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A Critical Assessment of the Adaptive Capacity of Land Use Change in Chile: A Socio-Ecological Approach

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Additional information is available at the end of the chapter

Abstract

Land use and land cover change (LULCC) can be defined as a socio-ecological system (SES): social, economic, and political processes in interaction with ecological processes result in a given land use trend. Instead of forest recovery, Chile has been identified as a case of a forest transition dominated by commercial plantations. This chapter aims to examine the process LULCC in Chile from a socio-ecological perspective. Drawing upon frameworks of SES by Scheffer et al., this chapter analyzes the adaptive capacity of LULCC in Chile. First, SES concepts are presented. The next section is a summary of the political and economic process that underpinned the plantation transition in Chile and its consequences on the landscape. In light of SES theory, the 518,174 hectares wildfire observed in 2017 is a consequence of the lack of adaptive capacity. Nevertheless, Chile's LULCC is unlikely to change due to abovementioned dynamics. Finally, this chapter discusses the implications for policy making and the global forest transition discussion. In summary, using the case of Chile, this chapter aims to contribute to SES theory and forest policy, seeking sustainable futures based on a systemic view.

Keywords: socio-ecological, forest transitions, global south, tree farms, policy

1. Introduction

Adaptive capacity can be defined as the ability of a system to adapt to changing internal demands and external circumstances [1]. Social and ecological systems are interlinked systems where outcomes result from the interaction between social and ecological dynamics. Dynamics among social and ecological systems can result in a socio-ecological system that has

high adaptive capacity—this is a system able to respond to changing condition—or a system that, despite the intensity of the stimuli, does not respond. Whether the stimulus is climate change, a natural disaster, a new societal preference, a new invasive species, an adaptive SES would respond to the new demands and stresses.

Land use and land cover change (LULCC) can be defined as a socio-ecological system (SES). LULCC is the result of the interaction between natural and human systems [2]. Social, economic and political processes in interaction with ecological processes result in a given land use trend [3]. Forest transitions describe a systemic land use trend change, where a geographic region switches from deforestation toward forest gains [4]. Chile has been identified as a case where, instead of forest recovery, the transition has been dominated by tree farms [5]. Despite the social demand for native forest protection that was raised after the fall of Pinochet's dictatorship, the native forest law, meant to foster and protect native vegetation, had no significant effect [6]. Moreover, in 2017 nearly 518,174 ha were burnt in a massive wildfire that lasted for at least 15 days, affecting three administrative regions. Nearly half of the area burned was fast-growing plantation [7]. Despite this disaster the Chilean State has created a new fund for tree farms. This chapter presents an analysis of the adaptive capacity of the land use trend observed in Chile from a socio-ecological perspective. Through this assessment, it is expected to draw lessons for other countries that are following the Chilean example, while providing deeper insights regarding theoretical questions of land use transitions in the Global South [8].

1.1. Afforestation in Chile

Similar to many developing countries, Chile had serious deforestation and related erosion problems in the twentieth century [9]. However, from 1973 to 2012, Chile expanded the extent of forestry plantations from 330,000 to nearly 2 million hectares (**Figure 1**) [9]. Chile has not only increased its afforested area during this 30-year period but also developed one of the most vigorous forestry sectors worldwide by increasing forestry exports more than a thousandfold in nominal terms, from US \$36.4 million in 1976 to US \$5.271 million in 2016 [10]. These policies have resulted in successful increases in tree cover, but not in native forest cover [11, 12]. Afforestation in Chile resulted from planting fast-growing trees under intensive management. These plantations use non-native of single species stands, such as *Pinus* and *Eucalyptus*. Tree farms in Chile can reach up to 1250 seedlings per hectare and require the intensive application of fertilizers and herbicides, while clear cuts are conducted every 18–20 years [9].

Compared to non-native species, native species have rarely been planted in Chile. The national statistics show that the rate of native species afforestation has been orders of magnitude smaller than tree farm afforestation. Moreover, in Chile the proportion of land area covered with native forest has diminished relative to tree farm areas. Between 1997 and 2011, the total covered by native forests increased by 169,008 ha but diminished by roughly 4% in its representation among total national forestry resources [13]. Although native forests still

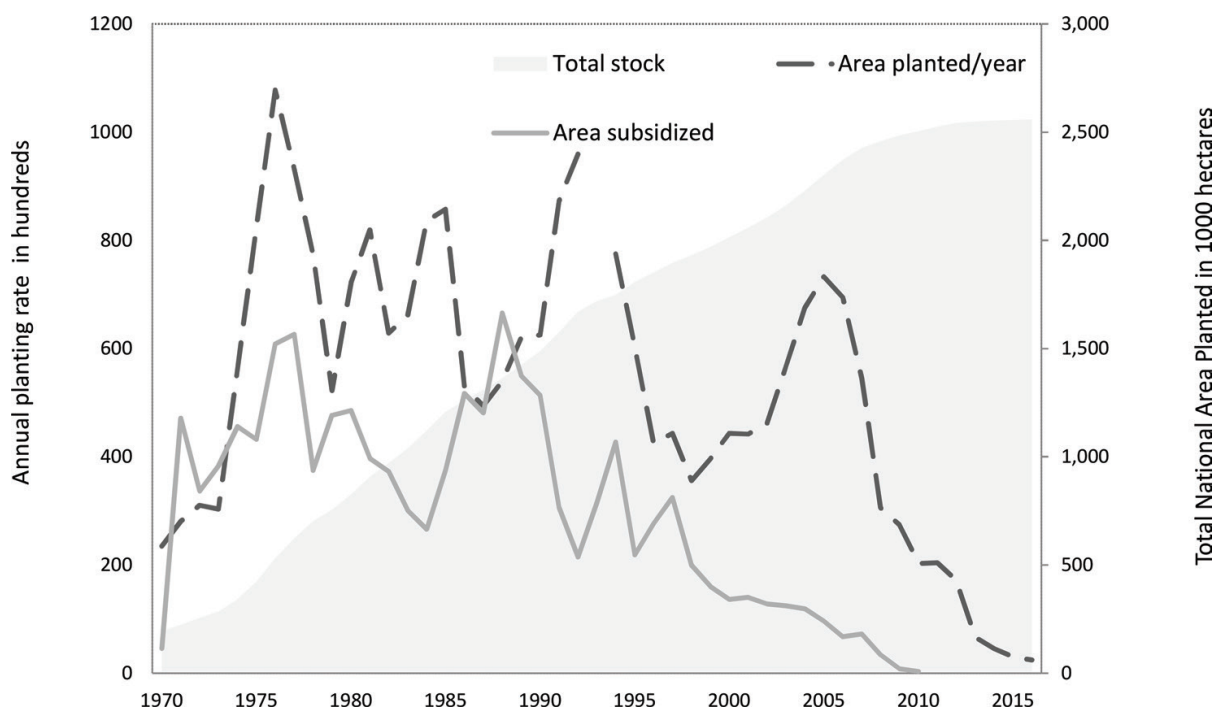


Figure 1. Tree farm national statistics for Chile. Solid area indicates the national stock for each year. Dashed line indicates the area planted with subsidy each year (DL 701), and the solid gray line indicates the area planted per year. (Sources: [7, 9, 74, 75]).

represent the majority of the national forestry resources, native forest are concentrated on the southernmost area of Chile where there is no overlap with biodiversity hotspots [14–16]. A closer look to the native forest subcategories shows that the most valuable native forest types are still diminishing. From an economic perspective, the most valuable woods (*Nothofagus* spp.) have not increased in area [13].

From an ecological perspective, valuable forest has also been lost. For example, mature forest that provides habitat for endemic and endangered forest specialist species, such as the families Rhinocryptidae and Berberidopsidaceae [17–19], has also diminished [13]. By differentiating between forest types and tree cover, comparisons indicate that Chile's afforestation policy has only increased the total area planted with non-native species, which has important consequences for ecosystem functions, such as water provision [20–22].

Even though afforestation came to solve serious erosion problem on the twentieth century (**Table 1**), today there are economic and political dynamics that limit SES adaptation to the new socio-economic conditions. The problem is not widespread erosion but water provision and regulation and resilience against climate change. Chile is already experiencing a mega-drought [23], and it is expected that the frequency of such events will increase [24]. The following section is an introduction, based on the work of Holling, Scheffer, and others, to some of the basic SES concepts.

Key milestones of the Chilean land use social-ecological system	
Deforestation and soil degradation	
1541	The capital of Chile, Santiago, is founded by Spaniard conqueror.
19 th C	Native forests are burnt and used in construction, mining and railroads. Native forest is replaced by agriculture.
1880s	First trials of Pine and Eucalyptus plantations.
1931	Fist Forestry Law provides tax breaks for forested areas.
1940's	Several experts publish books concerning deforestation and erosion. Erosion is estimated in 4,000,000 ha mostly located in the coastal area [48,89]
1952	Foundation of the forestry trade association, called National Wood Corporation (CORMA)
State-led national program of reforestation: Stock of non-native trees increased in 330,000 ha	
1960	Creation of the public Forestry Institute (INFOR)
1964	Foundation of the public national research institute of natural resources (IREN)
1970	Foundation of the first public agency for public national afforestation (CONAF). CONAF had 18,000 employees in 1973.
1972	The Corporation for Development Production (government) operated the first two pulp processing facilities (Celulosa Arauco and Celulosa Constitución)
Restoration through shock therapy; by the end of 1989 the stock of non-native trees increased in 1,303,160 ha.	
1973-1990	INFOR, IREN, CONAF, and most of the processing facilities become private institutions, or self-financed. Bans on log exportation are removed as well as price bands of competing commodities (e.g.: wheat price bands). State-owned facilities and more than 60,000 ha of state-owned plantations are sold to privates (Arauco, Constitución, Inforsa).
1973	A coup d'état led by Pinochet takes the government.
1974	DL701: Main subsidy for tree plantation is decreed. The state pays 75-90% of the costs of any tree plantation or forest improvement, regardless of the tree species planted. Tax breaks are maintained in place, private property is secured by several policy reforms.
1975	Establishment of a state-backed system of credits for afforestation.
1980	The military-led government decrees a new political constitution
1981-1983	Economic crisis resulted reinforced concentration of facilities and lands into few companies financed by international investors
1988	National referendum ends the dictatorship
Rigidity trap: by the end of 2011 the stock of non-native tree increased in 1,063,241 ha, while the stock of native species increased in less than 67,847 ha.	
1990-present	In this period Chile signs several free trade agreements
1990	A week after the democratically elected government takes offices, the president decreed the prohibition to cut the Monkey Puzzle tree (<i>Araucaria araucana</i>) (Supreme decree 59)
1992	The first draft of the Native Forest law is sent to the House of Representatives
1993	The Native Forest bill passes to the Senate.
1994	Chile is provisionally accepted in the North American Free Trade Agreement (NAFTA)
1998	DL701 is renewed for small landowners (Act 19,561)
2001	Chile signs the Free Trade Agreement with the United States
2007	Policy stakeholders agree on a short version for the Native forest bill.
2008	The Native Forest Law was enacted (Act 20,283).
2011-2012	The DL701 is renewed for two years due to the earthquake (Act 20,488).
2015	Act 20,488 expires without renovation.
2017	January: Large wildfire affected south central Chile
2018	CORFO launched a public-private investment platform

Table 1. Key milestones in the Chilean land use socio-ecological system.

2. Socio-ecological framework

The socio-ecological system (SES) is an approach to understand the outcomes that emerge from the interaction between both social and ecological dynamics [25]. Historically, social and natural sciences have developed independently of each other, thus generating valuable but separated knowledge [25]. Therefore, policy is often based on a single discipline and fails to address the complexity of the socio-ecological systems. Neglecting complexity can easily result in unintended consequences, surprises, pathologies, or traps [26, 27]. In rigidity traps, institutions become highly connected, self-reinforcing, and inflexible so that “forces of power, politics, and profit are reinforced one another” [1, 26]. At the same time, rigidity traps are “accidents” waiting to happen. In rigidity traps interconnectedness is so high that any random event, such as a fire or disease, can cause a system ripple [26]. By analyzing natural resource policy as a SES, it is possible to see those broader dynamics.

The adaptive change theory developed by Gunderson and Holling [26] was originated in ecological studies on population dynamics. The original ecological studies sought to explain why there could be multiple stable dynamics among two populations, as well as cycles of rapid change, including outbreaks and population decline [28]. The populations’ studies found that changes in slow-changing variables, as well as stochastic events, can explain outbreaks and population decline and even new stable states [28–30]. Based on these studies, Holling and others elaborated on the idea of multiple alternate state in SES, focusing on the relationships between “slow” and “fast” variables [26]. Gunderson and Holling [26] have proposed that social variables are slow-changing variables that control change in SES. More specifically, Scheffer et al. [31] argue that large-scale cultural variables function as the slow variables in SES.

Scheffer et al. [31], hereafter SSEF (Scheffer’s socio-ecological framework), proposed an explanation of how a SES might depart from an adaptive behavior by drawing on sociology, neo-classical economics, and systems ecology. Briefly summarized, SSEF starts by focusing on a hypothetical ecosystem where the relationship between the ecosystem integrity and the stress are noncontinuous and nonlinear.

The classical example is water turbidity and nutrient addition to a shallow lake. Low levels of nutrients result in low water turbidity. As more nutrients are added to the lake, turbidity increases up to a threshold where light levels are insufficient to support aquatic vegetation, and it disappears. After this point, turbidity continues to increase, but reducing nutrient concentrations does not result in more transparent water. SSEF works under the assumption that ecosystems do not have linear dynamics and restoration is much more than doing the opposite that damaged the system [31]. Because SSEF is a socio-ecological framework, it is important to consider how changes in the ecosystem affect total welfare of people. Total welfare is the third variable of the SES. In the SSEF, a hypothetical rational manager “knows” the optimal combination between ecosystem stress, ecosystem integrity, and maximum realizable welfare [31]. The realizable maximum welfare is different from the theoretical welfare because of the nonlinear relationship between stress and ecosystems integrity.

A more realistic account of SSEF includes the effects of politics. Different groups of people have different power, and, in some cases, political pressure from powerful groups influences

the rational manager. The rational manager allows more stress over the ecosystems than what is optimal, resulting in a maladaptive behavior. In reality, this hypothetical rational manager, rather than a superhuman entity, is the outcome of the political struggle itself [31]. This means that, even in an ideal democracy, the regulating entity or rational manager will be elected in some political process.

SSEF elaborates further on this framework by incorporating ideas from discourse analysis and political ecology. Powerful parties not only influence the regulator but also can shape the meaning of the problem itself through signification, legitimization, and domination [31]. Literature on environmental discourse and policy has shown that power dynamics affects the way the environment and policy are constructed; this is how the environment and people are treated [32–34]. Power dynamics are evident at the international governance level [33], at the national level in countries with strong postcolonial legacies [35], in segmented societies [34], and in countries with recent dictatorships, such as Chile [36]. The main argument of this chapter is that the political-economic context, sustained by specific discourses (legitimization), works as the “slow variables,” explaining the current lack of adaptive capacity of LULCC in Chile. The following section summarizes the political and economic changes that fostered timber plantations in Chile; this means 45 years of land use change through the lenses of the SSEF.

2.1. Soil degradation and the state-led national program of reforestation

By the beginning of the twentieth century, erosion and deforestation, partially inherited from the Spanish colonization, were important problem in Chile (**Table 1**). Since 1890, wealthy families started planting *Radiata pine* [37]. Studies done by one the first naturalists, named Albert, suggested that *Radiata pine* could be an appropriate species for reforestation due to its capacity of reaching harvesting size in just 15 years. In 1931 the first Forest Law, provided some tax breaks to forest owners. Nevertheless, the 1931 law did not have a large effect in terms of native forest conservation but did provide some incentive for non-native species. Between 1925 and 1936, 2.580 hectares were planted with non-native species [9]. By 1942, Elgueta [38] estimated that 4,000,000 ha were eroded and claimed that erosion was a national tragedy (**Figure 2**). As shown in **Figure 2**, the area is indicated as a continuous area of severe erosion. However, studies have shown that by 1955 and 1975, there were several large patches of native forest in the area, such as the land near Constitución or near Maule [5, 39]. It is unclear why this map was drawn in such a coarse resolution, but it is clear that the map shows erosive processes that covered a vast, continuous area, reinforcing the idea of an “environmental disaster.”

The 1929 economic crisis inaugurated a period of imports substitution in several countries in Latin America, including Chile [40]. The import substitution model aimed to foster industries that would complement the agricultural and natural resource sectors [40]. The Chilean Development Corporation, CORFO, was created to foster the industrial sector. The CORFO, through loans and public-private investments, provided access to capital to extend tree plantation and develop the first forest industries [37]. *Radiata pine* was the chosen species due to its capacity of providing large returns in a short time. Between 1939 and 1942, nearly 5.492

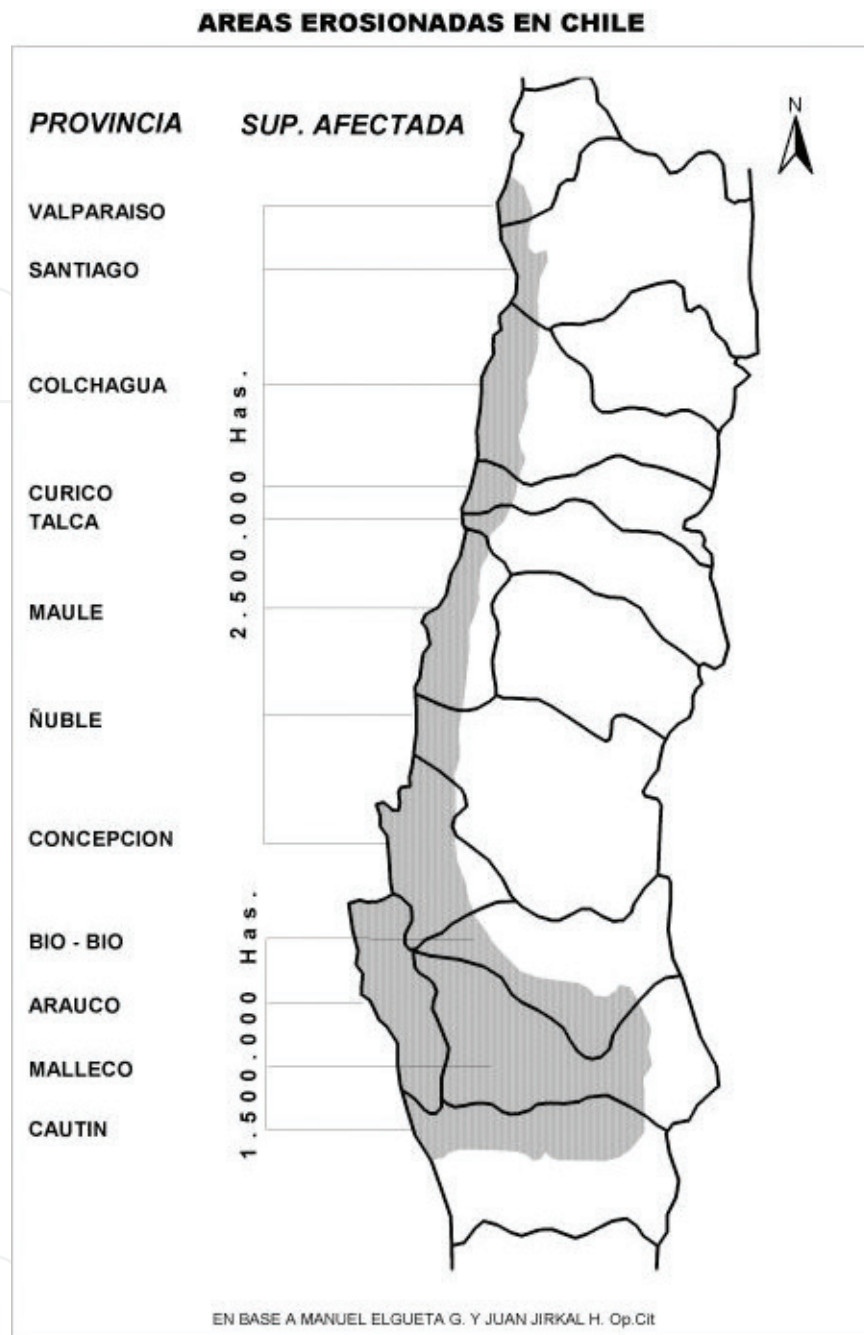


Figure 2. Map depicting the area under severe erosion in 1942 based on Elgueta and Jirkal. Notice the continuity of the eroded areas for over 12 provinces, accounting for 4,000,000 hectares (Reproduced with author's permissions).

hectares were planted. In 1950, the nascent pulp industry needed to secure the future supply of raw material [37]. The forestry industry requires long-term planning since it is dependent on tree's growth cycle. By 1952, several forestry entrepreneurs, including state-owned forestry companies, formed a single trade association called the National Wood Corporation (CORMA). The CORMA was created to advocate for the interest of the forestry companies [9]. In the next decade, a series of private and public-private forestry conglomerates were created, such as the Celulosa Arauco [37].

In the same period, the colonization of the frontier forest in southern and more isolated areas was a strategy to exert territorial presence and control. Colonization implied a new frontier for deforestation where this phenomenon wasn't already happening, implying further reduction of the area covered by native forest [9].

In the 1960s, the Frei Montalva administration led the agrarian reform. The CORMA managed to declare that the forested lands could not be legally expropriated under the reform. To protect their property, several landowners declared their land as forest land [9]. In parallel, the Frei Montalva administration created a national program of reforestation, the forest service (COREF, later called CONAF) and a national research institute of natural resources (IREN) [9]. Later, the democratically elected socialist president Salvador Allende took office in November 1970 and continued the afforestation program alongside the agrarian reform initiated in the previous administration. In September 1973, the president was overthrown by a military-led coup d'état. By 1973, at the national level, 330,000 hectares were planted with non-native plantations (**Table 1**). Although these LULCC figures are not negligible, the largest land use transformation was still ahead.

2.2. Renovation through shock therapy: 1973–1990

Between 1973 and 1990, Chile was ruled by a military dictatorship. The military took over in September 1973, shutting down the judicial and the legislative powers, destroying all opposition media, and executing or exiling political opponents. After the first years of the coup d'état, the objective of the military-led government was to restructure the economic system. The timber sector was seen as an important niche where Chile could develop a robust export market [37]. Following this logic, a series of policy changes were made. Land property rights were secured by a new constitution, and common land tenure was abolished. In 1974, the government passed the Decree Law 701 (DL 701) which states that the government would pay private owners between 75 and 90% of the costs of any tree plantation or forest improvement, regardless of the tree species planted, including both native and non-native species [41]. In terms of area, DL 701 came to subsidize large portions of the planted area at the national level. For example, in 1982 up to 88% of the planted area at the national level was subsidized through this law (**Figure 1**). The annual rate of afforestation passed from nearly 30,000 per year in 1972 to 85,772 ha in 1985. For the next 14 years, the average rate was 57,591 hectares per year (1976 to 1990, **Figure 1**). Until 1999, 94.2% of the subsidies were allocated to large and medium landowners (i.e., up to 200 ha or 800 ha in remote locations) [42].

CORMA's influence on the drafting of this decree was celebrated, as this trade association publication consigns:

It was in 1974 when the conditions were appropriate to enact a law that will actually encourage afforestation and really put the forest policies forward. Indeed, the Minister of Economy Mr. Fernando Leniz Cerda, who had served as president of the Chilean Wood Corporation (CORMA) for professional reasons, knew the forestry sector perfectly. [In addition] at that moment the Executive Director of the National Forestry Corporation was a forester with familial affinity [kinship] with the President of the Republic [Pinochet]. The DL 701 was developed and drafted exclusively by the Ministry of Economy,

without external interference, taking advantage of some ideas and suggestions from the National Forest and the Chilean Wood Corporation, [and from] the Association of Foresters and the Universities.

(“Temas de Fondo” Section p 127, CORMA vol 241, Nov-Dec emphasis added)

In other words, The CORMA had a monopoly in the design of DL 701 in 1974. Moreover, CORMA’s connection with the military government was not only ideological but also involved kinship ties between President Pinochet and the CONAF executive director Julio Ponce Lerou, recently charged with corruption [43]. In the same venue, two more laws benefiting CORMA’s interests were passed in this period: a decree allowing the exportation of wood products at any processing stage and Decree 600, which allowed foreign companies to buy Chilean external debt in exchange for state-owned companies [44]. During the 1981 economic crisis, the national currency was devalued relative to the US dollar as a means to reduce the external debt, which resulted in the bankruptcy of many forestry companies [9]. While small companies went bankrupt, large and medium forestry companies were taken over by the government and resold to holdings that could bring dollars to the country [9]. The removal of wheat price bands, as well as the removal of bans on logs export, also added to the profitability of tree farms [45]. The complete set of economic measures restructured the forestry sector and resulted in a massive rearrangement of land, companies, and facilities, which became concentrated in a few hands. As of 1997, 57% of forested land was owned by eight big companies [46].

Seven million hectares of native forest were lost in 30 years. Several studies indicate that at the national level in 1965, the nation had nearly 20 million hectares of native forest; meanwhile, in 1996 the national land cover assessment estimated a total of 13 million hectares [9]. A study including nine areas in south central Chile [39] estimated an average native forest loss of 31% for this period with an annual rate of deforestation of 2.9%. However, in the area where most of the processing facilities operate, nearly 72% of the area covered by native forest was then converted toward tree farms [39], which is the same area that harbors most of the plant diversity at the species level [16]. On average 20% of native forest loss was converted toward tree farms [39].

In summary, forestry plantations were seen as the best way to foster a competitive economic sector and recover the 4 million hectares eroded in south central Chile [47]. The tragedy of erosion, claimed in 1940, was skillfully used to extend tree farms, despite the erosion status of a particular area, as many of them were actually covered by native forest.

Looking through the lenses of adaptive theory, since 1973 the economic reforms conducted by the military-led government implied deeper systemic changes that generated an exceptionally stable land use trend. Yet the Chilean afforestation policy took place in the context of a dictatorship and resulted in a deep legacy of inequality and environmental risk sustained by very resilient political dynamics [48]. A single trade union (CORMA) was able to influence policy making without much counter balance during the dictatorship and afterward [36, 49]. This policy reform faced no political opposition, as was characteristic during the Pinochet dictatorship. Since economic reforms happened under a dictatorship, where political

opposition was repressed, it would be expected that once the democracy had returned to Chile a more “balanced” policy would be in place in terms of native forest conservation.

2.3. Rigidity trap: 1990 and on

Rather than a change in the land use trend, due to the new social context and social demands, in this period the expansion of tree farms intensified, while the legal regulation for native forest exploitation came only after 16 years of congressional discussion. In this period the average area planted with tree farms per year was 43.663 hectares, reaching a maximum of 95.933 ha in 1992 (**Figure 1**). Meanwhile, the deforestation rate for the period 1990–2000 was 1.6% per year, then increasing to 2.4% per year between 2000 and 2010. Compared to the 1970–2000 period, the figures on hectares converted from native forest to tree farms on average were reduced by a third but still accounted for a 35% of the forest loss [39].

Firstly, tree farm expansion and native forest loss continued due to the open economy policies fostered by the left coalition *La Concertación*, the maintenance of the subsidy for tree farms and the delay and reduction of the regulatory power of the Native Forest Law. Free trade agreements were the key to access new markets for timber products. *La Concertación* political project was based on the continuation of the open market economy [50]. Therefore, between 1990 and 2010, 17 trade agreements were signed, such as the MERCOSUR (Common Southern Market in 1996), Canada (1997), Mexico (1999), Caribbean nations (2005), the European Union (2003), the USA (signed by Chile in 2001, ratified 2004), China (2006), India (2007), and Japan (2007), to name a few. This implied that Chile had access to a much larger market where both timber farm products and native forest chips could be sold¹. Trade opening also fostered tree farms by making other land uses less competitive, such as wheat [45]. The economic reforms that started during the dictatorship were then intensified in the democratic governments.

Secondly, the subsidy for tree farms was maintained even though several studies indicated that tree farms were profitable enough without a subsidy [52, 53]. After the expiration of the subsidy in 1996, the political discourse turned to the “social” side of planting. In the previous period (1974–1996), the subsidy was concentrated in large landowners [54], so now a more social focus was needed. This discursive turn sought the promotion of tree farms among small and medium landowners: a frontier that could not be reached in the previous period. Thus, the DL 701, meant to last until 1995, was then replaced by another law [18, 55] to maintain the subsidy but reorienting it to small and medium landowners until 2008 [48]. Peasant’s associations played a large role in the subsidy extension. The discourse uttered by peasant organizations, which have the closest contact with native forest, presented significant tensions of identities. On one hand, peasant’s organizations understand themselves as a collective that has a historic relationship with land and forest, but those collective constructions were neglected in favor of a discourse of individual ownership. Given the political constitution of Chile, which only acknowledges individuals’ rights, the farmers and peasants’ organizations only get to claim political power when they articulate themselves as individual owners. In this

¹For example, in 2016, Chile exported \$2.8 billion dollars in wood pulp, and 66.7% went to Asia, where 45% went just to China. In contrast, 11 years before, in 1995 wood pulp exports were just a half, \$1.4 billion dollars, and 45.6% went to Europe, while none of the countries concentrated more than 18% [52].

way, legacies from the dictatorship are legitimizing today's construction of forest policy [36]. The tree farm subsidy expired again in 2010, but the massive earthquake (8.8 Mw) in this same year was used to maintain the subsidy for another 2 years. The presidential message, asking the congress for an extension, was addressed as follows:

The extension of this initiative is even more important, considering the current situation in the country, marked dramatically by the earthquake and tsunami of last February 27 of the current year. This initiative will create jobs in forest areas strongly affected by the catastrophe that hit our country [54].

The argument in 2010 implied that if the DL 701 was a job creation policy, then it could not be denied to the already vulnerable people. This new extension meant to last until 2014. Finally, the subsidy was not renovated in 2015 due to a large corruption case that involved the main forestry conglomerates, who are the natural buyer monopsony of forestry products [55]. Apparently, around 2010, tree farm expansion had reached a saturation point (**Figure 1**). Since 2006 the rate of plantations had diminished, while the stock of tree farms is constant. However, this statistical trend does not indicate a systemic direction change in terms of LULCC but the maintenance of the *status quo*. Since 2010 the total national stock has remained around 2.5 million hectares.

Thirdly, the Native Forest Law (NFL), created to respond to the social demand for native forest conservation, took 16 years to become a law and does not have an effect in promoting significant forest cover. In 1992, the Aylwin administration, the first democratic government after the dictatorship, decided to promote native forest conservation through the NFL, as a means to preserve the remaining forest (**Table 1**). The original version of the NFL included strict regulations for forest cuttings, subsidies for plantations, and a ban on native forest replacement by non-native species [54]. At the House of Representatives, the right-wing congressmen questioned the lawfulness of the bill, arguing that banning native forest replacement was a restriction over property rights, rights otherwise protected by Pinochet's constitution [56]. If a bill affected property rights, it would require 2/3 of the votes to pass through congress, which was very challenging, given Chile's bipartisan political system [57]. The law passed 16 years later, in 2008, called for minor regulations and promoted conservation only through a competitive fund for native species management (**Table 1**).

Despite the already mentioned effects of tree farm expansion on biodiversity, several ecosystem services, and the increasing demand for better forest conservation policies, there was no policy change. Rigid systems become "tragedies waiting to happen" [26]; these tragedies might be any random process, such as a drought or an insect outbreak. The rigidity means that the socio-ecological system becomes less able to deal with chance, reducing its own capacity for sustaining people.

The tragedy happened in January 2017. A rare combination of high temperatures and long drought fueled a large wildfire. The fire of January 15, 2017 was the first of a series of aggressive wildfires that lasted for at least 15 days. These fires affected 467,537 ha at the national level (**Figure 3**). Of the area burned, 248,204 ha were tree farms; this is nearly 12% of the national stock of timber farms. This wildfire affected 4,696 farmers, implying the loss of human lives, 850 houses, and the loss of the whole productive capacity of the farmers of the area: herd animals, fodder, crops, and beehives. This fire also affected 77,131 ha of native forest, 76,551 ha

of pastures and shrubs, and 512 ha of wetlands [58]. Nearly 76% of the natural ecosystems affected are in a precarious conservation status (danger or critical danger) [7].

In June 2017, the CORFO presented a 13-million-dollar plan to reactivate the economy in the area affected by the wildfire. This plan included direct planting and restoration. The ecological restoration would receive 31% of the funds, while the rest of the money would be used to clean, take out the burned barks, sell them, and plant the same species that were burnt in the large wildfire. In this case, the planting would not be done through DL 701 but as direct contracting through the CONAF. The goal is to replant 40,000 hectares of tree farms in 3 years [58].

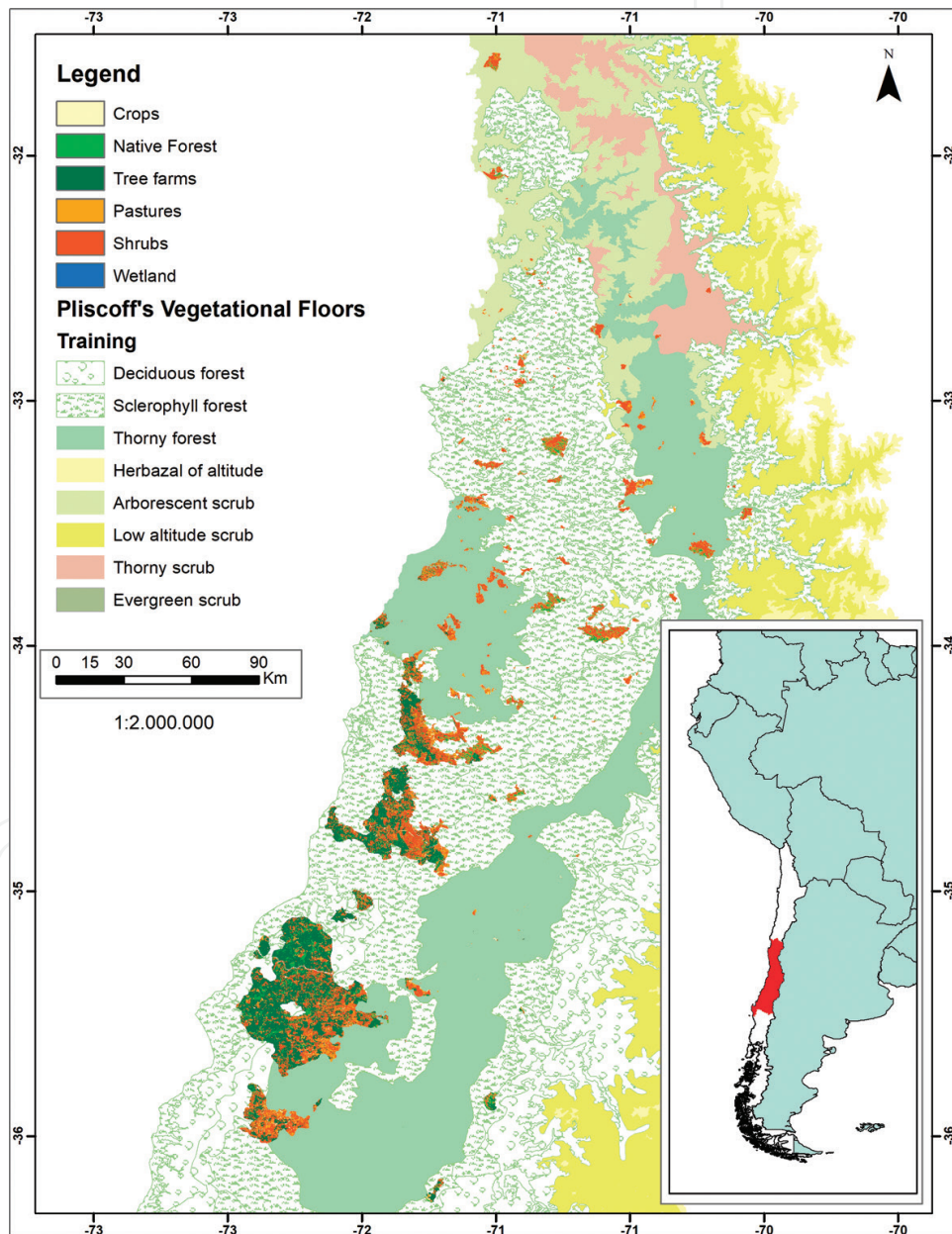


Figure 3. Area burnt in 2017 wildfire in Central Chile. The land use cover burn is indicted with solid bright colors, while vegetational formations (floors) are indicated with softer colors (Sources: [76, 77]).

Since the DL 701 will not be renewed in congress due to the corruption cases associated to the timber industry, the funds would need to come in another way. In September 2017 a new bylaw allowed the CORFO to create a new risk investment fund, called the risk investment funds for forestry and wood promotion. This fund was approved by CORFO's capital risk committee and the general comptroller of the republic [59]. In March 2018, the CORFO launched a platform for the forestry and wood sector [59]. This platform would be based in private and public investments, where the Chilean State, through CORFO, would add up to two-thirds of the fund for 30 years. This fund is meant to "achieve normal progress in the activities of the affected areas" [60]. As it happened in the 1960s, the CORFO articulated the capital needed to continue the tree farm planting, so the state of Chile backed the public- private ventures of tree farms expansion.

3. The adaptive capacity lenses

Using the idea of the rational manager from Scheffer et al. [31], this section will explore the questions: what is affecting the "behavior" of the rational manager? What is delaying adaptation in the Chilean SES despite the long-announced tragedy?

As stated at the beginning of this chapter, the political-economic context, which is sustained by specific discourses, works as the "slow variables" explaining the current lack of adaptive capacity of LULCC in Chile. The economic aspects of the timber plantations are clear. On one hand, the economic structure and the adaptation of specific tree species have configured a very profitable industry that would not have transformed the landscape without the strong support of the state. Now we see that even after the 2017 wildfire, state commitment for supporting these activities has been renewed by securing funds for the next 30 years, despite the change in the climate, vulnerability, and societal preferences. It remains to be seen whether this new fund would imply a second wave of forestry expansion, as it happened in 1975.

As proposed in the SSEF, the political articulation and the social construction of the environment is shaped by political dynamics and discourses. Given the political constitution of Chile, which only acknowledges individuals' rights, the farmers and peasants' organizations only get to claim political power when they articulate themselves as individual owners. The political constitution was utilized by opponents of the NFL to avoid any strong regulation for the conservation of the native forest. In this way, legacies from the dictatorship are legitimizing today's construction of forest policy. Historically, throughout the several policies that fostered timber farms, there was always a discourse that pivoted between the environmental tragedy, such as the erosion in the 1940s, the 2010 earthquake, or the need for fast recovery after the 2017 wildfire, as well as the social benefits of maintaining the DL 701 subsidy for small farmers. In summary, the political-economic variables legitimized, through a combination of strategies, the sustenance of a maladaptive behavior that has fostered landscape transformation for more than 40 years.

Few studies have simultaneously embraced both the social and ecological processes related to adaptive capacity and land use change. Allison and Hobbs found that ecological processes

can be the slow variables leading to rigidity traps. In Australia, soil salt increase has led to decreased production, which now resulted in a rigidity trap [61]. In Alaska, regulation and economic cycles also played a central role. The Alaskan timber industry enjoyed 15 years of a policy monopoly until production decreased, the material interest of small contractors was affected, and federal environmental regulations came into place [62]. Both studies highlight the importance of spatial and temporal scales and processes. The influence of economic cycles on land use change goes beyond the scope of this work, nevertheless in the future should be addressed.

3.1. Alternative land use trends? Implications for forest transition theory

As mentioned before, tree farms in Chile are very profitable, and even a large subsidy for native plantations and no subsidy for tree farms would not have implied a large change in the land area demanded for native forest in the late 1990s [52, 63, 64]. Furthermore, in Chile, it is more difficult to plant native species than to plant tree farms. This is due to the technical difficulties of planting native species, which include summer drought, lack of affordable seedlings, non-native wild herbivores, lack of lay knowledge, and the fact that most of the research funding is focused in the development of research and management techniques for non-native species [65]. This suggests that tree farms are a very “resilient” land use, due to the economic, political, and technological context. Nevertheless, forest’s natural regeneration can be a much more effective way of recovering the forest [66, 67]. Even though it is unlikely that a one-time payment for native forest management and conservation would initiate the reversal of a resilient land use trend—such as tree farms—forest can recover where tree farms are not planted [64]. Several studies show that if a land plot is not planted with tree farms, the native forest recovers [64, 66, 67]. Thus the evidence suggests that tree farms are hindering actual forest recovery. These results can have interesting implications for broader questions regarding forest transition theory.

Forest transition theory seeks to explain why and when a country switches from forest loss to recovery. The theory initially developed by Mather [4] argues that countries recover their forests when they reach some level of economic development. Mather’s explanation has guided much of the academic and policy-making discussion but has also obscured some relevant concepts, such as the difference between forest cover and tree cover. Although afforestation does provide some environmental benefits, tree farms do not necessarily provide the same benefits as native forest [68, 69]. Drawing from ecology, Putz and Romero [68] call for a critical assessment of forest recovery in the Global South. They call for more attention to the structure, function, and composition of forested ecosystems, rather than an oversimplified assessment of forest transition based solely on tree cover [68, 69]. Differentiating between forest cover and tree cover for assessing forest transitions becomes even more critical if trees are used mainly for industrial production, where inputs of energy and matter are inherently different from those of a natural system [20, 70–72].

Ecological theory combined with political ecology affords more insight on forest transition theory. Mansfield et al. [8] argue that forest transition theories “assume that the experience of the North reflects a general, desirable process that should be encouraged to ‘diffuse’ to

developing economies” [8]. Instead, political ecology calls for a recognition of the place-specific factor that led to uneven patterns of development, production, and consumption [8]. Although Chile is often celebrated as a case of forest recovery [73], it is a case of tree cover increase, and this fact should not be ignored when designing policy recommendations for other countries, as it might shape the future of land use and its governance [73]. As mentioned above, the “success” of the afforestation policy was mainly the result of the larger changes rooted in specific events of the political and social history of Chile. Moreover, given the current situation, tree farming seems irreversible, highlighting the nonreversible nature of socio-ecological systems (Section 2). Forest recovery assessments must differentiate tree cover from forest cover, while also considering forest transitions as context dependent.

4. Conclusion, policy recommendations, and research significance

This chapter describes some of the mechanisms that have hindered adaptive capacity in Chile regarding forest policy and land use. Overall, Chile’s case exemplifies how a land use trend can become resilient due to political, social, and economic processes. In the case of Chile, economic and political processes interact in a way that results in a rigidity trap across the social and ecological system. Current political and economic processes act as the “slow” variable and explain the current lack of adaptive capacity of LULCC in Chile.

To prevent rigidity traps, it is key to develop institutional mechanisms that break reinforcing dynamics between politics, power, and profits and foster change, diversity, adaptation, and learning [26]. More specifically for the case of Chile, it is difficult to claim that native forests would become a viable land use, without prior structural changes or some unimaginable surprise. Rather than providing panaceas for afforestation, Chile’s afforestation case provides insights about the socio-ecological underpinnings of a short-term increase in tree cover and the implications of its success on adaptive capacity in the long term.

Through a transdisciplinary approach, this research has contributed to the literature on adaptive capacity, socio-ecological systems, and land use transition, providing useful insights for policy makers and for scientific and humanities scholars who want to address current environmental issues without hindering future capacity for adaptation.

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Conflict of interest

I declare no conflict of interest.

Nomenclature

CONAF	National Forest Service (Corporación Nacional Forestal, private)
CORFO	Production Promotion Corporation (Corporación de Fomento de la Producción, public)
COREF	Afforestation Corporation (Corporación de Reforestación, public)
CORMA	National Wood Corporation (Corporación Chilena de la Madera, private)
DL 701	Decree Law 701
IREN	Natural Resource Research Institute (Instituto de Investigación de los Recursos Naturales, public)
MERCOSUR	Common Southern Market (Mercado Común del sur)
NFL	Native Forest Law (Ley de Bosque Nativo 20.283)
LULCC	land use and land cover change
SES	Socio-ecological systems
SSEF	Scheffer socio-ecological systems

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