Assessment of Post-Fire Forest Structural Diversity Using Neighborhood Parameter in the Sierra Madre Oriental, Mexico[1]

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Abstract

The objective of this research was to characterize the spatial structure patterns of a *Pinus hartwegii* forest in the Sierra Madre Oriental, affected by a fire in 1998. Sampling was stratified by fire severity. A total of three fire severity classes (low, medium and high) were defined. Three sample plots of 40m x 40m were established for each severity. Variables obtained for all trees with a diameter at breast height (DBH) ≥ 5 cm in each plot were: DBH (cm) to 1.30 m, height (m), special location by recording the azimuth (°) and distance (m) from the center of the plot to each tree. A total of three index groups were employed to describe the structure: "aggregation" (*Wi* and *Di*), "dominance" (*Ui*) and dimensional size (*TDi* and *THi*). The variance analysis showed significant differences (p>0.001) for dasometric parameter among low severities with respect to medium and high severities; this last two severities did not showed significant differences between them. Structural characterization results suggest that by increasing the fires severity degree, the aggregation degree increases, and the dimensional differentiation and dominance decrease as the severity degree increases.

Keywords: fire regimes, forest fire severity, spatial variation

Introduction

Fire is one of the most widespread natural disturbances in forest ecosystems (Perry and others 2008; Bekker and Taylor, 2010), which is presented as a natural disturbance factor (Omi, 2005). Almost all terrestrial ecosystems have a fire regime,

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ie, a fire history that has shaped or affected the structure and composition of species within that ecosystem. The presence of natural disturbances in forest ecosystems, such as fire, causes changes in its structure, which is reflected in the spatial distribution of trees (Gill and others 1999). These changes in the distribution of individuals cause that patterns and the spatial variation of the stand structure generate significant effects on the succession of forest ecosystems at the stand scale (Yu and others 2009).

In this context, research has shown that the fire effect on some forest ecosystems have undergone dramatic changes in its structure. Some authors report that the structural diversity at stand level is the result of fire severity and processes that operate at the stand scale during the absence of fire. The great variability generated in the structure of the stand contributes, in some cases, to the increase of the post-fire regeneration, also consider as fire effects (Lecomte and others 2006, Lampainen and others 2004, González and others 2008). In recent decades, we have developed different indices to assess forest structure, which include the set of indices developed by Gadow and Hui (2002), which measure small-scale variations in the position of trees, species and its dimensions based on neighborhood criteria. However, the application of these indices has focused primarily on assessing the effects of forest management, with minimal application to evaluate the fire effects on the forest structure. Therefore, the aim of this study was to characterize the spatial distribution of *Pinus hartwegii*, in three stands affected by different fire severity degrees during the summer of 1998, on the Potosí hill.

Methods

The present study was conducted on the Potosí hill, which is part of the Sierra Madre Oriental and is located within the municipality of Galeana, to the south of the state of Nuevo León, between 24°50’35’’ and 24°53’16’’ North and 100°13’12’’and 100°15’12” West (Figure1). It reaches an altitude of 3700 meters above the sea, which ranks it as the highest peak in northern Mexico (INEGI 1986). During the dry season of 1997-1998 under the weather conditions attributed to the phenomenon of "El Niño", a large forest fire occurred in this area; this conflagration significantly affected coniferous forests on the hill (Lozano 2006).

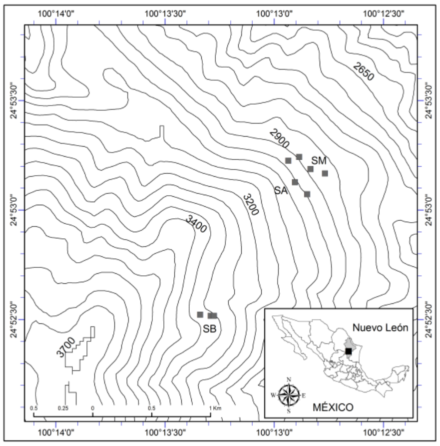

Figure 1—sampling site location in the study area. SB=low severity. SM=medium severity. SA=high severity.

Methodology

A total of three *Pinus hartwegii* stands with three different fire severity degrees (low, medium and high) each were selected. The classification made by Treviño and others (2000), who evaluated the areas burned in the south of Nuevo León by analyzing two Landsat TM satellite imagery and obtaining fire severity classes (this information was validated in the field), was taken as base to determine the severities. A total of nine sampling plots of 40 m x 40 m (three severities x three stands/severities) were established. For each plot, and only for those individuals with a diameter at breast height (DBH)) ≥ 5 cm, the following dasometric variables were obtained: diameter to 1.30 m (cm), height (m), distance (m) and azimuth (°) to each tree with respect to the center of the plot.

To describe the structure we used a set of indices to characterize the following stand parameters: "aggregation", which describes how trees are spread on the field, and "differentiation degree", which quantifies the differences in size of trees within the stand (Gadow and others 2001). The structural sampling method of five trees was the basis for the development of indices (Hui and Hu 2001), sampling developed to assess the structural attributes (size, species and the regularity of their positions) of the trees forming a forest stand (Gadow and others 2001, Aguirre and others 2003). Group determination was conducted using the program Winkelmass version 1.0.0 (2002), developed by researchers at the University of Göttingen, Germany. The index set used are shown below:

Table 1—Indices used for determining the structural groups evaluated.

indices	Where:
Gadow Uniformity Index *Wi*	n = number of neighboring trees considered; *Wij* = 1 when *j*-th angle ∝ between two next neighboring trees is less or equal to the standard angel ∝, otherwise it takes a value of 0. *Wi* can take values from 0 to 1, where a value close to zero represents regularity conditions, values close to 0.5 show a tendency to randomness and those close to 1 show clustering conditions
Distance index *Di*	Where: dij = i-th tree distance to its *j*-th neighbor, n = number of neighbors considered, = plot average distance *i* and N = number of structural groups determined by the Winkelmass program. The average distance of each severity were distributed in ten distance classes comprising ranges of 2 meters: class 1: 0 < Di ≤ 2 m; class 2: 2 m < Di ≤ 4 m;....; class 9: 16 m<Di≤ 18 m; class 10: 18 m < 20 Di.
Dominance index *Ui*	Where 0≤ Ui ≤ 1 and vj is equal to 1 if the tree *j* is less than the reference tree i and 0 if not.
Diameter differentiation Index (*TDi*) and Height differentiation Index (*THi*).	Where TD(i) and TH(i) = Diameter differentiation and plot height differentiation i; n = number of neighbors considered; N = number of measured trees; dmin, dmax, hmin and hmax = are the maximum and minimum diamter and height between i and each of its neighbors

Results

Table 2 shows the dasometric parameters by severity. This characterization results indicate that the three severities recorded low densities, showing a decrease as the fire severity increases. The same situation occurred in the case of basal area and diameter parameters. However, in the case of the variable height, high severity showed a height average higher than the average severity.

Table 2—Dasometric characteristics of the Pinus hartwegii stands in the different classes of severity studied on the Potosí hill. PHb=low severity, PHm=medium severity, PHa=high severity. ± Standard deviation. Equal letters in each column indicate no statistically significant differences between severities.*parameters weighted in accordance with the basal area.

Severity	Density (N/Ha)	Basal area (m^2/Ha)	*Diameter (cm)	*Heigh (m)
PHb	185±9.55	21.33±0.51[a]	38.30±1.03[a]	20.07±1.57[a]
PHm	183±20.09	14.45±1.02[b]	31.76±2.06[b]	14.89±0.82[b]
PHa	150±37.50	11.21±5.35[b]	30.46±6.83[b]	16.36±2.26[b]

Spatial distribution

Mean values of the Gadow Uniformity Index were *Wi* =0.528, 0.550 and 0.594 for low, medium and high severity, respectively. Hui and Gadow (2002), state that values less than 0.475 suggest a regular distribution and those over 0.517 had an irregular distribution with tendency to cluster. Consistent with this, the values of obtained for the three severities in this paper indicate an uneven distribution with a tendency to cluster. Severities showed the following values for the distances index Di: low severity with a

Fire-dependent ecosystems are characterized by presenting species that resist the passage of fire with adaptations that have acquired over time. Some of these adaptations are showed by *Pinus hartwegii* (Rodríguez 2008). Thus, dasometric characteristics and spatial distribution of *Pinus hartwegii* found in this study are consistent with those reported by some studies on fire ecology for this species. These studies refer to the ecological factor 'fire' as an important promoter of regeneration, because it facilitates the establishment of the species, which is favored by the conditions created by the fire disturbance, by opening up spaces in the understory, which favors the conditions for the establishment of new individuals (Rodríguez, 2008). The results obtained by the differentiation index and dominance index for diameter and height variables show that in high severity is where the greatest contrast of dimensions occurs. In addition, there is a rising trend of the aggregation and dimension differentiation as the fire severity increases, which consequently generates that dominance values decrease as the severity increases (Figure 2). These results are consistent with those reported by several related studies (Lecomte and others 2006, González and others 2008, Yu and others 2009 Bekker and Taylor 2010), who refer to dimensional heterogeneity conditions as fire impact effect on coniferous forests.

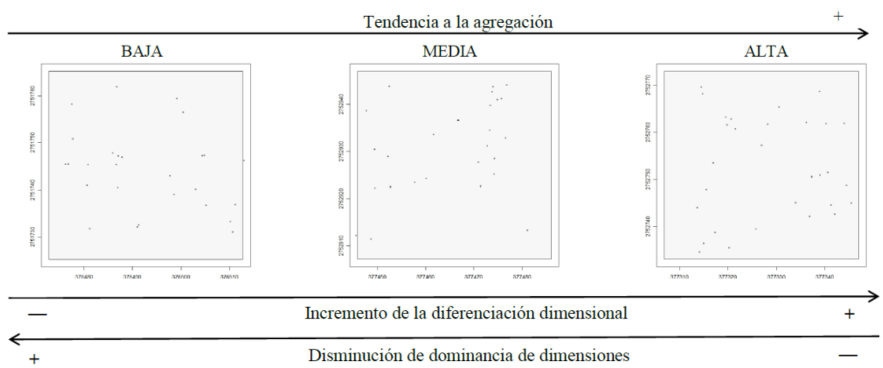

Figure 2—Spatial distribution by severity of the *Pinus hartwegii* individuals in the study area (the Potosí hill).

Furthermore, it is worth mentioning that the use of such indices in Mexico has been mostly aimed at assessing the impact of silvicultural treatments on forest ecosystem structures (Corral and others 2005), having a lower use with an ecological approach or to determine the influence of the fire disturbance on the forest structural characteristics (González and others 2008).

Conclusions

The results obtained indicate that when the severity degree of the fire increases, the degree of aggregation of trees and dimensional differentiation also increase. However, the degree of dominance in dimensions decreases as the severity fire degree increases.

Summary

The objective of this research was to characterize the pattern of spatial structure of a *Pinus hartwegii* forest in the Sierra Madre Oriental, affected by a fire in 1998. Sampling was stratified by fire severity. Three fire severity classes were defined (low, medium and high). Three sample plots of 40m x 40m were established for each severity. The variables obtained for all trees with a diameter at breast height (DBH) ≥ 5 cm in each plot were: DBH to 1.30 m (cm), height (m), spatial location by recording the azimuth (°) and distance (m) from center of the plot to each tree. To describe the stand structure three groups of indices were employed: “contagion” and “distances” (*Wi* and *Di*), “dominance” (*Ui*), and “size differentiation” (*TDi* and *THi*) for DBH and height respectively. An analysis of variance was performed to detect differences between dasometric parameters by fire severity. Statistical analysis shows significant differences (p>0.001) in the parameters such as basal area, diameter, and height, along the low, medium, and high fire severities. The characterization of the *Pinus hartwegii* spatial structure suggests that, with increasing degree of fire severity, the stands showed an increase on the aggregation index, however, the dimensional differentiation and dominance indices decreases as the fire severity increases.

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