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Article

Cosecha de madera de 20 coníferas en zonas de movimiento de germoplasma

Harvest of timber from 20 coniferous in germplasm movement zones

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Resumen

Para México, en las últimas décadas los bosques naturales de coníferas han proveído de beneficios económicos. No obstante, en ellos se demanda su administración con el menor impacto posible. La regionalización basada en las Zonas de Movimiento de Germoplasma (ZMG) es una alternativa para la gestión de las masas arbóreas, que no limita los esfuerzos económicos y técnicos de las áreas operativas locales, estatales o de unidades de manejo forestal; sin embargo, son pocos los trabajos desarrollados con esta visión. Para determinar la cosecha de madera de las principales coníferas del país en las ZMG, se analizaron datos estatales sobre volumen de madera producida para especies de *Pinus* y *Abies* de 2013 a 2017. Se determinó que 19 taxones de pino y uno de oyamel son los que más contribuyeron a la producción forestal nacional. En particular, *P. patula*, *P. douglasiana*, *P. maximinoi*, *P. pseudostrobus*, *P. teocote*, *P. oocarpa*, *P. montezumae* y *P. devoniana* proveyeron 81.39 % del volumen total de los pinos; y con respecto al otro género, *A. religiosa* suministró 100 % del volumen total. Asimismo, las zonas X.3, V.3, XII.5, XII.3, X.1, XII.2, III.1, III.2 registraron 84.14 % de la cosecha de madera de pino, y X.3 acumuló 72.16 % de la correspondiente al oyamel.

Palabras clave: *Abies*, coníferas de México, conservación de bosques, gestión forestal, *Pinus,* Semarnat.

Abstract

In the last decades the coniferous forests have provided economic benefits for Mexico. However, they demand a management with the least possible impact. Regionalization based on the Germplasm Movement Zones (GMZs) is an alternative for the management of the tree stands that does not limit the economic and technical efforts of the local, state or forest management units. However, few works have been developed with this vision. In order to determine the timber production of the main conifer species of the country in the GMZs, the data on the volume of timber produced from *Pinus* and *Abies* species by state from 2013 to 2017 were analyzed. Nineteen pine and one fir species contributed most to the national forest production. Specifically, *P. patula*, *P. douglasiana*, *P. maximinoi*, *P. pseudostrobus*, *P. teocote*, *P. oocarpa*, *P. montezumae* and *P. devoniana* provided 81.39 % of the total volume among the pines, and *A. religiosa* supplied 100 % of the total volume from the *Abies* genus. Likewise, zones X.3, V.3, XII.5, XII.3, X.1, XII.2, III.1, and III.2 account for 84.14 % of the timber production, and X.3 provided 72.16 % of the fir timber output.

Keywords: *Abies*, conifers species of Mexico, forest conservation, forest management, *Pinus*, Semarnat.

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Introduction

Globally, forests play an important role in providing humankind with goods and services, as well as with a wide range of economic and social benefits. The management of 1.2 billion hectares used for timber production (FAO, 2016) is estimated to generate a profit over time for holders of forest areas and companies involved in the process of transformation of products such as sawn timber, for example. The economic impact of forest harvesting has been calculated by considering the unit value (market price) and the volume of marketed product; while its social impact has been estimated with indirect measures that can be quantified and monitored over time (Moctezuma and Flores, 2020).

Mexico is classified as a country with forest aptitude due to the diversity of species found in its territory (Gernandt and Pérez-De la Rosa, 2014). Thus, in 2017, 65 692 000 hectares of forests were dedicated to the production of 8.5 million m^3 of roundwood (FAO, 2020; Semarnat, 2020), in which conifers stood out for their participation in the national Gross Domestic Product (GDP) (Inegi, 2020; Semarnat, 2020). This situation has led to the implementation of sustainable management programs at the local and state level, such as Forest Management Units, under forestry methods that seek to increase productivity and guarantee the continuity of taxa (Semarnat, 2018). However, such programs are not entirely clear as to the economic and social values that one or more species provide at different levels of management, for example, administrative zones with different geographic, climatic and taxa growth areas, or germplasm movement zones.

The Mexican National Forest Commission (Conafor) defined germplasm movement zones (GMZs) as homogeneous areas in terms of climate and latitudinal or longitudinal distribution (Conafor, 2016) for the regulation of seeds, fruits and vegetative material, whereby the movement of plant material out of its natural distribution has been reduced. These zones are home to species that can be operationally managed for several goods (*e.g.* timber harvesting), as they have an appropriate level of regionalization (Flores, 2019). In this regard, few studies have developed any proposal for the management of products or services derived from the

forest in the GMZs, such as *Abies religiosa* (Kunth) Schltdl. & Cham.) timber production (Flores, 2019) or the estimation of their potential, *e.g.,* the feasibility of restoring degraded areas with pine species (Flores *et al*., 2021).

Given the scarcity of information, the purpose of this study was to estimate the volume of timber harvested from Mexico's main conifer species. The document is intended as a basis for decision making during forest management and conservation. The objective of this research was to determine the timber harvest of 20 conifer species in the GMZs, for which the following questions were posed: 1) Is the volume of timber in the GMZs variable? and 2) Is the amount of conifer timber present in each GMZ different? This information will allow for increased forest management efforts in the areas of greatest timber harvest to ensure the sustainability of the species they harbor. The hypothesis formulated was that timber harvesting in the GMZs depends on the species present in the area.

Materials and Methods

The timber harvest of the main conifer species used in the Mexican forest industry, obtained from the natural forests of the GMZs, was determined. The GMZs defined by Conafor (2016) and distributed across the entire forest area of the country were selected; they were chosen because they have a level of regionalization that allows them to be used as areas for the management of forest species at the national level (Flores, 2019).

Two of the most harvested genera, which contribute 73.4 % of the national timber forest production in 2017, were analyzed (Semarnat, 2020): *Pinus* and *Abies*. These taxa are part of the cold temperate forests of the country's mountain ranges: Western *Sierra Madre*, Eastern *Sierra Madre*, Transversal Neovolcanic Axis, Southern *Sierra Madre*, Central American *Sierra Madre* and *Chiapas* Highlands. They are found in pure areas or mixed with other conifer species or with oaks (Rzedowski, 1979).

For each genus, the annual and average timber harvest was estimated from the databases of the species included in the state reports of the Ministry of Environment and Natural Resources (Semarnat, 2013 to 2017). The percentage contribution of each taxon to the total national volume was also calculated. This information was used because it is a record of the forest production by species, utilized to prepare the Statistical Yearbooks of Forest Production from 2013 to 2017.

On the other hand, the annual and average volumes of timber harvested from 2013 to 2017 in each GMZ were determined, using the Flores method (2019). This method consists in making the proportional allocation of the average timber forest production (m^3r) of each genus based on the distribution of the species, which was determined based on the geographic data (latitude and longitude) of the plots of the National Forest and Soil Inventory 2004-2007 (Conafor, 2018) depicted with the QGIS software (http://qgis.osgeo.org) (QGIS Development Team, 2015). In addition, the average timber harvest was calculated for the species with the highest contribution in the most productive GMZs.

Finally, the volumetric increments were measured at a compound interest rate for the *Pinus* and *Abies* genera with their respective species, and for the GMZs, using the average annual growth rate (AAGR), which is used in medium- and long-term periods (Moctezuma and Flores, 2020). In the case of the present study, the five-year period was medium-term. Its mathematical function is as follows (Cuevas- Reyes, 2017):

$$AAGR = [((Fv/Iv)(1/n - 1)) - 1] * 100$$

Where:

Fv = Final value for the period

Iv = Initial value for the period

n = Number of years of the period

In those instances in which certain species and GMZs exhibited series from which records for one or more years were absent, their AAGR was not considered because they were not comparable.

Data on timber volumes harvested by state are registered and available for consultation in the Zenodo repository (https://zenodo.org/), a European open access online repository of research results data. Reference must be made to the citation of this article in order to access this database.

Results

The timber harvest of 20 conifer species in the GMZs of Mexico was determined using state records for two genera. Specifically, *Pinus* had the highest contribution to timber volume with 19 species and *Abies* the lowest with one taxon (Table 1). As for the domestic timber harvest, the volumes of *P. patula* Schiede ex Schltdl. & Cham., *P. douglasiana* Martínez, *P. maximinoi* H. E. Moore, *P. pseudostrobus* Lindl., *P. teocote* Schiede ex Schltdl. *et* Cham., *P. oocarpa* Schiede ex Schltdl. *et* Cham., *P. montezumae* Lamb., and *P. devoniana* Lindl. timber made up 81.39 % of the total for the genus in the period considered; while in the case of sacred fir, *A. religiosa*, the percentage was 100 % because it was the only *Abies* species recorded in the consulted sources.

Considering the total timber harvest as the sum of the average forest production of *Pinus* species plus that of *Abies*, the contribution of this genus was 84.92 %, which shows that these are the dominant genera in the production of m^3 of timber in Mexico. As for the AAGRs of both genera during the study period (2013 to 2017), *Pinus* increased its harvested volume by 8.25 %, while *Abies* registered a decrease of -2.14 %. The pine taxa with the best AAGR were *P. devoniana*, with 86.94 %; *P. douglasiana*, with 77.94 %, and *P. herrerae* Martínez, with 74.98 %.

Table 1. Annual and average timber harvests by species, harvested from 2013 to 2017 from 20 species, and contribution by each species to the total volume of each genus in the GMZs.

Species	Timber harvest (m^3)						Contribution¶ (%)
	2013	2014	2015	2016	2017	Average	
P. patula Schiede ex Schltdl. & Cham.	50 915.61	87 239.74	136 142.31	142 085.75	142 688.55	110 029.69	25.49
P. douglasiana Martínez	5 027.34	54 639.14	80 414.68	55 691.94	89 693.43	56 554.19	13.10
P. maximinoi H. E. Moore	20 314.88	37 589.82	17 321.93	67 234.22	84 583.79	53 303.97	12.35
P. pseudostrobus Lindl.	13 065.69	27 256.49	28 308.44	39 340.66	63 816.59	35 667.48	8.26
P. teocote Schiede ex Schltdl. *et* Cham.	22 219.19	27 168.22	26 925.65	28 095.78	42 338.61	29 111.48	6.74
P. oocarpa Schiede ex Schltdl.	5 016.02	19 585.77	23 611.34	26 007.66	26 753.63	23 695.54	5.49
P. montezumae Lamb.	14 341.10	23 113.14	25 723.18	30 772.98	25 327.38	23 522.76	5.45
P. devoniana Lindl.	889.28	26 078.11	42 364.94	8 946.29	20 301.72	19 420.78	4.50
P. ayacahuite Ehrenb. ex Schltdl.	21 676.91	9 231.66	15 199.41	18 211.43	22 548.01	17 834.97	4.13
P. leiophylla Schiede ex Schltdl. *et* Cham.	14 285.00	11 678.57	27 653.48	9 781.02	15 217.49	15 549.68	3.60
P. arizonica (Engelm.) Shaw	44 363.84	9 940.10	8 684.43	1 309.76	635.00	13 409.88	3.11
P. engelmannii Carrière	21 167.73	18 484.27	5 019.29	2 119.46	4 440.39	10 651.16	2.47
P. durangensis Martínez	25 752.91	9 503.47	2 708.63	739.37	2 614.87	8 520.35	1.97
P. herrerae Martínez	1 070.40	1 756.61	2 475.20	10 915.88	17 556.70	7 678.13	1.78
P. lumholtzii B. L. Rob et Fernald	960.52	4 323.56	7 601.61	2 605.12	5 158.71	4 193.01	0.97
P. pringlei Shaw	0.00	0.00	0.00	716.72	6 787.35	1 876.02	0.43
P. hartwegii Lindl.	0.00	250.00	0.00	2 127.90	0.00	462.37	0.11
P. lawsonii Roezl ex Gordon	0.00	0.00	0.00	26.44	484.28	127.68	0.03
P. greggii Engelm. ex Parl.	0.00	0.00	11.19	4.73	127.75	27.94	0.01
Subtotal	261 066.41	367 838.67	450 165.70	446 733.12	571 074.25	431 637.08	100.00
Abies religiosa (Kunth) Schltdl. *et* Cham.	67 242.09	76 749.89	81 100.30	97 805.37	60 327.57	76 645.04	100.00
Subtotal	67 242.09	76 749.89	81 100.30	97 805.37	60 327.57	76 645.04	100.00
Total	328 308.50	444 588.55	531 265.99	544 538.49	631 401.82	508 282.12	

Source: Prepared by the authors with data from Semarnat (2013 through 2017).

The contribution of each taxon to the total volume in the GMZs was estimated based on the average harvest of five years (from 2013 to 2017).

In regard to the annual and average volumes of timber harvested by genus in each GMZ, the *Pinus* species were distributed among 20 GMZs and accounted for 84.55 % of the total timber harvest; the *Abies* species was located in five GMZs, and its timber harvest amounted to 15.45 % (Table 2). Therefore, these areas have an important potential for timber harvesting at the national level.

Table 2. Annual and average timber harvests from 2013 to 2017 from *Pinus* and *Abies* in each germplasm movement zone (GMZ).

GMZ	Timber harvest (m^3)					
	2013	**2014**	**2015**	**2016**	**2017**	**Average**
Pinus						
X.3	31 516.17	66 735.91	88 480.74	89 921.72	90 451.64	73 421.24
V.3	38 767.34	51 981.93	65 149.27	73 297.43	86 522.66	63 143.73
XII.5	27 556.26	45 694.58	65 926.89	69 958.82	67 258.82	55 279.08
XII.3	0.00	0.00	0.00	95 343.97	134 889.91	46 046.77
X.1	2 746.82	45 422.77	73 639.69	31 856.07	50 273.17	40 787.70
XII.2	1 780.11	23 945.71	35 015.13	34 613.41	55 052.44	30 081.36
III.1	51 946.94	21 120.42	14 262.50	13 339.68	14 052.27	22 944.36
III.2	64 212.22	26 841.44	10 290.43	2 310.45	2 238.73	21 178.65
XII.1	1 180.45	23 104.87	33 922.04	16 863.99	28 189.08	20 652.09
III.4	4 890.01	10 361.07	22 814.55	13 768.68	33 160.37	16 998.94
XIV.1	12 977.79	20 875.04	12 903.19	538.44	636.66	9 586.22
XV.1	8 215.46	19 320.20	16 806.04	1 364.88	700.60	9 281.44
III.3	8 456.20	3 822.50	2 642.49	1 440.57	3 828.23	4 038.00
XIV.2	3 875.36	6 618.79	3 556.55	225.39	208.89	2 897.00
VIII.3	465.30	1 530.27	1 000.55	1 238.58	2 224.21	1 291.78
VIII.4	2 416.67	336.41	345.06	637.82	1 380.34	1 023.26
V.1	0.00	0.00	3 037.74	0.00	0.00	607.55
XIV.3	29.30	114.54	135.60	12.52	4.72	59.34
V.2	0.00	0.00	233.67	0.00	0.00	46.73
IV.1	34.02	12.20	3.58	0.68	1.51	10.40
Subtotal	261 066.41	367 838.67	450 165.70	446 733.12	571 074.25	419 375.63
Abies						
X.3	50 162.41	59 391.72	65 074.14	60 916.03	40 984.52	55 305.76
X.2	15 158.80	13 945.04	12 843.20	27 541.02	14 704.31	16 838.47
XII.3	1 920.88	1 514.50	1 284.32	2 959.07	2 608.69	2 057.49
XII.1	0.00	1 107.53	1 107.53	3 727.06	1 184.20	1 425.27
X.1	0.00	791.10	791.10	2 662.19	845.85	1 018.05
Subtotal	67 242.09	76 749.89	81 100.30	97 805.37	60 327.57	76 645.04
Total	328 308.50	444 588.55	531 265.99	544 538.49	631 401.82	496 020.67

Source: Prepared by the authors with data from Semarnat (2013 to 2017).

In particular, eight GMZs (X.3, V.3, XII.5, XII.3, X.1, XII.2, III.1, III.2) excelled in the average *Pinus* timber harvest, as they contributed 84.14 % (Figure 1); however, only GMZ X.3 contributed a significant amount of *Abies* timber, i.e., 72.16 %; this was due to the presence of a higher density of trees in that zone (Figure 2).

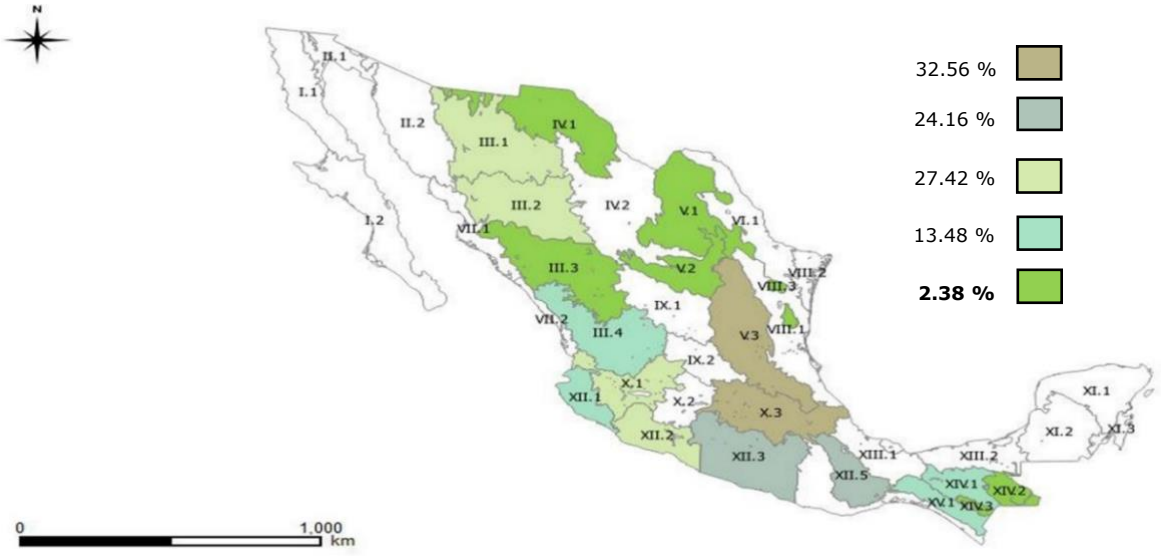

Figure 1. *Pinus* timber volume percentage harvested in the germplasm movement zones.

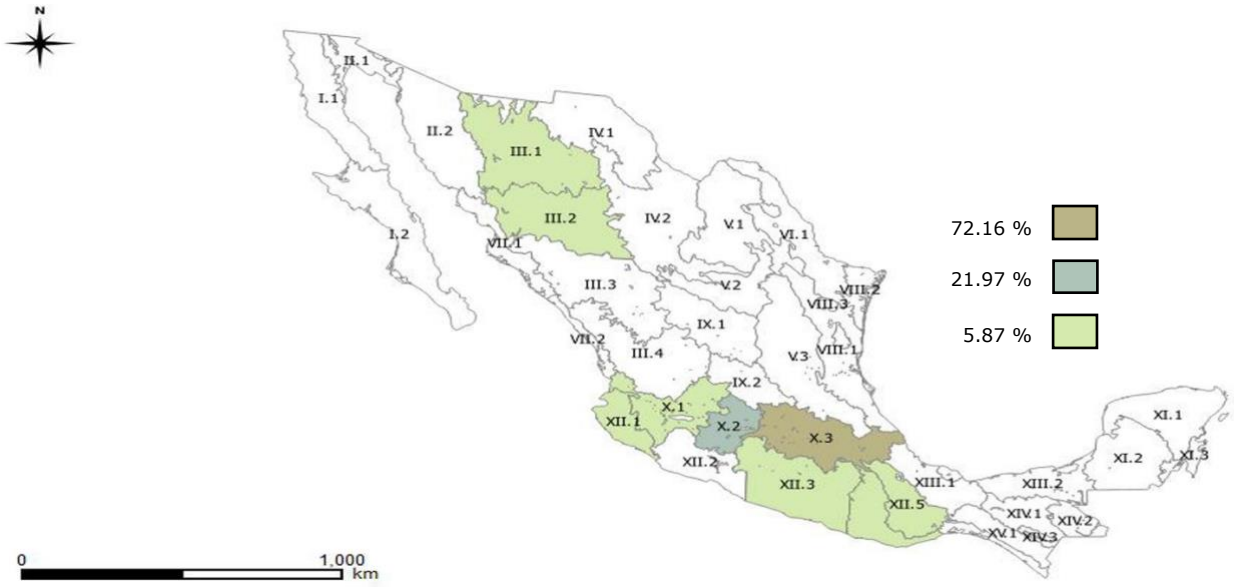

Figure 2. *Abies* timber volume percentage harvested in the germplasm movement zones.

The AAGR of the GMZs with *Pinus* was 16.95 %; while in those with the *Abies* genus, it decreased by -2.14 %; for the zones as a whole, on a weighted basis, it amounted to 13.78 %. The negative rate of *Abies* shows that the production of the species decreased during the analyzed period, which led to a decrease in its AAGR. The first year of analysis was 67 242.09 m^3, and the final year was 60 327.57 m^3; despite the fact that in the intermediate years the values were above the initial value.

In relation to the average timber harvest, the species with the highest contribution were: *P. patula, P. douglasiana, P. maximinoi, P. pseudostrobus, P. teocote, P. oocarpa*, *P. montezumae*, and *P. devoniana. A. religiosa* also contributed significantly (Table 3).

Table 3. Average timber harvest of nine conifer species in eight germplasm movement zones (GMZs).

Species	GMZ							
	X.3	**V.3**	**XII.5**	**XII.3**	**X.1**	**XII.2**	**III.2**	**III.1**
P. patula Schiede ex Schltdl. & Cham.	39 110.33	39 180.93	33 523.14	0.00	0.00	0.00	0.00	0.00
P. douglasiana Martínez	0.00	0.00	0.00	3 121.94	24 278.58	17 851.89	42.29	8.85
P. maximinoi H. E. Moore	0.00	0.00	0.00	23 517.33	3 112.06	4 409.50	0.00	0.00
P. pseudostrobus Lindl.	7 017.41	12 357.17	7 702.45	4 237.14	122.53	1 011.86	0.00	45.40
P. teocote Schiede ex Schltdl. *et* Cham.	20 260.80	5 116.29	0.00	990.64	0.00	24.16	39.49	0.00
P. oocarpa Schiede ex Schltdl.	0.00	84.71	0.00	9 066.82	0.00	870.05	5.76	0.00
P. montezumae Lamb.	4 269.21	6 329.16	12 807.63	324.31	0.00	0.00	0.00	0.00
P. devoniana Lindl.	0.00	0.00	0.00	202.73	7 609.81	3 695.75	0.00	0.00
Subtotal	70 657.75	63 068.26	54 033.21	41 460.91	35 122.98	27 863.21	87.55	54.25
A. religiosa(Kunth) Schltdl. & Cham.	54 211.26	0.00	0.00	2 057.49	1 018.05	0.00	0.00	0.00
Subtotal	54 211.26	0.00	0.00	2 057.49	1 018.05	0.00	0.00	0.00
Total	124 869.01	63 068.26	54 033.21	43 518.40	36 141.03	27 863.21	87.55	54.25

Source: Prepared by the authors with data from Semarnat (2013 to 2017).

Table 3 shows that the best zones for the *Pinus* genus, in order of importance, were X.3, V.3 and XII.5; while for *Abies* it was the X.3 zone. In general, the best GMZ was X3, which may be related to the density of trees in it and to the growth and increase in the number of forest stands in the zone (Flores, 2019).

Discussion

This study estimated the volume of timber harvested from the *Pinus* and *Abies* genera in the GMZs, which allowed to identify that eight pine species and one fir species had the greatest contribution to the total volume recorded in the germplasm movement zones. The results of the study showed that the amount of m^3 of timber in the GMZs was variable due to the presence/absence of different taxa in each zone.

According to the information obtained in the annual state reports of the General Directorate of Forest and Soil Management of Semarnat: *P. patula*, *P. douglasiana*, *P. maximinoi*, *P. pseudostrobus*, *P. teocote*, *P. oocarpa*, *P. montezumae*, and *P. devoniana* had the highest participation in the GMZs. Nevertheless, during the data analysis there were some states that were not included because they lacked records on the volume harvested by species, and only had them by genus; for example, *Durango*. The timber harvest of each taxon in the GMZs presented in this paper is an approximation of what is harvested.

In general, *Pinus* had an upward trend as measured by its AAGR for the 2013 to 2017 harvest, and so did *Abies* as well; the latter genus, however, exhibited a significant decrease in 2017. This is due to the fact that in Mexico there is a greater distribution of pine species than of firs, and consequently, the contribution of *Pinus* to the national timber output and GDP is higher (Moctezuma and Flores, 2020). Still, there may be increases in the volume harvested, as indicated by Torres-Rojo *et al.* (2016) who point out that the national forest harvest is variable and does not meet the annual demand for products, having a deficit of $6 165.60 million USD (Conafor, 2019).

As for the timber harvest by GMZ, those GMZs with significant *Pinus* participation had an average annual output of over 20 000 m^3 per year; while that of *Abies* was

>50 000 m^3. In this regard, zones X.3, V.3, XII.5, XII.3 and X.1 are considered very relevant; since, according to Flores (2018, 2019), a GMZ is taken as highly productive when the timber volume harvested in it is >40 000 m^3. This characteristic is related to tree density in natural forests (Ruelas and Dávalos, 1999). In both genera, the greatest volume harvested was concentrated in the zones located at the center of the country, which shows the need to implement sustainable management in that region, since the harvesting of the species studied is higher there than in the rest of the zones analyzed.

The eight GMZs that contributed most to timber harvesting require management in order to keep a sustainable production by species, for example, by legally authorizing forest harvesting and regulating the harvesting of forests subject to illegal logging (Caballero, 2005). As for the rest of the GMZs, strategies must be implemented to augment the logging volumes and the forest zones through actions that will increase the survival rate of the plants used in reforestation programs, and commercial forest plantations must be established.

The species with the greatest participation in the timber harvest in the GMZs have great relevance for the forestry sector and the forest industry of the country. Thus, *P. patula* and *P. oocarpa* are used in plantations because of their rapid growth and of the timber volume that they produce (Dvorak, 2012; Gwaze *et al.*, 2000); *P. pseudostrobus*, *P. oocarpa*, and *P. devoniana* have the potential to restore areas with a low or medium degradation (Flores *et al*., 2021); *P. douglasiana*, *P. montezumae*, and *P. maximinoi* are used in the sawmilling industry for the production of square timber (Zavala and Hernández, 2000); *P. devoniana* is used in the paper industry (Escoto *et al.*, 2017); *P. teocote* is important for resin production (Wadsworth, 2000); *P. ayacahuite* has an ornamental use, as a Christmas tree (Álvarez *et al.*, 2009), and *A. religiosa* is used to manufacture pulp for paper, packing boxes, poles, beams, pilings, firewood and charcoal (Arriola *et al*., 2015).

The results obtained on the annual timber harvest volume of the species under study show that regionalization by GMZs is an option for tree stand management, since it is based on the number of species and their distribution. These elements determined

the variability of the volume of timber in the zones, as well as the differences in the amount of wood from the conifer species analyzed.

Conclusions

Pinus and *Abies* are the main conifer genera that contribute to the timber harvest in the GMZs; and of these, the greater contribution comes from pine taxa, in particular: *Pinus patula*, *P. douglasiana*, *P. maximinoi*, *P. pseudostrobus*, *P. teocote*, *P. oocarpa*, *P. montezumae*, and *P. devoniana*; while in the case of fir, it comes from *A. religiosa*. This confirms the proposed hypothesis that timber harvesting in the GMZs depends on these species.

In regard to the impact of the results obtained based on the research questions formulated, the information generated on timber production in the GMZs was particularly helpful.

On the other hand, this study is a basis for decision makers, as it will allow them to prioritize activities in the preparation of forest development plans and programs to increase the management efforts in the zones with the highest timber harvest in order to guarantee the sustainability and conservation of the species they harbor.

In terms of growth, pine timber shows a positive trend over the five years of the study, which highlights its importance in production. The opposite is true of fir, which exhibits a negative behavior. This calls for the intervention of managers and officials from various government agencies and non-governmental organizations, as well as from national and international research centers, and public and private academic centers related to forest activities that contribute to the orientation towards forest research, management and transfer of the monetary, material and talent resources allocated to them.

Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Andrés Flores: conception of the idea, formulation of the methodology, data analysis, and drafting of the manuscript; Georgel Moctezuma-López: development of the methodology, data analysis and drafting of the manuscript. Both authors have read and agree to publish the document.

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