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Research article

Plant diversity in a forest under timber production during rainy and dry seasons

Diversidad vegetal en un bosque bajo producción maderable durante periodos de lluvia y de seca

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Abstract

Knowledge of diversity is key for sustainable forest management. The aim of this study was to analyze plant diversity in a forest under timber production during the dry and rainy seasons in the *Sierra Norte de Puebla*, Mexico. Field data came from 23 0.1 ha-sampling units with nested subplots for measurement of vegetation attributes, in five silvicultural treatments, during the rainy season (2023, 2024) and the dry season of 2024. Alpha diversity was assessed using the Shannon-Wiener index, and beta diversity was analyzed using the Jaccard index. Understory vegetation included 72 species, with higher richness and diversity during both rainy seasons. Regeneration and release cuttings showed higher values of herbs and shrub diversity. Tree layer included 11 species with *Pinus patula* and *Abies religiosa* dominance showed higher diversity values in thinning and selection cuttings, and lower richness and diversity in regeneration cuttings. Floristic similarity between silvicultural treatments ranged from 0.3 to 0.7, with minimal variation among seasons. Results show that silvicultural treatments shape plant diversity, while the rainy season favors increases in plant diversity and richness relative to the dry season. The study confirms the importance of silvicultural systems in the conservation of plant diversity in managed forests.

Keywords: Trees, shrubs, seasonality, herbs, Shannon-Wiener, silviculture.

Resumen

El conocimiento de la diversidad vegetal es clave para la gestión forestal sostenible. El objetivo del estudio fue analizar la diversidad vegetal en un bosque bajo producción maderable, durante la temporada seca y de lluvia en la Sierra Norte de Puebla, México. La información de campo se obtuvo de 23 unidades circulares de muestreo de 0.1 ha para el estrato arbóreo, con subunidades anidadas para la medición de atributos de la vegetación arbustiva y herbácea, en cinco tratamientos silvícolas, durante los periodos de lluvia (2023 y 2024) y seca de 2024. La diversidad alfa fue evaluada mediante el Índice de *Shannon-Wiener*, y la diversidad beta se analizó con el Índice de Jaccard. Se registraron 72 especies en el sotobosque, con la mayor riqueza y diversidad en el estrato herbáceo, durante los periodos de lluvia. Las cortas de liberación y de regeneración registraron los valores más altos de diversidad herbácea y arbustiva. El estrato arbóreo presentó 11 especies con dominancia de *Pinus patula* y *Abies religiosa*, mayor diversidad en cortas de aclareo y selección, y menor riqueza y diversidad en corta de regeneración. La similitud florística entre tratamientos silvícolas fue de 0.3 a 0.7, con mínimas variaciones entre periodos. Los resultados muestran que los tratamientos silvícolas determinan los valores de diversidad en tanto que el periodo de lluvias influye estacionalmente al aumentar la diversidad respecto al periodo de secas. El estudio confirma la importancia de los sistemas silvícolas para la conservación de la diversidad vegetal en bosques manejados.

Palabras clave: Árboles, arbustos, estacionalidad, hierbas, *Shannon-Wiener*, silvicultura.

Introduction

Species diversity in forest ecosystems is a key aspect for their sustainable use and conservation due to the close relationship between diversity and forest productivity (Ammer, 2019), as well as its role in forest resilience to climate change (Hong et al., 2022). It is generally assumed that a forest with high diversity reflects greater availability and heterogeneity of resources such as light, nutrients, and moisture at different stand development stages, and that climatic conditions play an important role in diversity, although the mechanisms of these processes are not entirely clear (Su et al., 2019). Particularly in forests managed for timber production, a major challenge is implementing silvicultural systems that promote biodiversity conservation. However, historically, silvicultural practices create homogeneous structures and conditions, which tend to reduce diversity in different vegetation strata (Bolton & D'Amato, 2019). Therefore, some silvicultural strategies seek to promote diversity and resilience through multi-species and multi-age structures (Bauhus et al., 2017; Bolton &

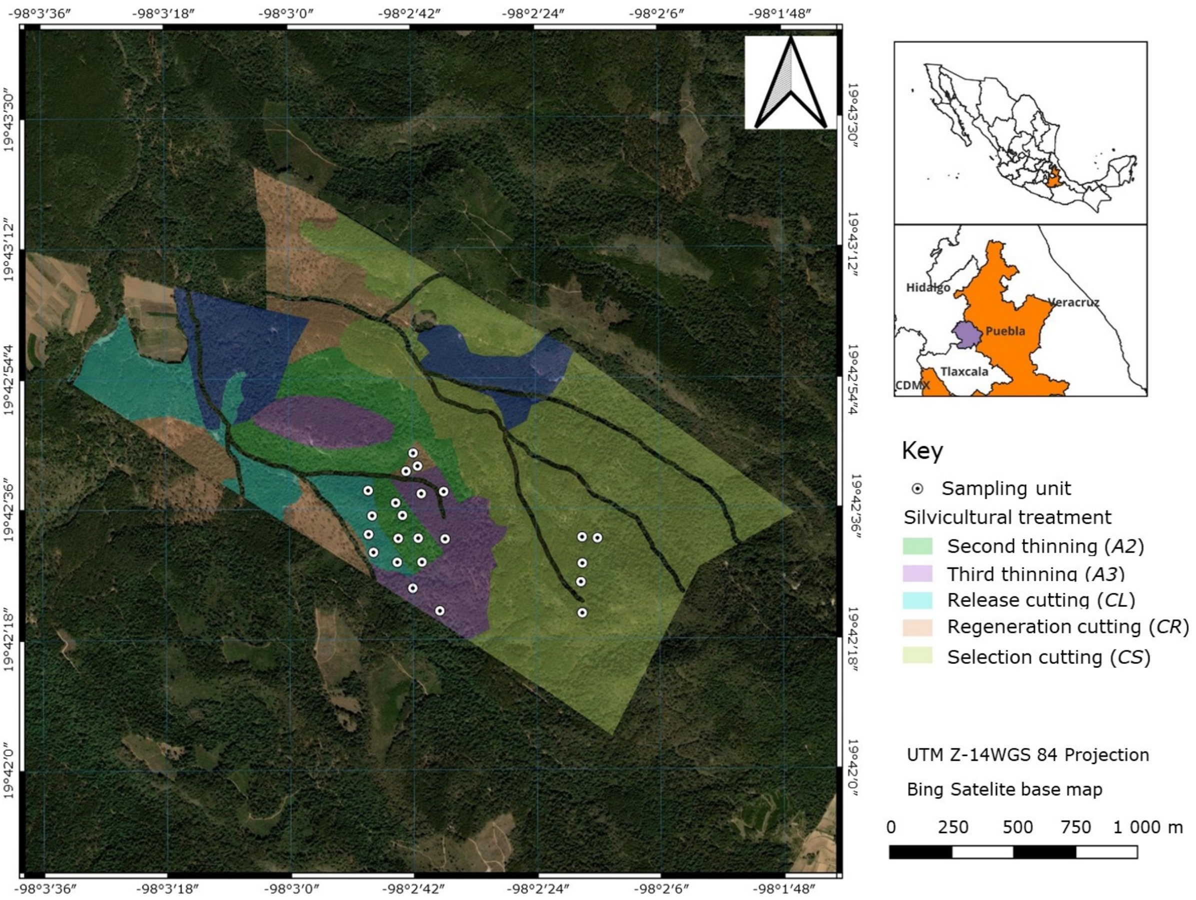
D'Amato, 2019). One way to analyze the impacts of silvicultural treatments on biodiversity is through specific indicators, which allow us to understand the variations in forest composition and structure (Graciano-Ávila et al., 2025).

The *Sierra Norte de Puebla* is the region with the highest timber production in the state and the first to implement forest management programs that integrate practices for biodiversity conservation (Comisión Nacional Forestal [Conafor], 2017). Currently, the magnitude of the impact of forest management on biodiversity conservation in the region is unknown (González-Ovando et al., 2016). Some studies have established baseline diversity in areas under forest management at a specific time (Caballero-Cruz et al., 2022; Rendón-Pérez et al., 2021; Silva-González et al., 2022). However, the lack of information on changes in plant diversity under different silvicultural and climatic conditions in managed forest areas remains significant. The objective of this study was to analyze the diversity in the tree, shrub and herbaceous strata of a forest managed under five silvicultural treatments: regeneration cuts, release cuts, thinning (in two phases), and selection cuts, during the dry and rainy seasons in the *Sierra Norte de Puebla*. The hypothesis is that diversity in the three strata varies according to the silvicultural treatments, while moisture conditions seasonally influence the diversity of the shrub and herbaceous strata. The increased humidity during the rainy season is expected to lead to increases in shrub and herbaceous diversity values each silvicultural treatment.

Materials and Methods

Study Area

The study was conducted in the *Emiliano Zapata ejido*, *Chignahuapan* municipality, in the North of the state of *Puebla*, Mexico (19°43'38.28" N, -98°3'44.51" W and 19°41'53.53" N, -98°1'37.99" W) (Figure 1), which has a forest area of 305.3 ha under management. The climate is temperate sub-humid with summer rains (Instituto Nacional de Estadística, Geografía e Informática [INEGI], 2008), with an annual precipitation of 703 mm and an average temperature of 13.7 °C (Servicio Meteorológico Nacional [SMN], 2020). Vegetation is made up of coniferous and broadleaf forests, in which pine and fir species stand out, in addition to associations of oak and other broadleaf trees (Salinas-Cruz et al., 2017).



Hidalgo = State of *Hidalgo*; *Veracruz* = State of *Veracruz*; *Puebla* = State of *Puebla*; *Tlaxcala* = State of *Tlaxcala*; *CDMX* = Mexico City.

Figure 1. Study area with the location of the silvicultural treatment polygons and sampling units in the *Emiliano Zapata ejido*, *Chignahuapan* municipality, *Puebla*, México.

The study area is subject to two management systems: an intensive one, called the Silvicultural Development Method (MDS, for its acronym in Spanish), which includes regeneration cutting, release cutting, and thinning treatments; and a less intensive one, known as the Mexican Method for the Management of Irregular Forests (MMOBI, for its acronym in Spanish), whose main treatment is selection cutting. Under the MDS, regeneration cutting involves seed trees, which are left standing in the cutting areas, and once regeneration is established, they are removed in the release cutting. Subsequent treatments are three-phase thinning cuts, which consist of partial tree removals to promote the orderly growth of the regenerated stand (a more detailed description of this method and its treatments can be found in Rosales-Salazar et al., 1982). As for the MMOBI, in the selection cut, overmature, damaged, malformed or infested trees are removed without completely opening the canopy, in order to gradually improve the quality of the remaining stand (López-Hernández et al., 2017).

Obtaining field data

In the managed area, 23 primary sampling units (PSUs) of 0.1 ha were established in a circular pattern. Based on the surface of the areas under the different silvicultural treatments, the PSUs were systematically distributed as follows: five PSUs in Second thinning (A2), Third thinning (*A3*), Release cutting (*CL*), Selection cutting (*CS*), and three in Regeneration cutting (*CR*) (Figure 1). In these areas, the tree stratum was measured (trees with Diameter at Breast Height *DBH*≥7.5 cm). *DBH* (1.3 m) was recorded using a model 283D Forestry Suppliers Inc.® diameter tape. Basimetric area was calculated from the *DBH* for each species as a measure of dominance within the PSUs. Each sampling unit (PSU) was divided into four quadrants. In three of these quadrants, equidistant sampling subunits were systematically placed 12.5 m from the center. These subunits consisted of two nested plots of 4 m^2 and 1 m^2 for measuring the shrub and herbaceous strata, respectively. Vascular plants were identified and quantified in each subunit. Herbs were defined as individuals less than 0.5 m tall, and woody plants greater than 0.5 m up to 2 m tall were defined as shrubs (Kutnar et al., 2026). Botanical samples were collected from individuals whose taxonomic identity could not be determined in the field for later identification using taxonomic keys (Calderón de Rzedowski & Rzedowski, 2001) and specimens from the TLXM University Herbarium of the Autonomous University of *Tlaxcala.* The measurements were taken during the summer of 2023 and 2024 (rainy period) and spring of 2024 (dry period).

During both rainy seasons, direct precipitation was measured using True-Check® rain gauges with a capacity of 150 mm and an accuracy of 0.1 mm. These gauges were installed at a height of 1.20 m, 8.5 m from the center of each PSU in North, East, South, and West directions, for a total of four rain gauges per PSU. Rainfall was recorded weekly in each gauge during the periods of August 21 to October 30, 2023 (11 weeks) and June 24 to November 11, 2024 (21 weeks) to capture the interannual variation of the rainy season.

Data Analysis

Alpha (α) Diversity

Species richness for the three vegetation strata was considered as the number of species recorded in the samplings, while diversity was calculated using the Shannon-Wiener index (Moreno, 2001).

Shannon-Wiener Index (*H′*):

$$H' = -\sum_{i=1}^{S} p_i \ln p_i \qquad (1)$$

Where:

H′ = Shannon-Wiener index

S = Number of species

p_i = Proportion of individuals of the *i* species

ln = Natural logarithm

For the tree stratum, in addition to the diversity indicators, the Importance Value Index (IVI) specific to each silvicultural treatment was calculated using the following formula (Rendón-Pérez et al., 2021):

$$IVI = \frac{(FR+DR+dR)}{3} \qquad (2)$$

Where:

IVI = Importance Value Index

FR = Relative frequency

DR = Relative dominance (measured as basimetric area)

dR = Relative density (number of individuals ha^{-1})

Beta diversity ($\boldsymbol{\beta}$)

Beta diversity, understood as the floristic similarity between two communities, was evaluated with the set of species of the shrub and herbaceous strata, comparing the silvicultural treatments analyzed, through the Jaccard index, which is expressed in the following equation (Moreno, 2001):

$$I_j = \frac{c}{a+b-c} \qquad (3)$$

Where:

I_j = Jaccard floristic similarity index

a = Number of species present in community *a*

b = Number of species present in community *b*

c = Number of species present in both communities *a* and *b*

Data processing and analysis were performed using the Vegan package of the *R* software, version 4.5.2 (R Core Team, 2026). From site abundance matrices, the alpha diversity indices were calculated: species richness (*S*) and Shannon-Wiener index (*H'*). Descriptive statistics (mean and standard deviation) were obtained for each period, for silvicultural treatments and vegetation strata, to evaluate differences between silvicultural treatments, using analysis of variance (ANOVA) and Tukey's multiple comparison tests (*a*=0.05) where appropriate. Since the rainy and dry seasons are not strictly treatments, they were not statistically compared and were only used as periods for comparing species richness and diversity among the silvicultural treatments.

Results

Precipitation

Monthly precipitation values in the study area are shown in Figure S1, which reflects the interannual variation in precipitation. The months of August-October 2024 registered a higher incidence than the same period in 2023. It is also noteworthy that in 2023, the rainy season ended in October, while in 2024, rainfall continued into November. Precipitation by silvicultural treatment is very similar, except for the *CS*, where August 2023 and July 2024 had lower precipitation values than the other treatments, although the values recorded in the remaining months are the same.

Alpha diversity

Shrub and herbaceous strata

The total understory richness was 72 species, of which 27 belong to the shrub stratum and 45 to the herbaceous stratum, distributed among 31 families, with Asteraceae standing out for its greater representation with 16 species; the other families recorded six or fewer species. In the shrub layer, *Fuchsia thymifolia* Kunth, *Baccharis conferta* Kunth and *Symphoricarpos microphyllus* (Humb. & Bonpl. *ex* Schult.) Kunth stand out for their constant presence in all treatments and periods, while in the herbaceous layer, *Salvia elegans* Vahl, *Smilax bona-nox* L., *Chimaphila umbellata* (L.) W. P. C. Barton., *Bromus carinatus* Hook. & Arn. and *Brachypodium mexicanum* (Roem. & Schult.) Link are prominent. In contrast, the least represented species are *Physalis acutifolia* (Miers) Sandwitt, *Physalis chenopodifolia* Lam., *Sedum praealtum* A. DC. and *Stevia monardifolia* Kunth, which were only observed during rainy periods in *CS* (Table MS1: https://tinyurl.com/3w895c44).

In the shrub layer, species richness remained relatively stable at 11 species between the rainy and dry seasons for treatments *A2*, *A3*, and *CL*. It showed a decrease in *CR* during the spring (dry) season of 2024 (6 species) and an increase in *CS* during the summer (rainy) season of 2023 (14 species). In the summer of 2024, *CL* reached its highest value with 14 species, while *CR* and *CS* showed the lowest values with 11 and 9 species, respectively (Table 1).

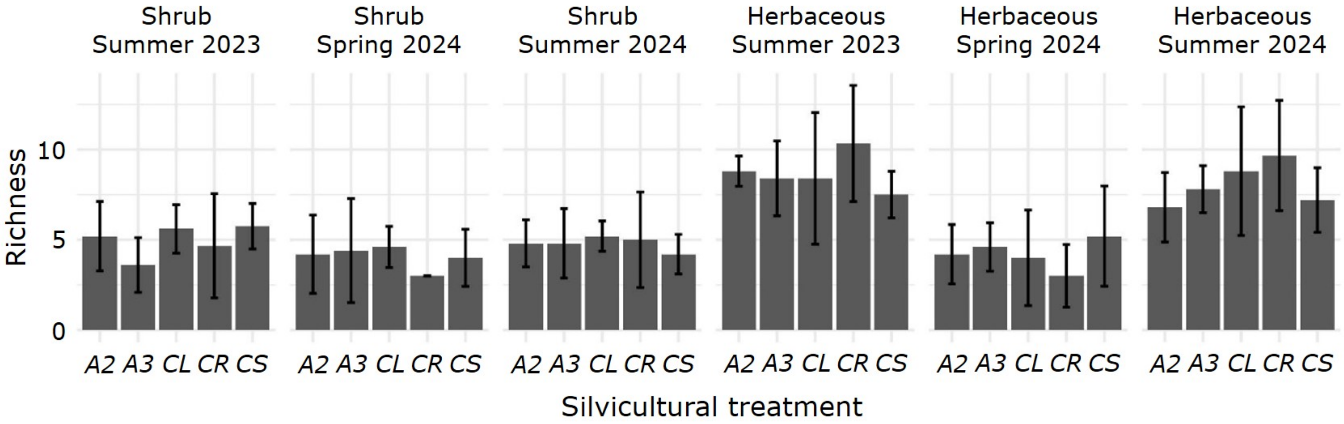
Table 1. Species richness (*S*) in the understory during different periods and silvicultural treatments in the *Emiliano Zapata ejido*, *Chignahuapan*, *Puebla*, Mexico.

Period	***A2***	***A3***	***CL***	***CR***	***CS***
		Shrub			
Summer 2023	11	11	11	9	14
Spring 2024	11	11	13	6	9
Summer 2024	13	10	14	11	9
		Herbaceous			
Summer 2023	17	20	22	20	13
Spring 2024	11	10	12	7	11
Summer 2024	14	17	24	19	15

A2 = Second thinning; *A3* = Third thinning; *CL* = Release cutting; *CR* = Regeneration cutting; *CS* = Selection cutting.

In the herbaceous layer, species richness values were higher and more variable. In summer 2023, *CL* showed the highest richness with 22 species, followed by *CR* and *A3* with 20 species each. In spring 2024, the values decreased considerably, with 12 and 11 species for *CL* and *CS*, respectively. It is worth noting that during the 2024 dry season, *CR* showed the lowest species richness values in both vegetation layers. In contrast, in summer 2024, *CL* again stood out with 24 species, while *CR* and *CS* reached 19 and 15 species, respectively.

Figure 2 shows the average number of species recorded in the different periods and silvicultural treatments. Although the observed differences were not significant (Table MS2: https://tinyurl.com/3w895c44), there is a clear trend of greater species richness in the summer (rainfall) for the herbaceous stratum, and a slightly less noticeable trend for the shrub stratum.



A2 = Second thinning; *A3* = Third thinning; *CL* = Release cutting; *CR* = Regeneration cutting; *CS* = Selection cutting.

Figure 2. Average species richness recorded by silvicultural periods and treatments in the *Emiliano Zapata ejido, Chignahuapan, Puebla*.

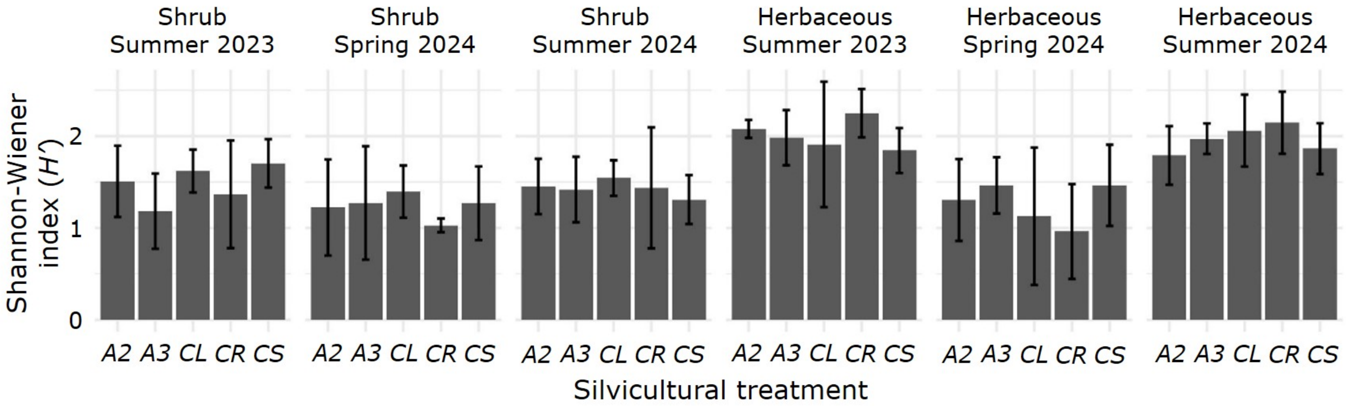
Table 2 shows the Shannon-Wiener index values. For the shrub layer, the values ranged from 2.02 to 2.52, with little difference between the study periods or the silvicultural treatments. The highest value was observed in the *CS* during the summer of 2023, while the lowest values were recorded in the *CR* and *CL* in the spring of 2024, similar to the distribution of species richness. For the herbaceous layer, the values were slightly higher, ranging from 2.1 to 2.99. The maximum value was observed in the *CL* (2.99) in the summer of 2024, representing the greatest diversity identified in the study. In general, the highest values of this index were detected during rainy periods, particularly in 2024.

Table 2. Shannon-Wiener index (*H′*) for the understory by periods and silvicultural treatments in the *Emiliano Zapata ejido*, *Chignahuapan*, *Puebla*, Mexico.

Season	***A2***	***A3***	***CL***	***CR***	***CS***
Shrub					
Summer 2023	2.21	2.22	2.11	2.02	2.52
Spring 2024	2.11	2.08	2.21	1.72	2.03
Summer 2024	2.26	2.02	2.30	2.30	1.96
Herbaceous					
Summer 2023	2.57	2.71	2.92	2.80	2.18
Spring 2024	2.15	2.10	2.16	1.86	2.10
Summer 2024	2.42	2.58	2.99	2.79	2.38

A2 = Second thinning; *A3* = Third thinning; *CL* = Release cutting; *CR* = Regeneration cutting; *CS* = Selection cutting.

Figure 3 shows the diversity values expressed by the Shannon-Wiener index in the different silvicultural treatments and vegetation strata. The trends with this index are similar to those observed with species richness, and although the differences are not significant (Table MS2: https://tinyurl.com/3w895c44), diversity values were notably lower and more variable in the herbaceous stratum during the dry period, while the shrub stratum showed greater homogeneity between treatments and periods.



A2 = Second thinning; *A3* = Third thinning; *CL* = Release cutting; *CR* = Regeneration cutting; *CS* = Selection cutting.

Figure 3. Average Shannon-Wiener index (*H′*) by periods and silvicultural treatments in the understory of the *Emiliano Zapata ejido*, *Chignahuapan*, *Puebla*, Mexico.

Tree stratum

A total of 11 species from five families were recorded in the tree stratum: Pinaceae (5), Fagaceae (3), Betulaceae (1), Ericaceae (1) and Rosaceae (1); with *Pinus patula* Schiede *ex* Schltdl. & Cham. and *Abies religiosa* (Kunth) Schltdl. & Cham. being the most frequent species, followed by *Quercus laurina* Bonpl. Diversity indexes by silvicultural treatment are shown in Table 3, where it can be observed that species richness remained constant with eight species in all treatments, except in *CR* where it was 5 species. The Shannon-Wiener index (*H′*) was highest in *A2* (1.47) and *A3* (1.38), and decreased in *CL* and CR to 1.03 and 0.86 respectively.

Table 3. Richness (*S*) and Shannon-Wiener diversity (*H'*) values of the tree stratum by silvicultural treatments in the *Emiliano Zapata ejido*, *Chignahuapan*, *Puebla*, Mexico.

	A2	***A3***	***CL***	***CR***	***CS***
Richness	8	8	8	5	8
Diversity (*H'*)	1.47	1.39	1.03	0.86	1.4

A2 = Second thinning; *A3* = Third thinning; *CL* = Release cutting; *CR* = Regeneration cutting; *CS* = Selection cutting.

Importance value

Table S1 shows the Importance Value indexes for tree species in each silvicultural treatment. *Pinus patula* has *IVIs* greater than 0.5 in all treatments except *A2*. In general, conifers dominate in almost all treatments with cumulative values greater than 0.5, especially in *CR*, where even with the lowest richness, the most relevant species are conifers with cumulative *IVIs* greater than 0.8. Among broadleaf trees, only *Quercus laurina* and *Q. rugosa* Née stood out in importance value, mainly in *A2*, while the other species are minimally represented in the silvicultural treatments.

Floristic similarity

The Jaccard index was used to assess the similarity in composition between silvicultural treatments in different periods, considering shrub and herbaceous species together, and the tree stratum separately.

The values obtained for the understory ranged from 0.35 to 0.7, which generally indicates a moderate similarity in composition between silvicultural treatments in different periods. In summer 2023, the lowest similarity value was 0.35 in *CS*-*CR*, and the highest value was 0.69 between *A2-A3*. In spring 2024, the similarity maintained an intermediate trend with values between 0.42 and 0.59, the latter value between *CS-CL* and *A2-A3*. In the summer of 2024, the values were higher compared to previous periods, mainly between *A2-A3* with a value of 0.7, indicating a general greater floristic similarity between treatments during this period (Table S2). In the tree stratum, the similarity values show a clearer trend, as the similarity in species composition is highest in the thinning treatments, while *CR* shows low similarity with all other treatments (0.44), especially with *CS* (0.3) (Table S3).

Discussion

Shrub and herbaceous strata

The species richness values in this study are higher than those of *Abies religiosa* forests on *Nevado de Toluca*, where Mejía-Canales et al. (2018) recorded 24 herbaceous and eight shrub species. In contrast, Rendón-Pérez et al. (2021) recorded 58 herbaceous and 10 shrub species in pine forests in *Epazoyucan*, state of *Hidalgo*. Both studies agree on the greater representation of the Asteraceae family, as it was also confirmed in the described here. Regarding some of the most common species, Mejía-Canales et al. (2018) classified *Symphoricarpos microphyllus* and the Poaceae (represented in this study by *Bromus carinatus* and *Brachypodium mexicanum*) as heliophytes; while *Fuchsia* sp., *Salvia* sp. annd *Stevia monardifolia* are considered part of the ecological group of sciophytes, meaning they are shade-tolerant. In this sense, the results obtained are consistent, since heliophytes are generally colonizers during disturbance processes, which explains their constant presence in all the silvicultural treatments analyzed. In contrast, *Stevia monardifolia*, which only appears in *CS* during the rainy season, confirms its affinity for sites with greater humidity and cover.

Although the differences in richness and diversity between silvicultural treatments were not significant, the trends observed in diversity during the analyzed periods coincide with the proposed hypothesis, reflecting variations depending on the silvicultural treatments and showing a response to humidity conditions. All the treatments involve tree removal with varying intensities and objectives. For example, involve the complete opening of the canopy (Pérez-López et al., 2020), unlike where canopy opening is less drastic (Silva-González et al., 2022). As with disturbance processes, canopy opening increases the availability and heterogeneity of resources, which favors increases in species diversity (Su et al., 2019). The greater herbaceous richness in suggests more opportunities for colonization after *CR*, especially since *CL* involves further canopy opening by removing seed trees. It has been observed that canopy opening modifies environmental conditions (light, temperature, and humidity) in the understory, allowing the establishment of colonizing species (Bolton & D'Amato, 2019) in addition to resident species in the harvested areas, thus increasing diversity (Kutnar et al., 2026). Species such as *Stevia monardifolia* and *Sedum praealtum*, *Arenaria* sp. and others, which are only present during rainy periods, confirm that higher humidity creates new environments that allow their establishment. According to the hypothesis, lower values of herbaceous diversity were observed in the harvested areas during spring. While moisture availability favors abundance and diversity in the understory, its mechanisms of influence are not necessarily linear and also depend on other soil factors, such as depth and drainage, among others (Su et al., 2019).

The low diversity values in the shrub layer across all treatments and periods have also been observed in other temperate forest studies (Mejía-Canales et al., 2018; Rendón-Pérez et al., 2021). The lower variability of indicators in the shrub layer between periods can also be explained by the fact that this layer mainly includes woody individuals that can better tolerate the decreases in spring moisture, as suggested by Liu et al. (2026). It is worth noting that, in the *CS* treatment, considered a conservative approach to tree removal (López-Hernández et al., 2017), the diversity values in the lower strata are similar to those in *A2* and *A3*, highlighting the importance of canopy retention in maintaining herbaceous and shrub diversity. Thinning treatments aim to promote the growth of remaining trees without excessively opening the canopy (Pérez-López et al., 2020), similar to what occurs with silvicultural systems (*CS*). Kutnar et al. (2026) highlight the importance of the canopy in understory richness, as it is considered a proxy for light availability in the lower parts of the canopy. Thus, the silvicultural conditions created by the treatments are consistent in terms of the effect of resource availability (light and moisture) on species diversity in the shrub and herbaceous layers.

Tree stratum

The species richness and diversity values recorded in this study are similar to those reported in mixed forests of the state of *Durango*, where 12 tree species were found in regeneration cutting areas with seed trees (Hernández et al., 2019). However, they are lower than the values reported in a managed forest in the state of *Hidalgo*, which showed a richness of 20 species (Rendón-Pérez et al., 2021). Likewise, they are lower than the values reported by Silva-González et al. (2022) in timber production forests in *Durango*, with 18 tree species. They are much lower than the 24 species stated by Pérez-López et al. (2020) in highly diverse managed forests in the state of *Chiapas.*

In general, the tree diversity values more clearly reflect the effects of silvicultural treatments. For example, the lower richness and diversity in *CL* and *CR* reflects the objective of these treatments to actively promote the establishment and development of regeneration of species with higher commercial value (Pérez-López et al., 2020), which in the study region are *Pinus patula* and *Abies religiosa* (Gutiérrez-Batalla et al., 2025). Likewise, Silva-González et al. (2022) refer that, over periods of several years, *CS* also maintain higher tree diversity values than other treatments such as *CR*, similar to what was observed in the present study.

On the other hand, the variation in diversity values in the thinning cutting (*A2* and *A3*) is also consistent with what is indicated in simulations of thinning scenarios in temperate forests, which show the differentiated response of tree diversity to the intensity and type of thinning (Rubio-Camacho et al., 2024).

The specific *IVI* for silvicultural treatments confirms the predominance of conifers in almost all treatments. The *IVI* values are similar to those reported for the states of *Chiapas* (Pérez-López et al., 2020) and *Hidalgo* (Rendón-Pérez et al., 2021), who observed *IVIs* greater than 50 % for conifer species in managed forests. This pattern, recurrent in managed forests in Mexico, is not exclusive to intensive systems, as it also occurs in less intensive systems, which also favor the regeneration and development of conifers (Hernández et al., 2019; Silva-González et al., 2022). The aforementioned trends are also reflected in the low prevalence of broadleaf species in the study area, regardless of the silvicultural system applied. This confirms the findings of Pérez-López et al. (2020) and Rendón-Pérez et al. (2021), who observed that these species are systematically displaced in harvested areas, with a consequent decrease in species richness and diversity within this stratum.

Floristic similarity

In general, the Jaccard index showed that the similarity in understory composition among the silvicultural treatments is moderate (0.3 to 0.7) and also affected by moisture conditions, suggesting that harvested areas share few species. These values are slightly lower than those reported by Rendón-Pérez et al. (2021) in different pine and broadleaf associations in *Epazoyucan*, *Hidalgo*, where they recorded values of 0.4 to 0.8 for the shrub and herbaceous strata. For the tree stratum, the similarity values are close to those of Gutiérrez-Batalla et al. (2025), who also detected the highest similarity values among thinning cuts in the *Sierra Norte de Puebla*.

The moderate similarity values suggest differences in the ecological conditions of the treatments, which possibly interact with other site conditions such as slope, aspect, soil type, moisture content, etc., which are also determinants of diversity in temperate forests (Su et al., 2019). For example, the fact that the extreme similarity values were recorded during rainy periods suggests that these periods promote greater resource heterogeneity, allowing for the establishment of new species under each condition. Greater resource availability and heterogeneity is one of the determining factors for diversity, as it facilitates the coexistence of plant species with different ecological requirements (Kutnar et al., 2026).

Conclusions

Prescribed cuttings in intensive methods to promote the regeneration of commercially valuable species resulted in higher levels of herbaceous and shrub diversity, but lower levels in the tree stratum, where *Pinus patula* had the highest importance value. In contrast, the highest tree diversity values were observed in the thinning and *CS* treatments, which are more conservative in tree removal and canopy opening. The Jaccard index showed floristic similarity values between 0.3 and 0.7 among treatments, with significant variations during rainy periods, reflecting greater resource availability and heterogeneity, which is key to higher diversity. The results consistently show that the conditions created by the silvicultural treatments influence diversity levels in all three strata, and that richness and diversity are affected by moisture conditions.

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Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Vidal Guerra-De la Cruz: conceptualization, structure, results analysis, and manuscript writing; Bossuet Gastón Cortés-Sánchez: data processing, analysis, and manuscript writing; José Luis Martínez y Pérez and Juan Carlos López-Domínguez: determination of species taxonomic identity and manuscript review; José Carlos Monárrez-González: sampling design, fieldwork, and manuscript review.

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