Regeneration of secondary forests in the understory of pure plantations of *Quercus castaneifolia* and mixed plantations of *Quercus castaneifolia* and *Zelkova carpinifolia* in northern Forests of Iran

(With 1 Figure and 4 Tables)

S. M. HOSSEINI[1),✉], E. ROUHI-MOGHADDAM[2)], E. EBRAHIMI[3)], A. RAHMANI[3)] and M. TABARI[1)]

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1. INTRODUCTION

The principal factors limiting tree regeneration in degraded lands can include scarcity of nutrients, soil compaction, lack or excess of soil humidity, high solar radiation, intra- and inter-specific competition (NEPSTAD *et al.,* 1991), little seed availability, seed predation (MC CLANAHAN and WOLFE, 1993; HOLL, 1998; TRUSCOTT *et al.,* 2004), and trampling by cattle (HARVEY and HABER, 1999).

The presence of trees, either in plantations, in groups, in lines or in isolated form may contribute to the recovery of environmental conditions favorable to tree regeneration processes (PARROTTA, 1995; GUARIGUATA *et al.,* 1995). The establishment of tree plantations in degraded areas may facilitate regeneration of native species that could not otherwise establish in open microsites or in competition by herbaceous species (LUGO, 1992). Several authors report on the role of tree plantations as catalizers of natural succession (PARROTTA, 1992; JUSSI *et al.,* 1995; KEENAN *et al.,* 1999; OTSAMO, 2000; CARNEVALE and MONTAGNINI, 2002). Results of some studies also suggest that tree plantations have a good potential for accelerating the processes leading to a recovery of biodiversity on degraded soils (GUARIGUATA *et al.,* 1995; POWERS *et al.,* 1997; PARROTTA, 1999; JOGISTE *et al.,* 2005; OHARA and WARING, 2005; KELTY, 2006).

Mixed plantations could promote the regeneration of a greater diversity of species in their understory than pure-species plantations by controlling the spontaneous competitive species such as mainly grasses and *Rubus spp.* (BALANDIER *et al.,* 2005) and also by creating a greater variability of habitat conditions that may favor seed dispersers and germination and the growth of tree species (GUARIGUATA *et al.,* 1995).

Stand structure is a key factor in the growth, function, and disturbance regimes of forests. Forest restoration and management based on natural disturbance ecology, has highlighted the value of a clearer understanding of the role of structure in mediating key ecosystem processes (BOYDEN *et al.,* 2005). Spatial pattern is one component of forest structure that may reveal insights about the historical and environmental processes, such as regeneration, climate, mortality and competition, which have shaped current stand structure.

Traditional descriptions of stand structure have focused on stand-level collective attributes such as average tree size, density, and basal area., the horizontal and vertical heterogeneity of forest structure influences tree growth, plant species diversity, wildlife habitat, and fire behavior (HARROD *et al.,* 1999; WALTZ *et al.,* 2003; YOUNGBLOOD *et al.,* 2004). Species diversity is the best known, but by far not the only kind of diversity (TURNER, 1995). Within forestry, genetic diversity and structural diversity are also important facets (NEUMANN and STARLINGER, 2001).

The temperate deciduous forest on the northern slopes of the Alborz Mountains (Hyrcanian forest) has a high biological diversity and many endemic species. Huge areas are still old-growth forest but logging and grazing have degraded large parts of the forest (NOACK *et al.,* 2010). Thus the potential for maintenance and expansion of oak forests by natural regeneration appears to be at best limited. In order to promote expansion and rehabilitatin of oak these forests, a program of oak seedling planting may be required (MOHADJER, 1999).

In the present study we investigated tree regeneration under plantations of native species in pure and mixed planting designs at the Chamestan Forest and Rangeland Research Station in the Hyrcanian (or Caspian) Forests of Iran. The species of this research were Oak (as target species), *Quercus castaneifolia* C.A.Mey. (Fagaceae), and Siberian Elm (as native component species), *Zelkova carpinifolia* (Pall.) Dippel (Ulmaceae). The following hypothesis were tested in this study: (1) Tree regeneration of native species is more abundant under the canopy of the Oak-dominated plantations than in adjacent areas without trees (control); and (2) tree regeneration is more diverse under the mixed plantations than under the pure-species plantations.

2. MATERIALS AND METHODS

2.1. Site description

The study area is located at the Chamestan experiment station in the Mazandaran province in the northern parts of Iran (36°29'N, 51°59'W). Experimental plots were located at an altitude of 100 m above sea level. The area is on flat, uniform terrain with low slope (0–3%). Annual rainfall averages 803 mm, with wetter months occurring between September and February, and a dry season from April to August. Monthly rainfall usually averages <40 mm for 4 months. Average daily temperatures range from 11.7 °C in February to 29.5 °C in August (HOSSEINI *et al.,* 2010).

The soils are deep, stone-free and have a silty clay loam and clay loam textures with a pH 6.0–7.5. According to USDA (2006) classification, the soil of study area is placed in Enceptisols order, suborder of Udepts, Typic Eutrodepts great group and Fine mixed mesic family. Previously (approximately 50 years ago) this area was dominated by natural forests containing native tree species such as *Quercus castaneifolia* C.A.Mey., *Gleditschia caspica* Desf., *Carpinus betulus* L., *Zelkova carpinifolia* (Pall.) Dippel. The surrounding area is dominated by agricultural fields and commercial buildings (HOSSEINI *et al.,* 2010).

[1)] Department of Forestry, Faculty of Natural Resources, Tarbiat Modares University, Noor, Mazandaran, Iran. 46414.

[2)] Department of Environment, Faculty of Natural Resources, Zabol University, Zabol, Iran.

[3)] Department of Forestry, Research Institute of Forests and Rangelands, Peykanshahr, Tehran, Iran.

✉) Corresponding Author: Dr. SEYED MOHSEN HOSSEINI. Department of Forestry, Faculty of Natural Resources, Tarbiat Modares University, Noor, Mazandaran, Iran. 46414. E-mail: hosseini@modares.ac.ir

2.2. Experimental design

Experimental plantations were established in 1995 using a randomized complete block design that included three replicate 25 m x 25 m plots of each of the following treatments:

(i) *Quercus castaneifolia* (100Q);

(ii) 70% *Q. castaneifolia* + 30% *Zelkova carpinifolia* (70Q:30Z);

(iii) 60% *Q. castaneifolia* + 40% *Z. carpinifolia* (60Q:40Z);

(iv) 50% *Q. castaneifolia* + 50% *Z. carpinifolia* (50Q:50Z);

(v) 40% *Q. castaneifolia* + 60% *Z. carpinifolia* (40Q:60Z);

(vi) Unplanted Control (grass).

Tree spacing within plantations was 1 m x 1 m and two species were systematically mixed within rows. The stands were never fertilized and weeded.

2.3. Tree and shrub regeneration studies

Tree and shrub regeneration in this research was investigated for each plantation plot, without two marginal planted rows (hence the measurement took place on 441 m^2 per plot) in 2006. All woody seedlings and saplings were identified and counted, and were sorted by height classes: class 1: 15 cm – 200 cm, class 2: > 200 cm. Similar sampling procedures were used in the adjacent unplanted natural regeneration control plots.

2.4. Biodiversity studies

2.4.1. Species Richness

Species richness can refer to the number of species present in a given area or in a given sample, without implying any particular regard for the number of individuals in each species (SANJIT and BHATT, 2005). Species richness can be numerical (or simply "species richness"; HULBERT, 1971) or be related to area (or simply "species density" , namely the number of species present in a given area; SIMPSON, 1964). Margalef index R (equation 1) was used in this study to calculate species richness (MARGALEF, 1958).

$$R = \frac{S-1}{LnN} \qquad \text{Equation 1}$$

where *S* is the number of taxa, *N* is the number of individuals.

2.4.2. Species Evenness

Species evenness can refer to the equitability or distribution of individuals among the present species (PIELOU, 1966). Evenness index of equitability J' is calculated as (equation 2):

$$J' = \frac{H'}{LnS} \qquad \text{Equation 2}$$

where *H'* is the Shannon diversity index and *S* is the number of taxa.

2.4.3. Species Diversity

Species diversity is a function of the number of species present (i.e. species richness or number of species) and the evenness with which the individuals are distributed among these species (i.e. species evenness, species equitability, or abundance of each species) (MARGALEF, 1958; LLOYD and GHRLARDI, 1964; PIELOU, 1966; SPELLERBERG, 1991). Species richness is easy to measure and understand, whereas the measuring of species diversity is complicated because measures of diversity vary in the relative emphasis they place on the number of species and their relative abundance. Moreover, species diversity, as it is usually measured, is an aspect of community structure Structurally, many rare species are minor components of a community (SANJIT and BHATT, 2005).

Fisher's alpha index S (FISHER *et al.,* 1943) was used in this study to calculate species diversity (equation 2).

$$S = aLn(1 + n/a) \qquad \text{Equation 3}$$

where *S* is the number of taxa, *N* is the number of individuals and a is Fisher's alpha (α = a constant derived from the sample data set).

2.4.4. Species Dominance

Species Dominance can refer to the number of individuals of the dominant taxon relative to the total number of individuals. The Berger-Parker index d was used in this study. This index accounts for both richness and relative abundance, presents the proportional importance of the most dominant species, and is simple and easy to calculate. It is expressed as (Equation 4):

$$d = \frac{N_{max}}{N} \qquad \text{Equation 4}$$

Tab. 1

Abundance of regenerating individuals and number of species under pure and mixed plantations, and in natural regeneration plots (standard errors between parentheses and means)[a].

Häufigkeit der Verjüngung und Artenzahl in reinen und gemischten Plantagen und auf Naturverjüngungsflächen (Mittelwerte (± Standardfehler)[a].

Treatment	Total number of seedlings/saplings/ha	No. of species/441 m^2
100Q	3020 (274) a	7.17 (0.47) ab
70Q:30Z	1157 (331) bc	5.33 (1.20) ab
60Q:40Z	1966 (408) b	8.67 (1.76) a
50Q:50Z	1474 (398) b	7.33 (0.88) ab
40Q:60Z	1483 (392) b	6.00 (0.57) ab
Natural regeneration	312 (72) c	3.75 (0.75) b

[a] Differences among means are statistically significant when the standard error is followed by different letters ($p < 0.01$).

where N_{max} is the number of individuals of the most abundant species and N is the number of all individuals (MAGURRAN, 1988). The Berger-Parker index is expressed in the reciprocal form (1/d), so that increases in the index value follows an increase in species diversity or a decrease in dominance.

2.5. Canopy shading and depth of the litter layer and soil pH

A scale suggested by POWERS *et al.* (1997) was used to relate natural regeneration with canopy shading in the plantation understory and in the natural regeneration controls. This scale uses values from 1 to 4, according to a visual estimation of the specific microsite under consideration, (1) full direct light; (2) diffuse light; (3) lateral light; (4) full shade.

For measuring the depth of the litter layer, four points were randomly located in each plot, and depth of the litter layer was measured with a ruler to 1 mm (CARNEVALE and MONTAGNINI, 2002).

pH values of the upper soil horizon (0–20 cm depth) were determined using an Orion Ionalyzer Model 901 pH meter in a 1:2.5 mixture of soil: deionized water.

2.6. Data analysis

Normality of variables was checked by Kolmogorov-Smirnov test and Levene's test was used to test for equality of variances. One-way analysis of variance (ANOVA) was used to compare the abundance of regenerating individuals among the different treatments, for each height class and for the totals (sum of the individuals in the two height classes) and also to compare the total number of tree species regenerating under each treatment. L.S.D. least significant difference (LSD) tests were used for comparisons among means (SCHEFFE, 1959). Pearson coefficients were used to correlate the number of individuals and the number of species with canopy shading, using the quantitative scale proposed by POWERS *et al.* (1997) as shown in the previous section. Correlations were also run among numbers of individuals and depth of the litter layer, and among numbers of species and depth of the litter layer, among numbers of individuals and pH values of the upper soil horizon, and among numbers of species and pH values of the upper soil horizon, also using Pearson coefficient.

3. RESULTS

3.1. Regeneration of woody species under each treatment

3.1.1. Abundance

The lowest average of total numbers of tree individuals (seedling and sapling, sum of the two height classes) was found in the control natural regeneration plots with only 312 individuals/ha (*Table 1*). Sorting the regenerating individuals by height classes, in class 1: 15 cm^{-2} m the lowest numbers of seedlings were also found in the control (*Fig. 1*). The number of tree regenerating individuals corresponding to height class 2: >2 m, ranged from 53 under 70Q:30Z to 238 individuals/ha under control, with no significant differences among treatments (*Fig. 1*).

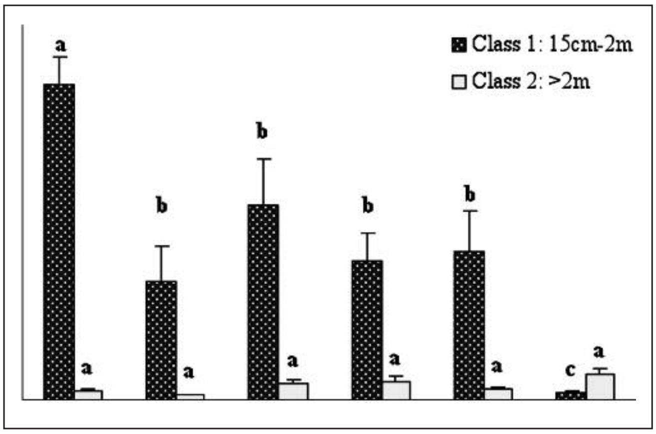

Fig. 1

Total number of regenerating tree seedlings by height class and treatment. Different letters show significant differences among treatments ($p < 0.01$).

Gesamtanzahl der Sämlinge nach Höhenklasse und Behandlung. Unterschiedliche Buchstaben weisen auf signifikante Unterschiede zwischen den Behandlungen hin.

Tab. 2

Environmental variables (Canopy shading index, Litter depth and pH values of the upper soil horizon under pure and mixed plantations, and in natural regeneration plots (standard errors between parenthesis and means)[a].

Umweltvariablen (Überschirmungsgrad, Höhe der Streuauflage, pH-Werte des oberen Bodenhorizonts in reinen und gemischten Plantagen und auf Naturverjüngungsflächen (Mittelwerte (± Standardfehler)[a].

Treatment	Canopy shading index	Litter depth (cm)	pH values of the upper soil horizon
100Q	2.83 (0.16) b	7.53 (0.51) a	6.77 (0.21) a
70Q:30Z	4.00 (0.00) a	7.40 (0.70) ab	7.08 (0.04) a
60Q:40Z	3.33 (0.33) ab	7.26 (0.49) ab	6.51 (0.19) a
50Q:50Z	3.66 (0.33) ab	6.03 (0.61) ab	6.61 (0.10) a
40Q:60Z	3.66 (0.33) ab	5.70 (0.25) b	6.61 (0.34) a
Natural regeneration	1.25 (0.25) c	0.12 (0.12) c	7.11 (0.08) a

[a] Differences among means are statistically significant when the standard error is followed by different letters ($p < 0.01$).

3.1.2. Number of tree species

The number of tree species at 11 years was significantly greater under 60Q:40Z treatment than in the control (*Table 1*).

3.2. Environmental variables (canopy shading, litter thickness and soil pH)

The lowest degree of canopy shading was found in the control plots (natural regeneration) (1.25), followed by pure plantation (2.83), 60Q:40Z treatment (3.33), 50Q:50Z and 40Q:60Z treatments (3.66) and 70Q:30Z treatment (4.00). Differences among treatments were statistically significant ($p<0.01$), except for the differences among 60Q:40Z, 50Q:50Z and 40Q:60Z treatments (*Table 2*).

The highest litter thickness was found under the pure Quercus plantations (7.53 cm), followed by 70Q:30Z (7.40 cm), 60Q:40Z (7.26 cm), 50Q:50Z (6.03 cm), 40Q:60Z (5.70 cm) and control plots (0.12 cm). There were statistically significant differences ($p<0.01$) among 100Q and 40Q:60Z and control plots, among 70Q:30Z, 60Q:40Z, 50Q:50Z treatments and control plots (*Table 2*).

Tab. 3

Biodiversity indices of regenerating species under pure and mixed plantations, and in natural regeneration plots (means and standard errors between parenthesis)[a].

Biodiversitäts-Indizes der Verjüngungsarten in reinen und gemischten Plantagen und auf Naturverjüngungsflächen (Mittelwerte (± Standardfehler)[a].

Treatment	Fisher alpha	Margalef	Equitability J	Berger-Parker
100Q	1.65 (.15) a	1.27 (.11) ab	0.55 (.03) a	0.67 (.02) a
70Q:30Z	1.58 (.42) a	1.11 (.28) ab	0.63 (.11) a	0.63 (.09) a
60Q:40Z	2.42 (.51) a	1.71 (.32) a	0.58 (.03) a	0.62 (.02) a
50Q:50Z	2.16 (.15) a	1.53 (.12) ab	0.67 (.01) a	0.47 (.01) a
40Q:60Z	1.66 (.06) a	1.21 (.05) ab	0.62 (.03) a	0.57 (.06) a
Control	1.91 (.53) a	1.01 (.22) b	0.78 (.13) a	0.56 (.13) a

[a] Differences among means are statistically significant when the standard error is followed by different letters ($p < 0.01$).

Tab. 4

Total number of regenerating individuals of each species per ha, under pure and mixed plantations, and in natural regeneration plots.

Gesamtanzahl der Verjüngung nach Arten (n/ha) in reinen und gemischten Plantagen und auf Naturverjüngungsflächen.

Control	40Q:60Z	50Q:50Z	60Q:40Z	70Q:30Z	100 Q	Species
11	794	484	1248	748	2032	*Quercus castaneifolia*
0	468	673	204	265	0	*Zelkova carpinifolia*
57	98	68	249	38	478	*Prunus avium*
6	8	30	30	15	140	*Mespilus germanica*
158	76	30	60	15	130	*Morus alba*
0	8	0	38	0	93	*Crataegus ambigua*
51	8	15	38	0	60	*Albizia julibrissin*
0	15	30	45	38	52	*Acer velutinum*
0	0	0	15	8	11	*Diospyros lotus*
6	0	23	8	0	8	*Jasminum officinale*
23	0	0	0	15	8	*Gleditschia caspica*
0	0	113	0	15	0	*Juglans regia*
0	8	0	15	0	8	*Carpinus betulus*
0	0	0	8	0	0	*Celtis australis*
0	0	8	0	0	0	*Acer cappadocicum*
0	0	0	8	0	0	*Eriobotrya japonica*
312	1483	1474	1966	1157	3020	Total number

pH values of the upper soil horizon were the following (in decreasing order): natural regeneration (7.11), 70Q : 30Z (7.08), 100 Q (6.77), 50Q : 50Z and 40Q : 60Z (6.61), and 60Q : 40Z (6.51). Differences among treatments were not statistically significant (*Table 2*).

3.3. Correlation among the abundance of tree regeneration and environmental variables

The correlation coefficient between the total number of individuals and the degree of canopy shading was 0.15. The correlation coefficient between the number of species and the degree of canopy shading was 0.34.

The correlation coefficient between the total number of individuals and the litter depth was 0.63. The correlation coefficient between the number of species and the litter depth was 0.59.

The correlation coefficient between the total number of individuals and the pH values of the upper soil horizon was – 0.32. The correlation coefficient between the number of species and the pH values of the upper soil horizon was – 0.44.

3.4. Biodiversity indices

In this study, species diversity (Fisher alpha), evenness (Equitability J) and dominance (Berger-Parker) indices did not show any significant differences among planting and control treatments (*Table 3*). Margalef's richness index was higher under the 60Q : 40Z treatment and lower in the control than in the pure oak, 70Q : 30Z, 50Q : 50Z and 40Q : 60Z treatments (*Table 3*).

3.5. Principal tree species in the six treatments

In this study, *Quercus castaneifolia* represented the greatest percentage of the total regenerating individuals in the different plantations and so did *Morus alba* in the control plots. *Table 4* shows the total number of regenerating individuals of each species, under pure and mixed plantations, and in natural regeneration plots.

4. DISCUSSION

The results of this study confirm the first hypothesis that tree regeneration was more abundant in the understory of the plantations than in areas free of trees in the Hyrcanian Forests of Iran. This coincides with results of other studies regarding this topic from various regions (PARROTTA, 1992; MC CLANAHAN and WOLFE, 1993; GUARIGUATA *et al.,* 1995; POWERS *et al.,* 1997; HOLL, 1999; PARROTTA, 1999; KEENAN *et al.,* 1999; JUG *et al.,* 1999; CARNEVALE and MONTAGNINI, 2002; YIRDAW and LUUKKANEN, 2003).

The second hypothesis of this research, that tree regeneration was more diverse under the mixed plantations than under the pure oak plantation, was slightly confirmed, since the 60Q : 40Z treatment had higher species numbers and higher Margalef's richness index values than the pure oak plantation.

But, the number of regenerating individuals in this research was more than all of other mixed treatments. This is maybe due to the crown structure and the dense branches of Siberian Elm (SIBLEY, 2009), which in mixed treatments with Oak causes to increase of crown intensity and decrease of light in the understory of these plantations.

In general, already a few years after tree establishment, an increase in floral and faunal diversity develops according to the status quo antes and possibilities for recolonization of species. This increase in biodiversity is of great importance due to the functional role, especially of soil fauna, for soil properties and self-regulation potential of intensive forest ecosystems (MAKESCHIN, 1994; JUG *et al.,* 1999).

The presence of a greater proportion of individuals of height class 1 (15 cm – 200 cm) in the understory of the all plantations than in adjacent areas without trees (control) suggests that the relatively high shading conditions and higher litter depth and presence of perches for seed dispersers in this treatments are favorable for arrival and germination and recruitment of tree seeds (PARROTTA, 1992; PARROTTA *et al.,* 1997; LUGO, 1997; CARNEVALE and MONTAGNINI, 2002) and also the spontaneous competitive species (mainly grasses and *Rubus spp.*) were controlled (BALANDIER *et al.,* 2005).

In primary stages of succession in open and destroyed area that the vegetation is not developed yoe, there are limited number of trees and shrubs in uppers strat, but due to presence of grasses the condition for seed germination is difficult and these ares are including low diversity and regeneration.

The results of the correlation analyses suggest that litter depth was factor influencing numbers of individuals, and litter depth and soil pH were factors influencing species richness, with soil pH values having a negative influence. Accumulation of litter contributes to inhibit growth of herbaceous species, thus favoring establishment by tree species. The degree of canopy shading has not influence on tree regeneration and species richness.

The diversity, evenness and dominance indices of the different treatments did not differ significantly. This result agrees with the findings reported by VATANI *et al.* (2007). On the contrary, KIASARY *et al.* (2007) who examined natural regeneration in the understory of *Acer velutinum* plantations and natural regeneration control plots in the Alborz Mountains (Hyrcanian forest) of Iran found that the diversity indices in control plots were higher than plantations.

As biodiversity equals variety at the species level of biological organization, the terms species richness and species diversity have become key concepts in conservation biology. Also species richness is the best tool for conservation biologists because it deemphasizes the many common dominant species in a community. We opine, therefore, the 60Q : 40Z mixture is recommendable to restore natural lowland forests.

In the case of plantations established primarily for rehabilitation of severely disturbed sites, watershed stabilization, and/or native forest restoration, additional knowledge of how planted trees can facilitate, or inhibit, natural successional processes that lead to the development of structurally diverse and functionally stable forest ecosystems is also needed (PARROTTA, 1999). Restoring tree species richness by planting works because the manager can match species to particular site conditions and thus overcome limiting factors that prevent the regeneration of species – rich forests on degraded sites. Once a forest canopy is established, microsite conditions change and wildlife is attracted. Animals are likely to disperse tree species from surrounding forest patches and regeneration of shade-intolerant species can be inhibited.The costs and benefits of managing the regenerating seedling and saplings as an alternative to clearing and replanting should be assessed. In addition to considering the ecological factors influencing tree regeneration, the socioeconomics feasibility of these plantations as practical systems for the recovery of biodiversity in deforested landscapes in the region should be also examined (CARNEVALE and MONTAGNINI, 2002).

5. ABSTRACT

The Regeneration structure and biodiversity of trees and shrub species in the understory of pure and mixed Oak plantations were investigated in the Chamestan Forest and Rangeland Research Station of Iran. Species including *Quercus castaneifolia* (as main species) and *Zelkova carpinifolia* (as associated species) were planted in five proportions (100Q, 70Q : 30Z, 60Q : 40Z, 50Q : 50Z,

40Q : 60Z) 15 years ago in northern Iran. seedlings and saplings of woody plants were divided into two height classes of 15–200 cm and more than 200 cm. Berger-Parker dominance index, α Fisher alpha diversity index, Margalef richness indexand Equitability J evenness indexwere used. The results showed more abundance and diversity of regenerated species in the understory of all oak plantations than in the unplanted control plots and also a greater abundance of regenerated species under pure stands of oak than in mixed plantations. The highest species richness was found in the 60Q : 40Z treatment. The presence of primary forest species in the understory of mixed plantation can help to restore natural forests.

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