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Effect of Fire Severity on the Species Diversity and Structure of a Temperate Forest in Northern Mexico

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Abstract: Forests experience disturbances, such as fire, that affect their functioning, structure, and species composition. The objective of this work was to compare the species diversity and forest structure at sites affected by different degrees of fire severity, 9 years after a forest fire event. We used the differenced Normalized Burn Ratio (dNBR) index. Vegetation was sampled in three severity levels: high (HS), moderate (MS), and low (LS) and included the unburned (U) level as control. In addition, we calculated the species richness (S), the Shannon index (H), and the Evenness Index (E). The structural diversity of tree diameters and heights was measured applying the indices $H$, $E$, and the coefficient of variation ($CV$). The differences in the indices calculated across the fire severity levels were determined through analyses of variance (ANOVA) and Tukey’s multiple comparison tests. The results showed no significant differences ($p \leq 0.05$) in the species diversity indices between fire severity levels. The structural diversity of tree diameters and heights was lower at the HS level. dNBR was negatively related to structural diversity; thus, it is concluded that HS tends to reduce structural variability in terms of diameter, height, and age. These results provide a baseline to understand how fire can modify forest structure and species diversity.

Keywords: dNBR; structural diversity; intermediate disturbance hypothesis (IDH); forest response; tree age structure; fire disturbance

1. Introduction

At the global level, forest ecosystems face increasingly frequent natural and human disturbances. Forest fires are one of the natural disturbances with the greatest impact on the dynamics of these ecosystems [1–3]. Specifically, the functioning of forests and the structure and composition of forest species are largely conditioned by the frequency and severity of fire [4,5]. Climate change projections indicate a trend toward higher severity and frequency of fires [6]. Given this situation, analyzing the response of ecosystems to fire is essential to support natural resource managers in anticipating the effects of future fires and determining better management practices [7,8].

Two approaches can be used to evaluate these responses: descriptive or process-based. The descriptive approach is used to measure the impacts of forest fires and generate a statistical description of the relationships between fire severity and ecosystem response. The process-based approach is based on controlled experimental conditions and studies the process including variables such as fire intensity measurements and ecosystem response variables [9].
In the descriptive approach, fire severity quantifies the ecological effects of a forest fire and the degree of change in ecosystem components [10]. Species diversity and forest structure are important features of a forest ecosystem, and the assessment of these features provides essential elements to analyze forest alteration and response [11].

Several studies have explored the response of ecosystems to fire. Barton and Poulos [12] found that fire and topography were drivers of plant diversity in a site in the southwestern United States. Berkey et al. [13] indicate that succession after a severe fire plays a central role in shaping forest structure. Other studies have identified a decrease in species richness as fire severity increases [14].

In Mexico, it has been found that as the severity of the fire increases, the trees tend to form dimensionally heterogeneous stands [15]. Moderate severity has also been found to favor the highest composition, structure, and diversity of forest ecosystems [16]. In parallel, it has been observed that a fire of moderate severity fosters the natural regeneration of trees and shrub species [17]. These results have been associated with the intermediate disturbance hypothesis, which states that moderate disturbance levels increase local species diversity [18].

The objective of this work was to compare the species diversity and forest structure at sites affected by different degrees of fire severity, 9 years after a forest fire event in a temperate mixed forest in the Sierra Madre Occidental (SMO). This study addresses the following questions: (1) Is there a relationship of vegetation structure and diversity with fire severity? (2) Do vegetation diversity and structure vary across the fire severity gradient? It is also hypothesized that species diversity and structural diversity are higher in areas affected by an intermediate or moderate fire severity.

2. Materials and Methods
2.1. Study Area

The study was carried out in the El Brillante ejido, located in the SMO mountain region within the Pueblo Nuevo municipality, southwest state of Durango, Mexico (23°37′12.97″–23°50′55.76″ N and 105°18′56.23″–105°31′9.84″ W) (Figure 1a). The average altitude is 2480 m a.s.l. and the local climates are semi-cold humid C(E)(m) and temperate subhumid C(w), both with summer rains [19]. The mean annual temperature ranges from 10 °C to 18 °C and the mean annual precipitation is 1000 mm [20]. The dominant soil types in the area are Luvisol and Regosol [20]. The predominant vegetation is mixed-conifer forest (mainly of the genus *Pinus*); in some cases, this vegetation is mixed with broadleaved trees (mainly *Quercus*) [21].

Forest fires in the study area are usually small and of low intensity, affecting mostly herbaceous and shrubby understory vegetation. They do not regularly exceed 100 ha; however, in years with adverse conditions, large fires of mixed severity may occur, which can cause tree mortality. This situation was present in 2012, when an atypical fire occurred, possibly influenced by the dominant dry conditions of the previous year [22]. According to the Comision Nacional Forestal (National Forestry Commission, CONAFOR), the agency that manages fires in Mexico, this fire was classified as mixed severity, affecting an area of near 1300 ha of pine-oak forest.

Through the “Forest Fire Hazard Prediction System of the National Forestry Commission (CONAFOR) of Mexico. Available online: http://forestales.ujed.mx/incendios2/" (accessed on 14 July, 2022)”, historical records of fire in this area were taken into consideration for this study. Some scared trees affected by fire in this area were also considered in this analysis, indicating that the area of influence of the 2012 fire was not burned for at least 14 years before the analyzed fire event and 9 years after the occurrence of this fire.

We determined the fire severity gradient of the 2012 fire using the differenced Normalized Burn Ratio (dNBR) index (Figure 1b), which represents the change in the landscape caused by fire and allows the classification of fire severity into different levels, namely unchanged, low, moderate, and high [23]. The dNBR was calculated from Landsat satellite images on the Google Earth Engine cloud-based platform using the command sequence.
from Parks et al. [24]. This code uses average pre- and post-fire dNBR values (‘composite mean’) over a specified period. Fire severity levels were based on the “United States Geological Survey (USGS) thresholds. Available online: https://un-spider.org/fr/node/10959 (accessed on 14 July, 2022)”, sorted into four severity levels: Unburned (U), Low Severity (LS), Moderate Severity (MS), and High Severity (HS).

Figure 1. (a) Location of El Brillante ejido and the area burned in 2012 in the Sierra Madre Occidental (SMO); (b) fire severity levels calculated through the dNBR and distribution of sampled sites by severity level.

2.2. Data Collection

Based on the dNBR index, the most representative pixels of each severity level were located; then, 40 circular plots with a surface area of 0.10 ha were set following a targeted approach. The distribution consisted of 10 sampling sites by severity level, including the U category, which was used as a control or reference category. Tree vegetation sampling was carried out in June 2021. At each sampling site, all live and dead trees with diameter $\geq 5.0$ cm were recorded; for each, we determined the condition (alive or dead), species, diameter at breast height (DBH in cm), overall height (m), and crown diameter (m). Additionally, using a Pressler increment borer, we obtained tree increment cores of each diameter class (5.0 cm classes) found in the site to determine age. Cores were extracted at a height closest to the ground; the number of rings was adjusted when the increment core did not contain the pith [25]. The regeneration by species was identified and counted the number of individuals per species, including height (cm) and diameter at ground level (cm).

2.3. Species Diversity and Structural Diversity

For each sampling site, we calculated the species richness ($S$), the species diversity through the Shannon index ($H$), and the Evenness Index ($E$). We analyzed the percent similarity in species composition between zones with different fire severity levels. This analysis was carried out by means of a Bray–Curtis dendrogram, which considers species abundances [26].
To measure structural diversity in terms of diameter and height, the indices $H$ and $E$ were applied. In this case, the number of species was replaced by the number of diameter or height-size classes, similar to the approached followed in other studies [11,27,28], which have reported relevant results. In addition, the coefficient of variation (CV) was included (Table 1). All the indices were calculated using the BiodiversityR package in R software (Version 4.1.0, Vienna, Austria) [29].

**Table 1.** Formulas for calculating species diversity and structural diversity indices.

<table>
<thead>
<tr>
<th>Index</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species diversity</td>
<td>$S = NS$</td>
</tr>
<tr>
<td>Shannon Index</td>
<td>$H = - \sum_{i=1}^{NS} n_i \times \ln(n_i)$</td>
</tr>
<tr>
<td>Evenness Index</td>
<td>$E = \frac{H}{\ln(NS)}$</td>
</tr>
<tr>
<td>Structural diversity</td>
<td>$H = - \sum_{j=1}^{NC} n_j \times \ln(n_j)$</td>
</tr>
<tr>
<td>Shannon Index</td>
<td>$E = \frac{H}{\ln(NC)}$</td>
</tr>
<tr>
<td>Evenness Index</td>
<td>$CV = \sqrt{\frac{\sigma^2}{\bar{X}^2}}$</td>
</tr>
</tbody>
</table>

$S =$ Species richness, $H =$ Shannon index, $E =$ Evenness index, $CV =$ Coefficient of variation, $NS =$ total number of species at sampling site, $n_i =$ individual number of the $i$-th species, $n_j =$ individual number of the $j$-th diameter or height class, $NC =$ total number of diameter or height classes or categories, as appropriate (a size-class of 5.0 cm was used for diameter and 1.0 m for height), $X =$ variable of interest (diameter or height).

### 2.4. Tree Age Structure

Increment cores were dated using conventional dendrochronological techniques [30]. The approximate age of each tree was estimated by counting the number of annual rings plus the estimated years taken for the tree to reach 1.3 m in height, adjusting for the missing years when the growth core did not reach the pith [31].

### 2.5. Statistical Analysis

For the statistical analysis, the species diversity and structural diversity indices calculated for each sampling site were tested for normality and homoscedasticity of variances. The differences in species richness, species diversity, and diameter and height structural diversity between fire severity levels were also assessed through one-way analyses of variance (ANOVA). When statistically significant differences were found at a 5% significance level, we conducted Tukey’s multiple comparison tests.

We explored whether fire severity (value of dNBR) and some topographic factors, such as elevation (m), slope (degrees), and slope exposure (degrees), were associated with data on the species diversity and structural diversity indices using a Pearson’s correlation analysis ($r$). Subsequently, those variables that showed a statistically significant correlation at a 5% significance level were included in a linear regression model to determine the relative influence of each factor on the diversity and structure indices. The explanation of the variation of the data in the different relationships explored was interpreted with the coefficient of determination ($R^2$) for each model. All the statistical analyses were performed in the R software [32].

### 3. Results

#### 3.1. Species Diversity

The study recorded 2065 trees belonging to 18 species in five families: **Pinaceae**, **Fagaceae**, **Cupressaceae**, **Ericaceae**, and **Betulaceae**. For $S$, by fire severity level, 15 species were found in U areas, 17 in LS, 13 in MS, and 14 in HS (Table 2).
Table 2. Tree species found by fire severity level.

<table>
<thead>
<tr>
<th>Unburned</th>
<th>Low Severity</th>
<th>Medium Severity</th>
<th>High Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinus cooperi</td>
<td>Pinus cooperi</td>
<td>Pinus cooperi</td>
<td>Pinus cooperi</td>
</tr>
<tr>
<td>Pinus durangensis</td>
<td>Pinus durangensis</td>
<td>Pinus durangensis</td>
<td>Pinus durangensis</td>
</tr>
<tr>
<td>Pinus leiophylla</td>
<td>Pinus leiophylla</td>
<td>Pinus leiophylla</td>
<td>Pinus leiophylla</td>
</tr>
<tr>
<td>Pinus teocote</td>
<td>Pinus teocote</td>
<td>Pinus teocote</td>
<td>Pinus teocote</td>
</tr>
<tr>
<td>Pinus engelmannii</td>
<td>Pinus engelmannii</td>
<td>Pinus engelmannii</td>
<td>Pinus engelmannii</td>
</tr>
<tr>
<td>Pinus lumholtzi</td>
<td>Pinus lumholtzi</td>
<td>Pinus lumholtzi</td>
<td>Pinus lumholtzi</td>
</tr>
<tr>
<td>Pinus strobliformis</td>
<td>Pinus strobliformis</td>
<td>Pinus strobliformis</td>
<td>Pinus strobliformis</td>
</tr>
<tr>
<td>Juniperus depeana</td>
<td>Juniperus depeana</td>
<td>Juniperus depeana</td>
<td>Juniperus depeana</td>
</tr>
<tr>
<td>Quercus sideroxyla</td>
<td>Quercus sideroxyla</td>
<td>Quercus sideroxyla</td>
<td>Quercus sideroxyla</td>
</tr>
<tr>
<td>Quercus urbanii</td>
<td>Quercus urbanii</td>
<td>Quercus urbanii</td>
<td>Quercus urbanii</td>
</tr>
<tr>
<td>Quercus crassifolia</td>
<td>Quercus crassifolia</td>
<td>Quercus crassifolia</td>
<td>Quercus crassifolia</td>
</tr>
<tr>
<td>Quercus rugosa</td>
<td>Quercus rugosa</td>
<td>Quercus rugosa</td>
<td>Quercus rugosa</td>
</tr>
<tr>
<td>Alnus sp.</td>
<td>Alnus sp.</td>
<td>Alnus sp.</td>
<td>Alnus sp.</td>
</tr>
<tr>
<td>Arbutus xalapensis</td>
<td>Arbutus xalapensis</td>
<td>Arbutus xalapensis</td>
<td>Arbutus xalapensis</td>
</tr>
<tr>
<td>Arbutus madrensis</td>
<td>Arbutus madrensis</td>
<td>Arbutus madrensis</td>
<td>Arbutus madrensis</td>
</tr>
</tbody>
</table>

No differences in $S$ were determined across fire severity levels ($F = 2.16, p = 0.110$) (Figure 2a). For species diversity, $H$ (Figure 2b) and $E$ (Figure 2c) values also did not show significant differences across fire severity levels at a 5% significance level ($H: F = 1.54, p = 0.222; E: F = 0.96, p = 0.421$).

![Figure 2](image)

**Figure 2.** Tukey's multiple comparison test of (a) species richness ($S$), (b) Shannon Index ($H$), and (c) Evenness Index ($E$) by fire severity level. Different letters indicate significantly different means ($p < 0.05$); the same letters indicate non-significant differences.

The similarity analysis showed two groups: one, zones affected by LS and U fire, and two, zones affected by MS and HS fires, indicating similarity of species (Figure 3).
3.2. Diameter Structural Diversity

The number of diameter categories (CATD) in the HS level was lower than the number of CATD in the other severity levels ($F = 10.32; p = 0.001$). In the severity levels U, LS, and MS, the number of CATD was not significantly different (Figure 4a).

Similarly, $H$ values for diameter (H-D) showed significant differences across the severity levels ($F = 14.34; p = 0.001$). Particularly, H-D for the HS level was the only structural diversity value that showed significant differences compared to the H-D values of the other fire severity levels. The means of severity levels U, LS, and MS were not statistically different between them (Figure 4b).

The $E$ index for diameter (E-D) (Figure 4c) and the $CV-D$ (Figure 4d) were statistically equivalent across fire severity levels at a 5% significance level ($E-D: F = 2.80, p = 0.054; CV-D: F = 2.66, p = 0.063$).

3.3. Height Structural Diversity

The number of height categories (CATH) was statistically different across severity levels ($F = 3.49; p = 0.026$). The highest number of CATH was observed in the U level and the lowest in the HS level (Figure 5a). The Shannon index for height (H-H) in the HS level was the lowest relative to the other fire severity levels ($F = 21.54; p = 0.000$) (Figure 5b).
the lowest in the HS level (Figure 5a). The Shannon index for height \( (H-H) \), Evenness Index \( (E-H) \), and coefficient of variation for height \( (CV-H) \) by fire severity level. Different letters indicate that means were significantly different \( (p \leq 0.05) \); the same letters indicate non-significant differences.

As regards the \( E \) index for height \( (E-H) \), statistically significant differences \( (F = 5.09; p = 0.005) \) were found across the fire severity levels. The \( E-H \) index values for U and HS were lower than those for the LS and MS levels. However, the \( E-H \) value for the HS fire level was even lower than the value for the U level (Figure 5c). The coefficient of variation for tree height \( (CV-H) \) was not statistically different \( (F = 5.09; p = 0.005) \) across fire severity levels (Figure 5d).

The Tukey’s multiple comparison test only indicated at what fire severity level there is higher or lower structural diversity; however, it did not indicate tree size (height or diameter). A graphical representation of the number of individuals in each diameter class across severity levels showed that most individuals in sites corresponding to HS and U levels belong to the smallest diameter classes \( (i.e., 5.0, 10.0, 15.0, \text{and } 20 \text{ cm}) \) (Figure 6a). The same trend was observed for tree height, that is, most individuals in sites subjected to HS and U fires belong to the smallest height classes (Figure 6b).

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Figure 5. Tukey’s multiple comparison test for (a) number of height categories \( (CATH) \), (b) Shannon index \( (H-H) \), (c) Evenness Index \( (E-H) \), and (d) coefficient of variation for height \( (CV-H) \) by fire severity level. Different letters indicate that means were significantly different \( (p \leq 0.05) \); the same letters indicate non-significant differences.

3.4. Tree Age Structure

In U areas, individuals of all age size-classes were found. Figure 7 displays the distribution of age classes by fire severity level. In areas affected by LS fire, the individuals found correspond to all age categories from 21 years of age (Figure 7b). In MS areas,
individuals were in most age categories from 31 years (Figure 7c). In contrast, in HS areas, most individuals (50%) belong to the youngest age classes (5.0-10.0 years), and the representativeness of individuals in other age size-classes was very low or nil (Figure 7d). The number of age classes in areas affected by HS fire was statistically different from those in the other areas, which were not different from each other at a 5% significance level ($F = 4.60; p = 0.004$).

![Figure 7](image_url)

**Figure 7.** Tree age structure by severity levels (a) unburned areas, (b) areas affected by low fire severity, (c) areas affected by medium or moderate fire severity, and (d) areas affected by high fire severity.

3.5. Correlation and Regression Analysis

The relationships between topographic variables and diversity indices through $r$ were statistically equal at a 5% significance level (Figures S1–S4). However, the relationship between the values of the structural diversity indices $CATD$, $H-D$, $CATH$, $H-H$, $E-H$ and dNBR was statistically different at a 5% significance level. The linear regression analysis between dNBR and structural diversity indices shows that all relationships are negative and statistically different at a 5% significance level (Figure 8).

Species diversity and structural diversity indices of the regeneration stratum were not statistically different across fire severity categories. Additionally, an analysis of the species diversity and structural diversity of regeneration by sprouting showed that there were also no statistically significant differences across fire severity categories.
Figure 8. Scatter plots showing the linear association between (a) CATD and dNBR; (b) H-D and dNBR; (c) CATH and dNBR; (d) H-H and dNBR; and (e) E-H and dNBR.

4. Discussion

Species diversity and structural diversity in a mixed temperate forest affected by different levels of fire severity were analyzed using different indices and fire severity levels. Since understanding fire behavior and the drivers of variability in forest structure and species composition support forest conservation and fire management [33], these results are a baseline for the analysis of forest responses after almost one decade of disturbance.

Although work is currently ongoing in Mexico on the establishment of fire assessment and monitoring protocols, particularly as regards the assessment of fire severity [34], the assessment of long-term ecological impacts is highly relevant, and fire severity thresholds play a central role [35]. Although the aim of the present study was not to assess fire severity “per se”, the preliminary analysis through dNBR was a very helpful tool for characterizing fire severity, particularly because the severity of fire is hard to characterize in the field 9 years after the event. In this sense, Flores-Rodriguez et al. [36] indicate that these indexes can be implemented when direct field assessment is challenging, such as in extensive, inaccessible areas, or when a rapid preliminary diagnosis is required.

4.1. Changes in Species Diversity

Regarding species diversity, it was found that the $S$ values estimated for the study area were similar to the values reported for this region by Domínguez-Gómez et al. [37]. Additionally, the $H$ index for each severity level is within the highest ranges reported for this region [37,38]. Studies at this respect, have found that fire severity modifies species diversity, mainly in the lower strata [12–14,39,40]. The results of this study show that the diversity of tree species did not differ across fire severity levels. This may indicate the adaptation of species to fire and their capacity to regenerate under the ecological conditions produced by fire [41].
4.2. Changes in Structural Diversity

In a forest ecosystem, diversity refers not only to species richness but also to the diversity of sizes of the tree species in it [11]. The assessment of diameters and heights through structural diversity indices allowed the characterization and comparison of the structure at sites affected by different fire severity levels. The most important findings of the present analysis are that \( CATD \) and \( H-D \) are lower in sites affected by HS than in sites under other fire severity levels, which do not differ from each other. In addition, regarding tree height, the \( CATH \), \( H-H \), and \( E-H \) indices were also lower in sites affected by high fire severity. An explanation of these results may be that the high fire severity is associated with higher mortality of the tallest trees, which in this case were more susceptible to high-intensity fires [42], which results in structures of similar size [43].

4.3. Tree Age Structure

The age structure of trees and the processes that shape this structural composition are also highly important for the proper management of forest ecosystems [25]. Age structure is commonly associated with disturbances, since age distribution is the result of tree mortality and the emergence of new cohorts after disturbances [44]. Fire is considered a key disturbance that influences forest age structure [25]. The results of the present study indicated that, similar to the structure of diameter and height, age structure was more uniform in areas affected by HS fire than in areas under other fire severity levels. The above is due to the fact that severe and infrequent fires trigger the replacement of the stand; later, suitable weather conditions favor a synchronous or pulsed establishment of trees with a uniform age structure [45]. In contrast, uneven-aged forests display a pattern of continuous regeneration that may be associated with frequent and slight disturbances such as shallow or low-intensity fires [46,47].

4.4. Implications of a Forest Homogeneous in Sizes and Ages

All our results suggest that the HS fire level did not affect species diversity. However, a lower structural diversity and tree age structure was found in areas affected by HS fires, resulting in homogeneous or even-aged forests. Although HS patches are smaller than patches subjected to the other fire severity levels, the former may produce adverse effects. For example, an even-aged forest is more susceptible to disturbance than an uneven-aged forest. In addition, a reduction in structural diversity may lead to a reduction in productivity, given the positive relationship between these two variables [27,28]. The homogenization of forest structure and species composition can also translate into more extensive and severe fires [43]. Additionally, trees affected by fire, given their stressed condition and loss of vigor, are more susceptible to pests such as bark beetles of the genus Dendroctonus [48].

4.5. Species Diversity-dNBR Relationship

This study also explored the relationship of species diversity and structural diversity indices with topographic variables and dNBR. Unlike other studies that have reported a relationship between species diversity and some biophysical variables [40], no relationship was observed between species diversity and topographic variables in the present study. With regard to the species diversity–fire severity relationship, no relationship was found either. However, the results may vary for different strata of the ecosystem, as reported in various studies. For example, Brodie et al. [49] found that the species richness in the understory increased in parallel with increasing fire severity. For their part, González-de Vega et al. [30] and Flores-Rodriguez et al. [17] indicate that moderate fire severity may foster natural regeneration. However, the relationship between alpha diversity and fire severity in higher vegetation strata is unclear [12]. The inclusion of other variables (i.e., species functional traits), including the adaptation of species to fire, regrowth capacity, and germination, among other physiological characteristics, may add clarity to this relationship [14].
4.6. Structural Diversity–dNBR Relationship

As regards structural diversity, a negative relationship was found between the structural diversity of diameter and height with dNBR. However, structural diversity showed no relationship with topographic variables. Although fire severity is known to strongly affect forest structure [43], biophysical variables also play a central role [13] since the fire severity gradient can be parallel to the altitude-related temperature and humidity gradients [43]. In this case, fire severity appears to be largely related to relief slope.

Finally, an aspect worth noting is the relationship observed between the structural diversity of diameter and height with dNBR since the forest structure variables were measured in 2021, while the dNBR was obtained from Landsat 7 ETM+ images captured in 2012. This fact supports our results on how the severity of fire triggered a change in forest structure in the study area, which has prevailed almost a decade after the disturbance. For example, Berkey et al. [13] suggest that the time elapsed after a fire event is also essential in determining forest structure. Therefore, future studies should explore the long-term effects of fire severity, considering the interannual variability of climate and the years after the fire, which will determine the potential influence of these variables on forest structure. In addition, most of the conifer and broadleaved species of the region are present in our study plots; this favors that the findings of this study could be applied in great part to the mixed-conifer ecosystems present in northern Mexico. This information could also provide knowledge to improve or to develop management strategies for future fires affecting this ecosystem.

5. Conclusions

Fire severity was not related to species diversity, but showed a negative linear relationship with structural diversity and did not influence the variation in species diversity. These results provide answers to our research questions. Structural diversity was different only in areas affected by high fire severity, a finding that differs from the research hypothesis. In this way, a fire of high severity tends to homogenize the forest, making it more prone to disturbance, including fire. These results represent an approximation to the response of forest to fire severity and establish a baseline on how fire shapes forest species diversity and structure in the study region. These findings can inform the development of similar studies in Sierra Madre Occidental. These results also provide valuable information for proper fire management in the study area, where preventive actions to avoid high-severity fires, such as prescribed burning to reduce litter in steep-slope areas, can contribute to the stability of forest communities.

Supplementary Materials: The supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/f13071121/s1, Figure S1: Scatter plots showing the association between tree diversity indices, structural diversity, and dNBR; Figure S2: Scatter plots showing the association between tree diversity indices, structural diversity, and slope (degrees); Figure S3: Scatter plots showing the association between tree diversity indices, structural diversity, and elevation (m); Figure S4: Scatter plots showing the association between tree diversity indices, structural diversity, and aspect (degrees).

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References
2. Sáenz-Ceja, J.E.; Pérez-Salicrup, D.R. The role of fire in the regeneration of conifer forests. Rev. Chapingo Ser. Cienc. For. y del Ambiente 2019, 25, 123–139. [CrossRef]
11. Fernández-García, V.; Marcos, E.; Fulé, P.Z.; Reyes, O.; Santana, V.M.; Calvo, L. Fire regimes shape diversity and traits of vegetation under different climatic conditions. Sci. Total Environ. 2020, 716, 137137. [CrossRef] [PubMed]