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The Forest Sector in Chile: An Overview and Current Challenges

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Chile has a strong forest sector based on plantations of exotic species and an extensive area of temperate rainforests with unique ecological features and a wealth of biodiversity and endemism. We present an overview of the forest sector of Chile focused on forest resources, silviculture, economy, social and environmental aspects, and forestry education and research. The Chilean forest sector is internationally known for its success. Although this is one of the most important economic activities of Chile, management between exotic species plantations and natural forests is very asymmetric. Currently, highly intensive silviculture is applied to forest plantations of *Pinus radiata* (radiata pine) and *Eucalyptus* (*Eucalyptus globulus, Eucalyptus nitens*) but only limited operational silviculture is applied to natural forests, even though there is considerable research to support it. There are still unresolved issues related to: conversion from natural forests to other land uses; pulp mills, and new efforts are needed from the government and large forestry companies to account for social and environmental demands. There is a good amount of university-level forestry education; however, there is an oversupply of professional foresters.

Keywords: temperate rain forests, *Nothofagus,* forestry plantations, sustainability

Chile has garnered national interest in recent decades for a variety of political and economic circumstances, including relatively fast economic growth compared with that of the rest of Latin America. For that reason, it has acquired a privileged position in the developing world and has established trade agreements with the United States and the European Union, among other large markets and now is in the Organization for Economic Co-operation and Development (OECD). On the other hand, the relatively recent reestablishment of democracy in Chile after 17 years of dictatorship has exposed the large social and economic differences within the Chilean population (Schatan 2001). The forest sector, particularly that associated with commercial plantations of exotic species, has played a key role in the economic growth of Chile but has also been controversial because of the contrasting perceptions about the current model of forestry among entrepreneurs, scientists, politicians, environmental nongovernmental organizations, landowners, and the general public.

Previous attempts to characterize the Chilean forest sector have been incomplete. Among the first English peer-reviewed publications on the forest sector of Chile are those of Recart (1973), Husch (1982), Jélvez et al. (1990), and Gwynne (1993). These mostly focused on forestry plantations and did not pay much attention to natural forests and the social aspects of forestry in Chile. Later, Lara and Veblen (1993) focused on the levels of substitution of natural forest areas by forest plantations and presented a rather pessimistic view of forest plantations in Chile. Paredes (2005), when referring to forest certification in Chile, gave a particularly negative view of natural forests for timber production. Finally, some recent studies focused on Chile (e.g., Clapp 2001, Wilson et al. 2005) have only presented brief overviews of forest conservation. Therefore, we aim to provide a more comprehensive and, hopefully, objective and updated forestry overview of Chile.

Forest Resources of Chile

General Features of Chile

Continental Chile has an area of 75 million hectares (ha) in southwestern South America and stretches from 17° to 56° S latitude, a length of 4,330 Km from the North to Cape Horn in the southernmost tip of

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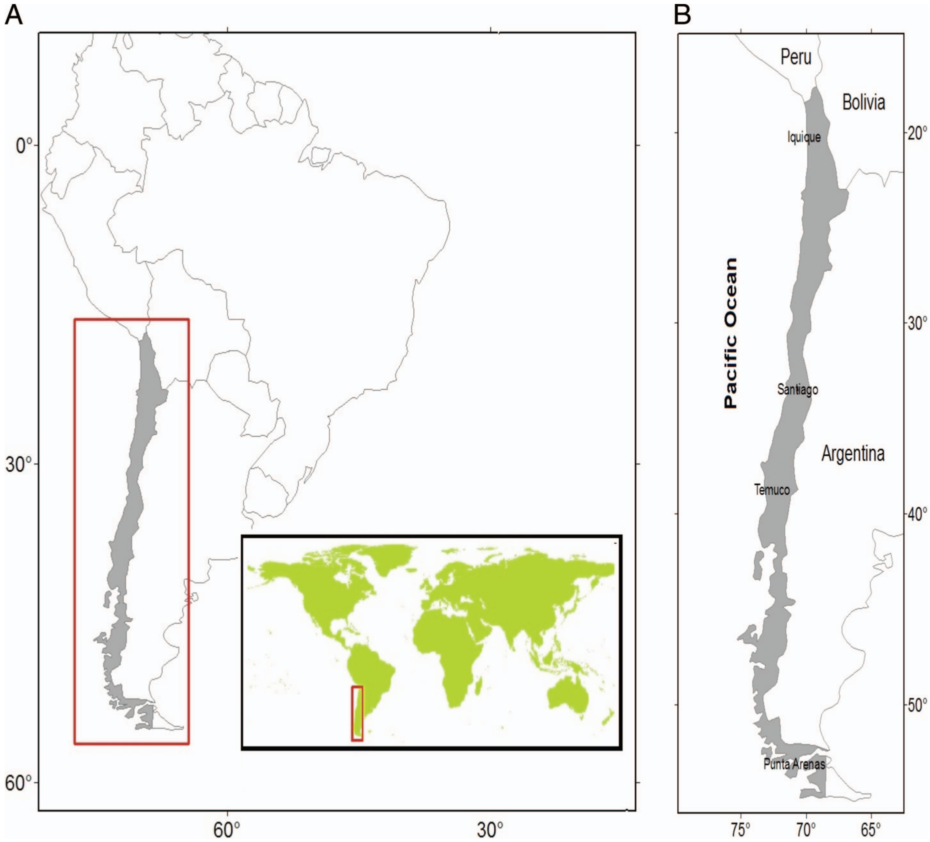

Figure 1. Chile in the world (A) and main cities and neighboring countries (B).

South America (Figure 1). Chile borders Peru to the north, Bolivia and Argentina to the east, Cape Horn to the south, and the Pacific Ocean to the west. One-third of its 17 million citizens live in Santiago, the capital and the country's largest city. From east to west, Chile is squeezed between the Andes Mountains range (or the Andean "Cordillera"[1]), the Central Depression, and the Coastal Cordillera. Chile is sometimes referred to as a geographical "island," because of its peculiar geographical isolation (Armesto et al. 1995), being located between the physical barriers of the Atacama desert to the north, the Antarctic Sea to the south, the Andes to the east, and the Pacific Ocean to the west.

Chile is within the Andean biogeographic region of Latin America (Morrone 2006). The Andean Cordillera decreases in elevation from north to south, with its peaks reaching about 7,000 m in northern and central Chile (17°–34° S), 3,000 m in south-central Chile (34°–45° S), and between 1,000 and 2,000 m in Patagonia (46°–55° S). The climate and vegetation of Chile are greatly determined by the orographic effects of the Andes (Veblen et al. 1996a). The Coastal Cordillera is lower in elevation than the Andes, rarely exceeding 1,000 m (Donoso 1996). In general, the Coastal Cordillera is geologically older than the Andes. The Central Depression (or central valley) is a structural depression between the Coastal and the Andean Cordilleras that has been filled to great depths with sediments eroded from the surrounding mountains (Donoso 1996). Soils in Chile are highly influenced by volcanic activity, which is a product of a very active volcanic system along the Andean Cordillera. In the foothills of the Andes, soils are derived from recent volcanic deposits of andesitic-basaltic origin, composed of very deep ashes and have excellent physical properties for tree growth. In the Central Depression, there is a great variety of geological material from the Andean Cordillera (Toro and Gessel 1999). Volcanic activity is one of the main natural causes of forest fires in Chile, the remaining being anthropogenic or, very rarely, ignited by lightning (González 2005).

Chile is divided into three major climatic regions: the north region, which contains the Atacama Desert, one of the driest regions in the world, is characterized by a hot and arid climate in the lowlands and occasional summer rain in the Andean highlands; the central region, extending about 900 m from 30° to 38° S, has a Mediterranean climate, with mild, wet winters averaging 11 °C, and long, dry summers averaging 18° C; and the south region, from 38° to 55° S, a region of mountains and fjords, with strong winds and the Valdivian temperate forests, the North Patagonian rain forests, and the Magellanic temperate forests (Donoso and Donoso 2007, Veblen 2007). Annual rainfall is always affected by variable elevation in the west-east axis that contains the two Cordilleras (the Coastal and the Andean), but on average it ranges from less than 508 mm in the north (with some places lacking rainfall records during the last few centuries), to 305–990 mm in the central re-

Management and Policy Implications

This work provides insights about the Chilean forestry sector and guidance for understanding the ecological, economic, social, and silvicultural complexity of its current framework. This review indicates that most of the challenges affecting large forestry companies come from social and environmental concerns. Improving the management of planted and natural stands, plus the relationship between large companies and indigenous communities, should be the focus of policymakers. In Chile, current socioenvironmental conflicts associated with large monoculture plantations and large clearcuts and the increasing high grading of natural forests have called for a new approach in the forestry sector. This new approach should consider the following: changes in silviculture and landscape management of forest plantations, including recovery of native forest patches in regions with large and continuous areas of monocultures of exotic species; adequate subsidies for promoting the conservation and management of natural forests, therefore reversing the high grading process that is now occurring in these forests; and forestry education and research that must serve these purposes to train professionals prepared for the challenges of a discipline with major environmental, social, and economic implications on people and local communities. Chile, with its high diversity and endemism, plus the opportunities for growing highly productive forests either from plantations or native forests, could become a model for forest ecosystem management.

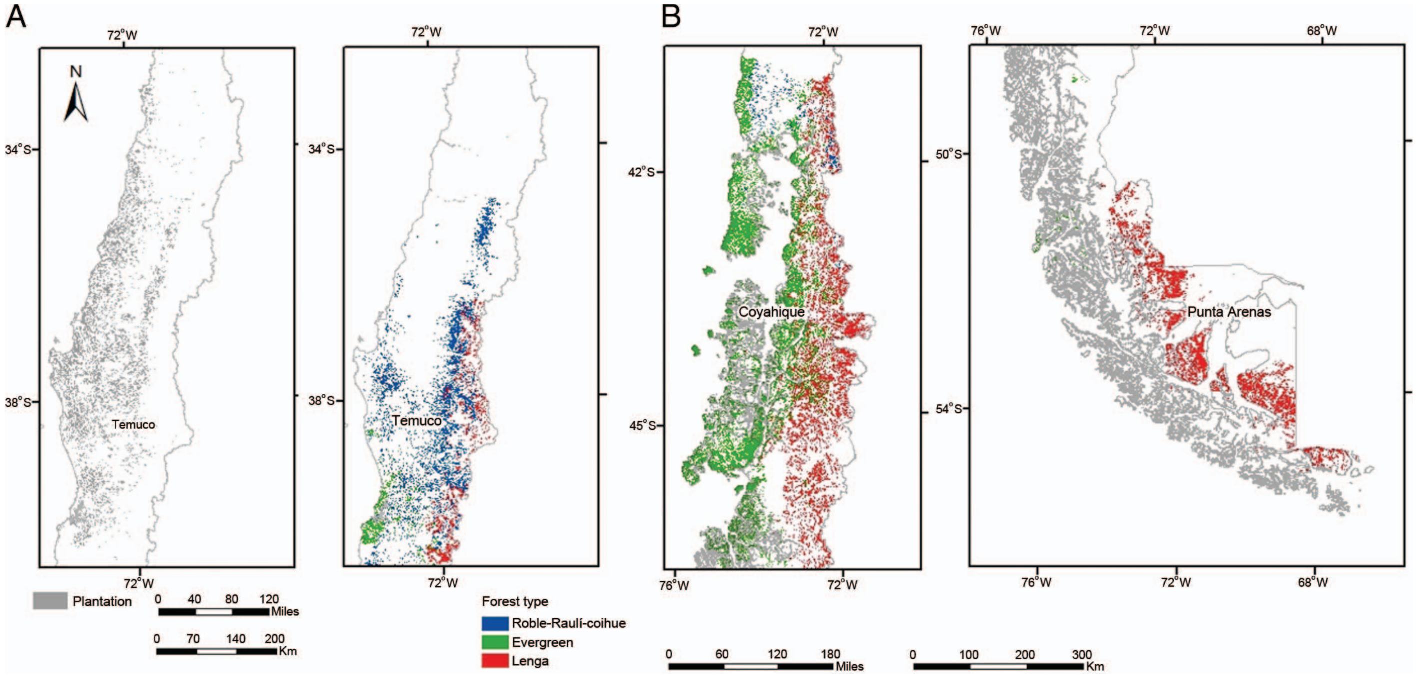

Figure 2. Geographic distribution of forestry plantations (A) and the three most abundant natural forest types (B) of Chile. The scale is given in km (200 km = 124 miles; 400 km = 249 miles).

gion, and up to 990–5,000 mm in the South. South of 40° S, rain occurs year-round (di Castri and Hajek 1976).

Forestry Plantations

Chile is one of the top 10 countries in the world in terms of land dedicated to forestry plantations and the fifth in the Americas (Cubbage et al. 2007), with 2.9 million ha (Corporación Nacional Forestal [CONAF] 2014). The principal species used in forest plantations are *Pinus radiata* (radiata or Monterrey pine), comprising 62% of the total of plantations, followed by *Eucalyptus* species (mainly *Eucalyptus globulus* and *Eucalyptus nitens*), representing 31% (Instituto Forestal [INFOR] 2012). Most plantations have been established from 37° to 41° S in the southcentral region (Figure 2A), with 71% of the radiata pine plantations located in the Coastal Range, 19% in the foothills of the Andes, and 10% in the Central Depression (Toro and Gessel 1999). There are also approximately 16,000 ha of *Pseudotsuga menziesii* (Douglas-fir) plantations (INFOR 2012), which have longer rotations than radiata pine, but better growth rates than in its natural range in North America, just like radiata pine. In addition, there are some *Pinus ponderosa* (Ponderosa pine) plantations in the South (in the North Patagonia) of Chile, where these plantations were established to rapidly recover large areas affected by extensive forest fires in the past century (Morales 1996). There are 6,500 ha of native species plantations, with *Nothofagus* (a native genus in Chile) species the most common.[2] Plantations of the main *Nothofagus* species (*Nothofagus obliqua:* "roble," *Nothofagus alpina*[3]: "raulí"; and *Nothofagus dombeyi:* "coigüe") have captured research interest during the last 40 years. They have also generated much interest in the United Kingdom, where growth rates surpass those of most other native broadleaves and approach those of the fastest growing conifers (Pearce 1977). Less extensive trial plantings with *Nothofagus* have been done in France (Salas and García 2006) and in Germany (Martin 1978). Currently in Chile, efforts to assess the growth potential of planted *Nothofagus* in terms of growth and timber quality indicate that these species can achieve excellent volumetric growth similar to that of radiata pine when intensive silviculture is applied early on appropriate sites (Donoso et al. 2009, Soto et al. 2009).

Natural Forests

Chile's temperate forests (Armesto et al. 1995, Donoso 1995, Veblen et al. 1996a, Donoso and Donoso 2007) are of high ecological importance and currently under threat, mainly because of illegal logging and land use change (Lara et al. 1997, Altamirano et al. 2013). These temperate rainforests represent the second largest remaining area of this type in the world (Donoso 1995, Wilcox 1996) and are internationally recognized for their ecological importance (Olson and Dinerstein 1998, Stattersfield et al. 1998). Chile's peculiar geographical isolation, located between the physical barriers described earlier, results in a high rate of plant and animal endemism (Armesto et al. 1995). As indicated by Wilson et al. (2005), despite their ecological importance, Chilean temperate forests have experienced a long history of destruction and are currently threatened by land-use changes and mismanagement. Furthermore, the strong biogeographic isolation of the southern temperate forest heavily restricts the possibilities of recolonization after habitat destruction or sudden climate change (Armesto et al. 1998).

Chilean temperate forests have experienced a long history of anthropogenic disturbance. The influence of the indigenous Mapuche through timber cutting and clearing fires before European colonization, prior to the 19th century, was not that important considering the small population (approximately 1 million) and the great forest cover in southcentral Chile (Otero 2006). During the colonization of Chile, Spaniards cleared vast areas of forests for agriculture and pasture, mainly those located in the Central Depression of Chile (Donoso 1983, Lara and Veblen 1993, Donoso and Otero 2005). This clearing, with the use of fire, continued into the first half of the 1900s by other European colonists, such as those from Germany, Switzerland, and Italy (Donoso and Lara 1999a). Many human-induced forest fires destroyed immense areas covered with natural forests, including more than 3 million ha in the austral region of Aysén (Otero 2006). With the promulgation of the Decree Law 701 (D.L. 701), of 1974, which subsidized plantations, between 160,000 and 200,000 ha of native forest were replaced by plantations of exotic species during the 1970s and 1980s (Lara and Veblen 1993). Since 1994, plantations have replaced an additional 40,000 hectares (Forest Stewardship Council [FSC]; FSC-Chile[4]).

Even though several classifications of the Chilean natural forests exist (e.g., Schmithüsen 1956, Oberdorfer 1960, Veblen and Schlegel 1982, Gajardo 1994), the one provided by Donoso (1981) is the most accepted by Chilean foresters, probably because it uses the dominant tree species and forest structure to differentiate among forest types. This classification also has been used for defining forest types in the current Chilean forestry legislation. Donoso (1981) classified the natural forest of Chile into 12 forest types (Figure 2B), from the sclerophyllous forest type with fairly scattered trees in central Chile to the simple *Nothofagus* forest types in the Tierra del Fuego region. The genus *Nothofagus,* which according to Hill and Dettmann (1996) is generally considered one of the key genera in understanding how southern biota have evolved and migrated, is represented in all but two Chilean forest types (Donoso 1995). Eight forest types are dominated by broadleaved trees, in six cases by *Nothofagus* species. Three forest types are named for their dominant conifer species: *Fitzroya cupressoides* ("alerce," the second-longest lived tree species of the world) (Lara and Villalba 1993), *Araucaria araucana* ("araucaria," a tree species associated with the indigenous people called "Mapuche-Pehuenche") (González et al. 2006), and *Pilgerodendron uviferum* ("Ciprés de las Guaitecas") (Lara et al. 2006). The other forest type is dominated by the Chilean palm *Jubaea chilensis.*

There are some natural forest types that are especially suitable for forest management. These are the roble-raulí-coigüe forest type of the Central Depression and low elevations in southcentral Chile (2 million ha), the coigüe-raulí-tepa (*Laureliopsis philippiana:* "tepa") forest type of the midelevations in the Andes of southcentral Chile (0.8 million ha), the evergreen forest type of southcentral Chile (4.3 million ha), and the lenga (*Nothofagus pumilio*) forest type in southern Chile (3.3 million ha). The roble-raulí-coigüe forest type is the most important for timber production because of the high wood quality of these three *Nothofagus* species and its location on the most productive sites in the Central Depression and foothills of the Andes (Figure 2B). Because of their proximity to human populations and the gentle terrain that they usually cover, these forests are very accessible. Currently, the roble-raulí-coigüe type is represented mostly in extensive areas of secondary-growth forests that originated after forest fires (both anthropogenic and natural from volcanic eruptions), clear cutting, and landslides. The old-growth forests of this type were largely cleared for agriculture (Veblen et al. 1996a), and only few remnants persist (Donoso 1995). The coigüe-raulí-tepa type is mainly restricted to the Andes between 38° and 41° S within 500–1,000 m of elevation (Donoso et al. 1986). The lenga forest type is especially important in Patagonia (from Coyhaique to Tierra del Fuego). The evergreen forest type covers the largest area, ranging from 37° to 45° S, especially above 500 m in both Cordilleras in their northern reaches, and from sea level in their southern extent.

Silviculture

Highly intensive silvicultural practices are applied to forest plantations, using chemicals and large-scale and mechanized harvesting. Radiata pine in Chile is managed as monoculture plantations, and management practices vary considerably according to factors such as final product, site, and ownership (Jélvez et al. 1990). Volume growth rates of radiata pine vary between 18 and 35 m^3/ha/yr (Toro and Gessel 1999) with an average of 25 m^3/ha/yr. According to Gerding (1991), Meneses and Guzmán (2000), and Cubbage et al. (2007) and our current knowledge, two silvicultural regimes (pulp-oriented and clearwood-oriented) are typically applied to radiata pine plantations owned by forestry companies. For pulpwood, the stands are established with 1,600–2,500 trees/ha, thinned once, and cut when they are between 18 and 25 years old, yielding 350–800 m^3/ha with about 800–1,000 trees/ha. For clearwood, stands are planted with 1,200–1,300 trees/ha, pruned two or three times to maintain a clear bole up to 4–6 m, generally thinned twice, and finally cut between ages 20 and 24, yielding 450–600 m^3/ha from 450 trees/ha. In both regimes, plantation establishment is highly intensive, and the final cut is only through clearcutting. However, there are almost no limitations to the size or slopes where clearcuts are done, which produces large clearcut areas in the landscape of up to 499 ha (Figure 3A).

Large-scale forest operations increase hydrologic and morphological risks (Mohr et al. 2011). Inadequate planning and execution of clearcuts have resulted in negative impacts on biodiversity, water and soil processes, and aesthetic values, which has increased opposition to these practices even where silviculturally warranted (McGinley et al. 2013). On the contrary to radiata pine plantations owned by forest companies, plantations owned by small landowners are mostly unmanaged (Gerding 1991) and therefore best suited to produce pulp logs. *Eucalyptus* species are largely used for pulp, and therefore they are neither thinned nor pruned. They are usually harvested around 14–15 years, with growth rates of 30–40 and 40–50 m^3/ha/yr for *E. globulus* and *E. nitens,* respectively (Geldres and Schlatter 2004, Muñoz et al. 2005).

Management of natural forests in Chile is allowed by law but is less prevalent than forest plantation management. Although a good amount of silvicultural research has been conducted in second-growth stands of roble-raulí-coigüe (e.g., Puente et al. 1979, 1981, Grosse 1989, Grosse and Quiroz 1999), lenga (e.g., Schmidt and Caldentey 2001, Rosenfeld et al. 2006), and evergreen forests (e.g., Donoso 1989a, 1989b, Donoso et al. 1999a, Navarro et al. 1999), only small areas have undergone silvicultural treatments, especially thinning of second-growth forests and selection cuttings (Figure 3D and F). This might be due to the fact that natural stands have been largely subjected to illegal cuttings of the best trees and therefore require further economic investment to become potentially productive units through thinnings, supplementary planting, and other restoration activities. This economic investment could be done mostly by forestry companies but is much more difficult for small landowners, given that there is a lack of suitable policy initiatives to support this long-term investment and the market for natural forest products is not as well developed as it is for plantations. Some simulated scenarios provide positive net present values

Figure 3. View of a typical clearcut in the landscape (A) and a high graded native forest in the Andes of southcentral Chile (B), a managed plantation of radiata pine (C), a stand of evergreen forest type under uneven-aged management (D), a plantation of well-managed *Eucalyptus nitens* in the Chilean Coastal Range, stream buffers with protection of native vegetation (E), and invasive species management for restoration to conserve the endemic forest of Robinson Crusoe Island (F). Photographs were taken by Pablo Donoso (A and D), Daniel Soto (B, C, and E), and Rodrigo Vargas (F).

for long-term management of these forests (Cubbage et al. 2007, Nahuelhual et al. 2007). The Chilean government, during 2008, approved a forestry law that would give some economic support to landowners willing to manage their natural stands under a sustainable framework, but its application has been negligible because of the small amount of the subsidies.

Natural stands of roble-raulí-coigüe are silviculturally important because of their high timber value and good growth rates. The greatest amount of silvicultural research plots (Lara et al. 2000) and published studies are concentrated in this type of forest. These species are mainly distributed in second-growth even-aged stands that are easy to manage because of their relatively homogeneous structure. The mean annual volume increment for unmanaged roble-raulí-coigüe second-growth stands is between 5 and 15 m^3/ha/yr (Donoso et al. 1993b, 1999b, Grosse and Quiroz 1999), but can be as much as 22 m^3/ha/yr under appropriate management (Donoso et al. 1993b). Studies dealing with this forest type have been focused on forest dynamics (Puente et al. 1979, 1981) and silvicultural research trials (Puente et al. 1981, Grosse 1989, Grosse and Quiroz 1999). Overall, roble-raulí-coigüe stands have both the potential to be managed based on current knowledge and economic interest.

Roble, raulí, and coigüe are promising species for use in forest plantations. These *Nothofagus* species are easy to propagate in the nursery (Donoso et al. 1999b), establish well (Wienstroer et al. 2003, Donoso et al. 2009) and are among the most valuable tree species of the Chilean natural forests (Siebert 1999, Díaz-Vaz et al. 2002). However, few studies have been done in roble-raulí-coigüe plantations (Donoso et al. 1999b, Wienstroer et al. 2003, Donoso et al. 2013). In the last 30 years, some research trials with plantations of these species have been established and during the last 10–15 years commercial plantations have been established as well. According to Cubbage et al. (2007), *Nothofagus* plantations could be harvested in rotations of 30–35 years with internal rates of return of 11–13%, compared to 16% in radiata pine plantations. A mixture of exotic and native species plantations also has been promoted and shows good empirical growth rates (e.g., Douglas-fir and *Nothofagus*) (Siebert 1999). Furthermore, in a financial assessment study conducted by Hildebrandt et al. (2010), a higher proportion of raulí in a mixed plantation with Douglas-fir was shown to be especially profitable under higher degrees of risk aversion scenarios.

The Forest Sector and Chilean Society

There are two public institutions related to the forest sector in Chile, the forest service (CONAF) and the institute of forest research (INFOR) both under the Ministry of Agriculture. In addition to enforcing forestry laws and promoting the development of the forest sector, CONAF supports the conservation of natural protected areas and the sustainable use of forest ecosystems. CONAF promotes the establishment of forestry plantations and the management of natural forests as a way to contribute to the economic, environmental, and social development of Chile. INFOR generates scientific and technological knowledge for the sustainable use of forest resources, including the statistical information for different aspects of the forestry sector.

Forest products provide Chile's second largest export income after minerals, with US$5.9 billion in 2011, 7.3% of total exports, contributing 2.7% of the total GDP and providing about 300,000 jobs (INFOR 2012). The forest sector is the third most important economic activity in the country and is based largely on forest plantations of radiata pine and *Eucalyptus* (Jélvez et al. 1990). Two major Chilean companies, CMPC (Compania Manufacturera de Papeles y Cartones) and CELCO (Celulosa Arauco y Constitucion), along with a few other large companies, own 70% of the plantations in Chile (INFOR 2005), concentrating the economic benefits in the hands of a few (Collins and Lear 1995). Natural forests, which cover 14.1 million ha (CONAF 2014), of which 21.6% are included in Chile's national system of protected areas (SNASPE), are mostly owned by small- and medium-sized landowners. It is estimated that these natural forests have been mostly subjected to high grading (i.e., cut the best and leave the worst) and that only between 5 and 25% have been managed (Lara et al. 1997). Chile's forest sector is asymmetric (Donoso and Otero 2005) in the sense that plantations are intensively managed for pulp and other wood products for export, with little value added (Gwynne 1993), whereas natural forests are mismanaged and high graded, mainly yielding firewood (Frêne and Núñez 2010).

The successes of the Chilean forestry sector have not benefited most of the population. Although the plantation subsector contributes the most forest-based exports, it has not increased the quality of life where most of these plantations have been established (Donoso and Otero 2005). Indeed, the regions with more forest plantation cover are the ones with the lowest human development index values of the country (Donoso and Otero 2005). Further details regarding the conflicts of the Chilean forest sector can be found in Reyes and Nelson (2014). As pointed out by Ward (2007), Chile's competitive advantages (e.g., natural resources and low-cost labor) come with their own baggage, which must be considered when forestry competitiveness among countries is compared (Sedjo et al. 1999).

For example, the relationship between large forestry companies and the Mapuche (i.e., the indigenous people in southcentral Chile) has always been tense, with ongoing disputes about land rights and documented incidents of violence and protests (Montalba and Carrasco 2005, Ward 2007, Frêne and Núñez 2010). Mapuche confrontations with corporate interests have grown more violent, and according to Aylwin (2009 and references therein), negligence from the government to resolve many of the Mapuche's historical demands have triggered these confrontations.

Indigenous people represent about 4.6% of the Chilean population (Instituto Nacional de Estadísticas 2003), and the government created an indigenous subsecretary (CONADI) in 1993 to support indigenous people's rights. However, several conflicts remain.

Reducing the negative environmental impacts of large-scale operations remains a challenge for forestry companies. Despite the fact that many people have portrayed forestry companies as having a poor environmental record, generally these forest companies have followed Chilean environmental laws. Nevertheless, the Chilean laws are too flexible in relation to a major and controversial forest activity: clearcutting (Donoso 2009). Although the size of individual clearcut units has decreased, especially among FSC-certified companies, clearcuts are much larger than those applied in North America and elsewhere, reaching a maximum allowed of approximately 500 ha (Ward 2007). The impacts of large-scale clearcuts in Chile have been addressed in Donoso (2009) and Huber et al. (2010).

Another controversial issue has been the conversion of native forests to forest plantations (i.e., substitution). Even though native forest replacement was more common in the past (Lara et al. 1997), it continues in the present (Miranda et al. 2015, Zamorano-Elgueta et al. 2015). For instance, according to the monitoring program led by CONAF in the region between 40° and 41° S, the average annual loss of natural forest has been about 2,000 ha.

In the last 10–15 years, Chilean forestry companies have become more concerned about environmental issues in their forest management operations. The total area of FSC-certified plantations in 2004 was 306,949 ha (Paredes 2005), mainly associated with either small plantation-based or natural forest-based companies. Today, this number is about 1.5 million ha (FSC-Chile[4]) after the incorporation of large companies into this system in recent years. Of the forestry plantations in Chile, 52% are now FSC-certified. However, two main concerns remain: plantations continue to be managed with traditional harvesting schemes (e.g., large clearcuts on steep slopes and intensive widespread use of chemicals to control competing vegetation), whereas environmental standards are mostly implemented in the matrix surrounding industrial plantations (e.g., creation of conservation areas) but not within plantations; and an increasingly empowered society is demanding environmental standards that are well beyond FSC standards to ensure water supply from planted watersheds near local communities, landscape quality (i.e., aesthetic and connectivity), and good maintenance of public roads.

Forest product facilities (mainly pulp mills) have experienced a number of environmental problems. For example, a recent ecological disaster that involved the deaths of multiple black-necked swans (*Cygnus melancoryphus*) in a sanctuary in southern Chile was linked to effluent from a local pulp mill. One of the two largest forestry companies, CELCO, built a US$1 billion bleached kraft-type paper pulp mill on the Rio Cruces near the city of Valdivia in southern Chile. Since this mill began full operations in February 2004, it has received multiple complaints from the public concerning noise, noxious odors, and water pollution (Marcotte 2006). An 30 km portion of the Rio Cruces north of Valdivia corresponds to a large wetland, now a Nature Sanctuary, derived from massive flooding after a major earthquake in 1960 (Lagos et al. 2008). In January 2004, there were more than 6,000 black-necked swans in the Sanctuary, however, during April to May 2004, dozens of these swans were found dead (Mulsow and Grandjean 2006). Studies have reported that the pulp mill effluent produced the decline of a subaquatic plant that is the main source of food of black-necked swans living in that Sanctuary, probably contributing to the death of these birds (Mulsow and Grandjean 2006, Lagos et al. 2008). The justice system found CELCO responsible for the pollution of the Sanctuary. Overall, the public (especially the inhabitants of Valdivia) has developed a negative perception of the CELCO pulp mill (Marcotte 2006).

Forestry Education and Research

Forestry education has a long tradition in Chile. Formal training in forestry in Chile came with the founding of two forestry schools in the mid-1950s: the Universidad de Chile and the Universidad Austral de Chile. During the "boom" of the forest sector, from the 1980s to the mid-1990s, several new forestry schools were opened in the country, producing an oversupply of foresters. There is a highly unbalanced proportion between the amount of forestry schools and both forested area and population size in Chile. Although in developed countries, there is one forestry school per 4–10 million inhabitants, at the end of 2004 in Chile there was one forestry school per 1.5 million inhabitants (Donoso and Otero 2005). Similarly, in Chile, there is one forestry school per 1.5 million ha, but this number is between 7 and 13 million ha in developed countries. In the last decade, foresters have difficulty in finding jobs, and several of the newer forestry schools have stopped offering forestry degrees (forest engineering) because of a decline in enrollment, as also pointed out by Nyland (2008) for the United States. We estimate that in the future only between two and four forestry schools will offer the traditional forestry curriculum, whereas careers in natural resources and environmental sciences continue to emerge. Nevertheless, there is high uncertainty regarding the job market for new careers in this area, because Chile's job market is mostly dominated by traditional professions. For instance, civil engineers are still largely preferred by companies and government organizations for many of their environmental duties.

There are three doctoral programs in forestry (i.e., Universidad Austral de Chile, Universidad de Chile, and Universidad de Concepción). In general, doctoral degrees held by Chilean forestry professors have been mostly obtained from German universities (e.g., University of Gottingen, University of Freiburg, and University of Munich) and Spain (e.g., Universidad Politécnica de Madrid, Universidad de Córdoba, and Universidad de Oviedo). However, in the past 15 years the proportion of professors being trained in universities from the United States (mainly Colorado State University, Oregon State University, and North Carolina State University) has been increasing. In the future, we expect an increasing number of doctoral programs in areas related to forest science (e.g., environmental sciences, ecology, and natural resources) rather than pure forestry programs. Regardless, there is still uncertainty about where the future doctoral graduates would work, given that new forestry schools and/or departments are not being created, INFOR has funding problems, and forestry companies do not usually hire individuals with doctoral degrees. We believe that master-level programs are much needed, because their graduates can work directly in different fields and are more related to the private sector. Masters programs can also be focused on different subdisciplines that can be applied to forestry problems, such as cartography, energy, economy, environmental education, and others.

There is no guaranteed funding for INFOR, the government-dependent institution for forest research. CONAF, the national forest service, is mainly in charge of applying forestry laws and managing SNASPE, but not for conducting research as the US Department of Agriculture Forest Service does. INFOR focuses its research almost exclusively on short-term projects, and its production of peer-reviewed publications is poor in comparison with those for traditional forestry schools (Acuña et al. 2013). Technological funding has been mostly granted to silviculture and industry technology-oriented topics, with only a small part focused on natural forests. However, there was an increase in projects granted to forest management of natural forests in the period from 2000 to 2004 (Díaz 2006). On the other hand, ecological restoration in degraded forests and recovery of areas replaced by fast-growing plantations in the past are important targets/challenges for researchers, companies, public service agencies, and landowners. Some experiences in ecological restoration are ongoing, but few of them have been published; some examples are the work in *Pilgerodendron uviferum* forests by Bannister et al. (2013), in the endangered endemic forest of Robinson Crusoe Island by Vargas et al. (2013), and in the coigüe-raulí-tepa forest type in the Andes (Donoso et al. 2013).

Researchers at INFOR usually apply for the same type of grants available for all forestry research projects in Chile, therefore, competing with research centers such as universities. Although INFOR has been obtaining a larger proportion of grants for technological projects in the last decade (Díaz 2006), their researchers lack independent funding for their own projects, e.g., nonproduction-oriented research, such as ecology and wildlife. Furthermore, INFOR does not have experimental forests where they could carry out long-term research (Donoso and Otero 2005).

Research on forest plantations has covered many topics in forestry or at least the most important for forest production, such as nursery establishment (e.g., Gerding et al. 1986, Rubilar et al. 2008), genetic improvement, integrated pest management (e.g., Lanfranco et al. 1994), thinning and pruning treatments, harvesting, forest planning (e.g., Weintraub and Abramovich 1995, Meneses and Guzmán 2000), growth simulators, and carbon markets (e.g., Espinosa et al. 2005), among others. On the other hand, research in natural forests has been largely focused on ecological aspects, such as forest dynamics (e.g., Donoso 1995, Veblen et al. 1996b), silvics (Donoso 2006), genetics (Donoso et al. 2004), and silviculture (Donoso and Lara 1999b, Donoso and Promis 2013). However, more extensive quantitative-oriented studies, particularly for natural forest stands, remain to be conducted (Salas and Real 2013).

Concluding Remarks and Future Challenges

Forestry in Chile has evolved with highly different rates of development for plantations of exotic species and for native forests. Political efforts should focus on developing sustainable forest management for plantations and natural forests with public funding for research in natural forests and private funding for forestry plantations. The declining enrollment in forestry schools is mainly a result of an oversupply of professional foresters, which results in unemployment and low salaries. The main challenges to the Chilean forest sector can be summarized as follows: (a) to improve the relationship between large forestry companies and indigenous and local communities; (b) to promote the silvicultural management of natural forests; (c) to enhance the potential of natural forest for climate change adaptation and ecosystem services (e.g., carbon sequestration, provision of quality water, tourism, and nontimber forest products); (d) to develop a high-value wood market for native species; (e) to reduce the allowable size and maximum slope for clear-cutting; and (f) to improve or create laws and regulations to address these challenges. We believe that advancing and promoting these issues will contribute to sustainable forest management of Chilean forests and plantations.

Endnotes

1. We use the Spanish word "Cordillera" when referring to either the Andes Mountains range or the Coastal Mountains range.
2. The area of native species plantations only covers the period between 1998 and 2013. This area was computed based on data available at sit.conaf.cl/, the CONAF system of land use information.
3. Two other scientific names, *Nothofagus procera* and *Nothofagus nervosa*, are also sometimes used; however, we prefer to use *Nothofagus alpina,* following the clarification given by Grant and Clement (2004).
4. Information available from FSC-Chile website cl.fsc.org.

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