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Original Article

Effects of fire on forest communities and sclerophyllous scrubs in Central Chile as a basis for the formulation of restoration guidelines

Orman yangınlarının Orta Şili bölgesindeki orman toplulukları ve sklerofil çalılıkları üzerindeki etkileri

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ABSTRACT

The effects of fire on forest and Mediterranean scrubs in four regions of Chile were studied. The main objective was to determine different levels of damage in watersheds with forest and native sclerophyllous scrubs belonging to the most valuable plant formations in Central Chile. The methodology consisted of the characterization of sampling areas that were qualitatively and quantitatively compared with the characterization of forests and shrublands without recent affectations of fires. Four regions of Chile were evaluated, where fires are concentrated in areas with sclerophyllous native vegetation. In each region, two sampling areas were selected to study the effects of fire. Three classifications were made based on structure, species composition, and response to fire. These were: deciduous scrub consisting of *A. caven* (tree), *R. moschata* (bush), and *A. barbata* (herbs); sclerophyllous evergreen scrub consisting of *L. caustic-C. alba*-and a mixed scrub of *P. boldus* (tree)-*R. trinervia* (scrub) and *A. barbata*. A dendrogram was produced on the relative abundances and the Bray & Curtis Similarity Index of the species. In addition, the results indicated an initial stage of damage to the soil structure, erosion processes, and water transport due to hydrophobicity at different levels of fire intensity, but recovery was observed a few weeks after the fire. Recovery was more apparent in the soil structure and cover of the scrub vegetation and later the tree species. These results provide useful background for the preparation of restoration, reforestation programs, and actions for the conservation of plant species vulnerable to the impact of wildfires.

Keywords: Fire behaviour, sclerophyllous forest, wildfires

ÖZ

Bu çalışmada, orman yangınlarının Şili'nin dört bölgesindeki orman ve Akdeniz çalılıkları üzerindeki etkileri incelenmeye çalışılmıştır. Çalışmanın ana amacı, Orta Şili bölgesindeki en değerli bitki oluşumlarına ait orman ve yerli sklerofil bodur çalılardaki farklı hasar seviyelerinin belirlenmesidir. Çalışma metodolojisi, ormanların ve çalılık örnekleme alanlarının, yangın etkileri olmaksızın nitel ve nicel olarak karşılaştırılmasından oluşmaktadır. Yangınların sklerofilöz doğal bitki örtüsüne sahip alanlarda yoğunlaştığı Şili'nin dört bölgesi değerlendirilmiştir. Her bölgede yangının etkilerini incelemek için iki örnekleme alanı seçilmiş olup, yapı, tür kompozisyonu ve yangına tepkiye göre üç sınıflandırma yapılmıştır. Bu sınıflandırmalar; *A. caven* (ağaç), *R. moschata* (çalı) ve *A. barbata* (otlar) bitkilerinden oluşan yaprak döken çalılık; *L. caustic - C. alba* sklerofilli yaprak dökmeyen çalılık ve *P. boldus* (ağaç), *R. trinervia* (çalı) ve *A. barbata* bitkilerinden oluşmaktadır.Çalışmada, bitki türlerinin alanda bulunma oranları ve Bray & Curtis Benzerlik İndeksi'ne göre bir dendrogram oluşturulmuştur. Elde edilen sonuçlara göre, farklı yangın yoğunluğu seviyelerinde su geçirmez toprak tabakaları nedeniyle, toprak yapısında, erozyon süreçlerinde ve su naklinde birinci derecede hasar oluştuğunu görülmüş olup, yangından birkaç hafta sonra alanda iyileşmelerin olduğu gözlenmiştir. İyileşmelerin daha çok maki bitki örtüsünün toprak yapısında ve örtüsünde ve daha sonra ağaçlarda olduğu görülmüştür. Elde edilen sonuçların, restorasyon çalışmaları, yeniden ağaçlandırma programları ve orman yangınlarının etkisine karşı savunmasız bitki türlerinin korunmasına yönelik çalışmaların hazırlanmasında yarar sağlayacağı düşünülmektedir.

Anahtar Kelimeler: Yangın davranışı, sklerofil ormanları, orman yangınları

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INTRODUCTION

The increase in forest fires of great extent and severity has been a common trend in practically all Mediterranean ecosystems of the world (Castillo et al., 2020). In forests and sclerophyllous scrub, the presence of fire is a part of the natural cycle. However, the increasing frequency, magnitude, and severity of fires in these habitats, compounded by recurrent droughts and climate change, has inadvertently increased their vulnerability. Vast areas of native forests are witnessing increases in dryness and wilting, conditions that favor the proliferation of fires. This has prompted the need to seek new strategies for forest recovery based not only on preventative measures but also on direct actions for the recovery of species in the ecological succession (Castillo et al., 2012). Additionally, strategies should include sound recommendations on soil treatment and burnt area management through modification of local soil conditions as well as the plants that will be part of the new vegetation cover. The area selected for this research corresponds to a vegetal landscape representative of the native flora of Central Chile, classified as an area of high ecological value with important fluctuations in temperature and humidity. It is also an area that is consistently affected by forest fires in periods of little rain and high temperatures with this risk being exacerbated by its remote location. In a study on the effects of fire on the native vegetation of Chile, Fernández et al., (2010), point out that fire can significantly alter the stability of ecosystems. Furthermore, it has a modifying effect on the structure and composition of species (Armesto et al., 2009), Fire also affects the functioning of post-fire regeneration (Pausas, 1999) and water availability for plant growth and consequently for soil protection (Becerra, 2017; Pausas et al., 2008). The interaction of these factors can cause a loss of ecosystem functions that are difficult to recover (Castillo et al., 2013; García-Chevesich, 2015).

Similar observations have been made by Castillo (2006) and Quintanilla (2000), who studied the effects of fire in the Mediterranean coastal zone of Central Chile. Under different intensities of post-fire rains, the effects on hillsides with different categories of fire severity were studied. In general, no significant differences were found in the loss of soils (Castillo, 2015), but in the availability of water for the regeneration processes at three and six months after the initial impact of the fires. In the case of large plant species, such as the Chilean palm (*Jubaea chilensis* Mol. Baillon), serious negative effects were found where there was a loss of mechanical stability of the soils and adult trees fell at an increased rate as a result of laminar erosion. This, together with the findings of Castillo et al., (2017) and Keeley et al., (2008) who reported on the varying effects of fire on the soil, water availability, and effects on vegetation, shows that the plant landscape is continuously adapting to shorter fire frequencies between episodes, thereby promoting changes from dense forests to degraded scrubs with a predominance of invasive species (De Luis et al., 2004). As a consequence of these findings, the current research is aimed at studying how the response to fire influences the interactions in the growth and development of the main plant species that make up the sclerophyllous forest and scrub. To achieve this, different combinations of species and populations in different geographical locations were related at different scales of magnitude with the intent of establishing suitable species combinations that are amenable to restorative actions. These interactions have been studied considering the most representative species that normally survive on burnt soil, and that belong to the main plant communities that are most vulnerable to recurrent fires in the geographical area.

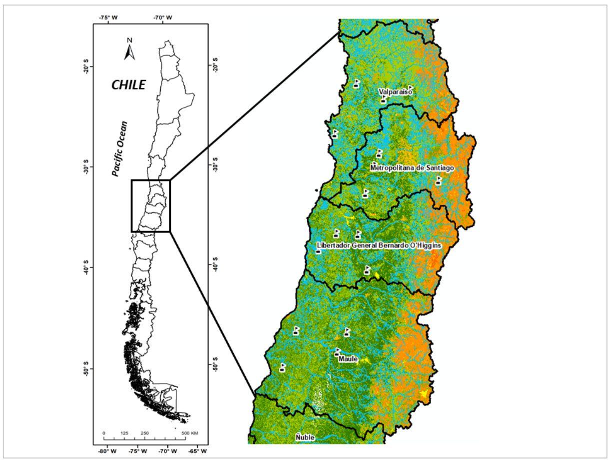

Figure 1. Study area. Central Chile. The flags show the sample regions in the main watersheds. The four regions are: Valparaíso, Metropolitan Region, Libertador General Bernardo O'Higgins, and Maule. Within each region are the sample plots (two for each region; numbered 1–8)

MATERIALS AND METHODS

A sample of forest fires that occurred between 2005 and 2019 in different watersheds in the central zone of Chile was considered for this study (Figure 1). During this period there was a significant shortage of rainfall, which resulted in considerable deterioration of vegetation and increased the frequency and magnitude of forest fires. The regeneration times for plants and the erosion processes on slopes in the watersheds exposed to the greatest fire damage were studied to determine the deterioration in the watersheds (Brown and Davis, 1973; Jardelet al., 2003; Jordan et al., 1987).

Forest fires that affected species belonging to the native forest and scrub that represented the sclerophyllous forests of Central Chile were selected. These are plant communities that are consistently affected by forest fires, and in recent years, have been exposed to escalating fire frequencies that cumulatively affect the hydrological cycle in watersheds as well as erosion processes (Keeley, 2009; Molina et al., 2014). The samples of forest fires were drawn from four regions in Chile and in each region, the sampling areas determined were representative of the plant communities. Two 1 km^2 (100 ha)samples were selected per region, inside which two sample plots and two control plots, each measuring 100 m^2 were delineated. This was repeated in all four regions.

Each plot inside a watershed region had the following characteristics: closed, approximately 50 hectares delimited by aerial photographs, with different degrees of vegetation cover, all possible exposures to be found, and with variable land inclination. In these last two aspects (exposure and slope), the plots were classified into eight classes (N, S, E, W, NE, NW, SE, SW) and five slope categories (0–15%, 16–30%, 31–45%, 46–60%,>60%). The delimitation of the 100 m^2 was made by incorporating random points into a Geographic Information System (GIS), for the definition of the center of the plot. In each case, the bearing-distance method was applied. To carry out a census of all the plants and trees affected by fire, scarring on logs and the ground, specifically the characteristics of the ashes and the regeneration time of shoots, were taken into account. Additionally, soil stability and the composition of post-fire plant communities were assessed. Fire effects on the hydrological cycle were evaluated on the surface, through the qualitative evaluation of the effect of rain on soil compaction and loss in the weeks after the fire.

Evaluations of the watersheds were based on the determination of fire severity (Fulé et al., 2003; Castillo et al., 2016), and hydrophobicity (water repellency) of surfaces burnt to varying degrees of severity (García et al., 2019). Additionally, a physiognomic characterization of the vegetation found on the steep slopes of the hills affected by the fire and their recovery characteristics, based on the physical and mechanical properties of the watersheds, were carried out. The severity scale used identified six categories of affectation where 'I' represented the lowest affectation and 'VI' maximum affectation (Castillo et al., 2016). In Castillo et al., (2016), the indicators for severity used include soil, water and, vegetation components while in the present study, the same scale will be applied for comparisons between burnt and unburnt areas.

RESULTS AND DISCUSSION

The watersheds affected by forest fires were evaluated by collecting data from the eight sample plots found in the four regions under study. An initial measurement showed a soil exposure with a high level of severity according to the Castillo et al., (2016) scale (Figures 1 and 2). The dragging processes of fine material after a fire caused an initial erosion process that was not significant enough to deter the reestablishment of the native plants. In fact, three weeks after a fire in five of the eight burnt areas, a first vegetation cover is produced which protects the watersheds and reduces the loss of primary soil productivity. García et al., (2019) carried out water repellency tests in basins affected by high-intensity forest fires in the same research areas and found that the infiltration capacity in burnt forests was not affected whereas it was in scrub and soils exposed to high levels of solar radiation on high terrain slopes.

Figure 2. a-d. Samples of soil and vegetation in burned sectors, belonging to two basins of the VII Region. Water repellency analyzes were performed on this material using the infiltration time. The areas with the highest fire intensity were considered for the construction of restoration works. Photos by the author (2019). (a) south exposure on the upper slope of the basin, with moderate severity (II), (b) north exposure with high severity (III-IV), (c) sector used for water repellency testing, (d) flat sector of the hydrologic watershed, with greater retention of nutrients and less superficial flow of burnt material

The composition and distribution of the main forest and native scrub species, affected by the forest fires, found in each of the eight sample plots were documented. Transportation of ash material was more apparent in slopes with a northern exposure compared to those with southern exposure. However, in both types of slopes and slopes of differing inclines, there was the regeneration of vegetation after fires by way of a population sequence (Table 1). This sequence was associated with the severity scale. It was observed that partial basin protection for regions V and VII occurred faster than in regions RM and VI. This is because areas with dense vegetation leave more burnt residue after a fire and this provides more burnt residual biomass for soil protection. Furthermore, this burnt residual biomass is a micro-habitat for fauna that start appearing 3–5 weeks post-fire and the establishment of new pasture. In four of the eight sample plots, specifically in the RM and VI regions, watershed protection and regeneration processes were affected by the presence of large animals (cows and horses).

The most severe effects were concentrated in the surface biomass and the first centimeters of soil and roots exposed to combustion.The most severe effects were focused observed in the upper parts of the basins, while in the lower parts the areas with the greatest slope and at highest risk of rainfall damage were also vulnerable. To prevent further degradation, two interventions were employed. The first was planting native species to cover the soil exposed to erosion, and to protect the slopes from the impact of the transfer of material from the upper parts of the basins to the lower parts (deposit zone). The second intervention was the construction of slope containment structures from remnants of the fire to also counter material drag as shown in Figure 3.

The process is based on the initial evaluation of fire intensity and severity described above, followed by an interpretation of the affectations (Saglam et al., 2008). This would subsequently be linked with the measures proposed for each of the sample plots for the restoration of the watershed with sclerophyllous forest and scrub. Being in different regions means the sample plots would experience different effects from the fires and as such their restoration and mitigation measures would differ (Muñoz and Fuentes, 1989).

In general, the floristic composition of all the habitats assessed is indicative of a history of intensive burning, logging, and use

Table 1. Sequence of species in the regeneration of burnt areas on the slopes of watersheds and their associated severity scales. The species presented correspond to a representative sample of the sclerophyllous forest and scrub of Central Chile

		Burnt areas of 100 m² (presence of plant species in decreasing order)					
Region	Sector	1	2	3	4	Test (without damage with fire)	Severity Castillo *et al.,* (2016)
RM	1	Litre → Quillay → Colliguay → Tevo	→Espino → Maitén → Quillay	Espino → Litre	Espino → Litre	Quillay → Espino → Colliguay → Maitén	III
	2	Litre → Quillay →Colliguay → Palqui → Cactáceas	Retamilla → Pingo Pingo → Cactáceas	Quillay → Litre	Litre → Quillay	Quillay → Litre	III
V	3	Espino → Tevo → Boldo → Litre	Boldo → Azara → Litre → Tevo → Molle	Espino → Tevo → Boldo	Espino → Tevo → Boldo → Litre	Espino → Tevo → Litre	V
	4	Chusquea → Litre → Molle	Litre → Tevo → Puya → Molle	Chusquea → Boldo → Litre	Peumo → Boldo → Molle → Litre → Matico	Chusquea → Litre	IV-V
VI	5	Espino → Boldo → Tevo	Boldo → Tevo	Quillay → Espino → Boldo → Tevo	Espino → Boldo → Tevo → Litre	Espj.ino → Tevo → Litre	III
	6	Espino	Espino → Maitén	Espino → Maitén → Boldo	Espino	Espino	IV-V
VII	7	Espino → Litre → Peumo → Boldo → Tevo	Espino → Litre → Tralhuén	Espino → Litre	Espino → Tralhuén → Boldo → Litre	Espino → Boldo → Berberis → Litre → Peumo	III-IV
	8	Espino → Maitén	Espino → Maitén	Espino → Maitén	Espino → Maitén	Espino → Litre → Maitén	II-III

Figure 3. Location of the lower part of a fine materials deposit basin after the first rains. In this case, the construction of a slope containment structure to reduce material drag. Photo taken in El Maule (Region VII), in January 2018

as pasture before the 2017 fires. The structure and composition of the vegetation are variable and show a gradient of human disturbance, from deciduous scrubs (greater degradation) to evergreen scrubs (less degradation). Vegetation types observed in the sample plots are as follows:

a) Deciduous scrub consisting of *A. caven* (tree), *R. moschata* (bush) and *A. barbata* (herb).
b) Sclerophyllous evergreen scrub consisting of *L. caustica–C. alba,*
c) Mixed scrub of *P. boldus* (tree)–*R. trinervia* (scrub) and *A. barbata.*

To integrate the information collected in the different sample plots, a dendrogram was prepared using the Bray and Curtis similarity methodology (Figure 4).

In the areas where *A. caven* (espino) was present, conditions were favorable for new plant propagation as well as regrowth of other companion species such as *R. moschata*, *Baccharis spp*, and other exotic species e.g. *Prunus sp*. This trend is also present in other communities of species associated with *A. caven*. This is in agreement with Smith et al., (2012) who concluded that *A. caven* protects seeds and provides shelter for other species from livestock and fire, among other factors.

These forest types also have strong structural differences within a sample plot and between watersheds. Crown coverage and herb coverage varies greatly. The level of coverage influences degradation and exposure to erosion processes. Deciduous scrubs are highly degraded, have poor tree and scrub cover, and a strong cover of native and exotic annual grasses. Mixed scrubs have less degradation, with greater coverage of trees and scrubs (sclerophyllous and deciduous) and less coverage of grasses (Figure 5). Sclerophyllous scrubs are mainly covered by trees, although due to the high degradation, a vibrant herbaceous and scrub component can still be found. The composition and structure of the forests in the study area are still far from an undisturbed evergreen sclerophyllous forest and can be described as a community containing *C. alba–L. caustica* and with a little cover of scrubs and exotic grasses.

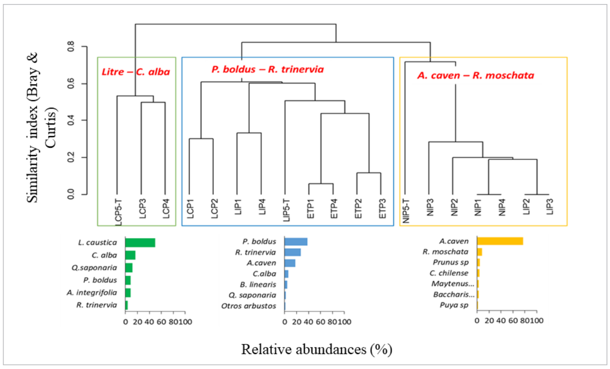

Figure 4. Types of vegetation in the sclerophyllous forest of the localities monitored between 2017 and 2018. The dendrogram shows the floristic dissimilarities between the plots raised in the localities of "*Los Coipos*" (LC) {sampling site 1}, "*Limache*" (LI) {sampling site 2}, "*Nirivilo*" (NI) {sampling site 5} and "El Toco" (ET) {sampling site 7}.

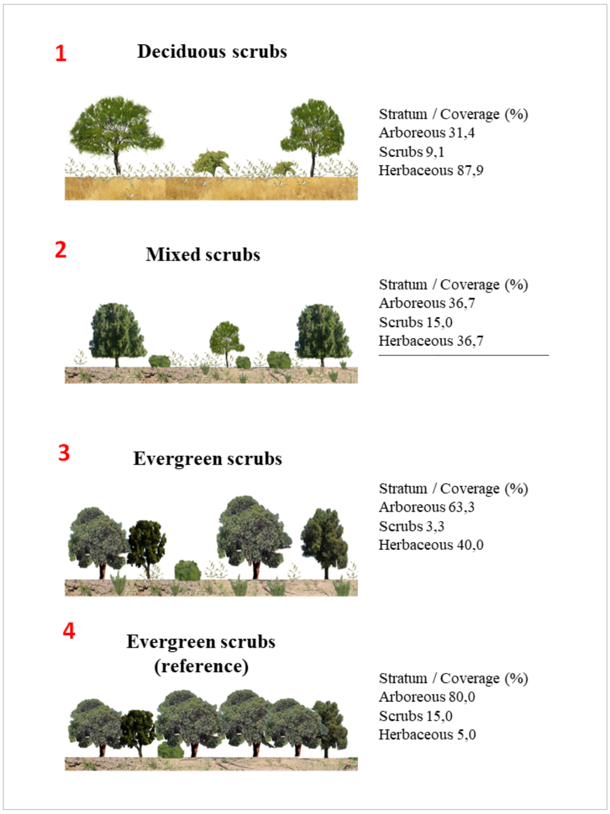

Figure 5. Structure of the different types of forests (from deciduous scrub to sclerophyllous scrub). The evergreen sclerophyllous scrub model is hypothetical

Development of guidelines for restoration

The findings on species interactions and speed of recovery after a fire provides a baseline for the establishment of guidelines for the recovery of these communities. These guidelines will also factor in the importance of protecting soils and improving biological processes, especially in areas exposed to higher severity (Murray et al., 2013). Therefore, our post-fire evaluation results allowed establishing three restoration guidelines, which are explained below.

Guideline 1: Species assembly

Based on historical data on the structure and composition of the species and the distribution of the functional traits in the study areas, three species assemblies were proposed to assist the restoration of native species.

a) Species assembly A. For deciduous scrubs (very degraded). The establishment of *A. caven* (60%), *Q. saponaria* (20%), and *T. trinervia* (20%) are important in these environments (Figure 6). These species are resistant to drought and high solar radiation. With water being the major limitation in these environments, *A. caven* and *Q. saponaria* are equipped with deep roots and can extract water from further below ground. Furthermore, because they have deep roots they will not compete for water with scrubs and grasses that have shallow roots and are highly competitive for this resource. The high growth rates in the spring and summer of these species, once their roots are deployed, can make it possible to establish trees in the first year. *T. trinervia* is a nitrogen-fixing species with superficial roots that can compete for water and light with herbs, out-competing them to reduce the quantity and quality of flammable material.

This scrub also contributes to the nitrogen pool of the soil allowing an increase in productivity in soils lacking nitrogen. As for recommendations we suggest planting *A. caven* in open soils separated by distances of three to five meters to avoid intra-specific competition for light and water. Seedlings of *Q. saponaria* and *T. trinervia* can be established under the cover of mature *A. caven* trees and take advantage of their nursing effect. The establishment of *A. caven* may be essential for establishing

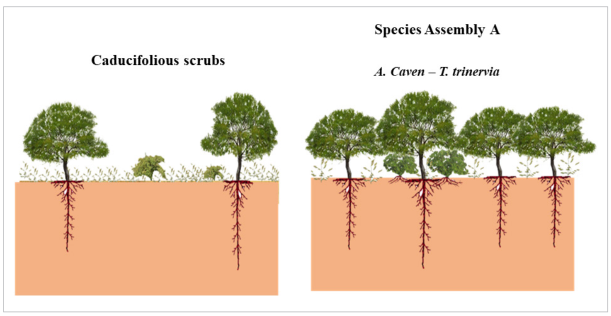

Figure 6. Species assembly A, for deciduous scrubs (very degraded). Left: before planting, Right: after planting.

late-successive sclerophilic species at a later stage. However, final planting densities should not exceed 600–800 plants per hectare.

b) Species assembly B. For mixed (degraded) scrubs. For this type of forest, we recommend the establishment of sclerophyllous and semi-deciduous species: *P. boldus* (30%), *C. alba* (20%), *L. caustica* (20%), and *A. caven* (30%) (Figure 7). The sclerophyllous species of *C. alba* and *P. boldus* are shade-tolerant and can benefit from the protective effect of scattered trees of *A. caven* and *Q. saponaria*. Young plants of these sclerophyllous species can be planted grouped under the cover of mature trees at high densities (0.5 x 0.5 m). Once established, they are expected to suppress *A. caven* and co-dominate with *Q. saponaria*. In this model we expect *A. caven* and *Q. saponaria* to reduce the radiation received by young plants in summer and not compete for water due to the wide differentiation in root growth and phenology present among these species. New *L. caustica* plants can be placed at high densities under the cover of mature *P. boldus* trees, because *L. caustica* is a shade-tolerant species and has wide crown plasticity, allowing it to co-dominate under the cover of other sclerophyllous species. As in the previous case, between this pair of species, there is a wide difference in root growth, phenology, and crown architecture. *A. caven* seedlings should be planted in bare soil on surfaces where there are no trees or scrubs. Because these species have the same life strategy, we suggest planting hawthorns at distances of four to five meters between individuals to avoid possible future competition for light and water resources.

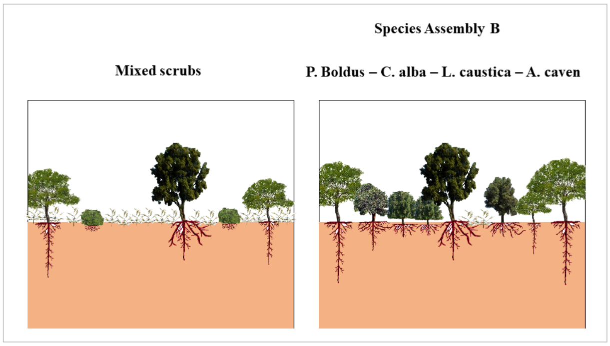

Figure 7. Species assembly B, for mixed (degraded) bushes. Left: before planting, Right: after planting

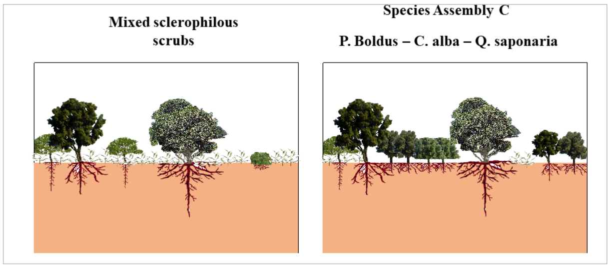

Figure 8. Species assembly C, for sclerophyllous scrubs (degraded). Left: before planting, Right: after planting

c) Species assembly C. Assembly for sclerophyllous scrubs (degraded). For this type of scrub we suggest applying an assembly of *C. alba* (60%), *P. boldus* (30%), *Q. saponaria* (10%) (Figure 8). As the vegetation type already has a larger proportion of sclerophyllous species, we suggest increasing the abundance of sclerophyllous species with complementary and favorable life strategies to allow a succession of late species. Seedlings of *C. alba* and *P. boldus* should be planted close to, but not below, the canopy cover of mature *L. caustica* and *Q. saponaria* trees at moderate densities (600–800 plants/ha). These species could occupy the surface layer of the soil by deploying surface roots, which will avoid competition for resources with their nurse plants. Additionally, these species are expected to co-dominate the canopy with mature trees initially established, as they are taller crown species. Seedlings of *Q. saponaria* should be established in open areas since they are a light-demanding species (Table 2).

Table 2. Growth, productivity, and shade tolerance of species recommended as restoration communities

Species	Life strategy	Root	Growing season	Treetop	Productivity	Shade tolerance	Post-fire regrowth capacity
A.caven	Deciduous tree	Deep root (5–6 m)	Spring-summer	Medium coverage	Medium	Low	High
R. trinervia	Deciduous scrub	Superficial root (<1 m)	Winter-Spring	Low coverage	Medium	Medium	High
Q. saponaria	Sclerophyllous Evergreen tree	Deep root (5–7 m)	Spring	High coverage	Medium	Low	High
L. caustica	Sclerophyllous Evergreen tree	Deep root (5 m) and lateral extended (4 m)	Summer	Medium coverage	Medium	Medium	High
P. boldus	Sclerophyllous Evergreen tree	Superficial root (<1 m) and very extended (2–3 m)	Spring-summer	Medium coverage	High	Medium	High
C. alba	Sclerophyllous Evergreen tree	Moderately deep roots (<3 m) and very extended (3–5 m).	Spring	High coverage	High	Low	Medium

It should be noted that there is no evidence that the proposed restoration assemblies will not encounter inter-specific interactions between woody seedlings and adult trees that are detrimental to their establishment. Therefore, the proposed use of these assemblies is purely experimental. For example, one of the recommended strategies is planting *P. boldus* at high densities under the cover of *A. caven* in a degraded scrub. However, it would also be important to plant some *P. boldus* plants outside the canopy of *A. caven* to compare the performance of the seedlings under both treatments. This can be useful for coming up with assemblies that allow the functional traits of each species to be managed more effectively (SER, 2004).

A. caven and *Q. saponaria* are the only species recommended to plant in open areas spaced 3–5 m apart so that they do not compete with each other. All other species should be planted in clusters or under favorable wetlands or microsites. Planting densities should not exceed 600–800 plants per hectare.

Guideline 2: Silvicultural actions

In Mediterranean-type formations, plant species are usually adapted to the occurrence of fires. Therefore, the regrowth of woody species and the re-establishment of herbaceous species are expected after the first rains of the following autumn, with the regeneration of woody species occurring alongside growth from seeds.

Silvicultural management can be used to improve the characteristics of future plant communities in terms of composition, structure, and condition. To accommodate silvicultural interventions in the restoration of native plant communities, the following procedures are proposed:

a) Treatment of burnt trees and scrubs

In scrubs of Espino (*A. caven*) and Maitén (*M. boaria*) partially affected by fire, partial cuts of stems and/or pruning of branches with evidence of burning can be carried out to promote a faster recovery of the burnt plant tissue. It is recommended that this be done during the subsequent autumn or winter. In specimens that have been extensively burnt, cutting can be done at a lower point on the plant to stimulate vigorous sprouting. This low cut should include all the stems (shoots) present, even if some appear healthy.

b) Treatment of new sprouts

This involves the selective cutting of sprouts when they reach a height of one meter regardless of whether they are in a burnt or unburnt plot. Sprouts that have been previously cut or pruned should also be subjected to selective cutting. In this first cut, between six and ten shoots should be left for each main species. Once the plants reach a height of two meters, a second selective cut should be made, lowering the density to two to four sprouts per species. Depending on the area's management objective, biomass production may be permanently controlled by maintaining plant height, or intermediate pruning of taller shoots, to allow for the growth of other trees and scrubs. Old sprouts and/or undesired species that compete vertically with the regrowth should be release cut. This is useful for altering the structure of the forest or scrub and also for livestock transit.

c) Species enrichment

Increased ground coverage and improved species composition can be achieved by planting native species. *Schinus latifolius* and *Maytenus boaria* are plants that can be used for this purpose. These can be planted in open spaces that allow the development of a complementary cover. New plants must have a minimum height of 15 cm and a stem diameter greater than 3 mm. The plants should be located in holes 30 cm wide and deep, with care being taken not to remove organic matter from the environment. Large stones should be removed from the vicinity of the plants. The plants should be irregularly spaced using a reference distance of 4 meters between them. A protection mesh of 0.5 m in diameter,75 cm high and at a depth of 10 cm should be placed around each plant. In the absence of rainfall greater than 5 mm, plants should be watered every 15 days (4–5 liters per plant) for the first two years.

In areas where *P. boldus* (boldo) and *Q. saponaria* (quillay) are present, these can be planted in open spaces with exposure to sunlight. The boldo plants should be located near or under plants with more height and coverage, while Quillay does well in slightly more open spaces or under larger plants with more spaced aerial coverage. The plants must have a minimum height of 15 cm and a stem diameter greater than 3 mm. The size of the planting holes and the care of the plants are similar to those proposed for other species. Depending on the slope of the planting area, a pair of small ditches can be dug to allow for water accumulation in the direction of the planting holes.

CONCLUSION

The development of plant communities in the forests and sclerophyllous scrubs of Central Chile has enabled adaptation to forest fires that have become an inherent part of the ecosystem regardless of the intensity, severity, magnitude, and extent of the fires. The current study has shown that the affectation of forest fires shapes the development trajectories of different plant communities, alternating their horizontal and vertical growth toward the formation of a multi stratum that partially covers the burnt soil. The differences with the control areas (without affectations by fire) remain up to six months on average after the action of the fire; thereafter, the shoot coverage improves the protection of the ground in steeper slopes. A more significant recovery is observed in areas that have less large fauna and that contain human interventions to protect the regrowth.

The highest severity categories were observed in regions V and VI, wherein there was an abundance of biomass to feed the fires. The biomass in these areas consisted of a dense scrub mixed with other species belonging to the tree stratum such as *A. caven* (Espino), *L. caustica* (Litre), and *P. boldus* (Boldo). When grown in a community, these three species favor rapid combustion due to the diversity of strata that form in the horizontal and vertical planes. The longer residence time of the flames due to the greater availability of biomass for combustion allows for higher levels of fire intensity and severity, which damages the soil especially in the first 30 cm from the ground.

In general, the four regions studied have a similar fire history, which is also a function of the native species associated with the Mediterranean forest and scrubs. The frequency of fires does not seem to be a significant factor in the regeneration and subsequent establishment of new plants. Samples obtained from the field at different severity scales show that regeneration begins by the formation of shoots and later mixtures of young communities that utilize fragments of the burnt biomass. In most of the sample plots, the formation of a new niche of species that coexist with the shoots or seeds of other species, usually exotic and with high seed productivity, was verified. This produces a regeneration layer that allows partial protection of the soil. An exception to this phenomenon is the open areas through which livestock traverses the area. The species found in these watersheds have adapted sprouting mechanisms adapted to the presence of fire and the effect of solar radiation, therey promoting the regeneration of buds just three weeks after a fire.

At stream crossings and the intersection of slopes, where landslides and erosion were observed after rains, the construction of structures based on wood and the remains of the burnt biomass was proposed to reduce erosion. These structures allowed for a larger area of plant establishment, improving the environment post-fire.

This research also considered the costs involved in the construction of dykes and erosion containment areas as well as the budget for the purchase of native plants, soil preparation, and subsequent planting. In this light, it is necessary to also consider the costs of fencing, monitoring, and maintenance of new plants. The water supply for irrigation and surveillance of the planted areas against animal damage must also be considered in the cost structure for the establishment of species in burned areas.

Our findings emphasize the main species that represent the vegetal formations of the forest and sclerophyllous scrub. Other species also interact with native species in the establishment of communities affected by fire, and these interactions form natural assemblies that allow the formation of a new forest. The difference in recovery, based on field evidence, is the change in structure from forest and dense scrub to degraded formations and with mixtures of other exotic species. These results, therefore, can be extrapolated to other species that also experience permanent forest fire events. An example of such species is *Jubaea chilensis* (Chilean palm), which has been extensively studied in the central areas and coast of Chile.

Finally, this study will contribute to the formulation of strategies for restoration such as interventions based on the establishment of planted communities.

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