Chapter 7
Native Forest Health in Chile: Toward a Strategy of Sustainable Management

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7.1 Introduction

Chilean temperate forests represent more than half of the temperate forest in the Southern Hemisphere (Donoso 2013; Miranda et al. 2017). Chile, in terms of natural resources, has 17,665,354 ha covered by forests, which corresponds to 23.3% of the national territory. It has been estimated that from the forest area, 82% corresponds to natural forests (14,411,031 ha) and 17.4% to planted forests (3,080,000 ha) (INFOR 2018). Within the native forest, the forest type Lenga is the most abundant with 3,632,349 ha, followed by the forest type evergreen with 3,505,545 ha, Roble-Raulí-Coihue with 1,635,807 ha, and esclerófilo with 1,386,038 ha (CONAF 2019). The Chilean native forest is protected through the SNASPE (National System of Wild Protected Areas of the State). Currently, there are 105 SNASPE units that protect about 15 mill ha of native forest (CONAF 2017).

Because of their abundance and diversity, insects play a major role in the functioning of the forest ecosystem (Dajoz 2000). The vast majority of insects that develop in natural forests in Chile are native and some cause damage, but in well-defined areas, with significant economic losses, however, they cannot be considered as a pest since they are part of the growth, development, and dynamics of these forests. They are partly responsible for the forests that we have today, given their multiple beneficial functional roles that they play in the different forest types in Chile. However, there are several cases where plantation programs have modified the ecosystem, for example, when fast-growing exotic trees come to dominate the

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landscape. In other cases, forest ecosystems are altered, as the native forests of southern Chile, with diverse and multi-stratified forest, have been simplified by selective logging, flowering, and colonizers coming mainly from Europe, followed by the reestablishment of the pioneer tree species (Gara 2010).

7.2 Wood Boring and Ambrosia Beetles in Native Forest

The borers of the xylem, wood consisting of sapwood and heartwood, are an important group of insects that have specialized to feed on woody tissues (Watanabe and Tokuda 2010). Often, the feeding pattern is related to the nutritional quality of the tissues and to ecological associations with microorganisms. Most borer insects are attracted to weakened, damaged, dying, or dead plants, being called secondary insects. However, there are those who attack healthy trees, which eventually can kill the host and are called primary insects (Drees et al. 2008).

From the various insect agents that cause damage to the Chilean native forest, the one with the greatest impact corresponds to those caused by the attack of wood borers of living trees, mainly because they affect the productivity of the resource (Díaz 2010). In second-growth forest of the genus *Nothofagus*, particularly in second-growth forest of *N. obliqua* and *N. dombeyi*, damage caused by native xylophagous insects has been reported (Kruuse 1981; Cameron and Peña 1982; Cabrera 1994; Aguilar et al. 1997), being *Nothofagus obliqua* attacked mainly by *Proholopterus chilensis* (= *Holopterus chilensis*) and *Nothofagus dombeyi* by *Cheloderus childreni* (Table 7.1). The damage is produced by their larvae when building the galleries inside the trunk during feeding; this can severely damage the basal logs of both species, affecting between 40 and 50% of the total volume of the tree. As a consequence, it is not used for the production of unstable wood, veneer, or sawn wood and only could be used for wood chips or fuel (Díaz 2010). Both insects are associated with living and often vigorous trees; however, they do not cause the death of the tree.

The attack begins with the oviposition on living trees, preferably on the same tree from which they emerge. They prefer trees with diameters greater than 15 cm, due to the roughness and thickness of the tree bark, which would give the insect better conditions for oviposition, since the eggs are more protected between the layers or bark plates (Suárez et al. 2005). When the females lose a little weight, they can fly to disperse and live a maximum of 14 days (Kruuse 1981). Díaz (1999) observed that each larva builds only one gallery that does not exceed 1 m in length, which widens as it feeds and develops. The same author also verified that there is no intersection between galleries of different larvae, so there would be no competition for the resource, but rather a distribution of it. The damage starts from the base to a height of 4 m in trees with diameters greater than 15 cm (Kruuse 1981; Baldini and Pancel 2002; Aguayo et al. 2008). The presence of this insect is easily recognizable since the larvae construct sawdust evacuation holes, accumulating at the base of the trees.

Table 7.1 Native insect agents associated with natural forests and plantations

Species	Order/family	Role/damage	Host
Porotermes quadricollis	Isoptera/Termopsidae	Wood boring	Native/exotic
Proholopterus chilensis	Coleoptera/Cerambycidae	Wood boring	Native
Chelodérus childreni	Coleoptera/Oxypeltidae	Wood boring	Native
Chilecomadia valdiviana	Lepidoptera/Cossidae	Wood boring	Native/exotic
Gnathotrupes spp.	Coleoptera/Curculionidae	Ambrosia beetles/wood boring	Native/exotic
Cinara cupressi	Hemiptera/Aphididae	Sap sucking	Native/exotic
Heteronomia mexicana	Phasmatodea/Heteronemiidae	Defoliator	Native/exotic
Coniungoptera nothofagi	Orthoptera/Tettigoniidae	Defoliator	Native/exotic
Antandrus viridis	Orthoptera/Acrididae	Defoliator	Native/exotic
Ormiscodes cinnamomea	Lepidoptera/Saturniidae	Defoliator	Native/exotic
Philomusaea brachyxista	Lepidoptera/Elachistidae	Defoliator	Native
Thanatopsyche chilensis	Lepidoptera/Psychidae	Defoliator	Native/exotic

Regarding the intensity of damage, Kruuse (1981) indicates that the highest attack intensity in Chile is located in the province of Valdivia. This suggests that host and climatic conditions, including temperature and relative humidity, are optimal for the development of *P. chilensis*. Suárez (2003), who developed an investigation in forest stands of the provinces of Valdivia, Osorno, and Llanquihue, determined that the global infestation level for *N. obliqua* was 9.5%, while for *N. dombeyi*, it was 11.8%. These levels of infestation are similar in magnitude to those reported by Manqui (2001) in the Araucanía region for forest stands of both *Nothofagus* species (7.1% and 6.5% for *N. obliqua* and *N. dombeyi*, respectively). However, compared with previous studies conducted for the province of Valdivia, they are relatively low. For *N. obliqua*, Cabrera (1994) and Díaz (1999) reported infestation levels of 22.4% and 43.5%, respectively, while for *N. dombeyi*, Carrasco (2000) reported an infestation level of 22.6%. Through various studies, it has been possible to determine that the variables density, tree composition, understory, altitude, sociological position, and bark presented a positive relationship with the attack of these insects.

In this context, there are also the wood-boring ambrosia beetles (Coleoptera: Scolytidae or Platypodidae) that do not consume the wood of their tree or log hosts, but build gallery systems in which they cultivate fungi as larval food (Kühnholz et al. 2001). Many ambrosia beetles can also be classified as secondary beetles, attacking a dying or dead host that is already exploited by at least one, often more aggressive and tree killing, primary bark beetle (Wood 1982). The genus

Gnathotrupes has 29 species distributed in Mexico, Central America, and South America. In Chile, 14 species are known, mainly associated with *N. dombeyi* and *N. pumilio*. Aguayo et al. (2008) mentions that despite the little knowledge of them, some damages of these species can be associated with this species complex, such as the death of whole branches or vertical segments of bark, branches, and twigs and death of complete trees and entry holes. The latter insects could leave the trees exposed to the attack of other agents.

7.3 Defoliators in *Nothofagus*

The Aysén region has the largest area of native forest (more than four million ha) in Chile. In this area, the Lenga (*Nothofagus pumilio*) forest type, a resource that is highly prized by the community since it is the main source of energy for heating in the area, in addition to serving as a livestock shelter, scenic beauty for tourism, and erosion control, among other things, can be found. However, since 2006, there have been strong outbreaks of defoliators in these forests, mainly produced by *Ormiscodes amphimone* (Table 7.1), affecting large forest areas of *N. pumilio* and *Nothofagus antarctica*, in different localities of Aysén region (Fig. 7.1).

According to historical observations by the Servicio Agrícola y Ganadero staff (SAG is an official organ of the State of Chile that is in charge of the trade of livestock and forestry), these irruptions previously occurred every 10–15 years, and today, they are more and more frequent, and they appear at their peak every 2 years, which has generated great concern in the population. Due to the high population levels, they have affected tourism, wood extraction operations, water courses, rural housing, and daily activities because many larvae roam inside and outside the houses and buildings around the spotlights.

Due to these outbreaks, the SAG, between 2009 and 2013, carries out a monitoring in order to identify the insect species causing the defoliation and its incidence to

Fig. 7.1 Damage and larvae of *Ormiscodes amphimone* in a forest of *Nothofagus pumilio* in Aysén region

know the situation and take preventive measures in this regard; it was started initially with the establishment of 30 monitoring stations with five trees each, distributed in the four provinces of the region, using a working protocol to consider three levels of attack, corresponding to the level of defoliation (percentage) caused by the pest, taking and sending samples of larvae and egg masses, and installation of light traps to identify the species that cause the defoliation, all sent to laboratory for breeding and analysis. The laboratory analysis allowed to determine that the presence of natural enemies was much lower in the stations with higher levels of attack as the stations established in Bajada de Ibáñez, Cerro Castillo, and surveys carried out in the Horquetas area in Mallín Grande than in stations where it could be possible to see, for example, a greater number of eggs with emergence of parasitoids (*Horismenus ancillus*), such as in Lake Polux and Lake Castor. The highest percentage of parasitoids emerged in laboratory conditions corresponded to *Apanteles* sp. and Diptera, Pteromalidae, and *Hiposoter* sp. in smaller presence. Finally, the capture of adult specimens in light traps determined that the specimens belonged to *O. amphimone*.

The field observations, regarding the behavior of this species in larval state, showed that by depletion of its main source of food (*N. pumilio* and *N. antarctica*), it migrates and feeds on other species that belong to the genera *Berberis* and *Ribes* and others like *Pinus ponderosa*, *Pinus contorta*, *Gaultheria* sp., and *Laureliopsis philippiana*, among others. However, the greatest impact of these outbreaks is generated in the overpopulation. Due to overpopulation, the daily activities of people are affected because this species migrates toward the interior of houses, home gardens, crops under plastic, camping areas, water courses that supply homes and animals, and meadows that dry up mainly due to the lack of oxygen produced by the layer larvae that come down from the trees to pupate and causes allergy problems for being a stinging species. It is important to point out that the defoliated trees recovered their foliage without problems, with the exception of trees in the stage of collapse. Due to their lower photosynthetic capacity and successive attacks, they ended up dying, which was also caused by the attack of other agents.

Historical field observations by SAG staff and according to a recent study conducted by researchers from the University of Chile and the University of Aysén showed that the minimum temperature of the forests of the Aysén region has increased almost 5 °C in the last decade (Olivares-Contreras et al. 2019), so less rigorous winters and hotter summers could favor the outbreaks of these insects. Although *O. amphimone* can be found annually in the forests, one of the last major outbreaks occurred during the summer season of 2016, where the defoliated area reached approximately 30,000 ha that comprised the zone of Lago Norte, Alto Mañihuales, El Gato, Lago Largo, and Villa Ortega, reaching the surroundings of the city of Coyhaique, so it is estimated that from the beginning of the outbreak in the region, it would exceed 100,000 ha, without considering that there are forests in places of difficult access that have been also affected.

Anticipating when and where these outbreaks would occur is still a challenge; however, in recent years, the trapping of light traps could be helpful in showing whether or not there is a considerable catch of adult specimens, as well as climatic variables such as temperature. This is how several questions arise. What is the impact of this species on these forests? Studies indicate that these forest host species are prepared and have a high degree of recovery after heavy defoliation, but should we be concerned about how recurrent they could be in the future and how the growth of the forest could be affected?

An important challenge would be to achieve the breeding of natural enemies in laboratory conditions and then make releases in the field to reestablish the biological balance between this agent of damage and its natural enemies.

7.4 Sap-Sucking Insect of Native and Urban Trees

Insects with mouthparts forming a rostrum adapted to piercing plant tissue and sucking juices are included in the order Hemiptera (Dajoz 2000). This diverse group contains many plant pests. All undergo simple metamorphosis (egg–nymph–adult) but tend to have complex life cycles. Some have alternate hosts and others have both sexual and asexual reproductive stages with winged and wingless forms (Ciesla 2011). Most of these insects are relatively small in size and injure the host in two ways: directly by sucking the host of part of its food supply and water, producing necrotic spots in host tissue, and indirectly by introducing plant diseases (Fairweather 2006). Many species occur in colonies, and feeding causes wilting and drying of affected plant parts. This leads to growth loss, branch dieback, and, in extreme cases, tree death. Aphids, psyllids, plant hoppers, and other sucking insects are vectors of plant viruses, mycoplasma-like organism (MLOs), or other pathogens (Markham 1988).

One of the most important sap-sucking insects associated with the native forest in Chile is the cypress aphid, *Cinara cupressi* (Buckton). Native to North America, it was first detected in the Tarapaca Region of Chile during 2003 on trees of *Cupressus* sp. (urban tree), and the occurrence of this pest was studied between 2005 and 2007 (INFOR 2008). Some authors have pointed out that the species present in Chile corresponds to *C. cupressivora* (Kairo and Murphy 2005; Moore 2009; Ciesla 2011), adding confusion to its specific identification. However, in 2014, the presence of a single morphological group within the *C. cupressi* complex was confirmed (Ruiz et al. 2014). Currently in Chile, it has been recorded on 23 different tree species, where the most important concerns for their ecological and biodiversity value are the native tree species *Austrocedrus chilensis* and *Fitzroya cupressoides*, which are in ecologically vulnerable and endangered categories (Aguayo et al. 2008; Montalva et al. 2010). In 2005, the presence of *C. cupressi* was determined in 92% of the prospecting stations in the native forest species *A. chilensis*. One of the most noteworthy things is related to the distribution of the insect in the whole national continental territory, which justifies the efforts that have been developed and that will have to be executed to avoid or diminish the negative action of the aphid, mainly on the native resource (INFOR 2008). At the beginning of 2009, due to a strong aphid infestation in the Cupresáceas of the main square of the city of Puerto Natales, it led to propose measures to decrease aphid populations and recover trees that are of great aesthetic, recreational, and also residential value for that city.

For this reason, the SAG is implementing a "Program for the Survey and Control of the Aphid (*C. cupressi*) in cypresses of the Magallanes and Chilean Antarctic regions." This project has an integrated control that includes the use of chemical products as well as biological control by the parasitoid *P. juniperorum* and *Xenostigmus bifasciatus* to reduce the populations of this aphid and thus recover the urban trees of this area.

In general, this aphid has several generations per year, with an approximate duration of 25 days at the optimum time of the growing season. Reproduction is both sexual and asexual, the latter occurring during the summer months by parthenogenesis, the process by which the female gives birth to nymphs. At low temperatures, reproduction is sexual, by winged individuals that appear in autumn. Oviposition takes place in rough areas of branches and foliage, where the eggs stay during the winter season (González et al. 2010). Ciesla (2011) indicates that in temperate climates, parthenogenesis is continuous throughout the year, a situation that would occur in Chile. Adults and immature stages are concentrated in groups of 20–80 individuals on twigs, branches, and occasionally on the trunk, showing a gregarious behavior.

The work and research made in other countries indicate the importance of this aphid pest in the development of some species of cypresses, due to its polyphagous nature and the effects of its attack on its host, characteristics that added to the nonexistence or limitations on the action of natural enemies which transform it into a highly damaging species for its hosts (González et al. 2010). The damage produced by this aphid is done at the time of feeding, inserting its buccal stylet into the plant until it reaches the phloem. The sap of the phloem is rich in sugars and poor in amino acids, which is why these organisms are forced to ingest large amounts of this liquid to obtain an adequate amount of food to ensure their survival. Along with the penetration of the stylet, the insect injects saliva containing enzymes that facilitate penetration between the cells of the plant (Carter and Maslen 1982; Chilima 1989; Eskiviski et al. 2005). Symptoms in the trees correspond to foliage chlorosis and reduced growth, especially in young trees, because saliva causes physiological effects, such as increased respiration and decreased photosynthesis (Carter and Maslen 1982; Penteado et al. 2000). Desiccation of shoots and even death of hosts could be the results of the damage caused by these aphids (INFOR 2008). In general, the affected tree dries from the inside to outward of the cup and from the bottom upward (Baldini et al. 2005). In addition, the aphid produces a sweet and sticky secretion, which covers the branches and foliage, facilitating the establishment of sooty mold (dense blackish layer of fungal hyphae of the genera *Capnodium* and *Limacinia*) that adheres to the foliage and interferes with photosynthesis (Carter and Maslen 1982; Chilima 1989).

7.5 Native Insects Damaging Fast-Growing Plantations

Changes in the structure and composition of the native forest induce problems with insects, and this also occurrs in Chile the exception. This started in 1974 with the approval of Decree Law DL701, which provides subsidies for afforestation costs as well as tax reductions (Lara and Veblen 1993), a factor that has driven the expansion of exotic plantations (Asmüssen and Simonetti 2007). With this increase comes the replacement of the native forest by fast-growing exotic plantation forests, in Chile mainly by *Pinus radiata* and *Eucalyptus globulus*. This substitution has brought consequently that species of native insects to adapt to this new host (Table 7.1). Global estimates indicate that between 1974 and 1992 more than 200,000 ha of native forests would have been replaced (Lara 1993).

One of the emblematic cases is *Ormiscodes cinnamomea*, where plantations of *P. radiata* were consumed by this herbivorous moth, becoming the first obstacle for the forestry sector 25 years ago. Successive defoliation was observed between the regions of Valparaíso to Biobío in large patches of 50–100 ha of forest stands of 10–15-year-old trees (Gara 1978; Cerda 1984). In a 12-year-old plantation near Arauco (Biobío region), it was estimated that even at low population densities, *O. cinnamomea* could cause severe defoliation. Evidently, as *Nothofagus* forests were replaced by plantations of *P. radiata* in the Cordillera de la Costa, this moth lost much of its original source of food. However, due to a wide ecological plasticity of this insect, it was able to add pine to its diet. Artigas (1994) mentions that the damage caused by the devastating consumption of the foliage in a relatively short period of time, consuming the foliage from the apex and lateral branches, continues toward the interior of the tree (Artigas 1994; Baldini et al. 1994). In addition, it was confirmed that the damage is not significant in trees older than 10 years.

At the end of the summer of 1977, in about 50 ha of a plantation of *P. radiata* near Constitución (Maule region), a high and impressive defoliation was observed by the stick insect, *Heteronemia mexicana* (= *Bacunculus phyllopus*). The defoliation was very intense that about 75% of the crown of each tree was eliminated by herbivory. Later and after a couple of years of drought, something similar happened again with *H. mexicana* and also with *Thanatopsyche chilensis* in several *P. radiata* stands of the Maule region, forcing sanitary cuts and/or the application of chemical products This has not happened again with these species or in that area (Artigas 1994; Gara 2010).

Another important case of massive defoliations was caused by *Antandrus viridis* and *Coniungoptera nothofagi*. According to Lewis (1996), the defoliating activity of these species was not known until October 1995, when they were discovered in adult plantations of *P radiata*, located in the pre-Andean zone of the Biobio region, causing damage of different consideration in a surface of approximately 1000 ha. *A. viridis* is an endemic species in Chile distributed between the regions of Coquimbo and Los Lagos. It is characterized for being aptera, and in its adult state, the females can reach 43 mm and the males 27 mm. The feeding mechanism is particularly harmful, since it bites the needle in the basal third, feeding only on that part. The defoliated trees and the presence of a large quantity of needles in the soil allow the detection of the attack, which occurs only in adult trees. On the other hand, *C. nothofagi* is a species described in 1985 (Rentz and

Gurney 1985) that was distributed between the region of Maule and Biobío. Biology or life cycle length is not known, but it is believed that it should last 1 year. The feeding mechanism is similar to that of *A. viridis*, since it is located at the base of the shoot and, when biting the needle, drops a large part (around 2/3), ingesting the remaining basal piece. The female has a saber-shaped ovipositor, about 20 mm long, curved and sawed at the end, which allows it to enter the bark and deposit the eggs inside. Eggs were detected under the bark from ground level to 21 m high. Both species have a huge potential for damage, since their feeding mechanism requires cutting a greater number of needles than they effectively consume (Lewis 1996).

On the other hand, in 1998, the presence of termites in living trees was detected in plantations of *E. nitens* and *E. globulus* as well as in stumps of *P. radiata*, located in lands of forestry companies in the regions of Biobío and La Araucanía. The species involved was identified as *Porotermes quadricollis*, belonging to the Termopsidae family (Ramírez 2010). In live trees of eucalyptus, termites center the damage in the lower third of the stem, with galleries that follow the pattern of the growth rings and exclusively affecting the heartwood, so they do not present symptoms that allow the affected individuals to be easily identified. In this study, losses of not more than 10% of the trees attacked were estimated (Flores 2002). In this sense, the drought would predispose the tree to suffer significant levels of stress during the summer season, which coincides with the period of greatest dispersion of breeding termites, which fly in search of suitable places to establish new colonies (Ramírez 2010).

Finally, in the year 1992, attack of *Chilecomadia valdiviana* was detected in commercial plantations of *E. nitens* in the pre-cordilleran zone of Collipulli (La Araucanía region). Subsequently, numerous outbreaks were found damaging almost exclusively and in different degrees plantations of *E. nitens*, located in the regions of O'Higgins, Maule, Biobío, La Araucanía, and Los Ríos, showing a rapid and effective adaptation process to this forest species (Cerda 2010). This led to a series of specific studies on this insect (Cerda 1996; Lanfranco and Dungey 2001; Bergmann et al. 2007). The *C. valdiviana* is a polyphagous insect that is associated with trees and bushes, including economically important species such as eucalyptus, avocado, and apples (Kliejunas et al. 2001). The damage consists of short and thick galleries (no more than 25 cm long and 1 cm wide) longitudinally in the stem. The galleries are abundant due to the constant reinfestation of the host (Cerda 1995). The damage occurs in living trees; The damage occurrs in living trees e.g., in *E. nitens* plantations, it can be found in 3-year-old trees with 4 cm of DAP (Cerda 1996). An intense attack can compromise much of the xylem in the affected section, product of the multiple galleries made by the larvae, which leads to a decrease in the strength of the stem, facilitating its eventual fall due to the effect of the wind. Observations in *E. nitens* indicate that their life cycle can last between 1 and 2 years, depending on the time of initiation according to the emergency and flight period (Cerda 1998).

7.6 Management Experiences in Chile

7.6.1 Wood Borer

Among the control alternatives for the populations of borer insects, the silvicultural method is the most recommended to minimize the damage caused by these insects. The results obtained through the National Native Forest Inventory (CONAF 2011) and by Díaz (1999) confirm that the current condition of *N. obliqua* second-growth forest would correspond to pure forests, where the species covers most of the strata and with different quality conditions, relevant aspects when defining a possible silvicultural control of the agent. In this regard, Kruuse (1981) established that pure *N. obliqua* stands are more intensely attacked than those where more species diversity exists. Díaz (1999) suggests the advisability of projecting forests with specimens of different tree strata and also forming a special multispecific mixture, which would increase the abundance of natural enemies and decrease the pressure exerted by the insect (Rojas et al. 2010). With regard to this, Donoso (1994) points out that diverse systems are the best guarantee to maintain the balance between prey and predators, thus avoiding the proliferation of pests and positively impacting forest health.

The attack produced by *P. chilensis* constitutes a limitation for the projection of existing secondary-growth forest as well as for the eventual establishment of plantations with the species, even though it is one of the most important and potential, especially due to the characteristics of its wood, its high natural durability, productivity, and wide distribution (Rojas et al. 2010). A project carried out between 2012 and 2014 entitled "Silvicultural Measures to Improve the Health Status in Secondary Growth Forest of *Nothofagus* in the Province of Valdivia" defined and validated in the field three quantitative health categories, through observation of signs and the use of a resistograph (instrument that measures the resistance of wood). These categories were proposed to be incorporated into the CONAF management plan guidelines to complement the current use of the Forest Inventory Form: Quality (Health and Form), which is considered when making sanitary thinnings.

Currently, through the CONAF Native Forest Research Fund, it is working on a new management proposal that will study the chemical communication mechanism of this xylophage insect, to identify sexual or aggregation pheromones. It is proposed to develop a sustainable management strategy through the identification and use of semiochemicals to be used in a monitoring system through massive trapping or sexual confusion. On the other hand, Cerda (2010) proposes that the management measures or actions, aimed to control these borers, should be done at two stages of their development: (a) prior to the emergence and flight of the adults, in order to decrease the population and avoid their flight and dispersion, and (b) during the flight season of adults, with emphasis on the summer months, the period in which the highest frequency of emergence and flight of insects is observed.

7.6.2 Defoliators

From the outbreaks of native species such as *O. amphimone* and other species such as the leafminer *Philomusaea brachyxista* (Lepidoptera: Elachistidae), the SAG has implemented a series of actions aimed at informing the community, doing talks, disseminating through media, (radio, posters, and written material), and conducting field activities in order to raise awareness about these increasingly recurring events. These actions have allowed to teach the community the implications of these outbreaks, the care that must be taken, and the biological cycle of these insect species. As was made with the population affected with the case of *O. amphimone*, the mitigation measures implemented were clearing the surroundings of the houses, removing nearby wood rucks where a large number of pupae could be found, protecting sources of water supply, collecting pupae, and elimination by flood; in extreme cases, some owners removed trees and underbrush very close to the houses because the large masses of larvae entered the houses affecting them directly. The genus *Ormiscodes* has a large number of associated natural enemies, mainly parasitoids of the orders Hymenoptera and Diptera. In 2013, egg masses coming from the field were brought into the laboratory, bred egg masses were made, and then, the emerged parasitoids were released in the area of Las Horquetas (Mallin Grande), an area where there have been outbreaks with defoliation that have covered a large area; the masses of eggs were collected in Puerto Natales, being an alternative control to increase the number of natural enemies, which in this case corresponded to *Dirphiphagus ancilla* and *Paridris chilensis*.

7.6.3 Sap Sucking

Jointly with INFOR-CONAF-SAG in 2005, a FDI-CORFO project "Integrated management: Technique for the recovery of the growth of *Austrocedrus chilensis*" was carried out with the aim of implementing an integrated management program for *C. cupressi* to protect *A. chilensis* and related conifers. Furthermore, to mitigate the damage caused by this aphid, chemical control or releases of the parasitoid *Pauesia juniperorum* (Hymenoptera: Braconidae) have been used, but both of these approaches yielded erratic results (Baldini et al. 2008). During a survey of natural enemies on *C. cupressi* between 2008 and 2012 in the south of Chile, Syrphidae larvae and Coccinellidae were found feeding on *C. cupressi* and in the southern city of Puerto Natales. Hemerobiidae (Neuroptera) was found regulating the population of this aphid in some colonies (Montalva et al. 2013a). Two entomopathogenic fungi were also found in the surveys on *Cinara* species: *Lecanicillium attenuatum* and *Neozygites osornensis* Montalva and Barta (Montalva et al. 2013b). Worldwide, mainly parasitoids associated with *Cinara* sp. have been described as well as some species of fungi and insect predators. However, the most used control agents under field conditions are parasitoids, most commonly species of *Pauesia* (Montalva et al.

2010). The study of such natural enemies of the cypress aphid as entomopathogenic fungi is highly important in Chile, since applications of chemical insecticides to control *Cinara* species associated with the native tree *A. chilensis* are forbidden in national parks without the permission of the national health authorities (CONAF 2006). Under laboratory conditions, the native Chilean *L. attenuatum* isolates proved to be pathogenic against *C. cupressi* nymphs and may very well have significant potential as biocontrol agents against this pest. However, further laboratory, formulation, and field studies will be needed to confirm the probable value of *L. attenuatum* as an alternative agent for the control of cypress aphids (Montalva et al. 2017). Currently, recent observations have shown that the implemented measures of integrated management of the pest have been able to decrease population densities producing a balance between the insect pest and its natural enemies.

7.7 Concluding Remarks

Environmentally temperate austral forests are of great importance for their biodiversity, both flora and fauna, with a huge number of endemic species, many of them in danger of extinction or with some degree of vulnerability in their state of conservation. For the tourism, the forests are fundamental, since they constitute the main attraction of the country, especially in the national parks, as much for national visitors as foreigners, who only by concept of visiting these areas generate an important economic income for the country. Despite the attempts made by institutions linked to the state, private companies, and universities, many aspects of the reaction of these forests to these outbreaks of native insect population, sometimes cyclical, sometimes not, they are still unknown. If we add to this the deterioration, simplification, and fragmentation of forest ecosystems, in addition to the climatic changes that have occurred in recent decades, it is necessary to implement sustainable management with an emphasis on guaranteeing the health and sustainability of the native forests.

References

Aguayo J, Alvarado A, Baldini A et al (2008) Manual de plagas y enfermedades del bosque nativo en Chile. Asistencia para la recuperación y revitalización de los bosques templados de Chile, con énfasis en los *Nothofagus* Caducifolios. FAO-CONAF, Santiago de Chile

Aguilar A, Carrasco C, Trincado G et al (1997) Evaluación de los insectos barrenadores de madera asociados al tipo forestal Roble-Raulí-Coigüe en la Provincia de Valdivia, X Región: una aproximación hacia la evaluación de pérdidas. CONAF/CPF SA/UACH. Informe de Convenio N° 235

Artigas J (1994) Entomología Económica. Insectos de interés agrícola, forestal, médico y veterinario (Nativos, introducidos y susceptibles de ser introducidos). Universidad de Concepción, Concepción

Asmüssen MV, Simonetti JA (2007) Can a developing country like Chile invest in biodiversity conservation? Environ Conserv 34(3):183–185
Baldini A, Pancel L (2002) Agentes de daño en el bosque nativo. Editorial Universitaria, Santiago de Chile
Baldini A, Le-Quesne C, Puentes O et al (1994) Daños bióticos en roble, raulí y coihue: guía de reconocimiento. Corporación Nacional Forestal
Baldini A, Aguayo J, Sartori Á (2005) El complejo *Cinara cupressi*. Chile Forestal 314:8–10
Baldini A, Oltremari J, Holmgren A (2008) Efecto de *Cinara cupressi* (Hemiptera: Aphididae) sobre el ciprés de la cordillera (*Austrocedrus chilensis*) después de aplicar control químico. Cienc Investig Agra 35(3):341–350
Bergmann J, Lopez K, Buono-Core G (2007) Identification and synthesis of some fatty acid derivatives from larvae of *Chilecomadia valdiviana* (Lepidoptera: Cossidae). Nat Prod Res 21(5):473–480
Cabrera P (1994) Impacto de *Holopterus chilensis* Blanch. en renovales de *Nothofagus obliqua* (Mirb.) Oerst. En la provincia de Valdivia: avances hacia la evaluación del daño. Dissertation, Universidad Austral de Chile, Valdivia
Cameron RS, Peña L (1982) Cerambycidae associated with the host genus *Nothofagus* in Chile and Argentina. Turrialba 32:481–487
Carrasco C (2000) Evaluación del daño y pérdidas de volumen ocasionados por *Cheloderus childreni* Gray. en bosques de *Nothofagus dombeyi* (Mirb.) Oerst. en la provincia de Valdivia. Dissertation, Universidad Austral de Chile, Valdivia
Carter CI, Maslen NR (1982) Conifer lachnids in Britain. Forestry Commission Bulletin Nº 58.
Cerda LA (1984) *Ormiscodes cinnamomea* F (Lep.: Saturniidae): relación de niveles poblacionales con daño ocasionado. Prospección Nacional Sanitaria Forestal CONAF/UACH. Serie Técnica 75
Cerda L (1995) Estudio y seguimiento del taladrador de la madera *Chilecomadia valdiviana* (Lep: Cossidae) en plantaciones de *Eucalyptus nitens* en el patrimonio de FORMIN SA. Informe de avance de temporada 1994–1995
Cerda L (1996) *Chilecomadia valdiviana* (Philippi) (Lepidoptera: Cossidae) Insecto taladrador de la madera asociado al cultivo del *Eucalyptus spp*. en Chile. Corporación Nacional Forestal. Programa Protección Sanitaria Forestal. Nota Técnica. Año 16
Cerda L (1998) Estudio biológico del taladrador de la madera *Chilecomadia valdiviana* (Lepidoptera: Cossidae) en plantaciones de *Eucalyptus* spp. Informe Final Primera Etapa (Temporada 1996-1997). Convenio CONAF/CPF/Universidad de Concepción. Comité Nacional de Sanidad Forestal
Cerda L (2010) Un Barrenador de madera nativa, *Chilecomadia valdiviana* (Philippi) (Lepidoptera: Cossidae) y su asociación con un hospedero introducido. Entomología Forestal en Chile. Ediciones Universidad Austral de Chile, Valdivia
Chilima CZ (1989) *Cinara cupressi*: a pest of Mulanje cedar and Cypress trees in Malawi. Forestry Research Institute of Malawi. Zomba, Malawi. FRIM Report (89009):8
Ciesla W (2011) Forest entomology: a global perspective. Wiley, Oxford
CONAF (2006) Normas de manejo del Sistema Nacional de Áreas Silvestres Protegidas del Estado, Chile
CONAF (2011) Catastro de los Recursos Vegetacionales Nativos de Chile. Monitoreo de cambios y actualizaciones. Período 1997-2011, Santiago de Chile
CONAF 2017. Manual para la planificación del manejo de las áreas protegidas del SNASPE. Santiago de Chile, Chile, pp 230
CONAF (2019) Parque Nacionales http://www.conaf.cl/parques-nacionales/parques-de-chile/ Accessed 3 may 2019
Dajoz R (2000) Insects and forests: the role and diversity of insects in the forest environment. Intercept Limited, Andover
Díaz A (1999) Evaluación del daño interno y estimación de pérdidas producidas por *Holopterus chilensis* (Blanch) en *Nothofagus obliqua* (Mirb.) Oerst., en la provincia de Valdivia, Décima Región. Dissertation, Universidad Austral de Chile, Valdivia

Díaz A (2010) La gusanera del roble: *Holopterus chilensis*. Entomología Forestal en Chile. Ediciones Universidad Austral de Chile, Valdivia
Donoso C (1994) Bosques templados de Chile y Argentina. Variación estructura y dinámica. Editorial Universitaria, Santiago de Chile
Donoso C (2013) Las especies arbóreas de los bosques templados de Chile y Argentina, Autoecología, Segunda edición. Marisa Cuneo Ediciones, Santiago
Drees BM, Jackman JA, Merchant ME (2008) Wood-boring insects of trees and shrubs. FARMER Collection, Texas
Eskiviski E, Agostini JP, Toloza R et al (2005) Daños producidos por el pulgón del pino *Cinara atlantica* (Hemiptera: Aphididae) en plantas jóvenes de *Pinus taeda* L Actas 11as Jornadas Técnicas Forestales y Ambientales, en CD–FCF, UNaM–EEA Montecarlo, INTA
Fairweather ML (2006) Field guide to insects and diseases of Arizona and New Mexico forests, 1st edn. USDA Forest Service Southwestern, Albuquerque
Flores J (2002) Caracterización de la presencia de termitas y su relación con variables de sitio, en focos ubicados en predios forestales de las Provincias de Biobío, Malleco y Valdivia. M.sc. dissertation, Universidad Austral de Chile, Valdivia
Gara R (1978) Protección forestal en Chile: Proposición de un plan nacional. FAO UNDP/CHI/76/003. FAO/DP/CHI/76/003 Documento de Trabajo No. 12. Santiago de Chile
Gara R (2010) Chile forestal y las plagas de insectos. In: Lanfranco D, Ruiz C (eds) Entomología Forestal en Chile. Ediciones Universidad Austral de Chile, Valdivia
González P, Ide S, Jaques L (2010) *Cinara cupressi* Buckton (Hem: Aphididae): el pulgón del ciprés. Entomología Forestal en Chile. Ediciones Universidad Austral de Chile, Valdivia
INFOR (2008) Manejo integrado: Técnica para la recuperación del crecimiento de *Austrocedrus chilensis*. Informe Final, Santiago de Chile
INFOR (2018) El sector forestal Chileno. Instituto Forestal, Santiago de Chile
Kairo MTK, Murphy ST (2005) Comparative studies on populations of *Pauesia juniperorum* (Hymenoptera: Braconidae): a biological control agent for *Cinara cupressivora* (Hemiptera: Aphididae). Bull Entomol Res 95(6):597–603
Kliejunas JT, Burdsall HH, DeNitto GA et al (2001) Pest risk assessment of the importation into the United States of unprocessed *Eucalyptus* logs and chips from South America. Gen. Tech. Rep. FPL-GTR-124. US Department of Agriculture, Forest Service, Forest Products Laboratory, 134, Madison
Kruuse L (1981) Algunos factores bióticos y abióticos que inciden en el nivel de ataque de *Holopterus chilensis* Blanch. (Col.: Cerambycidae) en *Nothofagus obliqua* (Mirb.) Oerst. Dissertation, Universidad Austral de Chile, Valdivia
Kühnholz S, Borden JH, Uzunovic A (2001) Secondary ambrosia beetles in apparently healthy trees: adaptations, potential causes and suggested research. Integr Pest Manag Rev 6(3–4):209–219
Lanfranco D, Dungey HS (2001) Insect damage in Eucalyptus: a review of plantations in Chile. Austral Ecol 26(5):477–481
Lara A (1993) Bosques Naturales: La sustitución: Dónde, cómo y cuándo? Actas Jornadas Forestales
Lara A, Veblen TT (1993) Forest plantations in Chile: a successful model? In: Mather A (ed) Afforestation: policies, planning and progress. Arizona State University, Arizona, pp 118–139
Lewis P (1996) Primer registro de la actividad defoliadora de dos especies de insectos nativos sobre *Pinus radiata* D Don en Chile. Bosque 17(1):101–103
Manqui R (2001) Contribución al conocimiento del daño provocado por *Holopterus chilensis* (Blanch.) en *Nothofagus obliqua* (Mirb.) Oerst. y *Cheloderus childreni* (Gray) en *Nothofagus dombeyi* (Mirb.) Oerst. en renovales de la IX Región de Chile. Dissertation, Universidad Austral de Chile, Valdivia
Markham PG (1988) Detection of mycoplasmas and spiroplasmas in insects. In: Hiruki C (ed) Tree mycoplasma and mycoplasma diseases. University of Alberta Press, Edmonton, pp 157–169
Miranda A, Altamirano A, Cayuela L et al (2017) Native forest loss in the Chilean biodiversity hotspot: revealing the evidence. Reg Environ Chang 17(1):285–297

Montalva C, Rojas E, Ruiz C, Lanfranco D (2010) El pulgón del ciprés en Chile: una revisión de la situación actual y antecedentes del control biológico. Bosque (Valdivia) 31(2):81–88

Montalva C, Rojas E, Barta M et al (2013a) Biological control agents of cypress aphid present in Chile. In: IV international symposium on biological control of arthropods, Pucón, Chile, 4–8 March 2013

Montalva C, Barta M, Pérez ER et al (2013b) *Neozygites osornensis* sp. nov., a fungal species causing mortality to the cypress aphid *Cinara cupressi* in Chile. Mycologia 105(3):661–669

Montalva C, Valenzuela E, Barta M et al (2017) *Lecanicillium attenuatum* isolates affecting the invasive cypress aphid (*Cinara cupressi*) in Chile. BioControl 62(5):625–637

Moore BA (2009) Global review of forest pests and diseases: a thematic study prepared in the framework of the Global Forest Resources Assessment 2005. Food and Agriculture Organization of the United Nations (FAO)

Olivares-Contreras VA, Mattar C, Gutiérrez AG et al (2019) Warming trends in Patagonian subantartic forest. Int J Appl Earth Obs Geoinf 76:51–65

Penteado S, Trentini R, Iede E et al (2000) Ocorrência, distribuição, danos e controle de pulgões do gênero *Cinara* em *Pinus* spp. no Brasil. Floresta 30:(1/2)

Ramírez JC (2010) Antecedentes de la presencia y efecto de termitas en plantaciones forestales de las provincias de Biobío y Malleco. In: Lanfranco D, Ruiz C (eds) Entomología Forestal en Chile. Ediciones Universidad Austral de Chile, Valdivia, pp 373–384

Rentz D, Gurney A (1985) The shield-backed katydids of South America (Orthoptera Tettigoniidae: Tettigoninae) and a new tribe of Conocephalinae with genera in Chile and Australia. Entomol Scand 16:69–119

Rojas E, Lanfranco D, Ruiz C (2010) Barrenadores de xilema. In: Lanfranco D, Ruiz C (eds) Entomología Forestal en Chile. Ediciones Universidad Austral de Chile, Valdivia

Ruiz C, Lanfranco D, Carrillo R et al (2014) Morphometric variation on the cypress aphid *Cinara cupressi* (Buckton) (Hemiptera: Aphididae) associated to urban trees. Neotrop Entomol 43(3):245–251

Suárez L (2003) Prospección del daño ocasionado por dos insectos xilófagos asociados a renovales de *Nothofagus* en las provincias de Valdivia, Osorno y Llanquihue, Décima Región. Dissertation, Universidad Austral de Chile, Valdivia

Suárez L, Aguilar A, Gonzáles W (2005) Patrones de infestación por insectos xilófagos en renovales de *Nothofagus obliqua* Mirb. y *Nothofagus dombeyi* (Mirb.) Oerst. (Fagales: Nothofagaceae). Rev Chil Hist Nat 78(1):23–32

Watanabe H, Tokuda G (2010) Cellulolytic systems in insects. Annu Rev Entomol 55:609–632

Wood SL (1982) The bark and ambrosia beetles of North and Central America (Coleoptera: Scolytidae): a taxonomic monograph. Great Basin Naturalist Memoirs 6