the most information is available, covering demographic and genetic aspects, as well as vulnerability to climate change (González-Elizondo & Wehenkel, 2022; Jaramillo-Correa et al., 2006; Ledig et al., 2000, 2010; Mendoza-Maya et al., 2015; Pinedo-Alvarez et al., 2019; Wehenkel & Sáenz-Romero, 2012).

This species can grow up to 40 meters tall and have a diameter at breast height (*DBH*) of approximately 90 cm. Its crown is conical (sometimes very narrow), with widely spaced branches; the lower branches are usually nearly horizontal or slightly pendulous, while the upper ones are somewhat upright. Its leaves are bluish-gray with a sharp, pointed tip (Figure 2C).

Although its *EOO* suggests that the species should be classified as "Near Threatened" (NT), its distribution is highly fragmented into small, scattered populations in *Chihuahua* and *Durango* (Figure S3). It grows in cool, damp ravines and is often found alongside other conifer species such as *Abies*, *Hesperocyparis*, *Pinus*, and *Pseudotsuga*, at altitudes ranging from 2 250 to 2 900 m asl.

Picea chihuahuana is classified as "Endangered" on both the Red List and NOM-059-SEMARNAT-2010. The assessments conducted in this study confirm its status on both lists of endangered species. The main threat is the trend toward rising average annual temperatures and more frequent and prolonged droughts. Genetic studies (Ledig et al., 2010) have shown that *P. chihuahuana* has one of the lowest levels of genetic diversity among Mexican spruce species, making it more vulnerable to environmental changes.

For this reason, *ex situ* propagation and the exchange of plants between different populations are emerging as vital strategies for its survival (Mendoza-Maya et al., 2015). Assisted reproduction through genetic exchange is appropriate in this situation

due to the extreme isolation and low genetic diversity of these populations, which pose the most immediate threat of extinction due to low variability and inbreeding effects (Ledig et al., 2010; Mendoza-Maya et al., 2015).

***Pinus cooperi* C. E. Blanco**

This species has been considered a variety of *Pinus arizonica* Engelm. (Farjon & Styles, 1997). However, it has distinctive characteristics that have led to its recognition as a separate species (García-Arévalo & González-Elizondo, 1998). Its most distinctive feature is its upward-curving leaves, which are bluish-green to grayish in color and are arranged toward the tip of the twig (Figure 2D), distinguishing it from *P. arizonica*, whose needles are straight, thinner, pale green to lime green in color, and distributed along the length of the twig (Figure 2E).

Pinus cooperi it is widely distributed throughout the Madrean region, at altitudes ranging from 1 650 to 3 200 m asl in *Chihuahua* and *Durango* (Figure S4). It is found on gently sloping hillsides with deep soils, where it tends to form pure stands.

This species is of great commercial importance to the region's forestry sector. Although its wood is often knotty due to the formation of low-growing branches, it is of good quality for the manufacture of various wood products (de la Paz-Pérez-Olvera & Dávalos-Sotelo, 2016).

Despite being harvested, sustainable forest management has helped maintain stable population dynamics, and only a few populations show moderate impacts from human activities. Among the main threats to the species are wildfires and future climate change scenarios, which could reduce its range by 30 % by the end of the century (Ruacho-González et al., 2025). These factors resulted in the species being classified

as "Vulnerable" on the Red List, its current status; however, under the *MERE*, it does not meet the criteria for any protection category.

***Pinus gordoniana* var. *sinaloensis* (Debreczy & I. Rácz) Frankis**

This species differs from *P. gordoniana* var. *gordoniana* Hartw. *ex* Gordon in its shorter stature, its very short sheath, and its broadly ovoid to subglobose cones that are rounded at the base. It was previously considered a variety of *P. yecorensis* Debreczy & I. Rácz, from which it is also distinguished by its shorter stature and smaller cones (Frankis, 2024) (Figure 2F). It is known to occur in *Sinaloa* and *Durango* at altitudes between 1 200 and 1 800 m asl, in transition zones between the pine-oak forests of the Tropical Madrean region and the tropical deciduous forest (Figure S4).

The *sinaloensis* variety has not been formally assessed for conservation status under current legal frameworks. Due to its limited distribution and the small number of individuals observed, it is likely to be more vulnerable to threats than other pine varieties with larger populations. Based on the Red List criteria, this taxon was identified as potentially "Endangered," primarily due to the limited number of locations. As for the *MERE*, it is classified as "Threatened" under NOM-059-SEMARNAT-2010, which constitutes a first step toward its conservation.

***Pinus maximartinezii* Rzed.**

The so-called blue pine is an iconic species because it is the pine tree with the largest cones and seeds in the world (Figure 2G). It is a medium-sized tree (5-15 m) that forms a broad, irregular crown; the bark of young trees is smooth and grayish, and as the tree matures, it develops irregular, grid-like patches of brown tones.

The range of this endemic pinyon pine is highly restricted to two known populations in the southern part of the *SMO* (Figure S4). Due to the small number of locations and its very limited *EOO* (345 km^2), it is listed as "Endangered" under both Mexican regulations and the IUCN. The evaluation of the criteria in this study confirms its classification in that category for both instruments.

Among the main threats that this species faces are habitat fragmentation and low genetic diversity (González-Elizondo et al., 2011). Studies by Ledig et al (1999, 2001) conducted on the population of *Zacatecas* identified a low percentage of polymorphic loci with only two alleles; although further studies integrating the two locations are needed, their morphological similarity suggests a similar genetic makeup. In addition, *ex situ* propagation efforts are underway to promote its cultivation as an ornamental plant. Because of its distinctive blue-gray foliage and the appearance of its cones, it has been used in urban reforestation programs (González-Elizondo et al., 2007) and for germplasm restoration or conservation projects in other parts of the world (Dvorak, 2012; Ledig et al., 1999).

***Pinus yecorensis* Debreczy & I. Rácz**

It is a medium-sized tree (10-18 m) with bright green foliage. It has five needles per fascicle, which are 28 to 35 cm long and slightly pendulous (Figure 2H).

Pinus yecorensis is endemic to the northern part of the *SMO*. It occurs at altitudes ranging from 900 to 2 300 m asl along the border between *Chihuahua* and *Sonora* (Figure S4). Unlike most pine trees, which are typically found at higher elevations or in colder climates, this species grows in warmer areas.

Pinus yecorensis is currently not listed on the IUCN Red List or in NOM-059-SEMARNAT-2010. The results obtained from applying these tools showed that the

taxon has a low *EOO*, placing it in the "Vulnerable" category; however, the criteria necessary to support this proposal are not met. In fact, a projection of its future distribution suggests that *P. yecorensis* may have some resilience to future climate change, as it exhibits a tolerance to the higher temperatures typical of that region in that part of the *SMO* (Ruacho-González et al., 2025). This study suggests classifying it under the "LC" (Low Concern) category until ecological studies are conducted to help determine the health of the populations.

In the *MERE*, the scores achieved are insufficient even for the "Subject to Special Protection" (Pr) category. Weaknesses identified include the low estimated population size cited in the literature (Debreczy & Rácz, 1995) and the risk associated with fires or deforestation (Lorence et al., 2018).

Comparison of the Red List criteria and the *MERE* criteria

Both the IUCN Red List and the Extinction Risk Assessment Method (*MERE*) outlined in NOM-059-SEMARNAT-2010 are key tools for assessing the conservation status of species and prioritizing management actions. However, they differ in terms of the level of detail they provide in their criteria and the weight assigned to each factor when assessing risk.

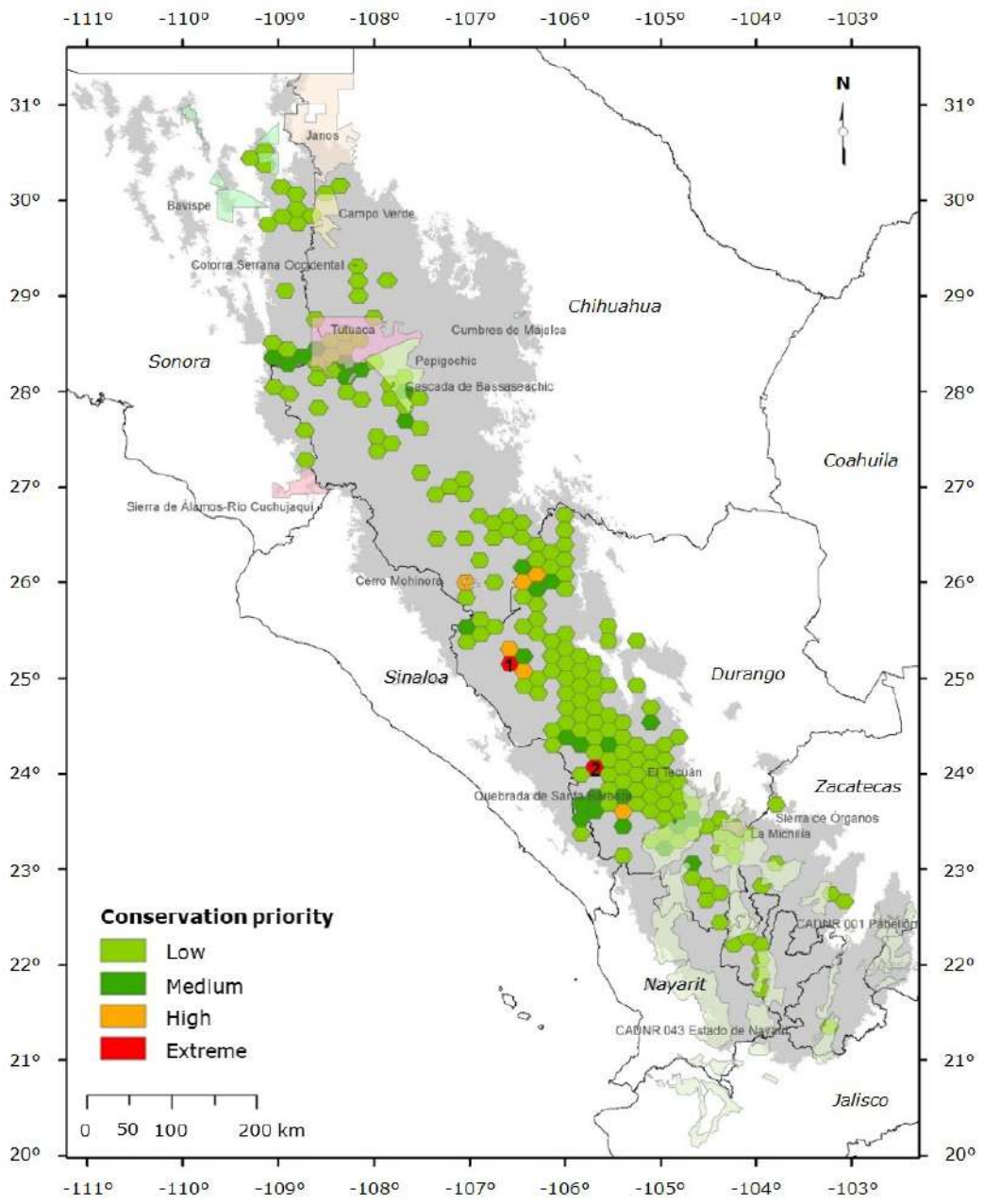
The Red List criteria are based on more quantitative and standardized factors, which helps minimize interpretive bias in the assessment (Brito et al., 2010). Nevertheless, doubts have been raised about the robustness of these criteria as a whole; although it is recommended that all criteria be evaluated, meeting just one is enough for a taxon to be classified within a specific threat category (UICN, 2012). This characteristic could lead to situations in which a species is classified as high-risk based on a single factor, without taking into account attributes for which information may not yet be available. On the other hand, because it takes a broad approach, it may

overlook threats at a more granular level within populations, or biological factors that could endanger a species—criteria that are indeed taken into account in the *MERE*.

The *MERE* was developed to serve as a practical yet robust tool that takes into account the context of species in Mexico (Sánchez-Salas et al., 2013). Unlike the strictly quantitative approach of the Red List, the *MERE* offers greater flexibility when data are scarce, allowing for the incorporation of qualitative criteria and the input of experts in the field. Its multidimensional approach takes into account environmental, anthropogenic, and biological factors, providing a more comprehensive view of the potential risk faced by the organisms. For this reason, it may be more useful for planning management and conservation measures at the regional level.

Priority conservation sites

The analysis using conservation value weighting identified two sites of extreme priority and three areas of high priority (Figure 3).



Cumbres de Majalca = *Cumbres de Majalca* National Park; *Cascada de Basaseachic* = *Cascada de Basaseachic* National Park; *Sierra de Álamos-Río Cuchujaqui* = *Sierra de Álamos-Río Cuchujaqui* Flora and Fauna Protection Area; *Cerro Mohinora* = *Cerro Mohinora* Flora and Fauna Protection Area; *Quebrada de Santa Bárbara* = *Quebrada de Santa Bárbara* Natural Resources Protection Area; Sierra de Órganos = Sierra de Órganos National Park; *CADNR 043 Estado de Nayarit* = Natural Resource Protection Area of the *Nayarit* Irrigation District 043 Watershed. 1 = Topia-Canelas Area; 2 = *Cerro Huehuento*.

Figure 3. Priority sites for the conservation of endemic conifers in the *Sierra Madre Occidental*, and their representation in Protected Natural Areas.

The first site of the highest priority is located between *Topia* and *Canelas* municipalities and is home to six of the 13 endemic conifers: *Abies durangensis*, *A. neodurangensis*, *Juniperus durangensis* var. *durangensis*, *J. durangensis* var. *topiensis*, *J. poblana* var. *decurrens*, and *Pinus cooperi*. These results are congruent with previous studies that indicate a high Lamiaceae species richness (González-Gallegos et al., 2022) and of pines (Ruacho-González et al., 2025).

In the other hexagon of extreme priority, there are *Abies durangensis*, *Juniperus blancoi* var. *huehuentensis*, *J. deppeana* var. *robusta*, *J. durangensis* var. *durangensis* and *Pinus cooperi.* The area covered by this site corresponds to the *Cerro Huehuento* region in *San Dimas*, an area of ecological interest due to its subalpine vegetation (González-Elizondo et al., 2012).

Among the high-priority areas is a hexagon that coincides with the "*Cerro Mohinora*" Flora and Fauna Protection Area, a region in which *Abies durangensis*, *Juniperus blancoi* var. *huehuentensis*, *J. deppeana* var. *robusta*, *Juniperus durangensis* var. *durangensis*, and *Pinus cooperi* are distributed; in addition to serving as a habitat for additional taxa of ecological concern such as *Picea mexicana* (González-Elizondo & Wehenkel, 2022), as well as various endemic species, such as *Salvia reginae* J. G. González & J. H. Vega (González-Gallegos et al., 2019) and *Stachys mohinora* B. L. Turner (Turner, 1994).

There is also an area consisting of several hexagons in the *La Rosilla* region of *Guanaceví* that is particularly interesting because it records the lowest temperatures in the country; there, one can find *J. deppeana* var. *robusta* and several populations of *Picea chihuahuana.*

Finally, the *Quebrada de Santa Bárbara* Natural Resources Protection Area was also given high priority. Fourteen species of conifers have previously been recorded in this area (Noriega-Villa et al., 2023). The endemic species include *Abies durangensis*, *Juniperus durangensis* var. *durangensis*, *J. deppeana* var. *robusta*, *Picea chihuahuana*, and *Pinus cooperi.*

Despite the concentration of taxa of high conservation value, current protection measures are insufficient. For example, *Pinus maximartinezii*, a species classified as

"Endangered", even though one of its two populations is located within the Natural Resource Protection Area of the *Nayarit* Irrigation District 043 Watershed, which has limited operational capacity. The area lacks a management plan and a designated official or office; responsibility for its management is occasionally divided between the northern and western regional offices of the National Commission for Protected Natural Areas (*Conanp*), a problem stemming from its numerous polygons and vast size, which makes it a vulnerable zone (Armendáriz-Villegas et al., 2015; Jardel-Peláez et al., 2017).

On the other hand, no Priority Terrestrial Sites for Biodiversity Conservation were identified that coincided with the proposal in this study. Research on biodiversity conducted in recent years in the *Sierra Madre Occidental* could help optimize these sites, which are underrepresented in the study region. The first step in the conservation process is identifying priority areas. Management strategies should be based on a holistic approach that takes into account the interactions among species, ecological and genetic processes, and the socioeconomic aspects of the region (Zhang et al., 2023).

Promoting gene flow between populations is particularly important in highly fragmented populations, as this increases their vulnerability to the effects of inbreeding, the loss of genetic diversity, and low resilience to drastic environmental changes (Bohm et al., 2025).

Finally, this study identifies several areas of opportunity that could be explored in future research. For example, it is essential to recognize taxonomy and systematics as the foundational pillars of understanding and conserving taxa. In this regard, the priority areas require: (a) Conducting systematic and phylogenetic studies that will allow for a better definition and understanding of the taxa (Gernandt et al., 2005); (b) Generating forest structure and population dynamics inventories to characterize the status of the populations (Corral-Rivas et al., 2013); (c) Identifying reproductive aspects of the taxa (pollination, seed dispersal, viability) (Williams, 2009); (d) Developing propagation strategies for taxa at risk of extinction (Hazubska-Przybył, 2019); and (e) Determining environmental requirements and exploring modeling studies of potential distribution under climate change scenarios (Sáenz-Romero et al.,

2010), for taxa with a sufficient number of records. Conducting this type of study is essential for enhancing the data robustness in the Red List and the *MERE*, thereby ensuring that these legal tools fulfill their role in protecting Mexico's biodiversity.

Conclusions

The application of the IUCN Red List and *MERE* criteria for plants to the conifer species and varieties analyzed in this study reveals an alarming situation, as it identifies various levels of threat that are not addressed in the current regulations. Species such as *Picea chihuahuana* and *Pinus maximartinezii* remain classified as "Endangered," underscoring the importance of their protection. Other taxa require constant monitoring due to their commercial importance or to the threats posed by climate change.

There is a notable and recurring lack of information to address all the assessed aspects; this shortcoming limits the ability of the two regulatory instruments to adequately reflect the true risk of extinction and, consequently, makes it difficult to formulate effective conservation strategies. The analysis of species records identified four high-priority sites and two extremely high-priority sites for the conservation of endemic conifers. These sites are crucial because of their rich biodiversity, and although some overlap with Protected Natural Areas, current protection measures are insufficient. This proposal emphasizes the need to focus conservation efforts on new, unprotected areas.

In addition to the above, implementing management strategies that prioritize the integrity of the vegetation cover to support soil conservation and water infiltration would be another way to help conserve these taxa. Sustainable forest management, combined with accurate taxonomic knowledge by forest managers and balancing biodiversity conservation with resource use, is essential to ensuring the long-term survival of the taxa studied herein and the well-being of the human communities that depend on them.

Acknowledgements

The data analyzed herein were obtained thanks to financial support from various programs and calls for proposals issued by such institutions as *Conabio*, *Conacyt* (now *Secihti*), *Conafor*, the *Instituto Politécnico Nacional* (National Polytechnic Institute), and *Universidad Juárez del Estado de Durango* (*Juárez* University of the State of *Durango*).

Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

Lizeth Ruacho-González: conceptualization of the project idea; responsibility for data collection and curation, application of the methodology, and drafting of the original manuscript; M. Socorro González-Elizondo and José Javier Corral-Rivas: data collection and processing, and validation of the results; Jesús Guadalupe González-Gallegos: data analysis, monitoring of the results, and revision of the original manuscript. All authors revised the final manuscript.

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