DOI: https://doi.org/10.29298/rmcf.v9i47.161

Article

Pattern of spatial distribution of the tree species of the *El Salto* region of *Durango*

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Abstract:

The purpose of this study was to determine the pattern of spatial distribution of trees present in the region of *El Salto*, *Pueblo Nuevo*, *Durango*. For this purpose, 12 communities that are representative of the conditions of the forests of the region were selected, where 269 round sites of 0.1 ha were randomly distributed at an altitude range of 1 500 to 3 000 m. The pattern of distribution of the trees by altitude level was determined by applying Cox's and Morisita's indices, and the pattern corresponding to each species was tested with the Poisson and negative binomial distribution adjustment tests. The level of aggregation was evaluated through the clustering parameter K, the ratio of the average density per taxon in relation to the mean 1/K, and the average number per individual per species in relation to the individuals present in the sampling unit m*. Cox's and Morisita's indices ranged from 12.05 to 17.39 and from 1.18 to 1.28, respectively, indicating that at each level of altitude individuals are distributed on an aggregate basis. At the same time, Cox's index and the negative binomial distribution adjustment (P>0.05) pointed out that the individuals per species are distributed in clusters. The values of the parameter K, 1/K and m*, which ranged from 0.002 to 0.454, from 2 to 500 and from 9 to 69, respectively, exhibit a high degree of aggregation between individuals.

Keywords: Negative binomial distribution, spatial distribution, Poisson distribution, Cox's Index, Morisita's Index, parameter K.

Fecha de recepción/Reception date: 13 de diciembre de 2017.

Fecha de aceptación/Acceptance date: 16 de abril de 2018.

Introduction

The organisms belonging to a population or community considered as a continuous inhabitable space can be distributed in a random, uniform or aggregated way. The random distribution implies that all the points in space have an equal possibility of being occupied and that the existence of an individual in a point does not affect the presence of another. In the uniform distribution, the individuals exhibit a negative interaction expressed by the competition for a resource, while the clustered distribution exhibits positive effects of attraction to form dense groups of individuals (Franco-López *et al.*, 1989).

The study of the spatial dispersion makes it possible to identify mechanisms and factors that promote inter- and intraspecies coexistence and the plant diversity of ecosystems (Montañez *et al.*, 2010). The analysis of the pattern of spatial distribution is an important action to determine the microenvironmental conditions required by each of the taxa that make up a community and thus, account for the establishment and renewal capacity, the skill development and growth, the probability of mortality and the competence of the species (Linares-Palomino, 2005).

In turn, the knowledge of the biological, ecological, biogeographic and anthropic factors that defines the distribution of species and their ecological affinities is important for the structuring of conservation plans (Maciel-Mata *et al.*, 2015). The spatial distribution of the taxa within the landscape is due to a differential selection of the biotic and abiotic resources that favor their optimal development (Díaz *et al.*, 2012).

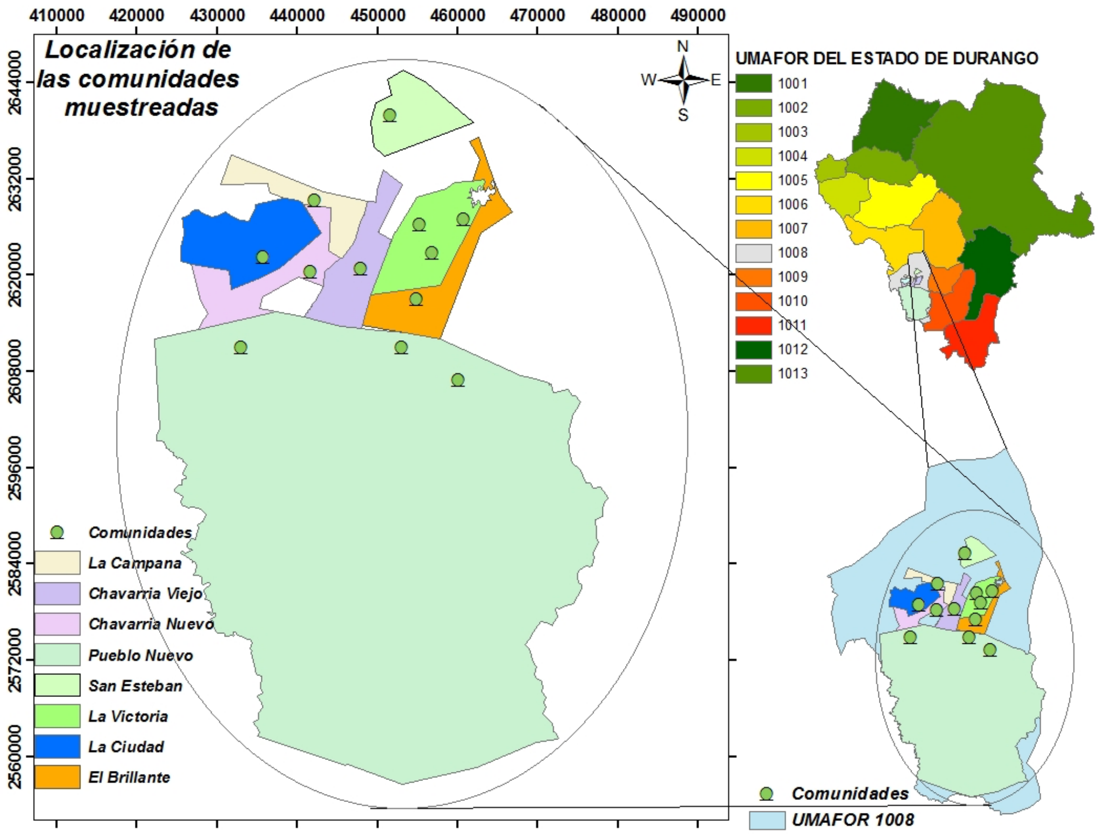
The analysis of the distribution pattern of individual trees is supported by different indexes and probabilistic methods; the application of some of them have special requirements with respect to the distribution, the size or shape of the sampling units, the spatial location of individuals and the distance between them (Clark and Evans, 1954; Ripley, 1977; Aguirre *et al.,* 2003). In particular, the analysis of Cox's and Morisita's indices, as well as the negative binomial and Poisson distribution adjustment tests make it possible to use non-contiguous samples and only require information about the abundance of individuals per sampling unit (Ledo *et al.,* 2012; Ledo, 2013).

Regardless of the vast knowledge that exists about the identification, the volumetric assessment and the growth rates of the timber taxa in the region of *El Salto*, *Durango*, little has been documented about the pattern of spatial distribution, and the basic and relevant information that helps to explain the influence of the local environment in the presence of the species. As a contribution to this knowledge, the purpose of this study was to determine the spatial distribution pattern in terms of the degree of aggregation, uniformity or randomness of the tree species, through an altitude gradient.

Materials and Methods

Description of the study area

The study was carried out in the forest region of *El Salto*, *Durango*, which is located in the massif of the *Sierra Madre Oriental* (Western Sierra Madre), to the southwest of the state (Figure 1). It covers approximately 507 127 ha; the altitudes above the sea level range from 1 400 to 3 000 m (INEGI, 2010).



Localización de las comunidades muestreadas = Location of the sampled communities; *UMAFOR del estado de Durango* = UMAFOR of the State of Durango

Figure 1. Location of the study area.

Sampling

12 communities that are representative of the conditions of the forests of the region were selected, where 269 round 0.1 ha sites were randomly placed in order to register the control variables of the site, as well as the location, presence and abundance of the species.

Distribution Pattern

The distribution pattern of the species for each level of altitude was estimated using Cox's and Morisita's indices (Ip). The former (Cox, 1971), also known as Strand's index (1953), is based on the estimation of the variance/mean ratio of the number of elements of the samples; while Morisita's index (1959) is a measure of dispersion, independent of the size of the sampling unit or the density present in each sample (Krebs 1999; Badii *et al.*, 2011). According to Ledo *et al.* (2012), both indexes are applicable when there is a lack of information regarding the location and the distance between the individuals and the necessary information comes from samples that are not necessarily contiguous —a situation which prevailed in this study.

$$Cox = \frac{S^2}{\bar{X}}$$

$$Ip = n\left[\frac{\sum {x_i}^2 - \sum x_i}{(\sum x_i)^2 - \sum x_i}\right]$$

Where:

$\bar{X}$ = Mean

S^2 = Variance

n = Sample Size

x_i= Number of individuals in quadrant *i*

If the result of Cox's index is equal to 1, it is established that the distribution is random; if it is lower or higher, then it follows that individuals are evenly distributed. The decision rule of Morisita's index is similar to that of Cox's (Ledo *et al.*, 2012), except that the reference value related to the random distribution is zero. Values below or above zero indicate the presence of a uniform or aggregated distribution, respectively.

The pattern of random distribution of individual trees by species within their area of occupation was tested using the Poisson distribution, and when this test was not significant, the negative binomial distribution was used to test whether or not they have a clustered distribution. The Poisson distribution function, $P(x)$ is expressed as:

$$P(x) = \frac{\lambda^x \, e^{-\lambda}}{x!}$$

Where:

e = Base of the natural logarithm (2.7183)

λ = Mean

$x_!$ = *x* factorial

The expected frequencies of *Poisson*, $E(x)$ were estimated by multiplying the total number of individuals registered in the sampling (N) by the Poisson probability function $P(x)$:

$$E(x) = (N)P(x)$$

The implementation of the function of the probability of the negative binomial involved the calculation of a first approximation of a K value, which is considered to be a measure of aggregation (Badii *et al.*, 2011):

$$K = \frac{\bar{X}^2}{S^2 - \bar{X}}$$

Where:

$\bar{X}$= Average number of individuals

S^2 = Variance in the number of individuals

This first approximation of the K value is applicable when it is below or equal to 3 and the mean is less than or equal to 1. If the above condition is not met, then the value of K is reestimated using the following equation:

$$\log\left(\frac{n}{n_0}\right) = Klog\left(1 + \frac{m}{K}\right)$$

Where:

K = Level of influence to the aggregation

n = Total number of samples

n_0 = Number of samples with zero individuals

m = Average number of individuals

K is determined by the method of trial and error, starting with the previously estimated value of K.

After calculating the value of K, the expected frequencies for zero individuals, f_0 , was estimated; this estimation required knowing the probability of failure, (q), which depends on the probability of success, p.

$$p = \frac{m}{k}$$

$$q = 1 + p$$

Subsequently, the frequencies for X_i individuals, fe_x, were estimated:

$$f_0 = \frac{n}{q^k}$$

$$fe_x = (fe_{(x-1)})\left(\frac{\bar{X}}{\bar{X}+k}\right)\left(\frac{x+k+1}{x}\right)$$

Where:

$p =$ Probability of success or the occurrence of an event in a binomial distribution

$q =$ Probability of failure or non-occurrence of the event in a negative binomial distribution

$x =$ Class number or number of individuals or elements

In order to determine the goodness-of-fit of the Poisson or negative binomial distributions, the statistical test Chi-square test was used (χ^2), at a significance level of 0.05:

$$\chi^2 = \sum\left[\frac{(Fx-Ex)^2}{Ex}\right]$$

Where:

$Fx =$ Observed frequencies

$Ex =$ Expected frequencies

If the value of the probability of χ^2 is within the range established by the values in the table of χ^2 (0.975 - 0.025), the distribution is random (Ludwig and Reynolds, 1998), but if the value of the result of χ^2 is higher, the distribution will be clustered; and if it is lower, the distribution will be uniform.

The degree of clustering was estimated upon the basis of the proportion in which the mean abundance of individuals of each species exceeds the average of the total abundance $\frac{1}{K}$ and the clustering index m* (Lloyd, 1967), which defines the average number per individual in relation to other individuals (m*).

$$m^* = m(1 + \frac{1}{K})$$

Where:

m^* = Clustering index

m = Average density

K = Parameter indicative of the clustering

Results and Discussion

Distribution pattern between species by level of altitude

Of the 12 *Pinus* species and 10 *Quercus* species recorded, *P. strobiformis* Engelm., *P. cooperi* C. E. Blanco, *P. durangensis* Martínez, *P. lumholtzii* Robins & Ferns, *P. michoacana* Martínez, *P. teocote* Schiede ex Schltdl., *Q. crassifolia* Humb & Bonpl., *Q. rugosa* Née, *Q. sideroxyla* Humb & Bonpl. and *Q. candican*s Née are located through the entire range of the studied altitude distribution (1 500 to 3 000 m). *Juniperus deppeana* Steud. is located at an altitude of 1 800 to 3 000 m; *Alnus firmifolia* Fern and *Populus tremuloides* Michx are located at an altitude of 2 400 to 2 700 masl. As for *Abies durangensis* Martínez var. *coahuilensis* (I.M. Johnston) Martínez and

Pseudotsuga menziesii (Mirb.) Franco, they are distributed between 2 400 to 2 700 and 2 700 to 3 000 masl, respectively.

Although Cox's index (12.05<X<17.39) and Morisita's index (1.18<IM<1.28) indicate that the species are clustered together, the degree of aggregation between levels was different. Table 1 shows that the level of aggregation was higher at altitudes of 1 800-2 100 (CI= 16.30 and MI=1.28) and 2 700-3 000 (CI=17.39 and MI=1.25).

Table 1. Values of Cox's and Morisita's indexes by level of altitude.

Level of altitude	Cox's index (CI)	Morisita's index (MI)
1 500-1 800	13.40	1.19
1 800-2 100	16.30	1.28
2 100-2 400	12.05	1.19
2 400-2 700	13.96	1.18
2 700-3 000	17.39	1.25

Pattern of distribution by species

The χ^2 test, applied to the Poisson distribution adjustment indicated that individuals of each species are distributed in a non-random way ($P<0.05$). On the other hand, the values of the clustering parameter K ($0.002<K<0.454$), the proportion of the average abundance of individuals in relation to the mean density 1/K ($2<1/K<500$), the mean clustering index m* ($9<m^*<62$) and the variance/mean CI ($4<CI<41$) evidenced the presence of a high level of clustering between individuals of the same species (Table 2). The minimum and maximum value of K, and, therefore, the minimum and maximum proportion of average abundance in relation to the average density, corresponded to *Q. sideroxyla* Humb. and *Q. urbanii* Trel., respectively, while the minimum and maximum clustering index, expressing the average number per taxon in relationship to the other individuals of the same sampling unit (Lloyd, 1967), occurred in *Q. durifolia* Seemen and *P. occarpa* Schiede ex Schltdl., which had the minimum and maximum Cox's index, respectively.

Table 2. Values of the spatial distribution by species.

Species	K	(1/K)	m*	CI (m/S^2)	Probability of the binomial
Pinus strobiformis Engelm.	0.324	3	14	9	0.003
Pinus cooperi C. E. Blanco	0.285	4	40	20	0.0003
Pinus douglasiana Martínez	0.027	37	17	8	0.002
Pinus durangensis Martínez	0.194	5	69	34	0.005
Pinus herrerae Martínez	0.057	18	15	14	0.252
Pinus leiophylla Schiede ex Schltdl. & Cham.	0.182	5	14	9	0.172
Pinus lumholtzii B.L. Rob. & Fernand	0.05	20	25	15	0.666
Pinus devoniana Lindl.	0.02	50	36	16	0.887
Pinus chihuahuana Engelm.	0.017	59	14	9	0.501
Pinus engelmannii Carr.	0.055	18	39	20	0.06
Pinus teocote Schiede ex Schltdl.	0.114	9	18	15	0.028
Pinus oocarpa Schiede ex Schltdl.	0.013	77	62	41	0.157
Quercus conzattii Trel.	0.015	67	27	24	0.793
Quercus crassifolia Humb. & Bonpl.	0.028	36	13	15	0.797
Quercus durifolia Seemen ex Loes	0.027	37	9	5	0.002
Quercus rugosa Née	0.191	5	12	9	0.945
Quercus sideroxyla Humb. & Bonpl.	0.454	2	21	14	0.107
Quercus candicans Née	0.012	83	23	12	0.879
Quercus eduardii Trel.	0.009	111	11	6	0.26
Quercus fulva Liebm.	0.003	333	10	4	0.796
Quercus urbanii Trel.	0.002	500	30	9	0.374
Quercus viminea Trel.	0.004	250	20	8	0.592
Juniperus depeana Steud.	0.252	4	15	11	0.359

The presence of the clustered distribution was corroborated, in most species, with the goodness-of-fit test of the negative binomial distribution (P>0.05). The exception occurred in *Pinus strobiformis* Engelm. (P=0.003), *Pinus cooperi* C. E. Blanco (P=0.0003), *Pinus douglasiana* Martínez (P=0.002), *Pinus durangensis* Martínez (P=0.005), *Pinus teocote* Schiede ex Schltdl. (P=0.028) and *Quercus durifolia* Seemen (p=0.002), for which the Poisson and negative binomial distribution tests did not exhibit a significant adjustment (P<0.05). In order to determine that the pattern of distribution of individuals corresponds to the added, using as a reference the estimators of K, 1/K and CI, whose values varied from 0.027 to 0.324, from 3 to 37 and 8 to 20, respectively.

According to Taylor (1961), the clustered distribution is the most common form in nature, especially in areas populated with trees in the initial stages of development, which, when their density decreases by effect of the mortality associated with the competition, tend to switch to a random distribution (Aldrich *et al.*, 2003; Rozas and Camarero, 2005). In the present study, the clustered distribution pattern determined at each altitude level can be attributed to the fact that the analysis of the distribution pattern was determined on the full forest mass existing at each level, which —being mixed, non-coeval and heterogeneous— consists of a high density of trees of smaller dimensions, complemented with a smaller amount of trees that correspond to the intermediate and upper strata. The presence of trees that develop under the upper strata indicates that there is a positive relationship between individuals of the same or different species.

Montañez *et al*. (2010) hold that, although the clustered species require common environmental conditions for their establishment and development, the formation of this type of distribution is due to the interactions between individuals of the same and different species, as well as between the individuals and the environment. According to Badii *et al.* (2011) and Montañez *et al.* (2010), the physiological response of plants to the abiotic microenvironmental conditions such as temperature, relative humidity, direction and wind speed, physical and chemical properties of the soil, slope and exposure of the areas may account for the ability of different species to cluster together. In general, dispersal limitation (Hubbel, 2001) or habitat specialization (Tilman, 1982) are the mechanisms that determine the distribution pattern of species.

The results of this study, as well as those obtained by Rossi and Huguchi (1998) in a study of a tropical forest of the Amazon, prove that Cox's and Morisita indices generate similar results, regardless of the estimation method, in the assessment of the distribution pattern of the species that make up the studied populations or communities. Malleux (1973), Linares-Palomino (1973), (2005), López (2008) and Zarco-Espinosa *et al.* (2010) documented the presence of species clusters in tropical forests; Ledo (2013), in tropical cloud forests; Aguirre *et al.* (2003), Domínguez-Calleros *et al.* (2014) and Montañez *et al.* (2010), in high mountain forests; Juárez-Sánchez *et al.* (2014) in temperate mixed forests, and Martínez-Antúnez (2014), in species of the temperate climate of the Western *Sierra Madre* across the state of *Durango*.

Conclusions

Cox's and Morisita's spatial distribution indexes indicate that the groups of tree species of the region of *El Salto*, *Durango*, tend to cluster, forming mixtures of species. Similarly, the clustering parameter K, the proportion in which the average density of each species exceeds the average density 1/K, the clustering index m* and Cox's index, corroborated by the negative binomial distribution adjustment test, indicate that the individuals cluster by species.

Acknowledgments

The authors wish to express their gratitude to the *Tecnológico Nacional de México* (National Technological Institute of Mexico), through the *Instituto Tecnológico de El Salto* (Technological Institute of El Salto); to the *ejidos* in the region of *El Salto, Durango*, and to the *Unidad de Prestadores de Servicios Ejidales* (Unit of Providers of Communal Land Services) in *El Salto, Durango*, for the support and facilities granted for the collection and processing of the information.

Conflict of interest

The authors declare no conflict of interest.

Contribution by author

Francisco Javier Hernández: field data collection, analysis of the information, drafting of the manuscript; Carlos Brian Navarro Mata: analysis of the information, collection of information related to the topic, drafting of the manuscript; Raúl Peña Montañez: collection of bibliographic information, analysis of the information, drafting of the manuscript; Abel Nájera Luna: support in the review, editing, and suggestions for improving the draft of the manuscript, design of figures and tables.