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Research article

# Efecto de la severidad de incendio en brotes de *Pinus* en Santiago, Nuevo León

# Effect of fire severity on *Pinus* shoots in *Santiago, Nuevo León*

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**Abstract**

The objective of the study was to characterize the trees and shoots of the genus *Pinus* by type of fire severity in *Cumbres de Monterrey* National Park. The fire severity was determined based on the difference in the Normalized Burn Coefficient. 60 circular sampling sites of 400 $m^2$ were established to measure the diameter and height of both trees and shoots. Two types of tree conditions were identified: (1) Living burnt and (2) Charred; the latter comprised the highest number of individuals with shoots. Moderate-high severity recorded more trees with shoots (488 individuals $ha^{-1}$). Of the total number of individuals sampled, 83 % corresponded to the species *Pinus teocote*, and 17 % to *Pinus pseudostrobus*. In the trees that exhibited shoots, the number of shoots per individual was recorded, in a larger quantity, in the low level of one to two shoots in the three severities. Low-severity corresponded to 864 shoots $ha^{-1}$, moderate-low to 626 shoots $ha^{-1}$, and moderate-high, to 994 shoots $ha^{-1}$. As the diameter category increases, the probability of shoot occurrence decreases, as does the height. The ability to sprout could potentially determine the difference between the dominance in an area of pines *versus* other species after a disturbance.

**Key words:** Adaptation, shoot, characterization, *Pinus*, regeneration, fire severity.

**Resumen**

El objetivo del estudio fue caracterizar a los árboles y brotes del género *Pinus* por tipo de severidad de incendio en el Parque Nacional Cumbres de Monterrey. La severidad de incendio se determinó a partir de la diferencia del Coeficiente Normalizado de Quemas. Se establecieron 60 sitios circulares de muestreo de 400 $m^2$, en ellos se midió el diámetro y altura tanto de los árboles como de los brotes. Se identificaron dos tipos de condición del arbolado: (1) Vivos quemados y (2) Carbonizados, estos últimos obtuvieron la cantidad superior de individuos con brote. La severidad moderada alta registró más árboles con brote (488 individuos $ha^{-1}$). Del total de individuos muestreados, 83 % correspondieron a la especie *Pinus teocote* y 17 % a *Pinus pseudostrobus.* En los árboles que presentaron brotes, la cantidad de estos por individuo se registró en mayor proporción en el nivel bajo de uno a dos brotes en las tres severidades. La severidad baja correspondió a 864 brotes $ha^{-1}$, la moderada-baja de 626 brotes $ha^{-1}$ y 994 brotes $ha^{-1}$ en moderada-alta. A medida que la categoría diamétrica aumenta, la probabilidad de aparición de brote disminuye, de igual manera ocurre para la altura. La capacidad de brotar podría significar, potencialmente, la diferencia entre la dominancia en un área de los pinos frente a otras especies después de una perturbación.

**Palabras clave:** Adaptación, brote, caracterización, *Pinus*, regeneración, severidad de incendio.

# Introduction

Anthropogenic activities such as recreation, ecotourism, agriculture, livestock, among others, have led to changes in ecosystems; an example of this is the disturbance generated by the fire regime (Paysen *et al.*, 2000). The fire regime is a mixture of temporal and spatial scenarios that depend on the frequency, intensity, extent, and seasonality of fire, which have a decisive influence on the patterns of ecological succession (Medina, 2007).

Certain types of vegetation throughout history have shown resilience to the presence of forest fires, which has given them adaptive value to the new environmental conditions imposed by the high frequency regime. However, there is also an alteration in species composition and structure that results in a transformation of their original state (González *et al.*, 2007; Alanís-Rodríguez *et al.*, 2012; Carbone *et al.*, 2017).

Certain species of the *Pinus* genus, due to the constant presence of fire, have developed adaptive strategies to cope with it, *e.g.*: thick bark (to protect the cambium), serotinous cones, protected apical buds, and the cespitose or branching stage (Rodríguez-Trejo, 2001).

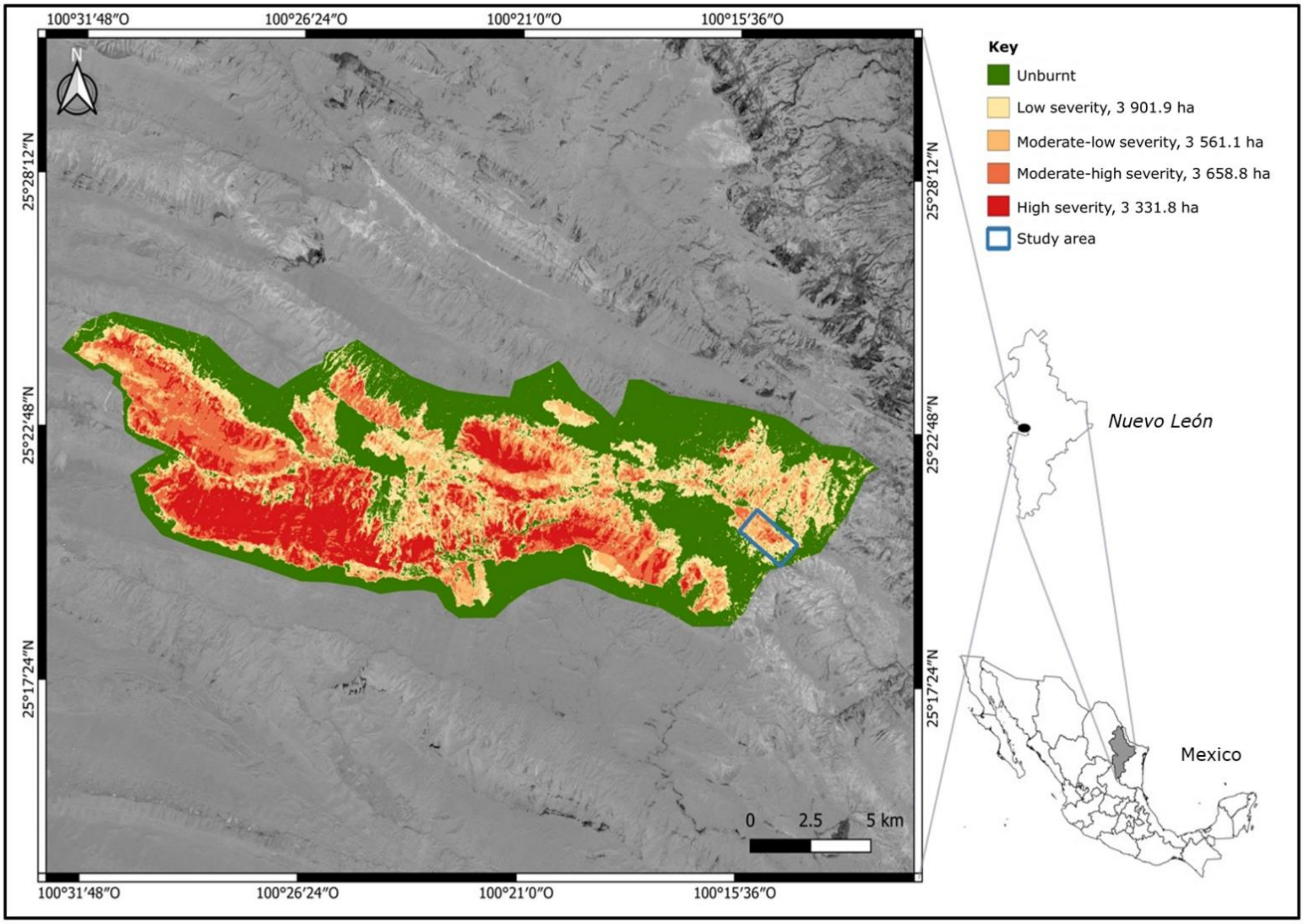
Also, another unusual phenomenon has been observed in response to fire: the appearance of shoots from the base of the stem of affected individuals, which can be perceived as part of an adaptation that favors them in the face of alterations in the fire regime (Pausas *et al.*, 2016). Although this phenomenon is not exclusive of the *Pinus* genus (Juárez *et al.*, 2012; Lilly *et al.*, 2012; García-Jiménez *et al.*, 2017), there are few records for it (Sánchez *et al.*, 2014; Gómez-Mendoza and Rodríguez-

Trejo, 2021). Therefore, the objective was to characterize the trees of the *Pinus* genus and their shoots by type of fire severity under the hypothesis that there are significant differences in shoot density between fire severities.

# Materials and Methods

## Study area

The study was carried out in a fraction of the Eastern *Sierra Madre*, in the *Cumbres de Monterrey* National Park (CMNP), specifically in the community of *El Tejocote* (25°20'38.2" N, 100°14'53.0" W), located west of *Santiago* municipality, *Nuevo León* State. The area is located at an altitude between 2 000 and 2 300 m, with a vegetation consisting mainly of pine-oak forest, where the presence of the following species stands out *Pinus teocote* Schltdl. & Cham., *P. pseudostrobus* Lindl., *P. greggii* Engelm. *ex* Parl., *Quercus canbyi* Trel., *Q. laceyi* Small and *Q. polymorpha* Schltdl. & Cham. The mean annual temperature is 14.1 °C, the maximum values range from 16.8 to 29.8 °C, and the minimum values from 0.8 to 9.4 °C, and the annual precipitation is 766.5 mm, with a maximum of 89.6 mm and a minimum of 13.5 mm (Cuervo-Robayo *et al.*, 2015a; Cuervo-Robayo *et al.*, 2015b). A fire occurred in the CMNP in March 2021 that affected 14 453.60 ha of land (Figure 1).




Source: Prepared by the authors.

**Figure 1.** Location of the study area and surface area affected by the fire by severity type.

## Fire Severity

The fire severity variable was determined by the *dNBR* (differenced Normalized Burn Ratio) index, using the difference between the pre-fire *NBR* (Normalized Burn Ratio) and the post-fire *NBR*: *dNBR*=pre-fire *NBR*-post-fire *NBR* (Valdez-Zavala *et al.*, 2019), in addition to a field record of fire evidence made for the purpose of correct interpretation (Keeley, 2009).

The *NBR* Index is recommended to delimit the polygons of burned areas and to determine their fire severity categorization, based on the near infrared (*NIR*) and shortwave infrared (*SWIR*) bands of the electromagnetic spectrum (Valdez-Zavala *et al.*, 2019). Pre-fire vegetation has a reflectance close to the *NIR* and a low reflectance in the *SWIR*, unlike recently burned sites, which have a low reflectance in the near infrared band and a high reflectance in the shortwave infrared band. Thus, the formula for calculating the *NBR* is as follows (Keeley, 2009):

$$NBR = (NIR - SWIR)/(NIR + SWIR) \qquad (1)$$

Where:

*NBR* = Normalized Burn Ratio

*NIR* = Near infrared

*SWIR* = Shortwave infrared

Sentinel-2 satellite images dated February 28th and March 30th, 2021, were used to obtain the pre-fire and post-fire *NBR*, respectively. Once the *dNBR* was calculated, the fire severity was determined considering as a reference the intervals of the classification proposed by the U. S. Geological Survey (USGS) (Keeley, 2009). The polygon with which we worked is a private property whose owner granted permission for sampling.

## Field sampling

Data were obtained from June to September, 2022, using systematic sampling, with a separation of 100 m between each site (Alanís *et al.*, 2020). Twenty 400 $m^2$ circular sites with a radius of 11.28 m were established by type of severity in order to facilitate data collection, based on the type of vegetation present in the study area (Ramírez *et al.*, 2017), and on the design of the sampling units of the National Forestry and Soil Inventory (*Inventario Nacional Forestal y de Suelos*) (Conafor, 2018).

All standing individuals belonging to the *Pinus* genus were considered; they were assigned a tree number, their species was identified, their height was measured with a Forestry Pro Nikon® hypsometer, and their diameter with a 283D Forestry Suppliers® diameter tape. In the case of individuals with shoots, the number of shoots, shoot height and shoot diameter were also recorded using a pro-Lock FX-5M Truper® measuring tape and a 4˝ Traceable® digital caliper. Some trees had shoots with cespitose or branching growth, therefore, these were considered as a single shoot if they emerged from the same point of origin.

## Structural features

**Trees with shoots.** The percentage of individuals with shoots was calculated for both burned and charred live trees, using the Equation:

$$(Living\ burned\ or\ charred\ trees\ with\ shoots\ /\ Total\ number\ of\ trees) \times 100 \qquad (2)$$

**Categorization of shoots with respect to their number per tree.** Four levels were established: 1. Nil shoot (0 shoots), 2. Low shoot: 1-2 shoots, 3. Medium shoot: 3-4 shoots, and 4. High shoot: +5 shoots.

**Distribution of shoots by diameter category and height class.** In the estimation of the number of shoots per diameter category, 5 cm intervals were established, with an upper limit of 60 cm and a lower limit of 2.5 cm. A frequency table of the number of shoots per height class was prepared, with intervals of 1 m, a lower limit of 1 m and an upper limit of 15 m.

## Data analysis

When the data met the criteria of normality and homoscedasticity, a one-way Analysis of Variance (ANOVA) was performed using the Statistica Advanced software; fire severity was considered as the independent variable, while the number of shoots was the dependent variable. A Spearman correlation test was applied in order to determine the association between shoot occurrence and the diameter category and the height class ($P \leq 0.05$).

# Results

In the analysis of the difference index of the normalized burning coefficient (*dNBR*), three different fire severities were determined: (I) Low, with a surface area of 74.73 ha, (II) Moderate-low, with 91.02 ha, and (III) Moderate-high, with 40.52 ha (Figure 2).

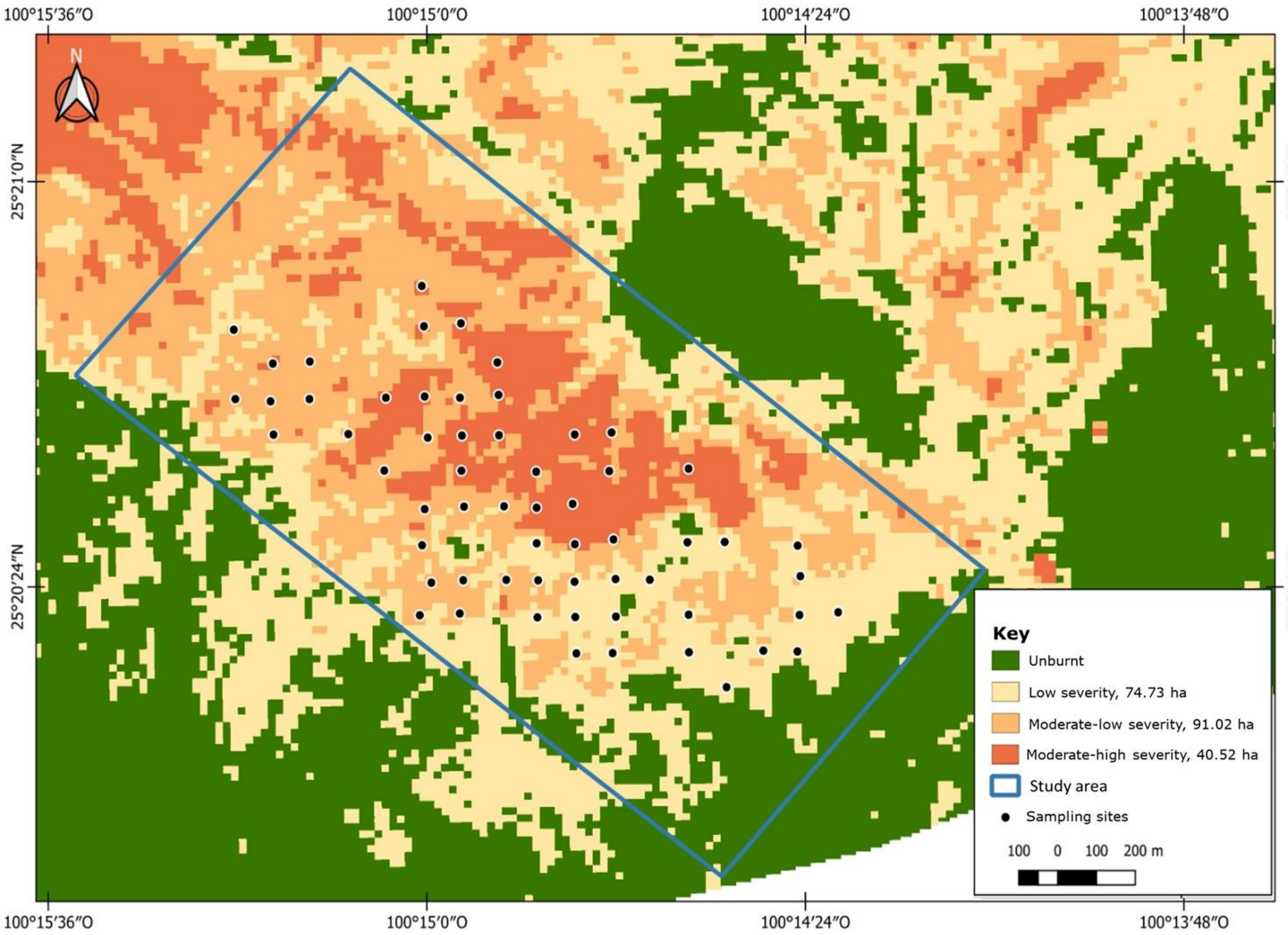



**Figure 2.** Fire severity and estimated surface areas.

The highest number of individuals occurred in the low-fire severity area; 31 % produced shoots. Two types of tree conditions were identified: (1) Living burnt and (2) Charred; the latter resulted in the highest number of individuals with shoots in all three severities. Moderate-high severity recorded more trees with shoots. In the three severity levels, the dominant proportion of trees did not bud (Table 1). Of the total number of individuals sampled, 83 % corresponded to the species *Pinus teocote*, and 17 % to *Pinus pseudostrobus*.

**Table 1.** Number of individuals ($ha^{-1}$) by tree condition and fire severity.

| Condition of the trees | Low | Moderate-low | Moderate-high |
|---|---|---|---|
| Living burnt with shoots | 103 | 78 | 125 |
| Charred with shoots | 280 | 215 | 363 |
| Living burnt without shoots | 333 | 103 | 68 |
| Charred without shoots | 530 | 305 | 498 |
| Total | 1 246 | 701 | 1 054 |

Over 50 % of the individuals in all fire-severity categories had no shoots. In the trees that exhibited shoots, the number of shoots per tree was higher in the low level, from one to two shoots in the three severities. The presence of five or more shoots per tree was the least frequent (Table 2).

**Table 2.** Number of individuals ($ha^{-1}$) by number of shoots and fire severity.

| Level of shoots | Low | | Moderate-low | | Moderate-high | |
|---|---|---|---|---|---|---|
| | Trees | % | Trees | % | Trees | % |
| Nil shoot (0) | 863 | 69 | 408 | 58 | 566 | 53 |
| Low shoot (1-2) | 262 | 21 | 195 | 28 | 327 | 31 |
| Medium shoot (3-4) | 103 | 8 | 88 | 13 | 158 | 15 |
| High shoot (+5) | 18 | 2 | 10 | 1 | 3 | 1 |
| Total | 1 246 | 100 | 701 | 100 | 1 054 | 100 |

The mean values of the mensuration variables of the trees in the moderate-low severity were higher than the others. Shoot height was greater in the moderate-high severity in a range of 8 to 83.1 cm, with an average of 32.3 cm, and the diameter of the shoots ranged between 0.3 and 1.9 cm, with a mean of 1.1 cm. The values were lower in the low-severity areas (Table 3).

**Table 3**. Height and diameter of trees and shoots by fire severity.

| Descriptive measure | | Low | Moderate-low | Moderate-high |
|---|---|---|---|---|
| Tree height (m) | Minimum | 1.4 | 1.2 | 1.1 |
| | Medium | 2.3 | 3.6 | 3.2 |
| | Maximum | 15 | 13 | 14 |
| | *SD* | 1.5 | 2.1 | 1.7 |
| | *SE* | 0.1 | 0.2 | 0.1 |
| Tree diameter (cm) | Minimum | 2.5 | 2.5 | 2.5 |
| | Medium | 4.4 | 7.6 | 6.8 |
| | Maximum | 60 | 43 | 55 |
| | *SD* | 3.7 | 5.5 | 4.9 |
| | *SE* | 0.3 | 0.5 | 0.3 |
| Shoot height (cm) | Minimum | 2 | 2 | 8 |
| | Medium | 28.0 | 31.1 | 32.3 |
| | Maximum | 70.7 | 82.5 | 83.1 |
| | *SD* | 15.1 | 20.1 | 20.3 |
| | *SE* | 1.2 | 1.9 | 1.6 |
| Shoot diameter (cm) | Minimum | 0.3 | 0.3 | 0.3 |
| | Medium | 0.6 | 0.8 | 1.1 |
| | Maximum | 1.8 | 1.9 | 1.9 |
| | *SD* | 0.4 | 0.5 | 0.5 |
| | *SE* | 0.1 | 0.1 | 0.1 |

*SD* = Standard deviation of the mean; *SE* = Standard error of the mean.

In the area with low fire severity, there were 12 diameter categories, the other fire-severity levels had nine. The 5 and 10 cm categories in the low and moderate-low fire severity levels had the largest number of trees, trees with shoots, and shoots; in the moderate-high severity areas, they were observed in the 10 and 5 cm categories. There was a larger number of trees with shoots and shoots in the moderate-high severity areas (Table 4).

**Table 4.** Trees and shoots (individuals ha$^{-1}$) by diameter category (cm) and fire severity.

| Diameter category | Low | | | Moderate-low | | | Moderate-high | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Trees** | **Trees with shoots** | **Shoots** | **Trees** | **Trees with shoots** | **Shoots** | **Trees** | **Trees with shoots** | **Shoots** |
| 5 | 948 | 294 | 613 | 356 | 151 | 318 | 416 | 179 | 360 |
| 10 | 158 | 68 | 188 | 218 | 100 | 233 | 505 | 255 | 515 |
| 15 | 48 | 10 | 45 | 58 | 25 | 53 | 63 | 48 | 113 |
| 20 | 40 | 8 | 13 | 15 | 8 | 8 | 28 | 0 | 0 |
| 25 | 10 | 0 | 0 | 10 | 3 | 8 | 15 | 0 | 0 |
| 30 | 3 | 0 | 0 | 18 | 3 | 3 | 8 | 3 | 3 |
| 35 | 5 | 3 | 5 | 13 | 0 | 0 | 0 | 0 | 0 |
| 40 | 10 | 0 | 0 | 10 | 3 | 3 | 8 | 0 | 0 |
| 45 | 8 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| 50 | 8 | 0 | 0 | 0 | 0 | 0 | 8 | 3 | 3 |
| 55 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| 60 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 1 246 | 383 | 864 | 701 | 293 | 626 | 1 054 | 488 | 994 |

The analysis of variance between the number of shoots in relation to fire severity showed that there is no significant difference ($p>0.05$); therefore, the hypothesis is rejected.

The results of the correlation tests for diameter and height category with respect to the occurrence of shoot break showed a strong significant association ($p<0.05$). The smaller the diameter of the shaft, the higher the probability of sprouting; when the diameter category variable increases, the probability of sprouting decreases.

There were 13 height classes in the low and moderate-low severities, and 14 in the moderate-high. At low severity, the 2 m class had the highest number of trees,

trees with shoots, and shoots; at moderate-high severity, the 3 and 4 m classes had the highest number of trees, trees with shoots, and shoots. The moderate-low severity area exhibited more trees and trees with shoots in the 2 m class; however, the 3 m class was superior in number of shoots (Table 5).

**Table 5.** Trees and shoots (ind. ha$^{-1}$) by height class (m) and fire severity.

| Height class | Low | | | Moderate-low | | | Moderate-high | | |
|---|---|---|---|---|---|---|---|---|---|
| | Trees | Trees with shoots | Shoots | Trees | Trees with shoots | Shoots | Trees | Trees with shoots | Shoots |
| 1 | 187 | 66 | 183 | 115 | 38 | 73 | 71 | 66 | 131 |
| 2 | 653 | 227 | 437 | 173 | 85 | 189 | 178 | 70 | 158 |
| 3 | 208 | 53 | 130 | 153 | 78 | 203 | 338 | 140 | 288 |
| 4 | 80 | 23 | 68 | 80 | 23 | 50 | 218 | 110 | 240 |
| 5 | 10 | 0 | 0 | 58 | 30 | 45 | 125 | 68 | 125 |
| 6 | 23 | 5 | 10 | 38 | 15 | 30 | 60 | 23 | 38 |
| 7 | 13 | 0 | 0 | 20 | 13 | 20 | 10 | 5 | 8 |
| 8 | 18 | 3 | 28 | 5 | 3 | 3 | 20 | 3 | 3 |
| 9 | 18 | 3 | 3 | 10 | 0 | 0 | 10 | 0 | 0 |
| 10 | 8 | 3 | 5 | 25 | 3 | 8 | 5 | 0 | 0 |
| 11 | 5 | 0 | 0 | 13 | 5 | 5 | 5 | 0 | 0 |
| 12 | 13 | 0 | 0 | 8 | 0 | 0 | 3 | 3 | 3 |
| 13 | 0 | 0 | 0 | 3 | 0 | 0 | 8 | 0 | 0 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| 15 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 1 246 | 383 | 864 | 701 | 293 | 626 | 1 054 | 488 | 994 |

# Discussion

Charred trees and the moderate-high fire severity area had the highest presence of shoots; likewise, Gómez-Mendoza and Rodríguez-Trejo (2021) refer that the probability of reshooting shows a direct relationship with the percentage of the crown affected by fire in *Pinus montezumae* Lamb.; González-Rosales and Rodríguez-Trejo (2004) state the opposite for *Pinus hartwegii* Lindl., although the classification of tree condition differed between the three studies.

Of the total population sampled in the three severities of fire, 39 % produced shoots. This percentage is lower than the one cited by Sánchez *et al*. (2014), who assessed the regeneration of *Pinus oocarpa* Schiede *ex* Schltdl. in the *La Primavera* forest, in *Jalisco* State, estimating 83 %. But it is higher than the value indicated by Baumgartner and Fulé (2007) for *Pinus leiophylla* Schiede *ex* Schltdl. & Cham. var. *chihuahuana* (Engelm.) Shaw, of 34 % in the Mogollon Rim, Arizona.

One strategy for tree recovery after a fire is sprouting. Juárez *et al.* (2012) researched this process *Pinus teocote* in *Chignahuapan*, *Puebla* State, and calculated 344 shoots ha$^{-1}$ and five shoots per tree; in this work the densities are higher and the level of sprouting is the least common in the areas.

The average height of the shoots in the three fire severities is less than that determined in *Chiapas* State by Rodríguez *et al.* (2019), which is 40 cm in *Pinus oocarpa* six months after a fire, and then that cited by Clabo and Clatterbuck (2019) for *Pinus echinata* Mill. (73 cm) in Morgan, Tennessee.

Gómez-Mendoza and Rodríguez-Trejo (2021) assessed and modeled the probability of mortality and regrowth in *Pinus montezumae*, *Pinus teocote*, and *Pinus patula* Schltdl. & Cham. nine months after a fire in the *Michac ejido*, *Chignahuapan*, *Puebla*, and they found that younger individuals had greater resprouting power than older ones, similarly to what was observed in the CMNP. The ability to sprout after a fire can vary according to the age of the trees, with older trees of some species producing few shoots (Miller, 2000).

This study supports the observation of Baumgartner and Fulé (2007) for *Pinus leiophylla* var. *chihuahuana* on the Mogollon Rim in Arizona, in the sense that most of the trees that sprouted from the base of the tree were in the 5 cm diameter class, as well as their results for the low and moderate-low severities.

The ability of conifers to sprout in response to disturbances, such as forest fires, can vary in space and time, as was studied as part of the fire ecology of *Pinus hartwegii* in Mexico City (Rodríguez, 1996); the results show that 28 % of trees between 1.3 and 4 m in height have an average of three shoots per tree, and 97 % of trees less than 1.3 m in height have seven shoots per tree. These values coincide with those of the present study, in which the lowest height classes have the highest shoot presence and an even larger number of shoots per tree.

Alanís-Rodríguez *et al.* (2012) assessed the composition and diversity of the natural regeneration in post-fire *Pinus-Quercus* natural communities in the *Chipinque* Ecological Park; they classified *Pinus pseudostrobus* as a non-sprouting species, which contrasts with what was described for the CMNP, where *Pinus* communities exhibited the presence of sprouting as a fire response adaptation.

Growth substances in the roots, particularly cytokinins, assist the sprouting of dormant buds at the base of the tree, though they may already be present in the shoots; however, a decrease in the ratio of auxins to cytokinins provides the stimulus for shoot growth, as the former are inhibitory to sprouting (Miller, 2000).

As a broad generalization, species growing on sites with higher impact or frequent disturbances are likely to sprout more vigorously and retain the ability to sprout longer than species growing on sites with less damage or less frequent disturbances (Del Tredici, 2001).

# Conclusions

*Pinus teocote* and *Pinus pseudostrobus* species exhibit shoots in the three fire severities; the most represented level of shoots is the lower one, of one to two shoots per tree. The area with the highest intensity of disturbance —moderate-high severity— has the highest density of trees with shoots, however, there are no differences between severities. Charred trees are predominant as to the presence of shoots. These develop mainly on individuals of the lowest diameter and height categories.

The ability to sprout as a form of regeneration after a fire is an important adaptive advantage; this ability may potentially determine the difference between the dominance of pines *versus* other species in an area after a disturbance.

Studies are suggested to explain the physiological reasons for sprouting after a fire, as well as what substances and in what proportion are necessary to activate this process because only certain trees of the same species have this capacity.

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## Conflict of interest

The authors declare that they have no conflict of interest.

## Contribution by author

José Israel Yerena-Yamallel: research coordinator, statistical analysis, drafting and revision of the manuscript; Victoria del Pilar García-Ortuño: severity analysis, field data collection, drafting and revision of the manuscript; Luis Gerardo Cuéllar-Rodríguez: data analysis, drafting and revision of the manuscript; Ángel Mario Reyna-González: mapping, severity analysis, field data collection, and revision of the manuscript.

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