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# Effect of *Pseudotsuga menziesii* Plantations on Vascular Plants Diversity in Northwest Patagonia, Argentina

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Additional information is available at the end of the chapter

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## 1. Introduction

Forests biodiversity conservation is a global concern because they are home to 80% of the biodiversity of terrestrial environments [1, 2, 3, 4]. The replacement of all or part of these ecosystems with monocultures creates mosaics of vegetation, contributing to habitat fragmentation [5]. The new landscape includes more homogeneous vegetation units and may differ in patterns and processes from the original landscape formed by primary or secondary forests.

During the second half of the twentieth century there was an increase of areas subjected to forestations with exotic species. It is estimated that about 187 millions ha were planted worldwide, which represents 5% of global forests [2]. The annual growth of forest plantations worldwide is estimated at 2-3 million ha per year [6]. Sixty percent (60%) of forest plantations are located in four countries: China, India, Russian Federation and United States. In the southern hemisphere, emerging forestry countries are: Brazil, New Zealand, Chile, South Africa, Argentina, Uruguay, Venezuela and Australia [7]. In non-tropical areas, a third of the area of native forest destroyed is used for forest plantations [3].

In the West of Chubut, Río Negro and Neuquén provinces in Argentina, the forested area with exotic species reached 70,000 ha in 2007 [8]. The species used are *Pinus ponderosa*, *Pseudotsuga menziesii*, *Pinus radiata* and *Pinus contorta*. In the late 1990's it was estimated that forestation had a rates of 10,000 ha per year [9, 10]. Exotic plantations effects on biological diversity in *Austrocedrus chilensis* forests and mixed shrublands in Temperate Forests of South America are still poorly understood.

Several studies have shown that species diversity decreases in areas of forestations, and seems to depend on the proximity of plantations to native environments and treatments

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prior to afforest. In Congo, diversity of vascular plants was compared in mixed stands of *Eucalyptus - Acacia - Pinus*, with secondary forests and the African savannah which showed a reduction in the number of species in plantations understory at compared to the understory of secondary forest. At the plantations edges, however, the loss of species richness was lower, so that proximity to the pre-existing forest help to maintain diversity over short distances [11]. In a conservation rainforest study, the richness of species was found to be lower in *Coffea arabica* and *Elettaria cardamomum* plantations than in the native forest [12]. On the other hand, at landscape scale, there has been that *E. cardamomum* plantations where shrubs and herbs strata were retained, connectivity was maintained among fragmented forest patches. Similar results were found when analyzing the feasibility of employing commercial pine plantations as complementary habitat to conserve threatened species in Chile [13, 14].

Besides the proximity to native environments, the diversity in forestations it was found related to age. For example, in 20 years old *P. radiata* plantations in New Zealand, *Rubus fruticosus* and other generalist species were frequently found while in later succession (40 years), *R. fruticosus* is replaced by several species of shade-tolerant native ferns and shrubs [15]. Similar results were found in other older plantations of *P. radiata* in New Zealand, where diversity of vascular plants was similar in plantations and nearby native forests, which also was confirmed that plantations provided habitat for some species of birds such as *Apteryx mantelli* [16, 17]. In some cases, older plantations increase the supply of habitat, increases in spatial and vertical heterogeneity, increases in light levels, development of organic soil layers and the associated fungal flora [4]. However, there are some studies that show that diversity does not increase with age of forest plantations. The diversity of the beetles ensemble was lower in older plantations of *Picea abies* than in younger plantations [18].

In Chilean temperate forests, where the replacement of native forests by exotic forestations was important, there was a decrease in the distribution of endangered and vulnerable vascular plants [19, 20]. There was also a loss of *Nothofagus* native forest structure, with the disappearance of strata, as well as decreases in species richness of vascular plants [21, 22]. Similar patterns with decreases in vascular plants, beetles and birds species were found in mixed plantations of *P. menziesii*, *P. radiata* and *Pinus sylvestris* installed in *Nothofagus* forests and *P. ponderosa* plantations instaled in the steppe in Argentina [23, 24]. In other studies it was found that the richness and composition of birds was more affected by the structure of plantations than by their tree species composition [25, 26]. While a study on ant assemblages showed that in plantations there are decreases in abundance and changes in the composition of species respect to the nearby steppe [27]. All these studies support the hypothesis that high individual density in forest plantations affect biodiversity within them, and propose lower density of trees as an alternative to improve biodiversity.

Diversity loss in South America temperate forests, is a topic of great interest since these ecosystems are characterized by high levels of endemism, a product of a deep biogeographic isolation with common ancestry biota, as well as its extremely heterogeneous floristic composition, derived from various biogeographical sources (e.g. Gondwana, Neotropical, Boreal) [28, 29]. The vascular flora has about 34% of woody genera endemic. Most of the

endemisms are monotypic with only one species per genus [28]. *Austrocedrus chilensis* is an endemic monotypic species of South America Temperate Forests, with a smaller distribution area than that occupied in ancient geological times [30, 31]. At the present, this species has serious conservation problems due to multiple anthropogenic disturbances, and is included in the IUCN Red List in the "vulnerable" status [32]. This chapter presents some results related to vascular plants diversity in *A. chilensis* forests, and mixed shrublands when they are replaced by the exotic conifer *P. menziesii* plantations.

### 1.1. Hypothesis

In *P. menziesii* forestations in Patagonia there is reduced vascular plant diversity compared with the natural communities they replace.

### 1.2. General aim

Study and compare the vascular plants diversity in *P. menziesii* forestations and *A. chilensis* forests and mixed shrublands adjacent in the Northwest of Chubut Province and Southwest of the Río Negro Province, Argentina.

### 1.3. Specific aims

1. To estimate the alpha and beta diversity of vascular plants in *P. menziesii* plantations and contiguous *A. chilensis* forests and mixed shrubland.
2. To analyze the similarity in the composition and abundance of herbaceous and woody shrubs growing in *P. menziesii* forestations, *A. chilensis* forests and mixed shrublands.

## 2. Methods

### 2.1. Study system

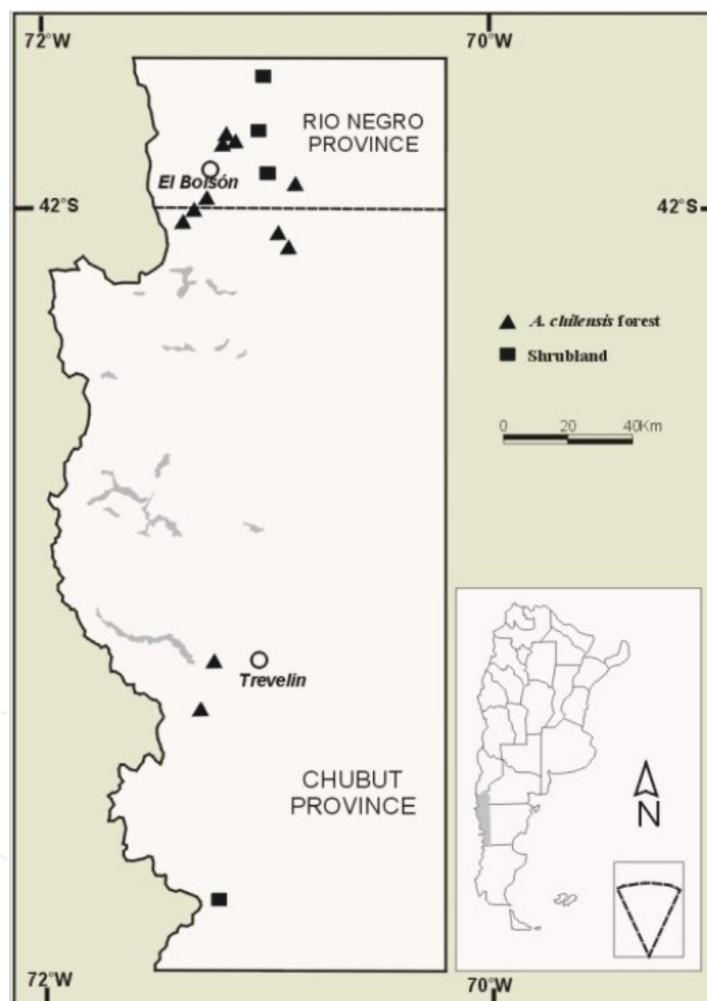
The study area includes the West of Chubut and the Southwest of the Río Negro Provinces, in Argentina, between the localities of Corcovado 43° 32' 36.54" South, 71° 26' 37.5" West and San Carlos de Bariloche 41° 8' 16.83 " South, 71° 17' 12.09" W (Fig. 1). In this area there are about 103 *P. menziesii* plantations. The planted surfaces vary between 0.5 and 12 ha, and initial densities are 1.000 trees per ha [9, 33]. The age of the plantations of *P. menziesii* studied for 2006, ranged between 17 and 35 years old, and all had reached reproductive maturity. *P. menziesii* is native to North America where it is distributed between 55° and 19° N, in temperate climates [34]. In Patagonia, Argentina, *P. menziesii* plantations were installed in a range of precipitations between 1500 mm to 600 mm. In this area, various native plant communities were replaced by afforestations, but the best growths are associated with the natural range of the forests of *A. chilensis* and the mixed shrublands, so that these environments have a higher substitution pressure.

The mixed shrublands are characterized by a shrub stratum of 5 to 7 m high, in which the most abundant species are: *Diostea juncea*, *Lomatia hirsuta*, *Embothrium coccineum*, *Schinus*

*patagonicus*, *Fabiana imbricata* and some isolated trees of *A. chilensis* and *Maytenus boaria*. It is also distinguished is a shrub sub-stratum with similar species composition, and a herbaceous stratum, dominated by species of the families *Poaceae*, *Asteraceae* and *Rosaceae*. In *A. chilensis* forests a distinguished tree stratum of 15 m in height is found, in which *A. chilensis* is the dominant species. The shrub stratum was mainly composed by *S. patagonicus*, *L. hirsuta*, and *E. coccineum*, among others. *Asteraceae* and *Poaceae* dominate the herbaceous stratum.

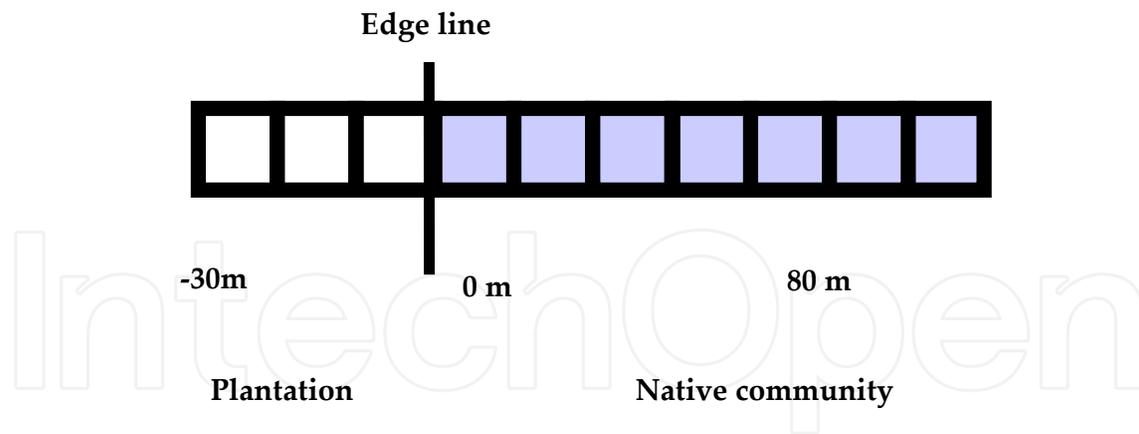
## 2.2. Sampling design

Four sites were selected where *P. menziesii* plantations were adjacent to mixed shrublands and eleven sites of *P. menziesii* plantations adjacent to *A. chilensis* forests (Fig. 1).



**Figure 1.** Map of the study area and locations of study sites.

On each site (plantation-native community edge area) a transect perpendicular to the edge line was established (Fig. 2). Each transect was subdivided into 11 plots of 100 m<sup>2</sup>, three plots were installed in plantations at -30, -20 and -10 m from the edge line, and eight in the native communities at 10, 20, 30, 40, 50, 60, 70 and 80 m from the edge line.



**Figure 2.** Scheme of a sampling transect established in a plantation-native community edge area, sampling units (plots) and edge line are indicated.

In each 100 m<sup>2</sup> plots, the composition and abundance of vascular plants was registered and measured, according to the following classification:

1. herbaceous stratum: included herbaceous and woody species seedlings below 10 cm height. The measurements were performed using four 0.5 m<sup>2</sup> circular plots randomly selected within each sampling unit of 100 m<sup>2</sup>. The species cover percentage was measured, and individual numbers for woody seedlings counted.
2. shrub stratum: included shrubs, woody vines and woody species saplings above 10 cm in height and below 5 cm in diameter at breast height (DBH). The number of individuals by species was counted on a plot of 25 m<sup>2</sup> randomly selected in each 100 m<sup>2</sup> plot.
3. tree stratum: includes trees and shrubs greater than 5 cm DBH. All individuals were counted in the 100 m<sup>2</sup> plot.

Vascular plant field samples were collected and identified in the laboratory. The reference of support was Patagonian Flora collection volume VIII, Parts I, II, III, IVa and b, V, VI and VII [35].

### 2.3. Alpha diversity data analysis

The Alpha diversity analysis was made by species accumulation curves, by using EstimateS software [36, 37]. The vascular plants diversity was analyzed in *P. menziesii* plantations and in the adjacent mixed shrublands, as in plantations and *A. chilensis* forests contiguous. The Clench equation was used, which has demonstrated good fits for multiple sampling of taxa of species [ $S_n = a*n / (1+b*n)$ ], where:

$S_n$  = mean number species for each sampling unit

a = increase rate of new species at the beginning of samplings

b = is a parameter related to the shape of the curve

n = number of sampling units

This function was applied using a nonlinear estimation, through the iterative adjustment of Simplex and Quasi-Newton algorithm with Statistica 7 [38, 39]. The fit of the equation to the accumulation curve, was analyzed by calculating the Determination Coefficient:  $R^2$ . The

slope of the curve (S) when the number of samples is maximum was used to assess sampling quality [ $S = a / (1 + bn)^2$ ] [39]. The flora proportions recorded provided further information on vegetation sampling quality [ $[S_{obs.}/(a/b)] * 100$ ] [39].

#### 2.4. Beta diversity data analysis

The diversity between habitats was analyzed by using the Jaccard similarity index [37]. This index calculated the species replacement degree across environmental gradients. Where environments are very different, and there are no shared species a 0 value occurs. If all species are shared the index value is set to 1.

This study the Jaccard similarity index [ $I_j = c / a+b-c$ ] was obtained for the following pairs of communities: *P. menziesii* plantations (A)-mixed shrublands (B), *P. menziesii* plantations (A) – *A. chilensis* forests (B).

Where:

a = vascular plant species number in A community

b = vascular plants species number in B community

c = vascular plants species number in both A and B communities.

#### 2.5. Analysis of similarity in composition and abundance of herbaceous and shrubs species strata by ANOSIM and MDS

In order to determine if plantations affected the species composition of native communities, the similarity in composition and abundance of herbaceous and shrubs in plantations and native communities were analyzed by using the multivariate ANOSIM method [40]. This analysis performs permutations on similarity matrices and produces a statistic (R) which is an absolute measure of distance between groups. An R value close to 1 indicates that the assemblages are very different, while a R value close to 0 indicates that the assemblages are similar [40]. To illustrate the assembly of herbaceous and shrub species found in plantations and native communities the Non-Metric Multidimensional Scaling (NMDS) method was applied with the similarity index of Bray-Curtis. These analyzes were performed using the statistical program PRIMER-E Ltd. [41].

### 3. Results

#### 3.1. Alpha diversity analysis in plantations and native communities

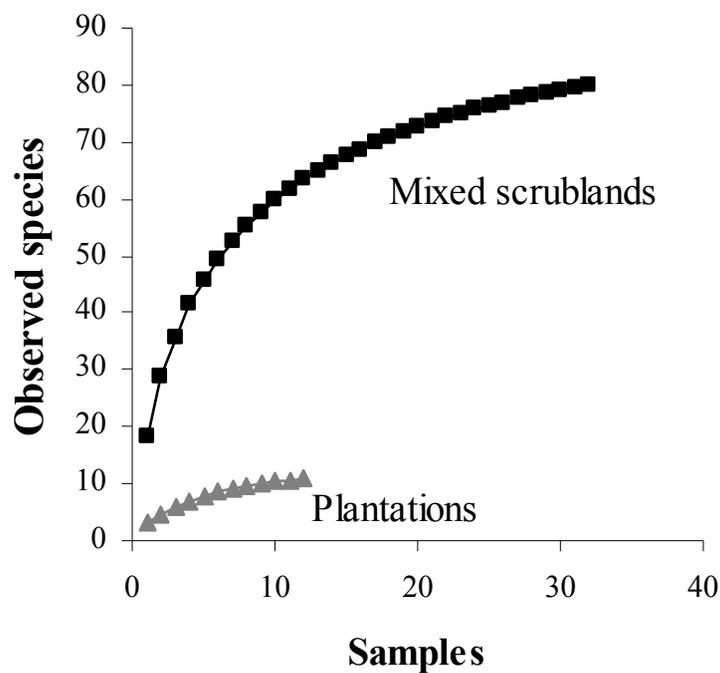
The species accumulation curves obtained from mixed shrublands and *P. menziesii* plantations are presented in Figure 3. Both curves show how species richness increases with increasing number of sampling units. They also show that species richness is higher in mixed shrublands than in contiguous *P. menziesii* plantations.

Model (1) describes the species accumulation curve in the mixed shrublands, the model (2) describes species accumulation curve in adjacent *P. menziesii* plantations (n = number of sampling units).

$$S_n \text{ mixed shrublands} = 18,4 * n / (1 + 0,2 * n) \quad R^2 = 0,99 \quad (1)$$

$$S_n \text{ P. menziesii plantations} = 3,3 * n / (1 + 0,22 * n) \quad R^2 = 0,99 \quad (2)$$

The Determination Coefficients ( $R^2$ ) of both models indicate that adjustments to the models accumulation curves are highly representative. Those models were used to calculate the slope of the tangent line when it reaches the maximum number of sampling units. For the species accumulation curve obtained in *P. menziesii* plantations, the slope was  $S = 0.25$  ( $n = 12$ ), so it would have been possible to add new species by increasing the sampling units number. The proportion of vascular plants recorded in *P. menziesii* plantations was 73%. In mixed shrublands, the slope was  $S = 0.33$  ( $n = 32$ ) with a proportion of 86% of vascular plants recorded.



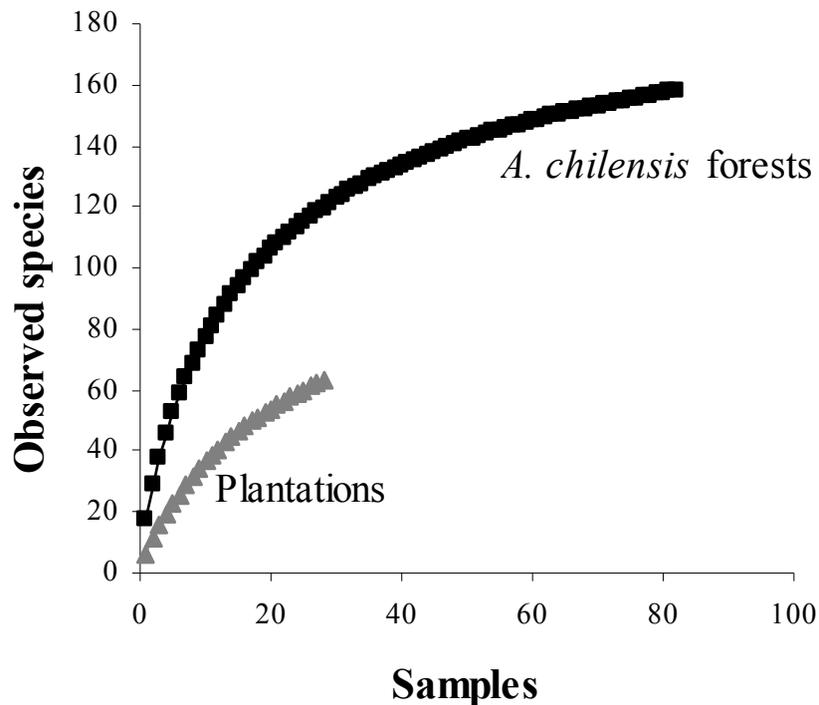
**Figure 3.** Species accumulation curves obtained from mixed shrublands and the adjacent *P. menziesii* plantations.

The species accumulation curves obtained from *A. chilensis* forests and *P. menziesii* plantations also show a greater species richness in *A. chilensis* forests than in *P. menziesii* plantations (Fig. 4).

Model (3) describes the species accumulation curve in *A. chilensis* forests, model (4) describes the species accumulation curve in adjacent *P. menziesii* plantations ( $n =$  number of sampling units).

$$S_n \text{ A. chilensis forests} = 13,05 * n / (1 + 0,07 * n) \quad R^2 = 0,99 \quad (3)$$

$$S_n \text{ P. menziesii plantations} = 5,71 * n / (1 + 0,05 * n) \quad R^2 = 0,99 \quad (4)$$



**Figure 4.** Species accumulation curves obtained from *A. chilensis* forests and the adjacent *P. menziesii* plantations.

The Determination Coefficients ( $R^2$ ) of both models indicate that adjustments to the models accumulation curves are highly representative. For the species accumulation curve obtained in *P. menziesii* plantations, the slope was  $S = 0.88$  ( $n = 28$ ), so it would have been possible to add new species by increasing the number of sampling units. The sampling registered only 60% of flora of *P. menziesii* plantations ( $n = 28$ ). In the *A. chilensis* forests contiguous afforestations, for  $n = 82$ ,  $S = 0.28$ , so that also have been possible to obtain a greater number of species by increasing the number of sampling units. There, sampling showed 85% of flora of *A. chilensis* forests.

### 3.2. Beta diversity

When similarity was analyzed between *P. menziesii* plantations and mixed shrublands, the Jaccard index was  $0.14 \pm 0.02$  ( $\pm$  SE), indicating that plantations and mixed shrublands contiguous are dissimilar in species composition. In the same way *P. menziesii* plantations and *A. chilensis* forests showed that both adjoining communities were dissimilar in vascular plants composition, the Jaccard index reached a value of  $0.17 \pm 0.04$  ( $\pm$  SE).

### 3.3. Floristic similarity between *P. menziesii* plantations, *A. chilensis* forests and mixed shrublands

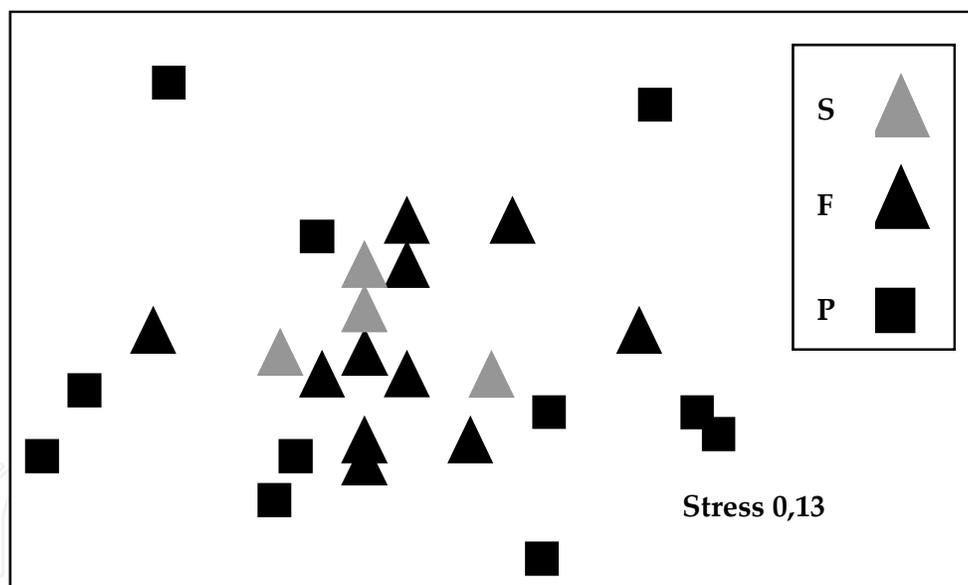
According to the R value obtained, herbaceous species composition was similar in the three communities studied ( $R = -0.106$ ,  $p = 4.3\%$ ). However, the confidence level for the analysis was not significant ( $p < 0.1\%$ ). The greatest similarities in herbaceous species composition were recorded from *A. chilensis* forests and adjoining plantations, while communities with

greater differences in herbaceous species composition are plantations and mixed shrublands (Table 1).

Groups	R	Significance levels (%)
<b>F-S</b>	0,256	95,6
<b>F-P</b>	-0,02	65,4
<b>S-P</b>	-0,366	<b>99,6</b>

**Table 1.** Analysis of similarity (ANOSIM) of herbaceous species found in *P. menziesii* plantations (P), *A. chilensis* forests (F), and mixed shrublands (S). R value is a measure of similarity of species in different communities, R values close to 1 indicate differences, and 0 indicate similarities in species composition. Significant values highlighted in bold ( $p < 0.1\%$ ).

Non-Metric Multidimensional Scaling (NMDS) analysis, showed greater variability in the composition and abundance of herbaceous species in the different sites corresponding to *P. menziesii* plantations. Most points (sites) were located towards the periphery of the graph and away from each other (Fig. 5). While in the center of the graph the cloud of points corresponding to mixed shrublands and *A. chilensis* forest sites, showed a more similar species composition between both native plant communities. Stress = 0.13, equivalent to a good level of confidence.



**Figure 5.** Graphical representation of herbaceous composition and abundance (NMDS) in different communities: F = *A. chilensis* forests, P = *P. menziesii* plantations, and S = mixed shrublands.

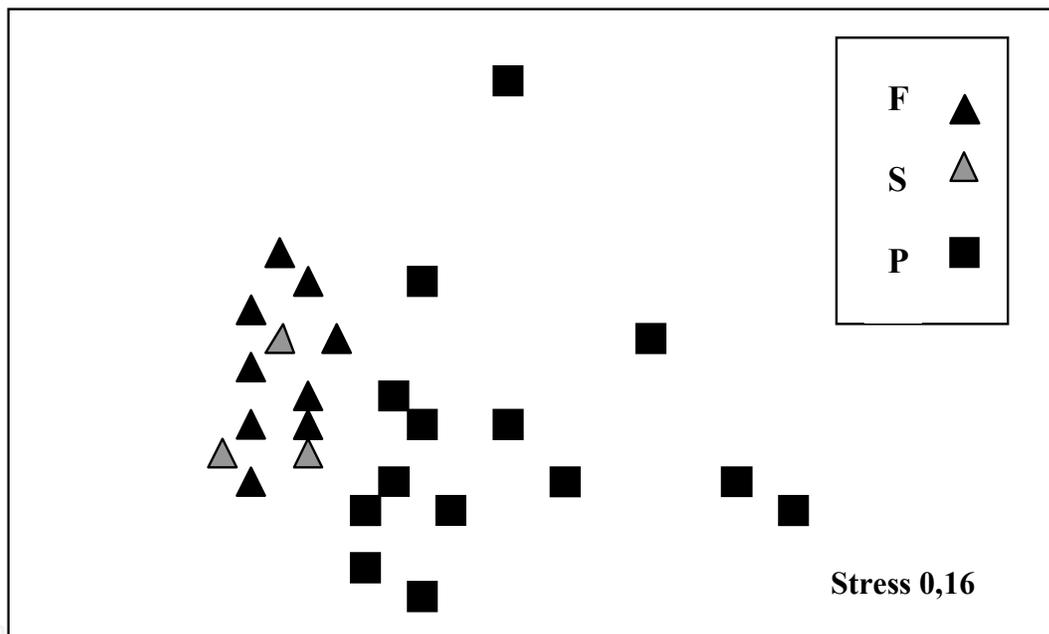
Shrub species composition was similar between the communities ( $R = 0.2$ ,  $p = 0.4\%$ ). The more similar communities to each other on shrub species composition were mixed shrublands and *A. chilensis* forests, but as the above analysis, the confidence level was not significant. The least similar communities were forests and plantations (Table 2).

The NMDS analysis shows two clouds of points, one to the right and the other one to the left of the graph (Fig. 6). The right cloud includes points corresponding to *P. menziesii*

plantations. This pattern indicates that composition and abundance of shrub species assemblages is more similar between plantations than between plantations and neighboring native communities. To the left, the points cloud is less scattered, includes sites of *A. chilensis* forests and mixed shrublands. This analysis shows greater similarity in the assembly of vascular plants in *A. chilensis* forests and mixed shrublands.

Groups	R	Significance levels (%)
F-S	-0,13	78,6
F-P	0,34	0,1
S-P	0,20	10,2

**Table 2.** Analysis of similarity (ANOSIM) of shrubs species found in *P. menziesii* plantations (P), *A. chilensis* forests (F), and mixed shrublands (S). R value indicates the species similarity between the different communities, R values close to 1 indicate differences, and 0 indicate similarities in species composition.



**Figure 6.** Graphical representation of the ordination (NMDS) of shrub stratum species in different communities: F = *A. chilensis* forests, P = *P. menziesii* plantations, and S = mixed shrublands.

#### 4. Discussion and conclusions

In the plant communities studied, the greatest vascular plant diversity was found in *A. chilensis* forests, where 168 vascular plants species were recorded, while in adjacent *P. menziesii* plantations were 37.5% of this number of species. In mixed shrublands 86 vascular plants species were recorded, and only 13% of this species number in contiguous *P. menziesii* plantations. Species accumulation curves allowed comparison of species richness in adjacent communities: *P. menziesii* plantations- *A. chilensis* forests, and *P. menziesii* plantations- mixed shrublands. Greater species richness was observed in native communities than in plantations, confirming that there is a loss of vascular plant diversity in *P. menziesii* plantations.

While the similarity analysis (ANOSIM) showed a similar species composition between all pairs of communities, these analyses was not significant. The similarity analysis based on the composition and abundance (NMDS) for herbaceous and shrub strata, showed that both mixed shrublands and *A. chilensis* forests are more similar to each other than with the contiguous *P. menziesii* plantations. It is striking that different native communities (forests and shrublands) separated by distances of up to 400 km presented the highest similarity of vascular plants. If there was no effect of plantations on vascular plants composition and abundance, a greater similarity between native community and their corresponding neighboring plantation would be expected. In general terms, this analysis confirms that *P. menziesii* plantations changed the native communities with a noticeable loss of diversity and changes in the abundance and composition of vascular plant.

The vascular plants loss in plantations adjacent to mixed shrublands can be explained by decreases in radiation and environmental heterogeneity in plantations [42]. The environmental heterogeneity is an important factor that promotes biodiversity [23, 43]. Differences in radiation between shrublands and plantations, are stronger than differences between *A. chilensis* forests and *P. menziesii* plantations. So understory species of *A. chilensis* forests, could find a more similar environment in adjacent plantations, than species in mixed shrublands [42]. Furthermore, *A. chilensis* forests are a major source of vascular plants diversity, which may spread to adjoining plantations. While the native communities proximity to plantations promotes species dispersal towards plantations, environmental conditions in plantations prevent the establishment.

The diversity loss found in *P. menziesii* plantations that replaced *A. chilensis* forests and mixed shrublands is similar to the results found in Chile, South Africa, New Zealand and Argentina [11, 19-23, 44, 45]. All these studies support the idea that there is a loss of diversity in forest plantations. This study shows the effects on vascular plants diversity when native ecosystems are replaced by exotic species forestations. In addition to changes in vascular plant diversity in forested areas, there are other edge effects that alter vascular plant structure in the native communities surrounding *P. menziesii* plantations [42]. One of the most important processes recorded in the edge areas is the establishment and dispersion of *P. menziesii* seedlings and saplings from *P. menziesii* plantations [46, 47]. These invasion processes together with diversity loss contribute to native ecosystems degradation.

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