Native Plant Production in Chile. Is It Possible to Achieve Restoration Goals by 2035?

Manuel Acevedo [1],*, Carolina Álvarez-Maldini [2], R. Kasten Dumroese [3], Jan R. Bannister [4], Eduardo Cartes [1] and Marta González [1]

1 Instituto Forestal, Centro Tecnológico de la Planta Forestal, Región del Biobío 7770223, Chile; ecartes@infor.cl (E.C.); mgonzale@infor.cl (M.G.)
2 Instituto de Ciencias Agro-alimentarias, Animales y Ambientales (ICA3), Campus Colchagua, Universidad de O'Higgins, San Fernando 2840440, Chile; carolina.alvarez@uoh.cl
3 USDA Forest Service, Rocky Mountain Research Station, Moscow, ID 83843, USA; kas.dumroese@usda.gov
4 Instituto Forestal, Oficina Chiloé, Castro 5700000, Chile; jbannister@infor.cl
* Correspondence: macevedo@infor.cl; Tel.: +56-41-2853263

Abstract: Facing rapid loss of biodiversity as a consequence of climate change, Chile has formally pledged to restore 600,000 ha of native forest by 2035. This effort, however, has not considered the amount and quality of native plants required to meet this pledge. Thus, we examined data collected during the annual, government-conducted census of small- and medium-sized nurseries from central Chile, which account for 78% of the nation's total plant production, to assess if current production is sufficient to meet Chile´s restoration needs. We coupled this with data collected during our series of ongoing research projects to determine if nurseries are currently meeting minimum seedling quality standards based on morpho-physiological attributes. Our four-year analysis (2016–2019) shows that the number of native seedlings has increased by only 4%, but because only 19% of nursery managers have training, just 29% of all seedlings meet quality criteria for restoration. Thus, under the current rate and quality of plant production, meeting restoration pledges desired by the year 2035 would not be achieved until 2181. This timeline can be accelerated through an urgent expansion of nursery space, implementation of a continuous program for technology and knowledge transference, and strong support through governmental policies.

Keywords: nurseries; management practices; international agreement; seedling attributes

1. Introduction

The severity of climate change has increased the pace of loss of biodiversity and the rise in CO_2 emissions [1]. Consequently, the United Nations (UN) declared 2021–2030 the "Decade of Ecosystem Restoration." In recognition of the critical role of forests in addressing challenges imposed by climate change [2,3], the Bonn Challenge and The New York Declaration of Forests aim to restore 350 million ha worldwide by 2030. This has led different countries to outline their commitments to forest restoration, prioritizing the conservation and restoration of remaining natural ecosystems [4]. One such priority area is the central–southern portion of Chile, where a high level of endemism of Chilean native species has led to this region's classification as one of the 35 global hotspots of biodiversity for ecological conservation (Figure 1A,B) [5–7]. Considering the challenge of prioritizing critical forests, global sustainability, and climate change, Chile has pledged to join several international agreements that, once ratified by the Chilean national congress, will become legally binding. Among these, as part of the Paris Agreement of 2015 (COP21), Chile vows "To afforest 100,000 ha mainly with native species" by 2030; these restored ha have the potential to sequester between 900,000 and 1,200,000 t of CO_2 annually [8].
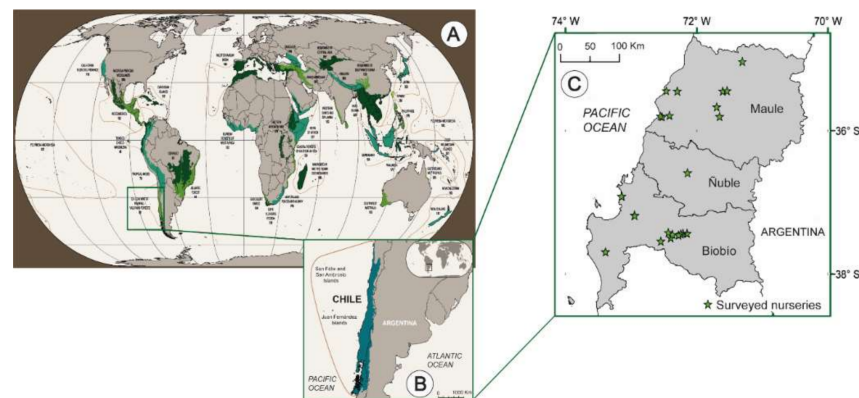
Figure 1. Global hotspots of biodiversity ((**A**); modified from [7]) including the Valdivian Forests of Chile (**B**) where the Maule, Ñuble, and Biobío regions occur (**C**). These three regions account for 78% of the national plant production. Green stars indicate locations of surveyed nurseries (**C**).

Within Chile, complementary policies have been developed with the objective of aligning global challenges, such as the "National Biodiversity Strategy (2017–2030) and its Action Plan" [9], with the "Plan for Climate Change Adaptation in Biodiversity" (2014-2019) [10]. Specifically, the "National Strategy of Climate Change and Vegetational Resources" [11] and the Chilean National Forest Policy (2015–2035) [12], hereafter Forest Policy, propose the "protection and restoration of the forest heritage," indicating "the incorporation to restoration processes of 500,000 ha with native species to 2035, preferentially in degraded lands owned by small and medium entrepreneurs with high levels of erosion, fragmentation, and with loss of biological corridors, or that present lower quality and quantity of water resources."

In addition, during the summer of 2017, Chile faced its most catastrophic wildfire of the last 50 years, affecting almost 600,000 ha, of which 239,490 ha were native forests [13]. This wildfire raised concern and prejudice among citizens regarding the negative consequences of planting extensive areas of exotic species on native biodiversity [14] and increased social desire for land restoration with native species for recovery of ecosystem services [15].

In order to meet global restoration challenges, direct seeding and seedling planting are the most common active strategies to restore degraded sites. However, results regarding seed use efficiency (seedling-to-seed ratio) and subsequent seedling survival with this methodology are low [16,17]. For example, a review of 120 experiments comparing direct seeding and outplanting seedlings concluded that seeding results in significantly fewer plants being established despite the higher use of seeds [18]. A similar review of 75 experiments regarding direct seeding in tropical and temperate forests determined that average germination was 44% and of the seeds that germinated, seedling survival after one season was only 21% [17]. Despite the fact that seeding is an attractive alternative because it reduces planting costs, its poor species performance and low seedling density achieved reduces its applicability [19–21]. Thus, planting native tree species to achieve restoration goals is the most promising option [17]. Given this, it is surprising that with ambitious national and international commitments for reforestation, the availability and production of quality plants for restoration is rarely considered within the restoration programs of countries, including Chile [15,22–24]. Furthermore, the poor quality and low supply of native plant species in nurseries were recognized as some of the major bottlenecks for the restoration of natural forests in Chile [15]. Within the next few years in Chile, the demand will increase for nursery-produced native plants grown under the concept of the "target plant" [25,26], meaning that the plants are cultivated to meet specific morphophysiological attributes determined according to the restoration project objective(s) and field characteristics. Without attention to this concept, the absence of desired plant

quality attributes will result in increased on-site mortality, leading to higher economic and environmental costs and an inability to achieve restoration goals [27].

2. Materials and Methods

In Chile, the common vernacular is to use the terms "reforestation" and "afforestation" when discussing the planting of exotic tree species on existing and new forest plantation sites, respectively, for future forest product use, whereas "restoration" is used when discussing planting native tree species for all ecosystem services, which may also include potential forest products [28].

In this paper, we more deeply discuss the bottleneck for restoring the restoration of Chile's natural forests [15], exploring three perspectives. First, we describe the current nursery capacity for the production of native plants needed for restoration to meet international and national commitments. For this, we used the Chilean National Forest Corporation (CONAF) database for the four-year period 2016 through 2019 [29–32]. We filtered this annual, government census of national plant production by the number of plants, species, region, number of growing seasons, and stocktypes.

Second, we leveraged the census data with data and observations obtained through several research and technology transfer projects led by our Centro Tecnológico de la Planta Forestal (CTPF; Technology Center for Forest Plants) program within the Chilean Forest Institute (INFOR) from 2014 to 2019. These activities were conducted within the Biobío, Ñuble (a portion of Biobío until 2018), and Maule regions because their nurseries account for 78% of the total national plant production (Figure 1C) [32], excluding nurseries from large forest enterprises that produce mainly non-native species. Within these regions, 27 small- (50,000 to 300,000) and medium-sized (300,000 to 2,500,000 plants) forest nurseries (17 from Biobío-Ñuble and 10 from Maule; size defined in [33]), which represent 60% and 98% of plants produced in these three regions, respectively, were characterized. Data included the education and experience level of managers, production system (bareroot or container), and specific propagation practices toward achieving morpho-physiological attributes. These data provided insight into the relationship between propagation practices and subsequent plant attributes and allow us to diagnose limiting factors in the current production process.

Third, we use the capacity and production factor information to suggest ways to adjust the pace and scope of Chilean efforts to meet restoration goals. Together, these perspectives address one of the greatest environmental challenges faced by the Chilean forestry sector this decade.

3. Results and Discussion

3.1. Availability of Plants and Species to Achieve Restoration Challenges

During the four-year period (2016–2019), Chilean nurseries doubled the number of trees and shrubs they grew annually for ecosystem restoration, reforestation, and afforestation; in 2019, about 169 million plants were in production (Table 1). Almost all of this increase was due to an expansion in the production of exotic seedlings in response to the 2017 wildfire, despite that almost half of the burned area corresponded to native forest. Exotic seedling production on average accounts for 89% of the total number of plants in production annually. Although the number of exotic species in production is high (287) and consistent across years (Table 1), three exotic species (*Pinus radiata* (D. Don), *Eucalyptus globulus* (Labill.), and *Eucalyptus nitens* (H. Deane & Maiden) Maiden) account for 95% of the total production of exotic plants.

Table 1. Number of native and exotic species and seedlings produced by season between 2016 and 2019. Trend values (%) indicate changes in plant production between 2016 and 2019 (average ± SD).

	2016	2017	2018	2019	Total	Average	Trend (%)
Native							
Number of seedlings							
Tree	9,618,953	10,984,804	10,938,390	9,684,443	41,226,590	10,306,648± 756,980	0.7
Shrub	431,084	744,752	883,556	1,027,296	3,086,688	771,672± 254,681	138
Others *	464,204	682,973	278,390	182,138	1,607,705	401,926± 220,933	−61
Total	**10,514,241**	**12,412,529**	**12,100,336**	**10,893,877**	**45,920,983**	**11,480,246 ± 918,451**	**4**
Number of Species							
Tree	59	65	75	94	–	73 ± 15	59
Shrub	44	52	72	104	–	68 ± 27	136
Others *	98	63	84	150	–	99 ± 37	53
Total	**201**	**180**	**231**	**348**	**–**	**240 ± 75**	**73**
Exotic							
Number of seedlings	72,053,797	67,535,380	118,915,285	158,296,526	416,800,988	104,200,247± 42,897,733	120
Number of species	288	292	282	284	–	287 ± 4	−1
Total	**82,568,038**	**79,947,909**	**131,015,621**	**169,190,403**	**462,721,971**	**115,680,493 ± 42,707,255**	**105**

* Cactus, climbing plants, herbaceous, etc.

The total number of native seedlings in production each year remained constant at about 11.5 million per year (Table 1). The overall number of native species increased by 73%, with about twice as many new shrub species added as tree species (Table 1). Although the annual average number of native species is high (240), just 10 native species were responsible for 65% to 71% of the total native species in production, with five tree species (four of them *Nothofagus*) accounting for about half of the production (*Quillaja saponaria* (Molina), 19%; *N. dombeyi* (Mirb.) Oerst, 13%; *N. pumilio* (Poepp. & Endl.) Krasser, 8%; *N. obliqua* (Mirb.) Oerst, 7%; and *N. alpina* (Poepp. & Endl.) Oerst. 6%). The contribution of native shrub seedlings to the total native seedling production increased from 4.1% to 9.4% (Table 1), with the most commonly produced species belonging to four genera: *Azara* spp., *Baccharis* spp., *Berberis* spp., and *Escallonia* spp.

In Chile, native plants are produced in three ways (i.e., stocktypes): (1) in larger-volume pots (>15 L) and polybags (500 mL to 40 L); (2) as bareroot stock in field soil; and (3) as "covered root" seedlings, which includes all hard-sided containers (54 to 280 mL) (Table 2). As already mentioned, on an annual basis, about 11.5 million native plants are in production. Almost one-third of the production is in pots and polybags (Table 2) that are not intended for restoration; these plants are for ornamental use (e.g., community landscapes, parks, etc.). The remaining 7.7 million native plants, grown as bareroot or covered root stocktypes, are destined for restoration. On an annual basis, nearly 60% of these one-season plants remain unsold (i.e., holdover stock) and are transplanted to larger pots and polybags and are maintained for several seasons in the nursery before outplanting (Table 2). These plants become unsuitable for restoration purposes because of root malformation [34–36] and nutrient deficiency owing to lack of fertilization during subsequent growing seasons [37]. This means that, on average, nurseries currently have about 11.5 (Table 2) million native plant seedlings in production every year, but only 3.3 million meet the criteria for outplanting and are delivered annually for restoration planting.

Table 2. Number of native plants produced between 2016 and 2019 according to stocktypes and the nursery growing season.

Stocktypes	Nursery Growing Season					
	1	**2**	**3**	**>4**	**N.I**	**Total**
Pots and polybags	1,059,216	1,335,589	818,568	424,783	52,155	3,690,310
Bareroot	285,205	624,765	233,724	75,632	–	1,219,326
Covered root *	3,023,906	3,031,489	338,096	80,073	4,000	6,477,563
Total	**4,368,327**	**4,991,842**	**1,390,387**	**580,488**	**56,155**	**11,387,199**

* Including speedling, tubes, and Patrick system. N.I: No information.

Chile's commitment to the Paris Agreement calls for planting 100,000 ha within the decade. The goal of the Forest Policy is more ambitious, requiring nearly 500,000 ha. Assuming an average establishment density of 1000 plants ha^{-1} (range between 400 and 1600 plants ha^{-1}; [28]) and 75% survival is achieved (an optimistic goal), then 1333 plants ha^{-1} will be required. Current nursery production rates will, therefore, be sufficient to plant about 2475 ha year^{-1}. Thus, also assuming that 80% of the committed ha are planted with native species, it will require 32 and 161 years, instead of the pledged 10 and 15 years, to achieve the goals of restoring the 80,000 ha under the Paris Agreement and the 400,000 ha under the Forest Policy provisions considering only native species, respectively. Clearly, improving nursery efficiencies to reduce the length of production cycles and expand nursery space is needed to increase the pace of the restoration trajectory. Refining nursery practices so that all container-native plants are produced within a single growing season would double potential planting to 5073 ha year^{-1}, thereby reducing the years required to meet the goals by half. Recent research has demonstrated that many of these native plant species can readily be grown in a single growing season with proper nursery cultural practices [38–42]. The remainder of this manuscript looks at factors that limit efficiencies within Chilean nurseries, and recent research that addresses those inefficiencies.

3.2. Diagnosing Nursery Production Factors that Limit Native Plant Production

Our survey revealed that only 19% of the nursery managers have a forest engineer or forest technician degree (equivalent to a four-year Bachelor of Science degree or two-year technical degree, respectively). Thus, managers and their staff rely mainly on previous experience or third-party recommendations, often lacking sound technical or scientific knowledge [27,35,43]. This lack of science-based, technology transfer has created barriers between these smaller nurseries and the larger nurseries operated by forest enterprises that possess more technology, access to scientific literature, and improved professional development. Thus, it is difficult for smaller nurseries to produce seedlings as efficiently as the larger nurseries, and often seedling quality is compromised. In terms of management opportunities to improve the pace of native plant seedling growth and overall seedling quality in small- and medium-sized nurseries, the three key challenges are understanding the roles of the growth substrate, fertilization, and irrigation on the growth of native plants.

The first challenge faced by nurseries is the use of composted *P. radiata* bark; 90% of the nurseries in Maule and 100% in Biobío and Ñuble use this as the main growth substrate [43,44]. In terms of nutrient availability, this substrate is inert [45]; therefore, all nutrients must be supplied through fertilization (after accounting for inputs via the irrigation water) and, according to our survey, this is rarely considered by managers. For native species, nutrient requirements are yet to be developed for specific species. This is in stark contrast to the exotic tree species *E. globulus*, planted for forest products in Chile, where detailed information regarding applied nutrient concentrations and nutrient foliar levels at the end of the production stage are well known [45,46].

The second challenge is proper fertilization. Our survey found that 100% of the responding nurseries use soluble fertilizers (e.g., Ultrasol®, SQM, Santiago, Chile; or Vitra® Vitra, Santiago, Chile) or controlled-release fertilizers (e.g., Osmocote® ICL Specialty Fertilizers, Summerville, SC, USA; or Basacote® Compo Expert, Santiago, Chile) that have been

specifically formulated for use on Chilean agricultural soils, not soilless media. These fertilizers have low concentrations of magnesium and sulfur (less than 1%) and almost no calcium. Therefore, it is common to observe deficiencies in these elements (Figure 2).

Figure 2. Deficiency symptoms of magnesium in *Eucalyptus nitens* (**A**) and phosphorus in *Eucalyptus globulus* (**B**) detected during the 2014–2015 growing season at nurseries in the Biobío region.

Proper application of irrigation is critical to efficient seedling production and is the third challenge to native plant production in Chile. Determining when and how much to irrigate can be achieved by many ways [47], including visual and tactile determination, container weight measurement, or through the use of a pressure chamber. Our survey found that 100% of responding nurseries base timing of irrigation events on "visual appearance," indicating a lack of objective irrigation criteria. This is the simplest method [47], but it is highly subjective and requires extensive experience. We found that using this technique has led nursery managers to schedule irrigation systematically rather than based on plant needs, often applying irrigation daily, and for some operations, up to three times per day [43,44,48]. The result is excessive irrigation and increased costs associated with the expense of water, energy use, and wear on equipment [44].

Basing irrigation on qualitative techniques can have deleterious biological impacts as well. The current irrigation technique promotes an environment with high relative humidity, increasing the occurrence of foliar pathogens such as *Botrytis* spp. (Figure 3A) and promoting the development of cryptogams (i.e., algae, moss, and liverworts) on the surface of the growth substrate, which becomes a physical barrier for water and nutrient absorption (Figure 3B) [49,50]. For example, Dumroese et al. [49], when comparing overhead and subirrigation techniques, observed that overhead irrigated plants had 3× more moss growth on the substrate than subirrigated plants. Excessive irrigation leaches nutrients from the growth substrate, decreasing element availability and absorption efficiency, which leads to lower seedling nutrient concentrations at the end of nursery production [51]. This problem is exacerbated when coupled with fertigation (irrigation water containing soluble fertilizers) applied at low nutrient concentrations. Combining frequent irrigations and with the application of low nutrient concentrations reduces the absorption of nutrients such as nitrogen (N). In *Picea glauca* (Moench) Voss, reducing irrigation up to 30% *v/v* decreased leachate volume by 65% and the quantity of N leached by 52%, without any negative effects on plant growth [52].

Figure 3. (**A**) Incidence on *Botrytis cinerea* on *Eucalyptus globulus* plants; (**B**) moss growth on the speedling surface due to excessive irrigation.

During our diagnostic survey performed during 2014–2017 in *E. globulus* plants produced in the Biobío region, leaf N concentrations were 0.69% (Table 3). This value is well below the proposed national standard for propagation material for forest use (i.e., NCh 2957/0.Of2006; [53]), which establishes an acceptable range from 1.7% to 2.5% of leaf N. This observed value is also well below other published results [45,46] (Table 3) that show it is possible to achieve these concentrations through integrated irrigation management and fertigation of species-specific N applications. Proper N concentrations are important because it has been extensively demonstrated that low N levels decrease field survival due to lower capability for root growth [39,54–56]. A recent review [55] indicated that nutrient-loaded seedlings performed better during outplanting in Mediterranean areas as a consequence of the increased growth of new roots. In agreement, Villar-Salvador et al. [56] reported that seedlings of two Mediterranean woody species, *Quercus coccifera* L. and *Quercus faginea* Lam., with higher N concentrations, performed better during field establishment than those with lower N concentrations; higher N values were positively correlated with root growth capacity. Accordingly, an increase in foliar N from 0.89% to 1.58% caused an increase in field survival from 40% to 80% in *E. globulus* seedlings [57]. While this work was done with an exotic *Eucalyptus* species, the concept likely applies to any woody plant in propagation, and research with native species in Chile confirms it. Ovalle et al. [39] reported a survival rate between 80% and 93% for the native *Q. Saponaria*, with foliar N concentrations between 2.2% and 2.7%, respectively. Similarly, Acevedo et al. [41] observed that increasing whole-plant N concentration from 0.61% to 0.93% increased first-year survival of *Nothofagus alessandrii* Espinosa from 28% to 51%.

Table 3. Applied nitrogen concentrations (mg L^{-1}) and subsequent leaf N concentrations (%) on *Eucalyptus globulus* plants produced in hard-sided containers in research nurseries [45,46], which we observed in production nurseries in the Biobío region during 2015.

Source		Treatments					NCh *
Monsalve et al. (2009) [46]	Applied N (mg L^{-1})	50	100	150	200	–	–
	Leaf N (%)	1.17	1.36	1.44	1.64	–	1.7–2.5
Acevedo et al. (2021) [45]	Applied N (mg L^{-1})	50	150	300	450	600	–
	Leaf N (%)	1.21	1.48	1.86	1.99	2.22	1.7–2.5
		Growing season 2013–2014					Mean
		Nur_1	Nur_2	Nur_3	Nur_4	Nur_5	
Biobío region (2015)	Applied N (mg L^{-1})	10	1.9	75	93	57	47.3 ± 40
	Leaf N (%)	0.87	0.75	0.66	0.60	0.58	0.69 ± 0.12

* Standards according to the Chilean norm NCh 2957/0. Of2006. Nur_n: different nurseries.

3.3. Increasing the Pace and Scope of Restoration

Considering the current national situation, Chile lacks the capacity to produce sufficient native plants to meet the timelines of the Paris Agreement and the Forest Policy. To address the insufficient quantity, it is necessary to shift production from pots and bags to restoration stocktypes/production types, expand current nurseries, and/or develop new nurseries.

Governmental policies and incentives are key to overcoming the bottleneck of plant production [15] and should promote the interest of private entrepreneurs to invest in the expansion or establishment of forest nurseries. This effort must be linked to the critical seed supply chain described by León-Lobos et al. [58] and Álvarez et al. [59]. These policies could transform restoration efforts by creating important economic activity that generates green jobs and income, especially in rural communities. Indeed, government incentives and investments in nurseries and seed collection activities for ecological restoration have spurred economic activity in Brazil [60,61].

A permanent program that transfers technology and knowledge about best management practices to nursery managers would help improve plant quality [27]. Well-trained nursery managers would attain adequate knowledge to implement technologies, solve problems, and implement the correct management practices to produce seedlings that meet morphological and physiological quality standards. This action should address the low levels of formal education presented by nursery managers by providing regular, science-based training, and instruction in efficient management techniques. The two most important and ongoing topics include proper fertilization and irrigation, which are interconnected. For example, training in designing appropriate fertilization schemes using customized or commercial fertilizers would increase fertilization efficiency, lower production costs, and yield plants with recommended nutrient concentrations to support improved survival and growth on the outplanting site. Likewise, training for the implementation of efficient irrigation techniques, monitoring, and scheduling based on the specific water demand of species, rather than systematic irrigation, would yield further benefits. The use of these best management practices should increase nursery efficiency by yielding more plants of higher quality in a shorter period of time, thereby reducing costs, decreasing resource inputs, and reducing the carbon footprint. Improved plant quality will have a positive effect on plant field survival and growth, thus increasing the pace and scope of successful restoration. The development of such a technology transference program may have additional benefits, such as providing the basis for a collaborative network among nurseries that promotes resource sharing, and fosters the exchange of native plant materials from those with surplus inventory to those needing stock, thereby balancing supply and demand issues and avoiding the problem of "holdover" stock.

All recommendations and decisions should be based on the best available science. Currently, the Chilean norm for plant quality is focused on exotic species, except for *N. alpina*. Thus, Chile has an urgent need for research aimed at developing appropriate standards for morphophysiological traits (i.e., seedling quality) of native tree and shrub species and the nursery management techniques required to achieve them. With the realization that other native plants are also important for other types of restoration activities (e.g., wetlands, prairies, riparian zones, xerophytic formations, etc.) focused research on less-known species and ecosystems that informs nursery production protocols and field establishment techniques would provide a more holistic approach to restoration in Chile and thereby avoid an oversimplification of the structure and functions of ecosystems to be restored [4,61,62].

4. Conclusions

In this study, we discuss in depth an important bottleneck proposed by Bannister et al. [14] for the restoration of natural forests in Chile. Meeting Chile's national and international commitments to forest restoration will require immediate action and diligence across the nursery, scientific, and policy sectors. Under the current scenario, Chile will not meet its pledged forest

restoration timelines and biodiversity goals. Instead of meeting the Paris Agreement pledge by 2030 and the national Forest Policy goal by 2035, realization will not be achieved until 2052 and 2181, respectively. This delay is caused by low production capacity (11.5 million seedlings per year) coupled with poor seedling quality (only 29% have sufficient quality for restoration), the latter exacerbated by inadequate training of nursery managers (only 19% with formal training). To address this native plant production bottleneck, we recognized three key needs: (1) the implementation of strong governmental policies that incentive the generation of nurseries as a new economic activity; (2) the development of science-based information for production and establishment techniques, including species from diverse forest ecosystems, which could serve as input for (3) the establishment of a permanent technology and knowledge transference program to nurseries. These challenges do, however, offer an opportunity to develop rural economies with improved resource sustainability that ultimately increase the pace and scope of forest restoration needed to conserve and restore Chile's remarkable endemic forest biodiversity.

Author Contributions: Survey design and data collection: M.A., E.C., and M.G. Performed data analysis and data search in CONAF database: M.A. Prepared the first draft of the manuscript: M.A. and C.Á.-M. Provided valuable insight and edits to revised manuscripts: R.K.D. and J.R.B. Edited manuscript language: R.K.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by INNOVA BIOBIO CORFO and the Regional Maule Government.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data from this study are available on request to the corresponding author.

Acknowledgments: The authors thank INNOVA BIOBIO CORFO and the Regional Maule Government for financing research projects. M.A., E.C., M.G. and J.R.B. thank the Chilean Ministry of Agriculture.

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

References

1. Intergovernmental Panel on Climate Change (IPCC). *An IPCC Special Report on the Impacts of Global Warming of 1.5 °C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways*; IPCC: Geneva, Switzerland, 2018.
2. Grassi, G.; House, J.; Federici, S.; den Elzen, S.; Penman, J. The key role of forests in meeting climate targets requires science for credible mitigation. *Nat. Clim. Chang.* **2017**, *7*, 220–226.
3. Bastin, J.F.; Finegold, Y.; García, C.; Mollicone, D.; Rezende, M.; Routh, D.; Zohner, C.M.; Crowther, T.W. The global tree restoration potential. *Science* **2019**, *365*, 76–79.
4. Strassburg, B.; Iribarrem, A.; Beyer, H.L.; Cordeiro, C.L.; Crouzeilles, R.; Jakovac, C.C.; Junqueira, A.B.; Lacerda, E.; Latawiec, A.E.; Balmford, A.; et al. Global priority areas for ecosystem restoration. *Nature* **2020**, *586*, 724–729. [PubMed]
5. Bannister, J.R.; Vidal, O.J.; Teneb, E.; Sandoval, V. Latitudinal patterns and regionalization of plant diversity along a 4270-km gradient in continental Chile. *Austral Ecol.* **2012**, *37*, 500–509.
6. Williams, K.J.; Ford, A.; Rosauer, D.F.; De Silva, N.; Mittermeier, R.; Bruce, C.; Larsen, F.W.; Margules, C. *Biodiversity Hotspots*, 1st ed.; Springer Publishers: London, UK, 2011; pp. 295–310.
7. Mittermeier, R.; Robles, P.; Hoffmann, M.; Pilgrim, J.; Brooks, T.; Mittermeier, C.; Lamoreux, J.; Da Fonseca, G. *Hostspot Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*, 1st ed.; Cemex: Mexico City, Mexico, 2004; pp. 9–53.
8. CONAF. Nota Informativa 01. Estrategia Nacional de Cambio Climático y Recursos Vegetacionales. 2015. Available online: https://www.conaf.cl/wp-content/files_mf/1443623122NotaInformativaN%C2%B01.pdf (accessed on 13 October 2020).
9. Ministerio del Medio Ambiente. Estrategia Nacional de Biodiversidad 2017–2030. Available online: https://mma.gob.cl/wp-content/uploads/2018/03/Estrategia_Nac_Biodiv_2017_30.pdf (accessed on 7 February 2020).
10. Ministerio del Medio Ambiente. Plan de Adaptación al Cambio Climático en Biodiversidad. Available online: https://mma.gob.cl/wp-content/uploads/2015/02/Plan_Adaptacion_CC_Biodiversidad_2.pdf (accessed on 7 February 2020).
11. CONAF. Estrategia Nacional de Cambio Climático y Recursos Vegetacionales 2017–2025 Chile (ENCCRV). Available online: https://www.conaf.cl/cms/editorweb/ENCCRV/ENCCRV-3a_Edicion-17mayo2017.pdf (accessed on 07 February 2020).
12. CONAF. Política forestal 2015–2035. Available online: https://www.conaf.cl/wp-content/files_mf/1462549405politicaforestal201520351.pdf (accessed on 07 February 2020).

13. CONAF. *Análisis de la Afectación y Severidad de los Incendios Forestales Ocurridos en Enero y Febrero de 2017 Sobre los Usos de Suelo y los Ecosistemas Naturales Presentes Entre las Regiones de Coquimbo y Los Ríos de Chile*; Informe Técnico; Corporación Nacional Forestal: Santiago, Chile, 2017; pp. 8–22.

14. Heilmayr, R.; Echeverría, C.; Lambin, E.F. Impacts of Chilean forest subsidies on forest cover, carbon and biodiversity. *Nat. Sustain.* **2020**, *3*, 701–709.

15. Bannister, J.R.; Vargas-Gaete, R.; Ovalle, J.F.; Acevedo, M.; Fuentes-Ramírez, A.; Donoso, P.J.; Promis, A.; Smith-Ramírez, C. Major bottlenecks for the restoration of natural forests in Chile. *Restor. Ecol.* **2018**, *26*, 1039–1044.

16. Chazdon, R.L.; Guariguata, M.R. Natural regeneration as a tool for large-scale forest restoration in the tropics: Prospects and challenges. *Biotropica* **2016**, *48*, 716–730.

17. Grossnickle, S.C.; Ivetić, V. Direct seeding in reforestation—A field performance review. *Reforesta* **2017**, *4*, 94–142.

18. Palma, C.P.; Laurance, S.G.W. A review of the use of direct seeding and seedling plantings in restoration: What do we know and where should we go? *Appl. Veg. Sci.* **2015**, *18*, 561–568.

19. de Souza, D.C.; Engel, V.L. Direct seeding reduces costs, but it is not promising for restoring tropical seasonal forests. *Ecol. Eng.* **2018**, *116*, 35–44.

20. Ceccon, E.; González, E.; Martorell, C. Is direct seeding a biologically viable strategy for restoring forests ecosystems? Evidences from a meta-analysis. *Land Degrad. Dev.* **2015**, *27*, 511–520.

21. Pérez, D.R.; González, F.; Ceballos, C.; Oneto, M.E.; Aronson, J. Direct seeding and outplanting in drylands of Argentinian Patagonia: Estimated costs, and prospects for large-scale restoration and rehabilitation. *Restor. Ecol.* **2019**, *27*, 1105–1116.

22. Gregorio, N.; Herbohn, J.; Harrison, S.; Smith, C. A systems approach to improving the quality of tree seedlings for agroforestry, tree farming and reforestation in the Philippines. *Land Use Policy* **2015**, *47*, 29–41.

23. Gregorio, N.; Herbohn, J.; Harrison, S.; Pasa, A.; Ferraren, A. Regulating the quality of seedlings for forest restoration: Lessons from the National greening program in the Philippines. *Small-Scale For.* **2017**, *16*, 83–102.

24. Harrison, S.; Gregorio, N.; Herbohn, J. A critical overview of forestry seedling production policies and practices in relation to smallholder forestry in developing countries. *Small Scale For.* **2008**, *7*, 207–233.

25. Dumroese, R.K.; Landis, T.D.; Pinto, J.R.; Haase, D.L.; Wilkinson, K.W.; Davis, A.S. Meeting forest restoration challenges: Using the target plant concept. *Reforesta* **2016**, *1*, 37–52.

26. Landis, T.D. The target plant concept—A history and brief overview. In *National Proceedings: Forest and Conservation Nursery Associations—2010; Proceedings, RMRS-P-65*; Riley, L.E., Haase, D.L., Pinto, J.R., Eds.; Tech. Coords.; US Department of Agriculture Forest Service, Rocky Mountain Research Station: Ft Collins, CO, USA, 2011; pp. 61–66.

27. Haase, D.L.; Davis, A.S. Developing and supporting quality nursery facilities and staff are necessary to meet global forest and landscape restoration needs. *Reforesta* **2017**, *4*, 69–93.

28. CONAF. *Guía Básica De Buenas Prácticas Para Plantaciones Forestales De Pequeños Y Medianos Propietarios*; Corporación Nacional Forestal: Santiago, Chile, 2013; pp. 23–48.

29. CONAF. Listado de Viveros Forestales. 2016. Available online: https://www.conaf.cl/wp-content/files_mf/1468589508BD_Censo_Viveros_Forestales_2016.xlsx (accessed on 7 February 2020).

30. CONAF. Listado de Viveros Forestales. 2017. Available online: https://www.conaf.cl/wp-content/files_mf/15263061591496683118BD_Censo_Viveros_Forestales_2017_actMAY08.xlsx (accessed on 7 February 2020).

31. CONAF. Listado de Viveros Forestales. 2018. Available online: https://www.conaf.cl/wp-content/files_mf/1548256797ListadoViverosForestales2018.xlsx (accessed on 7 February 2020).

32. CONAF. Listado de Viveros Forestales. 2019. Available online: https://www.conaf.cl/wp-content/files_mf/1562274595BDCensoViverosForestales2019Nacional.xlsx (accessed on 7 February 2020).

33. Quiroz, I.; Gutiérrez, B. *Propuesta Reglamento Para Semillas y Plantas Forestales*, 1st ed.; Instituto Forestal: Santiago, Chile, 2012.

34. Mathers, H.M.; Lowe, S.B.; Scagel, C.; Struve, D.K.; Case, L.T. Abiotic factor influencing root growth of woody nursery plants in container. *HortTechnology* **2007**, *17*, 151–162.

35. Takoutsing, B.; Tchoundjeu, Z.; Degrande, A.; Asaah, E.; Gyau, A.; Nkeumoe, F.; Tsobeng, A. Assessing the quality of seedlings in small-scale nurseries in the highlands of Cameroon: The use of growth characteristics and quality thresholds as indicators. *Small Scale For.* **2014**, *13*, 65–77.

36. Bayala, J.; Dianda, M.; Wilson, J.; Ouedraogo, S.J.; Sanon, K. Predicting field performance of five irrigated tree species using seedling quality assessment in Burkina Faso West Africa. *New For.* **2009**, *38*, 309–322.

37. Andivia, E.; Fernández, M.; Vázquez-Piqué, J. Assessing the effect of late-season fertilization on Holm oak plant quality: Insights from morpho-nutritional characterizations and water relations parameters. *New For.* **2014**, *45*, 149–163. [CrossRef]

38. Ovalle, J.F.; Arellano, E.C.; Ginocchio, R. Trade-Offs between drought survival and rooting strategy of two south American Mediterranean tree species: Implications for dryland forest restoration. *Forests* **2015**, *6*, 3733–3747. [CrossRef]

39. Ovalle, J.F.; Arellano, E.C.; Oliet, J.A.; Becerra, P.; Ginocchio, R. Linking nursery nutritional status and water availability post-planting under intense summer drought: The case of a South American Mediterranean tree species. *iForest* **2016**, *9*, 758–765. [CrossRef]

40. Álvarez, C.; Acevedo, M.; González, M.; Dumroese, R.K.; Cartes, E.; Quiroz, I. Field establishment techniques for guindo santo, an endemic species for central Chile. *Tree Plant. Notes* **2019**, *62*, 35–43.

41. Acevedo, M.; Álvarez, C.; Cartes, E.; Dumroese, R.K.; Gonzalez, M. Production and establishment techniques for the restoration of *Nothofagus alessandrii*, an endangered keystone species in a Mediterranean forest. *New For.* **2019**, *51*, 159–174. [CrossRef]

42. González, M.; Ríos, D.; Peña-Rojas, K.; García, E.; Acevedo, M.; Cartes, E.; Sánchez-Olate, M. Efecto de la concentración de fósforo y calcio sobre atributos morfo-fisiológicos y potencial de crecimiento radical en plantas de *Aextoxicon punctatum* producidas a raíz cubierta en la etapa de endurecimiento. *Bosque* **2020**, *41*, 137–146. [CrossRef]

43. INFOR. Informe Línea base. In *Proyecto "Agente de Difusión y Extensión Tecnológica para Pymes y Propietarios Forestales de la Región del Biobío"*; INNOVA BIO-BIO CORFO: Santiago, Chile, 2014.

44. Cartes, E.; Acevedo, M.; González, M.; Álvarez, C.; Mena, P.; García, E. *Manual de Manejo de Riego y Fertilización en Viveros de Plantas a Raíz Cubierta. Manual N° 51*, 1st ed.; Instituto Forestal: Santiago, Chile, 2018; pp. 49–81.

45. Acevedo, M.; Rubilar, R.; Dumroese, R.K.; Ovalle, J.F.; Sandoval, S.; Chassin-Trubert, R. Nitrogen loading of *Eucalyptus globulus* seedlings: Nutritional dynamics and influence on morphology and root growth potential. *New For.* **2021**, *52*, 31–46. [CrossRef]

46. Monsalve, J.; Escobar, R.; Acevedo, M.; Sánchez, M.; Coopman, R. Efecto de la concentración de nitrógeno sobre atributos morfológicos, potencial de crecimiento radical y estatus nutricional en plantas de *Eucalyptus globulus* producidas a raíz cubierta. *Bosque* **2009**, *30*, 88–94. [CrossRef]

47. Landis, T.D. Irrigation and water management. In *The Container Tree Nursery Manual*; Landis, T.D., Tinus, R.W., McDonald, S.E., Barnett, J.P., Eds.; U.S Department of Agriculture, Forest Service: Washington, DC, USA, 1989; Volume 4, pp. 69–118.

48. Coopman, R.; Escobar, R. Capítulo 5. Riego. In *Manual de Viverización Eucalyptus globulus a Raíz Cubierta*, 1st ed.; Escobar, R., Ed.; Centro Tecnológico de la Planta Forestal. Instituto Forestal: Santiago, Chile, 2007; pp. 147–162.

49. Dumroese, R.K.; Pinto, J.R.; Jacobs, D.F.; Davis, A.S.; Horiuchi, B. Subirrigation reduces water use, nitrogen loss, and moss growth in a container nursery. *Nativ. Plants J.* **2006**, *7*, 253–261.

50. Schmal, J.L.; Dumroese, R.K.; Davis, A.S.; Pinto, J.R.; Jacobs, D.F. Subirrigtion for production of native plants in nurseries—Concepts, current knowledge, and implementation. *Nativ. Plants J.* **2011**, *12*, 81–93. [CrossRef]

51. Dumroese, R.K.; Page-Dumroese, D.S.; Salifu, K.F.; Jacobs, D.F. Exponential fertilization of *Pinus monticola* seedlings: Nutrient uptake efficiency, leaching fractions, and early out planting performance. *Can. J. For. Res.* **2005**, *35*, 2961–2967. [CrossRef]

52. Stowe, D.C.; Lamhamedi, M.S.; Carles, S.; Fecteau, B.; Margolis, H.A.; Renaud, M.; Bernier, P.Y. Managing irrigation to reduce nutrient leaching in containerized white spruce seedling production. *New For.* **2010**, *40*, 185–204. [CrossRef]

53. INN. Norma Chilena Oficial. NCh 2957/0. Of2006. In *Material de Propagación de Uso Forestal*, 1st ed.; Instituto Nacional de Normalización: Santiago, Chile, 2006.

54. Simpson, D.G.; Ritchie, G.A. Does RGP predict field performance? A debate. *New For.* **1996**, *13*, 249–273.

55. Oliet, J.; Puértolas, J.; Planelles, R.; Jacobs, D.F. Nutrient loading of forest tree seedlings to promote stress resistance and field performance: A Mediterranean perspective. *New For.* **2013**, *44*, 649–669. [CrossRef]

56. Villar-Salvador, P.; Peñuelas, J.L.; Nicolás-Paragón, J.L.; Benito, L.F.; Domínguez-Lerena, S. Is nitrogen fertilization in the nursery a suitable tool for enhancing the performance of Mediterranean oak plantations? *New For.* **2013**, *44*, 733–751. [CrossRef]

57. Fernández, M.; Marcos, C.; Tapias, R.; Ruiz, F.; López, G. Nursery fertilisation affects the frost-tolerance and plant quality of *Eucalyptus globulus* Labill. Cuttings. *Ann. For. Sci.* **2007**, *64*, 865–873. [CrossRef]

58. León-Lobos, P.; Bustamante-Sánchez, M.A.; Nelson, C.R.; Alarcón, D.; Hasbún, R.; Way, M.; Pritchard, H.W.; Armesto, J.J. Lack of adequate seed supply is a major bottleneck for effective ecosystem restoration in Chile: Friendly amendment to Bannister et al. (2018). *Restor. Ecol.* **2020**, *28*, 277–281. [CrossRef]

59. Álvarez, C.; Acevedo, M.; González, M.; Cartes, E.; Bannister, J. Albinism detection among *Persea lingue* and *Cryptocarya alba* regeneration, from Cayumanque Mountain, Biobío Region, Chile. *Gayana Bot.* **2017**, *74*, 296–298. [CrossRef]

60. Mesquita, C.B.; Holvorcem, C.G.D.; Lyrio, C.H.; De Menezes, P.D. COOPLANTAR: A Brazilian initiative to integrate forest restoration with job and income generation in rural areas. *Ecol. Restor.* **2010**, *28*, 199–207. [CrossRef]

61. Moreira da Silva, A.P.; Schweizer, D.; Rodrigues-Marques, H.; Cordeiro-Teixeira, A.M.; Nascente dos Santos, T.V.M.; Sambuichi, R.H.R.; Badari, C.G.; Gaudare, U.; Brancalion, P.H.S. Can current native tree seedling production and infrastructure meet an increasing forest restoration demand in Brazil? *Restor. Ecol.* **2017**, *25*, 509–515. [CrossRef]

62. Isbell, F.; Calcagno, V.; Hector, A.; Connolly, J.; Harpole, W.S.; Reich, P.B.; Scherer-Lorenzen, M.; Schmid, B.; Tilman, D.; van Ruijven, J.; et al. High plant diversity is needed to maintain ecosystem services. *Nature* **2011**, *477*, 199–202. [CrossRef] [PubMed]