Feasibility of biological control of grey willow *Salix cinerea*

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Helen M. Harman

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Helen M. Harman

Landcare Research, PO Box 69, Lincoln 8152, New Zealand

A B S T R A C T

The feasibility of biological control of *Salix cinerea* (grey willow) in New Zealand was investigated. Although there are no native relatives of *S. cinerea* in New Zealand, other introduced species of both tree and shrub willows are used for soil stabilisation and river bank protection, and damage to any willow species used commercially is unlikely to be accepted. No invertebrates or pathogens currently appear to suppress *S. cinerea* in New Zealand. An extensive fauna has been recorded on *Salix* species in the Northern Hemisphere in the native range of *S. cinerea*. The nematine gall-forming sawflies show potential as biological control agents, with some species reputedly specific to *S. cinerea*. There could also be as yet unidentified host races of some species in other invertebrate groups, and a species restricted to the reproductive parts of *Salix* species is also a prospect. Any potential agents will require rigorous testing to determine host range. Of the diseases recorded on *Salix* species in the Northern Hemisphere, the *Melampsora* rusts have received much attention because they can devastate valued species. The *Melampsora* species already in New Zealand, however, may not be effective agents. Other *Melampsora* species may prove more useful, as may *Marssonina*. A survey in the native range may reveal other pathogens that could be biological control agents. Development of a mycoherbicide is also possible. Although biological control of *S. cinerea* in New Zealand may be difficult, this should be weighed against the extreme weediness of the plant. There are prospects for suitable biological control agents, particularly among the gall-formers. A biological control programme is therefore worth pursuing, with initial emphasis on nematine gall-forming sawflies.

Keywords: *Salix cinerea*, grey willow, biological control, invasive weeds, plant-feeding insects, plant pathogens.

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1. Introduction

Salix cinerea L. (grey willow) is one of the weediest willow species in New Zealand, and threatens many wetland and riparian sites. A report by Syrett (2002) recommended investigating the feasibility of biological control for grey willow. Although other willow species are used in New Zealand for soil stabilisation, a biological control agent specific to grey willow may be acceptable to users of these species. Landcare Research investigated for the Department of Conservation (DOC) the feasibility of finding biological control agents that could control this weed without posing unacceptable risks of damage to other willow species in New Zealand.

1.1 BACKGROUND

The genus *Salix* L. is one of four genera in the Family Salicaceae, and is thought to have between 300 and 500 species. These dioecious trees and shrubs originate mostly from northern temperate regions, although the native ranges of a few species occur as far south as the Andes and South Africa (Webb et al. 1988). The willows are often divided into three subgenera: *Salix* (tree willows); *Caprisalix* (*Vetrix*) (shrub willows – sallows and osiers); and *Chamaetia* (dwarf, arctic or alpine willows) (Van Kraayenoord et al. 1995). While the taxonomy of many of the species within subgenera is complex because of hybridisation (Webb et al. 1988), there are very few examples of hybridisation across the subgenera (Thompson & Reeves 1994).

No members of the Salicaceae are native to New Zealand. At least eleven species of *Salix* and five hybrids are, however, naturalised, along with six species and three hybrids of the genus *Populus* (also Salicaceae) (Webb et al. 1988). The ease of vegetative propagation and the rapid growth of most *Salix* species have resulted in their widespread distribution (Webb et al. 1988). Because willows are dioecious (i.e. male and female flowers are on separate plants), many species introduced to New Zealand are represented by only a single sex. Reproduction in these cases is vegetative, although sexual reproduction sometimes occurs between males of one species and females of another.

Salix cinerea, a sallow or shrub willow, originates from Europe, western Asia, and northern Africa (Roy et al. 1998) and is now found in Southern Hemisphere countries including New Zealand and Australia. It was first introduced to New Zealand in the early period of European settlement, and first recorded as naturalised in 1925 (Webb et al. 1988). Both subspecies, *cinerea* and, to a much lesser extent, *oleifolia*, are found in swamps, riverbanks, and other wet areas. Both sexes occur in New Zealand, and reproduction is almost exclusively by seed that is capable of very wide dispersal (Ladson et al. 1997; ARMCANZ et al. 2000). *S. cinerea* is generally regarded as an invasive weed, particularly in protected natural areas. For example, seven of 13 Department of Conservation (DOC) conservancies regard it as one of the top 10 environmental weeds in their conservancy (Froude 2002). The prolific production of light wind-dispersed seed is probably an important factor in the invasiveness of this species.

Naturalised hybrids in New Zealand include *S. cinerea*: *S.* × *reichardtii* (*S. caprea* and *S. cinerea*) and *S.* × *calodendron* (*S. caprea* and *S. cinerea*, and *S. viminalis*) (Van Kraayenord et al. 1995). Although it is relatively easy to produce willow hybrids artificially (Thompson & Reeves 1994), natural hybridisation probably does not occur frequently in the native ranges of willows (Thompson & Reeves 1994; Van Kraayenord et al. 1995). The situation in New Zealand may be more complex because species, often originating from different geographic regions, have been brought into contact in new environments where barriers to hybridisation, such as differing flowering times, may be broken. This has been the case in Australia, where introduced willows have been described as 'especially promiscuous', and a number of streams have become dominated by swarms of varied hybrids of unknown parentage (Cremer 1999).

Introduced willow species are also spreading in countries other than New Zealand, including Australia, South Africa and Canada (Cremer 1999). Concern in Australia has been sufficient for most willow species, including *S. cinerea*, to be declared Weeds of National Significance (Thorp & Lynch 2000).

1.2 OBJECTIVES

To gather information from various sources (literature, reports, personal communications) to identify how important willow species are in New Zealand, and how much damage to other willow species by introduced biological agents might be tolerated.

To carry out a literature/web search to determine which insects and diseases attack *Salix cinerea* (grey willow) and what is known about the host range of any potential control agents.

To assess the likelihood of success of a biological control programme for *S. cinerea* in New Zealand.

2. Methods

Information for this report was obtained by searching computer databases (*CAB Abstracts, Current Contents*) and Internet sites for information on *S. cinerea* and other *Salix* species, and on pests and pathogens of *Salix* species; and personal communication with: Mike Adye, Hawkes Bay Regional Council; Jo Berry, Landcare Research, Auckland; Stan Braaksma, Wellington Regional Council; Seona Casonato, Landcare Research, Auckland; John Charles, HortResearch, Auckland; Tony Dunlop, Environment Bay of Plenty; Simon Fowler, Landcare Research, Lincoln; Lindsay Fung, HortResearch, Palmerston North; Alison Gianotti, Landcare Research, Auckland; Graham Hanson, Hawkes

Bay Regional Council; Sarah Hurst, HortResearch, Palmerston North; Nicholas Martin, Crop and Food Research Auckland; Colin Meurk, Landcare Research, Lincoln; Quentin Paynter, Landcare Research, Auckland; Chris Phillips, Landcare Research, Lincoln; Jean-Louis Sagliocco, Keith Turnbull Research Institute, Australia; Adrian Spiers, Palmerston North; Margaret Stanley, Landcare Research, Auckland; Pauline Syrett, Christchurch; Tony Thompson, Auckland Regional Council; and Nick Waipara, Landcare Research, Auckland.

3. Results

3.1 IMPORTANCE OF WILLOW SPECIES IN NEW ZEALAND

Although willows, particularly *S. cinerea* and *S. fragilis* (crack willow), are among New Zealand's weediest species, a number of species and varieties are seen as desirable by various groups. Willows have been used extensively for riverbank protection and soil stabilisation since their introduction into New Zealand (van Kraayenoord et al. 1995). They are also used in shelterbelts, and species such as *S. babylonica* (weeping willow), have aesthetic value. For these reasons, it is important that biological control agents that could damage grey willow should not draw opposition from those who use other willow species.

Willows are still used widely for riverbank protection and soil stabilisation throughout New Zealand, and are promoted for specific purposes in fact sheets, pamphlets and web pages produced by Regional Councils and HortResearch (e.g. A practical guide for the establishment and care of willows, Auckland Regional Council, March 2000; Environment Canterbury InfoSheet 7: tunnel gully erosion control, http://www.ecan.govt.nz/land/rc-infosheets.html; http://www.hortresearch.co.nz/products/poplar/). Different regions rely on willows to varying degrees, and for some situations alternatives to willows are being used or considered. Auckland Regional Council, for example, tends not to promote the use of willows except as a short- to medium-term tool to deal with acute erosion. For river-bank control, poplars are planted further up banks, while stock exclusion and native plantings are used for the riparian areas (T. Thompson, pers. comm.). The River Managers' Group is encouraging river engineers to look at alternatives to willows, including native species, especially where river systems are less aggressive (Stanley 2002; S. Braaksma, pers. comm.). However, it was emphasised that there are absolutely no alternatives to willows currently available that can give the required level of flood protection in aggressive systems such as the gravel systems in Canterbury (C. Phillips, pers. comm.; S. Braaksma, pers. comm.). An additional consideration is the cost of replacing existing willows. The Wellington Region willow asset was valued at $9.2 million in 2000, based on re-establishment in willows. Costs of replacement would be considerably higher should alternative species be used (S. Braaksma, pers. comm.).

The main willow species used currently in hill country and river engineering are tree species, in particular clones of *S. matsudana* and hybrids of *S. matsudana* × *alba*, such as 'Tangoio' and 'Moutere' (L. Fung, pers. comm.). Although it is not supplied by breeders (L. Fung, pers. comm.), there is still reliance on the existing plants of *S. fragilis* in certain situations (T. Dunlop, pers. comm.; S. Braaksma, pers. comm.). Although regional councils mostly use tree willow species, shrub willow species also have their uses, for example, in transition zones, but the planting of these is infrequent in comparison with *S. matsudana*. One regional council is now planting more shrub species and varieties (e.g. *S. viminalis* "Gigantea", *S. schwerinii* "Kinuyanagi", *S. aegyptiaca*) as they seem to be more resistant to the introduced sawfly (*Nematus oligospilus*), although the shrub species do not necessarily provide all the functions of the tree species (G. Hanson, pers. comm.).

3.2 ACCEPTABILITY OF BIOLOGICAL CONTROL OF *S. cinerea*

S. cinerea was not used by any of the regions consulted, and no concerns were expressed by managers regarding it as a target for biological control. For one manager, the biggest concern of such a programme was any impact on crosses or hybrids that contain *S. cinerea* (e.g. *S.* × *reichardtii*) (T. Dunlop, pers. comm.). However, another manager's opinion was that any biocontrol agent that attacked only *S. cinerea* or hybrids containing *S. cinerea* (e.g. *S* × *reichardtii*) would have minimal impact (S. Braaksma, pers. comm.). Concerns were raised about the potential host range of agents introduced for biological control of *S. cinerea*. The self-introduced willow sawfly (*N. oligospilus*) damages many different willow species, as well as poplars, in New Zealand, with the host range being wider than was first anticipated. As a result, current users may not accept any level of damage to species other than *S. cinerea*. The exception to this would be the use of seed feeders, as damage to seed would not impact on existing plants. A reduction in seed production in non-target willow species could even be regarded as a bonus (L. Fung, pers. comm.).

These outcomes are consistent with suggestions in a report by Syrett (2002) that an agent specific to *S. cinerea* might be acceptable, as might a seed-feeding agent with a wider host-range encompassing other *Salix* species.

3.3 FEASIBILITY STUDY ON BIOLOGICAL CONTROL OF WILLOWS IN AUSTRALIA

Willows have been declared Weeds of National Significance in Australia (Thorp & Lynch 2000), and a National Willow Strategic Plan has been developed for their management (ARMCANZ et al. 2000). In 2001, researchers at the Keith Turnbull Research Institute (Melbourne) prepared a feasibility study for biological control of six weedy willow species. Because aspects of the study are commercially sensitive, the Institute was unwilling to provide a copy of the report for this study. However, general information about the report's findings was available through a published executive summary, a conference paper (Sagliocco & Bruzzese 2002), and personal communication with one of the authors (J.L. Sagliocco).

The report was based on a literature review of the six most invasive *Salix* taxa (*S. cinerea*, *S. alba* var. *vitellina*, *S. fragilis* var. *fragilis*, *S. rubens*, *S. nigra*, and *S. viminalis*) using electronic databases, and flora and fauna publications. Organisms that attacked the three most desirable taxa (*S. babylonica*, *S. × calodendron*, and *S. × reichardtii*) were excluded from the results. The review identified a large flora of willow-specific pathogens already present in Australia, but revealed a lack of knowledge on willow-specific arthropod fauna there. A large number (337) of insects and mites and additional fungal pathogens that have potential as candidate biocontrol agents were identified in the native range of willows (Appendix 1). These include fungi, nematodes, mites, Homoptera, Thysanoptera, Coleoptera, Diptera, Lepidoptera, and Hymenoptera. The number of known promising biological control agents is high. The report recommended that surveys be undertaken overseas and that several natural enemies be selected for further investigation. Additional studies to determine host range and impact of the three *Melampsora* rust fungi already recorded on willows in Australia were recommended to clarify whether additional species or pathotypes should be introduced.

The situation in Australia differs from that in New Zealand in that six species of willow in that country are regarded as particularly invasive weeds that require control, and only three willow species (*S. babylonica*, *S. × calodendron*, and *S. × reichardtii*) are seen as desirable taxa. Thus the host ranges of biological control agents introduced into Australia may be much broader than for those that might be introduced into New Zealand. Only a small proportion of the potential agents identified by Australia are likely to be suitable for controlling *S. cinerea* in New Zealand and host-range testing requirements for candidate agents will be different for each country. The fact that some of the weedy *Salix* taxa in Australia originated in North America whereas others originated in Eurasia, means a large area of the Northern Hemisphere needs to be searched for effective natural enemies.

3.4 POTENTIAL AGENTS FOR CONTROL OF *S. cinerea*

3.4.1 Invertebrates

In New Zealand, a number of invertebrates, mostly generalist species, have been recorded feeding on *Salix* species (see Appendix 2). Two specialised willow feeding species have established after accidental introduction. The willow gall sawfly *Pontania proxima* (Hymenoptera: Tenthredinidae), which produces galls on leaves of *Salix* species, has been present since before the 1930s (Muggeridge, J. 1931) but does not appear to be very damaging (Berry 1997). A more recently introduced sawfly *Nematus oligospilus* (Hymenoptera: Tenthredinidae) feeds on the leaves of many of the *Salix* species in New Zealand and is capable of defoliating and killing trees (Charles et al. 1999). This sawfly will also feed on *S. cinerea* (J. Charles, pers. comm.). While *S. cinerea* has not been systematically surveyed for invertebrate pests, its natural enemies appear to have little effect on the plant in New Zealand.

In Australia, the knowledge of willow-specific arthropod fauna is scanty (Sagliocco & Bruzzese 2002). Two exotic sawfly species have recently established (Naumann et al. 2002): *P. proxima* on *S. fragilis* in Tasmania and *Amauronematus viduatus* (Hymenoptera: Tenthredinidae) on *S. babylonica* in New South Wales. Two nematodes are present on *Salix* species in Australia (Sagliocco & Bruzzese 2002).

A very large invertebrate fauna feeds on willow species in their Northern Hemisphere native ranges. The literature is extensive, with searches of electronic databases (*Current Contents* and *CAB Abstracts*) producing over 1000 references to *Salix* species, although very few referred to *S. cinerea* (see Appendix 3). Most research has focused either on pests and diseases of species that are used for short-rotation coppice (SRC) in Europe (e.g. *Salix viminalis*), or on ecological studies of gall-forming and leaf-feeding insects found on various willow species in Europe and North America. Other references were host records for arthropods in various countries.

Although most of the references accessed from these searches did not reveal host ranges for the species investigated, it is clear that many herbivorous species on willows have a host range of more than one willow species (see Appendix 3). Host range may vary in different geographic regions according to availability of potential host species and phenology of both the invertebrates and plants in those locations. A narrow host range is critical to the success of a biological control programme for *S. cinerea* in New Zealand, and may need to encompass natural hybrids without damaging desirable hybrids and other species in the same genus present in New Zealand.

Leaf-feeding beetles (Chrysomelidae) are among the most damaging pests of SRC willows in the UK. For example, *Phratora* (= *Phyllodecta*) *vulgatissima* and *P. vitellinae* are capable of causing severe defoliation and reductions in biomass (Kelly & Curry 1991; Green et al. 2001). These two species, along with *Galerucella lineola*, are among the commonest pests of coppiced willows (Kendall & Wiltshire 1998). However, all three species feed on several species of *Salix* as well as other genera (Kolehmainen et al. 1995). These leaf-feeding beetles do not have an intimate association with their host plants, and cues to which they may respond (negatively or positively) can be common across groups of *Salix* species. For example, levels of phenolic (salicylate) glycosides can attract or deter different species (Denno et al. 1990; Kendall et al. 1996; Orians et al. 1997). Leaf-feeding beetles, therefore, may not show the required degree of specificity for controlling *S. cinerea* in New Zealand. All the species recorded from *S. cinerea* (Appendix 3) were recorded on other *Salix* species, with some showing very broad host ranges (e.g. *G. lineola* also on *Alnus* spp.; *Cryptocephallus exiguus* also on *Betula*).

Among species that do have intimate relationships with the host plant, such as gall-formers, it may be possible to find an appropriate level of host specificity for biological control of *S. cinerea*. *Salix* is second only to *Quercus* in the number of gall-formers it supports (Redfern & Askew 1992), and these include midges, sawflies, mites, and other groups. The Nematinae, a sub-family of Tenthredinidae (Hymenoptera), have been well studied in Europe and North

America. These sawflies induce galls on willows, and the 200 or so species have been divided into three genera (*Phyllocolpa*, *Pontania*, and *Euura*) depending on the type of gall they produce. Of these, the *Euura* species, which induce midrib, petiole, bud, and stem galls, are considered the most specialised and are generally species-specific (Smith 1970). Two species, *Euura gemmacinerae*, which galls flower buds of *S. cinereae* in central and northern Europe (Kopelke 2001), and *Euura* (*Euura*) *cinereae*, which galls stems of *S. cinerea* in central and northern Europe (Kopelke 1996, 2000, 2002), show some potential as biological control agents in New Zealand. In addition, some *Euura* species that have been regarded as polyphagous (such as the extremely polyphagous *E. mucronata*) may turn out to be complexes of cryptic host-associated sibling species (Nyman 2002). *E. mucronata* has been described as one of the commonest herbivores on *S. cinerea* (Price et al. 1987). The sibling species status of the bud gallers in the *E. mucronata* complex is unresolved, but Price et al. (1997) expected that two of the 'species' in their paper, one of which galls *S. cinerea*, would be diagnosed as separate species in the future. *E. atra*, a shoot-galling sawfly, has also been considered an extremely polyphagous species that attacks numerous species in the Salicaceae. However, host preference tests and allozyme studies have revealed four behaviourally different races, three of which exist sympatrically. Specialisation may have already led to the formation of two or three sibling species that are fully reproductively isolated (Roininen et al. 1993). One of the host plants in the study was *S. cinerea*. There is clearly potential for a very host-specific biocontrol agent to be found among the nematine gall-forming sawflies but careful testing and systematics input will be needed to determine host range. There is also great potential for gall-formers to be sufficiently damaging to control trees and shrubs. In South Africa, for example, three gall-forming agents, the gall wasps *Trichilogaster acaciaelongifoliae* and *Trichilogaster* sp. and a gall-forming rust fungus *Uromycladium tepperianum* are proving very effective agents for successful control of invasive *Acacia* species (Dennill 1990; Morris 1997; Hoffmann et al. 2002).

Other invertebrate groups recorded on *Salix* species may also show strong host specificity. These include the cecidomyid flies (*Dasineura* spp.) (e.g. Larsson & Ekbom 1995), the jumping plant-lice or psyllids (*Cacopsylla* spp.) (e.g. Hill & Hodkinson 1996), and eriophyid mites.

The Australian feasibility study identified species that will directly target the sexual reproduction of willows through damage to male and female flowers (Sagliocco & Bruzzese 2002). This tactic is suitable for New Zealand conditions, even if the host range is wider than the target plant, *S. cinerea*. A number of curculionid species that feed on *S. cinerea* have been described as catkin-living species (Cooter et al. 1991; Topp et al. 1992). Kopelke (1998) also described the bud-galling sawflies (*Euura* subgenus *Gemmura* Smith 1968) as never ovipositing onto vegetative buds but only into new flower buds (= catkins). For other *Salix* species, a number of jumping plant-lice or psyllids (*Cacopsylla* spp.) have been recorded primarily from catkins. Careful testing would be required for any species that targets the reproductive parts of *Salix* species other than *S. cinerea*, to ensure these are the only plant parts attacked in the environmental conditions encountered in New Zealand.

3.4.2 Pathogens

Because some species can exhibit a high degree of host specificity, pathogens can be very desirable biological control agents. To control *S. cinerea* in New Zealand, the challenge would be to find a pathogen that exhibits the appropriate level of specificity as well as the ability to damage. The pathogen must be effective across *S. cinerea* populations in New Zealand and also perhaps against any naturally occurring hybrids of *S. cinerea* that have invasive potential. If users of willow hybrids *S.* × *reichardtii* and *S.* × *calodendron* were to accept the possibility of damage to these two cultivars, the chance of finding effective pathogens would be much greater.

There are 216 records of plant diseases on *Salix* spp. in the New Zealand Fungi Database (http://www.landcareresearch.co.nz/databases); these include 76 different species names (Appendix 4). A number of records do not identify the species of *Salix* from which the accession was collected. All 15 accessions specifically recorded on *S. cinerea* were identified as the rust *Melampsora epitea*. This species was also recorded on *S. cinerea* × *viminalis*, and *S.* × *reichardtii* (a cross containing *S. cinerea*), as well as other species of *Salix*. Although many diseases affect willows in New Zealand, the impact of disease seems to be low (Van Kraayenord et al. 1995). The most important growth-limiting disease is the leaf rust caused by *Melampsora* species (Spiers & Hopcroft 1996).

In Australia, 51 fungal pathogens and one bacterium have been recorded on *Salix* species (Sagliocco & Bruzzese 2002). These include the willow rusts *M. epitea* and *M. coleosporioides*, the *Armillaria* root rot fungus, and willow anthracnose *Marssonina salicola* (Ladson et al. 1997; ARMCANZ et al. 2000). Although these pathogens seem to have little effect on willows in Australia (ARMCANZ et al. 2000), their impact on populations has not yet been determined (Sagliocco & Bruzzese 2002).

In the native range, a number of diseases have been recorded attacking *Salix* species. The Australian feasibility study noted 45 species of fungi recorded attacking *Salix* species in the Northern Hemisphere (Sagliocco & Bruzzese 2002), including leaf and stem spots, cankers, blights, powdery mildew, and several rust species. The willow leaf rusts (*Melampsora* spp.) have been well studied because they are very damaging to highly valued willow species such as *S. viminalis*, used for SRC (e.g. Pei et al. 2002). A search of the literature produced only four species recorded on *Salix cinerea* (Appendix 5), including the rust *M. larici-epitea* (e.g. Pei et al. 2002). This may reflect a lack of interest in diseases on *S. cinerea* compared with willows of economic importance. There is scope, therefore, to survey *S. cinerea* in its native range for more pathogens, including those that damage roots or reproductive parts (S. Casonato, pers. comm.).

The ability of the *Melampsora* rusts to devastate commercially grown willows indicates they could be very effective biological control agents. *M. epitea*, however, may not be a useful agent because strains already present in New Zealand do not appear to be very damaging to *S. cinerea* (A. Spiers, pers. comm.). Studies in the Northern Hemisphere indicate strains of *Melampsora* rusts can attack clones from more than one *Salix* species, although other clones from the same species may remain unaffected (e.g. Ramstedt 1999). Because *S.*

cinerea may have hybridised with other willows, much work may be required to find a *Melampsora* strain appropriately host specific and virulent for a biological control programme (A. Spiers, pers. comm.). One disadvantage of *M. epitea* is that it has alternate hosts. Other rust species in the native range, however, are known to have no alternate hosts (e.g. *Melampsora amygdalina* (Sagliocco & Bruzzese 2002)). Before exploring the option of importing additional rust species or virulent pathotypes, it would be advisable to undertake a comprehensive survey of fungal pathogens present on *S. cinerea* in New Zealand, with particular emphasis on *Melampsora* species, along with host range and impact assessments. Australian researchers have indicated an interest in *Melampsora* rusts (J.L. Sagliocco, pers. comm.) but stress they should be considered only after the taxonomic situation of those in Australia is clarified (Sagliocco & Bruzzese 2002).

Other fungal pathogens may be potential candidates for a biological control programme. As the anthracnose fungus, *Marssonina salicola*, is known to attack tree willows in New Zealand, the possibility of a specific *Marssonina* with limited host range is worth exploring (A. Spiers, pers. comm.). *Chondrostereum purpureum*, a wound pathogen present on willows in New Zealand, is currently being developed as a mycoherbicide for other New Zealand woody weeds (e.g. gorse *Ulex europaeus*) (N. Waipara, pers. comm.). If a mycoherbicide were deemed a useful addition to current methods of chemical control, with some extra funding *S. cinerea* could be added to this project.

Although pathogens can be highly specific, it may prove difficult to find one with the appropriate degree of specificity for local biological control of *S. cinerea*, given concerns about natural hybridisation and 'desirable' hybrids. Because rust species are typically wind-dispersed, any pathogens introduced to Australia have a good chance of dispersing to New Zealand, whether we want them or not. This has been the case with rusts in the past (Latch 1980; Spiers & Hopcroft 1996).

3.5 PROSPECTS OF SUCCESSFUL BIOLOGICAL CONTROL OF *S. cinerea*

S. cinerea does not appear to be suppressed by natural enemies in New Zealand, although an extensive number of invertebrates and diseases have been recorded from *Salix* species in the Northern Hemisphere. Some of these are highly damaging pests of commercially grown *Salix* species such as *S. viminalis*. This suggests the potential for introducing agents that would reduce the vigour and reproduction of *S. cinerea* in New Zealand is good. Many invertebrates may not show the required degree of specificity for controlling *S. cinerea* in New Zealand; however, *Salix* is host to a large number of gall-forming species. Gall-formers are known to often form close relationships with their host plants. Therefore it should be possible to find suitable host-specific biological control agents, and some of the nematine gall-forming sawflies (*Euura gemmacinerae* and *E. cinereae*) are reputedly monophagous on *S. cinerea*. An Australian study has identified species that will directly target the sexual reproduction of willows through attack on male and female flowers. This tactic has been identified as acceptable in New Zealand, even if the host range is wider than the target plant. Pathogens such as *Melampsora* and *Marssonina* species show some potential as biological control agents, although the status of the pathogens that already exist on *S. cinerea* in New Zealand would need to be assessed before significant work was undertaken. It is often only necessary to find one or a few effective host specific agents for a biocontrol programme to be successful, and because the natural distribution of *S. cinerea* is wide (Europe, western Asia and North Africa), the chances of doing so are increased.

The success of any programme for biological control of *S. cinerea* in New Zealand is potentially complicated by two related factors: hybridisation between *S. cinerea* and other *Salix* species in natural populations, and hybrids containing *S. cinerea* that are of interest to users of willows. The extent to which natural hybridisation occurs is unknown, but if hybrids have the potential to be as weedy as *S. cinerea* itself, a biological control agent would also need to be effective against these. If an agent is effective against the naturally occurring hybrids of *S. cinerea*, 'desirable' hybrids such as *S. × reichardtii* and *S. × calodendron* may also be damaged. This may not be a problem, as these hybrids do not seem to be widely used. In addition, there are probably other species that could replace these hybrids, and users who actively manage plants need to replace them every 15 years or so. If a biological control programme were implemented, there would be a number of years before the release of any agent, allowing users to replace plants over a period of time. *S. cinerea* is in a different subgenus of *Salix* from the tree willows; this enhances the prospects of finding species that do not attack the commercially valuable tree willow species.

Biological control of *S. cinerea* is likely to be a complicated project because very rigorous host testing will be required to ensure that potential agents are appropriately host-specific. This will also require collaboration with specialists for groups such as the nematine sawflies. The two gall-forming sawflies thought to be specific to *S. cinerea* have been collected from central and northern Europe, where studies have been carried out in recent years by a researcher in Frankfurt, Germany. This points to the possibility of CABI Bioscience, Switzerland, which already has strong links to other biological control programmes in New Zealand, conducting surveys in the native range and host-range tests. A biological control programme for the control of *Salix* species, including *S. cinerea*, is also likely to take place in Australia. There may be a possibility of collaboration between agencies from both countries, although the wider number of target species in Australia means host-range test requirements will be different for the two countries.

4. Conclusions and recommendations

There are a number of prospective biological control agents among the invertebrates and pathogens in the native range of *S. cinerea*. Compared with other biological control programmes in New Zealand, this is likely to be a complicated project because very rigorous host testing will be required to ensure that potential agents are appropriately host specific. However, this should be weighed against the extreme weediness of *S. cinerea*, particularly in vulnerable ecosystems. Therefore, it is recommended a biological control programme be initiated. Initial emphasis should be placed on the nematine gall-forming sawflies that have been identified as most likely monophagous on *S. cinerea*.

Based on previous biological control programmes and information provided in this report, it is recommended that the following actions be taken:

- Survey populations of *S. cinerea* in different seasons throughout its known range in New Zealand to determine which invertebrates and diseases are currently associated with this species here (likely cost $70,000–100,000 in total over 2 years).
- Survey *S. cinerea* at selected locations in the native range to identify prospective biological control agents, and conduct preliminary host-range tests with those gall-forming species that the literature suggests may be host-specific to *S. cinerea* (likely cost $50,000–100,000 per year over 2 years).
- Develop communication with Australian researchers on their progress towards biological control of *Salix* spp. in Australia and explore the possibility of collaboration (likely cost $1,000–5,000).
- On completion of surveys, review prospects for successful biological control of *S. cinerea* and, if appropriate, prepare a costed programme for consideration (likely cost $10,000–15,000).

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Appendix 1

Key groups of insects recorded feeding on Salix spp.

The following table was taken from Sagliocco & Bruzzese's (2002) literature search concentrating on the six most invasive *Salix* taxa using electronic databases and flora and fauna reference works. Several thousand references were examined and organisms already recorded attacking the three desirable *Salix* taxa (*S. babylonica*, *S.* × *calodendron* and *S.* × *reichardtii*) were excluded from the results.

ORGANISMS, BY ORDER AND FAMILY, RECORDED IN THE REGIONS OF ORIGIN OF *SALIX* SPP.

ORGANISMS	NO. OF SPECIES	REGION OF ORIGIN	PLANT ASSOCIATION
Fungi	45	E, A, NA	l, st, sh
Nematodes	1	E	r
Acari			
Eriophyidae	36	E, NA	l, b, c
Tetranychidae	3	NA, A	u
Homoptera			
Cicadellidae	14	E, NA, EA	l
Deltocephalidae	1	J	l
Triozidae	28	E, EA, NA	l
Psyllidae	35	EA	l, c
Aleyrodidae	2	E, fUSSR	l
Aphididae	30	E, NA, A	l, t, w
Coccoidae	2	fUSSR, C	l
Thysanoptera			
Thripidae	4	EA	l
Coleoptera			
Chrysomelidae	2	E	l
Curculionidae	1	E	c
Diptera			
Cecidomyiidae	36	E, NA	b, st
Lepidoptera			
Gracillariidae	6	E	l
Nepticulidae	5	E	l
Sesiidae	3	E, P	st
Noctuidae	4	E, EA	sh, l, c
Notodontidae	1	EA	l
Hymenoptera			
Tenthredinidae	78	E, EA, NA	l
Total	337		

A = Asia, E = Europe, EA = Eurasia, fUSSR = former USSR, J = Japan, NA = North America, b = buds, c = catkins, l = leaves, r = roots, sh = shoots, st = stems, t = trunk, tw = twigs, u = unknown.

Appendix 2

Insect herbivores recorded from *Salix* spp. in New Zealand

A. *Nematus oligospilus* Förster (Hymenoptera: Tenthredinidae): many *Salix* species, including tree and shrub willows (Berry 1997; Charles et al. 1999).

B. Data from Spiller & Wise (1982):

WILLOW SPECIES	INSECT SPECIES	INSECT FAMILY	REFERENCE
Salix spp.	*Cavariella aegopodii* (Scop.)	Homoptera	Cottier 1935
	Costelytra zealandica (White) (as *Odontria zealandica*)	Coleoptera	Hilgendorf 1924
	Eriococcus coriaceus Mask.	Homoptera	Miller 1935
	Icerya purchasi Mask.	Homoptera	Miller 1925
	Lepidosaphes ulmi (L.)	Homoptera	Miller 1935
	Liothula omnivora Fered.	Lepidoptera	Fereday 1878
	Planotortrix excessana (Walk.) (as *Tortrix excessana*)	Lepidoptera	Wise 1956
	Pontania proxima (Lep.)	Hymenoptera	Muggeridge 1931
	Pseudococcus obscurus Essig (as *P. maritimus*)	Homoptera	Miller 1935
	Quadraspidiotus perniciosus (Comst.) (as *Aspidotus perniciosus*)	Homoptera	Miller 1935
S. alba L. white willow	*Liothula omnivora* Fered.	Lepidoptera	Smith 1898
S. babylonica L. weeping willow	*Aenetus virescens* (Dbld.) (as *Hepialus virescens*)	Lepidoptera	Hudson 1928
	Cavariella aegopodii (Scop.)	Homoptera	Cottier 1953
	Hemiberlesia rapax (Comst.) (as *Aspidiotus camelliae*)	Homoptera	Maskell 1885
	Liothula omnivora Fered. (as *Oeceticus omnivora*)	Lepidoptera	Hudson 1928
	Pontania proxima (Lep.)	Hymenoptera	Lamb 1960
S. caprea L. goat willow	*Liothula omnivora* Fered.	Lepidoptera	Smith 1898
	Oemona hirta (F.)	Coleoptera	Miller 1925
S. fragilis L. crack willow	*Aenetus virescens* (Dbld.) (as *Charagia virescens*)	Lepidoptera	Hudson 1928
	Liothula omnivora Fered. (as *Oeceticus omnivora*)	Lepidoptera	Hudson 1928

Appendix 3

Insect species recorded on *S. cinerea*

(CAB Abstracts 1992–2003)

ORDER/FAMILY/SPECIES	OTHER HOSTS	REFERENCE	COMMENTS
Hymenoptera			
Tenthredinidae			
Nematus pavidus	*S. caprea* is most common host; also found on *S. alba*, *S. aurita*, *S. cinerea*, *S. nigricans*	Roininen & Tahvanainen 1989	Generalist
Phyllocolpa leucosticta		Askew & Kopelke 1989	Forms marginal leaf-roll
Phyllocolpa leucapsis		Kopelke & Amendt 2002	Leaf-fold gall
Pontania bridgmanii	*S. atrocinerea*, *S. aurita*, *S. caprea*, *S. phylicifolia*	Weiffenbach 1989; Redfern & Askew 1992; Askew 1995	
Pontania pedunculi	Mainly *S. aurita*, sometimes *S. caprea* and *S. cinerea*, *S. caprea-starkeana* hybrid complex	Kopelke 1990; Redfern & Askew 1992; Askew 1995; Kokkonen 2000; Kopelke & Amendt 2002	Leaf gall
Pontania proxima	*S. alba*, S. *fragilis*, *S. fragilis* × *alba* hybrid, *S. triandra*	Naumann et al. 2002	Bean shaped galls on leaves of various willow spp.
Euura mucronata	On many *Salix* spp.	Price et al. 1987; Redfern & Askew 1992	Bud-galling sawfly (= *E.saliceti*, Redfern & Askew 1992)
Euura gemmacinereae		Kopelke 2001	Flower bud gall; mid, north Europe
Euura atra	*S. alba*, *S. aurita*, other *Salix* spp.	Redfern & Askew 1992; Roininen et al. 1993	
Euura (Euura) cinereae		Kopelke 1996, 2000, 2002	Stem gall; middle, north Europe
Euura venusta	*S. aurita*, *S. caprea*	Askew 1995; Redfern & Askew 1992	
Monophadnoides [*Blennocampa*] spp.	also *S. atrocinerea* and *S. caprea*	Liston 1994	Adult grazing on leaf pubescence only, not larval
Monophadnus pallescens	Also *S. atrocinerea* and *S. caprea*	Liston 1994	Adult grazing on leaf pubescence only, not larval
Empria spp	also *S. atrocinerea* and *S. caprea*	Liston 1994	Adult grazing on leaf pubescence only, not larval
Dolerus spp.	also *S. atrocinerea* and *S. caprea*)	Liston 1994	Adult grazing on leaf pubescence only, not larval
Loderus vestigialis	also *S. atrocinerea* and *S. caprea*	Liston 1994	Adult grazing on leaf pubescence only, not larval
Diptera			
Cecidomyiidae			
Rhabdophaga heterobia	*S. aurita*, *S. triandra*, *S. viminalis*	Redfern & Askew 1992	
Rhabdophaga salicis	*S. aurita*, *S. caprea*	Redfern & Askew 1992	Including subspecies *oleifolia*
Rhabdophaga rosariella	*S. aurita*	Redfern & Askew 1992	

ORDER/FAMILY/SPECIES	OTHER HOSTS	REFERENCE	COMMENTS
Diptera			
Cecidomyiidae			
Rhabdophaga clavifex	*S. aurita*, *S. caprea*	Redfern & Askew 1992	
Rhabdophaga nervorum (= *noduli*)	*S. aurita*, *S. caprea*	Redfern & Askew 1992	
Helicomya pierrei		Redfern & Askew 1992	
Iteomyia major	*S. aurita*, rarely on *S. caprea*	Redfern & Askew 1992	
Iteomyia capreae	*S. appendiculata*, *S. aurita; S. caprea*, *S. caprea* × *appendiculata*	Redfern & Askew 1992; Kopelke & Amendt 2002	
Agromyzidae			
Hexomyza (*Melanagromyza*) *simplicoides*	*S. aurita*, *S. caprea*	Redfern & Askew 1992	
Coleoptera			
Chrysomelidae			
Plagiodera versicolora	*S. alba*, *S. fragilis*, *S. purpurea*, narrow-leaved species of *Salix*	Cooter 1991; Topp et al. 2002	Phyllophagous species
Lochmaea capreae	*S. alba*, *S. caprea*, *S. purpurea*; *Salix* spp., particularly *S. aurita*, *S. caprea*, *S. lapponum*	Dodge et al. 1990; Cooter 1991; Topp et al. 2002	Phyllophagous species
Galerucella lineola	*S. alba*, *S. caprea*, *S. fragilis*, *S. pentandra*, *S. purpurea*, *S. triandra*; *Salix* spp., particularly *S. viminalis; S. nigricans; Alnus* spp.	Denno et al. 1990; Cooter 1991; Kendall et al. 1996; Bjorkman et al. 2000; Topp et al. 2002	Phyllophagous species; generalist
Phyllodecta vulgatissima [*Phratora vulgatissima*]	*S. caprea*; *Salix* spp., *Populus* spp.; *S. aurita*, *S. caprea*, *S. viminalis*	Cooter 1991; Koch 1992; Kendall et al. 1996; Topp et al. 2002	Phyllophagous species
Phratora vitellinae	*S. alba*, *S. caprea*, *S. fragilis*, *S. pentandra*, *S. purpurea*; *Populus* spp., *Salix* spp., *S. myrsinifolia*	Cooter 1991; Rank et al. 1998; Topp et al. 2002	Phyllophagous species
Phratora polaris	Dwarf mountain species of *Salix*	Cooter 1991; Ikonen et al. 2001	Phyllophagous species
Gonioctena interpositus	*S. caprea*, *S. pentandra*	Topp et al. 2002	Phyllophagous species
Luperus flavipes	*S. caprea*; *Salix* spp.	Cooter 1991; Topp et al. 2002	Phyllophagous species; generalist
Luperus xanthopoda	*S. caprea*, *S. purpurea*	Topp et al. 2002	Phyllophagous species; generalist
Cryptocephalus octopunctatus	*S. alba*, *S. caprea*, *S. fragilis*, *S. triandra*	Topp et al. 2002	Rhizophagous species; generalist
Cryptocephalus pusillus	*Salix* spp. (especially *S. aurita*, *S. caprea*, *S. cinerea*), *Alnus*, *Populus*	Koch 1992	Polyphagous species
Cryptocephalus exiguus	*Salix* spp., *Betula*	Cooter 1991; Koch 1992	Generalist species
Cryptocephalus decemmaculatus		Topp et al. 2002	Rhizophagous species
Smaragdina cyanea	*S. caprea*, *S. purpurea*	Topp et al. 2002	Rhizophagous species; generalist
Smaragdina affinis	*S. caprea*	Topp et al. 2002	Rhizophagous species; generalist
Crepidodera aurata [= *Chalcoides*?]	*S. alba*, *S. caprea*, *S. fragilis*, *S. purpurea*, *S. pentandra*, *S. triandra*; [*Salix* spp., *Populus* spp.]	Topp et al. 2002; [Cooter 1991]	Rhizophagous species
Crepidodera aurea [= *Chalcoides*?]	*S. alba*, *S. caprea*, *S. fragilis*, *S. pentandra*; [*Salix* spp., *Populus* spp.]	Topp et al 2002; [Cooter 1991]	Rhizophagous species
Crepidodera fulvicornis [= *Chalcoides*?]	[*Salix* spp., *Populus* spp.]	Topp et al. 2002; [Cooter 1991]	Rhizophagous species
Clytra laeviuscula	*S. alba*, *S. triandra*	Topp et al. 2002	Rhizophagous species; generalist

ORDER/FAMILY/SPECIES	OTHER HOSTS	REFERENCE	COMMENTS
Coleoptera			
Chrysomelidae			
Phytodecta flavicornis		Koch 1992	Monophagous; montain not alpine; phyllophagous species
Phytodecta viminalis	*S. appendiculata*, S. *aurita*, *S. caprea*; *Salix* spp.	Cooter 1991; Koch 1992	Phyllophagous species
Phytodecta pallidus	*Alnus* spp.	Koch 1992	Polyphagous species
Curculionidae			
Phyllobius oblongus	*S. alba*, *S. caprea*, *S. fragilis*, *S. purpurea*, *S. triandra*	Topp et al. 2002	Rhizophagous species; generalist
Phyllobius maculicornis	*S. alba*, *S. caprea*, *S. fragilis*, *S. purpurea*, *S. triandra*	Topp et al. 2002	Rhizophagous species; generalist
Phyllobius pyri	*S. alba*, *S. caprea*, *S. fragilis*, *S. purpurea*, *S. triandra*	Topp et al. 2002	Rhizophagous species; generalist
Rhamphus pulicarius	*S. alba*, *S. caprea*, *S. fragilis*, *S. pentandra*, *S. purpurea*; *Salix* spp.	Cooter 1991; Topp et al. 2002	Leaf-mining species; generalist
Rhynchaenus stigma	*S. caprea*, *S. purpurea*; *Salix* spp.	Topp et al. 2002	Leaf-mining species; generalist
Rhynchaenus populi	*S. caprea*, *S. pentandra*, *S. purpurea*, *S. triandra*; *Salix* spp., *Populus* spp.	Cooter 1991; Topp et al. 2002	Leaf-mining species
Rhynchaenus salicis	*S. caprea*; *Salix* spp.	Cooter 1991; Topp et al. 2002	Leaf-mining species
Rhynchaenus decoratus	*S. fragilis*, *S. pentandra*, *S. purpurea*	Cooter 1991; Topp et al. 2002	Leaf-mining species
Rhynchaenus pseudostigma	*S. pentandra*, *S. purpurea*	Topp et al. 2002	Leaf-mining species; generalist
Acalyptus carpini	*S. fragilis*, S. *pentandra*, *S. purpurea*; *Salix* spp.	Cooter 1991; Topp et al. 2002	Catkin-living species
Acalyptus sericeus		Topp et al. 2002	Catkin-living species
Ellescus bipunctatus	*S. purpurea*, *S. caprea*; *Salix* spp.	Cooter 1991; Topp et al. 2002	Catkin-living species
Dorytomus taeniatus	*S. alba*, *S. caprea*, *S. fragilis*, *S. purpurea*; *Salix* spp., *Populus* spp.	Cooter 1991; Topp et al. 2002	Catkin-living species
Dorytomus melanocephalus	*S. alba*, *S. caprea*, *S. fragilis*, *S. pentandra*, *S. purpurea*, *S. triandra*	Topp et al. 2002	Catkin-living species
Dorytomus salicinus	*S. aurita*, *S. caprea*	Cooter 1991	
Dorytomus occalescens	*S. aurita*, *S. elaeagnos*, *S. fragilis*	Koch 1992	
Dorytomus salicis	*S. alba*, *S. aurita*, *S. caprea*, *S. repens*	Cooter 1991; Koch 1992	
Dorytomus salicinus	*S. aurita*, *S. caprea*, *S. purpurea*	Cooter 1991; Koch 1992	
Dorytomus majalis	*S. aurita*, *S. caprea*, *S. nigricans*, *S. pentandra*, *S. purpurea*, *S. rubens*; *Salix* spp.	Cooter 1991; Koch 1992	
Dorytomus dorsalis	*S. aurita*, *S. caprea*, *S. repens*	Koch 1992	
Dorytomus rufatus	*S. aurita*, *S. caprea*; *Salix* spp.	Cooter 1991; Koch 1992	
Curculio crux	*S. alba*, *S. caprea*, *S. fragilis*, *S. purpurea*, *S. pentandra*, *S. triandra*	Topp et al. 2002	Gall-living species
Curculio salicivorus	*S. alba*, *S. caprea*, *S. fragilis*, *S. purpurea*, *S. triandra*; *Salix* spp.	Cooter 1991; Topp et al. 2002	Gall-living species
Melanapion minimum	*S. alba*, *S. caprea*, *S. fragilis*, *S. purpurea*, *S. pentandra*, *S. triandra*	Topp et al. 2002	Gall-living species
Apion minimum	*S. alba*, *S. aurita*, *S. caprea*, *S. repens*, *S. viminalis*	Koch 1992	Gall-living species
Scarabaeidae			
Phyllopertha horticola	*S. capreae*, *S. fragilis*, *S. pentandra*	Topp et al. 2002	Rhizophagous species; generalist
Melolontha melolontha	*S. fragilis*	Topp et al. 2002	Rhizophagous species; generalist

ORDER/FAMILY/SPECIES	OTHER HOSTS	REFERENCE	COMMENTS
Coleoptera			
Buprestidae			
Trachys minutus	*S. alba*, *S. caprea*; *Salix* spp.	Cooter 1991; Topp et al. 2002	Leaf-mining species; generalist
Agrilus viridus	*S. caprea*; *Salix* spp., *Quercus* spp.	Cooter 1991; Topp et al. 2002	Xylophagous species; generalist
Agrilus subauratus	*S. purpurea*	Topp et al. 2002	Xylophagous species
Attelabidae			
Coenorhinus pauxillus	*S. alba*	Topp et al. 2002	Generalist species
Rhynchites caeruleus	*Salix* spp., *Populus tremula*	Cooter 1991; Topp et al. 2002	Generalist species
Cerambycidae			
Tetrops praeusta	*S. alba*, *S. caprea*, *S. purpurea*, *Prunus Rosa, Ulmus*, other genera	Koch 1992; Topp et al. 2002	Xylophagous species; generalist
Oberea oculata	*Salix* spp., *S. caprea*, *S. pentandra*, *S. triandra*, *S. viminalis*	Cooter 1991 Koch 1992; Jorum & Pedersen 1995	(= major hosts?)
Lamia textor	*S. caprea*, *S. repens*, *Salix* and *Populus* spp.	Koch 1992	
?			
Pselaphorhynchus longiceps	*S. purpurea*	Topp et al. 2002	Generalist
Pselaphorhynchus tomentosus	*S. alba*, *S. caprea*, *S. purpurea*, *S. triandra*	Topp et al. 2002	
Lepidoptera			
Gracillariidae			
Phyllonorycter salicicolella	*S. caprea*	West et al. 1996, 2001	Leaf miners (Silwood UK)
Sphingidae			
Smerinthus ocellatus	*Salix* spp., *Populus* spp.	Carter & Hargreaves 1986; Thomas & Hodkinson 1991	Generalist species
Notodontidae			
Phalera bucephala	sallow	Carter & Hargreaves 1986; Thomas & Hodkinson 1991	Generalist species
Saturniidae			
Saturnia pavonia	sallow	Carter & Hargreaves 1986; Alliende 1989	Larvae on leaves; generalist species
Lymantriidae			
Leucoma salicis		Wistow 1992	
Nymphalidae			
Apatura iris	*S. caprea* (Britain), also other *Salix* spp. in Europe	Carter & Hargreaves 1986	Europe
Geometridae			
Eulithis populata	*S. caprea*, other *Salix* spp. in captivity	Carter & Hargreaves 1986	Europe; generalist species
Semiothisa notata	*S. pendula*	Carter & Hargreaves 1986	Central and northern Europe; generalist
Abraxas glossuariata		Alliende 1989	Larvae on leaves
Noctuidae			
Xanthia icteritia	*S. caprea*	Carter & Hargreaves 1986	Europe; generalist species
Tortricidae			
Cydia (*Grapholita*) *servillana*	*S. caprea*	Redfern & Askew 1992; Emmet 1998	Galls; eggs laid singly on bud, larvae in gall on one-year-old twig
Epinotia cruciana	*Salix* species, especially, *S. cinerea*, *S. repens* or *S. aurita*	Emmet 1998	Larvae in unopened leaf-bud, or in spun leaves, especially those of a terminal shoot

ORDER/FAMILY/SPECIES	OTHER HOSTS	REFERENCE	COMMENTS
Lepidoptera			
Tortricidae			
Epinotia crenana	*S. aurita*, possibly other *Salix* species	Emmet 1998	Larvae in a spun terminal shoot
Nepticulidae			
Stigmella salicis	*S. aurita*, *S. caprea*	Emmet 1998	Underside of a leaf of one of rough-leaved *Salix* species
Yponomeutidae			
Argyresthia pygmaella	*S. caprea*	Emmet 1998	Larvae in a shoot or catkins
Yponomeuta rorella	*S. alba*; occasionally *S. cinerea*	Emmet 1998	Larvae on leaves, in a web, gregarious
Coleophoridae			
Coleophora viminetella	*Salix*, mainly *S. aurita*, *S. caprea*, *S. cinerea*, *S. repens*	Emmet 1998	Larvae mine leaves; generalist species
Coleophora albidella	*S. aurita*, *S. caprea*	Emmet 1998	Larvae burrow into expanding buds and then skeletonise leaves
Acari			
Eriophyidae			
Aculops tenatothrix	*S. alba*, *S. fragilis*, *S. purpurea*, locally common on *S. aurita*, *S. caprea*, *S. cinerea*	Redfern & Askew 1992	Galls?
Phytoptus iteinus	*S. aurita*, *S. caprea*	Redfern & Askew 1992	Galls?
Homoptera			
Psyllidae (Psyllids, jumping plant-lice)			
Bactericera curvatinervis	*S. alba*, *S. aurita*, *S. caprea*, *S. purpurea*, *S. repens*, *S. viminalis*	Burkhardt & Lauterer 1997	Widespread distribution; adults overwinter on conifers

Appendix 4

Plant diseases recorded on *Salix* spp. in New Zealand

Data from NZ Fungi Database (http://www.landcareresearch.co.nz/databases)

There are 216 records of plant diseases on *Salix* spp. in the New Zealand Fungi Database. These include 76 different species names (listed below). Fifteen accessions were specifically recorded on *S. cinerea*; all were identified as *Melampsora epitea.* The same species was also recorded on *S cinerea* × *viminalis*, and *S. reichardtii* (pussy willow), a cross that contains *S. cinerea*.

Agrocybe parasitica
Armillaria limonea
Armillaria novaezelandiae
Auriculariopsis ampla
Bisporella citrina
Bjerkandera adusta
Calonectria kyotensis
Chondrostereum purpureum
Colletotrichum acutatum
Corticium porosum
Coryneum salicis
Crepidotus
Cryptodiaporthe salicina
Cytospora
Daldinia concentrica
Diatrype bullata
Diplodia salicina
Discula brenckleana
Ductifera sucina
Exidia glandulosa
Favolaschia calocera
Fomitopsis nivosa
Fusicoccum lutem
Ganoderma australe
Gloeoporus thelephoroides
Glomerella miyabeana
Gloniopsis praelonga
Hyaloceras saccardoi
Hypomyces aurantius
Hypoxylon perforatum
Irpex brevis
Irpex zonatus
Kabatiella borealis
Laccaria tetraspora f. *tetraspora*
Lachnella furcata
Lopharia crassa
Lopharia cinerascens
Macrophoma salicaria
Marssonina salicicola
Melampsora coleosporioides
Melampsora epitea
Melanconium atrum
Melanomma cinereum
Merulius corium
Metasphaeria orthospora
Nectria ochroleuca
Nectria calami
Odontia arguta
Odontia lutea
Paxillus involutus
Pellicularia scabrida
Peniophora sambuci
Pestalotiopsis funerea
Pezicula alba
Phellinus gilvus
Pholiota
Phoma
Pseudospiropes simplex
Rigidoporus vinctus
Rosellinia novaezelandiae
Schizophyllum commune
Sphaceloma murrayae
Spirosphaera floriformis
Spirosphaera floriformis
Steccherinum ochraceum
Stictis radiata
Trametes zonata
Trametes versicolor
Trametes velutina
Tremella lutescens
Trichoderma
Tuber levissimum
Tyromyces tephroleucus
Valsa sordida
Venturia chlorospora
Xerocomus rubellus

Appendix 5

Diseases recorded on *S. cinerea*

(CAB Abstracts 1990–2003)

Melampsora larici-epitea (e.g. Pei et al. 2002)
Erwinia salicis (Patrick 1990)
Melasmia salicina (*Rhytisma salicinum*) (Abseitova 1993)
Botryosphaeria ribis black stem-rotting disease (Thakur 1995)