DOI: 10.29298/rmcf.v13i71.1017

Research Article

Evaluación del aprovechamiento forestal en la diversidad y estructura de un bosque templado en Durango

Assessment of the forest harvesting effect on the diversity and structure of a temperate forest in the state of Durango

Edgar Silva-González[1], Oscar Alberto Aguirre-Calderón[1]*, Eduardo Alanís-Rodríguez[1], Marco Aurelio González-Tagle[1], Eduardo Javier Treviño-Garza[1], José Javier Corral-Rivas[2]

Abstract

An analysis was carried out to assess the effect, over a period of 10 years, of the application of the forestry selection method on diversity and structure in a temperate forest of the mountain range of the state of *Durango*, Mexico. Twelve Permanent Forest and Soil Research Sites (PFS and SRS) were compared and remeasured. The comparative analysis was performed using the Shannon-Wiener diversity index; the Importance Value index —estimated by density, basal area, and species frequency at the sampling sites—, and three structure indexes for determining the species mixture, spatial distribution, and dominance of woodland. The Shannon-Wiener index did not exhibit significant statistical changes between the assessment periods when the Hutcheson t test was applied; the analysis showed that relative percentage values of abundance, dominance, and frequency, and the significance value index remained the same; structure indexes were not significantly modified in the 10-year interval after forest extraction; therefore, it was concluded that the forestry treatment applied does not modify the diversity or structure components of the tree stratum.

Key words: Space distribution, dominance, tree stratum, Importance Value Index, mix of species, silvicultural treatment.

Resumen

Se realizó un análisis para evaluar el efecto, en un periodo de 10 años, de la aplicación del Método Silvícola de Selección sobre la diversidad y estructura en un bosque templado de la Sierra de Durango, México. Se compararon doce Sitios Permanentes de Investigación Forestal y de Suelos (SPIFyS), los cuales fueron remedidos. El análisis comparativo se hizo mediante el índice de Diversidad de *Shannon-Wiener*; asimismo, se estimó el Índice de Valor de Importancia (*IVI*) mediante la densidad, el área basal y la frecuencia de las especies en los sitios de muestreo; también se calcularon tres índices de estructura para conocer la mezcla de especies, distribución espacial y dominancia del arbolado. El índice de *Shannon-Wiener* no evidenció cambios estadísticos significativos entre periodos de evaluación, cuando se aplicó la prueba de *t* de *Hutcheson*; el análisis mostró que los valores porcentuales relativos de abundancia, dominancia, frecuencia e Índice de Valor de Importancia se conservan. Los índices de estructura tampoco se modificaron significativamente en el intervalo de 10 años después de la extracción forestal, por lo que se determina que el tratamiento silvícola aplicado no modifica la diversidad ni los componentes de estructura del estrato arbóreo.

Palabras Clave: Distribución espacial, dominancia, estrato arbóreo, Índice de Valor de Importancia, mezcla de especies, tratamiento silvícola.

Fecha de recepción/Reception date: 8 de diciembre de 2021
Fecha de aceptación/Acceptance date: 4 de abril del 2022

[1]Facultad de Ciencias Forestales. Universidad Autónoma de Nuevo León, México.
[2]Facultad de Ciencias Forestales. Universidad de Juárez del Estado de Durango. México
*Autor para correspondencia; correo-e: oscar.aguirrecl@uanl.edu.mx

Introduction

In the sustainable management of mixed forests, it is essential to conserve biodiversity, maintain the floristic composition with its associated values and landscape (Hernández-Salas *et al*., 2013). The structure of an ecosystem is a good indicator of its biodiversity, which is likely to be affected by forestry practices and forest management regimes that may modify or deteriorate the habitat (Del Río *et al*., 2003; Corral-Rivas *et al*., 2005; López-Hernández *et al*., 2017). These changes in structure and diversity are likely to be generated by selective harvesting (Corral-Rivas *et al*., 2005; Hernández-Salas *et al.*, 2013).

The effect of silvicultural treatments on tree diversity is determined by its intensity, type and frequency, as well as by the stage of forest succession (Duguid and Ashton, 2013; Ammer, 2019; Monárrez-González *et al.*, 2020). Therefore, the conservation of tree diversity is a condition that can be manipulated through forest management in order to maintain the productivity of these ecosystems (Zeller *et al*., 2018).

Structure, composition and diversity are the attributes of the forest that are most commonly modified to achieve forest management objectives focused on timber production (Castellanos-Bolaños *et al.*, 2008; Ramírez-Santiago *et al.*, 2019). Diversity and structure indices are used to determine the effect of forestry practices (Aguirre-Calderón *et al*., 2003; Corral-Rivas *et al*., 2005), to measure differences in time and space (Magurran, 2004), to monitor changes caused by forest management, or to define practices leading to sustainable forest management (Corral-Rivas *et al*., 2005; Aguirre-Calderón *et al.*, 2008; Hernández-Salas *et al*., 2013).

An assessment of forest stands using diversity indicators based on abundance, dominance and frequency of species describes their relationships in a population (López-Hernández *et al*., 2017; Alanís-Rodríguez *et al*., 2020); their relative values are used to understand part of the functioning of ecosystems, which provides decision elements for decision making in order to contribute to good forest management (Castellanos-Bolaños *et al*., 2008; Graciano-Ávila *et al*., 2017).

Another way to characterize the tree layer is in terms of three components of structural diversity: the degree of mixture, which assesses the way in which trees of different species interrelate with one another; aggregation, which describes the distribution of the trees on the ground, and differentiation, which quantifies the difference in size between the tree individuals (Gadow and Hui, 2002; Corral-Rivas *et al.*, 2005; Solís-Moreno *et al.*, 2006).

From a technical point of view, forest management requires information on the diversity and structure of both commercial and ecologically valuable species in order to define the practices that lead to sustainable forest management (López-Hernández *et al*., 2017). The objective of this study was to evaluate, over a 10-year period, the effect of forest harvesting with the selection method on the diversity and structure of a temperate forest located in northwestern Mexico.

Materials and Methods

Study area and site locations

The study was carried out in the *Pueblo Nuevo* municipality, located in the *El Salto* region, which is part of the southwestern part of the state of *Durango*, Mexico, and within the Western *Sierra Madre* (Figure 1). Geographically, it is located between parallels 23°42'34.48" and 23°49'28.18" N, and meridians 105°30'11.83" and 105°40'6.56" W. It has an altitude of 2 500 to 2 900 masl. The soil types present are Lithosol, Cambisol, and Regosol with predominantly coarse to medium texture. The dominant rock type is acidic extrusive igneous (INEGI, 2015). In this zone, climates of type (A)C(w_2), C(w_2), C(E)(M) and C(E)(w_2) prevail, with an average annual rainfall of 945.3 mm and an average temperature of 11.5 ºC (Inegi, 2017).

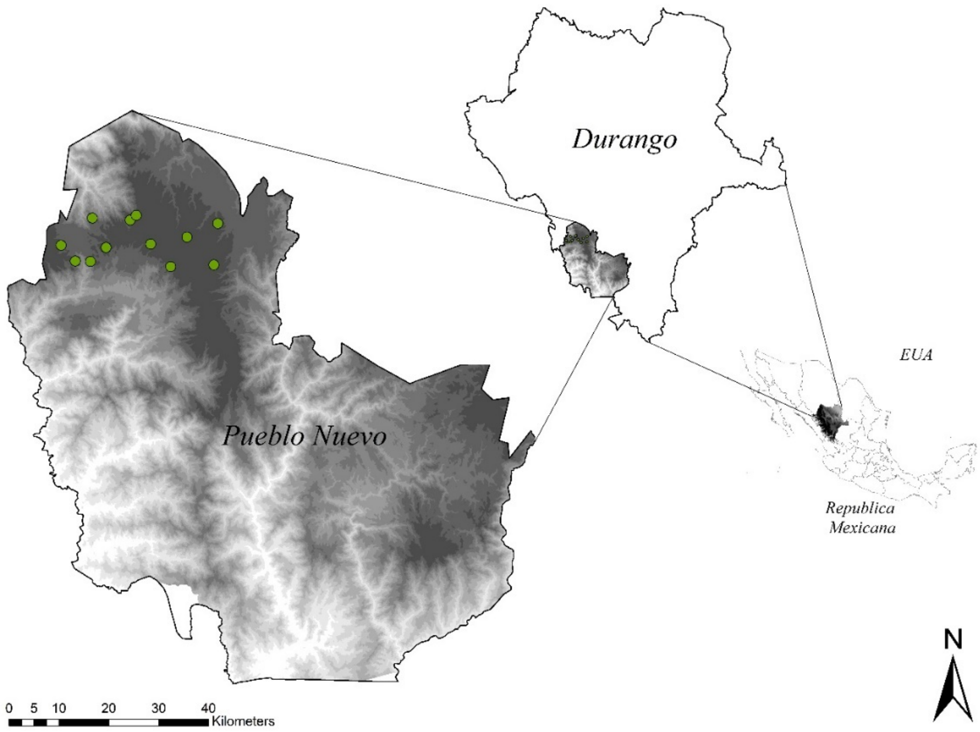

Figure1. Location of the study area and location of the Permanent Forestry and Soil Research sites under the individual tree selection silvicultural treatment.

The vegetation of the region is composed of mixed forests of *Pinus*, *Quercus*, *Juniperus, Arbutus* and *Alnus* species (Luján-Soto *et al*., 2015; Colín *et al*., 2018).

Obtaining mensuration data

The data were obtained from 12 Permanent Forestry and Soil Research Sites (SPIFyS), which were established according to Corral-Rivas *et al*. (2009 and 2013) —three in 2007 and nine in 2008 (first inventory)— and were remeasured 10 years later (second inventory), in the years 2017 and 2018, respectively. The evaluated sites exhibit evidence of forest management by the selection method, whose silvicultural intervention was carried out in different annual periods: at four sites, the treatment was applied one year after establishment; at one site, at three years; at one site, at six years; at one site, at seven years, and at the remaining three sites, at five years after establishment.

For each site, the following dasometric information was recorded: number of trees, species, normal diameter (>7.5 cm) (model 122450 Ben Meadows® diameter tape), total height (m) (model Pm5/360 Suunto® altimeter), azimuth, and distance from each of the individuals to the center of the site, whose surface area was 50 x 50 m (2 500 m^2).

Diversity

The Shannon-Wiener index (*H*') was used to estimate species diversity (Shannon, 1948):

$$H' = -\sum pi\,(ln\,pi) \qquad (1)$$

Where:

pi = Proportion of individuals of the species *i*, is obtained by the (*ni/N*) ratio

ni = Number of individuals of species *i*

N = Total number of individuals

ln = Natural logarithm

In order to determine whether there were significant differences in species diversity between the evaluation periods (first and second inventory), a Student's t-test modified by Hutcheson (Hutcheson's t-test) was performed (Magurran, 1988) according to Equation 2, and the degrees of freedom (*df*) were estimated using Equation 3 (Hutcheson, 1970). Several authors utilize this test for comparisons between evaluation periods of temperate forests under management (Moreno, 2001; Solís-Moreno *et al*., 2006; Corral-Rivas *et al*., 2005; Alanís-Rodríguez *et al*., 2010).

$$t = \frac{H'_1 - H'_2}{(VarH'_1 + VarH'_2)^{\frac{1}{2}}} \qquad (2)$$

$$gl = \frac{(VarH'_1 + VarH'_2)^2}{\left[\frac{(VarH'_1)^2}{N_1}\right] + \left[\frac{(VarH'_2)^2}{N_2}\right]} \qquad (3)$$

Where:

H'_1 = Shannon-Wiener index of the first inventory

H'_2 = Shannon-Wiener index of the second inventory

$VarH'_1$ = Variance obtained in the first inventory

$VarH'_2$ = Variance obtained in the second inventory

N_1 = Total number of individuals in the first inventory

N_2 = Total number of individuals in the second inventory

The estimation of the variances of the first and second inventories, respectively, was carried out with Equation 4.

$$VarH'_{(1;2)} = \frac{\sum pi(lnpi)^2 - (\sum pilnpi)^2}{N} - \frac{S-1}{2N^2} \quad (4)$$

Where:

pi = Proportion of individuals of the species *i*, is obtained by the (*ni/N*) ratio

ni = Number of individuals of species *i*

N = Total number of individuals

ln = Natural logarithm

S = Number of species

Ecological indicators

For each tree species, the relative abundance values (*RA*) were determined according to the number of trees; the relative dominance (*RD*), as a function of basal area; the relative frequency (*RF*), based on the presence of the species at the sites. The Importance Value Index (*IVI*) was also estimated, with the average of the previous ecological indicators in percentage values from 0 to 100 for each evaluation period (Magurran, 2004; Alanís-Rodríguez *et al*., 2020).

The statistical analysis of the ecological indicators (abundance and dominance) was performed based on the normal distribution of density and basal area in each measurement period. The means were compared using Student's t-test for dependent samples, or alternatively, the nonparametric Wilcoxon Ranks test, which compares the mean rank of two related samples and determines whether there are differences between them (Quispe-Andía *et al*., 2019).

Structure composition

Site structure was characterized using three methodologies: species mix, spatial distribution and size difference. These indices were calculated using the structural group as a sampling unit consisting of a set of five trees, of which one serves as a reference and includes the four closest neighboring trees with which it coexists (Pommerening, 2002; Kint *et al.*, 2003; Castellanos-Bolaños *et al.*, 2008 and 2010).

The degree of mixing of tree species was described in terms of Gadow's Mixing Index (*Mi*) (Füldner, 1995) which evaluates the species diversity of the neighborhood of a reference tree *i*, being defined as the proportion of the *n* neighbors that do not belong to the same species. Its value ranges from 0 to 1; values close to zero indicate that the taxa analyzed tend to group together and that they do not mix with the rest; on the other hand, values close to one indicate a preference for mixing with one another.

In order to quantify the spatial distribution of trees, the Angle Uniformity Index (*Wi*) was used, which is based on the measurement of angles between two trees neighboring the reference tree *i* and their comparison with the standard angle *α*; so that if four neighbors to the reference tree are considered, the *Wi* can take values of 0 to 1, where a value close to zero represents conditions of regularity, values close to 0.5 imply a tendency to randomness, and values close to one signify clustering of species.

In the present study, a standard angle of 72º was used for the estimation of the *Wi*, because in the simulations of Gadow and Hui (2002) this value was defined as the optimal standard angle, with an average of the *Wi* = 0.5 for a random distribution.

The variation in tree size was quantified with the Dominance Index (*Ui*) (Aguirre-Calderón *et al*., 2003), which is defined by the ratio of the four neighbors with different diameters to the reference tree. As with the other structure indices used, the values vary from 0 to 1: *Ui* = 0, if the four neighbors are larger than the reference tree *i* (deleted); *Ui* = 0.25, if three of the neighbors are larger than the reference tree *i* (intermediate); *Ui* = 0.50, if two of the neighbors are larger than the reference tree *i* (co-dominant); *Ui* = 0.75, if one of the neighbors is larger than the reference tree *i* (dominant), and *Ui* = 1, if none of the neighbors is larger than the reference tree *i* (very dominant). The five values of *Ui* correspond to the social classes developed by Kraft (1884). Table 1 shows the formulas for the structure indexes used.

Table 1. Structure indexes used in both measurement periods for the analysis of plots under management in the temperate forests of *Durango*, Mexico.

Index	Formula	Meaning
Gadow's Species Mingling	$M_i = \frac{1}{4}\sum_{j=1}^{4} mj$	mj = 0 when the neighboring tree *j* belongs to the same species as *i*; 1, otherwise.

Angle uniformity	$W_i = \frac{1}{4}\sum_{j=1}^{4} wj$	wj = 1 when angle *α* is smaller than 72º; 0, otherwise.
Dominance	$U_i = \frac{1}{4}\sum_{j=1}^{4} uj$	uj = 1 when the tree is smaller in diameter than the reference tree *i*; 0, otherwise.

The statistical analysis of the structure indexes was performed by means of a Student's t-test with the mean of the values obtained in each evaluation period (first and second inventory) (Silva-González *et al*., 2021). Once the normality of the data for each index was obtained, a comparison was used to determine whether there are significant differences between evaluation periods, with a confidence level of 95 %. Statistical procedures were performed with the IBM SPSS Statistics 25 statistical package (Statistical Package for the Social Sciences).

Elimination of the border effect

The structure indexes were estimated using the SAS statistical program (Statistical Analysis System Institute, 2009). The calculation of the indexes analyzed in this work will always be biased to those trees that stand close to the edges of the sites, the reason being that these individuals are problematic because their potential neighbors may be located outside the area of interest. The nearest neighbor edge correction method proposed by Pommerening and Stoyan (2006) was implemented in order to eliminate the edge effect and obtain unbiased information of the structural variables. By reducing the number of reference trees and assessing whether all *n* nearest neighbors of tree *i* are located within the observation sites; individuals located very close to the edges of the research site were eliminated.

The four nearest neighbors to a reference tree were listed in ascending order according to their distance; thus, all reference trees whose mean distance to the fourth tree was greater than the distance to the nearest edge were ignored.

Results

Twenty-three tree species were recorded, belonging to six families and eight genera. The Pinaceae family was the best represented with nine species (Table 2). The first inventory yielded a total of 21 taxa, and there were no records of *Pseudotsuga menziesii* var. *glauca* (Beiss.) Franco or *Prunus serotina* Ehrh.; in contrast, 20 species were identified in the remeasurement, with the absence of *Abies durangensis* Martínez, *Juniperus durangensis* Martínez, and *Pinus engelmannii* Carrière.

Table 2. Species recorded in both inventories of managed plots belonging to the 12 SPFyS studied in *Durango*.

Family	Scientific name	Common name
Pinaceae	*Abies durangensis* Martínez	Pino Mexicano
Betulaceae	*Alnus firmifolia* Fernald	Aliso
Betulaceae	*Alnus jorullensis* Kunth	Aliso
Ericaceae	*Arbutus arizonica* (A. Gray) Sarg.	Madroño liso
Ericaceae	*Arbutus bicolor* S. González, M. González & P. D. Sørensen	Madroño
Ericaceae	*Arbutus madrensis* S. González	Madroño roñoso

Ericaceae	*Arbutus tessellata* P. D. Sørensen	Madroño pegajoso
Ericaceae	*Arbutus xalapensis* Kunth	Madroño
Cupressaseae	*Juniperus deppeana* Steud.	Táscate
Cupressaseae	*Juniperus durangensis* Martínez	Táscate
Pinaceae	*Pinus cooperi* C. E. Blanco	Pino chino
Pinaceae	*Pinus durangensis* Martínez	Ocote
Pinaceae	*Pinus engelmannii* Carrière	Pino real
Pinaceae	*Pinus herrerae* Martínez	Ocote
Pinaceae	*Pinus leiophylla* Schiede ex Schltdl. & Cham.	Pino prieto
Pinaceae	*Pinus strobiformis* Engelm.	Pino blanco
Pinaceae	*Pinus teocote* Schied. ex Schltdl. & Cham.	Pino colorado
Rosaceae	*Prunus serotina* Ehrh.	Capulín
Pinaceae	*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco	Pinabete
Fagaceae	*Quercus crassifolia* Bonpl.	Encino prieto
Fagaceae	*Quercus obtusata* Bonpl.	Encino roble
Fagaceae	*Quercus rugosa* Née	Encino blanco
Fagaceae	*Quercus sideroxyla* Bonpl.	Encino colorado

Diversity

According to the Shannon-Wiener Index in the first and second inventories (H'_1 = 1.86 and H'_2 = 1.94), there were no significant statistical differences when Hutcheson's t-test was applied, α = 5 % (t = 0.026).

Ecological indicators

The total density of individuals showed an increase of 9.67 trees ha^{-1}, but without significant differences (p = 0.268). The most abundant genus was *Pinus*, with 381.33 trees ha^{-1}, which represented 68.14 % of relative abundance (*RA*) in the first inventory; value that decreased for the second sampling to 355.33 trees ha^{-1} and 62.41 % *RA*. *Quercus* spp. exhibited an increase of 20 trees ha^{-1}, which corresponded to 3.17 % of *RA*; *Arbutus* increased by 4.67 trees ha^{-1} (0.75 % de *AR*); *Juniperus* and *Alnus* increased their density with 2.33 and 8 trees ha^{-1}, respectively, corresponding to 0.34 and 1.34 % of RA (Table 3).

Table 3. Ecological indicators of tree species recorded in the first and second inventory of managed plots belonging to the SPFyS in *Durango*.

Specie	Abundance		Dominance		Frequency		*IVI*
	Trees ha^{-1}	***RA* (%)**	***BA* (m^2 ha^{-1})**	***RD* (%)**	***abs F***	***RF* (%)**	**(%)**
First inventory							
Pinus durangensis Martínez	258.00	46.10	13.09	51.18	12.00	13.48	36.92
Quercus sideroxyla Bonpl.	102.00	18.23	4.79	18.72	12.00	13.48	16.81
Pinus cooperi C. E. Blanco	56.33	10.07	2.70	10.57	9.00	10.11	10.25
Pinus strobiformis Engelm.	26.00	4.65	0.83	3.25	8.00	8.99	5.63
Juniperus deppeana Steud.	21.33	3.81	0.47	1.84	7.00	7.87	4.51
Pinus teocote Schiede ex Schltdl. & Cham.	20.67	3.69	0.47	1.84	8.00	8.99	4.84
Alnus firmifolia Fernald	15.00	2.68	0.21	0.81	2.00	2.25	1.91
Arbutus bicolor S. González, M. González & P. D. Sørensen	12.00	2.14	0.33	1.30	5.00	5.62	3.02
Pinus herrerae Martínez	10.00	1.79	0.64	2.52	1.00	1.12	1.81
Pinus leiophylla Schiede ex Schltdl. & Cham.	10.00	1.79	0.66	2.59	3.00	3.37	2.58
Quercus crassifolia Bonpl.	9.00	1.61	0.81	3.17	3.00	3.37	2.72
Arbutus madrensis S. González	6.33	1.13	0.13	0.52	5.00	5.62	2.42
Alnus jorullensis Kunth	5.00	0.89	0.08	0.30	4.00	4.49	1.90
Quercus obtusata Bonpl.	2.00	0.36	0.15	0.59	2.00	2.25	1.06
Arbutus arizonica (A. Gray) Sarg.	1.67	0.30	0.12	0.46	1.00	1.12	0.63
Arbutus xalapensis Kunth	1.67	0.30	0.04	0.17	2.00	2.25	0.90
Arbutus tessellata P. D. Sørensen	1.00	0.18	0.01	0.04	1.00	1.12	0.45
Quercus rugosa Née	0.67	0.12	0.01	0.05	1.00	1.12	0.43
Abies durangensis Martínez	0.33	0.06	0.02	0.07	1.00	1.12	0.42
Juniperus durangensis Martínez	0.33	0.06	0.01	0.01	1.00	1.12	0.40
Pinus engelmannii Carrière	0.33	0.06	0.01	0.02	1.00	1.12	0.40
Total	559.67	100	25.58	100	89	100	100
Second inventory							
Pinus durangensis Martínez	235.33	41.33	12.82	47.43	12.00	12.12	33.66

Quercus sideroxyla Bonpl.	121.33	21.31	5.59	20.70	12.00	12.12	18.04
Pinus cooperi C. E. Blanco	46.67	8.20	2.59	9.57	9.00	9.09	8.95
Pinus strobiformis Engelm.	28.67	5.04	1.01	3.73	7.00	7.07	5.28
Pinus teocote Schiede. ex Schltdl. & Cham.	28.00	4.92	0.72	2.66	8.00	8.08	5.22
Juniperus deppeana Steud.	24.00	4.22	0.61	2.27	8.00	8.08	4.85
Alnus firmifolia Fernald	22.33	3.92	0.36	1.33	4.00	4.04	3.1
Arbutus bicolor S. González, M. González & P. D. Sørensen	14.67	2.58	0.42	1.55	5.00	5.05	3.06
Quercus crassifolia Bonpl.	9.33	1.64	0.98	3.62	4.00	4.04	3.1
Pinus leiophylla Schiede ex Schltdl. & Cham.	9.00	1.58	0.65	2.39	2.00	2.02	2.00
Pinus herrerae Martínez	7.67	1.35	0.56	2.07	2.00	2.02	1.81
Arbutus madrensis S. González	7.67	1.35	0.19	0.69	6.00	6.06	2.70
Alnus jorullensis Kunth	5.67	1.00	0.13	0.47	4.00	4.04	1.84
Arbutus tessellata P. D. Sørensen	2.33	0.41	0.02	0.09	4.00	4.04	1.51
Quercus obtusata Bonpl.	2.00	0.35	0.19	0.71	2.00	2.02	1.03
Arbutus arizonica (A. Gray) Sarg.	1.33	0.23	0.11	0.41	2.00	2.02	0.89
Arbutus xalapensis Kunth	1.33	0.23	0.06	0.21	3.00	3.03	1.16
Quercus rugosa Née	1.00	0.18	0.02	0.06	2.00	2.02	0.75
Pseudotsuga menziesii var. *glauca* (Beissn.) Franco	0.67	0.12	0.01	0.02	1.00	1.01	0.38
Prunus serotina Ehrh.	0.33	0.06	0.01	0.01	1.00	1.01	0.36
Total	569.33	100	27.02	100	98	100	100

RA = Relative abundance; *BA* = Basal area; *RD* = Relative dominance; *absF* = Absolute frequency; *RF* = Relative frequency; *IVI* = Importance value index.

The dominance represented by basal area (*BA*) showed an increase of 1.44 m^2 ha^{-1}, with no significant statistical differences (p = 0.73) between evaluation periods. At the genus level, *Pinus* presented the highest values of basal area, 18.41 m^2 ha^{-1} in the first sampling and 18.34 m^2 ha^{-1} in the second, with a decrease of 0.08 m^2 ha^{-1} corresponding to -4.11 % of relative dominance (*RD*); *Quercus* increased by 1.02 m^2 ha^{-1} (2.56 % de *RD*); *Arbutus* and *Juniperus* registered an increase of 0.17 m^2 ha^{-1} and 0.14 m^2 ha^{-1}, with a *RD* of 0.48 % and 0.42 %, respectively.

Pinus durangensis Martínez and *Quercus sideroxyla* Bonpl. were present in all sites in both inventories, and their highest relative frequency (*RF*) corresponded to 13.48 % in the first inventory and 12.12 % in the second. *Abies durangensis*, *Juniperus durangensis*, and *Pinus engelmannii* were recorded in the first inventory, with 1.12 % *RF* for each, but were displaced in the next measurement; in contrast, for the second inventory, *Pseudotsuga menziesii* and *Prunus serotina* were incorporated, representing a *RF* of 1.01 %. In general, *Pinus* presented a decrease in relative frequency of 6.79 %, *Quercus*, of 0.02 %, and *Juniperus*, of 0.91 %; the genera *Arbutus* and *Alnus* increased their *RF* values by 4.47 % and 1.34 %, respectively. This behavior is due to the silvicultural treatment applied, which is specifically aimed at *Pinus* taxa.

The highest *IVI* in both measurements corresponded to *P. durangensis*, followed by *Q. sideroxyla* and *P. cooperi* C. E. Blanco. *Pinus* presented an *IVI* of 62.43 % in the first inventory, which was lower than the *IVI* of the second (56.89 %), with a decrease of 5.54 %; the *IVI* of the *Juniperus* genus decreased 0.5 %; while *Quercus* and *Arbutus* registered an increase of 1.6 %, and *Alnus*, an increase of 1.12 % (Table 3).

Structure composition

Table 4 summarizes the number of individuals registered in the two inventories per site, in addition to the values for each of the indices used (species mixture, angle uniformity and dominance) and the average for each of them. Site 6 exhibited the lowest values of species mixture in both samplings (Mi_1 = 0.173, Mi_2 = 0.311); in contrast, the highest values were registered at sites 4 and 11. The Student's t-test performed to compare the means between evaluation periods showed no significant differences, which indicated that the selection method applied at the sites did not modify the existing species mix (p = 0.081).

Table 4. Number of individuals recorded and values of structural indices in both evaluation periods for the 12 SPFyS assessed in *Durango*.

Site	N_1	N_2	Mi_1	Mi_2	Wi_1	Wi_2	UI_1	UI_2
1	159	191	0.563	0.543	0.541	0.546	0.484	0.525
2	249	234	0.536	0.529	0.535	0.510	0.513	0.517
3	57	65	0.547	0.652	0.537	0.524	0.499	0.513
4	170	185	0.724	0.706	0.524	0.526	0.514	0.505
5	79	74	0.597	0.587	0.527	0.553	0.534	0.566
6	74	69	0.173	0.311	0.518	0.519	0.503	0.500
7	191	164	0.627	0.628	0.524	0.528	0.514	0.516
8	143	140	0.334	0.327	0.551	0.555	0.521	0.522
9	199	151	0.524	0.567	0.522	0.514	0.505	0.513
10	158	223	0.676	0.700	0.546	0.535	0.493	0.523
11	108	105	0.712	0.724	0.559	0.548	0.531	0.532
12	92	104	0.453	0.561	0.490	0.518	0.534	0.526
		Mean	0.539	0.570	0.531	0.531	0.512	0.521

N_1 = Number of individuals in the first inventory; N_2 = Number of individuals in the second inventory; *Mi* = Species mixture rate; *Wi* = Spatial distribution index; *DI* = Dominance index.

The spatial distribution analysis showed several changes between pairs of sites; however, there are no significant statistical differences (p = 0.971). The distribution of species was maintained. Most of the plots had a random distribution with a tendency to form clusters. Gadow and Hui (2002) values below 0.475 suggest a regular distribution, and those above 0.517 suggest a random distribution with a tendency to form clusters, which coincides with what was observed for most of the sites in this study, as well as for the average for each evaluation period (Wi = 0.531).

The dominance index did not reflect changes in tree diameter dimensions, according to p = 0.073, with no significant differences between evaluation periods; the averages obtained UI_1 = 0.512 and UI_2 = 0.521, for the first and second inventory, respectively, indicate that the sites have trees of different sizes, so that any selected tree can have two neighbors with a larger diameter and two with a smaller diameter, a characteristic of the irregular forests under management in the state of *Durango* (Soto-Cervantes *et al*., 2021).

Discussion

Diversity

The average values recorded according to the Shannon-Wiener index (H'_1 = 1.86 and H'_2 = 1.94) are higher than those cited by Hernández-Salas *et al.* (2013), in a cool temperate forest with silvicultural practices using the selection method in the *El Largo* ejido y Anexos, in the *Madera* municipality of *Chihuahua*, Mexico, in three assessments, conducted in the years 1986 (H'_1 = 0.400), 1996 (H'_2 = 0.401) and 2006 (H'_3 = 0.347), and that documented by Solís-Moreno *et al.* (2006) for a temperate forest in *Tepehuanes*, *Durango*, where a value of H' = 1.21 was reported. The same is true for other similar studies. Thus, Ramírez-Santiago *et al.* (2019) obtained a value of H' = 1.25, when the group selection method was applied in a temperate forest in the *Sierra de Oaxaca*; Vásquez-Cortez *et al.* (2018) registered an *H'* = 1.14 for an area intervened with a root killer in *Ixtlán de Juárez*, *Oaxaca*, and Návar-Cháidez and González-Elizondo (2009) cite a *H'* = 0.55 in an area with 100 % removal of the basal area, intervened 15 years before the tree assessment, in *San Dimas* municipality, *Durango*.

The difference in the Shannon-Wiener index values obtained in this study, with respect to the results of various authors, is due to a greater diversity of species recorded and to the proportions of each one of them.

Hutcheson's t-test revealed that there are statistically no significant changes in species diversity between evaluation periods, which indicates that despite the application of the selection method no major changes occur. This finding differs from those of the records of Hernández-Salas *et al.* (2013), who point out that the tree diversity recorded in 2006 is different from that determined 10 and 20 years earlier, with greater diversity in 1986 and 1996. The above responds to the number of trees ha^{-1} and the *RA* of each species in the evaluation periods; in the SPFyS evaluated in *Durango*, a difference of ten individuals was obtained in the ten-year period, while Hernández-Salas *et al.* (2013) registered higher values.

Ecological indicators

The total density of individuals did not show significant changes over the 10-year period, with an increase of 9 trees ha^{-1}; Hernández-Salas *et al.* (2013) cite a reduction of 179.35 trees ha^{-1} from 1996 to 2006, and of 45 trees ha^{-1} from 1986 to 1996, but without significant statistical difference (F = 2.865, gl = 2, P = 0.060).

The total basal area increased from 25.58 to 27.02 m^2 ha^{-1}; Hernández-Salas *et al.* (2013) document basal area increases of 4.12 m^2 ha^{-1} from 1986 to 1996, and a decrease of 1.54 m^2 ha^{-1} in the period from 1996 to 2006; in both studies, the genus *Pinus* presented the highest values of basal area (*BA*) and relative dominance (*RD*).

In the present investigation, *P. durangensis* had the highest values in *DR*: 51.18 % and 47.43 % for the first and second measurement, respectively; while Hernández-Salas *et al*. (2013) registered *P. arizonica* Engelm. with values of 67.02 %, 68.36 %, and 68.61 % *RD* in their three evaluations.

The *Quercus* genus increased its *RD* values from 22.52 % to 25.05 %; this is due to the fact that, in the selection treatment, *Pinus* individuals are mainly used because they are the most commercially valuable; Hernández-Salas *et al.* (2013) reported a reduction in *RD* in *Quercus* spp. from 15.1 % in 1986 to 5.4 % in 2006, due to the application of silvicultural interventions that favor the development of other genera, particularly *Pinus*, as it is the dominant genus in the region. Ramírez-Santiago *et al.* (2019) recorded an increase in *BA* of 5.95 m^2 ha^{-1} for an area intervened by the group selection method during a 5-year evaluation period; in addition, a decrease of 4.43 m^2 ha^{-1} in an area intervened by the parent tree method during the same period.

The most important ecological species was *P. durangensis*, with an *IVI* of 33.66 % after the silvicultural intervention; this species has been indicated as the one with the highest ecological value by Hernández-Salas *et al.* (2013) and Graciano-Ávila *et al.* (2017). At the genus level, *Pinus* presented an *IVI* of 56.89 %, a lower value than those documented by Alanís-Rodríguez *et al*. (2011), Hernández-Salas *et al.* (2013), and López-Hernández *et al.* (2017), who cite values higher than 80 % in forests of *Nuevo León*, *Chihuahua* and *Puebla*, respectively. Rendón-Pérez *et al.* (2021), in an analysis of three tree associations dominated by *Pinus montezumae* Lamb., *Pinus pseudostrobus* Lindl. and *Pinus patula* Schiede ex Schltdl. & Cham., operated under the Silvicultural Development Method obtained the following *IVI* values: 67.5, 45.8, and 62.2 %, respectively.

Structure composition

The average value of the *Mi* after silvicultural intervention was 0.57, which indicates that, more often than not, out of every four neighbors to the reference tree, two are of the same species and two differ from each other. Castellanos-Bolaños *et al.* (2008) indicate a *Mi* = 0.69 for an old forest condition in *Ixtlán de Juárez* in *Oaxaca*; *i.e.*, on average, of the four closest neighbors to the reference tree, three belong to different species; Castellanos-Bolaños *et al.* (2010) obtained an *Mi* = 0.346 for an average of five circular sites of 500 m^2, in a community of *Pinus rudis* Endl. The above indicates that most of the trees have one or two neighbors of different species. In the study documented here, site six presented a similar value (*Mi* = 0.311), and it is assumed that there is a clear dominance of *P. durangensis*.

Solís-Moreno *et al.* (2006) recorded values of *Mi* = 0.30 and *Mi* = 0.44 for plots intervened by thinning and selective cutting, respectively; values lower than the average obtained in this study: *Mi* = 0.539 for the first inventory, and *Mi* = 0.57 for the second inventory. Species abundance is more heterogeneous in sites with thinning treatments, as these favor the growth of species of higher commercial value (Solís-Moreno *et al*., 2006). Silva-González *et al*. (2021) cite average values of *Mi* = 0.51 for 10 sites evaluated over a 5-year period under thinning management in the *Sierra de Durango*.

According to the average values of *Wi* = 0.531 in both measurements, the spatial distribution in the SPFyS studied turned out to be random, but with a tendency to form clusters; Solís-Moreno *et al.* (2006) cite a spatial distribution in aggregates with values of *Wi* = 0.57; Castellanos-Bolaños *et al.* (2008) document a random distribution (*Wi* = 0.54) in a plot with medium forest condition. Aguirre-Calderón *et al.* (2003) register random distributions (*Wi* = 0.50, 0.52, and 0.5) on three plots excluded from forest management for coniferous forests in *Durango*; Pommerening (2002) reports a random distribution (*Wi* = 0.57) for adult plantations dominated by *Quercus petraea* (Matt.) Liebl. and *Fagus sylvatica* L., in the German federal state of *Rhineland-Palatinate*. Random distributions are more common in areas without intensive management (Aguirre-Calderón *et al*., 2003; Corral-Rivas *et al*., 2005; Solís-Moreno *et al*., 2006); whereas, regular distributions are often the result of treatments such as thinning, since their objective is to eliminate competition and provide equal growing space for the remaining species. This did not occur in the present research, because individuals were removed, leaving space for the new growth, so that the spatial structure tends to be occupied by new individuals.

The dominance index exhibited average values close to 0.5, which indicates that the vegetation is heterogeneous, and two of the trees closest to the reference tree are larger and two are smaller; these values are characteristic of forests managed by selection methods, in which individuals of different diameter categories can be found. Solís-Moreno *et al.* (2006) registered values of *UI* = 0.44 in a plot treated by the selection method; Castellanos-Bolaños *et al.* (2008) indicate *UI* values of 0.52 for the pole stand; of 0.56 for young shafts; of 0.70 for the mid-range shafts, and of 0.83 for old forests. This is because, as the tree stand develops, so does the dominance of a certain species, until, in the old-growth condition, it becomes the dominant taxon, and three of its nearest neighbors are thinner than the reference tree.

Conclusions

With the selection management method, the evaluated forest community does not exhibit statistically significant changes in diversity and structure indices over a 10-year inventory period; there are also no significant losses or changes in the analyzed vegetation. Forest harvesting through the selection method maintains the diversity and mix of tree species. The spatial arrangement defined as random with a tendency to form clusters and size difference in tree diameter is preserved. Therefore, the silvicultural forest treatment applied maintains the attributes of the forest.

It is important to carry out continuous evaluations, forest monitoring and analysis of the impact of forest management in order to obtain information on the results of silvicultural activities in the medium and long term; since, in general, studies on the effect of forest management on ecosystems are carried out over short periods of time and, thus, they do not show its effects over longer periods of time.

Acknowledgments

Gratitude for *Conacyt* must be expressed for having provided the financial support granted to the first author (Edgar Silva-González) to study the Doctorate program at the *Facultad de Ciencias Forestales* (Graduate School of Forest Sciences) of the *Universidad Autónoma de Nuevo León*.

Conflict of interests

The authors declare no conflict of interest.

Contribution by author

Oscar Alberto Aguirre-Calderón: review of the manuscript and correction of data analysis; Edgar Silva-González: writing of the manuscript; Eduardo Alanís-Rodríguez: writing and review of the manuscript, data analysis coordination; Eduardo Javier Treviño-Garza and José Javier Corral-Rivas: review of the manuscript, data analysis and review of literature.

Referencias

Aguirre-Calderón, O. A., G. Hui, K. V. Gadow and J. Jiménez-Pérez. 2003. An analysis of spatial forest structure using neighbourhood-based variables. Forest Ecology and Management 183(1):137-145. Doi: 10.1016/S0378-1127(03)00102-6.

Aguirre-Calderón, O. A., J. J. Corral-Rivas, B. Vargas-Larreta y J. Jiménez-Pérez. 2008. Evaluación de modelos de diversidad-abundancia del estrato arbóreo en un bosque de niebla. Revista Fitotecnia Mexicana 31(3):281-289. Doi: 10.35196/rfm.2008.3.281.

Alanís-Rodríguez, E., A. Mora-Olivo y J. S. Marroquín-de la Fuente. 2020. Muestreo ecológico de la vegetación. Editorial Universitaria de la Universidad Autónoma de Nuevo León. Monterrey, N. L., México. 259 p.

Alanís-Rodríguez, E., J. Jiménez-Pérez, A. Valdecantos-Dema, M. Pando-Moreno, O. A. Aguirre-Calderón y E. J. Treviño-Garza. 2011. Caracterización de la regeneración leñosa post-incendio de un ecosistema templado del parque ecológico Chipinque, México. Revista Chapingo Serie Ciencias Forestales y del Ambiente 17(1):31-39. Doi: 10.5154/r.rchscfa.2010.05.032.

Alanís-Rodríguez, E., J. Jiménez-Pérez, M. Pando-Moreno, O. A. Aguirre-Calderón, E. J. Treviño-Garza y P. C. García-Galindo. 2010. Efecto de la restauración ecológica post-incendio en la diversidad arbórea del Parque Ecológico Chipinque, México. Madera y Bosques 16(4):39-54. Doi: 10.21829/myb.2010.1641159.

Ammer, C. 2019. Diversity and forest productivity in a changing climate. New phytologist 221(1), 50–66. Doi: 10.1111/nph.15263.

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

Castellanos-Bolaños, J. F., E. J. Treviño-Garza, O. A. Aguirre-Calderón, J. Jiménez-Pérez y A. Velázquez-Martínez. 2010. Diversidad arbórea y estructura espacial de bosques de pino-encino en Ixtlán de Juárez, Oaxaca. Revista Mexicana de Ciencias Forestales 1(2):39-52. https://www.redalyc.org/articulo.oa?id=63438955004 (24 de febrero de 2022).

Colín, J. G., O. A. Aguirre-Calderón, J. J. Corral-Rivas, E. Viveros-Guerrero, S. Corral-Rivas y F. Crecente-Campo. 2018. Influencia de la competencia en el crecimiento diamétrico de *Pinus durangensis* Martínez en Durango, México. Revista Mexicana de Ciencias Forestales 9(45):94-121. Doi: 10.29298/rmcf.v9i45.145.

Corral-Rivas, J. J., O. A. Aguirre-Calderón, J. Jiménez-Pérez and S. Corral-Rivas. 2005. An analysis of the forest utilization effect on the structural diversity in «El Cielo» cloud forest, Tamaulipas, Mexico. Investigación Agraria: Sistemas y Recursos Forestales 14(2):217-228. Doi: 10.5424/srf/2005142-00885.

Corral-Rivas, J. J., B. Vargas-Larreta, C. Wehenkel, O. A. Aguirre-Calderón, J. G. Álvarez-González y A. Rojo-Alboreca. 2009. Guía para el establecimiento de sitios de investigación forestal y de suelos en bosques del Estado de Durango. Ed. Universidad Juárez del Estado de Durango. Durango, Dgo., México. 60 p. https://www.researchgate.net/publication/305640430_Guia_para_el_establecimiento_de_sitios_de_investigacion_forestal_y_de_suelos_en_bosques_del_Estado_de_Durango (24 de febrero de 2022).

Corral-Rivas, J. J., B. Vargas-Larreta, C. Wehenkel, O. A. Aguirre-Calderón y F. Crecente-Campo. 2013. Guía para el establecimiento, seguimiento y evaluación de sitios permanentes de monitoreo en paisajes productivos forestales. Editorial Comisión Nacional Forestal (Conafor) y Consejo Nacional de Ciencia y Tecnología (Conacyt). Durango, Dgo., México. 93 p. http://forestales.ujed.mx/monafor/archivos/descargas/guias_manuales/Guia_para_el_Establecimiento_Seguimiento_y_Evaluaci%C3%B3n_de_Sitios_Permanetes_de_Monitoreo.pdf (27 de octubre de 2020).

Del Río, M., F. Montes, I. Cañellas y G. Montero. 2003. Revisión: Índices de diversidad estructural en masas forestales. Investigación Agraria: Sistemas y Recursos Forestales 12(1):159–176. Doi: 10.5424/795.

Duguid, M. C. and M. S. Ashton. 2013. A meta-analysis of the effect of forest management for timber on understory plant species diversity in temperate forests. Forest Ecology and Management 303:81-90. Doi: 10.1016/j.foreco.2013.04.009.

Gadow, K. V. and G. Hui. 2002. Characterising forest spatial structure and diversity. In: Bjoerk, L. (Ed). Proceedings IUFRO Int. workshop "Sustainable forestry in temperate regions". University of Lund. Lund, Sweden. Pp. 20-30.

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

Hernández-Salas, J., O. A. Aguirre-Calderón, E. Alanís-Rodríguez, J. Jiménez-Pérez E. J. Treviño-Garza, M. A. González-Tagle, C. Luján-Álvarez, J. M. Olivas-García y L.

A. Domínguez-Pereda. 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):189-199. Doi: 10.5154/r.rchscfa.2012.08.052.

Hutcheson, K. 1970. A test for comparing diversities based on the Shannon formula. Journal of Theoretical Biology, 29(1):151-154. Doi: 10.1016/0022-5193(70)90124-4.

Instituto Nacional de Estadística Geografía e Informática (INEGI). 2015. Carta topográfica. Escala 1:50,000 F13A18. El Salto, Durango, México. https://www.inegi.org.mx/contenidos/productos/prod_serv/contenidos/espanol/bvinegi/productos/geografia/imagen_cartografica/1_50_000/889463824817_geo.pdf. (16 de abril del2022).

Instituto Nacional de Estadística y Geografía (INEGI). 2017. Anuario estadístico y geográfico de Durango 2017. Aguascalientes, Aguascalientes, México. https://www.inegi.org.mx/contenido/productos/prod_serv/contenidos/espanol/bvinegi/productos/nueva_estruc/anuarios_2017/702825092115.pdf (16 de Abril de 2022).

Kint, V., M. V. Meirvenne, L. Nachtergale, G. Geudens and N. Lust. 2003. Spatial methods for quantifying forest stand structure development: A comparison between nearest-neighbour indices and variogram analysis. Forest Science 49(1):36-49. Doi: 10.1093/forestscience/49.1.36.

Kraft, G. 1884. Beiträge zur lehre von den durchforstungen, schlagstellungen und lichtungshieben. Verlag Keind-worth. Hannover, Alemania. 147 p.

López-Hernández, J. A., O. A. Aguirre-Calderón, E. Alanís-Rodríguez, J. C. Monárrez-González, M. A. González-Tagle y J. Jiménez-Pérez. 2017. Composición y diversidad de especies forestales en bosques templados de Puebla, México. Madera y Bosques 23(1):39-51. Doi: 10.21829/myb.2017.2311518.

Luján-Soto, J. E., J. J. Corral-Rivas, O. A. Aguirre-Calderón and K. Gadow. 2015. Grouping forest tree species on the Sierra Madre Occidental, Mexico. Allgemeine Forst und Jagdzeitung 186(3-4):63-71. https://www.researchgate.net/publication/275640880 (24 de febrero de 2022).

Magurran, A. E. 1988. Ecological diversity and its measurement. Editorial Princeton University Press. Princeton, New Jersey, EE.UU. 200 p.

Magurran, A. E. 2004. Measuring biological diversity. Editorial Blackwell Publishing. Oxford, United Kingdom. 261 p. https://books.google.es/books?hl=es&lr=&id=CxRSEAAAQBAJ&oi=fnd&pg=PR7&dq=Magurran,+A.+E.+2004.+Measuring+biological+diversity.+Blackwell+Publishing.+Oxford,+UK.+256+p.&ots=sNX4OTZsIP&sig=8f2EOqQjqwGiWNJAVbuXohgvVtg#v=onepage&q&f=false (24 de Febrero de 2022).

Monárrez-González, J. C., M. S. González-Elizondo, M. A. Márquez-Linares, P. J. Gutiérrez-Yurrita and G. Pérez-Verdín. 2020. Effect of forest management on tree diversity in temperate ecosystem forests in northern Mexico. PLOS ONE 15(5):e0233292. Doi: 10.1371/journal.pone.0233292.

Moreno, C. E. 2001. Métodos para medir la biodiversidad (Vol. 1). Ciencia y Tecnología para el Desarrollo (CyTED), ORCYT/UNESCO y Sociedad Entomológica Aragonera (SEA). Zaragoza, España. 87 p. https://www.researchgate.net/publication/304346666_Metodos_para_medir_la_biodiversidad (04 de marzo de 2022).

Návar-Cháidez, J. J. y S. González-Elizondo. 2009. Diversidad, estructura y productividad de bosques templados de Durango, México. Polibotánica (27):71-87. http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1405-27682009000100005&lng=es&tlng=es. (02 de Marzo de 2022).

Pommerening, A. 2002. Approaches to quantifying forest structures. Forestry 75(3):305-324. Doi: 10.1093/forestry/75.3.305.

Pommerening, A. and D. Stoyan. 2006. Edge-correction needs in estimating indices of spatial forest structure. Canadian Journal of Forest Research 36(7):1723-1739. Doi: 10.1139/x06-060.

Quispe-Andía, A., K. M. Calla-Vasquez, J. S. Yangali-Vicente, J. L. Rodríguez-López e I. I. Pumacayo-Palomino. 2019. Estadística no paramétrica aplicada a la investigación científica con software SPSS, MINITAB Y EXCEL. Editorial EIDEC, Vol. 1. Colombia. 80 p. https://www.editorialeidec.com/wp-content/uploads/2020/01/Estad%C3%ADstica-no-param%C3%A9trica-aplicada.pdf. (01 de marzo de 2022).

Ramírez-Santiago, R., G. Ángeles-Pérez, P. Hernández-de La Rosa, V. M. Cetina-Alcalá, O. Plascencia-Escalante y R. Clark-Tapia. 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):e2531818. Doi: 10.21829/myb.2019.2531818.

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

Shannon, C. E. 1948. A mathematical theory of communication. The Bell System Technical Journal 27(3):379-423. Doi: 10.1002/j.1538-7305.1948.tb01338.x.

Statistical Analysis System Institute (SAS). 2009. SAS/STAT® 9.1. User’s Guide. SAS Institute Inc. Cary, N. C., USA. 5136 p.

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

Solís-Moreno, R., O. A. Aguirre-Calderón, E. J. Treviño-Garza, J. Jiménez-Pérez, E. Jurado-Ybarra y J. J. Corral-Rivas. 2006. Efecto de dos tratamientos silvícolas en la estructura de ecosistemas forestales en Durango, México. Madera y Bosques 12(2): 49-64. Doi: 10.21829/myb.2006.1221242.

Soto-Cervantes, J. A., J. R. Padilla-Martínez, P. A. Domínguez-Calleros, A. Carrillo-Parra, R. Rodríguez-Laguna, M. Pompa-García, E. García-Montiel y J. J. Corral-Rivas. 2021. Efecto de cuatro tratamientos silvícolas en la producción maderable en un Bosque de Durango. Revista Mexicana de Ciencias Forestales 12(67):56-20. Doi: 10.29298/rmcf.v12i67.991.

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

Zeller, L., J. Liang and H. Pretzsch. 2018. Tree species richness enhances stand productivity while stand structure can have opposite effects, based on forest inventory data from Germany and the United States of America. Forest Ecosystem 5(4). Doi: 10.1186/s40663-017-0127-6.