DOI: 10.5152/forestist.2021.21029
Forestist 2022: 72(2): 112-119

ISTANBUL UNIVERSITY
CERRAHPAŞA

Original Article

Proposals of Rehabilitation and Management Actions for the Protection of Sclerophyllous Forests Affected by Forest Fires

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ABSTRACT

The damage and effects of fire on the native vegetation of Central Chile have been increasing in recent years due to drought conditions and the state of abandonment of the Mediterranean forests. The objective of this research was to study the damage and effects of fire in four regions of Central Chile, in order to establish adequate post-fire restoration proposals. The method consisted of the analysis of eight data sampling areas on native plant species affected by fire and sectors for statistical comparison (not burned). Consequently, it was possible to establish physical restoration measures and recovery proposals based on planting native species of the place affected by the fire. In conclusion, it can be indicated that Mediterranean landscapes need measures to accelerate the process of ecological restoration, due to the scarce recovery of vegetation due to the increase in the recurrence and intensity of forest fires.

Keywords: Fire severity, forest plantation, restoration of forest ecosystems, sclerophyllous vegetation, soil protection, wildfires

Introduction

The damage and detrimental effects of forest fires have been increasing in recent years, especially in Mediterranean ecosystems in Europe, the United States, and South America. Chile has not been immune to the occurrence of vegetation fires (Úbeda & Sarricolea, 2016). The records of the last 57 years in Chile (1964–2021) indicate an average occurrence of 4380 fires/year, with an affected area of 58,890 ha/year (Corporación Nacional Forestal [CONAF], 2021). The variability of these figures has been remarkable, possibly due to the paucity of data prior to 1990 and the changes in the dynamics of occurrence and causality in the last 15 years. The largest and most disastrous forest fires in contemporary Chilean history occurred in the 2016–2017 season (Bowman et al., 2017). In just 3 months, more than 600,000 ha of native forest, scrubland, and plantations were destroyed by fire, further accentuating the need to develop initiatives and studies for the restoration of ecosystems degraded by fire. Vegetation fires have serious consequences on the functioning of ecosystems, even those that are apparently adapted to frequent fires.

Fire can completely destroy large areas of native vegetation and forest plantations, with the consequent impact on ecosystem services, in addition to economic damage. It has been reported that fire can also significantly damage soils, particularly by facilitating their loss by erosion and nutrient washing as a consequence of the formation of hydrophobic layers (García-Chevesich, 2015; Pausas et al., 2008). However, parallel to these effects, fire acts as a selective factor that results in the coevolution of living organisms; sometimes this adaptation can even become dependence. In the Mediterranean vegetation of Chile, there are several species that exhibit adaptations to fire, among them the Chilean Palm (*Jubaea chilensis* Mol.), Peumo (*Criptocarya alba* Mol. Looser), Boldo (*Peumus boldus* Mol.), Litre (*Lithraea caustica* Mol.), and Quillay (*Quillaja saponaria* Mol.) (Gajardo 1994; Quintanilla 1999). However, increased landscape fragmentation, changes in land use, and increasing water scarcity have left many species in the native forest of Central Chile currently vulnerable.

The native forests of Central Chile, like other regions with a temperate Mediterranean climate, host a large number of endemic species in relation to their total biodiversity. However, recently, these ecosystems have not

Cite this article as:
Castillo, M. E., & Plaza, A. J. (2022). Proposals of rehabilitation and management actions for the protection of sclerophyllous forests affected by forest fires. *Forestist*, 72(2), 112-119.

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Received:
July 7, 2021
Accepted:
September 8, 2021
Available Online Date:
December 3, 2021

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only faced devastating fires, but also changes in meteorological conditions, such as rising temperatures, prolonged droughts, and increasingly strong winds, which increase the probability that new fires, possibly more severe and intense, will occur in the future. Therefore, it is urgent to provide these forests with immediate protection.

Studies to characterize the behavior of vegetation fires have seen a notable increase in recent years, along with the increase in the frequency and severity of fires in different regions of the world (Costafreda-Ampliades et al., 2017; Keeley et al., 2008). This knowledge is transcendent, since it contributes, on the one hand, to initiatives for the prevention, management, and combat of fires, and on the other, to the development of methods for the evaluation of direct and potential damages caused by fires. The estimation of the potential damages and the dangerous condition in recovery processes, based on the evaluation of the intensity and severity of fires (Keeley, 2009), points in this direction. From the ecological point of view, the study of fire behavior in landscapes with permanent disturbances related to forest fires helps to understand the dynamics of the vegetation response, for example, in Mediterranean ecosystems (Pausas et al., 2008), and also in the understanding of the damages and effects at different scales of analysis (Keeley et al., 2008). There are some studies on fire behavior that have been carried out both in Chile (Castillo et al., 2012; Fernández et al., 2010; Julio et al., 1997) and in other Mediterranean regions of the world. These results show the relationships between the characteristics of vegetation, climate, and climate change, with the intensity and severity (behavior) of fire and the implications for recovery (De Luis et al., 2004; Saglam et al., 2008).

The most common vegetation types in the Mediterranean climate zone of Central Chile are scrub and sclerophyllous forests, corresponding to a territory that spatially coincides with the areas with the highest frequency, extension, and intensity of forest fires. This area is predominated by tall evergreen shrubs of hard consistency, low xerophytic shrubs, thorny shrubs, succulents, and sclerophyllous, thorny, and very tall laurifolian trees. These are plant associations that have coexisted with human presence and the impact of forest fires since the establishment of human activity and the transformation of the territory (Castillo, 2006). This vegetation, comprised within the Mediterranean ecosystems, extends along the slopes of the Cordillera de la Costa and the Cordillera de Los Andes, encompassing the central valley. Gajardo (1994) describes five large types of sclerophyllous forest based on floristic and geographical criteria, with emphasis on arboreal features dependent on water currents and less arid habitats, but including scrub features related to intense anthropic disturbance. The current state of the sclerophyllous forest in the area of this research corresponds to a regressive climax type state (Castillo et al., 2012, 2017), with communities of species adapted to a structure of sparse forest and degraded scrub, with recurrence in the domain of fast-growing invasive species and accelerated regeneration patterns (Castillo, 2015), among other factors, due to the permanent and recurrent presence of fire.

These ecosystems have been subjected to increasing pressure from agricultural, livestock, extraction, and urban activities, which has significantly reduced their coverage (Schulz et al., 2011). This pressure is very dynamic, with frequent changes in the use and abandonment of cultivated fields. These forests have also presented profound recent disturbances as a result of forest fires that affected an approximate area of 16.7% of the total stock in 2017, equivalent to 335,000 ha, considering the entire area of distribution of the sclerophyllous forest type.

Becerra et al. (2011) studied these ecosystems to elucidate the effects of fragmentation on landscapes. Among the most important aspects are the deterioration of the biological connectors that support the genetic exchange between communities, and the conservation of biodiversity within forests (Smith-Ramírez et al., 2011). Normally, recurring fires modify these natural processes, accelerating degradation and increasing the edge effect. These effects are more evident in the plains of the intermountain valleys of the coast and a part of the lower areas of the foothills. Becerra (2017), in this same type of forest, shows the effect of herbivory as the main explanatory variable of the low regeneration by seeds after the passage of fire, analyzing conditions under canopy and without protective cover.

This article reports recommendations for rehabilitation and restoration measures for Mediterranean forest ecosystems, based on the results of a fire characterization analysis in the Central Chile region, focusing on the vegetation fires that occurred in this region during the 2016–2017 season. This characterization combines field studies with the use of simulation models aimed at evaluating the condition of potential danger in the recovery of the vegetation. This study was conceived as a basis for the design of post-fire restoration strategies of the native vegetation of the Mediterranean area of Central Chile.

Methods

Study Area

The geographical delimitation 32°22′–36°48′S corresponds to an area with permanent occurrence of native vegetation fires. In the vast majority of cases, it is necessary to carry out urgent and permanent actions for restoration. Within this area, there are areas that are especially sensitive to forest deterioration, mainly those close to roads that enable urban–rural connectivity and in places where horizontal continuity promotes the uncontrolled advance of fire.

In this research, representative areas of four regions of Central Chile included between these parallels were taken, preferably close to areas related to human activity, and in which there is permanent fire activity in the contiguous area (Figure 1). In these sampling areas, post-fire regeneration and survival plots were designed considering different scales of affectations and indicators of intensity and severity in the field. With these results, we propose actions for the management of burned areas, considering guidelines for the restoration.

Proposed Silvicultural Interventions

In order to stimulate post-fire recovery in the areas of this research, the following silvicultural interventions were recommended in order to promote accelerated restoration at a reasonable cost. Decisions were made based on field history and literature review. In addition, the initial response of the post-fire vegetation and the potential danger present in each sample plot were considered:

Treatment of Developing Regrowth

Before starting the treatment for regrowth, a release cut is proposed by eliminating the dry portions of the original burned specimen. In order to evaluate the effectiveness of this treatment, it is proposed to leave some specimens without this type of felling as controls.

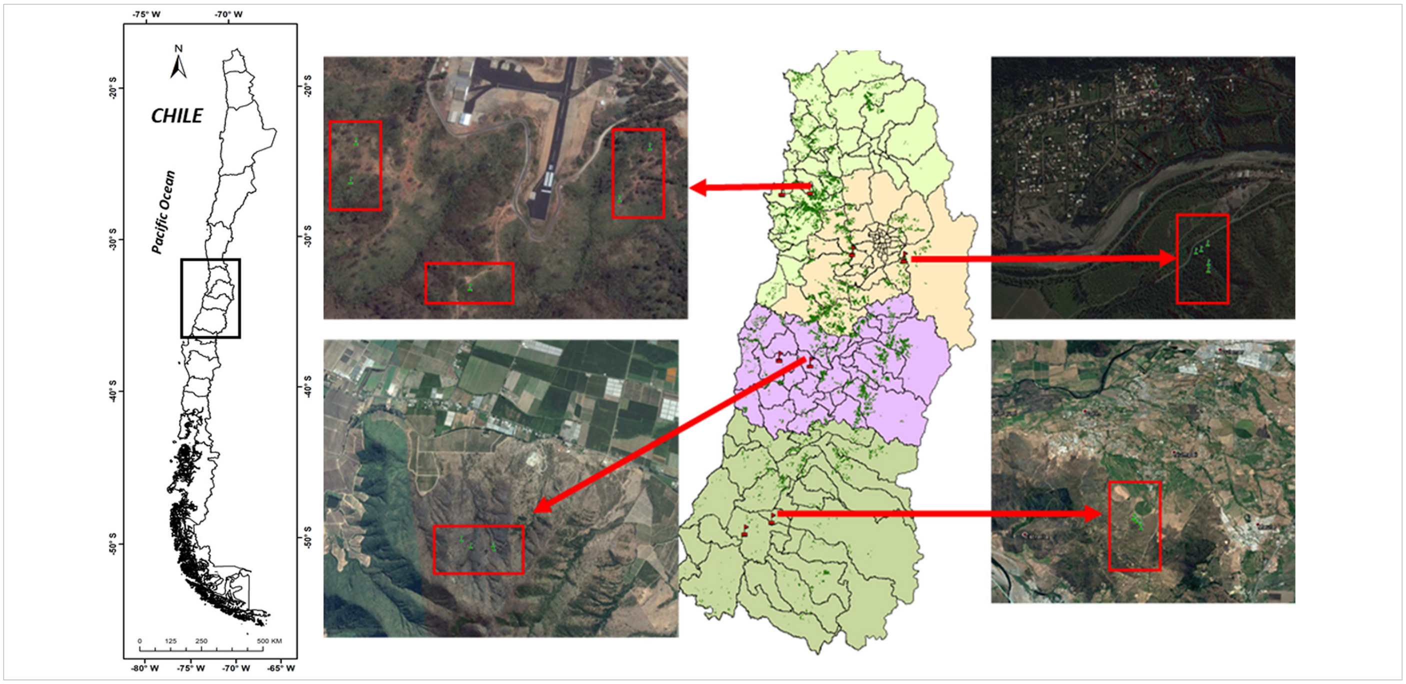

Figure 1.
Sampling Areas Considered for Monitoring Sclerophyllous Vegetation Affected by Fires. Source: CONAF Project 008/2016.

Considering the state of development of the regrowth produced, it is proposed to thin the sprouts for the next autumn or winter. In this first thinning, between six and eight stems per vine should be left standing. Once the specimens reach a height of 2 m, a new thinning must be carried out, lowering the density to between two and four sprouts per vine. Subsequently, depending on the management objective of the area, a scrub structure of boldo leaves may be maintained, for example, in the event that the purpose of biomass production predominates; or alternatively, a state of high forest may be achieved by means of thinning.

Enrichment

This treatment allows increase in the coverage and improves the composition by incorporating both species that previously exist in the formation and others that do not, through sowing and planting.

For the selection of species, it is very important to keep in mind the previously existing species and the associations in which they participate. For example, while *Acacia caven* and *Q. saponaria* usually grow in the same basins, they generally do not grow in the same patches. *A. caven* tends to grow in the early successional stages or associated with species such as *P. chilensis*, *Proustia cuneifolia*, *Baccharis linearis*, *M. hastulata*, or *Cestrum parqui*, while *Q. saponaria* is almost always associated with *L. caustica*, and may also be accompanied by *Cryptocarya alba*, *Azara petiolaris*, *Schinus latifolius*, and *Retanilla trinervia*. These associations are not random; studies under laboratory conditions indicate that some of these species could present chemical incompatibilities (Plaza et al., 2017, 2018), so it would be counterproductive to enrich a forest in which *Q. saponaria* naturally grows, for example, with *A. caven,* or vice versa.

For the sites analyzed, planting was considered favorable to sowing, and was recommended based on the higher probability of success than direct sowing (Becerra, 2017). It was proposed to plant mainly specimens of *P. boldus* and *Q. saponaria* in the clearings, ensuring that the specimens were arranged in the most appropriate microsites according to their requirements. The boldo specimens were located near or under nurse plants, while quillay could be located in slightly more open spaces or under nurse plants with a thinner crown. It was ensured that the specimens had a minimum height of 15 cm and a neck diameter greater than 3 mm. The plants were placed in planting boxes of 30 cm on each side and depth, and organic matter was not removed from the soil. Stones larger than 5 cm in any of their dimensions were removed from the substrate when filling the planting boxes and placed around the stem on the newly removed soil, to improve the retention of moisture in the substrate. Considering the slopes of the sites to be enriched, a pair of collectors consisting of small ditches converging toward the squares was prepared for the boxes, and the runoff water from the slope was harvested (Vita, 2007).

The specimens were installed according to an irregular spacing, considering a reference distance of 4 m between them. A protection (metal mesh) was placed on each planted individual. These protections were designed to be .5 m in diameter and 75 cm high, being buried at a depth of 10 cm. The plantation was carried out during the winter period, in the second fortnight of the month of July. In the absence of rainfall greater than 5 mm, we proceeded to the application of biweekly irrigations at a rate of 4–5 liters per specimen, at least during the first and second year after planting. In case of weeds, it was necessary to extract them in the direct environment of the plant stem, considered as maintenance and cleaning work.

Germplasm Propagation

Although the entire central zone of Chile corresponds to the temperate Mediterranean climate, each basin has its own microclimate and specific conditions, and the individuals of the species that live there present particular adaptations for these conditions. That is why care must be taken, as far as possible, for enrichment with local species.

Since individuals are not always available in local nurseries, one must be prepared to collect seeds in the field and grow them before starting enrichment work. In this sense, one of the best alternatives is *A. caven*, since it appeared as a pioneer in the early successional stages of most of the Mediterranean area of Chile, and it presents a high percentage of germination in very short times (over 80% of germination in less than 2 weeks; some batches can reach over 90% in the first week), the seedlings are vigorous with low initial mortality, and have rapid growth under nursery conditions (Figure 2). However, as we mentioned earlier, *A. caven* is not compatible with all sclerophyllous associations in this area. In addition, its characteristics vary remarkably depending on the origin (e.g., the conditions to achieve the natural scarification of the seeds). Therefore, for no reason should specimens from different basins be introduced, since the contamination of the germplasm could, in the long term, damage the natural regeneration capacity of the forest.

Another alternative is to use species that are not local. In that case, a good alternative is *Schinus molle*. It is a native tree in the northern part of Chile, and is therefore adapted to more arid conditions than those found in the Mediterranean area. The advantage of using plants from more arid areas is that in general, their development can be remarkably accelerated in nursery conditions, which are less demanding than their natural habitat (Figure 3), and they survive well in conditions of high exposure

Figure 2.
Production of Acacia caven *Plants. (A) Germination Tray. (B) Seedling.*

Figure 3.
Two-year-old Schinus molle *Nursery Specimens Grown in Different Light and Water Conditions. Both Specimens Came from Seeds of the Same Individual and Were Planted in the Same Season.*

to sunlight, little ground cover, and low content of organic matter in the soil––conditions which occur after fires––and once the forest recovers, the availability of light decreases and the microclimate becomes more humid, they are generally unable to compete with the local flora.

Results

Vegetation Response to Fire

According to what was observed in the field work for the different sampling plots, a vigorous regrowth of the strain of the sclerophyllous species that were affected by the fire was evidenced, in particular, by the dominant species *P. boldus* (Boldo). Likewise, in points where the fire was soft or null, seedlings of *A. caven* (hawthorn) were observed.

Operationalization of Land Patterns Physical Works and Enrichment With Native Species

The sectors where the enrichment would later take place were identified, ensuring that the plantation was immersed within the area of influence of the previously built channel mitigation works (Figure 4). In accordance with the woody plant species that are naturally found in the place, it was decided that the species *Q. saponaria* and *A. caven*, would be arranged on the upper slope of the access road, while the species *Schinus polygamus*,

Figure 4.
Indication of the Areas Used for Restoration Work at the Los Coipos Estate, Region VII, Owned by Forestal Arauco. The Work Was Carried Out in Conjunction with the Los Castaños Ltda. Crew, Which Was Arranged by the Water, Soil, and Biodiversity Unit (ASB) of Forestal Arauco, Constitución area. Photograph Taken a Few Days After the Fire, Which Occurred in 2017.

P. boldus, and *B. linearis* remained on the lower slope. The location of these tasks is illustrated in Figure 5. Having defined the plantation sectors and the distribution of the groves on the ground, we proceeded to clear the remaining dead material. As the microsites were released for planting, part of the crew proceeded to make the planting squares, which were determined at a distance of 2 × 2 m from the level curve, as shown in the following photographs. To carry out the planting, boxes of 40 cm × 40 cm × 40 cm were made (Figure 6), in order to remove the compacted area of the soil and to allow the plant to develop its root system in an optimal way.

A mesh was placed in the environment of each individual to be planted, due to the herbivory present in the area selected for enrichment. Raschel mesh can be used to improve individual survival (Becerra, 2017). Irrigation is recommended for at least the first two years, administering 16 L/ plant/month, gradually decreasing to 2 L every 3 months. This is preferably done through a drip or dispersion irrigation system, to avoid erosion.

First, the clearing tasks were carried out, followed by making the squares (Figure 7). Having made the boxes, we proceeded with the planting of the *Q. saponaria* and *A. caven* specimens (Figure 8).

Figure 5.
Determination of the Areas and Distribution of the Stands in the Place.

Due to the characteristics of the area to be enriched, the planting in groves of other species that act as reinforcement in the survival and provide root support in the environment, and that were also resistant to the initial stages of water deficit, was considered. A grove plantation was established with *Shinus polygamus*, *P. boldus*, (Figure 9), and *B. linearis* (Figure 10).

Once the plantation task was advanced, it was decided to begin with the placement of individual protections to prevent herbivory (Figure 11), a task that was completed with the installation of signage denoting the work carried out.

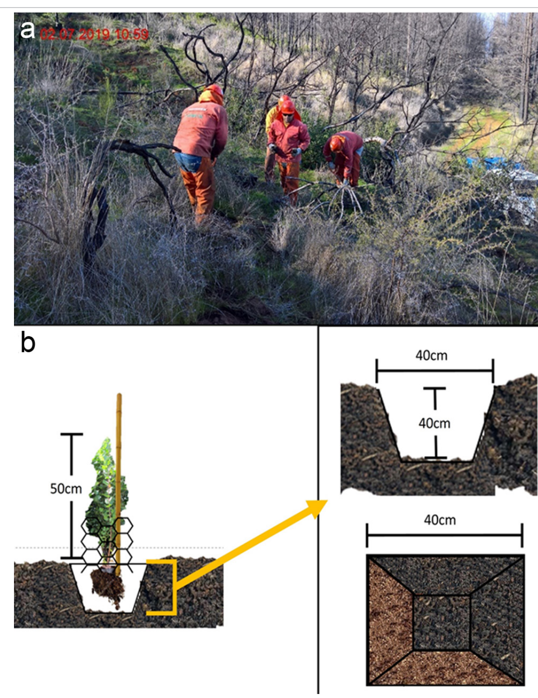

Figure 6.
Planting Methodology. (a) Crew Working in Preparation of Land for Plantation. Hualañé Sector. Forestal ARAUCO. Photo: CONAF Project 008/2016. (b) Description of Plantation Squares.

Figure 7.
Clearance and Start of the Work to Make Boxes for the Plantation.

Figure 8.
Planting of Quillaja saponaria *Specimens. Part of the Previous Palisade Construction Works Can Be Seen.*

Figure 9.
Peumus boldus *Specimen Planted at the Site.*

Figure 10.
Baccharis linearis *Specimen Planted in Place.*

As part of the recovery activities of sites subject to forest fires, where erosion processes are activated as a result of the loss of vegetation cover, works were designed to mitigate the impact of runoff in those streams that had been exposed. For this, palisades were built on the riverbeds of the streams to help retain the entrained material (Figure 12), and a reforestation in forests was carried out in the contributing area to increase the vegetation cover. Considering the execution costs, 2 palisades of 1.5 m at their maximum width and 0.5 m at their highest point were considered. Each palisade was built with smooth logs impregnated with pine, 3–4 inches thick and 2.44 m long, arranged horizontally, perpendicular to the direction of flow (Figure 13).

Figure 11.
Completion of the Plantation and Installation of Individual Protections for the Plantation.

Figure 12.
Bucking and Installing Palisades. Los Coipos Estate.

Subsequently, the same waste plant material remaining from the fire was used, which was available upstream and downstream of the work, to slow down and help retain the advance of sediments. In the case of the plantation, the cost of the plants placed in the nursery was considered, as well as the cost of the 45 cm × 15 cm corrugated alveolar polypropylene shelter type protections and colihue stakes, without considering the transfer of the latter. In the case of the plantation, an average yield was considered for a crew of 4 people, of 400 specimens with planting box, including the installation of their protections.

Discussion, Conclusion, and Recommendations

The restoration guidelines must be in accordance with the damages evaluated, not only in the vegetation cover but also in the different components of the soil, roots, organic matter, cracks in the bark, and aerial structures of plants and larger woody plants. These evidences must also be considered in terms of the formation of a hydrophobic layer as a result of the caloric intensity in the soil. However, these effects were not described in the evaluated plots, although the repellent effect in hualo forests was measured in a sector of the Maule Region, in order to take advantage of the short-term effects of a recent fire that occurred in 2017.

The guidelines refer to the initial condition of retaining the higher productivity of the post-fire soil. This condition can be achieved hardly two or three weeks after the disturbance, due to the vigorous conditions in vegetative regeneration and the more intense sunlight produced by the opening of the canopy. In summary, we propose to build containment works in palisades, considering woody material from the same place and in consideration of a sectorization of the priority for restoration. To do this, a multicriteria analysis is first carried out that accounts for the most relevant physiographic and vegetative variables that affect the possibilities of recovery of the local environment affected by fire.

Figure 13.
Palisade Completed. Los Coipos Estate.

The study of fire behavior is installed as a useful element to predict the most probable response of regeneration and vegetative growth after the fire, using fire behavior parameters specifically designed and validated for the vegetative types of the Mediterranean native forest studied. The results show a high level of danger, for which it is urgent to develop cartographic studies of the regenerative response of the vegetation on a larger scale. These evidences are also possible to evaluate and characterize, using the scale of affectations of Castillo et al., (2017), elaborated precisely for this type of ecosystems affected by forest fires.

Chile's sclerophyllous forest has had repeated fire episodes, which exceed the natural recovery period. This is a phenomenon that occurs in all native species considered in this study. This situation implies that preventive actions against the impact of fires should not only focus on the preparation of measures aimed at the management of combustible vegetation, but also on the proposal of practical actions that can be applied by farmers and forest owners, in accordance with the guidelines and norms established by Law 20,283 on the recovery of the Chilean native forest.

In addition to the results presented in this research, especially those associated with the techniques of planting and caring for restoration works, the cumulative effect of the prolonged drought that affects Chile must be considered, which has been expressed in a sustained increase in the number of forest fires and in the degree of their severity, resulting in the destruction of extensive areas of native trees. The actions of restoration and recovery of native forest species, as well as in the protection of the soil and landscape, contribute to rethinking new forms of management in the vegetal landscape, at a cost that is close to the possibility of implementation with real certainty, based on the silvicultural treatments proposed here.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – M.C.S., A.P.V.; Design – M.C.S., A.P.V.; Supervision – M.C.S., A.P.V.; Resources – M.C.S., A.P.V.; Data Collection and/or Processing – M.C.S., A.P.V.; Analysis and/or Interpretation – M.C.S., A.P.V.; Literature Search – M.C.S., A.P.V.; Writing Manuscript – M.C.S., A.P.V.

Acknowledgments: To the Conaf 008/2016 Project.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: This study was funded by the Chilean Native Forest Research Fund.

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