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ORIGINAL RESEARCH ARTICLE

Effect of silvicultural treatments on forest diversity and structure in temperate forests under management in Durango, Mexico

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ABSTRACT

The present study evaluated the effect of silvicultural treatments on the diversity and structure of species in temperate forest ecosystems in the Municipality of Pueblo Nuevo in the State of Durango, Mexico; it was carried out to know if forest use modifies the diversity, mixture of species, spatial distribution, and dimensional differentiation of individuals in these ecosystems. The evaluation was carried out by comparing 10 plots with management history, which were measured before the application of the treatment and five years later. The diversity indices of Shannon, Simpson and Margalef were compared, as well as indices of structure of mixture of species, spatial distribution, and dimensional differentiation. According to the silvicultural treatments applied, the values of the indices do not present significant differences in their evaluations ($p > 0.05$), which indicates that forest use does not modify the diversity and structure of species of the tree stratum of this plant community.

Keywords: plant community; dimensional differentiation; space distribution; tree stratum; species structure

1. Introduction

In sustainable forest management, it is essential to conserve and maintain biodiversity, floristic composition, the mixture of its elements and the ecosystem landscape[1]. The structural characterization of the tree stratum is a way to estimate the condition of forest stands at a given time and their evolution over time[2-4] and, in turn, has become an essential tool for decision-making on resource management in locations subject to harvesting or in protected areas, in which natural succession processes or damage caused by anthropogenic activities are observed. Knowing and monitoring the structure is important to guarantee sustainable management[5-7].

The structure of forest stands is an indicator of biodiversity[8] so it is considered as one of the most important aspects in the characterization of forest ecosystems[9], in addition it has become an important

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factor for its analysis and management[10]. From a technical point of view, forest management requires information on structural characterization to evaluate the impact of various silvicultural treatments and contribute to decision-making on management plans, conservation and sustainable use of forest resources [11].

Forest structure refers to how tree attributes are distributed within a forest in a forest ecosystem; diversity refers not only to species richness, but to a set of phenomena that determine heterogeneity within a tree community, including the variety of sizes and their location[12]. Structural characterization can be described by three parameters: a) species diversity and species mix that assess how trees are related; b) spatial distribution that describes how individuals are arranged on the surface; and c) dimensional differentiation that quantifies the difference in tree sizes[13]. Therefore, an adequate and accurate way to describe the structure is the characterization of forest stands considering the aforementioned parameters[14]. For this, it is necessary to use indexes or variables that reflect these characteristics in small areas or stands [15]; species diversity and structure of forest stands can be measured through indexes that provide information to prescribe better silvicultural practices and formulate forest management strategies[16].

In Mexico, several studies have been conducted to analyze the effect of management on the diversity and structure of forest ecosystems[17-19], demonstrating that silvicultural practices modify the forest stands of these ecosystems by changing their diversity and structure. For this study, the hypothesis is presented that the application of silvicultural treatments (first or second thinning) modifies the diversity and structure of species by changing the mixture and composition of their elements.

2. Objectives

The objective of this study was to evaluate the effect of silvicultural treatments on the diversity and structure of tree species in temperate forest ecosystems in the municipality of Pueblo Nuevo, Durango, Mexico.

3. Materials and methods

3.1. Study area

The present investigation was carried out in the region of El Salto, Municipality of Pueblo Nuevo, located in the southwest of the state of Durango, in the elevated zones of the Sierra Madre Occidental, at parallels north latitude and west longitude (**Figure 1**). The altitude above mean sea level ranges from 2492 m to 2644 m[20]; it has an average annual precipitation of 1300 mm and a temperature of 18 °C [21].

In the plant communities evaluated, timber harvests were carried out under the Silvicultural Development Method (MDS), the vegetation of the site consists of mixed forests of Pinus, Quercus, Juniperus, Arbutus and Alnus species; they are second growth stands that have been subject to forest harvesting for more than 100 years[22].

3.2. Data collection

The data come from ten permanent forest and soil research sites (spifys) which were inventoried in 2008, before the application of the thinning treatment, and five years after it, in 2013. The methodological guidelines for the establishment of research sites in the state of Durango proposed by Corral-Rivas et al. (2009), and Corral-Rivas, Vargas-Larreta, Wehenkel, Aguirre-Calderón and Crecente-Ocampo (2013), respectively, were followed for the installation and remeasurement of the plots. In the research plots, silvicultural treatments corresponding to the first or second thinning were applied one year after installation. Plot dimensions were 50 m × 50 m (0.25 ha), systematically located within the region.

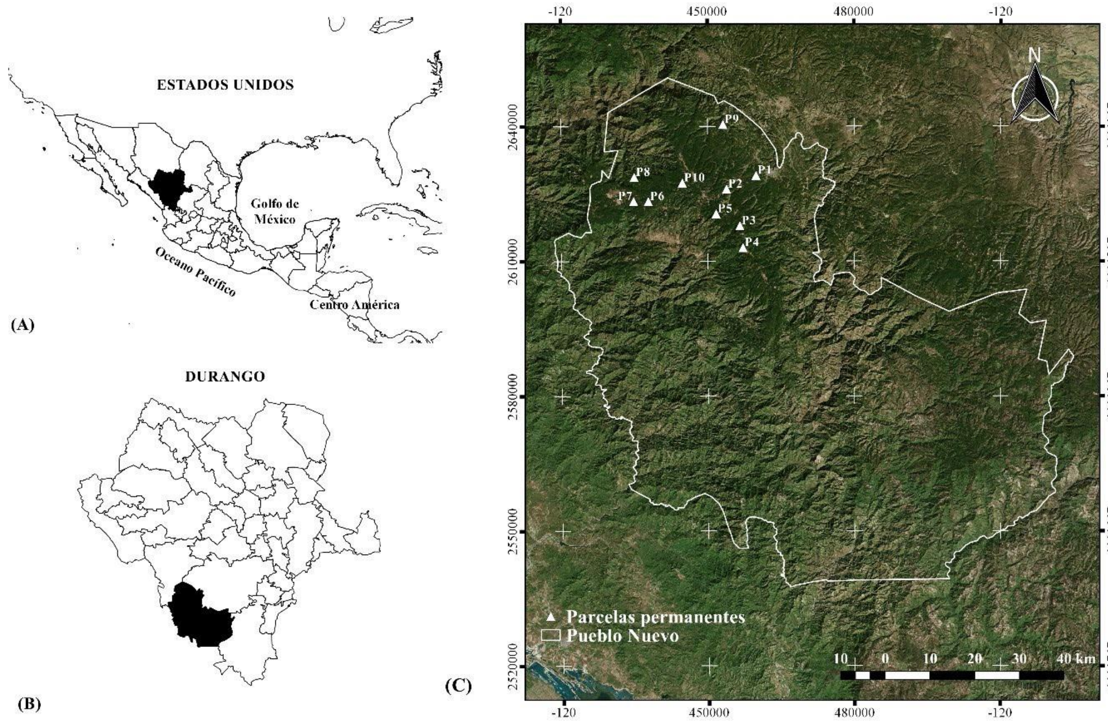

Figure 1. Location of permanent plots under management (C), in El Salto, Municipality of Pueblo Nuevo, Durango, Mexico.

The following dasometric information was recorded for each plot: tree number, species, dominance, normal diameter (> 7.5 cm), total height (m), two crown diameters (north-south, east-west), azimuth and distance from each individual to the plot center. In addition to recording this information for live trees, the presence of stumps, standing or fallen dead individuals, and incorporated trees (regeneration) was also recorded.

3.3. Information analysis

The Shannon, Simpson and Margalef indices were used to estimate diversity, dominance and species richness, respectively. To determine the degree of species mixture, spatial distribution and dimensional differentiation, we used Gadow's species mixture index, Gadow's angle uniformity, dimensional differentiation in diameter and height, and the dominance index[24].

3.4. Shannon-Wiener Index (HH')

Species diversity for each plot was described through this index, which is a measure of diversity derived from information theory, since it is based on logic[23]. Gadow (1993) mentions that the Shannon index (H') is one of the most used variables for the estimation of species diversity and reflects in a good way the diversity of floristically rich populations.

$$H' = -\sum pi \; ln \, pi \tag{1}$$

Where:

(pi)= relative abundance of each species i (in number of individuals per hectare)

ln (pi)= natural logarithm of the relative abundance of each species i

The value of the Shannon index (H') increases as a greater number of species and the proportion of their individuals is more homogeneous. Therefore, HH' depends not only on the number of species present in an ecosystem, but also on the frequency with which they are represented.

3.5. Simpson's index (DD)

It is one of the parameters used to measure the richness and diversity of organisms. In ecology it is also used to quantify the diversity of a habitat (Eq. 2).

$$D = 1 - \sum pi^2 \quad (2)$$

Where:

pi =proportion of individuals of species i, with respect to the total number of individuals.

Simpson's dominance index represents the probability that two randomly selected individuals within a habitat belong to the same species; that is, the closer the value is to zero, the greater the possibility of dominance of a species and population, and the closer it is to unity, the lower the dominance [25].

3.6. Margalef Index (MI)

It is used to estimate the richness of a community based on the numerical distribution of individuals of the different species, as a function of the total number of individuals in the sample analyzed (Eq. 3).

$$IM = \frac{(S-1)}{(LnN)} \quad (3)$$

Where:

S= number of species

L= total number of individuals

The minimum value it can take is zero and occurs when there is only one species in the sample (S=1, so S-1=0).

3.7. Forest structure indexes

The characterization of the structure, which evaluates a) species mix, b) spatial distribution and c) dimensional differentiation, was based on the estimation of five indices. The determination of these indices was based on a sampling method known as the five-tree structural group. This sampling system was developed by a group of researchers at the University of Göttingen, Germany, to evaluate the structural attributes of the trees that make up a forest stand[26-28].

a) Mixed species

Species diversity is an important aspect that should be considered within the concept of sustainable forest structure and management. Its monitoring at spatial and temporal scales allows detecting changes in key indicators of sustainable forest management.

3.8. Gadow's species mixing index (Mi). It is a measure of the spatial segregation of individuals of different species where the index value of the reference tree i is defined as the proportion of neighbors belonging to species different from that reference tree[29-32].

$$M_i = \frac{1}{4}\sum_{j=1}^{4} v_j \quad (4)$$

vj is a discrete binary variable that takes the value of 0 when the j-th tree is of the same species as reference tree i, and the value of 1 if it is of different species. Mi can take five different values (0.0, 0.25, 0.50, 0.75 and 1). Values close to zero indicate that species tend to group together and do not mix with each other; conversely, values close to one indicate a preference to mix[33].

b) Spatial distribution

To evaluate the spatial distribution of individuals in the plots, Gadow's uniformity index (W_i) was used, since it is simple to calculate and has proven to be efficient for the description of this structural component[34].

Gadow's uniformity index (W_i). The determination of Gadow's uniformity index W_i, (Eq. 5; Gadow and Hui is based on the measurement of the angles between two neighbors to the reference tree i and its comparison with a standard angle α, such that considering four neighbors to the reference tree W_i can take values of 0.0, 0.25, 0.50, 0.75 and 1, with spatial conditions of very regular, regular, random, irregular, irregular and very irregular, respectively.

$$W_i = \frac{1}{4}\sum_{j=1}^{4} v_j \qquad (5)$$

vj is a discrete binary variable that assumes the value of 1 if the j-th angle between two neighboring trees is less than or equal to the standard angle α and 0 otherwise.

In this work, a standard angle of 72º was used, because, in the simulations of Hui and Gadow (2002), this value was found to be the optimal standard angle producing an average of WW =0.50 for a random distribution of trees.

c) Dimensional differentiation

The last characteristic that defines the structure of a stand is the variation between the sizes of the trees that constitute it. To evaluate this structural component we used the dimensional differentiation indexes in diameter, TH_i (Eq. 6) and height, TH_i (Eq. 7); as well as the dominance index, Ui (Eq. 8). These indexes have proven to be useful to describe the horizontal and vertical structure of forest ecosystems [34].

3.9. Dimensional differentiation index. This index can be applied to any variable representing tree size, in this case diameter and height.

$$TD_i = \frac{1}{4}\sum_{j=1}^{4} v_j \frac{\min(Di, Dj)}{\max(Di, Dj)} \qquad (6)$$

$$TH_i = \frac{1}{4}\sum_{j=1}^{4} v_j \frac{\min(Hi, Hj)}{\max(Hi, Hj)} \qquad (7)$$

Where:

TD and TH = differentiation in diameter and height, respectively.

i= reference tree

Dp= diameter of tree i

Dj=tree diameter j

Hp=tree height i

Hj=height of tree j

The value of both increases as the average difference in the sizes of the trees close to the reference tree increases. A value of zero corresponds to a situation where all trees have the same size. In this work, five groups of dimensional differentiation were integrated according to Aguirre et al. (1998), with the following categories: (Scarce: 0.0 $< TDi$ and THi < 0.2; Moderate: 0.2 $< TDi$ and THi < 0.4; Medium: 0.4 $< TTDi$ and THi < 0.6; High: 0.6 $< TDi$ and THi < 0.8; Very High 0.8$< TDi$ and THi < 1).

3.10. Dominance index. The dominance of a reference tree i (Ui) is defined as the proportion of the four neighbors that are larger than that tree[35].

$$U_i = \frac{1}{4}\sum_{j=1}^{4} v_j \qquad (8)$$

vj is a discrete binary variable that assumes a value of 1 when the tree DD is smaller than the reference tree i, and a value of 0 otherwise.

Like the indices of species mixture, angle uniformity and dimensional differentiation their values range from 0 to 1. Considering four neighbors their results are as follows: Ui = 0 if all four neighbors are larger than reference tree i (suppressed); Ui = 0.25 if three of the neighbors are larger than reference tree i (intermediate); Ui =0.50 if two of the neighbors are larger than reference tree i (codominant); Ui =0.75 if one of the neighbors is larger than reference tree i (dominant) and Ui =1 if none of the neighbors is larger than reference tree i (very dominant). The five values of Ui correspond to the social classes developed by Kraft (1884).

3.11. Edge effect

The calculation of the structure indices will always be biased to those trees close to the edges of the plots, unless a correction scheme for edge effects is applied in their estimation. The reason is that these trees are problematic because their potential neighbors may be located outside the area of interest. To eliminate the edge effect and obtain unbiased results of the structural variables, a n nearest neighbor edge correction method proposed by Pommerening and Stoyan (2006) [36] was used in the SAS routines. This technique allows obtaining unbiased estimates for the mean values of all the indices, as well as the true distributions of their values. The principle is based on the concept of "minus sampling" and evaluates whether all n nearest neighbors of a reference tree i are truly located within the observation plot, eliminating those individuals that are very close to any of the plot edges. Because the four nearest neighbors to a reference tree i are normally listed in ascending order according to distance, all reference trees whose mean distance to the fourth tree is greater than the distance to the nearest edge were ignored in this study.

3.12. Statistical analysis

To evaluate whether the indices used in this work imply a significantly different diversity and structure between measurements, a dependent means comparison test (Student's t-test) was applied considering a 95% significance level. The evaluation was carried out by comparing the means of the different indices using the SAS statistical program [37].

4. Results and discussion

A total of 20 species belonging to five families and seven genera were recorded in all the plots. The genus Pinus presented the highest richness with six species; its distribution is found throughout the mountainous system of the country[38-40]. LópezHernández et al. (2017) [41] and Graciano Ávila et al. (2020) [42] recorded that Pinus has greater abundance in temperate forests of Puebla and Durango. In the present study, the genera Quercus and Arbutus were present with five species each (**Table 1**). Of the 20 species observed in the two inventories only 17 are shared, since Abies durangensis and Pinus engelmannii were recorded in 2008 but were not found in 2013. The presence of Pseudotsuga menziesii, which was absent in 2008, was observed in 2013. The presence or absence of species in one or another year of measurement is possibly due to the low absolute abundance (number of trees per hectare) and because they are subject to greater competition and a high mortality rate.

For the sampled plots, Table 2 shows the number of species recorded in the two sampling years (S1 and S2), the number of trees, the number of stumps, the number of dead or fallen individuals, the number of trees incorporated and the silvicultural treatment applied to each plot. Plot 3 presented an increase in the number of its individuals (+2), the remaining plots presented a reduction in the number of trees; the plots with the greatest number of trees removed were 5 and 6, with 91 and 119 individuals, respectively; on the other hand, plot 5 presented the greatest number of regeneration individuals with 69 incorporations.

4.1. Diversity indexes

Table 3 shows the values for the different diversity indexes evaluated. In plot 4 the Shannon index (H') presented the lowest values; this is due to the dominance of one species (P. cooperi) over the others (H' = 0.235 in 2008 and H'= 0.253 in 2013). Solís Moreno et al. (2006) found value of H' = 0.72 in a plot with thinning management and H'= 1.21 in a plot managed by the selection method; plot 2 presented the highest value in 2008 (H'= 1.722), but its value decreased in 2013 (H'=1.616). In contrast, plot 9 presented the highest value in 2013 (H'= 1.707), which is higher than that calculated in 2008 (H'=1.667). The application of the thinning treatment significantly favors the fact that the genus Pinus becomes dominant, since the cuts are directed to those species with lower commercial value (Solís Moreno et al., 2006).

In plot 4 there was a record of four species, P. cooperi presented high density of individuals in both measurements, which is reflected in Simpson's dominance index (D) (D= 0.093 and 0.101, for 2008 and 2013, respectively). The Margalef index (IM) showed that plot 2 had the highest richness for 2008 (IM= 2.142) and for 2013 (IM = 1.973), plot 4 exhibited the lowest richness, for 2008 (IM =0.536) and for 2013 (*IM=0*.537). In the two assessment years, the average Margalef diversity indices (2008 = 1.252 and 2013 = 1.205) were higher than those calculated by Hernández-Salas et al. (2013) in three assessment periods (1986 = 0.812, 1996 = 0.905 and 2006 = 0.900) in a temperate forest in northwestern Mexico and to those obtained by Návar and González (2009) in plots with a cutting intensity of 20% basal area removal in temperate forests of Durango (1982 = 1.08, 1992 = 1.04 and 2004 = 1.02).

Table 1. Species and families recorded during 2008 and 2013 in ten plots established in the study area in El Salto, Municipality of Pueblo Nuevo, Durango, Mexico.

Species	Family	2008	2013
Abies durangensis	Pinaceae	×	
Alnus jorullenisis	Betulaceae	×	×
Arbutus arizonica	Ericaceae	×	×
Arbutus bicolor	Ericaceae	×	×
Arbutus madrensis	Ericaceae	×	×
Arbutus tessellata	Ericaceae	×	×
Arbutus xalapensis	Ericaceae	×	×
Juniperus deppeana	Cupressaceae	×	×
Pinus ayacahuite	Pinaceae	×	×
Pinus cooperi	Pinaceae	×	×
Pinus durangensis	Pinaceae	×	×
Pinus engelmannii	Pinaceae	×	
Pinus leiophylla	Pinaceae	×	×
Pinus teocote	Pinaceae	×	×
Pseudotsuga menziesii	Pinaceae		×
Quercus conzatti	Fagaceae	×	×
Quercus crassifolia	Fagaceae	×	×
Quercus obtusata	Fagaceae	×	×
Quercus rugosa	Fagaceae	×	×
Quercus sideroxila	Fagaceae	×	×

Table 2. Description of individuals sampled in ten plots in El Salto, Municipality of Pueblo Nuevo, Durango, Mexico, in the years 2008 and 2013.

Plot	S1	S2	Number of trees 2008	Stump	Dead	Trees incorporated	Number of trees 2013	TS
1			249			23 (-7)	242	First thinning
			170			11 (-11)		Second thinning
			114		1	10 (2)		Second thinning
			269			24 (-3)	266	First thinning
5	5		240	91	0	69 (-22)	218	First thinning
			323			3(-130)	193	First thinning
			191			(-34)		Second thinning

	(-18)	182	First thinning
238	3 (-34)		First thinning
	(-38)		Second thinning

S1= species in 2008; S2= species in 2013; TS= silvicultural treatment; S2= species in 2013.

Table 3. Values obtained for diversity indices in the two inventories (2008 and 2013) in ten plots in El Salto, Municipality of Pueblo Nuevo, Durango, Mexico.

Plot	*Shannon* (H')		Simpson (D)		Margalef (IM)	
	2008	2013	*2008*	2013	*2008*	2013
1	1.215	1.249	0.570	0.578	0.906	1.093
	1.722	1.616	0.740	0.712	2.142	1.973
	1.454	1.498	0.707	0.722	1.689	1.473
	0.235	0.253	0.093	0.101	0.536	0.537
5	0.510	0.580	0.222	0.271	0.730	0.557
	1.209	1.247	0.623	0.660	1.038	0.950
	1.537	1.570	0.752	0.764	1.142	1.187
	1.232	1.178	0.527	0.512	1.699	1.537
	1.667	1.707	0.729	0.748	1.462	1.504
	0.970	0.999	0.459	0.467	1.172	1.234
Media	1.175	1.19	0.626	0.554	1.252	1.205

4.2. Student's t-test for diversity indices

Table 4 shows the t, gl and p values obtained. The results indicate that in none of the cases there are significant differences in the indices between each evaluation period ($P > 0.05$), which shows that despite the application of some thinning, the diversity, dominance or richness of species in these ecosystems is not modified. These results differ from those of Graciano (2001), who found that the silvicultural treatment of selective cutting decreases tree diversity, and from those of Corral Rivas et al. (2005), who reported that forest harvesting through selective cutting modifies the diversity and abundance of tree species. Ramírez-Santiago et al. (2019), when evaluating the specific richness in mixed stands in Oaxaca under different management conditions, found significant differences between an area without intervention designated as reference forest (BR) and two areas managed using the group selection method (SG) and parent trees (AP).

4.3. Forest structure indexes

The results of species mix, spatial distribution and dimensional differentiation for 2008 and 2013 are presented in Table 5. The values for the species mixture index are similar between the evaluations; the averages M_i = 0.51, in both years of evaluation, were higher than those estimated by Solís Moreno et al. (2006) [43], who recorded values of M_i = 0.30 and M_i = 0.44, in plots managed by thinning and selection method, in forest ecosystems of the Sierra de la Candela, Tepehuanes, Durango, Mexico. Castellanos-Bolaños et al. (2008) obtained values of M_i = 0.45, 0.56, 058 and 0.69 in four silvicultural conditions defined as: latizal, young forest, medium forest and old forest, respectively, in Ixtlán de Juárez, Oaxaca, Mexico; of the four conditions, young forest (M_i = 0.56) presented values similar to those calculated in this study. The species mixture index is determined by the relative abundance of tree species. Species with a high proportion of individuals will reflect low values of mixing since they will be surrounded by neighbors of the same species [44].

The average values for spatial distribution were W_i = 0.52 for 2008 and W_i = 0.50 for 2013. Taking the study of Hui and Gadow (2008) as a reference, the spatial distribution can be considered random in both measurement years. These authors mention that values lower than 0.475 suggest a uniform distribution and values higher than 0.517 suggest a distribution with a tendency to form clusters. Corral Rivas et al. (2005) determined a random distribution with values of W_i = 0.52, since it is a value very close to the upper limit established by Hui and Gadow (2008) for random distributions. Aguirre et al. (2003) defined as a random distribution a plot with values of W_i = 0.528 but with a tendency to form clusters, Castellanos-Bolaños et al. (2008) defined a random distribution values of W_i = 0.54 for a medium forest condition; Mora-Donjuán et al. (2016) for four shrubland sites with no vegetation removal and no record of productive activity for more than 28 years presented an average value of W_i = 0.57 indicating a regular distribution with a tendency to cluster formation. Aguirre et al. (2003); Corral Rivas et al. (2005) and Solís Moreno et al. (2006) mention that random distributions are more common in areas without intensive management, while regular distributions are the product of a treatment such as thinning, since the objective is that residual trees increase in size by decreasing competition, providing uniform growth space (Moeur, 1993; Cano, 1998; Smith, Larson, Kelty and Ashton, 1966 and Solís Moreno et al, 2006); in this study, despite the application of thinning treatment, the spatial distribution is randomly determined.

The averages of dimensional differentiation in diameter and height were for 2008 TH_i = 0.67 and TH_i = 0.58, and for 2013 TH_i = 0.66 and TH_i = 0.57, respectively. Considering the differentiation classes proposed by Aguirre Calderón et al. (2008), the differentiation in diameter is considered high; likewise for Solís Moreno et al. (2006), who obtained values of TH_i = 0.58 and 0.60 in plots managed with thinning and selection methods. On the other hand, Corral Rivas et al. (2005) observed differentiation in diameter of medium class with a value of TH_i = 0.42 for a plot managed with selection; for this study, the differentiation in height was considered medium class, since the management was done by thinning, which coincides with Solís Moreno et al. (2006) when they found values of TH_i = 0.53. These same authors obtained values of TH_i = 0.7 for a plot managed by the selection method, considering a high differentiation class.

Table 4. Values obtained from Student's t-test for diversity indices in the two inventories (2008 and 2013) in ten plots in El Salto, Municipality of Pueblo Nuevo, Durango, Mexico.

Index	*T1-T2*	*D.E.*	*Error*	*t*	*gl*	*p* (> 0.05)
Shannon	-0.015	0.053	0.017	-0.871		0.407
Simpson	0.072	0.267	0.084	0.858		0.413
Margalef	0.047	0.133	0.042	1.119		0.292
Menhinick	-0.0002	0.059	0.019	-0.011		0.992

T1=mean 2008; T2=mean 2013; S.D. standard deviation; t=t value; gl=degrees of freedom; p =p value.

Table 5. Values obtained for structure indices in the two inventories (2008 and 2013) in ten plots in El Salto, Municipality of Pueblo Nuevo, Durango, Mexico.

Plot	M_i 1	M_i 2	$_iW1$	$_iW2$	TH_i 1	TH_i 2	TH_i 1	TH_i 2	U_i 1	U_i 2
1	0.59	0.58	0.47	0.44	0.70	0.73	0.59	0.58	0.50	0.51
2	0.62	0.57	0.60	0.53	0.70	0.67	0.67	0.63	0.53	0.54
3	0.85	0.88	0.46	0.46	0.82	0.77	0.79	0.85	0.50	0.43
4	0.05	0.04	0.46	0.47	0.47	0.51	0.40	0.36	0.49	0.52
5	0.42	0.38	0.54	0.51	0.65	0.60	0.53	0.45	0.47	0.49
6	0.54	0.56	0.53	0.52	0.70	0.70	0.56	0.49	0.51	0.48
7	0.52	0.61	0.53	0.56	0.69	0.63	0.65	0.64	0.58	0.57
8	0.36	0.32	0.59	0.50	0.64	0.66	0.55	0.52	0.51	0.54
9	0.54	0.58	0.53	0.50	0.65	0.64	0.57	0.56	0.51	0.51
10	0.56	0.57	0.48	0.48	0.68	0.68	0.55	0.56	0.50	0.45
Media	0.51	0.51	0.52	0.50	0.67	0.66	0.58	0.57	0.51	0.50

Mi =mix of species; W_i =uniformity of angles; TH_i =differentiation in diameter, TH_i =differentiation in height, Ui =dominance, 1=2008, 2=2013.

The average dominance index yielded values of Ui = 0.51 and 0.50 for 2008 and 2013, respectively. According to the social classes developed by Kraft (1984) for tree dimensions, the reference tree of the different structural groups was considered as co-dominant, where two neighbors are larger than the center tree, which coincides with Solís Moreno et al. (2006) who found values of Ui = 0.47. For this study it was assumed that there are trees of different sizes in diameter and height, which determines that it is a heterogeneous forest stand.

4.4. Student's test for forest structure indices

According to the p-values obtained (> 0.05) and the comparison between years of evaluation for the five structure indices, no significant differences were found that indicate that the application of thinning modifies the tree structure (**Table 6**). It is presumed that the mix of species is maintained in the two evaluation periods; likewise, the spatial distribution is maintained, showing that the individuals are randomly distributed. Finally, the differentiation of dimensions in diameter and height is not affected by evidence of forest management for these ecosystems subjected to treatments with first or second thinning. These results differ from those of Corral Rivas et al. (2005), who found significant differences in the analysis of structure indicating that forest harvesting decreased species diversity, modified the spatial distribution of trees and changed the dimensional differentiation of individuals. Hernández-Salas et al. (2013) mention that forest harvesting modifies the diversity and composition of the tree stratum; their study includes three evaluations with 10-year intervals (1986, 1996 and 2006); for this study the evaluations include an interval of 5 years, which may be the reason for not registering significant changes with the application of some type of thinning.

Table 6. Values obtained from Student's t-test for structure indices in the two inventories (2008 and 2013) in ten plots in El Salto, Municipality of Pueblo Nuevo, Durango, Mexico.

Index	T1-T2	D. E.	Error	t	gl	P (>0.05)
M_i 1 - M_i 2	-0.004	0.043	0.014	-0.292		0.777
W_i 1 - W_i 2	0.022	0.036	0.012	1.908		0.089
TH_i 1 - TH_i2	0.011	0.035	0.011	0.982		0.352
TH_i 1 - TH_i2	0.022	0.04	0.013	1.73		0.118
U_i =1 - U_i =2	0.006	0.035	0.011	0.557		0.591

T1=mean 2008; T2=mean 2013; M_i =mix of species; W_i =uniformity of angles; TH_i =differentiation in diameter; TH_i =differentiation in height; U_i =dominance; 1=2008, 2=2013, S.D. standard deviation, *t*=t-value, *gl*=degrees of freedom, p=p value.

Another factor that may influence the fact that the results of this research differ from other evaluations may be due to the silvicultural treatment applied. In this case, timber harvests corresponding to the MDS were carried out, where the plant communities evaluated have silvicultural treatments based on first and second thinning; however, the treatments in studies conducted by Corral Rivas et al. (2005) and Solís Moreno et al. (2006) were carried out through selection cuts operated by the MMOBI (Mexican Method for the Management of Irregular Forests).

5. Conclusions

The silvicultural treatments applied corresponding to the first and second thinning in the sampling plots managed to maintain species diversity, composition and structure in the two sampling intervals. The spatial distribution of the species in the measurements maintained its randomness. No significant difference was found between diameter and height dimensions after the application of any cutting. The hypothesis that the silvicultural treatments corresponding to first or second thinning modify the diversity and structure of the tree stratum was rejected, since the mix of species present in the study area was maintained.

Conflict of interest

The authors declare no conflict of interest.

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