Chapter 1

PLANTATION FORESTRY IN CHILE WITH PARTICULAR REFERENCE TO DISEASE AND INSECT PROBLEMS

1.0 INTRODUCTION

Chile, one of the largest forestry exporters in the world, has a rapidly growing forestry industry, based on exotic commercial plantations of *Pinus radiata* D. Don and various *Eucalyptus* spp. (Lowy 1995). Approximately 11 % of the Country's land is forested and about 2.1 million ha are being used for commercial plantations (WFI 1999). Almost all commercial plantations are linked to industry and these are all managed by private companies. The most important forestry products are pulp, paper, wood chips, log and sawn lumber, with an estimated value of US$ 2 205 million that was exported in 2001 (INFOR 2002). The major export markets are in countries of Asia, Europe and South America (Lowy 1995, INFOR 2001, WFI 1999).

Pinus radiata was introduced into Chile from California (USA) at the end of the 1800s and is the most widely planted species. This is because the species grows rapidly in a variety of environmental conditions and on a wide diversity of sites (Cerda & Nuñez 1998). The second most commonly planted trees are species of *Eucalyptus*, which were introduced into Chile in the 1800's from Australia. Propagation of both *Pinus* and *Eucalyptus* species in plantations has been subsidised by the Chilean government. Currently, there are approximately, 1.5 million ha of *P. radiata* and 360 000 ha of primarily *Eucalyptus globulus* Labill. and *Eucalyptus nitens* (Deane & Maid.) Maid. planted in Chile (INFOR 2000, Kliejunas *et al.* 2001).

Thus far, needle blight caused by *Dothistroma septospora* Hulbary and the pine shoot moth *Rhyacionia buoliana* Dennis et Schiff. have resulted in the most serious sanitary problems on *Pinus radiata* in Chilean plantations. The pitch canker fungus *Fusarium circinatum* Nirenberg and O'Donell (= *F. subglutinans* (Wollenw. and Reinking) Nelson *et al.* f.sp. *pini* Correll *et al.*), was detected late in 2001 and although it is still confined to nurseries, its presence in the country is of considerable concern (Wingfield *et al.* 2002). *Dothistroma septospora* and *R. buoliana* are well known, and it is important to understand the biology and management options for these and other pests and diseases present in Chile. However, Chile is also threatened by a large number of pests and diseases that do not yet occur in the country. It is, therefore, crucial to have a clear understanding of these potential threats.

Eucalyptus plantations have been damaged by several pathogens and insects in the past, but the most severe damage has been caused by species of *Mycosphaerella* Johanson. Two of the most widely planted species in Chile, *E. globulus* and *E. nitens* are both susceptible to Mycosphaerella leaf disease (MLD), which results in leaf necrosis and defoliation (Carnegie 2000, Dungey *et al.* 1997). *Mycosphaerella* spp. are well known as important pathogens of *Eucalyptus* spp. MLD is one of the most important constraints to *Eucalyptus* propagation in various parts of the world, where it can be responsible for severe reduction in tree growth (Crous 1998). Studies in *E. nitens* plantations in South Africa, have shown that defoliation caused by *Mycosphaerella* leaf spot caused a 38% drop in tree height and a loss of 25% in diameter (Lundquist & Purnell 1987). In countries such as New Zealand, the disease has been more serious on seedlings and saplings than on adult trees (Ganapathi 1979).

With the exception of Dothistroma needle blight and the pine shoot moth (*R. buoliana*), very little research has been conducted on pests and diseases in commercial forestry plantations in Chile. In the future, it will be important to build a sustainable internal capacity to deal with pests and diseases present in the country. In addition, attention will also need to be given to those pests and diseases that are likely to appear in the future. The aim of this review is to summarize the available literature pertaining to diseases and insect pests that have been associated with damage to forest plantations in Chile. In addition, I hope to provide a background to the studies on two diseases of *Eucalyptus* that are treated in subsequent chapters of this thesis.

2.0 FOREST PLANTATIONS IN CHILE

Continental Chile extends approximately 4 300 km in length and is 427 km wide at its widest point. The country is divided into 12 administrative regions from North to South (17° 30' S - 56° S). Chile is 75.5 million ha in size and approximately 11 % of this area is afforested (Lowy 1995). This forested area is comprised of approximately 4.75 million ha of unprotected native forest, 1.4 million ha of protected native forest and approximately 7.5 million ha of commercially productive native forest (Brownie 2001). The Southern-central part of Chile (35° S - 42° S) is considered to be the most important area for commercial forestry. This is because it provides conditions most suitable for the growth of forest tree species such as *P. radiata* and *Eucalyptus* spp. (Jayawickrama, Schlatter & Escobar 1993).

Extensive establishment of commercial plantations began in the 1970's with the implementation of government incentives. These substantially promoted the expansion of the forest products industry and subsidised the majority of costs for reforestation and plantation establishment (Brownie 2001, WFI 1999). The rate of tree planting has been high, with 65 413 ha of *P. radiata* and 11 953 ha of *Eucalyptus* spp. planted in 1978, in contrast to 59 411 ha of *P. radiata* and 36 781 ha of *Eucalyptus* spp. planted in 2000. The highest level of establishment of *P. radiata* was in 1981 when 88 529 ha were planted. Likewise, in 1993 approximately 53 293 ha of *Eucalyptus* spp. were planted. Currently commercial plantations make up approximately 2.1 million ha (INFOR 2002). Most of these plantations are concentrated between Northern-central to Southern-central regions of (approximately from V to X administrative regions) Chile (Figure 1).

Almost all commercial plantations in Chile are industrial and all are privately owned. Larger timber companies have purchased smaller companies. For example, in 1977, 14 companies owned 88 % of the forest land and by the end of the 1980's, four groups controlled over 90 % of the timber industry (Lowy 1995). Currently, two large forestry groups, Forestal Arauco and CMPC, own approximately 50 % of *P. radiata* forests and 75 % of all pulp production in the country (Brownie 2001). Chile is the largest exporter of wood chips into Latin America and is the world's third-largest chip exporter, after Australia and USA. Japan is the largest importer of Chilean wood chips, followed by Finland (Lowy 1995).

Forest products represent the second most important Chilean export product after copper. The forestry industry has focused mainly on pulp, paper, wood chips, log exports, sawn lumber, boards, furnishing and packaging (Lowy 1995, WFI 1999). The total volume of forest products exported in 2001 was estimated at US$ 2 205 million. The major market for the Chilean forestry industry was Asia with approximately 50 % of the total trade, Europe (20 %) and South America (17 %). Pulp and paper are the principal export products with 54 % of the total, including wood chips (9.8 %), sawn lumber (9.4 %) and logs (6.1 %) (WFI 1999, INFOR 2001).

2.1 *Pinus radiata*

Pinus radiata (radiata pine or Monterrey pine), was introduced into Chile from California towards the end of 1800's. It is now the most widely planted species for forestry and comprises approximately 1.5 million ha (74.1 %) of the commercial plantations (INFOR 2000). This species grows well in areas with poor soil and low rainfall and is planted on various land types, other than deserts, swamps, and areas subjected to snow and low temperatures (Cerda & Nuñez 1998, WFI 1999). Most forestry companies consider the optimum rotation age for a well-managed plantation of *P. radiata* to be between 18 to 25 years for pulpwood and 25 to 35 years for solid timber (Balocchi, Ahumada & Ramirez 1999, INFOR 2000). *Pinus radiata* can produce up to 25 m^3/ha/yr of wood and the average yield per hectare at harvest is 470 m^3 (Williams 1998). During 2000, the consumption of *P. radiata* was approximately 18.8 million m^3. The future stock of wood during the next rotation has been calculated at approximately 64.3 million m^3 (INFOR 2001).

2.2 *Eucalyptus spp.*

Eucalyptus spp. were introduced into Chile in 1823 and an extensive forest base was rapidly developed in the early 1900's (FAO 1979, Lopez *et al.* 2001). Commercial planting of *Eucalytus* spp. began in the 1930's to complement coal mining (Jayawickrama *et al.* 1993). As the global demand for wood increased in the 1980's, government loans subsidised the planting of additional *Eucalyptus* trees. Currently almost 360 000 ha of *Eucalyptus* spp. have been established in Chile and more than two-thirds of the plantations are under 5-years-old (INFOR 2001, Kliejunas *et al.* 2001).

The most widely planted *Eucalyptus* species in Chile are *E. globulus*, which is distributed, from central to Southern Chile and *E. nitens*, planted in colder areas. *E. globulus*, is adaptable to a wide range of climatic and soil conditions, flourishing along the coast and inland areas that are not subjected to severe frost. They grow best in areas with 800 mm or more of precipitation (Jayawickrama *et al.* 1993). *E. nitens* has also been widely planted due to its rapid growth, desirable pulping properties, and frost tolerance. It is estimated that both *E. globulus* and *E. nitens* can grow at 40 m^3/ha/yr on sites such as the coastal area of the Southern-central region of Chile (Kliejunas *et al.* 2001). Rotations between 8 to 10 years are envisaged for pulpwood production and up to 25 years for solid wood production

(Jayawickrama *et al.* 1993). Other species of *Eucalyptus* such as *E. camaldulensis* Dehnhardt, *E. cladocolyx* F. Müeller and *E. siderexylon* A. Cunningham: Woolls are planted in the drier, northern and central areas of Chile. *Eucalyptus regnans* F. Muell., *E. fastigata* Deane & Maiden, *E. delegatensis* R.T. Barker and *E. viminalis* Labill. have also shown promise in the South of Chile (Jayawickrama *et al.* 1993, INFOR 1997).

In addition to the most important products obtained from *Eucalyptus* spp., other less important uses include fuel, veneers, mouldings, fence posts, firewood, and structural elements (Jayawickrama *et al.* 1993). The consumption of *Eucalyptus* products during 2000 in Chile was approximately 4 million m^3 (INFOR 2001). Harvest of plantation-grown *Eucalyptus* spp. is predicted to increase from 2 million m^3 in 1995 to more than 7 million m^3 by 2004 (Brownie 1996). The future stock of wood for the next rotation (10 years) is calculated at approximately 27.4 million m^3 (INFOR 2002).

3.0 INSECT AND DISEASE PROBLEMS IN COMMERCIAL PLANTATIONS

Pinus and *Eucalyptus* species in Chilean forestry have not been without pest and pathogen problems. During the last 15 years several insects and diseases have been detected in the country. Forestry companies have been conducting surveys, plantation assessments and strategies including chemical and biological control against these pest and disease problems in order to reduce their impact. Commercial plantations were considered virtually free from insect pests and diseases for several decades (Alfaro & Singh 1997). Viewed in the context of the number of diseases and insects that could damage *P. radiata* and *Eucalyptus* spp. in Chile, the country has been relatively fortunate in having avoided the impact of many of these pests and diseases (Wingfield 2001, unpublished report).

Almost every year since 1997, a new pest or disease has been detected in *Pinus* or *Eucalyptus* plantations in Chile (Table 2). This unpredictable increase of various problems, can be attributed to the increase in the extent of commercial plantations, an increase in world trade in unmanufactured wood articles, as well as, an increase of tourist activity (Gonzalez & Parra 1994, Tkacz 2002). The main pest and pathogen problems in both *Pinus* and *Eucalyptus* plantations are described in the following section.

3.1 *Pinus* Plantations

Pinus radiata has been considered as a healthy species in Chile, despite its high susceptibility to several insect pests and diseases, such as the pine shoot moth (*R. buoliana*), Dothistroma needle blight (*D. septospora*) and Pitch canker (*F. circinatum*). More exotic than native insects have been considered important in terms of damage they may cause to commercial plantations of *P. radiata*. Lanfranco (2000) classified these species according to their taxonomic group, origin, type of damage, and risk or importance to commercial plantations (Table 1).

3.1.1 Insects

Chile is considered relatively fortunate in terms of the presence of insect pests in commercial *Pinus* plantations (Alfaro & Singh 1997). Since 1981, when *Hylurgus ligniperda* Fabr. and *Hylastes ater* Payk. were detected on commercially grown trees, only two introduced pest species have been reported. Of these, *R. buoliana* is by far the most important insect pest affecting Chilean plantations. In addition *Sirex noctilio* Fabr. is a species that has recently reached Chile and is one of the species with a high potential to cause damage (Iede, Penteado & Schaitza 1998, Rawlings & Wilson 1988). Native insects have also been reported in *P. radiata* plantations and some of them have resulted in significant but infrequent damage (Lanfranco 2000).

Bark Beetles

Many forest entomologists consider bark beetles to be one of the most economically important groups of forest insects. They infest logs or pine cargo crates containing strips of bark and in this way, they have been spread to various countries (Sato 1975, Ciesla 1993). In 1981, the first exotic insect pests were detected in Chilean *P. radiata* plantations. These were two bark beetle (Coleoptera: Scolytidae) species (*H. ligniperda* and *H. ater*). Later, *Orthotomicus erosus* Wollaston was also introduced into Chile (1983), apparently in containers from Europe (Ciesla 1993, Lanfranco 2000).

Bark beetles are known to vector pathogenic fungi. These include the genera *Ophiostoma* H. & P. Sydow, *Ceratocystis* Ellis & Halsted and *Leptographium* Lagerberg & Melin

(Upadhyay 1981, Wingfield, Seifert & Webber 1993). Some of these fungi can lead to serious tree diseases, and the majority cause blue stain of timber (Jacobs & Wingfield 2001). In Chile, emerging *H. ater* adults feed on the roots of one-to-two year old seedlings and on the root collars, causing tree mortality (Ciesla 1993). However, these insects have not resulted in severe damage in commercial plantations in Chile. They are, however, considered as potentially damaging in the USA (Ide *et al.* 2000, Tkacz 2002). These bark beetles could potentially be effective vectors for black stain root disease (*Leptographium wageneri* (Kendrick) M.J. Wingf.), which is one of the most serious pathogens of conifers in the western USA (Jacobs & Wingfield 2001, Tkacz 2002).

Recently, two ophiostomatoid fungi, *Ophiostoma ips* (Rumbold) Nannfeldt and *Ceratocystiopsis minuta* (Siem.) Upadhyay & Kendrick have been associated with *H. ligniperda* in Chile (Zhou *et al.* 2002). *Hylastes ater* has also been associated with other ophiostomatoid fungi such as *Ophiostoma geleiformis* (Bakshi) Mathiesen-Käärik, *O. huntii* (Rob.-Jeffr.) de Hoog & R. J. Scheff. and a *Pesotum* sp. (Zhou *et al.* 2002). Studies are currently underway to determine the full spectrum of fungal associates of *H. ater* and *H. ligniperda*, as well as to determine the potential for these insects to vector the pitch canker pathogen, *F. circinatum*.

Pine shoot moth

The European Pine Shoot Moth (EPSM) *R. buoliana* was the second exotic pine-infesting insect to be detected in Chile. This insect was first found in the country in 1985 (Espinoza, Lobos & Gomez 1986). Thus far, the pest has resulted in the most severe impact to commercial Chilean forestry (Cogollor & Ahumada 1990, Lanfranco 2000). The characteristic symptoms associated with EPSM is the presence of resin in the shoots, chlorosis of the shoot tip and needles and tip dieback, caused by larval feeding and mining, resulting in shoot destruction (Figure 2). When the attack is in the main shoot or stem, some trees can recover but the majority will be deformed (Figure 2), (Ahumada & Smith 1993, Alzamora *et al.* 1996, Ide & Lanfranco 1996).

Reduction in growth of trees due to EPSM has been calculated to be approximately 20 - 40%, thus causing a substantial overall loss of production (Alvarez de Araya, Ramirez & Parra 1991). The distribution of *R. buoliana* has expanded at a rate of approximately 50 km/year. This relatively local movement is attributed to adult insect dispersal, which is facilitated by wind currents and, cloud mass movement. In addition, insects have been recorded to be moved on vegetative material (branches and small trees) to be transported between different areas in Chile (CONAF 1998, Bioforest unpublished report).

A substantial effort has been instituted by the various forestry companies, collectively with the Chilean Forest Service as the lead agency, to control *R. buoliana*. This includes chemical control and, silvicultural management to reduce pest populations. Actions also include biological control measures using both a native (*Coccygomimus fuscipes* Brullé; Hymenoptera: Ichneumonidae) and an introduced parasite (*Orgilus obscurator* Ness.;Hymenoptera, Braconidae) (Lanfranco & Cerda 1986, Lanfranco 1996, Bravo & Ahumada 1998a). Good success has been achieved in Chile with these biological control agents (Ahumada, Alfaro & Ojeda 1999). Ten years after the first introduction of the exotic parasite from Europe, parasitism levels of 80 % have been achieved (Ahumada & Brieva 2000).

Sirex wood wasp

Sirex noctilio was detected at the beginning of 2001 in the central part of Chile. Its high potential to damage pine plantations, is due to its capacity to attack and spread more than 100 km/yr. (Tribe 1997). However, in Chile the insect infestation is still concentrated around the area where it was originally detected (SAG 2001, unpublished report) and has not caused any damage in commercial plantations. Both forest service and forestry companies have already prepared a strategy for its control, based on biological control with the nematode *Deladenus siricidicola* Bedding and improved plantation management. These strategies have proven affective in management of this pest in Australia, Brazil and New Zealand (Rawlings & Wilson 1988, Haugen & Underdown 1990, Iede, Penteado & Schaitza 1998).

Native insects

Some native insects have developed the capacity to damage pine plantations in Chile. These insects result in damage, particularly associated with long periods of drought, poor site quality, stress due to inadequate silvicultural practices or opportunistic behaviour of the insects (Lanfranco 2000). Very little research has been undertaken in order to understand the impact of these native pest outbreaks. The most important damage has been caused by species of *Ormiscodes*, *Rhyephenes*, *Antandrus*, *Coniungoptera* (Lewis 1996, Lanfranco 2000). Bioforest, a research company of the Arauco Forestry group, has been studying the life cycle of two native insects, *Antandrus viridis* Blanchard (*Acrididae*) and *Coniungoptera nothofagi* Rentz & Gurney (*Tettigonidae*), as well their impact in commercial plantations (Ahumada & Brieva 2001).

3.1.2 Diseases

Disease caused by introduced pathogens have not been less important than insect pests in terms of impact on commercial plantations. Some of the more important pathogens are *Sphaeropsis sapinea* (Fr.) Dyko & Sutton, *D. septospora* and recently *F. circinatum* (Wingfield 2001, 2002 unpublished reports). Other less important pathogens in plantations include *Cyclaneusma minus* (Butin) DiCosmo, Peredo & Minter, *Ceratocystis picea* (Munch) Bakshi (=*Ophiostoma piceae* (Münch) H. & P. Sydow), *C. pilifera* (Fr.) C. Moreau (=*Ophiostoma pilifera* (Fries) H. & P. Sydow) and *Armillaria mellea* (Vahl ex Fr.) Kumm. *sensu lato*. In nurseries, fungi such as *Macrophomina phaseolina* (Tassi) Goid., *Colletotrichum acutatum* Simmds. f. *sp. pinea* Dingley & Gilmour, *F. oxysporum* Snyder & Hansen, have been recorded. None of these fungi are considered to be associated with serious problems at this time (Mujica & Vergara 1980, Butin & Peredo 1986).

Recently, Zhou *et al*. (2002) isolated five Ophiostomatoid fungi *C. minuta* and *O. ips* from *H. ligniperda* and *O. geleiformis*, *O. huntii* and *O. quercus* (Georgévitch) Nannfeldt from galleries and *H. ater*. These are the first records of the fungi from Chile. Further studies on these fungi are planned and these will especially concentrate on their importance.

Sphaeropsis sapinea shoot blight

The first pathogen reported in Chilean *P. radiata* plantations was *S. sapinea*, which was detected in 1942 (Gonzalez & Jorquera 1997, Lanfranco 2000). Since its detection, it has only been a problem occasionally, specifically after high stress situations, where trees have displayed dieback in several commercial plantations (Butin & Peredo 1986). One of the concerns with this disease is that, the pathogen has the capacity to enter through prunning wounds and if this should occur, these trees might be more susceptible to attack by the Sirex woodwasp.

Dothistroma needle blight

Dothistroma septospora (teleomorph: *Mycosphaerella pini* Rostr.) has been the most important disease affecting Chilean commercial plantations of *P. radiata*. This tree species is considered as one of the most susceptible species to Dothistroma needle blight (Evans 1984, Butin & Peredo 1986). The disease was first reported from Chile in 1965 (Dubin 1965) and the pathogen is present in most of the commercial plantation areas (35° S - 42° S), especially in the Southern (below 41° S) area of Chile (Lanco, Valdivia, Los Lagos, La Union).

Because Dothistroma needle blight is the most important disease affecting commercial pine plantations, much research has been conducted since the disease was first reported in Chile. This research has been focused on biology, life cycle, mechanism of infection, foliage loss, management and economic impact (Bustamante 2000). However, much remains to be known regarding the disease in Chile, especially issues pertaining to impact and control.

Dothistroma needle blight occurs when the conidia of *D. septospora* are liberated from the fungal fruiting bodies into a film of water, from where they are dispersed by water-droplets (Gibson, Christensen & Munga 1964). Conidia, which land on needles of susceptible host species germinate, and penetrate through the stomata (Gadgil 1967). In Kaingaroa, New Zealand, spray trials on 13-year-old *P. radiata* trees has indicated that trees with 25 % or more infection, sprayed on three occasions, have 30 to 40 m^3/ha more volume at the end of a rotation, compared to unsprayed trees (Kershaw *et al.* 1988). Other studies have shown that the height of the trees is affected if the defoliation is greater than 30 % to 40 % (Van der Pas 1981). Similarly, the increment of the tree is decreased by 50%, if the infection level is more than 50 % of the active foliage (Van der Pas 1981, Whyte 1969). In Chile, several studies have shown that with infection levels lower than 25 %, effects on growth are unimportant. However, if the infection levels are greater than 50 %, the annual increment is strongly affected (Perez 1973, Contreras 1988, Hauer 2000, Bioforest 2000 unpublished reports).

Studies carried out in Chile have shown that Dothistroma needle-blight levels start to increase in winter and reach a peak in early summer. Thereafter, they drop in late summer, and remain stable in autumn, before starting to increase again in winter (Bulman, Gadgil & Ahumada 2000, unpublished report). Research conducted in the USA has shown that *Pinus nigra* Arnold. and *P. ponderosa* (Watson) Weber, are two of the most susceptible pines in central and eastern USA, while *P. radiata* and *P. contorta* (Engelm.) Critchfield are severely affected in California and the Pacific Northwest (Christensen 1998, Peterson 1965, Peterson 1982, Peterson & Wysong 1986, Sinclair, Llyon & Johnson 1987). In both cases those species suffer severe infection during wet periods from May to October (Christensen 1998).

The control strategy for Dothistroma needle blight used in the USA, New Zealand and Chile has been similar. Aerial application of chemicals based on copper fungicides has been implemented as one of the most important control measures (Bulman & Gadgil, pers. comm.). In all three countries, two spray applications have been used when the infection has been greater than 30 % of the tree crowns. In USA, the first application is made in later spring (May), and the second in midsummer (July) (Peterson 1982). In New Zealand, the first application is also between spring and summer (Bulman & Gadgil, pers. comm.). The situation in Chile does not differ much from that in the USA and New Zealand and, chemical control is applied in the late spring and summer. New Zealand and Chile have implemented an intensive silvicultural management (pruning and thinning) in most of the commercial plantations and the positive impact of these silvicultural strategies is known (Bioforest 2000, unpublished report). In the past ten-years, thousands of hectares (between 3 to 10-year-old) were sprayed once or twice per year, depending on infection levels. Particularly in young plantations, the amount of inoculum was drastically reduced (Bioforest 2000, unpublished report) (Figure 3).

Experience in the past with selection of trees resistant to Dothistroma needle blight, has been inconsistent. However, evidence from New Zealand, Australia and USA suggests that different families of *P. radiata* differ in their susceptibility to *D. septospora* (Contreras 1988, Elmudesi 1992), (Figure 4). This aspect of the disease deserves significantly more attention in the future (Peterson 1982, Wingfield 2001, unpublished report).

Pitch canker

The most recent pathogen to be detected on pine trees in Chile is the pitch canker fungus, *F. circinatum*, which was first reported in 2001 (Wingfield *et al.* 2002). Pitch canker is one of the most serious fungal diseases affecting *Pinus* spp. in the world (Viljoen *et al.* 1997a, Britz *et al.* 2001, Wingfield *et al.* 2001, 2002). At present, very little is known about the pathogen in Chile and damage has only been to *P. radiata* plants in nurseries (Figure 5). The disease has, as yet, not been found on older trees in plantations (Wingfield *et al.* 2002). Nonetheless, the presence of the disease in Chile is of substantial concern, not only to this country but also to other countries growing *P. radiata* (Wingfield 2001, 2002, unpublished reports).

Fusarium circinatum has caused significant losses on a wide variety of pine species (Dwinell, Barrows-Broaddus & Kuhlman 1985, Viljoen *et al.* 1995, 1997b, Gordon, Storer & Wood 2001). The pathogen has been isolated from different parts of the trees, including stems, branches, cones and root collars of seedlings (Viljoen 1994, Britz *et al.* 2001). At present, it is difficult to predict how pitch canker will affect the commercial plantations in Chile. One concern is that the pathogen might be able to enter wounds made by insects such as *R. buoliana* and *H. ater*. These aspects of the disease in Chile will need to receive careful study in the future (Wingfield 2001, 2002, unpublished reports).

Armillaria root rot

Armillaria spp. are pathogens with a worldwide distribution, that usually exist as saprophytes on stems and roots, but can also infect living tissue (Butin & Peredo 1986, Pronos & Patton 1977). The disease usually referred to as Armillaria root rot, causes reduction in growth, yellowing and browning of foliage until death. Damage is especially severe on stressed trees. In *P. radiata* plantations in Chile, however, this pathogen has not been important (Osorio, pers. comm.)

Native pathogens

Thus far, the Chilean literature has registered very little information regarding important disease outbreaks caused by native pathogens. Little research has been conducted in order to identify and understand native fungi, adapted or present in these productive plantations.

3.2 *Eucalyptus* Plantations

In contrast to pine plantations, very little attention has been given to pests and diseases in plantations of *Eucalyptus* spp. Since the early 1980's preliminary assessments have been conducted in order to determine the general disease condition within Chilean *Eucalyptus* plantations. One of the first national assessments of *Eucalyptus* plantations was made in 1993 by Government agencies and private forestry companies. From these evaluations, it was found that Eucalyptus leaf spot was the most important problem associated with commercial *Eucalytus* plantations. In contrast there was no evidence of any significant insect problems (CONAF 1994, CONAF 2002).

3.2.1 Insects

***Eucalyptus* Longhorn borer**

One of the first insects reported affecting *Eucalyptus* spp. in Chile, was *Phoracantha semipunctata* Fabricius (Coleoptera: Cerambycidae). This insect was discovered in 1973 on *E. globulus* in the central region of Chile, where it began to cause problems in plantations subjected to water stress, due to low precipitation or to soils with poor water retention (Cogollor 1986, 1991). This insect has been well studied and its life cycle, symptoms, damage and control strategies are well understood (Cogollor 1986). In 1998, the parasite *Avetianella longoi* Siscaro (Hymenoptera: Encyrtidae), was introduced into Chile from South Africa and biological control has already proven useful (SAG, unpublished report).

In 1997, *Phoracantha recurva* Newman (Coleoptera: Cerambycidae), was detected in Chile for the first time (Perez & Pinar 1999). This species has not been a problem and has been confined to the area where it was first detected (Beeche, pers. comm.).

Australian weevil

Gonipterus scutellatus Gyllenhal (Coleoptera: Curculionidae) was detected for the first time in Chile in 1998, and it was apparently introduced from Argentina (Bravo & Ahumada 1998b, SAG 1999). Like *P. semipunctata*, *G. scutellatus* is native to Australia and both adult and larval stages feed on the foliage of a wide range of *Eucalyptus* spp. It particularly favours *E. globulus* and *E. viminalis*. There have been few serious outbreaks of this insect and it is not regarded as a major pest of *Eucalyptus* in Australia. However, it has become a major pest in many countries where *Eucalyptus* spp. are grown as an exotic plantation species (Ojeda 1994). After the initial detection of *G. scutellatus*, some small areas planted with *E. globulus* showed damage produced by larvae and adults of *Gonipterus* (Figure 6). The first action undertaken was to spray the affected area with insecticides (SAG 1999). Subsequently the biocontrol agent, *Anaphes nitens* Girault (Hymenoptera: Mymaridae), was also introduced into Chile from South Africa. Thus far, *G. scutellatus* has been confined in the area where it was originally detected and, the population has remained at a low level (Beeche, pers. comm.).

Blue Gum Psyllid

The insect pest most recently detected on *Eucalyptus* in Chile, is the blue gum psyllid, *Ctenarytaina eucalypti* Maskell, (Homoptera: Psyllidae), which was reported in 1999. Since its original detection, the psyllid has expanded its distribution in a short time and now occurs throughout all commercial plantations of Chile (Lanfranco & Dungey 2001). Clusters of yellow eggs are deposited at the bases of the terminal leaves and axial buds. The nymphs settle and feed on the leaves or stems, where the eggs are deposited. The nymphs secrete wax-coated honeydew spheres as well as copious amounts of waxy filaments, which can conceal them from view. Feeding by psyllids causes acute damage, such as inhibition of new shoot formation and distortion in the shape of new leaves (Dahlsten *et al.* 1993, Hodkinson 1999). A variety of control measures have been taken in order to reduce the damage caused by the *C. eucalypti* insects in commercial plantations. These include chemical application using pyrethroids and biological control through releasing *Psyllaephagus pilosus* Noyes (Hym. Encyrtidae). In addition, the impact of the pest on *Eucalyptus* plantations is uncertain and is currently being evaluated (Bioforest, unpublished reports).

3.2.2 Diseases

Very little is known regarding *Eucalyptus* diseases in Chile. Indeed, this provides the key motivation for undertaking the studies presented in this thesis. The following section provides a brief review of the pathogens known to occur. Some of the studies that have been undertaken, have not been published and there is generally a paucity of knowledge of this topic.

One of the first sanitary assessments in *Eucalyptus* plantations in Chile was made by Mujica & Vergara (1980). In this study, the authors found the fungi *Fairmaniella leprosa* (Fairm.) Petrak. & Syd. and *Botrytis cinerea* Pers. damaging *E. globulus* foliage. Ten years later, Peredo (1990) reported the presence of *Hainesia lythri* (Desm.) Hohn. and subsequently, Gonzalez & Parra (1994), identified *Mycosphaerella cryptica* (Cooke) Hansf., *M. molleriana* (Thüm.) Lindau, *Harknessia globosa* B. Sutton, *Sonderhenia eucalypticola* (A.R. Davis) H.Swart & Walker, *Microthyrium* spp., *Pestalotiopsis* spp. and *Phoma* on *Eucalyptus globulus*.

Wingfield *et al.* (1995) provided a detailed description of several leaf pathogens of *Eucalyptus* spp. in Chile. They detected species such as *Aulographina eucalypti* (Cook & Mass) Arx & Muller, which is a well-known pathogen of older *Eucalyptus* foliage. In Chile it has, however, not been a problem but has been the cause of serious leaf spot in Australia, Brazil, New Zealand, United Kingdom and South Africa (Wall & Keane 1984, Ferreiras 1989, Dick 1982, Spooner 1981, Crous 1998). The second potentially important pathogen that Wingfield *et al.* (1995) found was a *Ceuthospora* sp. from *Eucalyptus* leaves and leaf litter. Little is known, however, of its pathogenicity. *Fairmaniella leprosa* was also found on *E. globulus* leaves, causing round to irregular, dark brown leaf spots, and appeared to be a common but unimportant leaf inhabitant (Wingfield *et al.* 1995). *Harknessia globosa* was isolated by Gonzalez & Parra (1994) and although this species appeared to be pathogenic, it was associated with only small lesions on *Eucalyptus* foliage.

Two species of *Mycosphaerella*, *M. cryptica* and *M. walkeri*, were isolated and identified through the observation of pseudothecia and acervuli of their anamorph (*Colletogloeopsis nubilosum* (Ganap. & Corbin) Crous & M.J.Wingf. and *Sonderhenia eucalypticola*, respectively). *Mycosphaerella cryptica* occurred on both juvenile and adult leaves of *E.*

globulus and *E. nitens* (Wingfield *et al.* 1995). This species causes lesions on leaves that vary from regular, circular spots to larger blotches (Park & Keane 1982) and is considered as one of the most destructive species on mature *Eucalyptus* foliage (Carnegie 2000). *Mycosphaerella walkeri* and its anamorph *S. eucalypticola* were also collected from *E. globulus* and *E. nitens* and often occurred in association with *M. cryptica*. Another species that was identified by Wingfield *et al.* (1995) was *Thyriopsis sphaerospora* Marasas, which according these authors, appears not to be a serious pathogen.

An epidemiological study of *Eucalyptus* foliar diseases was carried out by Gonzalez (1997) in different areas in the southern part of Chile, during 1996 and 1997. In this study, the health of species such as, *E. globulus*, *E. nitens*, *E. camaldulensis*, *E. viminales* and *E. delegatensis* was assessed. Gonzalez (1997) found *S. eucalypticola* on *E. globulus* and *E. viminalis*. Also, like Gonzales and Parra (1994) and Wingfield *et al.* (1995), he found *H. globosa* (*E. globulus* and *E. viminalis*) and *F. leprosa* (*E. globulus* and *E. viminalis*). Additionally, he was able to identify species of *Harknessia* (*E. globulus* and *E. viminalis*), *Coleophoma* sp. (*E. globulus* and *E. viminalis)*, *Coniella minima* (Sutton & Thaung) Sutton (*E. viminalis*), *Pestalotiopsis* sp. (*E. delegatensis*), *Septoria* sp. (*E. globulus*), *Oidium* sp. (*E. globulus* and *E. nitens*) and *Hainesia lythri* (*E. globulus*). Gonzalez (1997) also found species belonging to the *Mycosphaerella* complex, such as *M. cryptica* on juvenile and adult leaves and from *E. globulus, E. nitens, E. viminalis* and *E. delegatensis*. *Mycosphaerella molleriana* was only found on juvenile leaves from *E. globulus* and *E. nitens* and *M. walkeri* on juvenile leaves from *E. globulus* and *E. viminalis*. *Mycosphaerella parva* was found only on *E. globulus*. In contrast to Wingfield *et al.* (1995), Gonzalez (1997) did not detect *A. eucalypti*.

Muñoz (1999) identified 29 pathogens (11 *Acomycetes* and 18 *Deuteromycetes*) from leaves of six *Eucalyptus* species. This study was based on morphological features, ascospore germination patterns and the presence of anamorph stages. Fifteen fungi were identified to species level; 11 to genus level and three were only assigned to class level. Of the 29 species identified, eight represented new records for Chile, including: *Botryosphaeria dothidea* (Mougeot ex Fries) Cesati & de Notaris, *Coleophoma empetri* (Rostr.) Petrak., *C. minima, H. eucalypti*, *Microsphaeropsis callista* (H. Syd) Sutton, *Sonderhenia eucalyptorum* (Hansf.) Swart and Walker, *Thyrinula eucalypti* (Cooke and Mass.) Swart and *Zoellneria eucalypti* (= *Torrendiella eucalypti auctt.*) Berk. and Dennis.

Another species found on both juvenile and adult leaves on *E. nitens* was a *Sphaerulina* sp., that according to the author was associated with *M. cryptica*. Muñoz (1999), also found *M. cryptica* on different ages of *E. globulus* leaves, including adult and intermediate leaves on *E. camaldulensis* and juvenile and adult leaves of *E. nitens*, *E. viminalis* and *E. delegatensis*.

Gonzalez (2000, unpublished report) examined different plantations of *E. globulus* with severe defoliation of both juvenile and adult leaves. *Mycosphaerella cryptica*, *M. molleriana* (as a synonym of *M. nubilosa*), *M. walkeri*, *S. eucalypticola* and *H. globosa* were identified in this study. Mohammed (2001, unpublished report), as well as Gonzalez (2000, unpublished report) surveyed similar areas of planted *E. globulus* and *E. nites* and identified *M. cryptica, M. walkeri, Harknesia* sp., *H. globosa, S. eucalypticola*, *Ceuthospora* and *Cladosporium*. However, all of these identifications, as well as others previously, were based only on morphological characteristics and ascospore germination patterns of *Mycosphaerella* ascospores.

Wingfield (2001, unpublished report) confirmed that the serious defoliation problem observed on juvenile leaves of *E. globulus* during the year 2000 was associated with two species of *Mycosphaerella*. One of these was tentatively identified as *M. marksii*. The other included smaller *Sonderhenia* type spots caused by *M. walkeri*, that has an asexual state known as *Sonderhenia eucalypticola*. However, he suggested that neither *Mycosphaerella* species nor any other biotic agent had caused the defoliation of adult *E. globulus* leaves. Wingfield (2001, unpublished report) also observed that some of the worst affected stands were on the best sites. *Eucalyptus nitens* stands, however, always showed lower levels of MLD than *E. globulus* stands. One site in Southern-central Chile (Valdivia area), distinct leaf spots that are rather different to those typical of *Mycosphaerella* infections was observed. According to the initial observations of Wingfield (2001), the fungus most closely associated with these spots is a species of *Sphaerulina*, which is characterized by 3-celled ascospores. Wingfield (2001, unpublished report), also noted a relatively serious dieback problem on *E. globulus* hedge plants apparently caused by the opportunistic basidiomycete, *Chondrostereum purpureum* (Pers:Fr) Pouzar, but did not find any evidence of *Mycosphaerella cryptica* or *M. nubilosa* on *Eucalyptus* spp. in Chile, as had been suggested previously.

4.0 CONCLUSIONS

As compared with the extent of damage that might potentially occur, Chile has been relatively fortunate in not having been seriously affected by diseases or pests in its extensive plantations of *P. radiata*. However, Dothistroma needle blight and Pine shoot moth have caused substantial damage and their impact might be viewed as an indication of the importance of pests and diseases in the country.

Eucalyptus plantations are relatively new in Chile and are much less extensive than those of *Pinus* spp. Thus far, the most important problem that has been recorded on these trees is Mycosphaerella leaf disease, which appears to be most important on juvenile leaves in *E. globulus* plantations, particularly in the Northern-central area of Chile (Arauco area).

All indications are that new pests and diseases are appearing in Chile with regular or even increased frequency. This is a trend that is likely to continue. The recent discovery of the devastating pitch canker pathogen in Chile is an example of the level of problems that can appear, relatively rapidly. Special attention will need to be given to protecting the forestry resource. Pests and diseases will be one of the most important constraints to the sustainability of exotic plantation forestry in the future and every effort must be made to reduce this threat.

Very little research has been conducted on *Eucalyptus* diseases in Chile. The studies that make up this thesis were, therefore, intended to improve this situation. They focus on *Mycosphaerella* spp. associated with leaf blight and *Botryosphaeria* spp. associated with tip dieback, both of which have been important in recent years. It is thus hoped that these studies will significantly improve our knowledge of the diseases associated with these complexes of pathogens.

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Table 1. Insects that cause damage on *Pinus radiata* plantations in Chile.

Order	Family	Specie	Origin	Damage	Risk Level
Coleoptera	*Anobiidae*	*Ernobius mollis*	Exotic	Bark	Low
	Buprestidae	*Buprestis novenmanculata*	Exotic	Bark	Low
	Cerambycidae	*Callideriphus laetus*	Native	Bark	Low
		Colobura alboplagiata	Native	Bark	Low
	Curculionidae	*Rhyephenes maillei*	Native	Bark	Low
	Scolytidae	*Hylastes ater*	Exotic	Bark	Low
		Hylurgus ligniperda	Exotic	Bark	Medium
		Orthotomicus erosus	Exotic	Bark	Low
		Xyleborinus saxeseni	Exotic	Bark	Low
Homoptera	*Adelgidae*	*Pineus borneri*	Exotic	Tissue	Low
Hymenoptera	*Siricidae*	*Urocerus gigas*	Exotic	Wood	Low
		Sirex noctilio	Exotic	Wood	High
Lepidoptera	*Psychidae*	*Thanatopsyche chilensis*	Native	Crown	Low
	Saturniidae	*Ormiscodes cinnamomea*	Native	Crown	Low
	Tortricidae	*Rhyacionia buoliana*	Exotic	Shoot	High
Orthoptera	*Acrididae*	*Antandrus viridis*	Native	Defoliation	Low
	Tettigoniidae	*Coniungoptera nothofagi*	Native	Defoliation	Low
Phasmatodea	*Pseudophasmatidae*	*Bacunculus phyllopus*	Native	Defoliation	Low

Table 2. Chronological order of detection of pests and pathogens in Chile. Graphic representation from the data.

Insect or Pathogen	Year of detection	Host
Pineus borneri	1900	*P. radiata*
Buprestis novenmaculata	1940	*P. radiata*
Sphaeropsis sapinea	1942	*P. radiata*
Xyleborinus saxeseni	1953	*P. radiata*
Ernobius mollis	1963	*P. radiata*
Dothistroma septospora	1965	*P. radiata*
Phoracantha semipunctata	1973	*Eucalyptus spp.*
Hylurgus ligniperda	1981	*P. radiata*
Hylastes ater	1981	*P. radiata*
Orthotomicus erosus	1983	*P. radiata*
Rhyacionia buoliana	1995	*P. radiata*
Phoracantha recurva	1997	*Eucalyptus spp.*
Gonipterus scutellatus	1998	*Eucalyptus spp.*
Cteranytaina eucalypti	1999	*Eucalyptus spp.*
Sirex noctilio	2001	*P. radiata*
Fusarium circinatum	2001	*P. radiata*

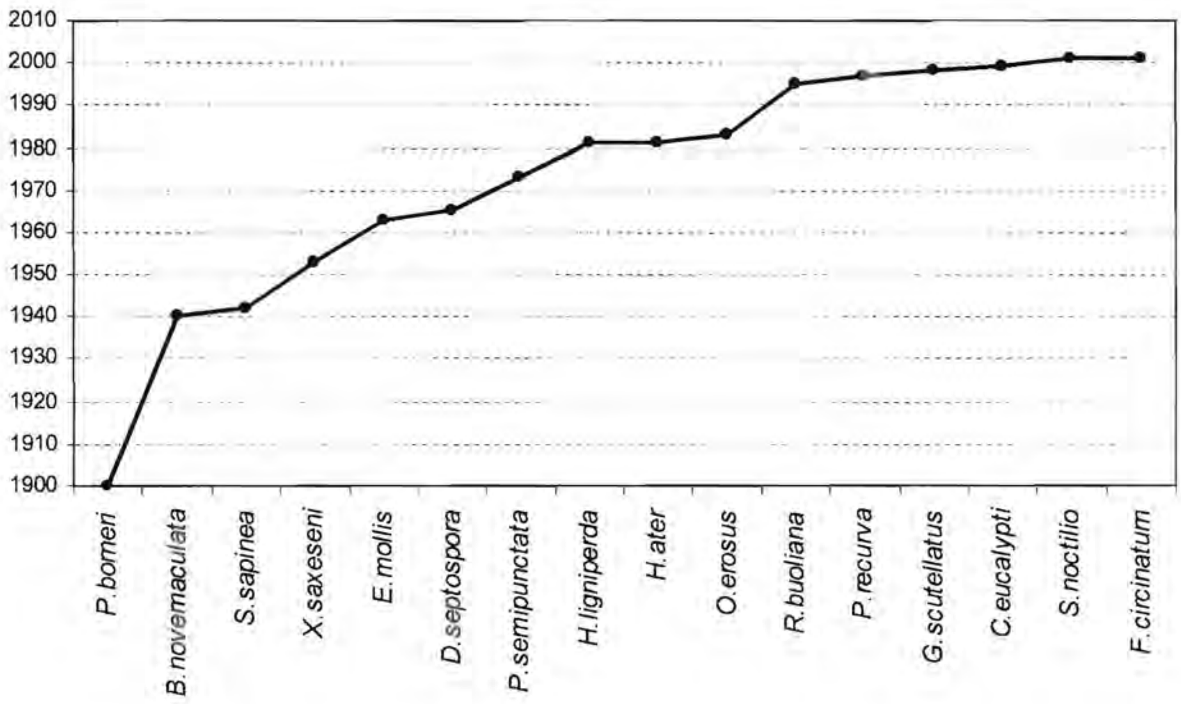


Figure 1. Administrative regions (from I to XII), geographic distribution and area of the commercial plantations in Chile (1000 x ha).

Plantations (1000 x ha) **Administrative Regions of Chile**

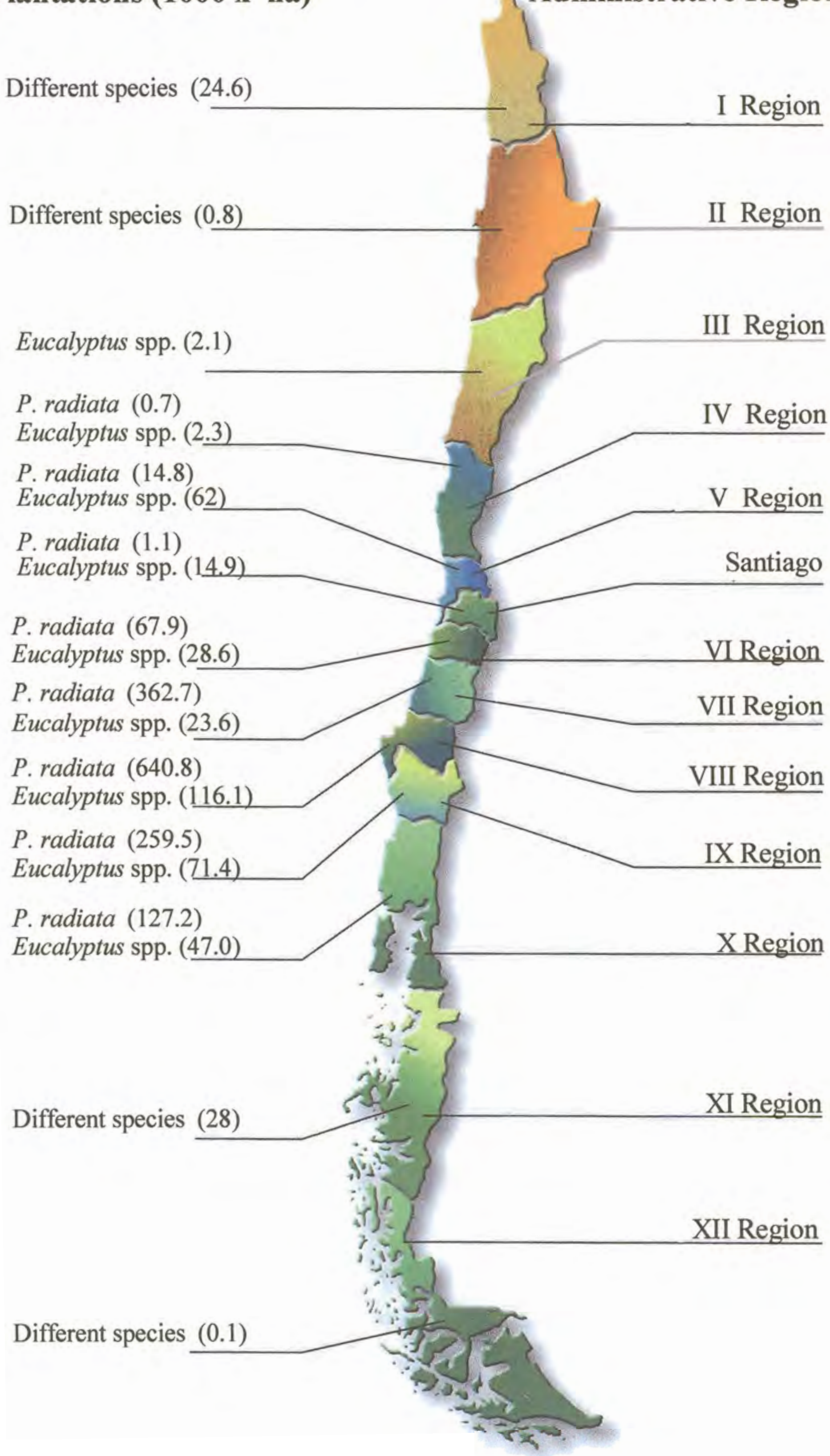


Figure 2. *Rhyacionia buoliana* on *Pinus radiata*. (**A**) Larvae feeding on a pine shoot (**B**) Initial deformation and shoot damaged (**C**) Chlorotic shoot due to a high infestation level (**D**) Apical deformation (**E**) Stem deformation.

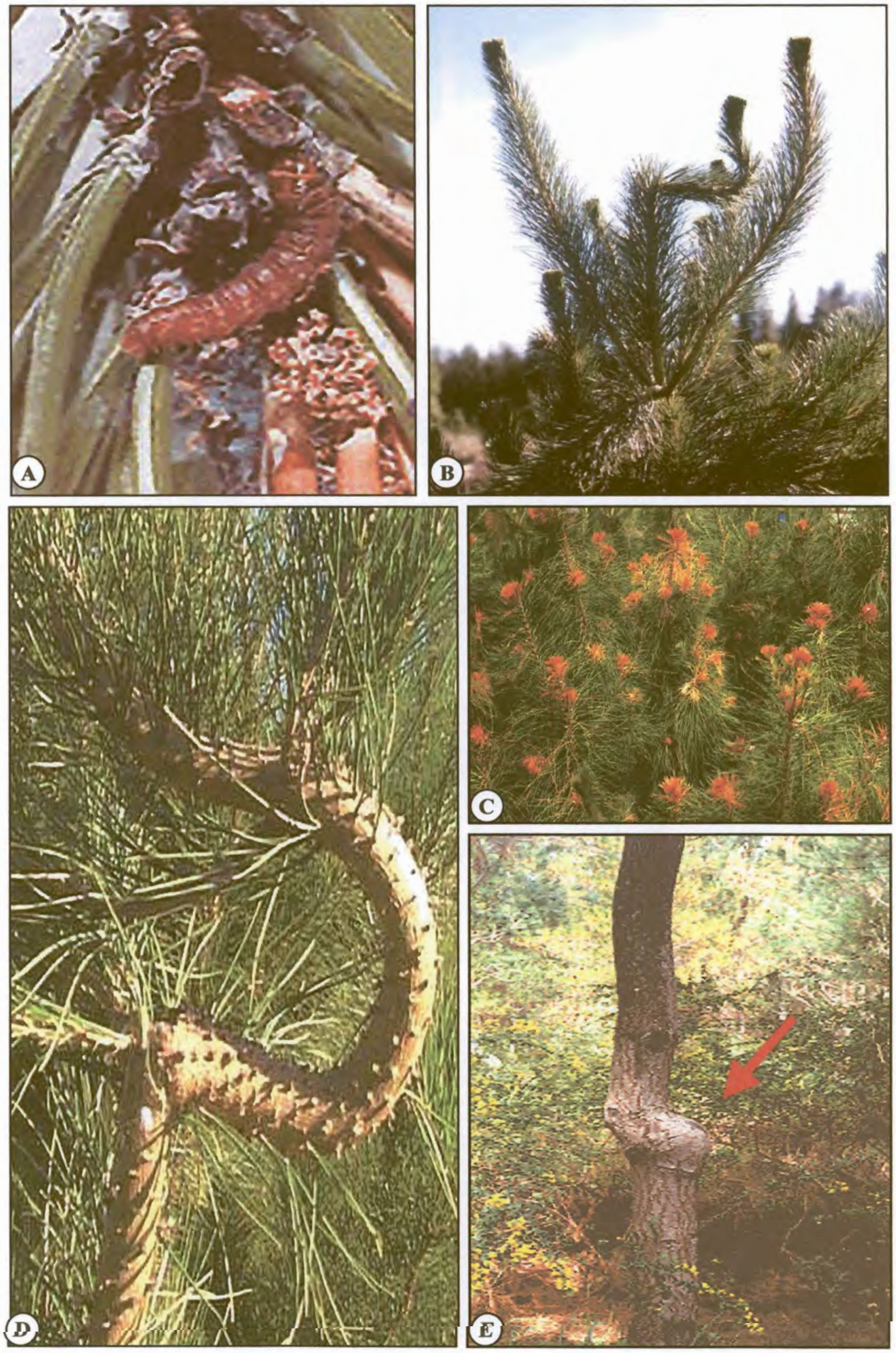
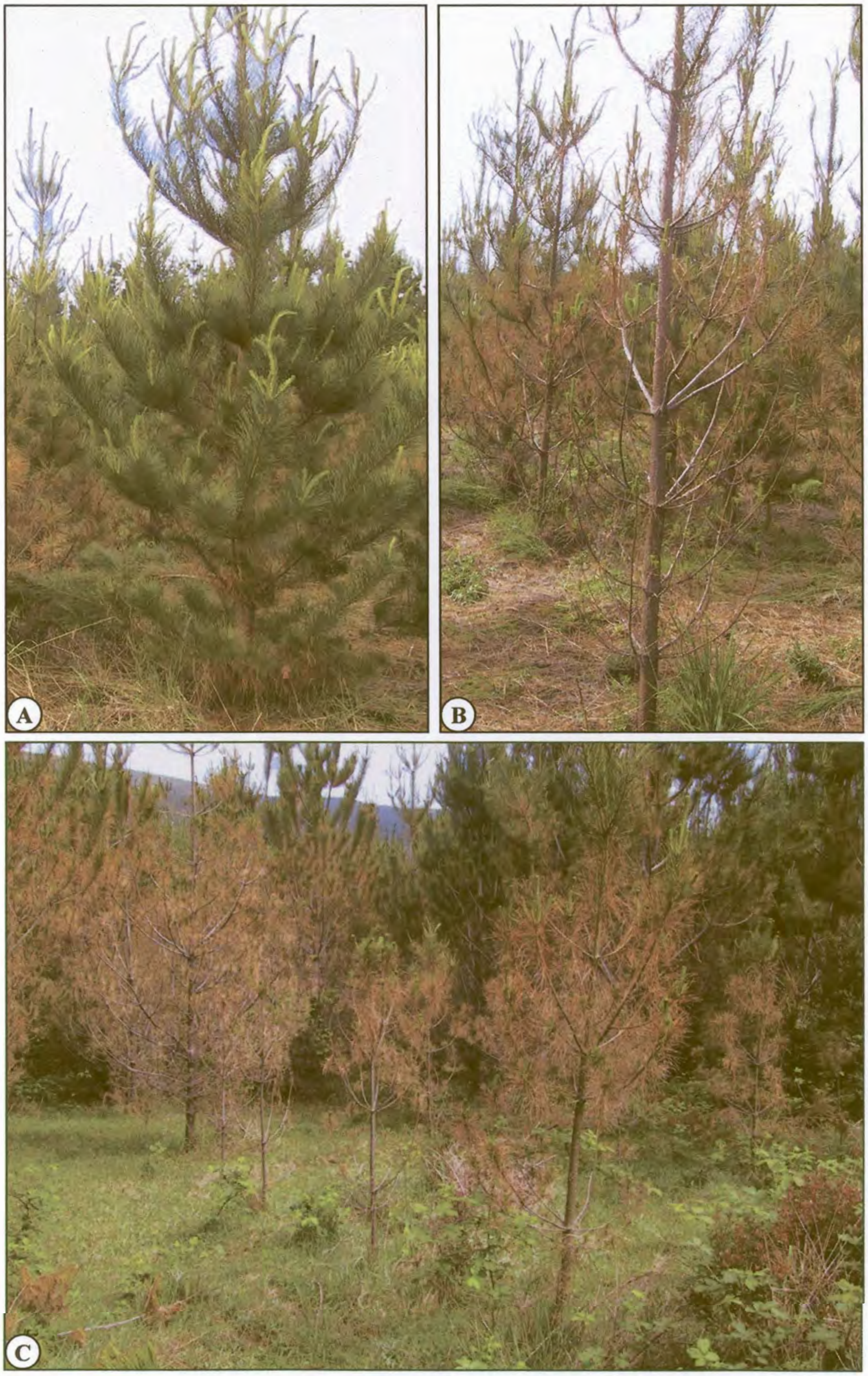

A
B
C
D
E

Figure 3. Damage caused by *Dothistroma septospora* (**A**) Plantation with silvicultural management (thinning and pruning) and chemical control (**B**) Plantation without management and chemical control.


A


B

Figure 4. Susceptibility to *Dothistroma* (**A**) Tree with low susceptibility (**B, C**) Trees with high susceptibility to *Dothistroma* attack.


A
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C

Figure 5.Pitch canker present in Chilean nurseries (**A**) Plants dead by *Fusarium circinatum* attack (**B**) Pitch canker symptoms in dying plants in a nursery from Chile.

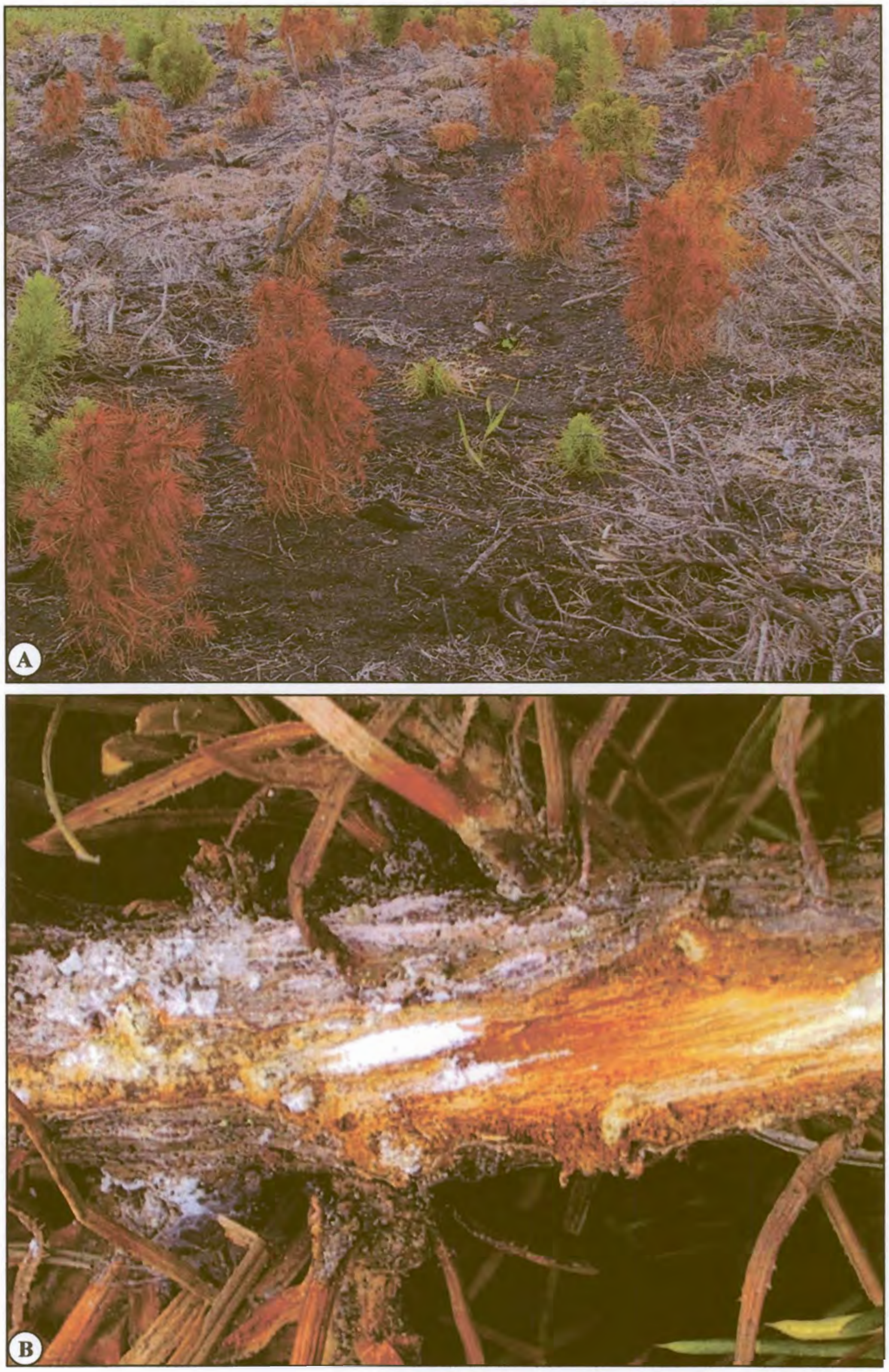
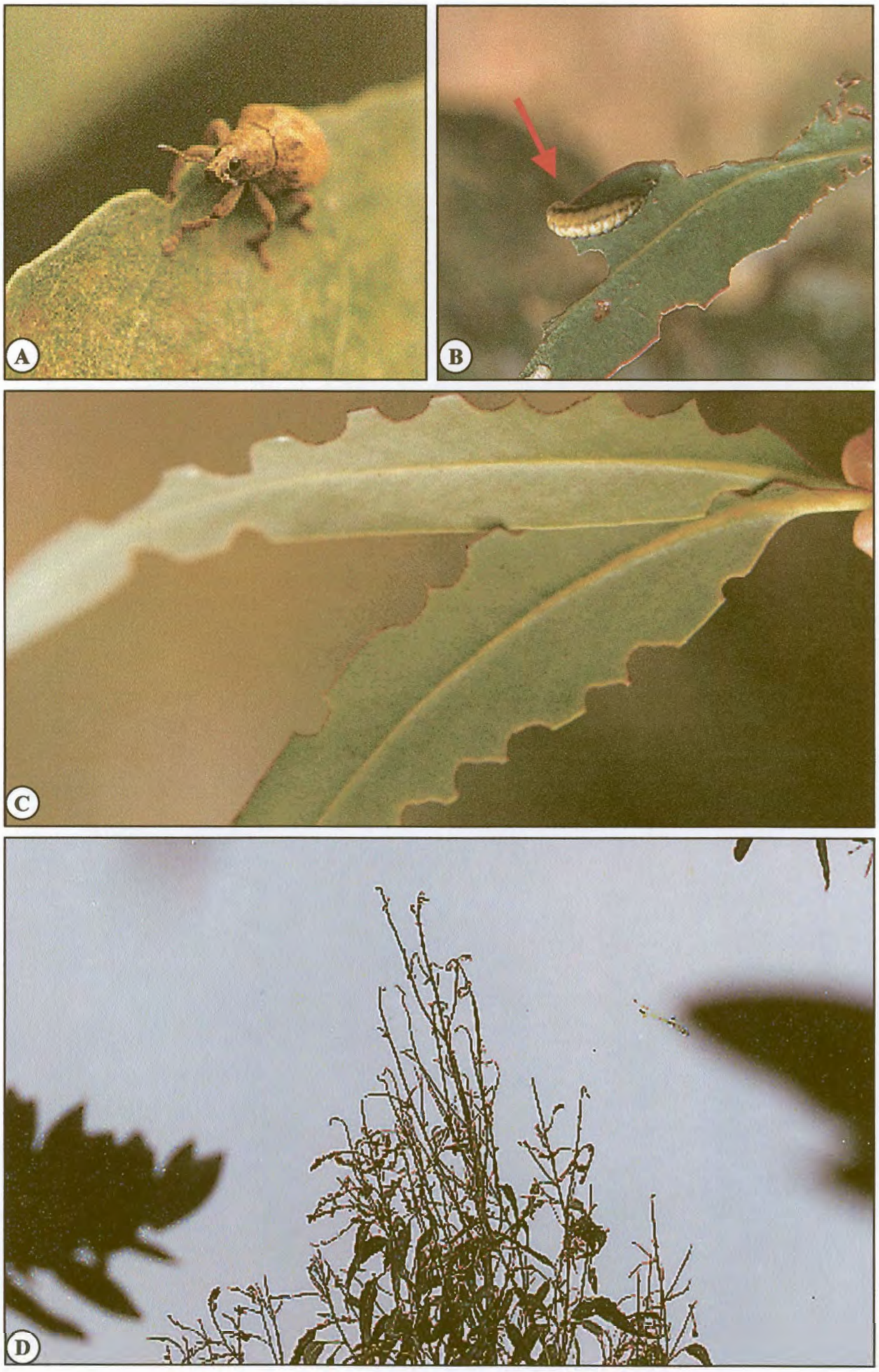

A
B

Figure 6. *Gonipterus scuttelatus* on *Eucalyptus globulus* plantations in Chile (**A**) Adult insect (**B**) Larvae (**C**) Characteristic damage in leaves due to adult feeding (**D**) Damage on the plantation where the insect was detected in Chile.


A
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