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Research article

Efecto del manejo forestal maderable sobre la estructura y diversidad del bosque de *Pinus* L. en Oaxaca, México

Effect of timber forest management on the structure and diversity of the *Pinus* L. forest in *Oaxaca* state, Mexico

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Abstract

Regeneration cutting methods in forest management generate changes in the vegetation structure. The objective was to evaluate two forest management methods and analyze the application of three forestry treatments: group selection, regeneration cutting of parent trees and individual selection (TS) on the structure of stands in *Santa María Jaltianguis*, *Oaxaca* state, Mexico. The evaluation was carried out in 2023 in 30 circular sites of 400 m^2 in which the tree, shrub and herbaceous stratum were measured, all individuals were identified and the forest inventory variables of greatest interest were considered: diameter at breast height. The TS were differentiated using a generalized linear model and test of means (Tukey, 0.05). The greatest richness was recorded in the rainy season with a total of 49 species belonging to the Asteraceae, Pinaceae, Rosaceae and Fagaceae families; the effect of forestry treatments in the vegetation strata was more evident in herbaceous plants; in the tree stratum, *Pinus patula* was the species with the highest frequency and greatest importance (*IVI*), the highest diversity was obtained in the tree stratum, regeneration cutting treatment Shannon=2.25, and the lowest in individual selection cutting in the shrub stratum Shannon=1.27, presenting significant differences. These results are important to consider in the application of TS for decision making in forest management and conservation.

Key words: Tree stratum, herbaceous, diversity index, Importance Value Index, species richness, forestry treatments.

Resumen

El tratamiento de cortas de regeneración en el manejo de los bosques genera cambios en la estructura y diversidad de la vegetación. El objetivo fue evaluar dos métodos de manejo forestal y analizar la aplicación de tres tratamientos silvícolas: corta de regeneración de selección en grupos, corta de regeneración de árboles padres y selección individual (TS) sobre la diversidad y estructura de rodales en Santa María Jaltianguis, Oaxaca, México. La evaluación se realizó en 2023 en 30 sitios circulares de 400 m^2, en los cuales se midió el estrato arbóreo, arbustivo y herbáceo; se identificaron todos los individuos y se consideró al diámetro normal como la variable dasométrica de mayor interés, además de conocer la distribución diamétrica irregular de los TS, los cuales se diferenciaron mediante un modelo lineal generalizado y la prueba de medias tipo *Tukey* (α=0.05). La mayor riqueza se registró en la temporada de lluvias con 49 especies pertenecientes a las familias Asteraceae, Pinaceae, Rosaceae y Fagaceae. El efecto de los tratamientos silvícolas fue más evidente en el estrato herbáceao; en el arbóreo, *Pinus patula* fue la especie más frecuente y de mayor importancia (*IVI*). La más alta diversidad de *Shannon*=2.25 se obtuvo en el estrato arbóreo, tratamiento de corta de regeneración de árboles padres; la más baja en corta de selección individual en el estrato arbustivo con *Shannon*=1.27, con diferencias significativas. Estos resultados deben considerarse en la aplicación de los TS para la toma de decisiones en el manejo y conservación de los bosques.

Palabras clave: Estrato arbóreo, herbáceas, índice de diversidad, Índice de Valor de Importancia, riqueza de especies, tratamientos silvícolas.

Introduction

Mexico's and the world's forests in general have experienced considerable deterioration in recent decades due to inappropriate public policies, the incorrect implementation of forest management programs, deforestation caused by various activities, natural and social phenomena (Romo et al., 2016). Research, evaluation and monitoring of forest management are essential to ensure the sustainability of ecosystems through management and conservation (Castellanos-Bolaños et al., 2008).

Today, forest ecosystems have gained relevance due to global phenomena such as climate change and the adoption of new perspectives that consider forests as providers of ecosystem services to society through sustainable forest management (Aguirre-Calderón, 2015). Forest management is associated with forest structure, timber production, and the provision of other goods and services (Rendón-Pérez et al., 2021).

The evaluation of forest structure is always of interest to forest managers, which serves to make decisions on the activities to be carried out to maintain or improve them, it is also essential for the development of better management practices and contributes to the conservation of biodiversity (Aguirre-Calderón, 2015). In the sustainable management of forest stands, it is essential to conserve biodiversity, maintain the forest composition, its associated values, and the ecosystem landscape (Hernández-Salas et al., 2013).

Changes in forest structure and diversity can be generated by selective harvesting and silvicultural practices that favor a select and reduced number of species (Corral et al., 2005). Ramírez et al. (2019) indicate that the implementation of silvicultural practices in temperate forests reduces the variety of species in the forest. Knowledge of the composition and variety of tree species in temperate forests is crucial for their management and conservation (Graciano-Ávila et al., 2017).

Assessing the impact of activities on species composition, with forest management it is much easier to conduct it within the most favorable levels, in terms of species richness, environmental value, ecosystem stability and economic value. Forest management is essential to preserve diversity, to adjust the structure at the population level and to describe the relationship of species through diversity indicators such as abundance, dominance and frequency (Hernández-Salas et al., 2013).

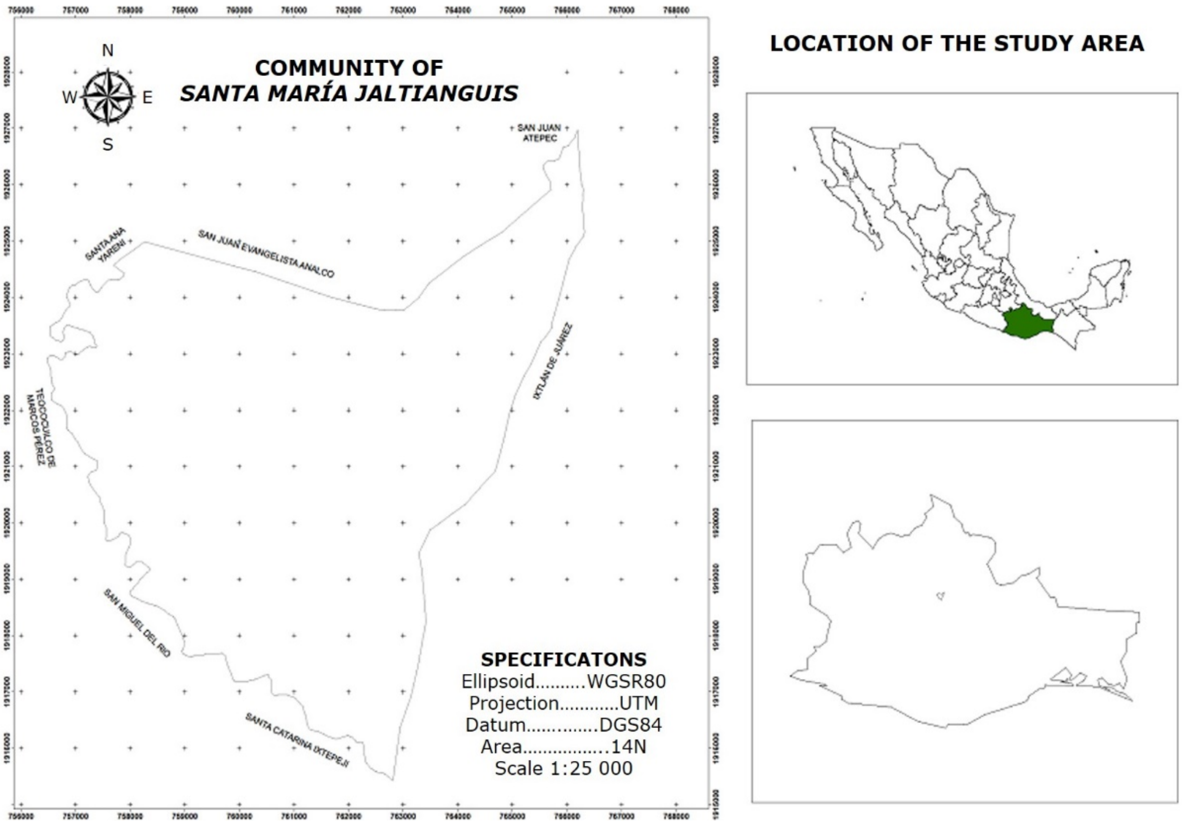
Therefore, it is important to consider the application of regeneration treatments, since they modify the structure of the forests; research on the structure of managed forests agrees that they are indicators of forest diversity (Corral et al., 2005) and with silvicultural interventions can be modified.

In the communal forests of the state of *Oaxaca*, Mexico, there are areas with clear problems for the establishment of regeneration of the taxa of greatest interest due to climatic conditions of high humidity, as well as the abundant presence of herbaceous plants and shrubs with a greater capacity to colonize and occupy available growth spaces, which causes an important imbalance in the composition of the forest; it is therefore important to generate management conditions that are more conducive to the establishment of natural regeneration of pine species, due to their intolerant characteristics (Servicios Técnicos Forestales de Santa María Jaltianguis [STF], 2017). The objective of this study was to evaluate two forest management methods and to analyze the effect of silvicultural treatments on the diversity and seasonal population structure in managed stands in the forests of *Santa María Jaltianguis, Oaxaca* state, Mexico. The hypothesis was to determine whether the application of silvicultural regeneration treatments modifies the diversity and structure of forests under forest management.

Materials and Methods

Study Area

The study area is located in the municipality of *Santa María Jaltianguis*, a *Zapotec* community in the *Sierra Juárez* of *Oaxaca* (Southern Mexico). The UTM location coordinates are 765345.90 m and 755789.00 m E, and 1927446.56 m and 1917737.00 m N, at an average altitude of 2 270 m (Figure 1). The climate is temperate sub-humid with summer rainfall and semi-warm sub-humid with summer rainfall; the types of soil present are: Luvisol (78.30 %), Acrisol (20.38 %), Fluvisol (0.86 %), and Cambisol (0.46 %) (STF, 2017).



Santa Ana Yareni = Santa Ana Yareni municipality; *San Juan Evangelista Analco = San Juan Evangelista Analco* municipality; *San Juan Atepec = San Juan Atepec* municipality; *Ixtlán de Juárez = Ixtlán de Juárez* municipality; *Santa Catarina Ixtepeji = Santa Catarina Ixtepeji* municipality; *San Miguel del Río = San Miguel del Río* municipality; *Teococuilco de Marcos Pérez = Teococuilco de Marcos Pérez* municipality.

Figure 1. Location of the study area.

Sampling sites

Thirty 400 m^2 circular sample plots were established and measured, selectively located in areas under forest management: three plots for each annuality in a total of 10 annualities, where regeneration cutting treatments in group selection, regeneration cutting of parent trees, and individual selection were evaluated. These are management practices applied in forests in order to take advantage, improve and regenerate naturally existing species. Data on mensuration variables were collected in these plots; two forest management methods and their silvicultural treatments were evaluated. The Silvicultural Development Method (SDM) with the parent tree treatment and the Mexican Method of Management of Irregular Forests (MMOBI) with the individual selection and group selection treatments.

On-site evaluation

Four quadrants were delimited in the plots and the plant individuals of the existing species were identified; the mensuration variable of greatest interest was the normal diameter ≥7.5 cm, which was measured in centimeters with a model 800mm Mantax Blue Haglöf® Sweden's caliper, with which the basal area was calculated using the following formula:

$$A = \frac{\pi}{4} \times d^2$$

Where:

A = Surface area (m^2)

π = Constant value of 3.1416

d = Normal diameter converted to m

The number of individuals and species nomenclature was verified using the Tropicos® platform (Missouri Botanical Garden, 2022). For each site, the geographic coordinates and altitude (m) were recorded with the support of a model GPSMAP 64SC GARMIN® satellite geopositioner.

Analysis of the population structure of the areas under management

In each plot of 400 m^2 a concentric site of 100 m^2 was installed for the evaluation of the natural regeneration, the pine seedlings were counted, the diameter at the base was measured in (mm), this was done for the treatment of selection regeneration cutting in groups due to the short time of having applied the treatment (1 to 4 years). To evaluate the shrub stratum, which included individuals with heights greater than 25 cm, two 9 m^2 sites, the species was recorded, the diameter (cm) at the base was measured with a model cal-6mp Truper® caliper, and the total height (m) was measured with a model geosw-5-5m Geo-surv® stadia rod (Rendón-Pérez et al., 2021). In each quadrant, 1 m^2 sites were delimited to evaluate the herbaceous stratum and the existing species were recorded (Figure 2). Measurements were carried out during the rainy and dry seasons.

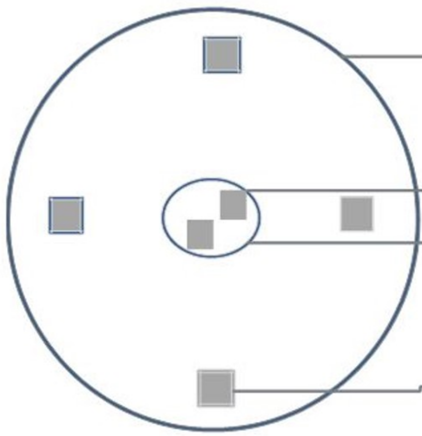


Figure 2. Design of plots and data collection sites.

The structural diversity, richness and composition of the tree, shrub and herbaceous stratum in the different treatments applied were evaluated using the alpha and beta diversity indexes with the Excel® program. The Margalef and Shannon indexes were used to determine alpha diversity and the *Sørensen* Similarity Index was used to determine beta diversity (Juárez-Agis et al., 2016; Leyva-López et al., 2010; Moreno, 2001).

Statistical analysis

Normality and homogeneity of variances were tested using the Shapiro-Wilk and Bartlett's test (α=0.05) with the UNIVARIATE procedure (Chávez-Pascual et al., 2017; García-Aguilar et al., 2021). The variables were transformed using $\sqrt{\frac{X}{100}+1}$ (Espinoza-Zúñiga et al., 2023); the silvicultural treatments were differentiated using the general linear model (PROC GLM) and the means test (Tukey, α=0.05). Analyses were performed utilizing the SAS 9.0 statistical software (SAS Institute Inc., 2021).

Results and Discussion

Species composition and richness

During the rainy season, a total of 49 plant species belonging to 25 families were recorded (Table 1). The highest richness was found in the herbaceous stratum with 31 taxa, followed by the arboreal stratum with 11, and the shrub stratum with seven; the first two strata shared seven species. Luna-Bautista et al. (2015) 41 species were identified in areas under forest management, with a dominance of taxa belonging to the Asteraceae, Fagacea and Fabaceae families; Vázquez-Cortez et al. (2018) obtained 12 species in the shrub stratum.

Table 1. Species richness during the rainy season in managed forests (species are presented in alphabetical order).

Species	Common name	Family
	Stratum: Shrub	
Arbutus xalapensis Kunth	Texas madrone	Ericaceae
Baccharis conferta Kunth	Chaparral broom	Asteraceae
Cercocarpus macrophyllus C. K. Schneid.	Mountain mahogany	Rosaceae
Clethra lanata M. Martens & Galeotti	Mexican clethra	Clethraceae
Litsea glaucescens Kunth	Mexican bay leaf	Lauraceae

Prunus serotina Ehrh.	Black cherry	Rosaceae
Rumex obtusifolius L.	Bitter dock	Polygonaceae
	Stratum: Tree	
Pinus ayacahuite C. Ehrenb. *ex* Schltdl.	Ayacahuite pine	Pinaceae
Pinus douglasiana Martínez	Douglas pine	Pinaceae
Pinus lawsoni Roezl *ex* Gordon	Lawson's pine	Pinaceae
Pinus leiophylla Schiede *ex* Schltdl. & Cham. var. *leiophylla*	Smooth-leaf pine	Pinaceae
Pinus oaxacana Mirov	*Ocote*	Pinaceae
Pinus patula Schltdl. & Cham.	Mexican weeping pine	Pinaceae
Pinus pseudostrobus Lindl.	Smooth-bark Mexican pine	Pinaceae
Quercus corrugata Hook.	White oak	Fagaceae
Quercus crassifolia Bonpl.	Chilillo oak	Fagaceae
Quercus laurina Bonpl.	Laurel oak	Fagaceae
Quercus rugosa Neé	Netleaf oak	Fagaceae
	Stratum: Herbaceous	
Ageratum corymbosum Zuccagni	Flat-top whiteweed	Asteraceae
Alchemilla pectinata Kunth	Lady's mantle	Rosaceae
Arenaria lanuginosa (Michx.) Rohrb.	Spreading sandwort	Caryophyllaceae
Arracacia moschata (Kunth) DC.	Musk Arracacia	Apiaceae
Calliandra houstoniana (Mill.) Standl.	Tree powderpuff	Fabaceae
Ceanothus caeruleus Lag.	*Azure ceanothus*	Rhamnaceae
Centropogon grandidentatus (Schltdl.) Zahlbr.	Large-toothed centropogon	Campanulaceae
Cologania broussonetii (Balb.) DC.	Mexican cologania	Fabaceae
Commelina tuberosa L.	Blue spiderwort	Commelinaceae
Crusea coccinea DC.	Saucer flower	Rubiaceae
Dahlia imperialis Roezl *ex* Ortgies	Bell tree dahlia	Asteraceae
Elaphoglossum latifolium (Sw.) J. Sm.	Broadleaf tonguefern	Dryopteridaceae
Fragaria mexicana Schltdl.	Wild strawberry	Rosaceae
Fuchsia thymifolia Kunth	Thyme-leaved fuchsia	Onagraceae
Gaultheria erecta Vent.	*Borrachera* fruit	Ericaceae
Gnaphalium viscosum Kunth	Sticky rabbit-tobacco	Asteraceae
Iostephane heterophylla Benth.	*Camorreal*	Asteraceae
Maianthemum paniculatum (M. Martens	False Solomon's seal	Asparagaceae

& Galeotti) LaFrankie		
Matudanthus nanus (M. Martens & Galeotti) D. R. Hunt	Motherwort	Commelinaceae
Oxalis latifolia Kunth	Broadleaf woodsorrel	Oxalidaceae
Phytolacca rugosa A. Braun & C. D. Bouché	Pokeberry	Phytolaccaceae
Polypodium californicum Kaulf.	California polypody	Polypodiaceae
Pteridium arachnoideum (Kaulf.) Maxon	Tropical brackenfern	Dennstaedtiaceae
Roldana angulifolia (DC.) H. Rob. & Brettell	Angled thistle	Asteraceae
Roldana candicans (Née) Villaseñor, S. Valencia & Coombes	Groundsel	Asteraceae
Rubus adenotrichos Schltdl.	Tropical Highland blackberry	Rosaceae
Rubus glaucus Benth.	Andean raspberry	Rosaceae
Russelia sarmentosa Jacq.	Firecracker plant	Plantaginaceae
Salvia patens Cav.	Gentian sage	Lamiaceae
Sambucus nigra L.	Black elder	Viburnaceae
Tagetes lucida Cav.	Sweet mace	Asteraceae

Litsea glaucescens Kunth was the only species registered in the Official Mexican Standard NOM-059-SEMARNAT-2010 of the Ministry of the Environment and Natural Resources (NOM-059-SEMARNAT-2010, 2010) as an endangered species; *Matudanthus nanus* (M. Martens & Galeotti) D. R. Hunt is a taxa endemic to the state of Oaxaca (García-Mendoza & Meave, 2011).

Most of the richness corresponded to the Asteraceae family (eight species), in which herbaceous species dominate; followed by the Pinaceae family (seven species), Rosaceae (six species), and Fagaceae (four species). Asteraceae is the most diverse (1 040 species) in the state of *Oaxaca* (Villaseñor, 2018). Rendón-Pérez et al. (2021) point out that the genera *Pinus* L. and *Quercus* L. include a larger number of species, among which the Pinaceae and Asteraceae families are prevalent.

A lower richness was observed during the dry season, with a total of 41 species, amounting to a reduction of 16.4 % (Figure 3). It should be noted that during the dry season, the establishment of certain herbaceous plants is conditioned (Yan et al., 2015). These results support the finding that species richness and diversity are higher during the rainy season.

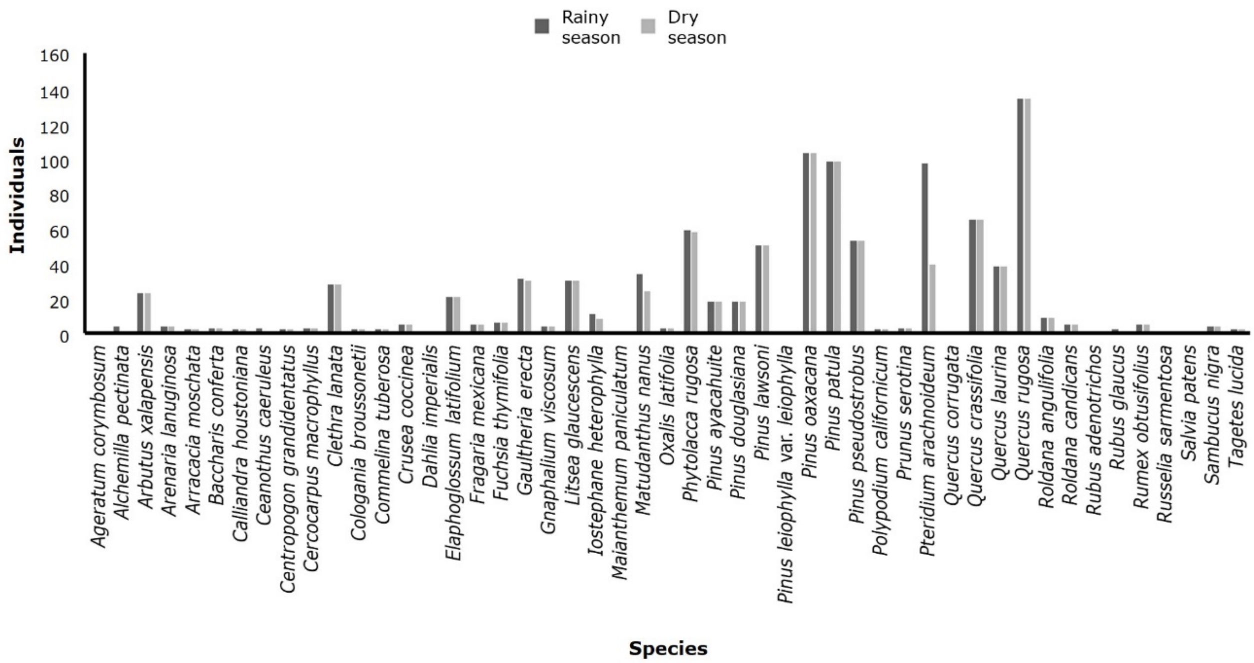
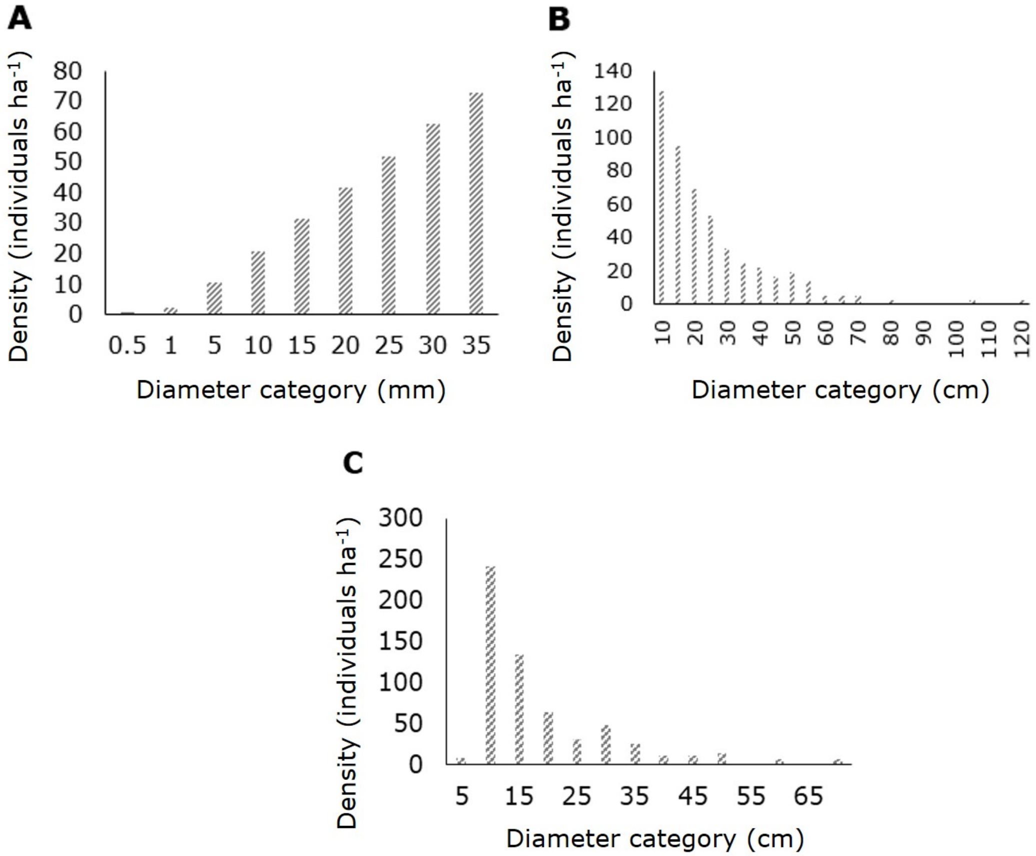


Figure 3. Density of individuals in the rainy and dry seasons.

Effect of forest management on diameter structure

The group-selection regeneration cutting treatment in the 2018-2021 annual periods maintains a structure with an upward distribution as the diameter increases. The regeneration of trees aged 1, 2, 3, and 4 years increases their density as a response to the new developing forest (Figure 4A), favoring the renewal of *Pinus* species, as the treatment opens clearings that provide better conditions for the establishment of pines.



A = Group selection treatment; B = Regeneration cutting treatment; C = Individual selection treatment.

Figure 4. Diameter structure of the evaluated forestry treatments.

The regeneration cutting treatment applied in the 1993-2003 felling cycle exhibits an "inverted J" diameter distribution, which shows a high number of individuals at the initial stages of stand development and gradually decreases in frequency as the diameter increases. In this treatment, the predominant species were of the *Pinus* and *Quercus*, as well as other leafy species; *Pinus* still maintains a considerable volume due to a higher density of standing trees —trees of considerable dimensions, with diameters between 60 and 105 cm, and an average total height of 46 m—. The lack of a release cutting has prevented the release of established regrowth and has limited the ability to generate space for a broader natural regeneration of the *Pinus* genus (Figure 4B). Regeneration cutting is the stage at which most of the tree stratum is removed and the number of tree species is significantly reduced (Pérez-López et al., 2020).

The individual selection treatment exhibited an irregular diameter distribution (Figure 4C) due to the presence of different diameter classes resulting from the implementation of the Mexican Irregular Forest Management Method. This approach favors the natural regeneration of species with the greatest presence of individuals in the smallest diameter categories, notably of *Quercus* sp., *Pinus* sp., and other leafy species. It is crucial to consider this aspect in the management of these species and to promote the growth of those with economic and ecological value.

Leyva-López et al. (2010) consider that silvicultural or forestry treatments are not always applied with the required intensity, resulting in a different species composition.

It should be noted that, in the application of the group-selection regeneration cutting forestry treatment, the genus of the tree stratum with the lowest density was *Pinus*, with a total of 390 individuals' ha^{-1} (Table 2), because the trees were felled to promote regeneration conditions during the 2018-2021 annual periods. A density of 3 796 individuals ha^{-1} was obtained for the shrub stratum, and of 174 167 individuals ha^{-1} total, for the herbaceous stratum. Rzedowski (2006) points out that the dominance of herbaceous plants is due to the greater amount of light and space, whose presence is attributed to their anemochorous seed propagation. In addition, they move very easily, which allows their annual distribution and is related to the amount of water available.

Table 2. Abundance, dominance, frequency, and Importance Value Index (*IVI*) by forestry treatments applied in the tree stratum of managed forests.

Species	Abundance Absolute (N ha^{-1})	Abundance Relative (%)	Dominance Absolute (m^2 ha^{-1})	Dominance Relative (%)	Frequency Absolute	Frequency Relative (%)	*IVI* (%)
			Group-selection regeneration cutting treatment				
Pinus ayacahuite C. Ehrenb. *ex* Schltdl.	38	9.63	0.00	0.27	4	16.67	8.85
Pinus lawsoni Roezl *ex* Gordon	6	1.60	0.01	1.20	2	8.33	3.71
Pinus oaxacana Mirov	133	34.22	0.15	18.32	3	12.50	21.68
Pinus patula Schltdl. & Cham.	131	33.69	0.28	33.98	8	33.33	33.67
Pinus pseudostrobus Lindl.	81	20.86	0.38	46.23	7	29.17	32.08
Total	390	100	0.82	100	24	100	100
			Parent-tree regeneration cutting treatment				
Litsea glaucescens Kunth	11	2.22	0.13	0.34	2	5.26	2.61
Arbutus xalapensis Kunth	11	2.22	1.45	3.91	3	7.89	4.68
Cercocarpus macrophyllus C. K. Schneid.	6	1.11	0.14	0.37	1	2.63	1.37
Clethra lanata M. Martens & Galeotti	69	13.89	1.22	3.29	4	10.53	9.23
Pinus douglasiana Martínez	8	1.67	1.04	2.81	2	5.26	3.25
Pinus lawsoni Roezl *ex* Gordon	44	8.89	1.64	4.41	1	2.63	5.31
Pinus oaxacana Mirov	56	11.11	4.77	12.87	4	10.53	11.50
Pinus patula Schltdl. & Cham.	97	19.44	8.33	22.46	7	18.42	20.11
Pinus pseudostrobus Lindl.	39	7.78	8.32	22.46	3	7.89	12.71
Quercus crassifolia Bonpl.	42	8.33	3.05	8.23	3	7.89	8.15
Quercus laurina Bonpl.	56	11.11	5.00	13.49	4	10.53	11.71

Quercus rugosa Neé	61	12.22	1.99	5.37	4	10.53	9.37
Total	500	100	37.07	100	38	100	100
			Individual-selection regeneration cutting treatment				
Arbutus xalapensis Kunth	31	5.12	0.30	1.31	5	14.71	7.04
Pinus douglasiana Martínez	42	6.98	6.67	28.74	5	14.71	16.81
Pinus lawsoni Roezl *ex* Gordon	86	14.42	4.98	21.47	7	20.59	18.83
Pinus leiophylla Schiede *ex* Schltdl. & Cham. var. *leiophylla*	3	0.47	0.38	1.66	1	2.94	1.69
Pinus oaxacana Mirov	53	8.84	4.23	18.22	2	5.88	10.98
Quercus corrugata Mirov	3	0.47	0.07	0.30	1	2.94	1.24
Quercus crassifolia Bonpl.	108	18.14	1.14	4.91	5	14.71	12.58
Quercus rugosa Neé	272	45.58	5.43	23.39	8	23.53	30.83
Total	597	100	23.20	100	34	100	100

In the arboreal stratum, the parent trees regeneration treatment produced an abundance of 500 trees ha^{-1}, of which 48.9 % belonged to the genus *Pinus* and 31.7 % to *Quercus* and other leafy species (19.4 %) (Table 2). According to Hernández-Salas et al. (2013), the implementation of intensive cutting to promote the regeneration of parent trees does not exclusively ensure the regeneration of individuals of the genus selected as the parent tree, since in the intervened areas there are other taxa with different regeneration mechanisms. Likewise, in the shrub stratum, 4 321 shrubs ha^{-1} were recorded, among which oak (51.43 %) and other shrubs (48.57 %) were the dominant species; while 54 444 individuals ha^{-1} were recorded for the herbaceous stratum (Table 2). Castelán-Lorenzo and Arteaga-Martínez (2009) documented densities of 4 200 trees ha^{-1}, resulting from a good application and monitoring of forestry treatment to ensure forest regeneration. The parent tree treatment modifies the diversity in the regeneration, while the application of forestry treatments maintains the richness of tree species, but tends to produce a change in the number of individuals (Hernández-Salas et al., 2013).

In the individual selection areas, the abundance of the tree stratum was 597 trees ha^{-1}, of which 64.19 % were oaks, 30.70 % *Pinus*, and 5.11 % other leaves. The shrub stratum contained 1 605 trees ha^{-1} with 53.9 % of oaks and 46.2 % of other leaves (Table 2). The results obtained by Ríos-Altamirano et al. (2016) showed a higher abundance in the tree stratum dominated by *Pinus*, which is of commercial interest. Graciano-Ávila et al. (2020) report results of greater abundance of *Pinus* in temperate forests of the states of *Puebla* and *Durango*. The absolute tree abundance differed significantly (p=0.02) between the group-selection regeneration cutting, the parent tree regeneration cutting, and the individual selection treatments; the dominance was 0.82 m^2 ha^{-1} in those areas where the group-selection regeneration cutting treatment was applied for the *Pinus* genus; 37.07 m^2 ha^{-1} with the regeneration treatment of parent trees, and 23.20 m^2 ha^{-1} with the individual selection. The reduction in the dominance of the *Pinus* genus is due to the growth of new tree stands due to the application of the group-selection regeneration cutting treatment; the greatest dominance was obtained in the regeneration treatment of parent trees due to the concentration of trees with larger diameters. The species with the highest frequency records in the group-selection regeneration cutting treatment were *Pinus patula* Schltdl. & Cham. and *Pinus pseudostrobus* Lindl. In those areas where regeneration felling of parent trees was carried out, the most frequent taxa were *Pinus patula*, followed by *Pinus oaxacana* Mirov, *Quercus laurina* Bonpl., *Q. rugosa* Neé, and *Clethra lanata* M. Martens & Galeotti; while, in the individual selection areas, they were *Q. rugosa* and *P. lawsoni* Roezl *ex* Gordon. *Pinus patula* was the most frequent species in the areas under forest management, and *Pinus leiophylla* Schiede *ex* Schltdl. & Cham. var. *leiophylla* was the one with the lowest frequency. Hernández-Salas et al. (2013) point out absolute frequencies dominated by the genus *Pinus*, with 89.1 %, followed by *Quercus*, with 6.5 %.

The differences in abundance between treatments were significant, with the greatest dominance occurring in the parent-tree regeneration cutting treatment. The species with the highest frequency, among which *Pinus patula* was predominant, varied according to the areas of distribution, which is important because they are genetically differentiated to adapt to changes in climate; examples of such adaptive traits are the time and rate of growth, and resistance to frost damage or drought stress (Sáenz-Romero et al., 2016). These results are relevant for the conservation of forest resources, which supports the hypothesis that regeneration treatments modify the structure of forests under management.

Importance Value Index (*IVI*)

In the group-selection regeneration cutting treatment, the *IVI* of the tree stratum was 100 % for *Pinus* species, particularly *Pinus patula* (33.67 %). This is because these are areas where forestry treatment contributes to the establishment of natural regeneration and favors pines and, to a lesser extent, associated species that are not yet prevalent. For the areas with parent-tree regeneration cutting, the *Pinus* genus obtained an *IVI* of 52.88 %; *Pinus patula* was also the predominant species (*IVI*=20.1 %). In the areas with individual selection treatment, the *Pinus* genus again stood out with a value of 48.3 %. Hernández-Salas et al. (2013) obtained *IVI* values of 85.1 % for *Pinus*, while Silva-González et al. (2022) recorded an *IVI* of 62.4 % for this same genus. Moreno (2001) points out that the *IVI* analysis allows monitoring and tracking of changes in species management.

Species diversity

The forestry treatments showed significant differences (p=0.05) in the evaluated diversity indexes. The group-selection regeneration cutting treatment for the tree stratum had the lowest Shannon-Wiener (H') diversity value, of 1.35. Vásquez-Cortez et al. (2018) determined an H' value of 1.14 for an area with clear-cutting because one species is dominant there (Silva-González et al., 2021). The H' index of the herbaceous stratum exhibited a value of 1.96 (Table 3), which represents a low diversity. In those areas where parent-tree regeneration cutting treatments were applied, a value of H' of 2.25 was obtained for the tree stratum, while the highest value was obtained in the herbaceous stratum, with an H' of 2.37, which amounts to a median diversity. While in those areas where individual selection treatments were applied, the herbaceous stratum dominated with an H' of 1.89, while the arboreal stratum exhibited an H' of 1.55, a value slightly higher than that of 1.21 indicated by Solís et al. (2006) for an area under management with a selection treatment. Ramírez et al. (2019) estimated a value of H' of 1.25, which indicates a low diversity. Flores-Morales et al. (2022) estimated a Margalef Index of 1.53 and a Shannon Index of 1.74, corresponding to a low richness and diversity, respectively. According to Hernández-Salas et al. (2013), forestry intervention leads to a decrease in tree diversity. The results of this study agree with their hypothesis because the application of regeneration treatments modifies the diversity by reducing the number of species.

Table 3. Values of the indexes evaluated by stratum with the various forestry treatments applied in the forest management areas.

Stratum	Shannon-Weiner			Evenness			Margalef		
	GS	PT	IS	GS	PT	IS	GS	PT	IS

Tree	1.35	2.25	1.55	0.84	0.90	0.75	0.76	2.12	1.30
Shrub	1.65	1.53	1.27	0.79	0.85	0.91	1.88	1.41	1.17
Herb	1.96	2.37	1.89	0.68	0.88	0.74	3.18	3.60	2.81

GS = Group selection; PT = Parent-tree regeneration cutting; IS = Individual selection.

In those areas where group-selection regeneration cutting was applied, the Margalef species richness index reached the highest values in the herbaceous stratum (3.18); in the tree stratum with parent-tree regeneration cutting, the estimate was 2.12, and in the herbaceous stratum, it was 3.60; in those areas with individual selection, the herbaceous stratum stood out with 2.81 (Table 3). Silva-González et al. (2021) determined values of 2.14, which showed a greater richness.

Both the group-selection and parent-tree regeneration cutting treatments showed a qualitative Sørensen Index of 0.40, as they shared 62 % of the species. The parent-tree and individual-selection treatments shared an index of 0.39, with a 48 % similarity. For the group-selection and individual-selection regeneration cutting treatments, a value of 0.14 with a species similarity of 31 % was estimated. This is because the selective silvicultural interventions aimed at reducing species of lower commercial value in favor of the *Pinus* genus (Solís et al., 2006).

Conclusions

The evaluation of the two management methods applied shows an uneven distribution of tree diameters. In the regeneration treatment, abundance and dominance are most notable in the herbaceous stratum, with a diversity index *H'* of

2.37, and in the arboreal stratum, with an *H′* of 2.25. In the individual selection treatment, herbaceous plants also have a higher abundance and dominance, although with a lower diversity (*H'* of 1.89), in contrast to the tree stratum, with an *H'* of 1.55. For the group-selection regeneration cutting treatment, the diversity in the tree stratum is one of the lowest, with an *H'* of 1.35, while the shrub stratum has the highest diversity, with an *H'* of 1.65, and the herbaceous stratum has an *H'* of 1.96 because the larger spaces generated thereby favor diversity. There represents a greater richness in the herbaceous and shrub stratum, while, in the tree stratum of the group-selection regeneration cutting treatment, *Pinus patula* stands out with an Importance Value Index of 33.67 % and, in the parent-tree regeneration cutting treatment, with an *IVI* of 20.11 %, followed by *Quercus laurina*, with an *IVI* of 11.71 %. In the individual selection treatment, *Quercus rugosa* excels with an *IVI* of 30.83 %.

Sørensen's Index shows a greater similarity between species under the group-selection and parent-tree regeneration cutting treatments, but there is a species dissimilarity between the group-selection and the individual-selection regeneration cutting treatments. The greatest richness is recorded in the rainy season. The study results indicate that the safe application of any timber forest management program requires periodic evaluation and monitoring in order to ensure the persistence of the forest resources.

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Conflict of interest

The authors declare that they have no conflict of interest. Eduardo Alanís Rodríguez declares that he has not participated in any of the stages of the editorial process of this article.

Contribution by author

Julio Aurelio Ruiz-Aquino and Javier Jiménez-Pérez: research design, measurement of field mensuration variables, and statistical analysis; Óscar Alberto Aguirre-Calderón: revision of the manuscript; Eduardo Alanís-Rodríguez and Gerardo Rodríguez-Ortiz: data processing.

References

Aguirre-Calderón, O. A. (2015). Manejo forestal en el siglo XXI. *Madera y Bosques*, *21*(Núm. esp.), 17-28. https://www.scielo.org.mx/pdf/mb/v21nspe/v21nspea2.pdf

Castelán-Lorenzo, M. y Arteaga-Martínez, B. (2009). Establecimiento de regeneración de *Pinus patula* Schl. *et* Cham., en cortas bajo el método de árboles padres. *Revista Chapingo Serie Ciencias Forestales y del Ambiente*, *15*(1), 49-57. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-40182009000100006

Castellanos-Bolaños, J. F., Treviño-Garza, E. J., Aguirre-Calderón, O. A., Jiménez-Pérez, J., Musalem-Santiago, M. y López-Aguillon, R. (2008). Estructura de bosques de pino pátula bajo manejo en Ixtlán de Juárez, Oaxaca, México. *Madera y Bosques*, *14*(2), 51-63. https://doi.org/10.21829/myb.2008.1421212

Chávez-Pascual, E. Y., Rodríguez-Ortiz, G., Enríquez-del Valle, J. R., Velasco-Velasco, V. A. y Gómez-Cárdenas, M. (2017). Compartimentos de biomasa aérea en rodales de *Pinus oaxacana* bajo tratamientos silvícolas. *Madera y Bosques*, *23*(3), 147-161. https://doi.org/10.21829/myb.2017.2331627

Corral R., J. J., Aguirre C., O. A., Jiménez P., J. y Corral R., S. (2005). Un análisis del efecto del aprovechamiento forestal sobre la diversidad estructural en el bosque mesófilo de montaña "El Cielo", Tamaulipas, México. *Investigación Agraria, Sistemas y Recursos Forestales*, *14*(2), 217. https://doi.org/10.5424/srf/2005142-00885

Espinoza-Zúñiga, P., Leos-Rodríguez, J. A., Rodríguez-Ortiz, G., Montiel-Batalla, B. M. y Valdivia-Alcalá, R. (2023). Carbono estructural y compartimentos en bosques certificados por el Forest Stewardship Council, en Oaxaca, México. *Ecosistemas y Recursos Agropecuarios*, *10*(1), Artículo e3474. https://doi.org/10.19136/era.a10n1.3474

Flores-Morales, E. A., Aguirre-Calderón, O. A., Treviño-Garza, E. J., González-Tagle, M. A., Alanís-Rodríguez, E., Ángeles-Pérez, G. y Huizar-Amezcua, F. (2022). Diversidad y estructura arbórea de un bosque templado bajo manejo en el municipio de Pueblo Nuevo, Durango, México. *Polibotánica*, (54), 11-26. https://doi.org/10.18387/polibotanica.54.2

García-Aguilar, J. A., Luna-Cedeño, J. J., Rodríguez-Ortiz, G. y Leyva-López, J. C. (2021). Acumulación de biomasa en estacas de cuatro especies de *Bursera* en Oaxaca. *Ciencia ergo-sum*, *28*(2), Artículo e126. https://doi.org/10.30878/ces.v28n2a9

García-Mendoza, A. J. y Meave del C., J. A. (2011). *Diversidad Florística de Oaxaca: De musgos a angiospermas (colecciones y lista de especies)* (2ª edición). Instituto de Biología de la Universidad Nacional Autónoma de México y Comisión Nacional para el Conocimiento y Uso de la Biodiversidad

Graciano-Ávila, G., Alanís-Rodríguez, E., Aguirre-Calderón, O. A., González-Tagle, M. A., Treviño-Garza, E. J. y Mora-Olivo, A. (2017). Caracterización estructural del arbolado en un ejido forestal del noroeste de México. *Madera y Bosques*, *23*(3), 137-146. https://doi.org/10.21829/myb.2017.2331480

Graciano-Ávila, G., Alanís-Rodríguez, E., Aguirre-Calderón, O. A., González-Tagle, M. A., Treviño-Garza, E. J., Mora-Olivo, A. y Corral-Rivas, J. J. (2020). Cambios estructurales de la vegetación arbórea en un bosque templado de Durango, México. *Acta Botánica Mexicana*, *127*, Artículo e1522. https://www.scielo.org.mx/pdf/abm/n127/2448-7589-abm-127-e1522.pdf

Hernández-Salas, J., Aguirre-Calderón, O. A., Alanís-Rodríguez, E., Jiménez-Pérez, J., Treviño-Garza, E. J., González-Tagle, M. A., Luján-Álvarez, C., Olivas-García, J. M. y Domínguez-Pereda, L. A. (2013). Efecto del manejo forestal en la diversidad y composición arbórea de un bosque templado del noroeste de México. *Revista Chapingo Serie Ciencias Forestales y del Ambiente*, *19*(2), 189-200. https://doi.org/10.5154/r.rchscfa.2012.08.052

Juárez-Agis, A., Herrera C., N. D., Martínez y P., J. L. y Reyes U., M. (2016). Diversidad y estructura de la selva mediana subperennifolia de Acapulco, Gro., México. *Revista Iberoamericana de las Ciencias Biológicas y Agropecuarias*, *5*(10), 50-69. https://www.ciba.org.mx/index.php/CIBA/article/view/58

Leyva-López, J. C., Velázquez-Martínez, A. y Ángeles-Pérez, G. (2010). Patrones de diversidad de la regeneración natural en rodales mezclados de pino. *Revista Chapingo Serie Ciencias Forestales y del Ambiente*, *16*(2), 227-239. https://doi.org/10.5154/r.rchscfa.2010.06.038

Luna-Bautista, L., Hernández-de la Rosa, P., Velázquez-Martínez, A., Gómez-Guerrero, A. & Acosta-Mireles, M. (2015). Understory in the composition and diversity of managed forest areas in Santa Catarina Ixtepeji, Oaxaca. *Revista Chapingo Serie Ciencias Forestales y del Ambiente*, *21*(1), 109-121. https://doi.org/10.5154/r.rchscfa.2014.08.037

Missouri Botanical Garden. (2022, 9 de enero). *Tropicos v3.4.2*. http://www.tropicos.org

Moreno, C. E. (2001). *Métodos para medir la biodiversidad*. Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo (Cyted), Oficina

Regional de Ciencia y Tecnología para América Latina y el Caribe (Orcyt), y Sociedad Entomológica Aragonesa (SEA). https://www.researchgate.net/publication/304346666_Metodos_para_medir_la_biodiversidad

NOM-059-SEMARNAT-2010. (2010, 26 de noviembre). NORMA Oficial Mexicana NOM-059-SEMARNAT-2010, Protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio-Lista de especies en riesgo. *Diario Oficial de la Federación*, *Segunda Sección*, de 30 de diciembre de 2010. http://biblioteca.semarnat.gob.mx/janium/Documentos/Ciga/agenda/DOFsr/DO2454.pdf

Pérez-López, R. I., González-Espinosa, M., Ramírez-Marcial, N. y Toledo-Aceves, T. (2020). Efectos del "Método de Desarrollo Silvícola" sobre la diversidad arbórea en bosques húmedos de montaña del norte de Chiapas, México. *Revista Mexicana de Biodiversidad*, *91*, Artículo e913326. https://doi.org/10.22201/ib.20078706e.2020.91.3326

Ramírez S., R., Ángeles P., G., Hernández de La R., P., Cetina A., V. M., Plascencia E., O. y Clark-Tapia, R. (2019). Efectos del aprovechamiento forestal en la estructura, diversidad y dinámica de rodales mixtos en la Sierra Juárez de Oaxaca, México. *Madera y Bosques*, *25*(3), Artículo e2531818. https://doi.org/10.21829/myb.2019.2531818

Rendón-Pérez, M. A., Hernández-de la Rosa, P., Velázquez-Martínez, A., Alcántara-Carbajal, J. L. y Reyes-Hernández, V. J. (2021). Composición, diversidad y estructura de un bosque manejado del centro de México. *Madera y Bosques*, *27*(1), Artículo e2712127. https://doi.org/10.21829/myb.2021.2712127

Ríos-Altamirano, A., Alfonso-Corrado, C., Aguirre-Hidalgo, V., Ángeles-Pérez, G., Mendoza-Díaz, M. M., Rodríguez-Rivera, V., Roldán-Félix, E. y Clark-Tapia, R. (2016). Abundancia y distribución del género *Pinus* en Capulálpam de Méndez, Sierra Juárez, Oaxaca. *Madera y Bosques*, *22*(3), 61-74. https://doi.org/10.21829/myb.2016.2231457

Romo G., D., Valtierra P., E., González G., M. de J., Valdez L., J. R. y Vivar M., R. (2016). Organización social ejidal y manejo del capital natural forestal maderable en Carbonero-Jacales, Huayacocotla, Veracruz. *Revista Mexicana de Ciencias Forestales*, *7*(34), 85-99. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S2007-11322016000200085

Rzedowski, J. (2006). *Vegetación de México* (1ª Edición digital). Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. https://www.biodiversidad.gob.mx/publicaciones/librosDig/pdf/VegetacionMx_Cont.pdf

Sáenz-Romero, C., Lindig-Cisneros, R. A., Joyce, D. G., Beaulieu, J., Bradley St. C., J. & Jaquish, B. C. (2016). Assisted migration of forest populations for adapting trees to climate change. *Revista Chapingo Serie Ciencias Forestales y del Ambiente*, *22*(3), 303-323. https://doi.org/10.5154/r.rchscfa.2014.10.052

SAS Institute Inc. (2021). *SAS/STAT® User's Guide*. SAS Institute Inc. https://documentation.sas.com/api/collections/pgmsascdc/v_016/docsets/statug/content/sashelp.pdf

Servicios Técnicos Forestales de Santa María Jaltianguis. (2017). *Programa de manejo forestal para el aprovechamiento y conservación de los recursos forestales maderables de Santa María Jaltianguis* (Ciclo de corta 2017-2027). Servicios Técnicos Forestales de Santa María Jaltianguis.

Silva-González, E., Aguirre-Calderón, O. A., Treviño-Garza, E. J., Alanís-Rodríguez, E. y Corral-Rivas, J. J. (2021). Efecto de tratamientos silvícolas en la diversidad y estructura forestal en bosques templados bajo manejo en Durango, México. *Madera y Bosques*, *27*(2), Artículo e2722082. https://doi.org/10.21829/myb.2021.2722082

Silva-González, E., Aguirre-Calderón, O. A., Alanís-Rodríguez, E., González-Tagle, M. A., Treviño-Garza, E. J. y Corral-Rivas, J. J. (2022). Evaluación del aprovechamiento forestal en la diversidad y estructura de un bosque templado en Durango. *Revista Mexicana de Ciencias Forestales*, *13*(71), 103-132. https://doi.org/10.29298/rmcf.v13i71.1017

Solís M., R., Aguirre C., O. A., Treviño G., E. J., Jiménez P., J., Jurado Y., E. y Corral-Rivas, J. (2006). Efecto de dos tratamientos silvícolas en la estructura de ecosistemas forestales en Durango, México. *Madera y Bosques*, *12*(2), 49-64. https://doi.org/10.21829/myb.2006.1221242

Vásquez-Cortez, V. F., Clark-Tapia, R., Manzano-Méndez, F., González-Adame, G. y Aguirre-Hidalgo, V. (2018). Estructura, composición y diversidad arbórea y arbustiva en tres condiciones de manejo forestal de Ixtlán de Juárez, Oaxaca. *Madera y Bosques*, *24*(3), Artículo e2431649. https://doi.org/10.21829/myb.2018.2431649

Villaseñor, J. L. (2018). Diversidad y distribución de la familia Asteraceae en México. *Botanical Sciences*, *96*(2), 332-358. https://doi.org/10.17129/botsci.1872

Yan, H., Liang, C., Li, Z., Liu, Z., Miao, B., He, C. & Sheng, L. (2015). Impact of precipitation patterns on biomass and species richness of annuals in a dry steppe. PloS ONE, *10*(4), Article e0125300. https://doi.org/10.1371/journal.pone.0125300