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Coverage changes of pine trees at risk in collection sites in northern Mexico

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ABSTRACT

Objective: To analyze the changes in land-use and vegetation (LUV), from 1985 to 2014, in the sites in northern Mexico where 16 pine trees listed in the NOM-059-SEMARNAT-2010 are collected.

Design/Methodology/Approach: Based on consultations in botanical collections, a georeferenced database of the species under study was developed. A point coverage was created to which LUV vector information from Series I (1985) and VI (2014) was added. Subsequently, LUV class changes were identified during the evaluation period through spatial analysis and geoprocessing.

Results: A total of 2,242 georeferenced records of pine species were obtained. Fifty percent of the pine records consulted in collections with Series I information belong to other non-primary forest categories of LUV, while with Series VI information with this condition rose to 58.7%. Consequently, in the study period major changes occurred in the conversion of primary forests to agricultural lands, pasture, secondary vegetation in coniferous and oak forests, and mainly urban areas.

Limitations/Implications: The availability of larger-scale cartographic material limited the generation of a risk analysis study about the changes and threats to forest conservation.

Findings/Conclusions: The number of collection sites registered in coniferous forest, scrubland, and primary oak forest in Series I —which are now agricultural lands, water bodies, pastures, and urban areas— was significantly lower than in Series VI.

Keywords: Temperate forests, botanical collection, forest ecosystems, threatened species, *Pinus* spp.

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INTRODUCTION

Forest ecosystems cover 70.5% of the national territory; 10.7% of the said territory is made up of pine and mixed forests (CONAFOR, 2019). The forests found within the Mexican territory are home to 94 species that belong to the six conifer families recognized worldwide; 43 of these species are endemic and 18 can only be found in three or fewer states (Gernandt and Pérez, 2014).

Image by Zdeněk Chalupský at Pixabay

Mexico is one of the three countries considered as a secondary diversification center of the genus *Pinus*, since 49 out of the 111 species currently existing on the planet can be found in its territory (CONABIO, 2020; Gernandt and Pérez, 2014; Sánchez, 2008). According to NOM-056-SEMARNAT-2010, some of these pine species are classified within a level of risk (special concern, threatened, or endangered), because their distribution and habitat quality are considered to be limited. Given its biological condition, its population is highly fragile in the face of anthropic activities and impacts (Aguirre and Duivenvoorden, 2010; SEMARNAT, 2010). According to data from CONAFOR (2020), the deforestation of the national territory reached 166,337 ha in 2018, which suggests the need to identify the areas where the species at risk are distributed, in order to determine their vulnerability to vegetation changes. In practice, the evolution of the natural geographic distribution of the pine species at risk in Mexico has not received any attention (if any at all). The objective of this study is to determine the changes in land-use and vegetation (LUV), from 1985 to 2014, in the sites in northern Mexico where 16 pine trees listed in the NOM-059-SEMARNAT-2010 are collected. The research hypothesis is that the geographic distribution of the species has at least remained constant during the evaluation period.

MATERIALS AND METHODS

Description of the study area

The study area corresponds to the north of Mexico. It is made up of the states of Baja California, Baja California Sur, Sonora, Chihuahua, Coahuila, Nuevo León, Tamaulipas, San Luis Potosí, Zacatecas, Aguascalientes, Durango, Sinaloa, and Nayarit (Figure 1). From a geographical point of view, the scope of the work included more than the northern half of the Mexican territory.

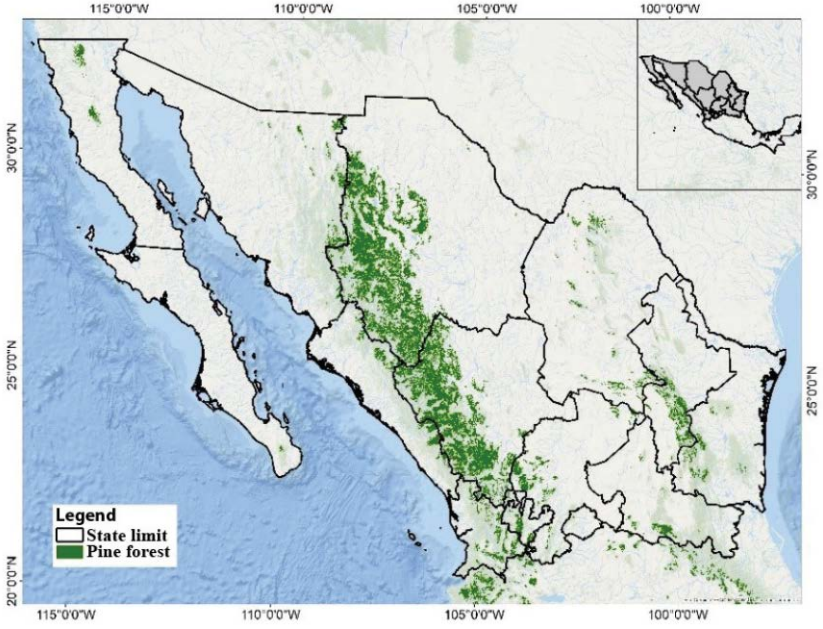


Figure 1. Location of the study area (Source: INEGI, 2016a).

Record of pines at risk

This research focuses on the pines that grow naturally in northern Mexico and are in a level of risk status, according to the Official Mexican Standard NOM-059-Semarnat-2010 (SEMARNAT, 2010). The study focused on the following 16 species: *Pinus Attenuate* Lemmon, *P. contorta* Douglas ex Loudon var. *murrayana* (Balf.) Engelm, *P. coulteri* D. Don, *P. culminicola* Andresen et Beaman, *P. jeffreyi* Greville & Balf., *P. johannis* M. F. Rob.-Pass., *P. lagunae* (Rob.-Pass.) Passini., *P. martinezii* E. Larsen, *P. maximartinezii* Rzed., *P. monophylla* Torr. & Frém., *P. muricata* D. Don., *P. nelsonii* Shaw., *P. pinceana* Gordon, *P. quadrifolia* Parl. Ex Sudw., *P. remote* (E. Little) D. K. Bailey *et* Hawksw., and *P. strobiformis* Engelm.

The methodology used in the research was based on the suggestions of Ruiz *et al.* (2018), who mainly recommended obtaining botanical-geographic records of pines in a level of risk from different herbaria whose specimens were collected from 1836 to 2018. However, the analysis considered only the years between the creation of Series I and Series VI of INEGI. For this purpose, the types of vegetation were assumed to be constant and coincide with those reported in the collection dates before the base year of Series I of INEGI. Both physical and virtual botanical-geographical records were obtained from national and international sources. The database was complemented with information queries from the Inventario Nacional Forestal y Suelos (CONAFOR, 2014) and corroborated with information available in another bibliographic source (Pérez *et al.*, 2019).

Integration and geoprocessing of geographic data

A database was developed based on the following variables: identifier, registration date, scientific name of the species, geographic coordinates in decimal degrees, state, municipality, and locality. A cleansing was carried out in order to eliminate repeated observations and incomplete records. The .xls database was exported to ArcMap™ 10.2.1 in order to create a points shapefile using the *XY add data* module. Subsequently, the georeferenced database of the point layer was analyzed and validated with information about the coverage of states and municipalities (INEGI, 2021), as well as land-use and vegetation from Series VI (INEGI, 2016a).

The modifications to the landscape of the pines collection sites were analyzed based on the layers of land-use and vegetation (LUV) Series I (INE-INEGI, 1997) and Series VI (INEGI, 2016a), at a 1:250,000 scale. The former contains 88 LUV types and the latter, 76. Based on the differences between the classes defined for LUV in Series I and VI, a homogenization process was carried out using documents from INEGI (1998), INEGI (2016b), Meave *et al.* (2016), and Velázquez *et al.* (2002). The first step was to list all the vegetation types in each series to identify those that had elements in common, in order to bring down the classes to a manageable number. Based on INEGI's own documentation and other authors (Meave *et al.*, 2016; Velázquez *et al.* 2002), 15 large classes were obtained that grouped the respective categories of Series I and VI. The main large classes were: agriculture, coniferous forest, oak forest, water bodies, scrubland, pasture, jungle, without vegetation, hydrophytic vegetation, secondary vegetation (coniferous forest), secondary vegetation (oak forest), secondary vegetation (scrubland), secondary vegetation (pasture), secondary vegetation (jungle), and urban area.

Based on this information, the ArcMap™ 10.2 Intersect geoprocessing tool was used, with the point layers of the records of pines at risk and Series I and VI of INEGI as inputs. This method was used to obtain the point layer (shapefile) and its attribute for the LUV categories of each Series. As a final step, the table of attributes of the coverage resulting from the previous operation was exported to Excel™ 2016 and Rstudio™ 3.5, to analyze the descriptive statistics and graphs, in order to compare the LUV changes between series of every record of pines at risk.

RESULTS AND DISCUSSION

Number of consulted records

A database with 2,242 records of the 16 pine species in the risk category from the year 1836 to 2018 was developed. *Pinus attenuate* and *P. strobiformis* were the species with the lowest and highest percentages in the records, with values of 0.5 and 34.28%, respectively. The rest of the species had percentages that did not exceed 11% (Table 2). The states that make up the study area are characterized by low coniferous forests (Sierra Madre Oriental and Occidental of Mexico). The main states included in this area are Chihuahua, Durango, Coahuila, and the northern end of Baja California (Figure 2).

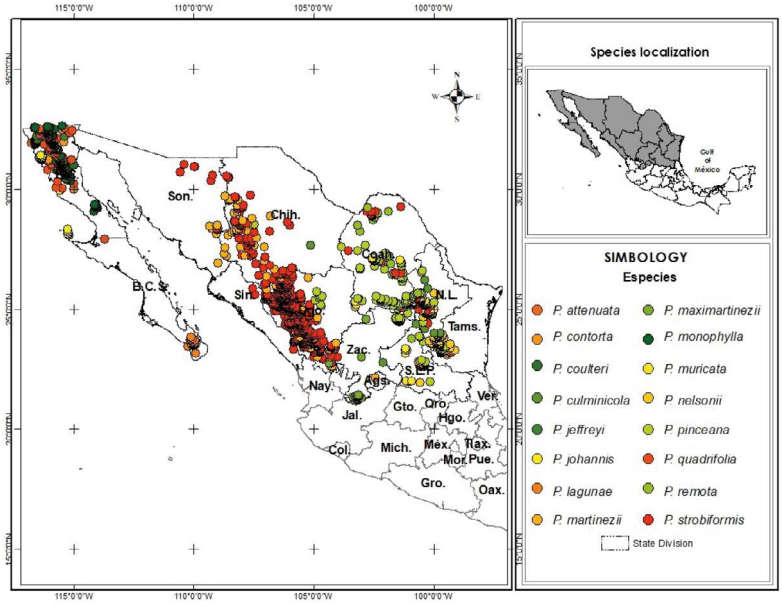


Figure 2. Geographic location of the records of pine species at risk per state in northern Mexico.

Table 2. Percentages of the 16 pine species at risk recorded in northern Mexico, consulted in herbaria and data collections.

Number	Especie	%	Number	Especie	%	Number	Especie	%	Number	Especie	%
1	Patt	0.50	5	Pjef	4.50	9	Pmax	3.12	13	Ppin	7.85
2	Pcon	2.50	6	Pjoh	2.90	10	Pmon	3.93	14	Pqua	8.15
3	Pcou	4.60	7	Plag	1.87	11	Pmur	2.27	15	Prem	1.56
4	Pcul	6.50	8	Pmar	5.00	12	Pnel	10.47	16	Pstf	34.28

P. attenuata: Patt; *P. contorta*: Pcon; *P. coulteri*: Pcou; *P. culminicola*: Pcul; *P. jeffreyi*: Pjef; *P. johannis*: Pjoh; *P. lagunae*: Plag; *P. martinezii*: Pmar; *P. maximartinezii*: Pmax; *P. monophylla*: Pmon; *P. muricata*: Pmur; *P. nelsonii*: Pnel; *P. pincena*: Ppin; *P. quadrifolia*: Pqua; *P. remota*: Prem; *P. strobiformis*: Pstrf.

Records by states

The states that record the highest number of pine species were Durango, Baja California, Chihuahua, Coahuila, Nuevo León, Tamaulipas, and Zacatecas. Those Figures amounted to 93.68% of the national total. In particular, given their relative frequency, *P. strobiformis* stands out in Durango, *P. nelsoni* in Tamaulipas, and *P. quadrifolia* in Baja California (Figure 3). Although the pine species under analysis can be found in most of the states of the study area, their representativeness in Aguascalientes is practically null (0.04%).

Distribution of pine trees per land-use and vegetation

Figure 4 shows the distribution of the pine records under study, according to the different LUV categories of Series I and VI. Globally, Series I had proportions (percentages) of up to 0.8, while in Series VI the maximum value was 0.6.

In coniferous forests, scrublands, oak forests, and secondary vegetation (scrubland), the number of records decreased in the passage from Series I (Figure 4a) to Series VI (Figure 4b). In fact, the reduction percentage in the coniferous forest exceeded 5%. Meanwhile, for agriculture, pasture, secondary vegetation (coniferous forest), secondary vegetation (oak forest), and urban area, the number of records increased during the same evaluation period. The secondary vegetation (coniferous forests) category obtained the best benefits: its gain percentage rose by almost 10 %.

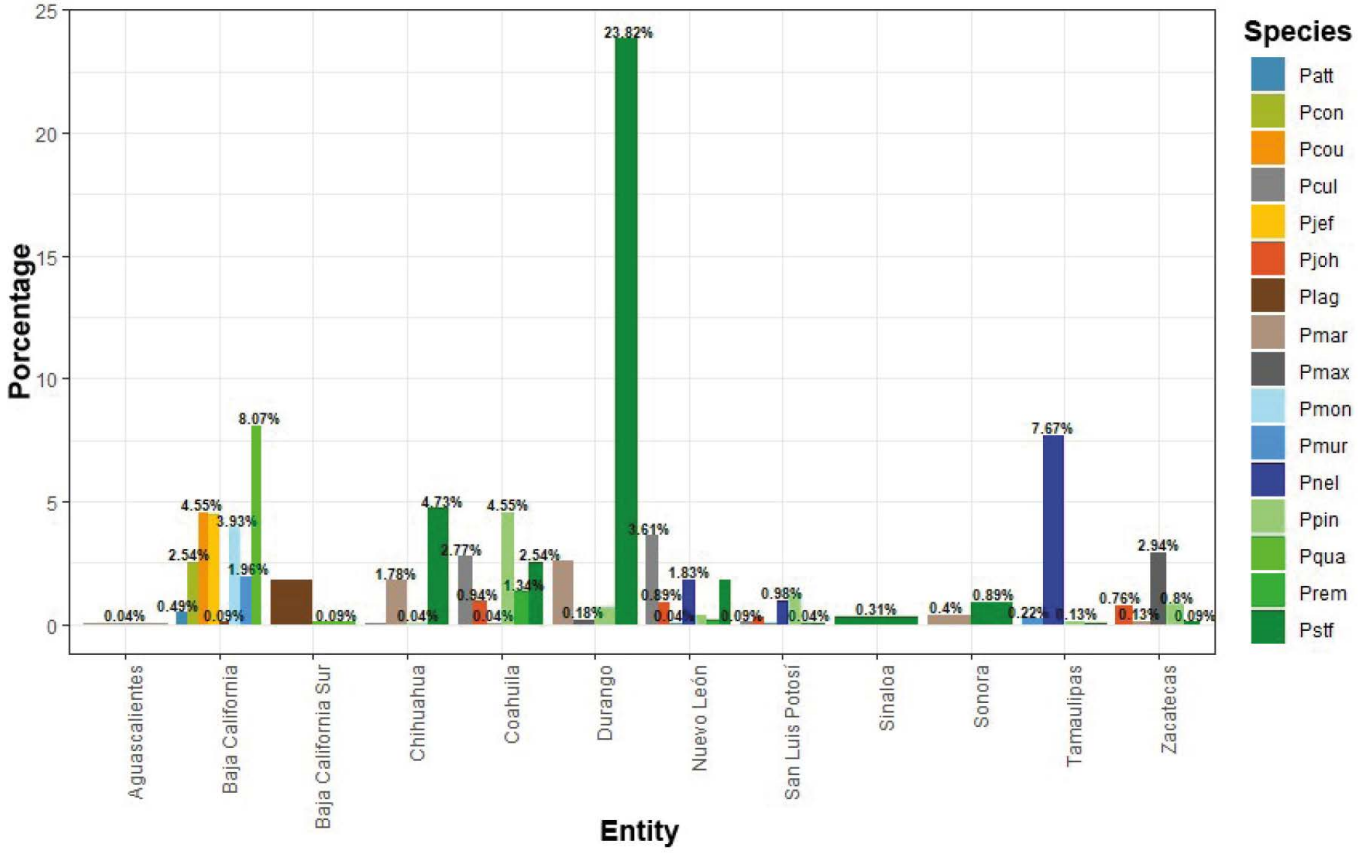
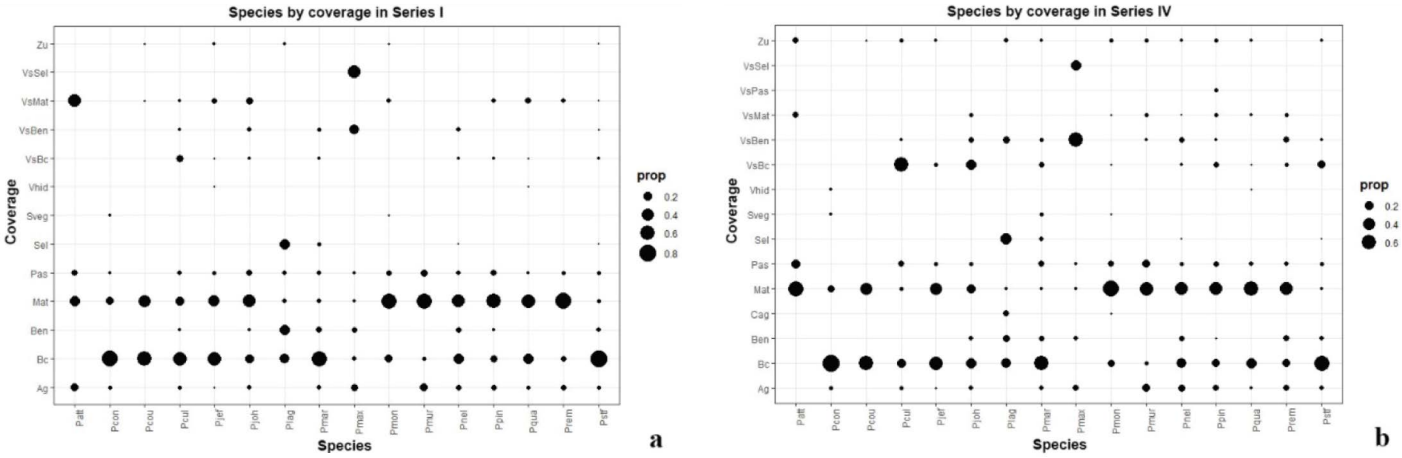


Figure 3. Percentage of the records of pine species at risk in the northern states of the Mexican Republic.



Agriculture: Ag; Coniferous Forest: Bc; Oak Forest: Ben; Scrubland: mat; Pasture: Pas; Jungle: Sel; Without vegetation: Sveg; Hydrophytic vegetation: Vhid; Secondary vegetations: Vs; Urban area: Zu.

Figure 4. Percentage distribution of the records of the pine species at risk, according to the coverage of Series I (a) and VI (b) per states in the north of the Mexican Republic.

In particular, the area of the oak forest and scrubland categories was reduced and, consequently, the number of records was also negatively altered, while the area of agriculture, pasture, secondary vegetation (coniferous forest), secondary vegetation (oak forest), and urban zones increased in the period analyzed (Table 2).

The comparison of Series I with Series VI (Table 2) shows that the points on the diagonal that represent the LUV remain stable in the same category in the two Series and represent 72.26%. The points outside of the diagonal indicate movements between categories. Changes from scrubland records to coniferous forest (equivalent to 1.83% of Series I), oak forests (0.31%), secondary vegetation (coniferous forests, 1.83%), and secondary vegetation (oak forest) were identified. There were changes in the pine records, from coniferous forest to secondary vegetation (coniferous forest, 7.40%), to secondary vegetation (oak forest, 0.67%), and to pasture, agricultural, and urban areas (2.63% in total). There were also records of pines in oak forests that changed to secondary vegetation (oak forest, 0.58%).

The changes in the number of records in the categories from Series I to Series VI are mainly attributed to anthropogenic factors (García *et al.*, 2012; Pineda *et al.*, 2009). These authors highlight that population growth and density contribute to the transformation of the natural landscape, the increase in land used for agriculture, and the reduction of forest area.

Fires have negative impacts on forests and consequently alter the ecosystem goods and services they provide. Despite the planning, coordination, and execution efforts carried out by the Comisión Nacional Forestal to timely detect and fight such catastrophic events, the annual loss of forest resources in Mexico is inevitable. From 1998 to 2021, an average of 340,466 ha/year was reported in the whole nation; in 2015, a total of 88,538 ha was impacted, 32.11% of which is located in the study area (CONAFOR, 2022; FAO, 2020). This situation is reflected in the results of our research: a reduction of 12.4% was observed in the records of pine species that fell initially in the category of coniferous and oak forests

Table 2. LUV change matrix of the number of collection sites for pines at risk from Series I (S1) to Series VI (S6).

S6 / S1	Ag	Bc	Ben	Cag	Mat	Pas	Sel	Sveg	Vhid	VsBc	VsBen	VsMat	VsPas	VsSel	Zu	Total
Ag	63	6			6	4				1				3	19	**102**
Bc	29	855	10	2	14	27				166	15				3	**1121**
Ben		8	62			1	1	2		5	13		3			**95**
Mat	15	41	7		460	13	1			41	14	13			6	**611**
Pas	7	9	1	3	5	54		1	1	5	1	3	3	1	6	**100**
Sel							20									**20**
Sveg								2								**2**
Vhid					1				2							**3**
VsBc	2	2				2				43						**49**
VsBen		2				4					37					**43**
VsMat	2	3			41	4				4		2			2	**58**
VsSel						1					16			15		**32**
Zu															6	**6**
Total	**118**	**926**	**80**	**5**	**527**	**110**	**22**	**5**	**3**	**265**	**96**	**18**	**6**	**19**	**42**	**2242**

Agriculture: Ag; Coniferous Forest: Bc; Oak Forest: Ben; Water bodies: Cag; Scrubland: mat; Pasture: Pas; Jungle: Sel; Without vegetation: Sveg; Hydrophytic vegetation: Vhid; Secondary vegetation (coniferous forest): VsBc; Secondary vegetation (oak forest): VsBen; Secondary vegetation (scrubland): VsMat; Secondary vegetation (pasture): VsPas; Secondary vegetation (jungle): VsSel; Urban area: Zu.

and were subsequently included in another type of LUV. In a study carried out from 2013 to 2017, in an area of 1,260.73 ha in southwestern Chihuahua identified as burned areas using the Normalized Burn Ratio (NBR) and field verification, Valdez *et al.* (2019) recorded a change of coverage and a transition from forest coverage to secondary vegetation in 82% of the area.

The findings of this research —which in themselves reflect the dynamics of forest ecosystems— are similar to the results of other studies about land-use change in Mexico. In this sense, increases in spaces transformed by humans were observed, including agricultural, induced pasture, and urban areas. In addition, a loss in forest area was recorded, as a result of conversions to agricultural areas and pasture (Pérez *et al.*, 2011). Challenger and Dirzo (2009) affirm that by 1976 the original vegetation coverage of the country had suffered a 38% reduction; around 1993, it only covered 54% and, by 2002, it occupied only 50% of its original surface. Sanchez *et al.* (2009) refer that the growth of human settlements and urban areas have had a significant increase since the 1970s. Currently, this is the most important land-use change in some regions of the country (SEMARNAT, 2010).

Finally, as a result of the specific characteristics of cartographic studies about the regional or national LUV changes, the scale of work is a highly relevant factor, since the availability, temporality, and spatial resolution of the databases directly influence the accuracy of the results (Franco *et al.*, 2006; Peralta *et al.*, 2019). In this sense, the findings of the present research depend on the information contained in Series I and VI of INEGI, and, therefore, may change if more accurate scales are used in specific study areas.

CONCLUSIONS

The records of the 16 pine species at risk in northern Mexico showed changes in the land-use and vegetation categories during the analysis period. From 1985 to 2014, a decrease in the number of matches in the records of the pine species at risk in coniferous forests, scrublands, and oak forests was observed. This phenomenon is part of the land-use changes that took place between the two series. In addition, an increase in records was identified in categories deeply altered by humans, such as urban areas and agricultural lands. Consequently, it is uncertain whether or not these recorded species can currently be found in the initial collection areas, highlighting the importance of further studies on a smaller scale to evaluate national programs for the conservation of the genus *Pinus* in the risk level and the ecosystem services they provide.

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