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Cost Analysis of Seed Conservation of Commercial Pine Species Vulnerable to Climate Change in Mexico

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Abstract: Mexico is home to 40% of the pine species in the world. By the year 2050, 20% of the Mexican forests could be lost because of climate change and other human-related activities. In this paper, we determine the potential areas for seed collecting of four species of the genus *Pinus* and its ex situ economic value under different future Climate Change Scenarios (CCS). The species analyzed were *Pinus oocarpa* Schiede ex Schltdl, *P. rudis* Endl., *P. culminícola* Andresen et Beaman and *P. leiophylla* Schiede ex Schltdl. and Cham which together accounts for 19% of the timber production in Mexico. Potential areas of distribution of populations in habitats with Annual Mean Maximum Temperatures (AMMT) for seed collection were modelled through a Geographic Information System and climate database. The seed storage economic value was determined by using the Collection Cost Method. The AMMT of *P. oocarpa*, *P. rudis*, *P. culminícola* and *P. leiophylla* were 28 °C, 20 °C, 18.3 °C and 27.4 °C, respectively. The economic losses from shortages of these species due to CCS in 2050, were estimated of 88.5 million (USD) and 67.16 million (USD) with severe and conservative future CCS, respectively. The nominal investment rate would be 8.84% or more, for storing seeds of the four species and withstanding climate change. An ex situ seed bank is a medium and long-term investment; among its benefits are establishing a market price for the use and conservation of species in the face of possible adverse scenarios.

Keywords: seed accession; climate change; collection cost; nominal investment rate

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1. Introduction

In Mexico, pine forests are mainly located in mountainous areas with temperate and sub-humid climates. They occupy 21% of the national territory and contain 24% of the recorded flora [1]. The country houses the highest world diversity of the *Pinus* species, having 45 [2]. The *Pinus* species is economically important in Mexico, accounting for 70.87% of the timber production in 2017 [3]. The Community Forestry Enterprises (CFEs) contributed 70% of the timber production [4–6], and locally the forest activity represents almost 30% of the domestic economy of its members [7,8]. Due to the wide distribution of the *Pinus* genus, it is important for the country's economy [9].

Unfortunately, it is predicted that by the year 2050, 20% of the Mexican forests could be negatively lost due to climate change and other related human activities, which could negatively affect both biodiversity and commercial forest timber production [4,10]. During the same period, the natural distribution areas of some of the commercial forest species of the genus *Pinus* are expected to decrease to 50%. Consequently, as a preventative measure for their conservation, it is urgent to collect and bank seeds from different populations of *Pinus* species that are tolerant to drought and able to withstand future higher temperatures [4,11,12].

Germplasm conservation can be done in the form of ex situ or in situ conservation either dynamically or statically [13]. In situ conservation is short term and is important because for many species the method of seed storage or planting is unknown [14]. However, ex situ conservation is long-term and the seed production is affected by the response to the selective forces of the ex situ environment. After the seed or sample is collected and the plantation established for conservation purposes, gene frequencies change through time under the influence of natural or artificial selection [13]. Seed banks (SB), pollen, tissue culture, DNA, and clonal banks, are an alternative to static ex situ conservation. Particularly, SBs allow the conservation of seeds in a reduced space and with a minimum risk of genetic damage. In addition, the wild forest populations constitute a biological resource for the genetic improvement of the species, including the documentation of their current and future distribution range and the evaluation of their seeds for establishing collection sites for its use and conservation [12,15]. In the coming decades, SBs surely will be strategic spaces for the conservation of Mexico's floristic resources [1,16]. Contrary to BS, seed orchards are a dynamic ex situ conservation alternative that allows the propagation of the germplasm of individuals with outstanding characteristics, of economic interest and resistance to extreme environmental seed factors [17]. Although seed orchards are very important to conserve those species that produce recalcitrant seeds, that is, short-lived, such as mahogany and cedar, they can only conserve one or a few species, while SBs allow the conservation of many species of interest at the same time.

However, germplasm conservation through SBs involves ex situ and in situ costs. In situ conservation costs are mainly surveillance, fences, silvicultural treatments, and land rent. On the other hand, ex situ conservation costs involve spending on facilities, energy, fieldwork and maintenance. However, both ex situ and in situ conservation, have expected benefits from the resources that are stored, especially conservation of germplasm of withstanding species that are commercially valuable and important for food security [18]. Therefore, the storage of germplasm of forest species that are resistant or adaptable in seed orchards or SBs requires a benefit–cost analysis of storage and future use [4,19], to build up an integral collection-conservation strategy for their germplasm.

In Mexico, there are no published studies regarding the economic value of seeds from wild plants [3]. The economic value of seeds of pine commercial species that are stored in SBs, is required for understanding the changes of germplasm value in a potential market. We can also determine the degree of scarcity that the seeds will reach during the planning period (i.e., 2020 al 2050) [20]. The above will serve to the generation of consistent public and private policies for in situ and ex situ germplasm maintenance, as well as for the evaluation of adverse climate change scenarios [4].

A variety of economic methods (use value, contingent valuation, damage function, etc.) can be applied for assessing the economic value of conserving natural resources [21–23]. For instance, Camacho [24] and Mora and Echeverría [25] assessed the economic value of germplasm of coffee and palmetto, respectively, and concluded that the annual cost of operating a germplasm bank is considerably lower than the profits that the forestry producers could obtain from using the higher-yield varieties stored in it. In addition, worldwide ex situ seed conservation is estimated to cost just a 1% of in situ conservation [18].

This study aimed to assess the cost of seed storage of four *Pinus* species in a SBs and explore its relationship with abundance and distribution due to climate change. To estimate the cost of seeds collection and their future value in storage conditions, the Collection Cost

Method [26] was used by applying an investment rate to document the future scarcity of them [27]. The environmental application of this method can be seen in the study of mangrove forests [23,26], and the economic costs of generation and management of municipal solid waste [28].

2. Materials and Methods

The research was carried out at the Fes-I UNAM Seed Bank (FESI-SB) of the Faculty of Higher Education, Iztacala (FESI), of the National Autonomous University of Mexico (UNAM). We used information from the FESI-SB regarding the collection and storage of seeds. In addition, we used price quotes and personal information on the costs of seed collection for commercial forest species from the technical forestry service providers (TFSP) and civil agents from the National Forestry Commission (Comisión Nacional Forestal), which is the agency in charge of applying the forestry policy in Mexico.

This research represents a case study of four commercial forest species: *Pinus rudis* Endl., *P. leiophylla* Schiede ex Schltdl. and Cham (commonly known as *P. chihuahuana),* *P. oocarpa* Shiede ex Schltdl, and *P. culminicola* Andresen et Beaman, whose distribution areas are predicted to drastically decrease under future climate change scenarios [4,11,12]. The study was carried out in two phases: (1) the identification of the potential areas for seed collecting of four *Pinus* species adapted to extreme climate conditions, and (2) the assessment of the economic value of seed storage from 2018 to 2050, under their scarcity scenario.

2.1. Identification of Potential Seed Collection Areas from Population Adapted to More Extreme Climatic Conditions

The climatic forecast for Mexico in 2050 predicts severe climate change. Currently, the average temperature rate is 22.2 °C and the average precipitation rate is 793 mm. However, the temperature and precipitation rates will change to 22.7 °C and 660 mm, respectively. Under a conservative scenario, these variables will change to 21.8 °C and 721 mm (IPCC Website http://ipcc-ddc.cru.uea.ac.uk/ (accessed on 22 May 2019)). The response of the four species of pines to these two scenarios: severe and conservative is a decrease in their distribution area of an average of 52.8% and 40.2%, respectively [4] (Table 1).

Table 1. Changes in the potential distribution of Pine species under future severe (HHGGA50) and conservative (HHGSDX50) climate change scenarios.

Species	Potential Distribution km^2			Surface Reduction (%)	
	HH	HHGGA50Mex *	HHGSDX50Mex *	HHGGA50Mex	HHGSDX50Mex
Pinus culminicola	217	127	177	41.5	18.4
P. leiophylla	1737	758	883	56.4	49.2
P. oocarpa	6614	3305	3278	50	50.4
P. rudis	1368	498	783	63.6	42.8
				Average: 52.87	Average: 40.2

Source: [4]; HH = current ecenario; HHG-GA50 = Severe regionalized scenario; HHGSDX50Mex = Conservative regionalized scenario: * Climate change scenarios according to the Intergovernmental Panel on Climate Change (IPCC website http://ipccddc.cru.uea.ac.uk/ (accessed on 22 May 2019)).

A search for the existence of potential populations of the four species located in habitats with extreme climate ranges (extreme mean annual temperature) was undertaken, using the method (recruitment in the ecotone) proposed by Astudillo-Sánchez et al. [29]. We can also use a digital data analysis platform in ArcGis® 9-ArcMap TM Version 9.2, the SMN database [30], and records of the species based on 1336 and 1398 georeferenced points from the vascular plants´ database of the National Biodiversity Information System (Sistema Nacional de información de la Biodiversidad de México) compiled by the National Commission for the Use and Knowledge of Biodiversity (Comisión Nacional de Uso y Conocimiento de la Biodiversidad, CONABIO, http://www.conabio.gob.mx (accessed on 13 May 2019)), and verified by the Worldwide Network of Biodiversity Information [2,31,32].

The following criteria were used for selecting the potential collection areas (PCA): (1) climatic units; (2) current distribution of the four *Pinus* species; and (3) layer overlapping: (a) distribution points of the selected species and (b) most extreme annual average temperatures of the climatic distribution intervals for each species (average temperature of the warmest month and the annual average (Figure 1).

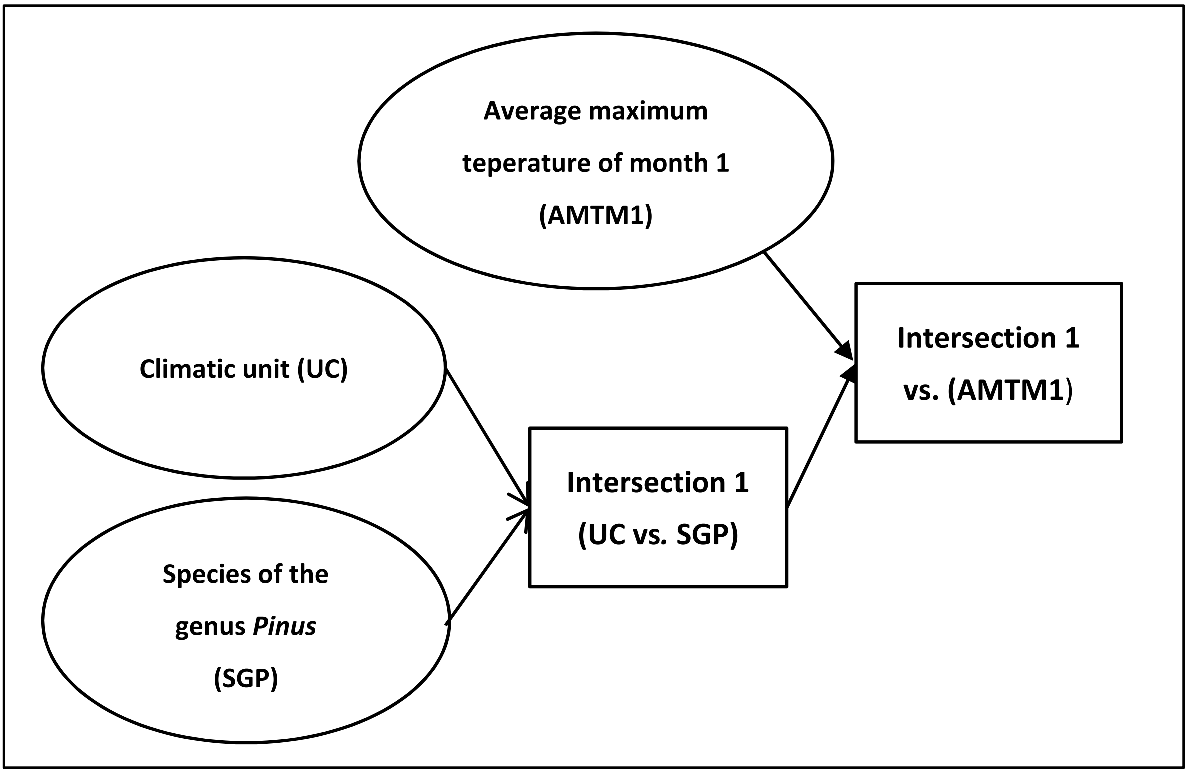

Figure 1. Process for the identification of collection zones.

The basic evaluation unit is a seed accession of each of the four *Pinus* species, which is a sample of 3000 to 4000 differentiable and uniquely identifiable seeds, that represent a cultivar, an improved line, or a population, which is kept in storage for its conservation and use [33].

2.2. Calculation of the Economic Value of Seed Storage for the Period 2018–2050

The economic value of a seed accession was assessed by: (a) estimation of the total collection costs per accession (TCCA); (b) calculation of the yield rate (r) of the accession storage, under its scarcity scenario, and (c) evaluation of the stored accession in the year 2050.

2.2.1. Total Collection Costs per Accession (TCCA)

The total cost of accession is the sum of the fixed and variable costs [27]. In this case, the TCCA is the sum of the fixed costs (FC), which in this case are represented by the infrastructure investment (Equation (1), Table 2), the variable costs or expenses (Equation (2), Table 2) for collecting seeds in different regions of the country and the overall processing and preparation work previous to their storage.

Table 2. Summary of equations utilized in this study.

Name	Equation
Total Collection Cost per Accession (TCCA)	$$TCCA = VC + FC \quad (1)$$ where: TCCA = total collection cost per accession; VC = variable cost; FC = fixed cost.
Variable cost (VC)	$$VC = \left(\sum_{j=1}^{m} Yj * Pj\right) \quad (2)$$ where: VC = variable cost; Yj = stage j of processing the accession for that species; Pj = cost of stage j.
Total cost per accession or lot of storage-ready seeds (TCA)	$$TCA = 2 * VC \quad (3)$$ where: TCA = Total cost per accession or lot of storage-ready seeds; VC = variable cost.
Yield rate (r)	$$\left(\frac{PV2050}{CPV}\right)^{\frac{1}{t}} - 1 = r \quad (4)$$ where: PV2050 = Predicted value of forest production of the genus *Pinus* in the year 2050; CPV = current value of timber production of the genus *Pinus*; t = time, in years, until 2050; and r = movement rate.
Stored seed value in the year 2050 (SSV2050)	$$SSV2050 = (TCA) * (1 + i)^t \quad (5)$$ where: SSV2050 = value of the stored seed in 2050; i = yield rate of storage of one accession under a scarcity scenario of the resource; t = planned period of storage of the seeds.

The criterion for estimating the FC followed the recommendation of Ávila [34], who points out that many organizations establish a markup of nearly 100% of the VC, when it is difficult to predict those costs. Accordingly, the cost per accession or lot of storage-ready seeds is expressed in Equation (3).

2.2.2. Calculation of the Storage Yield Rate (r) of an Accession under a Seed Scarcity Scenario

To calculate the storage yield rate, we used the formula proposed by Brambila [35] (Equation (4), Table 2), based on the data series from the year 1993 to 2016 from INEGI [36], of the forest production value (FPV) of the genus *Pinus*, as well as the participation in the FPV of the four species included in this work. This rate represents a baseline from which it is possible to project the 50-year model, considering a seed scarcity scenario. This is by subtracting the volume of the four species studied by reducing their areas in this ideal scarcity scenario.

2.2.3. Stored Seed Value in the Year 2050 (SSV2050)

To calculate the value of the stored seeds in the year 2050, we used Equation (5) (see Table 2) [24] to compound the interest rate, which consists of obtaining the future value using a nominal rate (see Table 2).

3. Results

3.1. Identification of Potential Seed Collection Areas from Species Adapted to More Extreme Climate Zones

Table 3 and Figure 2 summarize the collection locations for the populations of the selected commercial forest species in habitats that show annual mean maximum temperature (AMMT). The results show that *P. oocarpa* and *P. leiophylla* have the highest AMMT, with 28.0 °C and 27.1 °C, respectively, while *P. culminicola* showed the lowest AMMT of 17.3 °C (*P. rudis* 20.0 °C). To facilitate the collection of germplasm from the four species, we propose two collection points, which correspond to AMMT found in the analysis for each species.

Table 3. Collection locations for seeds from populations of the genus *Pinus*.

Genus *Pinus*	State	Municipality	Community	AMMT (°C)	Coordinates (UTM)	
					Latitude	Longitude
P. oocarpa	Oaxaca	Santo Domingo Tehuantepec	Tehuantepec	28.0	−95,260	16,360
	Oxaca	Santo Domingo Tehuantepec	Buenos Aires	26.1	−95,478	16,336
P. rudis	Jalisco	Ayutla	Ayutla	20.0	−104,346	20,128
	Jalisco	Teocaltiche	Teocaltiche	18.0	−102,573	21,433
P. culmicola	Nuevo León	Galeana	Galeana	18.3	−100,075	24,823
	Nuevo León	Galeana	Cumbre de Sierra la Marta	17.3	−100,394	24,210
P. leiophylla	Michoacán	Tangancicuaro	Patamban	27.4	−102,283	18,800
	Michoacán	Pátzcuaro	El estribo	25.6	−103,283	18,316

Where: AMMT = Annual mean maximum temperature.

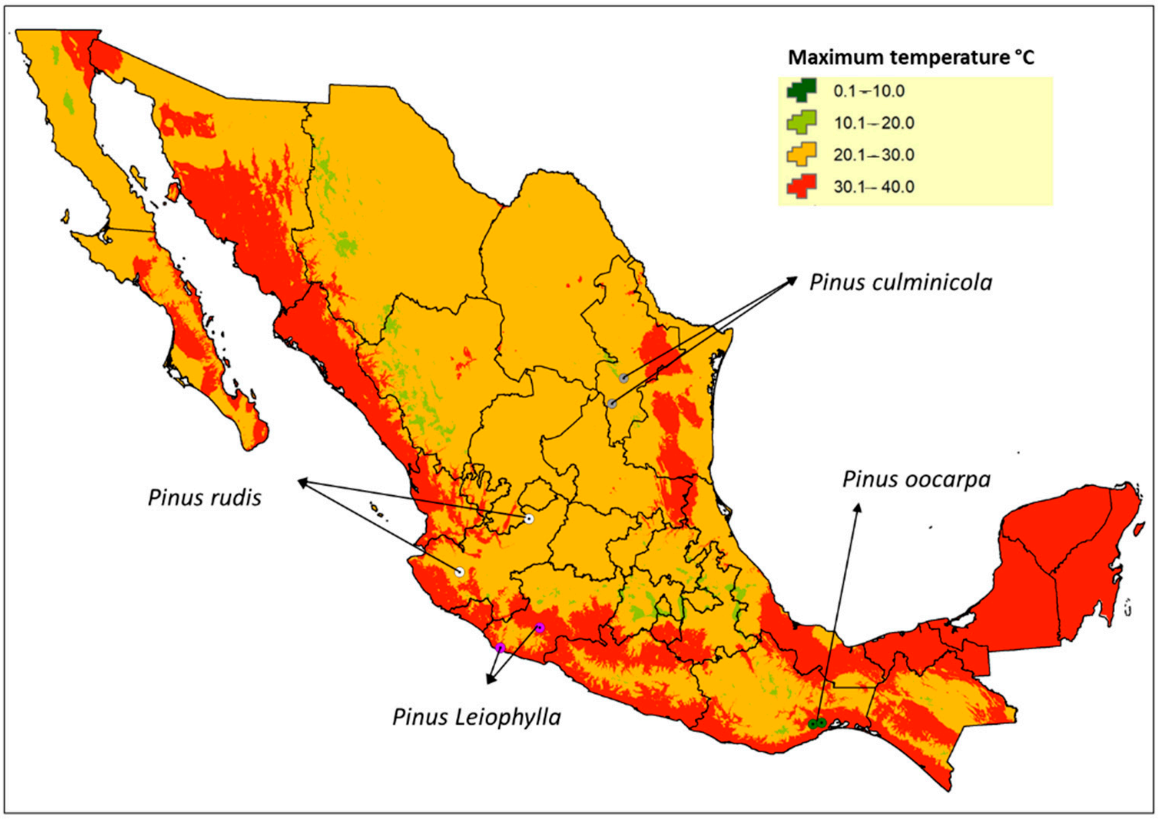

Figure 2. Geographical location of the four pine species in the monthly maximum average temperature models. Source: National Weather Service (SMN) daily weather base 1902–2011. (http://atlasclimatico.unam.mx/atlas/kml/ (accessed on 22 May 2019)).

3.2. Calculation of the Economic Value of Seed Storage for the 2018 to 2050 Period

Total Collection Costs per Accession (TCCA)

In the FESI-SB, the unit cost of collection, preparation, and storage of the seed accessions follow the guidelines expressed in the Kameswara et al. [33] manual. In the FESI-SB there are two collection cost values (one for the northern and southern regions and another one for the central zone). Thus, the different geographic distribution areas of the seeds of the species collected in the country FESI-SB staff are summarized in Table 4. To obtain precise estimations of the total costs (fixed costs plus variable costs), we followed the recommendations of Ávila [34] and Brambila [35], who suggest that TC is equal to twice the VC. Table 5 shows a summary of the TC for seed collection from populations of the four species with the AMMT.

Table 4. Summary of the costs of collection for one accession in US Dollars.

Item	Northern Region (USD)	Central Region (USD)	Southern Region (USD)
(1) Field activities			
Payment (salary) for collection (one person)	16.53	13.63	16.53
Salary for one researcher (team leader) during collection	37.20	29.76	37.20
Food per person (three people)	33.07	26.56	33.07
Transportation to the northern region of the country (three people)	41.33		
Transportation to the central region of the country (three people)		20.67	
Transportation to the southern region of the country (three people)			41.33
Airfare (three people)	86.81	0.00	86.81
Other (equipment and materials for the trip)	28.93	27.93	28.93
Subtotal (1)	243.88	118.55	243.88
(2) Permits and shipment of seeds			
Local permits	12.40	10.42	12.40
Shipment of seeds	10.33	0.00	10.33
Subtotal (2)	22.73	10.42	22.73
TOTAL = (1) + (2)	266.61	128.97	266.61

Note: The quantity and quality of seed collected to obtain an accession will be done according to the manual by Kameswara et al. [33]. Source: Generated by the authors using information from the working group at the FESI-SB.

Table 5. Locations of seed collection of populations o the genus *Pinus*.

Genus *Pinus*	State	Region	VC (USD)	FC (USD)	TC (USD)
P. oocarpa	Oaxaca	Sur	266.61	266.61	533.22
	Oaxaca	Sur	266.61	266.61	533.22
P. rudis	Jalisco	Centro	128.97	128.97	257.94
	Jalisco	Centro	128.97	128.97	257.94
P. culmicola	Nuevo León	Norte	266.61	266.61	533.22
	Nuevo León	Norte	266.61	266.61	533.22
P. leiophylla	Michoacán	Centro	128.97	128.97	257.94
	Michoacán	Centro	128.97	128.97	257.94

Where: VC = variable cost; FC = fixed cost; TC = total cost. Source: Generated by the authors using information from the working group at the FESI-SB.

If the seeds from the four species are collected and stored in an SB, the total costs (TC) for their preparation and storage are shown in column 4 of Table 6. Salaries for cleaning and maintenance make up 63% of the variable costs.

Table 6. Annual cost for the treatment and storage of one accession in a SB.

Item	VC (USD)	FC (USD)	TC (USD)
(1) Sample treatment, viability and germination tests			
Seed cleaning (salary of a technician)	7.40	14.8	22.2
Disposable material	1.81	3.62	5.43
Equipment	0.18	0.36	0.54
Subtotal (1)	9.39	18.78	28.17
(2) Storage			
Maintenance of storage freezer	5.44	10.88	16.32
Annual maintenance	1.09	2.18	3.27
Bags, jars, sealer, markers, etc./annual	1.81	3.62	5.43
Salary for one person to do that job annually	10.88	21.76	32.64
Annual maintenance of the drying room	0.27	0.54	0.81
Subtotal (2)	19.50	39	58.50
TOTAL = (1) + (2)	28.89	57.78	86.67

Where: VC = variable cost; FC = fixed cost; TC = total cost. Sources: Generated by the authors using information from the storage and maintenance staff of the FESI-SB. Calculation of the storage yield rate (r) of one accession under a seed scarcity scenario.

Several authors have studied the participation of the four study species in timber production and their value (Table 7). In the National Forest and Soil Inventory (Inventario Nacional Forestal and de Suelo) and the Forestry Statistics Yearbook [7], the two main documents of forestry statistics in Mexico, the information is given at the genus level. However, they estimate the percentage of timber production of the main forest species, which make up 60% of the national market, as well as some other species. The average percentages of timber production for the species included in this study are: *P. oocarpa* (7%); *P. rudis* (6%); *P. culminicola* (2%); and *P. leiophylla* (4%). Together, they account for 19% of the national timber production.

Table 7. Contribution of the four pine species to the national timber production of the genus *Pinus* according to different authors.

Genus *Pinus*	% Participation, Source
P. oocarpa	6%, [30]; 6%, [37]; 9%, [7]
P. rudis	4%, [38]; 8%, [12]; 6%, [37]; 6%, [7]
P. culminicola	2%, [39]
P. leiophylla	3%, [40]; 5%, [37]; 4%, [7]

Table 8 summarizes the possible timber production loss (millions of USD) due to the reduction of the four forest species studied, under adverse climate change scenarios until the year 2050, accordingly, we used the 1993–2016 time series [20] of the FPV to project.

Table 8. Forest production value of the genus *Pinus* and the study species under climate change scenarios.

FPVt2050 (Million USD)	FPVp (19)2050 (Million USD)	Reduction in Surface (%)		PPFse2050 (Million USD)	
		Severe Scenario	Conservative Scenario	Severe Scenario	Conservative Scenario
881.14	167.41	52.87	40.20	88.50	67.16

Where: FPVt2050 = forest production value of the genus *Pinus* projected to the year 2050; FPVp (19)2050 = participation in the forest production value of the study species projected to the year 2050; PPFse2050 = losses due to average area of reduction of the study species under climate change scenarios. Fuente: the authors.

Figure 3 shows the projection model of FPV (solid line, growth rate 2.4%), by subtracting the volume of the four forest species that will be affected (dotted lines, growth rate 1.84%), according to the climate change scenario.

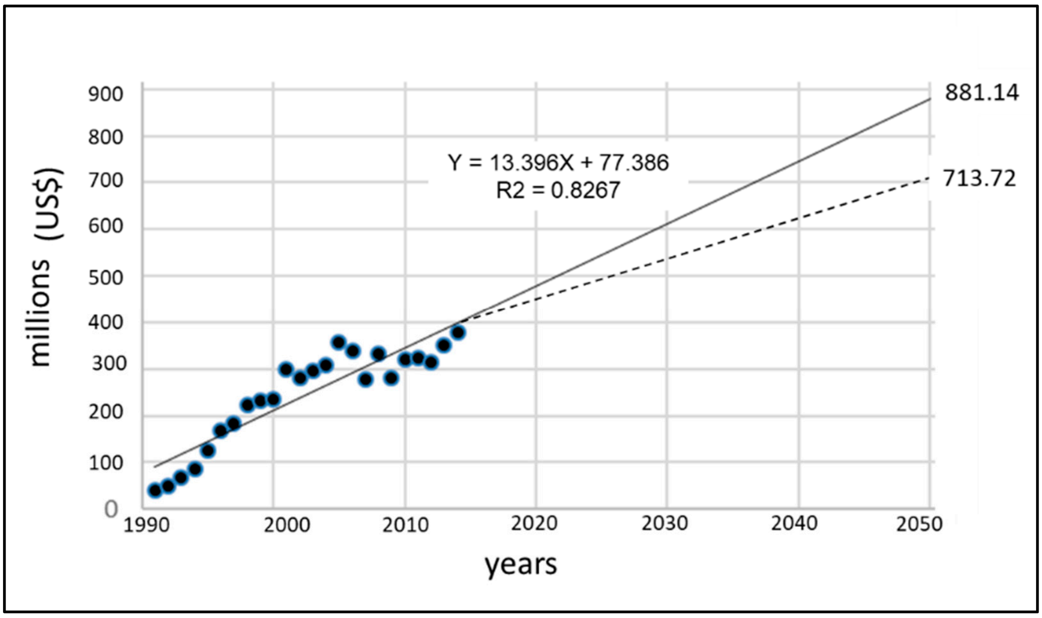

Figure 3. Model projecting the forest production value in 2050. Source: 1993–2016 time series of forest production value [36].

For seed storage in an SB to be profitable, it is important to consider the historical inflation, the opportunity costs, and the adverse events. BANXICO [41] suggests that any investment project should utilize a nominal interest rate at or above 7%. Table 9 summarizes the value of the seeds from the collection points and stored in 2050 (SSV2050) (with an interest rate of 8.84) (7% opportunity cost plus 1.8% due to scarcity).

Table 9. Value of seeds stored in the FESI-BS by the year 2050.

Genus *Pinus*	TCC (USD)	TSC (USD)	SSV2050 (USD)
P. oocarpa	1066.44	177.34	10,840
P. rudis	515.88	177.34	6042
P. culminicola	1066.44	177.34	10,840
P. leiophylla	515.88	177.34	6042

Where: TCC = total collection cost; TSC = total storage costs; SSV2050 = stored seed value in the year 2050.

4. Discussion

There is a similarity between the annual mean maximum temperature (AMMT) found in this work of the four species and that reported by CONABIO [32]. According to CONABIO, the AMMTs for *Pinus rudis*, *P. oocarpa*, and *P. leiophylla* are 20 °C, 26 °C and 30 °C, respectively, and for *P. culminicola* is 23 °C [42]. The little differences may be due to the data collection. In this study, points of distribution of the species were taken (approximately 1300), while CONABIO uses satellite images and polygons [32].

To determine the feasibility of the potential areas for collecting germplasm from the forest species that are resistant to high temperatures, we have used the AMMT. Several studies [43–45] consider that the mean annual temperature is one of the main indicators for the genetic improvement of forest species. However, to improve the precision of geographic coordinates, the method applied for the selection and definition of desired characteristics for forestry species resistant to climate change should include variables such as precipitation, altitude, slope, and exposure [45–47]. In both cases, the collection costs would be the same.

Some authors, such as Castellano-Acuña et al. [47], have considered the mean annual temperature as an indicator of the genetic improvement of *P. leiophylla*, while Sáenz-Romero et al. [5] had used the potential distribution and collection of germplasm to carry out assisted migration in *P. oocarpa*. In the case of *P. culminicola*, it coincides with that reported by García-Aranda et al. [42] on the potential distribution of this species under adverse climate change scenarios in Galaena, Nuevo León.

Although geographic information systems (GIS) are very helpful tools for identifying potential collection areas, these must be complemented with validation in the field. This study proposes that the collection zones should be complemented with research work that includes field data to propose the viability of Forest Germplasm Production Units (FGPU) [7] to guarantee the mass production of the superior genetic material of known origin, and to carry out feasibility studies in terms of costs and benefits to establish seed orchards from the germplasm of the FGPU. Due to the effects of climate change, these forests as sources of local seeds will be increasingly difficult to regenerate [48]

With respect to the value of the seed, Hanemann [26] establishes that one of the challenges of using the collection cost method is evaluating the externalities of a good (SB). For example, it is important to identify the variables that are governed by the market rules, and the main component of the evaluation process is the collection costs. In Mexico, there are no studies on seed collection costs. However, there is a market for the sale of seeds of some forest species (price quotes from TFSP and CONAFOR public servants) with an average price of 42.51 (USD), compared to the calculation of 266.61 (USD) in the northern and southern regions and 128.97 (USD) for the central region (see Table 4). These two organizations have different objectives; while the TFSP and CONAFOR attempt to minimize costs and maximize profits from seed collection and storage, the FESI-SB has the goal of storing seeds for their conservation and research. On that subject, Mattana et al. [49] consider that any investment in research and conservation of phytogenic resources in SBs is minimal compared to the large benefits they provide.

Some authors (see Table 7) differ in their published figures of the national forest production (NFP) and the contribution of each of the study species in percent terms. Caballero [40] points out that this is one of the main problems in the equity accounts of the genus *Pinus*, since the official data are not detailed at the species level. However, CONAFOR-SEMARNAT [7] consider *P. oocarpa* among the species of the genus *Pinus* that make up 60% of timber production. The 19% contribution of the four species is an economic indicator of the NFP under adverse CC scenarios.

Given the predicted scarcity of the study species in the year 2050, losses of 88.5 million (USD) and 67.16 million (USD) are predicted under the severe and conservative CC scenarios (see Table 6). The value of a lot of stored seeds of these species in the year 2050 must consider the following two aspects: (1) to be profitable, any investment project should consider a nominal rate of investment of 7.0%, and (2) according to Brambila [24], the rate to measure movement in NFP is the basic instrument, that allows the dynamic economic analysis to compensate an investment's losses or gains. In this sense, the investment rate for storing a lot of seeds of any species studied should be 8.84%. By the year 2050, the value of accession of any of the four species will be nearly 4000 (USD). This rate differs from the one used by the United States government of 11% for investment in seed improvement and storage of commercial forest seeds, which is one of the highest in the world [50]. According to the FAO [46], this (11%) is because the USA is one of the three countries that dominate timber production worldwide. While FPV2050 served as the main instrument for obtaining the investment rate due to scarcity, it gives an idea of the differences between the total costs and benefits of conserving a resource: nearly 4000 (USD) vs. economic losses due to resource scarcity of 88.5 million (USD) and 67.16 million (USD) under severe and conservative CC scenarios, respectively.

Based on the results of the conservation of seeds from populations of commercial forest species, that are potentially resistant to climate change, valuable information will be available for investment projects, valuation of opportunity costs, public policy building, and as a reference for present and future research related to germination tests to determine the cardinal temperatures of commercial forest species.

Concerning investment and opportunity costs, these could be estimated using a "scarcity rate", product of a "nominal base rate". The assignation of public resources to the storage of germplasm that is resistant to climate change scenarios will always be minimal, even with the high investment rates used by BANXICO.

In this research, we estimate and analyze the costs of collecting and storing seeds from four pine species by using a storage yield rate in a scarcity scenario. Future studies should focus on obtaining the benefits of in situ and ex situ conservation of these species, as well as determining their economic feasibility. Likewise, carry out studies of the profitability of the forest lands that the owners could obtain for the conservation and commercialization of germplasm of the species. Although the methodology has only been applied to four species in this study, it can be applied to other vulnerable species or that may be favored by climate change. For example, it has been observed that *Cedrela odorata* L. is a species that can expand its natural distribution in the face of such changes [51], hence the importance of estimating how these changes could affect the profitability of conservation.

5. Conclusions

It is possible to locate potential collection areas for populations of commercial forest species that are better adapted to future climate change scenarios as a function of their natural distribution by using the annual mean maximum temperature.

The investment rate for storage of accession of seeds from populations of the forest species *P. oocarpa*, *P. rudis*, *P. leiophylla* and *P. culminicola* should be equal to or greater than the 8.84% nominal interest rate. The total cost of conserving an accession from a CC-resistant species until the year 2050 is nearly 4000 (USD).

The economic losses due to scarcity of *P. oocarpa*, *P. rudis*, *P. leiophylla* and *P. culminicola* under possible CC scenarios could be up to 88.5 million (USD) and 67.16 million (USD) under severe and conservative CC scenarios, respectively.

From the economic point of view, an ex situ SB is a medium and long-term investment, among its benefits: establishing a market price for the use and conservation of species in the face of possible adverse scenarios.

This research is important because of the methodological approach it proposes to economically evaluate the storage and conservation of seeds under future CC scenarios. The study approach can not only be applied to the forest species studied, but also to any forest species or population that presents social, economic and environmental interest and that is threatened or in danger of extinction due to CC, changes in the use of the earth, fires, hurricanes, others. By identifying the spatial distribution of the species of interest based on the AMMT, it is possible to identify those areas with a potential distribution where the seeds of interest can be collected. However, to specify the collection areas, the methodology should be expanded considering, in addition to the AMMT variables, precipitation, altitude, slope and exposure.

Determining the value of germplasm collection and conservation can have different benefits for the actors involved. For landowners who possess desirable germplasm, there is an opportunity cost of conserving in situ, either through FGPU or seed orchards, on land that maintains seed-producing forests and that they can now quantify, through this proposed method, a real or added value of the non-timber forest resource. For the government, it is responsible to conserve the natural heritage as a public good and have a policy with a strategic vision, anticipating possible potential events. It should encourage institutions or individuals to conserve either in situ or ex situ these forest species or others that have a benefit, for what it represents in terms of cost benefits, higher profits. For society in general and the environment, this is one of the few works that establish a methodology to evaluate ex situ conservation before the CC, for which it is an ethical responsibility to ensure natural heritage for new generations and with it all the economic and environmental benefits that this entails.

To continue this research, it is suggested to prioritize the importance of the species of interest, determine which species of germplasm should be protected ex situ, which would be those priority conservation areas (in situ) and which conservation strategies. Finally, what would be the costs and benefits of collecting, storing and conserving for a long period. In addition, in future research, it is recommended to use this same research pattern to collect and value the seeds of those species that could be potentially at risk and that are important from the economic, social and environmental point of view.

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