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Structure and diversity of trees on post-fire regenerated areas in Sierra de Guerrero, Mexico

Estructura y diversidad de árboles en sitios regenerados post-incendio en la Sierra de Guerrero, México

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Abstract

Background: It is known that forest ecosystems have the capacity to regenerate over time. However, the anthropogenic influence over them arises the question on how different the original ecological conditions are after regeneration.

Question: Do fires and agrochemicals have an influence on tree diversity in the study area?

Studied species/ Data description/ Mathematical model: The structure and diversity data obtained from tree communities on four different areas were evaluated. The evaluated areas were a control area (mature forest without management) and three areas with different managements: reforested area, restored area and fumigated area.

Study site and years of study: The study area was located in the Sierra de Guerrero, Mexico on areas affected by a fire that occurred in 2005. Seven years after the fire, in 2012, the investigation was performed.

Methods: In each selected area a census of all tree species was carried out. The density, dominance, frequency, and importance value index were determined per species. Moreover, the diversity at community level and richness were estimated.

Results: The control area showed highest values of density and dominance. The regenerated and reforested area showed highest values of specific richness and diversity.

Conclusions: The evaluated areas showed significant differences when comparing diversity and structure indexes. It is recommended to implement reforestation actions in areas affected by forest fires.

Keywords: density, dominance, mixed forest, *Pinus radiata*, *Quercus glaucescens*, species richness.

Resumen

Antecedentes: Es conocido que los ecosistemas forestales tienen la capacidad de regenerarse con el tiempo. Sin embargo, la influencia antropogénica hace surgir la pregunta de qué tan diferentes son las condiciones ecológicas originales después de la regeneración.

Preguntas: ¿El fuego y los agroquímicos tienen una influencia en la diversidad arbórea en el área de estudio?

Especie en estudio / Descripción de datos / Modelo matemático: Se analizó la información de estructura y diversidad de comunidades arbóreas en cuatro áreas diferentes. Las áreas evaluadas fueron un área de control (bosque maduro sin manejo) y tres áreas con diferentes manejos: un área reforestada, una restaurada y una fumigada.

Sitio de estudio y fechas: El área de estudio se localizó en Sierra de Guerrero, México, en áreas afectadas por un fuego que ocurrió en 2005. La investigación fue realizada siete años después del incendio forestal durante el 2012.

Métodos: Se realizó un censo de todas las especies arbóreas en cada área seleccionada. Por cada especie se determinaron la densidad, frecuencia y el índice de valor de importancia. También se estimó la diversidad y riqueza de especies por cada área.

Resultados: El área de control mostró los valores de densidad y dominancia más altos. El área regenerada y el área reforestada mostraron los valores más altos en riqueza específica y diversidad de especies.

Conclusiones: Las áreas evaluadas presentaron diferencias significativas al comparar los índices de estructura y diversidad. Es recomendable implementar acciones de reforestación en áreas afectadas por incendios.

Palabras clave: bosque mixto, densidad, dominancia, *Pinus radiata*, *Quercus glaucescens*, riqueza de especies.

The vegetation is organized in biomes and vegetation types that are the result of precipitation and temperature combinations (Walter 1973, Whittaker 1975, Ratnam 2019). However, it is also widely agreed that while those temperature and precipitation combinations define the biomes at major scale, the local state turnover in vegetation types can be driven by differences in topographic and edaphic conditions but most commonly by vegetation disturbances that can result in very different ecosystems within similar climatic conditions (Hoffmann *et al.* 2012, Charles-Dominique *et al.* 2015, Pausas & Dantas 2017, Ratnam 2019).

Among the common causes of vegetation disturbances in Mexico are the forest fires, which are transforming landscapes and ecosystems rapidly due to the increase of man-made fires (Martínez-Hernández & Rodríguez-Trejo 2008, Rodríguez-Trejo & Myers 2010). Also, anthropogenic activities on the transformation of forest land to agricultural fields with the use of fire, which is an ancestry activity in Mexico, especially in Sierra Madre del Sur (Beaty & Taylor 2008, Chávez *et al.* 2016), where, marijuana and poppy crops have caused significant environmental impacts to the natural ecosystems (Medel *et al.* 2015), can be assessed through the structure and diversity of the plant communities affected (Alanís-Rodríguez *et al.* 2008, González-Tagle *et al.* 2008, Rodríguez-Trejo & Myers 2010, Jiménez-Pérez & Alanís-Rodríguez 2011). Until now, there are not studies that explore the effect of fires, landscape conversion and agrochemicals for crop maintenance on the original vegetation conditions (Alanís *et al.* 2008, González-Tagle *et al.* 2008, Rodríguez-Trejo & Myers 2010, Jiménez-Pérez & Alanís-Rodríguez 2011, Viana-Soto *et al.* 2017). Sierra de Guerrero, Mexico, is an ideal place to give answer to our research question: Do fires and agrochemicals have an influence of tree diversity? Therefore, the aim of this study is to evaluate the structure and diversity of post-fire regenerated areas in Sierra de Guerrero, Mexico, contrasting four areas with different conditions: a control area and three regenerated post-fire areas with different treatments (fumigated, reforested and regenerated).

Materials and methods

Study area. The research was carried out in the Sierra Madre del Sur in the municipality of Chilpancingo, Guerrero (Southern Mexico) (Figure 1). The temperature range between 14 to 28 °C and rainfall between 800-2,500 mm. The weather is warm and sub-humid with rains in summer. The soil type is luvisol and regosol, while dominant vegetation is forest with agricultural areas (INEGI 2009). The study area shows a high biological richness and the presence of endemic species (Luna-Vega & Llorente-Bousquets 1993). Preliminary field surveys determined the main vegetation type in the area as *Pinus*-*Quercus* mixed forest. Also, surveys with local people were used to define the common conditions of post-fire regenerated vegetation communities.

Therefore, four areas with different management conditions were chosen: 1) Reforested 2) Fumigated, 3) Regenerated and 4) Control. Excepting the Control area, the reforested, fumigated and regenerated areas showed post-fire plant communities under different management

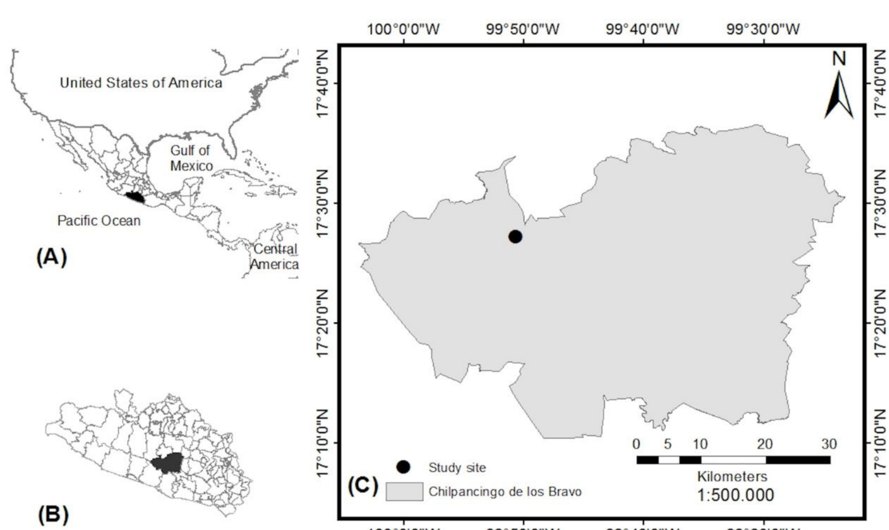

Figure 1. Study area location. A) Mexico, B) Guerrero State, and C) municipality of Chilpancingo.

conditions. All the areas are similar in physiographic characteristics (2,100 m asl slope of 20 %, and northeast exposure; Méndez-Osorio *et al*. 2014).

The forest fires were originated from prescribed burns that went out of control, the fires had an average severity and occurred between April and May (surveys with local people). The reforested area was burned in 2005 but reforested shortly after with *Pinus douglasiana*, Martínez. The fumigated area was burned in 2004 and fumigated with a broad spectrum non-selective herbicide that acts by contact (Rao 2014). The regenerated area presented unassisted natural succession, after a fire burned it down in 2005. The control area presented a mature forest community conformed by no-native vegetation species because it was intensively reforested during the 60s and early 70s with *Pinus radiata* D. Don (Arteaga-Martínez 2000).

Evaluation of the vegetation. The sampling was performed on September of 2012, during the rainy season. Five circular plots of 1,000 m^2 were established for each area, for a total of 20,000 m^2. A census of all the tree species was carried out, recording dendrometric measurements of total height (h), normal diameter (DBH) and crown diameter.

Data Analysis. Relative and absolute values of density, dominance (coverage) and frequency and Importance Value Index (IVI) were determined by each species (Curtis & Mcintosh 1951). Species richness (S) was quantified as the total number of species and the Shannon index and Index of entropy (H´) was calculated for each area (Magurran 2004). The equations used to determine the diversity indexes and ecological indicators of the species are showed in Table 1.

In order to draw conclusions about the differences in diversity and structural variables between areas, we analyzed the data using two different approaches. When the data satisfied the parametric assumptions, we used the analysis of variance ANOVA and, as Post Hoc, the Tukey HSD test. However, when data did not satisfy these assumptions, we employed the non-parametric Kruskal-Wallis with the Wilcox test as Post Hoc approximation (Zar 2010). The statistical analysis where carried out using R (R Core Team 2016).

Results

There were 14 species, 12 genera and 11 families. Families having two species were: Betulaceae, Pinaceae, Fabaceae and Fagaceae (Table 2). *Alnus acuminata* and *Carpinus caroliniana* (both Betulaceae) were only present in the regenerated area, while *Acacia farnesiana* and *Indigofera palmeri* (both Fabaceae) were in the regenerated and fumigated area. *Quercus* was present in all areas with species such as: *Quercus glaucescens* and *Q. uxoris* and Pinaceae was represented by *Pinus radiata* and *P. douglasiana* in the regenerated, reforested and control area.

Absolute and relative density (R_{den}). The control area registered the highest relative density values: 720 ± 15 N ha^{-1} (average ± standard deviation) followed by the reforested area with 626 ± 4 N ha^{-1}, which was different from the other sampled areas (F = 130, df = 3, p < 0.001). The fumigated area showed the lowest relative density (122 ± 12 N ha^{-1}) (Figure 2A). The species with the highest relative density per area were reforested, *Pinus douglasiana* (45.1 %); regenerated, *P. radiata* (52.6 %); fumigated, *Wigandia urens* (54.1 %) and control: *P. radiata* (42.8 %; Table 2).

Absolute and relative dominance (R_{dom}). The contrast of means allows us to detect differences between sampling areas. Regardless of species, the higher canopy cover per area was observed in the control above all the areas (F = 36.7, df = 3, p < 0.001); however, other contrasts showed no significant differences. The control area showed a higher canopy coverage of 8,018 ± 536 m^2 ha^{-1} while the fumigated area showed the lowest (86 ± 30 m^2 ha^{-1}). The canopy coverage value per dominant species were as follows: *P. douglasiana*: 49.5 % in the reforested area; *P. radiata*: 56.7% in the regenerated area, *W. urens*: 73.2 % in the fumigated area, while in the control area the dominant *P. radiata* showed 49.6 % of canopy coverage (Table 2).

Species richness (S). In order to make contrasts, the species richness (S) was computed by area, which allows to compute means, medians and standard errors for each area. Significant differences were found through the Kruskal-Wallis test (χ^2 = 13.4, df = 3, p = 0.003). The fumigated area showed the lowest average specific richness: 4 ± 1 species (average number of species ± standard deviation), however, significant differences were found in the reforested area (p = 0.016) with the highest number of species (6 ± 1) and in the control area (p < 0.008), (Figure 2C).

Shannon index (H'). Shannon index values showed the same trend as the species richness, registering significant differences (F = 7.37, df = 3, p = 0.002). The index of entropy showed significant differences (F = 7.97, df = 3, p = 0.002) (Figure 3). The area with the highest values of H' was the reforested with H' = 1.46 ± 0.15, which corresponds to 4 equally common species (exp$^{H'}$), followed by the regenerated area (H' = 1.11 ± 0.29) which corresponds to

Table 1. Equations used to determine indexes and ecological indicators for each species.

Equation	**Where:**
Absolute density (A_{den}) and relative density (R_{den})	
$A_{den} = \frac{N_1}{S}$	A_{den} = Absolute density
	R_{den} = Relative density per species
$R_{den} = \left(\frac{A_{den}}{\sum j = 1 A_{den}}\right)*100$	N_i = number of individuals of species *i*
	S = sampling area (ha)
	Source: Curtis & Mcintosh (1951)
Absolute dominance (A_{dom}) and relative dominance (R_{dom})	
$A_{dom} = \frac{B_a}{S}$	A_{dom} = absolute dominance
	R_{dom} = relative dominance of species *i* respecting the total dominance
$R_{dom} = \left(\frac{A_{dom}}{\sum j = 1 A_{dom}}\right)*100$	B_a = basal area of species *i*
	S = sampling area (ha)
	Source: Curtis & Mcintosh (1951)
Absolute frequency (A_{fre}) and relative frequency (R_{fre})	
$A_{fre} = \frac{P_i}{NS}$	A_{fre} = absolute frequency
	R_{fre} = relative frequency of the species i respecting the total frequency
$R_{fre} = \left(\frac{A_{fre}}{\sum j = 1 A_{fre}}\right)*100$	P_i = area number in where the species *i* is present
	NS = total number of sampling areas
	Source: Curtis & Mcintosh (1951)
Importance value index (*IVI*)	
$IVI = \frac{R_{den} + R_{dom} + R_{fre}}{3}$	IVI = importance value index
	R_{den} = relative density per species respecting the total density
	R_{dom} = relative dominance of species i respecting the total dominance
	R_{fre} = relative frequency of the species i respecting the total frequency
	Source: Curtis & Mcintosh (1951)
Shannon index (H') and index of entropy (^1D)	
$H' = \sum_{i=1}^{S} p_i * \ln(p_i)$	H' = Shannon index
$p_i = {n_i}/{N}$	S = number of species
$^1D = exp^{(H')}$	N = total number of individuals
	n_i = number of individuals of species i
	^1D = Index of entropy
	exp = exponential
	Source: Magurran (2004) & Jost (2006)

Table 2. Ecological relative parameters of density, dominance, frequency and Importance Index Value of the species founded in the study area.

Family	Scientific name	Fumigated area				Regenerated area				Reforested area				Control area			
		R_{den}	R_{dom}	Rf_r	*IVI*	R_{den}	R_{dom}	Rf_r	*IVI*	R_{den}	R_{dom}	Rf_r	*IVI*	R_{den}	R_{dom}	Rf_r	*IVI*
Betulaceae	*Alnus acuminata* subsp. *arguta* (Schltdl.) Furlow					6	2	15	8								
Betulaceae	*Carpinus caroliniana*					6	2	15	8								
Clethraceae	*Clethra mexicana* DC.	7	7	8	7												
Dilleniaceae	*Curatella americana* L.									4	7	15	8				
Ericaceae	*Arbutus xalapensis* Kunth													41	2	29	24
Fabaceae	*Indigofera palmeri* S. Watson	24	9	31	21												
Fabaceae	*Acacia farnesiana* (L.) Willd.					9	9	20	13								
Fagaceae	*Quercus glaucescens* Bonpl.	15	11	23	17	26	30	25	26					12	44	29	28
Fagaceae	*Quercus uxoris* McVaugh									8	3	17	10	5	4	13	7
Hydrophyllaceae	*Wigandia urens* (Ruiz & Pav.) Kunth	54	73	38	55												
Malphigiaceae	*Byrsonima crassifolia* (L.) Kunth									18	6	17	13				
Melastomataceae	*Conostegia xalapensis* (Bonpl.) D. Don ex DC.									15	3	17	12				
Pinaceae	**Pinus radiata* D. Don					53	57	25	45	11	31	17	20	42	50	29	41
Pinaceae	**Pinus douglasiana* Martínez									44	50	17	37				
	∑ =	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

R_{den}= Relative density, R_{dom} = Relative dominance, Relative frequency = R_{fre}, IVI = Importance value index, * = introduced species.

3 equally common species (exp$^{H'}$), and the control area (H' = 1.06 ± 0.18), which corresponds to 3 equally common species (exp$^{H'}$). The fumigated area had the lowest value of diversity with H' = 0.70 ± 0.34 (Figure 2D), which corresponds to 2 equally common species (exp$^{H'}$).

Relative frequency (R_{fre}). In the reforested area, the species with highest relative frequency were: *P. radiata*, *P. douglasiana*, *Q. uxoris*, *Byrsonima crassifolia* Kunth and *Conostegia xalapensis* D. Don with 17 % each. In the regenerated area: *Pinus. radiata* and *Quercus glaucescens* Bonpl, both species represented 25 % and in the fumigated area *W. urens* represented 38.5 %. In the control area the highest relative frequency was represented by three species, *Q. glaucescens, P. radiata* and *Arbutus xalapensis* Kunth 29.4 % (Table 2).

Importance Value Index (IVI). Pinus radiata and *Q. glaucescens* were the species with highest IVI (Table 2), these species were recorded in three of the four analyzed areas. *Pinus radiata* presented the highest IVI values in the regenerated (45 %) and control areas (41 %), and the second in the reforested area (20 %). *Quercus glaucescens* was the second species with the highest IVI in the regenerated (26 %) and control areas (28 %), and the third species with the highest importance value index in the fumigated area (17 %). In the reforested area, the species with the highest importance value index was *P. douglasiana* (37%) (Table 2).

Discussion

Alnus acuminata and *Carpinus caroliniana* belonging to Betulaceae were found only in the regenerated area. Those species are usually present in secondary successional stages of Pine forest and Pine-Oak forests, this can be explained as a direct consequence of the forest destruction and habitat fragmentation (CONAFOR 2020, Luna-Vega 2003). *Acacia farnesiana* that was also in the regenerated area is often occurring in disturbed areas as an important element of secondary vegetation (CONABIO 2020). The Fagaceae and Pinaceae families were the most representative in this study, which is similar to previous studies conducted in mixed forests under different conditions in Mexico (Alanís *et al.* 2012, Almazán-Núñez *et al.* 2016, Graciano-Ávila *et al.* 2017).

The statistical difference between the relative density in

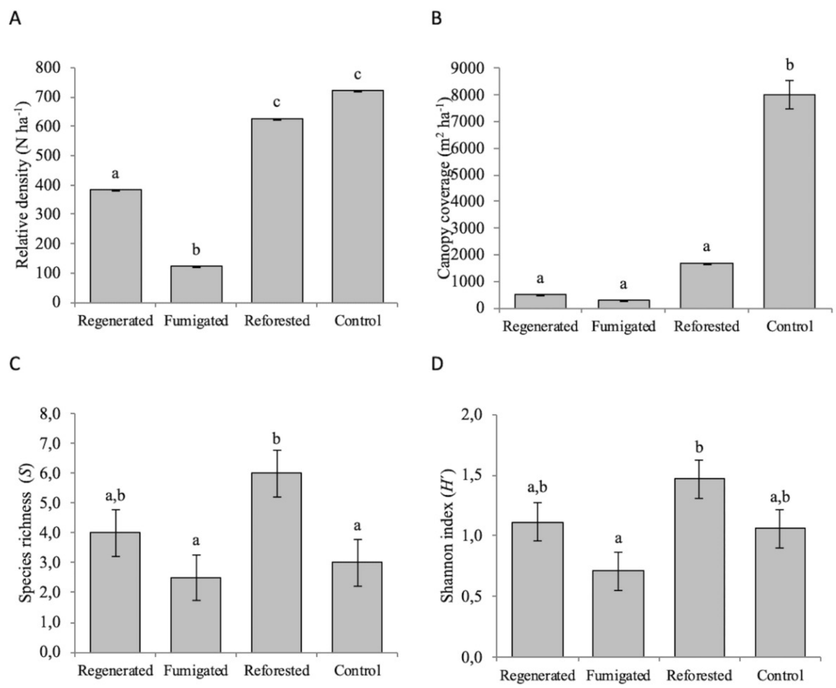

Figure 2. A) Relative density (N ha^{-1}), B) canopy coverage (m^2 ha^{-1}), C) Species richness (S), and D) Shannon index (H'). Average and standard deviation values for each evaluated area was showed. Different letters indicate significant differences (Tukey, $p < 0.05$).

the regenerated and fumigated areas could indicate that the fumigation process affected the development of individuals in the area after the fire. No differences were detected for the reforested and control areas, which is similar to what was found by Almazán-Núñez *et al.* (2016), who evaluated a secondary mixed Pine-Oak forest in the Sierra Madre del Sur at different successional stages. Relative density in post-fire environment species adaptation plays an important role, such is the case of *Pinus douglasiana* that showed the highest number of individuals (which is expected because *P. douglasiana* was used for reforestation of the area). This species has the capacity to grow with success in post-fire environments because it requires abundant light when growing (CONAFOR 2018a).

The forest fires promote the dehiscence of the cones of *P. radiata* individuals, allowing the dispersal of seeds (Vallejo *et al.* 2012). Also, some factors that could be influencing individuals of *P. radiata* include orientation (northeast) and slope conditions (CONAFOR 2018b) variables that could be included in further studies. Regarding the adaptation of individuals to the fumigated area we observed that *W. urens* could be important to agrochemical treatments since it was a species with high density despite being in a highly disturbed area (Nash 1979, Vibrans 2009). The effect of the forest fire on the canopy coverage is significant since all the areas were compared to the control area, which showed the highest canopy coverage. Previous studies such as Almazán-Núñez *et al.* (2016), reported the highest canopy coverage on a mature mixed forest.

The results regarding richness and diversity of species of this study were similar to some previous studies where it was found that fire do not affect trees diversity and on the contrary enhance species number in some cases, being considered as a significant evolutionary force (Keeley *et al.* 2011, Gallegos-Rodríguez *et al.* 2014, Hedo *et al.* 2015, Pereira *et al.* 2016, Foster *et al.* 2017). The diversity of the fumigated area was similar to the control area but lower to the other areas. The influence of fire and fumigation was negative for plant community restoration, resulting on a lower value of richness and diversity of species for the fumigated area (Figure 2). The frequency was different in species, where *W. urens* was the most frequent. Rubio-Camacho *et al.* (2016) found this species in an area with evidence of fire but without concluding any relation. This opens the opportunity to further research regarding post-fire and species adaptation.

The importance value index of species of *Q. glaucescens* was second highest in this study for all areas; however, it was reported by Alanís-Rodríguez *et al.* (2012) and Rubio-Camacho *et al.* (2016) as the highest on post-fire studies; proving that *Quercus* species have a high cope capacity to fire. The species of *Quercus* have an evolutionary strategy to re-sprout; thus, individuals of this species are present in the burned area (Pausas 2004, Encina-Domínguez *et al.* 2009, Alanís-Rodríguez *et al.* 2012).

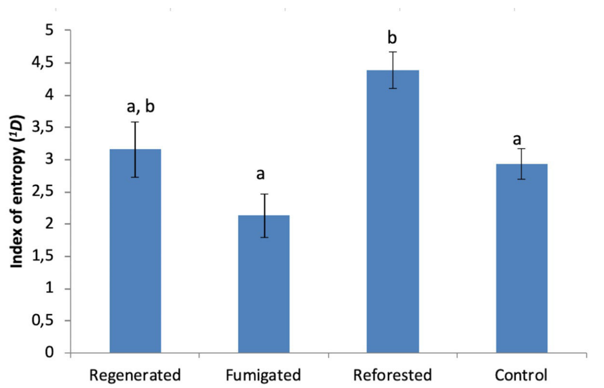

Figure 3. Index of entropy in the four areas post-fire regenerated in the Sierra de Guerrero, México. Different letters indicate significant differences (Tukey, $p < 0.05$).

As general conclusions, we found that the highest IVI on *Pinus* and *Quercus* genera, which indicated fire resilience on *P. radiata*, *P. douglasiana*, *Q. glaucescens* and *Q. uxoris* species. However, the area where the agrochemicals were used showed the lowest values of abundance, dominance, species richness and measured indexes. This suggests that fire associated with fumigation activities on plant communities affects significantly the structure and diversity of entire areas. Further studies on post-fire areas under different treatments are encouraged to increase the knowledge of the restoration of plant communities.

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