

## Article

# Changes in Structure and Diversity of Woody Plants in a Secondary Mixed Pine-Oak Forest in the Sierra Madre del Sur of Mexico

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Academic Editors: Mark S. Ashton and Timothy A. Martin

Received: 29 February 2016; Accepted: 15 April 2016; Published: 22 April 2016

**Abstract:** The biotic province of the Sierra Madre del Sur presents a mosaic of woodlands at different successional stages due to frequent modifications in land use. In this study, we analyzed changes in woody flora across three successional stages of pine-oak forest: early, intermediate, and mature. Vegetation composition and diversity were characterized in 10 plots (each 0.28 ha). The mature stage had the highest values for species richness, abundance, and diversity. Pioneer plants were dominant in the early-successional site and may promote the establishment of late-successional species. The vegetation structure was more complex in the mature stage, where members of the *Quercus* genus were co-dominant with *Pinus* species. Pine tree richness was highest in the early-successional stage, and its abundance increased at the intermediate-successional site. These results suggest that *Pinus* species can grow in perturbed and sunny environments but also require favorable edaphic and microclimatic conditions, such as those found in intermediate woodlands. Results of this fieldwork support the initial floristic composition succession model, which suggests that species present at early stages will also occur in subsequent stages. Ecological succession may be considered to be a natural restoration process, and thus, conservation strategies should focus on maintaining distinct successional communities in addition to mature forests in order to preserve a high number of species.

**Keywords:** pine-oak woodland; initial floristic composition; successional stage; abiotic factors; biotic province

## 1. Introduction

Although pine-oak woodlands provide environmental goods and services, such as the conservation of biological diversity, carbon sequestration, and the regulation of climate and hydrological cycles [1–3], in Mexico and other parts of the world these forests have undergone anthropogenic modifications due to agriculture [4] and overharvesting [5,6]. Furthermore, temperate forests are susceptible to fires, landslides, and storms [7–9]. Currently, many of these landscapes are characterized by secondary pine-oak forest intermixed with scrublands, grasslands, and farmlands [10],

in addition to small areas of mature pine-oak woodland that have been preserved due to their location along steep slopes or in abrupt canyons [7,11].

In addition to soil, climate, and biotic factors, such as competition and seed dispersal, the type of disturbance (frequency, intensity, and duration) may also explain patterns of species diversity across successional gradients [12–15]. In particular, seed dispersal and seedling recruitment determine the spatial distribution of adult trees in a forest community [16,17]. In contrast to tropical dry forests, the successional dynamics and natural regeneration of temperate pine-oak forests are less influenced by climatic seasonality [18,19]. Additionally, disturbed forests have an open canopy that leads to less fertile soils due to a lower incorporation of organic matter [1]. Also, this open canopy may promote variations in understory temperature and humidity [20]. These changes can limit the regeneration of many tree species [6,21]. Furthermore, the presence of dominant *Pinus* (pine) and *Quercus* (oak) species may strongly influence seedling recruitment rates, including those of other tree species [22]. For example, in sites with slightly open overstories where *Pinus* spp. are dominant, the growth of *Quercus* and various ligneous species increases due to the favorable effect of intermediate shade on seedlings and juveniles of these species [9,23,24]. On the other hand, pine regeneration diminishes under closed canopies, especially in oak-dominated landscapes [7,25]. In fact, most pine species tolerate direct solar radiation and grow in disturbed sites, and are therefore commonly considered to be pioneer species in temperate forests [26].

Environmental modifications in forested areas resulting from human activities can critically influence the early recruitment of species and have an impact on forest composition, structure, and dynamics [27,28]. Studies on plant succession in temperate environments have mainly focused on the role of fires (post-fire) in the natural dynamics of these ecosystems [26,29–33]. However, studies on the secondary succession of temperate woodlands have received little attention in comparison to dry or humid tropical environments.

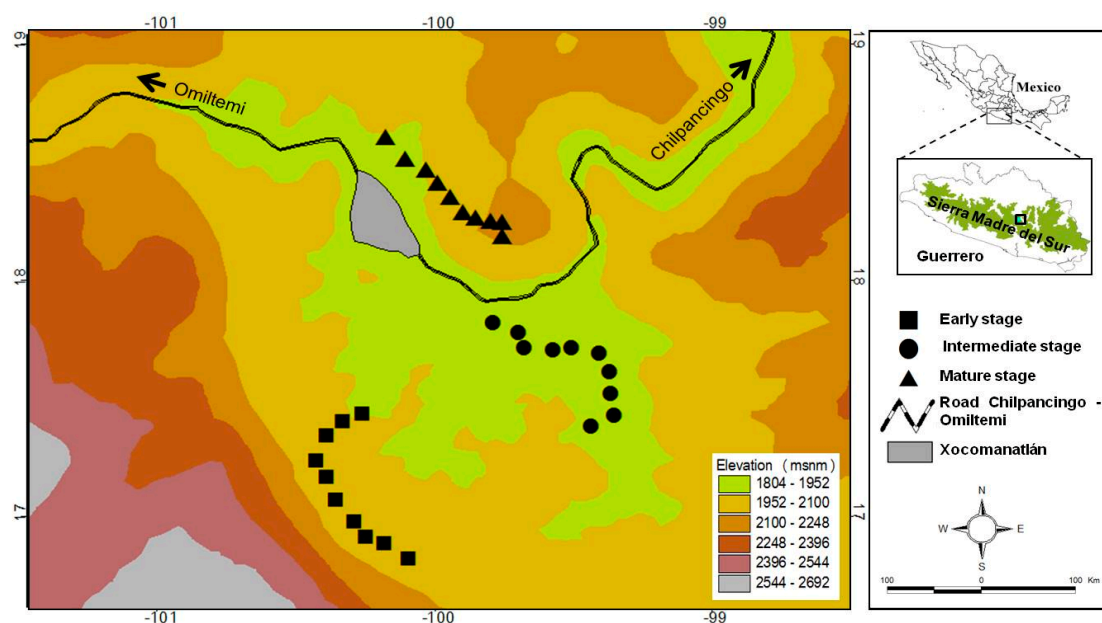
The biotic province of Sierra Madre del Sur, Guerrero, has been over-exploited due to a high demand for timber and other forest resources. This, together with agricultural activities has resulted in frequent changes in land use [34]. These changes in land use have resulted in a patchy landscape represented by various successional stages. In this study, we analyzed the changes in composition, diversity, and structure of woody flora along a successional gradient in a mixed pine-oak forest. Since soil nutrients are limited in early successional stages, the rates of photosynthesis in *Pinus* and *Quercus* are therefore also affected [7,35,36]. Thus, we tested the following hypotheses: (1) Woody species will have a less complex structure (*i.e.*, foliage cover, foliage height diversity, relative importance value) in the initial successional stage in comparison to the intermediate and mature stages, as well as lower species richness and diversity; (2) Since succession depends on the seeds remaining in the soil after a disturbance [37], the composition of the plant communities will only vary slightly among stages without a total replacement of one community by another [38]. As *Pinus* spp. grow in open environments and the development of seedlings is dependent upon light penetration to the ground level, the relative foliage cover of pines will be higher in early successional stages. Accordingly, the relative pine cover will be lower in the mature stage. Also in the first seral stage we expected more anemochorous pioneer species; (3) The growth of oaks will be favored by habitats with closed canopies, since many oak species require fertile soils with high humidity that are developed under this type of habitat.

## 2. Materials and Methods

### 2.1. Study Area

This study was carried out in the locality of Xocomanatlán in the biotic province of the Sierra Madre del Sur, located in the state of Guerrero between 17°33′20.67″N and 17°31′29.81″N and 99°41′02.25″W and 99°38′15.59″W (Figure 1) at ~1900 m above sea level. The region is characterized by a diverse and rugged topography [39]. The prevailing climate, according to the Köppen

classification [40], is temperate sub-humid. Soils are predominantly luvisol and limestone. All the study area consists of conifers and broadleaf forests.



**Figure 1.** Study area and sampling plots in a temperate pine-oak forest of the Sierra Madre del Sur, Guerrero, Mexico.

## 2.2. Sample Sites

Three sites of pine-oak forest in distinct successional stages were selected: early (last disturbance *ca.* five years ago), intermediate (last disturbance *ca.* 20 years ago) and mature (last disturbance *ca.* 40 years ago). Due to the topography (inclination  $>45^\circ$ ) and rocky substrate of the mature site, agricultural activities on a large scale have been impeded, although tenants have partially cut trees to obtain forest goods. However, the site continues to maintain elements of the original flora. The early and intermediate successional sites were cleared by the traditional slash and burn method to plant corn and, to a lesser extent, peach, pear, apple, and hawthorn (*tejocote* in Spanish) orchards. The dates of the last major disturbance and type of management at each site were obtained from informal interviews with farmers.

## 2.3. Vegetation Sampling

At each selected site, we randomly delimited 10 plots of 0.28 ha (Figure 1). Within each plot, we traced two perpendicular lines with a rope, oriented to the four cardinal points. The taxonomic identity of all trees and shrubs with branches intersecting the rope and a diameter at breast height (DBH)  $\geq 10$  cm was determined. Foliage cover for each of these plants was estimated with the ellipse formula, using the length of the maximum and minimum diameters [41]. Foliage stratification was estimated by an optical square marked with two perpendicular axes [42]. The square has three mirrors arranged so that upon looking horizontally through the device, the height of objects above may be assessed. In each plot, we recorded foliage height and the number of times that foliage touched the point of intersection of the two axes. This procedure was repeated every 50 cm along the two transects, representing a total of 60 observational data points [19]. Foliage heights were estimated with the electronic clinometer Hagl f HEC and were grouped at 1 m intervals.

The determination of plants was accomplished by consulting botanical specimen collections, and plants were deposited at the Herbarium of the Chemistry and Biological Sciences Academic Unit of the Autonomous University of Guerrero. The list of species present in the study area follows the

family classification of Stevens [43], and the genera and species nomenclature was assigned according to the database of the Missouri Botanical Garden [44].

#### 2.4. Statistical Analysis

For each successional stage, we used a non-parametric richness estimator, Chao 2, to evaluate the efficiency of the sampling effort. It has been shown that this estimator allows for reliable approximations when using sample units of a relatively small size (*i.e.*, circular plots) [45,46]. These analyses were performed with the software EstimateS, version 8.0 [47].

We used the Shannon-Wiener index ( $H'$ ) to calculate species diversity, the Pielou index ( $J$ ) to determine evenness, and the Simpson index ( $D$ ) to measure dominance [48]. For the analysis of vegetation structure, the following values were calculated for dominant plant species at each site: relative density (proportion of the number of individuals of a species to the total sampled area), frequency (proportion of the number of plots with species presence to the total number of plots per site), and foliage cover (obtained with two perpendicular diameters of the plant canopy) [41]. From these three measurements, we obtained the relative importance value (RIV) for each plant species. In addition, we evaluated the diversity in foliage height using the Shannon-Wiener index, where values were recorded along 1 m intervals of the transects. To compare the mean diversity indices between successional stages, we applied an analysis of variance (one-way ANOVA). Similarly, plant cover, density, and diversity of foliage were compared among sites using one-way ANOVAs, following a prior analysis of normality and homoscedasticity. Comparisons were analyzed *a posteriori* with the HSD (honest significant difference Tukey test).

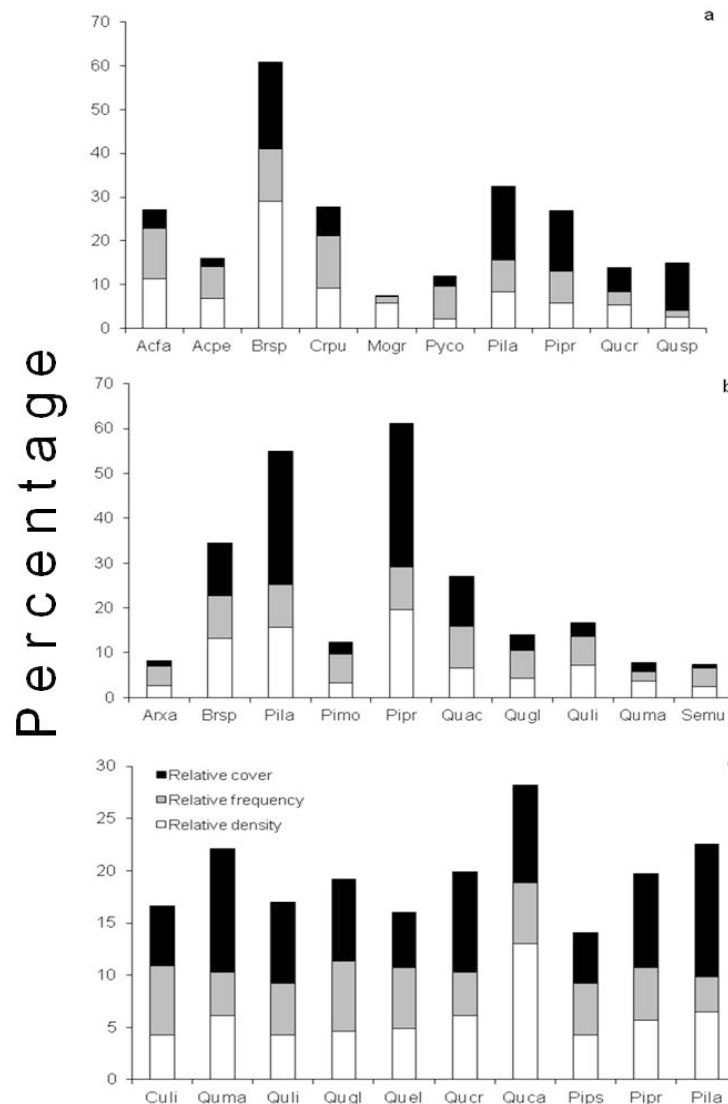
A classification of sample plots was performed using the unweighted pair-group average method (UPGMA) with the Bray-Curtis coefficient as a measure of dissimilarity, based on the values of relative importance for each plant species. This analysis was performed using the multivariate statistical package MVSP 3.13r [49]. To ascertain if the groups resulting from the classification differed statistically, we conducted a discriminant function analysis using the Wilks' Lambda criterion ( $\lambda$ ), which gives values ranging from 0 (groups differ significantly) to 1 (groups do not differ). Also, an arrangement of sample plots was performed with a non-metric multidimensional scaling (NMDS). This method graphically shows similarities in the composition and abundance of species among sampling plots. The distance between points indicates the degree of similarity. We used NMDS because it is not based on any assumptions of data distribution [50]. Kruskal's stress [51] was calculated to determine fit, resulting in values ranging from 0 (perfect fit) to 0.20 (bad fit). Also, we performed a one-way analysis of similarity (ANOSIM), which is a permutational non-parametric test that operates on similarities matrices [52]; in this case, we used the Bray-Curtis distance coefficients.

### 3. Results

#### 3.1. Floristic Composition

We recorded 892 individuals in the three successional stages, corresponding to 19 shrub species and 34 tree species belonging to 20 families (Table A1). The family with the highest number of species was Fagaceae (10 species), followed by Fabaceae (eight), Pinaceae (five), and Compositae and Rosaceae with four species each (Table A1). These families represented 59.6% of the total species present in the study sites, while the remaining families had three or fewer species (see Table A1).

The highest RIV in the early stage corresponded to *Brickellia* spp., *Pinus lawsonii* Roetzl ex Gordon., *Acacia farnesiana* (L.) Willd., *Pinus pringlei* Shaw., and *Crataegus pubescens* (C. Presl) C. Presl (Figure 2A) and in the intermediate stage to *Pinus pringlei*, *P. lawsonii*, *Brickellia* spp., *Quercus acutifolia* Née., and *Q. liebmannii* Oerst. ex Trel. (Figure 2B). In the mature stage, *Quercus candicans* Née., *Pinus lawsonii*, *Quercus magnoliifolia* Née., *Q. crassifolia* Benth., and *Q. glaucescens* Bonpl. had the highest RIV (Figure 2C).



**Figure 2.** Highest relative importance value (RIV) for woody plants in a temperate pine-oak forest successional gradient. (a) early stage; (b) intermediate stage; (c) mature stage. Acfa = *Acacia farnesianna* (L.) Willd., Acpe = *Acacia pennatula* Benth., Brsp = *Brickellia* spp., Crpu = *Crataegus pubescens* C. Presl., Mogr = *Montanoa grandiflora* DC., Pyco = *Pyrus communis* L., Pila = *Pinus lawsonii* Roetzl ex Gordon, Pipr = *Pinus pringlei* Shaw., Qucr = *Quercus crassifolia* Benth., Qusp = *Quercus* spp. L., Arxa = *Arbutus xalapensis* Kunth., Pimo = *Pinus montezumae* Gordon & Glend., Quac = *Quercus acutifolia* Née., Qugl = *Quercus glaucescens* Bonpl., Quli = *Quercus liebmanni* Oerst. ex Trel., Quma = *Quercus magnoliifolia* Née., Semu = *Senna multiglandulosa* (Jacq.) H.S. Irwin & Barneby., Culi = *Cupressus lindleyi* Mill., Quel = *Quercus elliptica* Née., Quca = *Quercus candicans* Née., Pips = *Pinus pseudostrobus* Lindl.

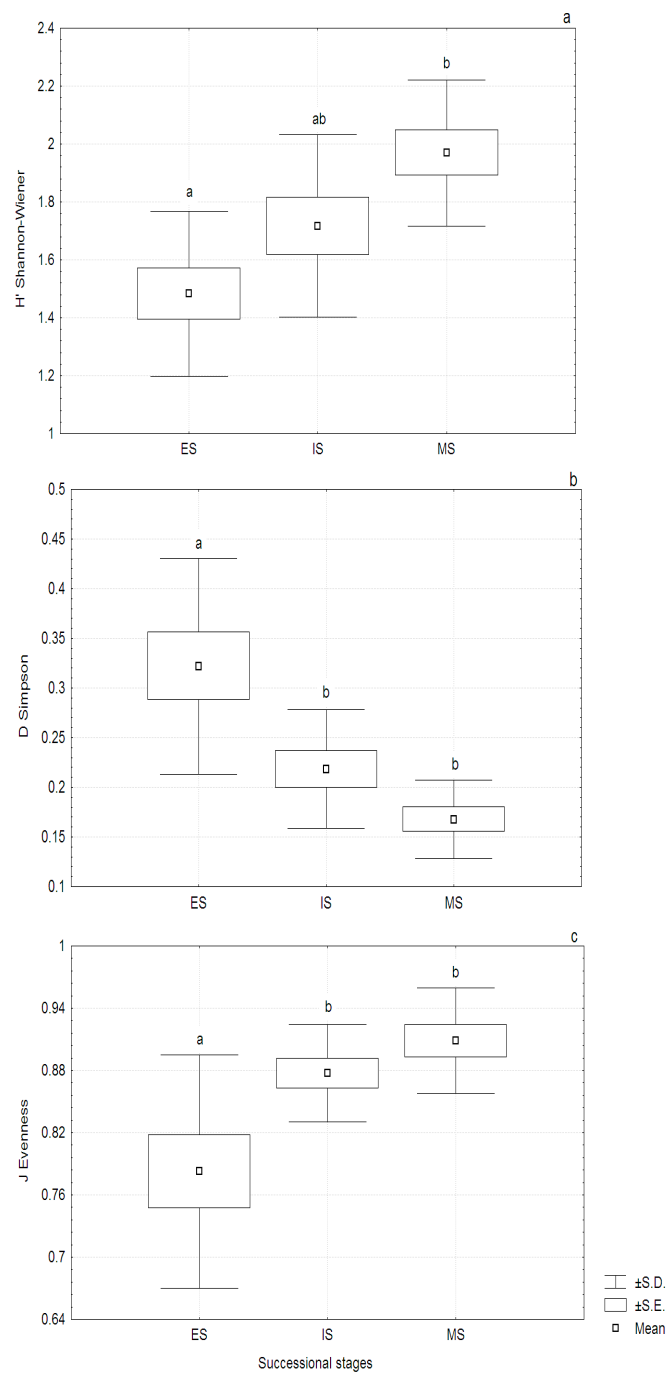
### 3.2. Species Richness, Abundance, and Diversity

According to the Chao 2 estimator, 83% of the species present in the mature stage, 87% in the intermediate stage, and 88% in the early stage were recorded. The mature forest had the highest richness with 35 species (Table 1). Trees were more abundant in the mature stage, while shrubs were better represented in the early stage (Table 1).

The Shannon-Wiener diversity was significantly higher in the mature site than in the early site ( $F_{2,27} = 7.27$ ,  $p = 0.003$ ; Figure 3A). However, dominance was higher in the early stage ( $0.32 \pm 0.03$ ) in comparison with the intermediate and mature stages ( $F_{2,27} = 10.95$ ,  $p < 0.001$ ; Figure 3B). The mature successional site also had the highest value of equitability ( $F_{2,27} = 7.41$ ,  $p = 0.003$ ; Figure 3C).

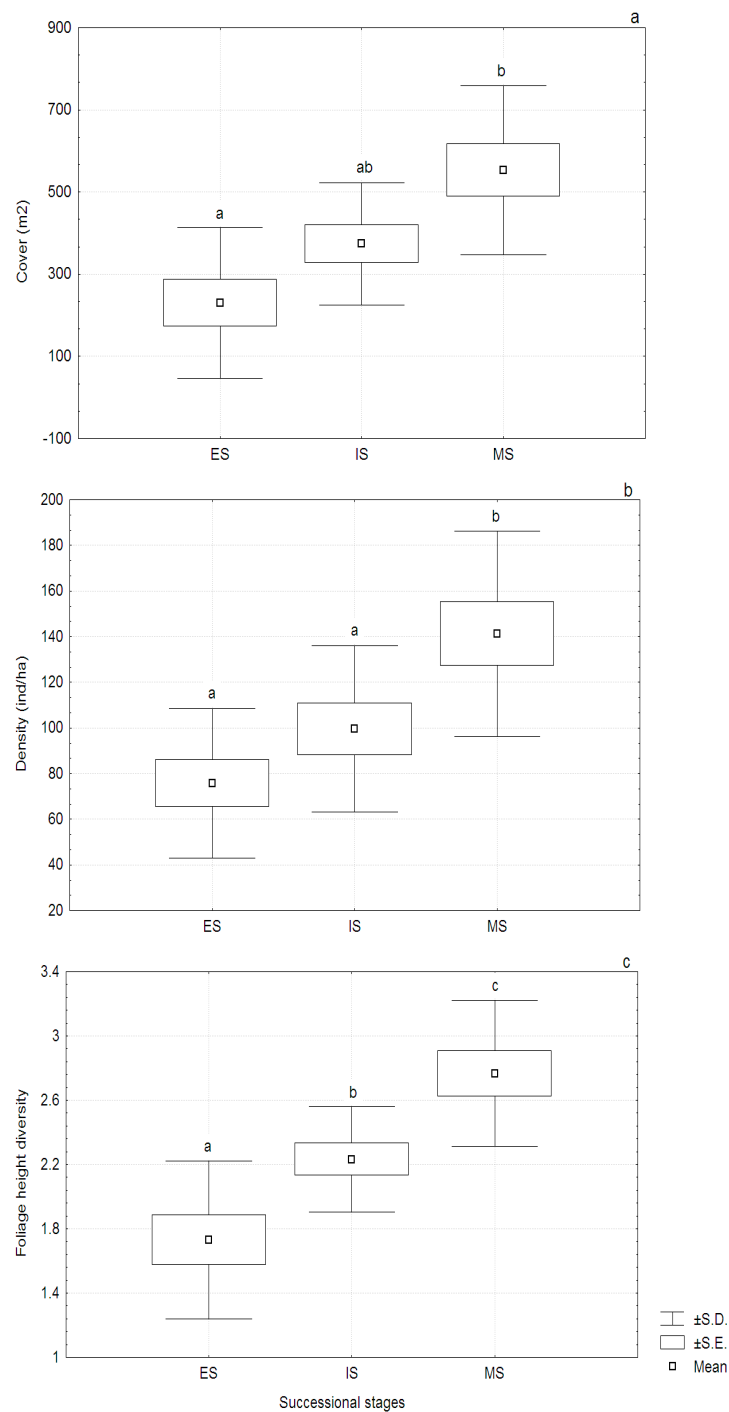
**Table 1.** Woody species richness (observed and expected) in the three successional stages of pine-oak forest in the Sierra Madre del Sur, Guerrero, Mexico.

Successional Stage	Shrub Species Number	Tree Species Number	Observed Richness	Expected Richness (Chao2)	Chao2 %	Abundance of Shrubs	Abundance of Trees
Early	8	14	22	25	88.0	102	117
Intermediate	10	17	27	31	87.1	97	226
Mature	9	26	35	42	83.3	65	428

**Figure 3.** Mean values of diversity indices for woody plants along a temperate forest successional gradient. (a) Shannon-Wiener; (b) Simpson; (c) evenness. Different letters indicate significant differences (Tukey,  $p < 0.05$ ). ES = early stage, IS = intermediate stage, MS = mature stage.

### 3.3. Vegetation Structure

Total plant cover was greater in the mature ( $373.83 \pm 46.93$ ) and intermediate forests ( $552.83 \pm 65.05$ ); however, differences were only significant between the early and mature stages ( $F_{2,27} = 8.01$ ,  $p = 0.002$ ; Figure 4A). Density increased significantly in the mature stage ( $F_{2,27} = 8.20$ ,  $p = 0.002$ ; Figure 4B). Foliage height diversity was lower in the early and intermediate stages and differed significantly from the mature stage ( $F_{2,27} = 14.46$ ,  $p < 0.001$ ; Figure 4C).

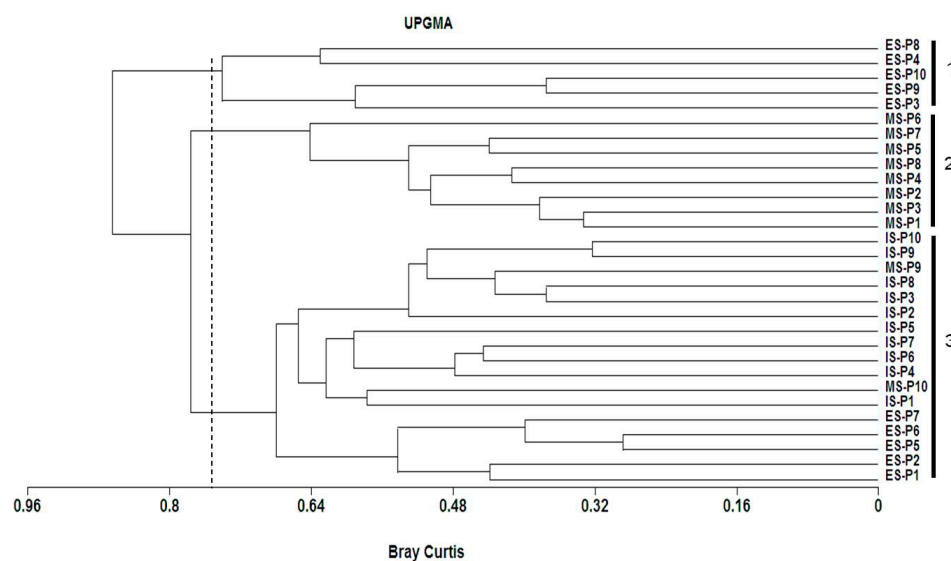


**Figure 4.** Mean values of woody plant structure along a temperate forest successional gradient. (a) cover; (b) density; (c) foliage height diversity. Different letters indicate significant differences (Tukey,  $p < 0.05$ ). ES = early stage, IS = intermediate stage, MS = mature stage.

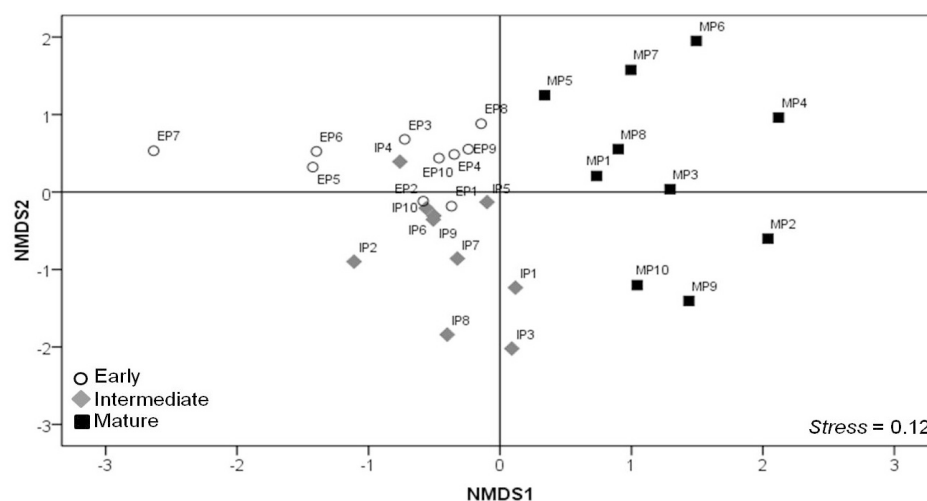


### 3.4. Spatial Distribution of the Plant Species

The classification analysis showed three main groups (Figure 5) at a similarity level of 75%. The first group included five plots of the early stage, and the second group included eight plots of the mature stage. Finally, the third group included all plots of the intermediate stage in addition to the remaining plots of early and mature stages (Figure 5). The discriminant analysis indicated that the groups identified by the classification were significantly different (Function 1:  $\lambda = 0.000$ ;  $\chi^2 = 276.75$ ,  $df = 120$ ,  $p < 0.001$ ; Function 2:  $\lambda = 0.000$ ;  $\chi^2 = 158.69$ ,  $df = 92$ ;  $p < 0.001$ ). The NMDS coincided with the classification and separated the majority of the mature stage plots from the rest of the plots. In addition, some of the plots of the intermediate and early stages intermingled, while others were segregated (Figure 6). The Kruskal's stress value of 0.12 indicated an acceptable fit given the corresponding distances. Overall, the plant community composition was significantly different among successional stages (ANOSIM global  $R = 0.741$ ,  $p < 0.001$ ).



**Figure 5.** Classification of sample plots of the three successional stages of temperate pine-oak forest using the relative importance value (RIV). The dotted line represents the 75% level, used as the cut-off.



**Figure 6.** Non-metric multidimensional scaling (NMDS) of the values of relative importance showing differences in species composition among plots in three successional stages of pine-oak forest. EP = plots of early stage, IP = plots of intermediate stage, MP = plots of mature stage.



#### 4. Discussion

In our study sites, the natural sequence of successional stages that occurred subsequent to changes in land use showed a gradual increase in the total number of plant species from the early to the intermediate and mature stages. In the early stage, the lower number of species and abundance, in comparison to the latter stages, confirmed our first hypothesis. These results agree with other studies on the early stages of secondary succession in temperate forests of other parts of the world [4,6,7] where, in general, the quality of the environment under regimes of severe disturbance decreases dramatically. For example, soil fertility is negatively affected and, since variations in temperature are more extreme, these factors further affect the dynamics of the succession [1,12,20,36]. Some species of oaks (*Quercus* spp.) require specific soil conditions during their seed and seedling phase (i.e., accumulation of humus, nutrients) in addition to particular humidity and temperature conditions. Meanwhile, the *Pinus* genus requires environments with a high incidence of light. These factors gradually change along the disturbance gradient and thus influence species dominance [36,53,54]. Furthermore, the limited presence of biotic seed dispersers in early stages is due to the decrease of food and refuge sites [55] and, coupled with grazing cattle and anthropogenic disturbances, may potentially halt the process of plant succession [56]. Since the soil seed bank may be considerably reduced in disturbed fragments [57], seed dispersal can play an important role in the recruitment of plants, and hence contribute towards the composition and density of woody plants and the eventual restoration of these forests [17,58,59]. On the other hand, besides humidity and temperature, other abiotic differences such as inclination and rocky hillsides between mature forest and intermediate and early forest may be influencing the differences in richness and structure of the successional stages.

The early stage was characterized by a high species dominance and low evenness. This pattern is typical of disturbed plant communities where pioneer species have high values of relative importance in relation to other species [60,61]. In fact, *Brickellia* spp. and *Acacia pennatula* presented densities almost twice as high as those in the intermediate stage and five times higher than in the late-successional stage. However, the total density of trees remained lower in the early stage due to the low abundance of certain characteristic species, such as *Quercus*, as well as other species present in temperate forests (e.g., *Juniperus flaccida* Schltdl., *Arbutus xalapensis*) that are usually abundant at less disturbed sites [62]. We noted the same tendency in foliage cover and stratification, which were greater in the mature stage due to the presence of taller and larger trees (e.g., oak, pine, and cypress) and the absence of recent climatic or anthropogenic disturbances [8].

In response to the second hypothesis, we found a gradual shift in species assortment between successional stages (according to the initial floristic composition hypothesis) [37,60]. This is consistent with other studies conducted in the temperate forests of Mexico [35]. Complete floristic and structural replacements have been reported in the temperate ecosystems of Chiapas, Mexico, although in this case, the chronosequence comparison was between truly open areas with a predominance of grasses and herbs and the early stages of more developed forests [4,7].

Some characteristic species of early forest were absent in the mature stages of our study sites (*Vallesia glabra* (Cav.) Link., *Leucaena leucocephala* (Lam.) de Wit). Also, several dominant species decreased considerably in abundance at this stage, including *Brickellia* spp., *Montanoa grandiflora*, *Senna multiglandulosa*, *Acacia farnesiana*, and *A. pennatula*. On the other hand, some pine species such as *Pinus montezumae* and *P. pringlei* occurred in the early stage. Often these species grow in open and degraded environments [7,9,25], and are frequently used for the restoration of areas with heavily degraded soils [26]. Apparently, the presence of pines allows for the later installation of other plants, including some species of *Quercus*. We recorded five species of pine in the early stage, although their crown cover was low since the trees were young individuals.

Conversely, in the intermediate and mature stages, species representative of advanced successional stages, such as *Quercus candicans*, *Q. castanea*, *Q. crassifolia*, *Q. magnoliifolia*, *Juniperus flaccida*, and *Pinus oocarpa* Schiede ex Schltdl. were dominant. In addition to the gradual replacement of species from one site to another, the presence of these species in late successional forest suggests a process of facilitation,

where pioneer species alter environmental conditions to make them more suitable for the arrival of late successional species [63], such as *Quercus*.

Additionally, some studies have reported that various mechanisms of seed dispersal can contribute differentially to local species diversity and favor ecological succession in temperate forests [13,64]. For example, in a montane oak forest in Costa Rica, Wilms and Kappelle [13] found that numerous birds forage on the fruits of mature forest trees also forage on those that occur in pastures. Thus, they may serve as key dispersal agents, transporting tree seeds from mature, closed forests into non-forested secondary scrublands or pastures. Nonetheless, in addition to seed dispersal by animals, some plant species are anemochorous [58]. Indeed, in the early stage anemochorous species are more common (e.g., genus *Brickellia*, *Acacia*). On the other hand, while it is true that several species of pines of intermediate and mature forests have winged seeds adapted for wind dispersal, they owe much of their establishment to scatter-hoarding animals [16]. Despite the fact that pines are pioneer species, in our study we do not consider them to be true facilitators. If this were true, they would allow for the establishment of other species that would later become dominant. In this case, the density of pines would diminish in the advanced seral stages and eventually be lesser than that of the facilitated species. However, this does not occur with pines in the current study area, as they are still present in large numbers at the mature stages. Another explanation may be that in the early stages, the shade conditions provided by some legume plants (genus *Acacia*) during summer drought reduces water stress, whereby these species facilitate the establishment of seedlings [33,65,66] and can fix nitrogen in the soil. We also observed that species with very high densities, such as *Brickellia* spp., contribute to the shading effect for some recruited plants of mature forest (e.g., *Quercus*, *Juniperus*, and some *Pinus*). Furthermore, the presence of grazing livestock is greater in the early stage, and consequently, the ability of young pine species to provide physical protection to regenerated vegetation in this stage is rendered more difficult. Therefore, in this case, it is likely that shrubs (*Acacia* and *Brickellia* species) serve as pioneers and facilitators in creating plant communities of higher density [67].

Moreover, even if *Quercus* and *Pinus* species represent two biologically and ecologically distinct taxonomic groups [68], they usually coexist spatially and temporarily. Interestingly, in the study area oaks were better represented in communities with advanced succession, which is consistent with another study [69]. Indeed, the composition of *Quercus* increased, and its structure (higher RIV) was more complex in the mature stage, confirming the third hypothesis. Another factor contributing to the marked dominance of mainly adult oak individuals in mature succession may rest on their lower light requirement [23,35]. Inversely, the same condition could explain the decrease in the composition and structure of pines in the mature stage, due to their high demand for light [7]. This idea may be confirmed, since the clearing and selective cutting of oaks, whether natural or due to human activities, leads to an increase in the presence of *Pinus* individuals. This phenomenon has been documented in other secondary forests around the world [4,7,70]. On the other hand, the two plots of the mature forest that were grouped with intermediate successional forest can be explained due to similar abiotic conditions; for example, the soils of the majority of the intermediate plots are not very deep [17] as well as those found in these two plots of mature succession [39]. Further, the altitude, slope inclination, and microclimatic variations may be influencing this grouping (*sensu* Tansley [71]). The groups formed with the sample plots indicate possible differences in the age of the forest stands; however, this also could be due to other abiotic differences (e.g., soil water content, bulk density of soil, pH) that weren't considered in the study.

In the highlands of the Sierra Madre del Sur, Guerrero, the continued fragmentation and modification of forest habitats will affect successional dynamics and increase the susceptibility of non-tolerant species to abrupt environmental changes. Since ecological succession may be considered to be a natural restoration process, strategies and conservation priorities should be aimed at maintaining different successional plant communities with heterogeneous physiognomy in addition to mature forests in order to sustain regeneration processes and a high level of plant diversity.

**Acknowledgments:** This research is the result of the collaboration of the academic group Biodiversity and Sustainable Environmental Management (*Biodiversidad y Gestión Ambiental Sustentable de Guerrero*; UAGro-CA-170). The authors thank the Chemistry and Biological Sciences Academic Unit of the Autonomous University of Guerrero for the facilities provided for this research. Pablo Sierra produced Figure 1. Special thanks are extended to Pablo Sierra, Nefris Jacinto, Antonio Estrada, Genesis Benitez, Lucely Muñoz, and Juan Carlos Gomez, who supported the fieldwork. The manuscript was greatly improved by the comments of two anonymous reviewers. Allison M. Jermain reviewed the English translation.

**Author Contributions:** R. Carlos Almazán-Núñez conceived and designed the study; Liliana Parra-Juárez and R. Carlos Almazán-Núñez performed the experiments; R. Carlos Almazán-Núñez, Pablo Corcuera, and Gregory Michäel Charre analyzed the data; R. Carlos Almazán-Núñez, Pablo Corcuera, Liliana Parra-Juárez, Javier Jiménez-Hernández, and Gregory Michäel Charre all contributed to the writing of the paper.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix 1

**Table A1.** Plant species composition identified in three successional stages in a pine-oak forest in the Sierra Madre del Sur, Mexico. ES = early stage, IS = intermediate stage, and MS = mature stage.

Family	Species	Life Form	ES	IS	MS
Anacardiaceae	<i>Rhus</i> spp. L. 1753	Tree			x
	<i>Actinocheita potentillifolia</i> (Turcz.) Bullock 1937	Shrub			x
Apocynaceae	<i>Vallesia glabra</i> (Cav.) Link 1821	Shrub	x		
Arecaceae	<i>Brahea dulcis</i> (Kunth) Mart. 1838	Tree		x	x
Asteraceae	<i>Brickellia</i> spp.	Shrub	x	x	
	<i>Baccharis heterophylla</i> Kunth 1820	Shrub		x	
Betulaceae	<i>Carpinus caroliniana</i> Walter 1788	Tree			x
	<i>Alnus acuminata</i> Kunth 1817	Tree		x	x
Burseraceae	<i>Bursera cuneata</i> (Schltdl.) Engl. 1880	Tree			x
Cactaceae	<i>Opuntia</i> sp. Mill. 1754	Shrub			x
Clethraceae	<i>Clethra mexicana</i> DC. 1839	Tree		x	x
Compositae	<i>Vernonia alamanii</i> DC. 1836	Shrub		x	
	<i>Montanoa grandiflora</i> DC. 1836	Shrub	x	x	
	<i>Piqueria trinervia</i> Cav. 1794	Shrub			x
	<i>Coreopsis mutica</i> DC. 1836	Shrub	x	x	x
Cupressaceae	<i>Cupressus lindleyi</i> Klotzsch ex Endl. 1847	Tree		x	x
	<i>Cupressus lusitanica</i> Mill. 1768	Tree	x		
	<i>Juniperus flaccida</i> Schltdl. 1838	Tree			x
Ericaceae	<i>Arbutus xalapensis</i> Kunth 1818	Tree	x	x	x
	<i>Arctostaphylos discolor</i> (Hook.) DC. 1839	Shrub		x	x
Fabaceae	<i>Leucaena leucocephala</i> (Lam.) de Wit 1961	Tree	x		
	<i>Eysenhardtia polystachia</i> (Ortega) Sarg. 1892	Shrub			x
	<i>Senna multiglandulosa</i> (Jacq.) H.S. Irwin & Barneby 1982	Shrub	x	x	
	<i>Mimosa tenuiflora</i> Benth 1846	Tree			x
	<i>Acacia farnesiana</i> (L.) Willd. 1806	Tree	x	x	x
	<i>Acacia pennatula</i> (Schltdl. & Cham.) Benth. 1842	Tree	x	x	
	<i>Dalea lutea</i> (Cav.) Willd. 1802	Shrub			x
Fagaceae	<i>Calliandra grandiflora</i> (L'Hér.) Benth. 1840	Shrub	x	x	
	<i>Quercus acutifolia</i> Née 1801	Tree	x	x	
	<i>Quercus candicans</i> Née 1801	Tree			x
	<i>Quercus castanea</i> Née 1801	Tree			x
	<i>Quercus crassifolia</i> Benth. 1840	Tree			x
	<i>Quercus liebmannii</i> Oerst. ex Trel. 1924	Tree	x	x	x
	<i>Quercus magnoliifolia</i> Née 1801	Tree			x
	<i>Quercus</i> spp. L. 1753	Tree	x		
	<i>Quercus elliptica</i> Née 1801	Tree		x	x
	<i>Quercus martinezii</i> C.H. Mull. 1954	Tree		x	x
	<i>Quercus glaucescens</i> Bonpl. 1809	Tree		x	x
Flacourtiaceae	<i>Xylosma flexuosum</i> (Kunth) Hemsley 1879	Shrub		x	
Labiatae	<i>Salvia sessei</i> Benth. 1833	Shrub			x
	<i>Litsea glaucescens</i> Kunth 1817	Shrub		x	x
Myricaceae	<i>Myrica cerifera</i> L. 1753	Shrub	x		

Table A1. Cont.

Pinaceae	<i>Pinus lawsonii</i> Roehl ex Gordon 1862	Tree	x	x	x
	<i>Pinus pringlei</i> Shaw 1905	Tree	x	x	x
	<i>Pinus oocarpa</i> Schiede ex Schltdl. 1838	Tree	x		x
	<i>Pinus pseudostrobus</i> Lindl. 1839	Tree	x	x	x
	<i>Pinus montezumae</i> Gordon & Glend. 1858	Tree	x	x	
Rosaceae	<i>Crataegus pubescens</i> (C. Presl) C. Presl 1826	Tree	x		
	<i>Prunus serotina</i> Ehrh. 1783	Tree			x
	<i>Pyrus communis</i> L. 1753	Tree	x		
	<i>Cercocarpus fothergilloides</i> Kunth 1823	Tree		x	x
Rubiaceae	<i>Randia echinocarpa</i> DC. 1830	Tree			x
Solanaceae	<i>Datura candida</i> Voigt 1845	Shrub	x		

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