Article

Recovery of the tree stratum in a high mountain ecosystem affected by fire

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Abstract:

In order to evaluate the ecological recovery the floristic and horizontal structures of the arboreal vegetation impacted by fire in a high mountain forest ecosystem were compared. Two adjacent areas were considered; one impacted by fire and other not impacted. Under each zone five sampling units were established in the form of a conglomerate composed for four circular sites of 400 m^2, where all tree were registered (DBH ≥ 7.5 cm). The vegetation at community level was characterized by the importance value index (*IVI*), a diametric categorization and the estimation of species richness and diversity using the Margalef (D_{Mg}) and Shannon (H') indices respectively. A statistical analysis of medians considering two variables of the floristic structure (Margalef index and Shannon index) and three of the horizontal structure (density, crown area and basal area) was performed. In both conditions, *Pinus pseudostrobus* was the most representative specie. The variables of the floristic structure (Margalef index and Shannon index) and density were not statistically different ($p > 0.05$), while in the horizontal structure, the values of the crown area and basal area were statistically different ($p < 0.05$). The results indicate that 19 years after the occurrence of the fire, the tree vegetation has a partial recovery.

Key words: Pine-oak forest, species diversity, forest fires, Margalef index, Shannon index, species richness.

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Introduction

Forest fires are alterations caused by fire on forest vegetation; their effects can be positive or negative based on their intensity, duration and type of impacted vegetation. The positive effects are reflected in particular on those species that have managed to develop certain adaptations that allow them to tolerate the defoliation and even the destruction of their stems by the action of fire, while the negative ones are present mainly in the low size vegetation of the shrub because its bark is generally thinner (Pellegrini *et al.,* 2017).

In Mexico, this phenomenon became very important for the public sector and the scientific community, especially after the fires in 1998 due to the large number of events (14 445 fires) and the impacted area (849 632 ha). The most affected vegetation at that time were grasslands (42 %), followed by other types (35 %) and to a lesser extent forests (23 %) (FAO, 2002). Although the proportion of burned areas provided with arboreal vegetation was not as significant in comparison with others, their effects have had a greater impact because their recovery has been more prolonged.

The effects of fire on vegetation have been studied in various parts of the world. Crotteau *et al.* (2013) assessed the dynamics of vegetation after nine and ten years of being impacted by fires at different levels of severity in three types of forest in Northern California, United States of America. Verma and Jayakumar (2015) weighted the impact of fire frequency over a 15-year period in tropical dry deciduous forests of Western Ghats, India. Marzano *et al*. (2012) described and quantified the fire impact and short-term responses of a Mediterranean forest affected by a high-severity crown fire from the compositional and structural diversity of living and dead trees.

There has been some research in this regard in Mexico, as that accomplished by Méndez *et al.* (2014) who analyzed the regeneration in a pine-oak forest of the *Sierra de Guerrero* after seven years of a sinister of this nature from the ecological parameters of value of importance, richness and diversity of species and some mensuration relationships. Alanís-Rodríguez *et al.* (2012) focused on the medium-term natural regeneration of woody species in a mixed *Pinus-Quercus* forest subjected to high recurrence of fires (years 1972, 1984 and 1998) of medium and high intensity in northeastern Mexico, considering ecological and dasometric variables, species diversity and their relation to hillside exposure.

Other very important aspects that have rarely been evaluated are the recovery of impacted ecosystems and the time they take to return to their original condition. The recovery of a forest ecosystem is integral and involves recomposing the conditions and interactions of the elements that constituted it. Considering the vegetation slope, recovery is estimated in relation to the system's ability to achieve vegetation cover levels, and physiognomic and floristic properties prior to fire (Pérez-Cabello *et al.,* 2011).

One way to evaluate the recovery levels of vegetation cover and physiognomic and floristic properties is to analyze some variables of floristic and horizontal structure. The former are associated with the ecological characteristics of plant populations such as importance values and species richness and diversity, while the latter are related to the dimensions and densities of individuals (Gutiérrez *et al*., 2015). The floristic structure is directly related to the horizontal structure, since the behavior of the different dimensions and densities of each of the individuals present in the community, give rise to different values of importance and influence the values of species richness and diversity.

The recovery of vegetation impacted by fire is of paramount importance in all forest ecosystems, but there are parts that due to their physical and biological characteristics require greater attention. In Mexico, forestry legislation considers forest ecosystems as high as 3 000 masl, as high priority areas for forest conservation. Based on the importance of these areas, it is necessary to carry out studies to know their recovery after forest fires, which will help in the implementation of restoration work. In this context, the objective of this work was to estimate the recovery of the arboreal vegetation of a high-mountain pine-oak forest impacted by fire, through an analysis of the floristic structure and some dasometric variables of the horizontal structure.

Materials and Methods

The study area is located in northeastern Mexico, in the southeastern part of the state of *Nuevo León*, in the physiographic province called *Sierra Madre Oriental*, between the geographical coordinates 23°49.2' and 23°51.4' north and 99°49.5' and 99°51.3' west (Figure 1).

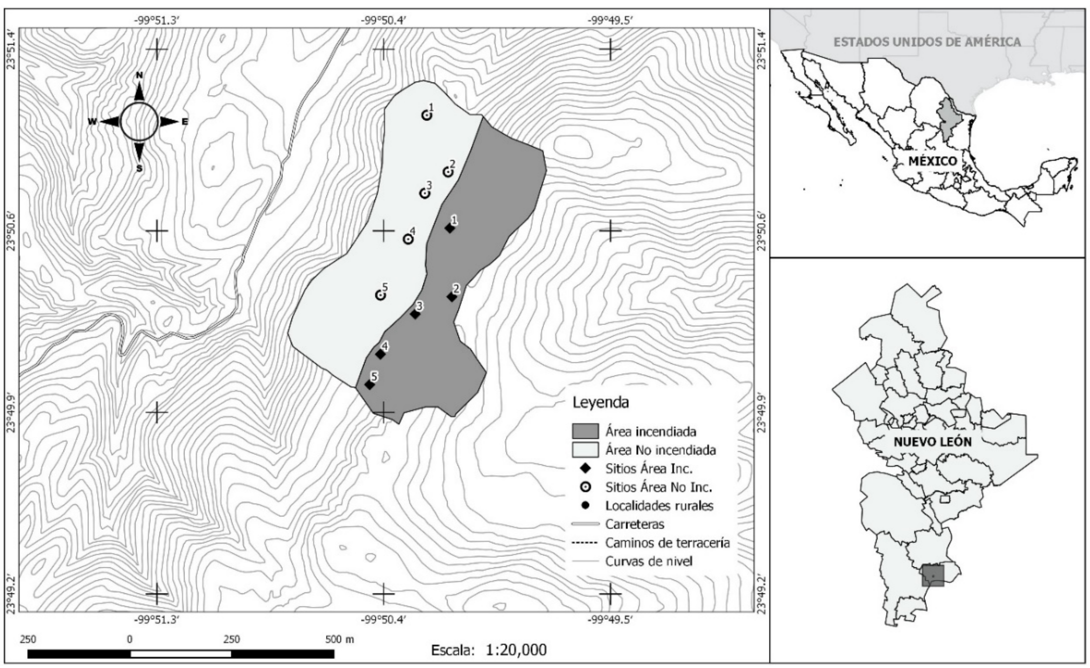

Figure 1. Location of the study area and distribution of the sampling units.

The climate is of the C type C(E)(w1)(x’) sub-humid semicold, with an annual mean temperature that oscillates between 5 and 12 °C and an annual mean rainfall of 700 mm with rains in summer (Inegi, 2001). The topography is rugged with steep slopes and an altitude of 3 000 m, with northeast exposure. As reported in the land use and vegetation cartography provided by the *Instituto Nacional de Estadística y Geografía (*Inegi*) (*National Institute of Statistics and Geography) (Inegi*),* these conditions favor the development of a pine-oak forest (Inegi, 2012). Part of the forest was impacted by a forest fire in 1998 caused by lightning associated with the meteorological conditions attributed to the *El Niño*-Southern Oscillation (ENSO) phenomenon, whose severity implied partial damage (Yocom *et al.,* 2010; Treviño *et al*., 2000).

Two scenarios were considered free of forest use: an area affected by fire 19 years ago with partial damages to the vegetation and another adjacent without burning, both without protection fence, which means that they are susceptible to grazing. It was assumed that the pre-fire conditions of the vegetation and that the general environmental processes (meteorological and physiographic for example) that occurred from the fire until the date of measurement were reasonably similar in the two scenarios. Under both conditions, five sampling units were established in the form of a clump following the *Inventario Nacional Forestal y de Suelos* (National Forestry and Soils Inventory) (Conafor, 2012). Each clump consisted of four 400 m^2 circular sites accommodated in inverted "Y" form, with distances of 45.14 m from the central site, from the first site the second was established with a free north course, the third with a southeast course azimuth of 120° and the fourth with southwest azimuth bearing of 240°. Tree species with a diameter at breast height (DAP) greater than or equal to 7.5 cm were recorded at each site, the DAP and cup diameter were measured in two directions (north-south and east-west). A botanical collection was carried out for the identification of the species.

Prior to the analysis of the recovery of the arboreal vegetation, a description was made at the community level for both conditions, in order to have an overview of the species gathered there, their behavior and the richness and diversity they represent in the ecosystem. This characterization was carried out by the importance value index (*IVI*), a diametric categorization and an estimation of ecological diversity through species richness and diversity.

The *IVI* was determined with ecological indicators of abundance (*Ar*), dominance (*Dr*) and frequency (*Fr*) as relative values. Ar was calculated by dividing the number of individuals of each species (*n*) by the total number of them (*N*). For Dr the crown area was used, dividing the occupied area of each species between the occupied surface of all species. Fr was estimated by dividing the frequency of each species (*f*) between the sum of frequencies of all species (*F*). Each indicator was multiplied by 100 to obtain relative values. The sum of the three indicators resulted in the IVI of each species (Müeller-Dombois and Ellemberg, 1974).

To determine species richness, the Margalef index (Margalef, 1957) was used, which is defined by equation 1.

$$D_{Mg} = (S-1)/ln(N) \qquad (1)$$

Where:

D_{Mg} = Species richness

S = Number of present species

ln = Natural logarithm

N = Total number of individuals

Species diversity was calculated using the Shannon index, which considers two aspects: the number of species present and their relative abundance (Shannon and Weaver, 1949). This index is defined by equations 2 and 3.

$$H' = -\sum_{i=I}^{S} P_i * In\,(P_i) \qquad (2)$$

$$P_i = {}^{n_i}/_{N} \qquad (3)$$

Where:

H' = Species diversity

P_i = *S*pecies ratio

In = Natural logarithm

n_i =Number of individuals of the *i* species

N = Total number of individuals

Afterwards, a statistical comparison was made between the two conditions to determine vegetation recovery using two variables of the floristic structure (richness and diversity of species) and three variables of the horizontal structure (density, crown area and basimetric area).

For the variables of the floristic structure, the richness and diversity of species was calculated again, but this time individually for each of the four sites that made up the sampling unit, in order to have the average values and be in possibility to make statistical comparisons. For the variables of the horizontal structure, the data were analyzed by the average values of each of the four sites the study sites as well. Density was determined by dividing the number of individuals (*N*) by the surface area unit *(A)* (Mostacedo and Fredericksen, 2000). The basimetric area was estimated according to Dieguez *et al*. (2003) through equation 4, which was used, too, for the calculation of the crown area:

$$g = \frac{\pi}{4} * d^2 \qquad (4)$$

Where:

g = Basimetric area

π = 3.1416

d = Diameter

Before the statistical analysis, the data were subjected to preliminary normality and variance equality tests. As the floristic and horizontal structure variables did not show a normal distribution, a median comparison was chosen by using the U test of Mann-Whitney (Spiegel and Stephens, 2002). The statistical analysis were performed with the 3.2.1. R statistical program.

Assuming that the vegetal restoration involves achieving levels of plant covering, and pre-fire physiognomic and floristic properties are known (Pérez-Cabello *et al.,* 2011), it was considered that total recovery would take place if the variables analyzed in the horizontal and floristic structures reached statistical levels equal to those prior to the event, while if only the levels were reestablished in some of the variables, the recovery would be partial.

Results and Discussion

The description of the tree vegetation made at the community level reveals that in the burned area, Pinaceae was the family with the highest *IVI*, being *Pinus pseudostrobus* Lindl. (*IVI* = 190.1) and *Abies vejarii* Martínez (*IVI* = 69.5), the most representative, while in the non- burned area, *Pinaceae* and *Fagaceae* were the most outstanding, with *Pinus pseudostrobus* (*IVI* = 146.7) and *Quercus sideroxyla* Bonpl. (*IVI* = 97.7) (Table 1).

Table 1. Ecological indicators and Importance Value Index of the assessed areas.

Species	Abundance[1]		Dominance[1]		Frequency[1]	IVI
	N ha^{-1}	(%)	m^2 ha^{-1}	(%)	(%)	
Burned area						
Pinus pseudostrobus Lindl.	125	67.1	3197.2	70.4	52.6	190.1
Abies vejarii Martínez	45	24.2	985.8	21.7	23.7	69.5
Arbutus xalapensis Kunth	11	6.0	293.1	6.5	15.8	28.3
Pinus hartwegii Lindl.	3	1.3	62.4	1.4	5.3	8.0
Populus tremuloides Michx.	3	1.3	3.6	0.1	2.6	4.1
Total	186	100	4542.1	100	100	300
Non- burned area						
Pinus pseudostrobus Lindl.	89	43.0	4 477.2	60.4	43.2	146.7
Quercus sideroxyla Bonpl.	81	39.4	2 116.6	28.6	29.7	97.7
Arbutus xalapensis Kunth	34	16.4	769.0	10.4	21.6	48.4
Abies vejarii Martínez	1	0.6	35.6	0.5	2.7	3.8
Populus tremuloides Michx.	1	0.6	11.4	0.2	2.7	3.5
Total	206	100	7 409.9	100	100	300

IVI = Importance Value Index; N = Individuals; [1] = Calculated from average values.

In the burnt area, tree individuals of *Quercus* spp. were found too, which had small diameters and as such were not taken into account for the analysis but are part of the natural recruitment of the forest mass in the community; they may be affecting the use of space and resources as well as other ecological functions at the site level (eg, mobility and shelter of fauna).

The analysis of the diametric categorization reflects the results obtained in the valuation of the species through the *IVI*; under a condition without fire, *Pinus pseudostrobus* and *Quercus sideroxyla* are present in most categories; 56 % of pines are distributed in categories of 35 to 55 cm (mature trees), 37 % in categories of 15 to 30 cm (young trees) and the remaining 7 % is in categories ≥ 60 cm (old trees).

In regard to *Quercus sideroxyla*, 77 % of the trees is classified in the categories from 10 to 30 cm and the resting 23 % in the ≥ 35 cm category. It is possible that this situation is generating unfavorable conditions for *Pinus pseudostrobus*, in particular for those pines in the categories between 15 and 30 cm (young trees), from the competence that is having with the oak (Figure 2).

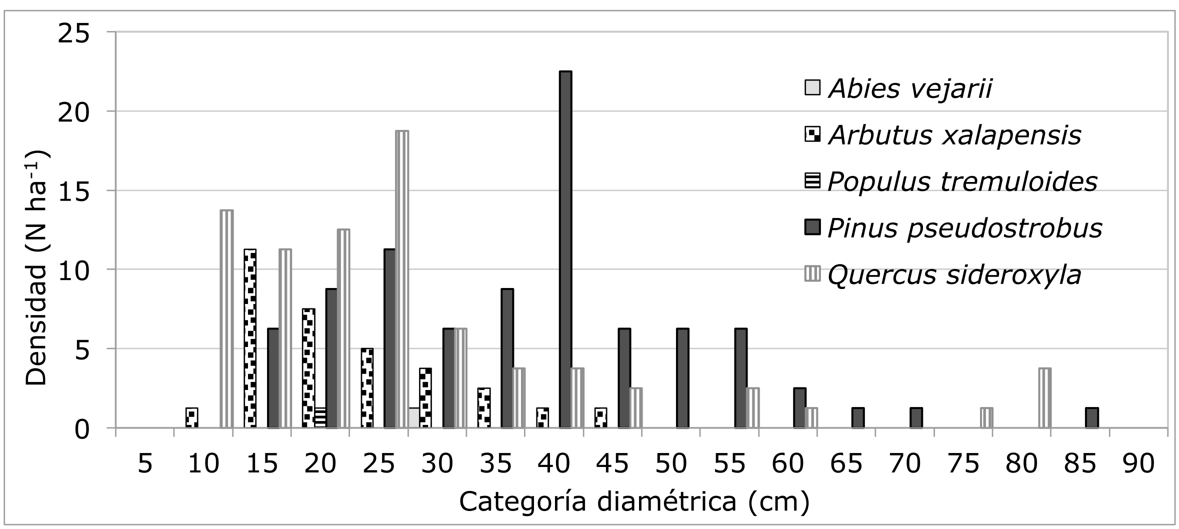

Figure 2. Diametric categorization of the tree species in the not -burnt area.

On the other hand, the data of the zone with fire incidence seem to show that the loss of old trees of the diametric categories ≥ 60 cm and the reduction of the broadleaves is undoubtedly linked to this factor. Such a condition, apparently, favored the development of the softwoods, *Pinus pseudostrobus* and *Abies vejarii,* which are preferably distributed in the lower categories of 40 cm, which suggests a young forest mass (Figure 3).

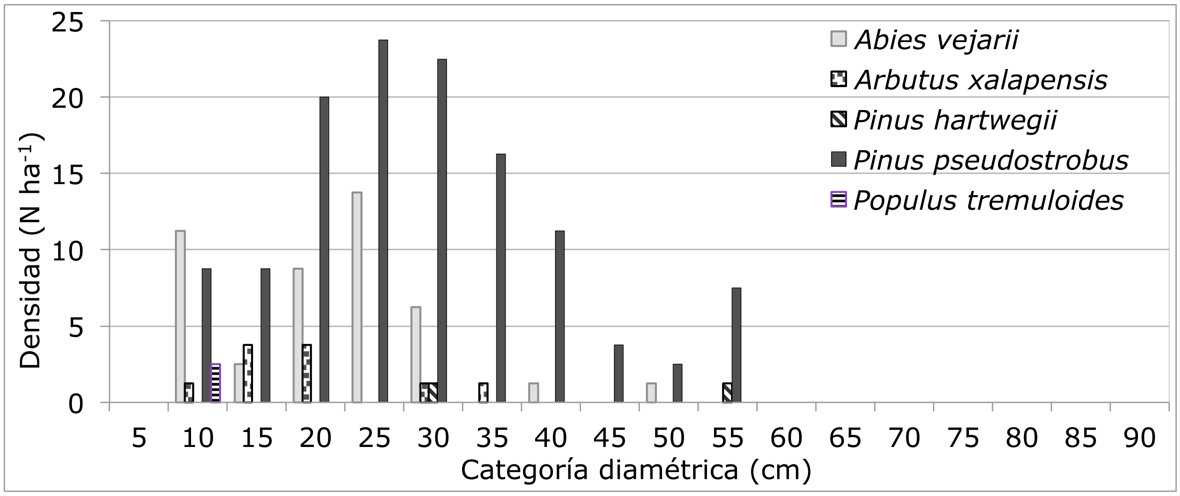

Figure 3. Diametric categorization of the tree species in the burnt area.

In the burned ecosystem, a species richness (D_{Mg} = 0.80) similar to that of the non - burned one (D_{Mg} = 0.78) was recorded; similarly, the species diversity values of the burned area (H'= 0.9) compared to the non-burned area (H' = 1.09) were similar. The results agree with those of Alanís-Rodríguez *et al.* (2008), who found that the values of richness and diversity of tree species of a pine-oak forest not restored after nine years of being impacted by fire increased with respect to a reference and a rehabilitated ecosystem.

Regarding the direct evaluation of the vegetation recovery, statistically the results obtained in the comparison of medians indicated that the floristic structure variables (richness (D_{Mg}) and diversity (H') of species did not present significant statistical differences (P> 0.05), which means that, as predicted in the community characterization, the richness and diversity of species present in both conditions are the same (Table 2).

Table 2. Statistical results of the floristic and horizontal structures.

Variable	Burnt	Not burnt	Value-p[1]
	Floristic structure		
Margalef index (D_{Mg})	0.44 a	0.42 a	0.978
Shannon index (*H´*)	0.53 a	0.57 a	0.697
	Horizontal structure		
Density (N ha^{-1})	188 a	188 a	0.786
Crown area (m^2 ha^{-1})	3 944 a	6 813 b	0.022
Basimetric area (m^2 ha^{-1})	13 a	20 b	0.008

[1] = Value from the Mann-Whitney's U test. Numbers followed by the same letter in each line are statistically equal.

In the horizontal structure, the density values in the burned area were similar to those of the reference area, as they did not show significant statistical differences (p> 0.05) in the comparison of medians (Table 2). In this respect, the values in both conditions approximate those recorded by Jiménez *et al.* (2001) in a mature pine-oak forest ecosystem located in the *Sierra Madre Oriental* in the state of *Nuevo León*, indicating that these densities are typical of such ecosystems in the region.

The recovery in density, according to some authors is attributed to the regeneration of tree species after the fire, exerted by species of vegetative reproduction and the germination of seeds from species adapted to this type of sinister, as some conifers (De las Heras, 2015). The latter disperse their seeds after being stimulated by heat and are favored by competition free spaces, with abundant light and more favorable soil conditions (Godínez *et al.,* 2016).

On the other hand, values of basimetric area and basimetric area in the burned area were lower than those of the reference area, which had significant differences (p <0.05) (Table 2). The reduction in the cup differs from the results of Alanís-Rodríguez *et al.* (2011), who characterized the woody vegetation of a pine-oak forest after 12 years of being impacted by fire, and recorded a canopy cover above those obtained in the actual investigation.

The results of the basimetric area coincide with those of González-Tagle *et al.* (2008), who recognized a reduction of the same in pine-oak stands after eight years of being impacted by fire in relation to non-impacted stands in more than 70 years. The decrease in the values of crown area and basimetric area that still prevail, are attributed to the tree vegetation had a total and partial loss of individuals, in addition to that the woody regeneration after the fire has not yet concluded and still does not reach final dimensions in these criteria.

Conclusions

It was assumed that the pre-fire conditions of the vegetation and that the general environmental processes (meteorological and physiographic for example) that occurred from the fire until the date of measurement were reasonably similar in the burned and in the unburned area and, based on the importance value of the tree species, it can be established that fire was a decisive factor of the differences observed in the composition of this value.

The most representative species in the burned area were *Pinus pseudostrobus* (IVI = 190.1) and *Abies vejarii* (*IVI* = 69.5); These two species are well represented within young categories that became part of the natural regeneration and that had no competition on the part of the adult tree and the leafy species that were before the fire The incidence of fire mainly affected the adult trees and The number of leaf species suffered a significant decrease.

At the community level, the tree vegetation burned apparently presented a recovery in richness (D_{Mg}) and diversity of species (H'). It is concluded that 19 years after the occurrence of the fire, the tree vegetation presents a partial recovery.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

José Israel López Martínez: planning, surveying and analysis of information, writing of the manuscript; Eduardo Javier Treviño Garza: planning, analysis of the information, writing and review of the manuscript; Oscar Alberto Aguirre Calderón: review of the manuscript; Enrique Buendía Rodríguez: analysis of the information and review of the manuscript; Juan Carlos Ramos Reyes: survey and analysis of information.