DEPARTMENT OF
PRIMARY INDUSTRIES

Willow Sawfly (*Nematus oligospilus*) in Victoria

Status Report, July 2006

Victoria
The Place To Be

Willow Sawfly (*Nematus oligospilus*) in Victoria: Status Report, July 2006

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Disclaimer

Executive Summary

The recent arrival of willow sawfly, *Nematus oligospilus*, in Australia is of concern to river managers as this insect has the potential to significantly impact on willow management and on riparian management activities. Analysis of the literature relating to this species, the experience of New Zealand river managers and scientists with willow sawfly, and the current distribution of willow sawfly in Australia is presented in this report. The key findings are as follows:

Willow Sawfly Development:

- willow sawfly can progress through the lifecycle of egg, larva, pupa and adult in about 4 weeks;
- development is most rapid in spring and in warmer conditions;
- between 4 and 6 generations of willow sawfly per season have been reported overseas;
- willow sawfly over-winter in cocoons, often in the leaf litter around willow trees.

Impact of Willow Sawfly:

- large populations of willow sawfly larvae can completely defoliate large willow trees;
- several defoliation events can occur in a single season;
- tree death occurs as a result of several defoliation events over a period of two or more seasons;
- younger trees die more quickly than older trees, but all ages are vulnerable to sawfly;
- repeated defoliation events cause a significant reduction in root biomass;
- it is unlikely that willow sawfly will affect any plants other than willows, and possibly poplars to a limited extent, in Australia.

Current Australian Distribution (July 2006):

- willow sawfly is widespread and well-established, and cannot be eradicated from Australia;
- wide-scale chemical control of willow sawfly is not feasible;
- willow sawfly is now present in ACT, NSW, eastern South Australia, Victoria and Tasmania;
- in Victoria confirmed reports of willow sawfly have been made from:
  - several sites in the north-east;
  - three sites spread across Gippsland (Rosedale, Tambo Crossing, Bendoc);
  - Yea;
  - East Keilor;
  - Geelong;
- it is expected that willow sawfly will spread across Victoria over the next two - three seasons.

Susceptible Taxa:

- tree willows are generally more susceptible to willow sawfly than shrub willows;
- willow sawfly has the potential to defoliate (and possibly kill) the following taxa:
  - crack willow (*S. fragilis* and hybrids)
  - black willow (*S. nigra*)
  - white willow (*S. alba*)
  - golden upright willow (*S. alba* var. *vitellina*)
  - Peking willow and New Zealand hybrids (*S. matsudana* and hybrids);
- willow sawfly is likely to occur on the following species, although its likely impact is unclear:
  - weeping willows (*S. babylonica, S.* x *sepulcralis* var. *chrysocoma* and *S.* x *sepulcralis* var. *sepulcralis*)
  - Chilean pencil willow (*S. humboldtiana* = *S. chilensis* ‘Fastigata’)
  - purple osier *(S. purpurea*, a shrub willow).

Diagnostics:

- key identifying features of the larvae include brown stripes on the head, running from behind each eye to the top of the head;
- the larva may also have a brown triangle on the front of the head;
- the larva may also curl up in a distinctive S-shape;
- the defoliation pattern is also distinctive with the larva initially eating a key-hole shape in the margin of the leaf;
- overall tree defoliation (starting on the lower canopy), leaving only bare mid-ribs is also a distinguishing feature.

Outlook for Victoria:

It is highly likely that willow sawfly will continue to spread across Victoria over the next two to three seasons, and be present in all areas with significant willow populations within three seasons.

If environmental conditions are favourable to the development of willow sawfly populations, defoliation of willow trees is likely. Warm, dry spring conditions seem to favour population increases, and if defoliation events occur in November or December, then several defoliation events are likely to occur throughout a season in situations where trees produce new leaves after each defoliation.

If defoliation events are frequent and serious, there is a high likelihood of tree deaths amongst susceptible willow taxa.

Tree deaths will occur more rapidly if trees suffer several defoliation events in one season, but trees may still die if they are unable to replace defoliated leaves until the following spring and remain bare for a significant portion of the season, if this pattern of defoliation occurs for several years.

However, it is not known whether or not sawfly population numbers will develop to potentially damaging levels in all areas or every season. The factors that influence population development are not fully understood, and factors such as temperature and predation by other insects may limit sawfly numbers. It is possible that in the medium to long term willow sawfly will have only a minor effect on willows and will not require a change in current willow management programs.

There are many variables that affect willow sawfly and its interaction with willow trees that are currently poorly understood and so it is not possible at this stage to determine the most likely outcome of the impact of willow sawfly on willows in the Victorian context.

Index

Section **Page Number**

List of Tables and Figures

Table/Figure **Page Number**

Section 1

Introduction

The recent arrival in Australia of willow sawfly, *Nematus oligospilus* Förster (Hymenoptera: Tenthredinidae) is of concern to river managers as this insect has the potential to significantly impact on willow management programs. This report synthesises current knowledge about willow sawfly from both the peer-reviewed and the "grey" literature (such as unpublished reports and conference abstracts), and from experience gained with the sawfly in New Zealand over the past nine years. An update of the status of sawfly in Australia as at July 2006 is provided, together with possible outcomes of the impact of willow sawfly on willow management.

Electronic literature searches were undertaken using two database systems. The peer-reviewed literature was searched using CAB Abstracts and Agricola, while Google and Google Scholar were searched for reports from the grey literature. Very few papers or reports were found in total, as limited work seems to have been done on this insect species. For example, there appear to be only two publications dealing with *N. oligospilus* in South Africa.

The information on willow sawfly in New Zealand was gained through both analysis of written material and through discussions with staff from HortResearch and from the Hawke's Bay Regional Council during a study trip undertaken by the author in May 2006. HortResearch is the government funded research agency that has led research into willow sawfly in New Zealand, with entomologists and plant breeders contributing to the research program. This program has involved collaboration with a number of Regional Councils across New Zealand, which are the agencies responsible for catchment management.

The analysis of the current status of sawfly in Australia relies heavily on data collected in the 2005/06 season across southern Australia by Dr Kyla Finlay as part of a DPI Frankston project funded by the Commonwealth 'Defeating the Weed Menace' program, that investigated the invertebrate and fungal taxa associated with willows. A case study of the arrival of willow sawfly in north-east Victoria has been provided by Andrew Briggs of the North East Catchment Management Authority (NECMA).

The taxonomy of willows is complicated, particularly as willows hybridise very easily. The scientific and common names used in this report follow the nomenclature used in the Willow Strategic Plan published by the National Weeds Strategy Executive Committee (2001), with one exception. In this report Chilean pencil willow is referred to as *Salix humboldtiana* (not *S. chilensis* 'Fastigata'), as this is the name used by authors in South America and New Zealand.

The term "taxa" is used in this report to denote all willow species, sub-species, hybrids, cultivars and varieties in the broadest sense. Willows are often divided into two groups - tree willows (subgenus *Salix*) which generally have a single stem and tree habit (e.g. crack willow - *S. fragilis*, black willow - *S. nigra*, and the weeping willows), and the shrub willows (subgenus *Vetrix*) with a shrubby, multi-stemmed growth form (e.g. grey sallow - *S. cinerea*, osier - *S. viminalis*).

Section 2

Taxonomy of *Nematus oligospilus* Förster (Hymenoptera: Tenthredinidae)

The willow sawfly is a member of the sawfly family, Tenthredinidae, which is a cosmopolitan family containing more than 6,000 species (Nyman *et al*., 2006). *Nematus* is one of the approximately forty genera within the subfamily Nematinae. The taxonomy of the genus is complex (Nyman *et al*., 2006) and the total number of species in the *Nematus* genus exceeds 120 (Benson, 1958).

The larvae of a number of *Nematus* species feed on various *Salix* (willow) species, as do species in other genera of sawfly (Nyman *et al.*, 2006). This accounts for the confusion surrounding the use of the common name, willow sawfly, which is applied to several sawfly species.

In South America a sawfly that attacks willows and poplars was identified as *Nematus desantisi* Smith in the early 1980's (Smith, 1983). However, this species has been determined as being the same species as *N. oligospilus* (Koch and Smith, 2000), and so information relating to *N. desantisi* has been included in this review.

Section 3

Life Cycle of *Nematus oligospilus*

A full taxonomic description of the male and female adults of *N. oligospilus* is given by Koch and Smith (2000). Berry (1997) also provides a description of the final larval instar and pupa, as well as the adult female, while Urban and Eardley (1995) provide line drawings of an early larval instar, a late larval instar and the adult female, in addition to written descriptions of all life stages.

Male sawflies are found in endemic populations in the Northern Hemisphere, however, populations of *N. oligospilus* in the Southern Hemisphere all appear to be composed entirely of females, which reproduce by parthenogenesis. Female-only populations have also been recorded in North America (Carr *et al.*, 1998).

The life cycle of the willow sawfly involves four stages - egg, larva, pupa and adult.

Section 3.1: Egg

The adult uses her ovipositor to saw a pouch under the cuticle of the leaf surface where she lays a single egg (Urban and Eardley, 1995). The length of time required to lay each egg is between 30 and 35 seconds (Ovruski, 1994).

Several eggs may be laid on the same leaf, with 30 or more eggs per leaf commonly found on willows in populations in Argentina (Dapoto and Giganti, 1994), while Ovruski (1994) reported up to 14 eggs per leaf, also in Argentina. In contrast, Urban and Eardley (1995) reported an average of 2 eggs per leaf on *S. babylonica* (weeping willow) in southern Africa. And only one egg per leaf (rarely two) was generally observed on a range of willows surveyed in southern Australia in the 2005/06 season (K. Finlay, pers. comm.).

Eggs may be laid on either leaf surface but are more often laid on the upper leaf surface (Charles *et al.*, 1998). Eggs are generally laid on mature, fully expanded leaves.

The eggs are about 1 - 2 mm long, and oval or kidney-shaped (reniform) (Urban and Eardley, 1995). They range from bright green to yellowy-green in colour (Figs. 1 - 3).

Section 3.2: Larva

The larva emerges from the egg and chews a hole through the leaf. The larva feeds along the margin of the leaf, and the resultant damage to the leaf (Figs. 12 - 13) is a useful diagnostic tool.

Larvae develop through between 5 and 7 instars (Charles and Allan, 2000) and the final larval instar may reach 20 mm in length (Charles *et al.*, 1999).

Early instar larvae are yellow-green in colour, with a light coloured head (Fig. 3). They may have darker green - brown stripes running down the body. As the larvae grow, the body colour deepens to green (Fig. 4). Larvae can be quite difficult to see on willow leaves, especially when small.

The head of the larva is cream-coloured, with black eyes. A key identifying feature of willow sawfly larvae is a brown stripe which runs from just behind each eye to the top of the head in later larval instars (Figs. 5 - 6). There is also sometimes a brown triangle on the front of the head (Fig. 5). Pale brown stripes may also run down the centre of the head. The larvae also sometimes curl into a distinctive S-shape (Fig. 12), which is another useful diagnostic tool.

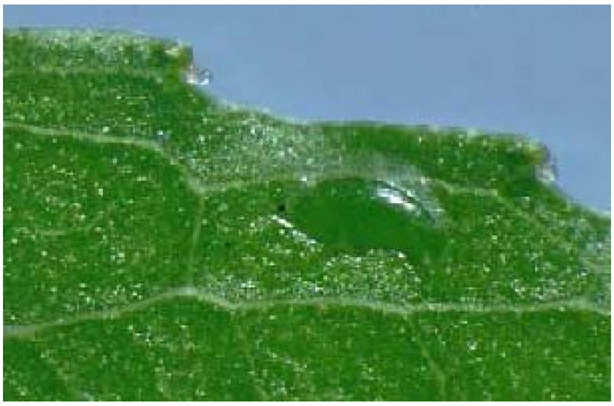

Fig. 1. Willow sawfly egg (1 - 2 mm).
(Photo: D. Allan, HortResearch)

Fig. 2. Willow sawfly egg.
(Photo: Copyright, Australian Department of Agriculture, Fisheries and Forestry)

Fig. 3. Willow sawfly egg and early instar larva (approximately 5 mm).
(Photo: D. Allan, HortResearch)

Fig. 4. Willow sawfly larva (to 20 mm long when mature).
(Photo: D. Allan, HortResearch)

Fig. 5. Willow sawfly larva showing head and body stripes, and brown triangle on head.
(Photo: Copyright, Australian Department of Agriculture, Fisheries and Forestry)

Fig. 6. Willow sawfly larva head, showing stripe behind eye.
(Photo: D. Allan, HortResearch)

Section 3.3: Pupa

Mature larvae pupate in cocoons. Urban and Eardley (1995) reported that mature larvae usually drop from the tree and spin a cocoon on understorey plants or under the leaf litter. However, in southern Australia, pupal cases were routinely found attached to willow leaves during recent field surveys or, less commonly, in crevices of the bark of willow trees (K. Finlay, pers. comm.).

The oblong cocoon is up to 10 mm in length, and domed with a flat bottom (Fig. 7). Those observed in southern Australia were lime green in colour and very obvious (K. Finlay, pers. comm.). Urban and Eardley (1995) described two types of cocoons - one type is thinly spun, translucent and pale-brown, with the contents visible, while the second type of cocoon is thickly spun, opaque and dark-brown.

Section 3.4: Adult

The adult is about 7 - 8 mm long, and has antennae which are 4 - 5 mm in length with 9 segments (Figs. 8 - 11). The lower portions of the antennae are dark coloured, with light-coloured upper segments (Urban and Eardley, 1995; Berry, 1997; Koch and Smith, 2000).

The head and thorax of the adult is yellowish-orange/brown in colour, and shiny (Fig. 8), while the abdomen is green (Figs. 9 - 11) (Urban and Eardley, 1995; Berry, 1997). Large dark eyes are prominent on the head.

The wings of the adult are transparent, with dark brown veins. The uppermost vein in the forewing (the costa) is thicker than other veins and is yellow, and there is a yellow-coloured compartment in the upper mid-part of the wing (known as the stigma) (Berry, 1997).

Sawfly adults can fly 50 - 60 km (J. Charles, pers. comm.).

The adults can feed on nectar from extra-floral nectaries (J. Charles, pers. comm.), but it does not appear that feeding is essential to maintain the activity of the adults, nor is it clear whether feeding prolongs the adult life span.

Section 3.5: Over-wintering

As willows are deciduous, foliage on which the larvae feed is not available in winter. In order to over-winter in relative safety, the willow sawfly undergoes diapause. This is a physiological resting stage, whereby the final stage larva spins a cocoon and instead of pupating into an adult in this cocoon immediately, the larva remains in a pre-pupal stage for about five months (J. Charles, pers. comm.). Pupation occurs at the end of this period, and the adults emerge in spring, after willow leaves have been produced so they can lay their eggs on fully expanded, mature leaves.

The cocoons in which willow sawfly over-winter are strongly made and provide a high degree of protection, especially against cold winter temperatures (J. Charles, pers. comm.). Given the natural range of this insect, cold winters are unlikely to kill diapausing individuals.

Entry into diapause appears to be regulated by photoperiod (day-length) with final stage larvae entering diapause when the day-length reduces to between 11 hours and 11 hours and 10 minutes when reared under laboratory environment (J. Charles, pers. comm.). Larvae which are not yet fully grown may continue to feed for some time after this critical photoperiod is reached, and enter diapause later, although larvae that emerge from eggs close to the critical date are unlikely to complete their development and probably die. Those larvae that enter diapause later may stay in that state over an entire season, and emerge in the spring 18 months later (J. Charles, pers. comm.).

In southern Australia this critical photoperiod occurs in about mid-April. However, Charles *et al.* (1999) reported that in Auckland, free living sawflies entered diapause in May in 1997 and in 1998, so it is likely that entry into diapause in southern Australia may occur over an extended period in late autumn.

Fig. 7. Willow sawfly pupa (to 10 mm long).
(Photo: D. Allan, HortResearch)

Fig. 8. Willow sawfly adult. Body length 7 - 8 mm, antennae 4 - 5 mm.
(Photo: D. Allan, HortResearch)

Fig. 9. Willow sawfly adult, top view.
(Photo: Copyright, Australian Department of Agriculture, Fisheries and Forestry; www.insectimages.org)

Fig. 10. Willow sawfly adult, side view.
(Photo: Copyright, Australian Department of Agriculture, Fisheries and Forestry; www.insectimages.org)

Fig. 11. Willow sawfly adult, underside.
(Photo: Copyright, Australian Department of Agriculture, Fisheries and Forestry; www.insectimages.org)

Fig. 12. S-shape of willow sawfly larva, a diagnostic tool for species identification.
(Photo: E. Bruzzese)

The exit from diapause is less well defined by environmental cues and the trigger mechanisms are not understood (J. Charles, pers. comm.). Adults emerge from their cocoons over a long period in spring, ensuring that any risk to the population from adverse conditions is low and that at least some emergent adults will find conditions suitable for egg-laying. Thus the life cycle of the insect is not synchronised, so at any time in the season it is possible to find all stages of the life cycle, from eggs through to adults. The first sawfly to emerge from diapause in New Zealand conditions were observed in October in both 1997 and 1998 (Charles *et al.*, 1999).

Section 4

Influences on Willow Sawfly Development

Section 4.1: Geography and Temperature

The length of time the willow sawfly spends in any stage of the life-cycle appears to be quite variable in different parts of the world and in different environmental conditions, as shown by the information in Table 1. Some authors did not give development times for all life stages.

Table 1: Development times (days) of willow sawfly life stages and number of generations per year

Location	Egg	Larva	Pupa	Adult	Generations per Year	Reference
Arizona, USA	9-11	19-20	-	-	-	Carr *et al*. (1998)
Argentina	6-7	21	4-8	3-7	4-5	Dapoto and Giganti (1994)
Chile	-	-	-	-	2	Gonzalez *et al*. (1986)
Southern Africa	6	14	9	-	4	Urban and Eardley (1995)
East Coast, North Island, NZ	-	-	-	-	5-6	Charles *et al*. (2004)
NZ: 11.3^{o}C (lab)*	17	51	40	-	-	Charles and Allan (2000)
NZ: 15.5^{o}C (lab)	9	21	14	-	-	Charles and Allan (2000)
NZ: 17.3^{o}C (lab)	7	16	10	-	-	Charles and Allan (2000)
NZ: 19.0^{o}C (lab)	6	14	9	-	-	Charles and Allan (2000)
NZ: 23.0^{o}C (lab)	5	10	7	-	-	Charles and Allan (2000)
NZ: 26.0^{o}C (lab)	4	13	5	-	-	Charles and Allan (2000)
NZ: 28.8^{o}C (lab)	**	12	5	-	-	Charles and Allan (2000)

* - these temperatures were maintained constantly in a laboratory environment
** - no eggs survived at 28.8^{o}C

Charles and Allan (2000) reared willow sawfly eggs, larvae and pupae under constant temperatures in the laboratory, and found the shortest development period (22 - 23 days) occurred at the three highest temperatures (Table 1). However willow sawfly eggs did not survive when the temperature was maintained at 28.8^{o}C. It is not known how tolerant the willow sawfly is to high temperatures, but it is possible that being native to the cooler parts of the Northern Hemisphere, the willow sawfly is not tolerant of the high temperatures that regularly occur in the Australian summer. Information about tolerance to temperature fluctuations is also unknown.

However, Charles and Allan (2000) did calculate the theoretical minimum temperature for development of willow sawfly as being 8.1^{o}C, and determined that 321 degree days above this threshold were required for willow sawfly to complete one generation.

Using the data gained from these temperature experiments and climate data, Charles and Allan (2000) predicted the number of willow sawfly generations for two summer temperature scenarios for several regions of New Zealand. This modelling predicted 6 - 7 sawfly generations in Auckland and Northland, 5 - 6 generations on the east coast of the North Island (which fits well with field observations, see Table 1), but only 2 - 4 generations in southern South Island locations.

Section 4.2: Seasonal Influence

There is also a seasonal influence on development of willow sawfly, with the most rapid development of the newly hatched larva through to adulthood occurring in spring (November). Development times were slowest in autumn (March), and intermediate in January in laboratory trials (J. Charles, pers. comm.). The effect of seasons differed between taxa, with only minor seasonal differences observed in *S. matsudana* (Peking willow) and *S. fragilis* (crack willow), compared with large seasonal differences in the poplar clone tested (J. Charles, pers. comm.).

Section 4.3: Willow Taxa

Laboratory trials have tested the impact of willow and poplar taxa on sawfly development times (J. Charles, pers. comm.). It was found that the period of time required for the newly hatched larva to mature through to the adult ranged from 19 to 28 days, with the most rapid development occurring on *S. alba* (white willow), *S. purpurea* (purple osier), *S. nigra* (black willow) and *S. matsudana* (Peking willow).

Willow sawfly development on the two *Populus* (poplar) taxa tested was relatively slow, but the sawfly did complete development on these species. Development on *S. babylonica* (weeping willow) was also slow in comparison with development on other willow taxa. Willow sawfly larvae were able to complete their development on all taxa tested.

Section 4.4: Food Source

The impact of the nutritional value of willow foliage on willow sawfly development has been demonstrated to some extent. Carr *et al*. (1998) undertook a series of trials on *S. lasiolepis* (arroyo willow, a shrub willow) in Arizona, USA. They found that willow sawfly laid more eggs on vigorous willow shoots, and that the survival of eggs and larvae was greater on these shoots, and the development time more rapid than on less vigorous shoots. Leaves on the highly vigorous shoots were more nutritious than leaves on less vigorous shoots.

Similar results were found with willow cuttings. Larval development tended to be more rapid when raised on willow leaves from current season cuttings which were well fertilised compared with leaves from one year old plants which had had no recent fertiliser additions (J. Charles, pers. comm.). This trend was more obvious in spring than in autumn and there were variations in the response between willow taxa. It is hypothesised that these trends and the seasonal influences on willow sawfly discussed above reflect the greater availability of foliar nitrogen and foliar water in spring and in well fertilised foliage, which promote sawfly development (J. Charles, pers. comm.).

Analysis of leaf chemistry has been undertaken to determine if there are any relationships between the levels of phenolglucosides in foliage from different willow taxa and the development time of sawfly on those taxa (I. McIvor, pers. comm.). Phenolglucosides are a group of plant sugars and are known to affect insect development. A number of compounds in this chemical family have been isolated from willow and poplar leaves. However, no clear relationship between the chemical composition of leaves and sawfly development data has been found. It has been speculated that as the production of secondary metabolites, such as phenolglucosides, decreases in times of stress (e.g. drought), and if higher phenolglucosides levels do provide a degree of protection from sawfly attack, that drought-stressed plants may be more vulnerable to willow sawfly (J. Charles, pers. comm.).

A relationship between food quality and entry into diapause has been observed, with some larvae entering diapause earlier (when the photoperiod is 12 hours) if they are feeding on a poorer quality host plant (J. Charles, pers. comm.).

Section 4.5: Fecundity

The fecundity, or number of eggs laid by each female, is a variable characteristic in willow sawfly. Fecundity is important because the number of eggs laid by adults influences the rate at which the population can increase. Temperature and willow taxa have been shown to affect egg laying potential in laboratory trials.

Adults from southern African populations laid an average of 63 eggs over a period of 3 - 5 days (Urban and Eardley, 1995). Similarly, females laid an average of 65 eggs, with the maximum number of eggs (20.3) laid on the first day of adult life, in studies in Argentina (Ovruski, 1994). Females in this study emerged with 93% of their eggs mature. In contrast, Dapoto and Giganti (1994) reported that the number of eggs laid per female ranged from 13 to 24 in the Argentinian willow sawfly populations they studied. In Arizona, USA, fecundity was found to range from 29 - 35 eggs per female (Carr *et al.*, 1998).

Trials involving offering different willow taxa for oviposition in New Zealand found that on average, females laid 49 eggs, with one female laying 100 eggs (Charles *et al.*, 1998). The maximum oviposition rate was 21 eggs per day. In these trials, more eggs were laid on lowest (oldest) leaves on shoots, and fewer on the youngest leaves. Adults lived for 10 - 12 days, with most eggs being laid in the first 4 - 5 days (J. Charles, pers. comm.).

In a second series of trials, the potential fecundity of adults raised on different willows and poplar taxa was assessed by dissecting dead adults and counting the number of eggs in the ovaries. The number of eggs varied from about 50 to 100 for adults raised on the different taxa (J. Charles, pers. comm.). Females raised on *S. fragilis* (crack willow), *S. alba* (white willow), *S. purpurea* (purple osier), *S. nigra* (black willow) and *S. matsudana* (Peking willow) contained about 90 eggs.

Potential fecundity has been found to also vary with the temperature at which the insects were reared (Charles and Allan, 2000). Those reared at between 15.5^{o}C and 19^{o}C had an average potential fecundity of between 99 and 104 eggs per female, compared with 70 eggs per female for those raised at 26^{o}C (no data were given for the 23^{o}C treatment).

Females were found to be larger and more fecund (contain more eggs) in spring (November) than in January or March (J. Charles, pers. comm.).

Section 5

Factors Affecting Willow Sawfly

Section 5.1: Climate

As discussed above, temperature affects the rate of development and fecundity of the willow sawfly. Generally the opinion of both on-ground staff and scientists in New Zealand is that a warm, dry spring facilitates population build-up in the willow sawfly, while cool, wet spring conditions inhibit population growth.

Field staff from the Hawke's Bay Regional Council in New Zealand believe that it is possible that minimum overnight temperatures may be the limiting factor in the development of sawfly population levels (G. Eyles, pers. comm.), but this theory remains untested to date.

In Southern Hemisphere populations where spring and summer temperatures are warm to hot, between 4 and 6 generations of willow sawfly develop each season (Table 1).

Although rain does not directly affect willow sawfly development, it has been noted in New Zealand that during rain showers, willow sawfly larvae were less active and tended to hang below the leaves and cease feeding (Disbury *et al.*, 2004).

In Argentina, Alderete and Liljesthröm (2004) have studied willow sawfly populations in two locations. The delta of the Parana River has broad continuous willow plantations and a humid-temperate climate, while the Tafi Valley is an elevated valley bordered by mountains with a sub-humid cold climate, and rains concentrated in spring and summer. Willow populations in the Tafi Valley are small and isolated. Both localities experienced high sawfly populations coupled with severe willow defoliation events twice in the early to mid 1990’s. These authors found no significant differences in mean temperature, mean maximum temperature, or rainfall totals between years with sawfly outbreaks and non-outbreak years. The impact of natural enemies on sawfly populations was significant however (see Section 5.3).

Section 5.2: Seasons

The rate of development of willow sawfly is more rapid and the fecundity of adults greater in spring than in autumn (J. Charles, pers. comm.), giving the population the greatest potential for rapid increase in spring.

The seasonality of available foliage on which the larvae feed also affects the life cycle of the willow sawfly, with larvae entering diapause in autumn and over-wintering as pre-pupae in cocoons as described above (Section 3.5).

Section 5.3: Predators and Parasitoids

There are some species that parasitise *N. oligospilus* (Table 2), with Carr *et al*. (1998) reporting variable levels of parasitism on willow sawfly eggs in different willow populations in Arizona, USA, with more than 80% of eggs parasitised at one site. The parasitic species were not identified.

In Australia, there are only three native species in the sawfly family (Tenthredinidae) (Naumann *et al*., 2002), so it is unlikely that there are many predators or parasites in the Australian invertebrate fauna which will attack willow sawfly specifically, but generalist native species may impact on willow sawfly populations (Bruzzese and McFadyen, 2006).

It is interesting to note that Alderete and Liljesthröm (2004) found in studies on willow sawfly in the Tafi Valley in Argentina, that the exclusion of natural enemies led to a significant increase in sawfly larval survivorship. Larval mortality was found to be density-dependent (with climatic factors not having a significant impact on population numbers as discussed above, Section 5.1), and the impact of natural enemies was sufficient to regulate the willow sawfly population.

Table 2: Predators and parasitoids found on willow sawfly

Location	Species	Order: Family	Reference
California, USA	*Trichogramma aurosum*	Hymenoptera: Trichogrammatidae	Alderete and Fidalgo (2004)
	Trichogramma sibericum	Hymenoptera: Trichogrammatidae	Alderete and Fidalgo (2004)
	Olesicampe californica	Hymenoptera: Ichneumonidae	Alderete and Fidalgo (2004)
Argentina	*Podisus nigrolimbatus*	Hemiptera: Pentatomidae	Dapoto and Giganti (1994)
	Cirrospilus gracielae	Hymenoptera: Eulophidae	Dapoto and Giganti (1994)
	Isdrornas gigantii	Hymenoptera: Ichneumonidae	Dapoto and Giganti (1994)
	Pteromalidae sp.	Hymenoptera: Pteromalidae	Dapoto and Giganti (1994)
Chile	*Polistes buyssoni*	Hymenoptera: Vespoidae	Gonzalez *et al.* (1986)
	Podisus chilensis	Hemiptera: Pentatomidae	Gonzalez *et al.* (1986)
	Dibrachys cavus(?)	Hymenoptera: Pteromalidae	Gonzalez *et al.* (1986)
Southern Africa	*Dibrachys cavus*	Hymenoptera: Pteromalidae	Urban and Eardley (1995) and (1997)
	Pteromalus sp.	Hymenoptera: Pteromalidae	Urban and Eardley (1995)
	Pediobius sp.	Hymenoptera: Eulophidae	Urban and Eardley (1995)
	Macrorhaphis sp.	Hemiptera: Pentatomidae	Urban and Eardley (1995)
New Zealand	*Gelis tenellus*	Hymenoptera: Ichneumonidae	Berry (1997)

Section 6

Impacts of Willow Sawfly in the Field

Section 6.1: Individual Leaves

Sawfly larvae initially eat the margins of willow leaves (as shown in Figs. 13 - 15), which is a distinctive feature of this insect and a useful diagnostic tool. However, as the larva grows, it eats the entire leaf blade (lamina), leaving only the midrib. Larvae eat about two willow leaves during their development (Cowie, 2006) and can devour an entire leaf in their final day as a larva (J. Charles, pers. comm.).

Defoliated shoots retain only the remaining midribs. New leaves are formed at the apex of the shoot as it grows, which results in a shoot with no leaves at the base and new leaves at the apex (Fig. 16).

Section 6.2: Tree Defoliation and Death

Sufficient numbers of willow sawfly larvae can entirely defoliate large, adult willow trees (Figs. 17 - 20, 24). If larval numbers are insufficient to defoliate the entire tree, partial defoliation of the lower canopy of the tree will occur, leaving the upper portion of the canopy intact.

In Hawke's Bay, on the east coast of the North Island of New Zealand, severe infestations of willow sawfly have resulted in 4 - 5 defoliation events on the same trees in one season, with the first defoliation events occurring in November or December (G. Hansen, pers. comm.). Defoliation continued through to about mid-April (I. McIvor, pers. comm.).

In the north-east of Victoria, defoliation of one stand of willow trees was observed in summer 2006, and a second flush of leaves was produced. However, before those leaves could fully mature, sawfly larvae reinfested the trees and ate the emerging leaves. The trees did not produce another flush of leaves, and stayed bare for the remainder of the season (A. Briggs, pers. comm.).

Tree deaths as a result of willow sawfly activity have been reported from South America (Dapoto and Giganti, 1994; Alderete and Fidalgo, 2004), southern Africa (Urban and Eardley, 1997) and New Zealand (Charles *et al*., 2004; G. Eyles, pers. comm.; I. McIvor, pers. comm.).

The experience of catchment managers in the Hawke's Bay and elsewhere in the North Island of New Zealand suggests that tree deaths can occur in the second season of severe willow sawfly infestations (I. McIvor, pers. comm.). In Hawkes Bay, four or more defoliation events in a season can kill trees, with two successive years of 2 - 3 defoliation events sufficient to kill trees, while two to three successive years of defoliation at lower frequencies can also kill trees (G. Eyles, pers. comm.; G. Hansen, pers. comm.).

Younger trees tend to die more quickly than older trees as they have fewer resources available to continue developing new leaves after severe defoliation events (G. Eyles, pers. comm.; I. McIvor, pers. comm.). However there does not seem to be any correlation between overall tree health and susceptibility to sawfly attack. It is interesting to note that observations in New Zealand have found that willow sawfly larvae will eat the foliage around a gall on a willow leaf formed by willow gall sawfly (I. McIvor, pers. comm.).

Defoliation events that do not lead to complete tree death can result in death of branches, which become brittle and fall, and the loss of significant amounts of root biomass (I. McIvor, pers. comm.). Debilitated trees may also become more prone to infection by rusts (G. Eyles, pers. comm.). In severely affected trees, regrowth of foliage may occur from buds directly on the tree trunk or stem (epicormic buds) (I. McIvor, pers. comm.).

Section 6.3: Impact of Defoliation on Root Biomass

The loss of foliage on root biomass has been investigated in a controlled environment study with potted willow cuttings (I. McIvor, pers. comm.). Willow plants were subjected to defoliation events either on a 4-weekly cycle or an 8-weekly cycle. The process of defoliation was somewhat artificial, with all leaves being manually removed from the plants at the same time. Plants were kept in either a warm environment or a cool environment over the experimental period.

The decline in root biomass from these defoliation treatments was dramatic, with more than 90% of root biomass lost in those plants subjected to the 4-weekly defoliation cycle, regardless of temperature. Plants defoliated on an 8-weekly cycle which were grown in the cooler environment lost more than 80% of root biomass, while those grown in the warm environment lost 50% of root biomass (I. McIvor, pers. comm.).

Field observations from Hawke's Bay indicate that willow trees can lose 90% of their root biomass after 3 defoliation events, and trees that die from sawfly defoliation generally have very limited live root biomass (G. Hansen, pers. comm.).

Fig. 13. Feeding pattern of willow sawfly larva on willow leaf.
(Photo: D. Allan, HortResearch)

Fig. 14. Damage to willow leaves from initial feeding of willow sawfly larvae.
(Photo: C. van Kraayenoord, HortResearch)

Fig. 15. Damage to willow leaves on willows near Kiewa River, NE Victoria, Feb, 2006.
(Photo: F. Ede)

Fig. 16. Completely defoliated leaves, with only mid-ribs remaining. New foliage developing at top of shoot.
(Photo: F. Ede)

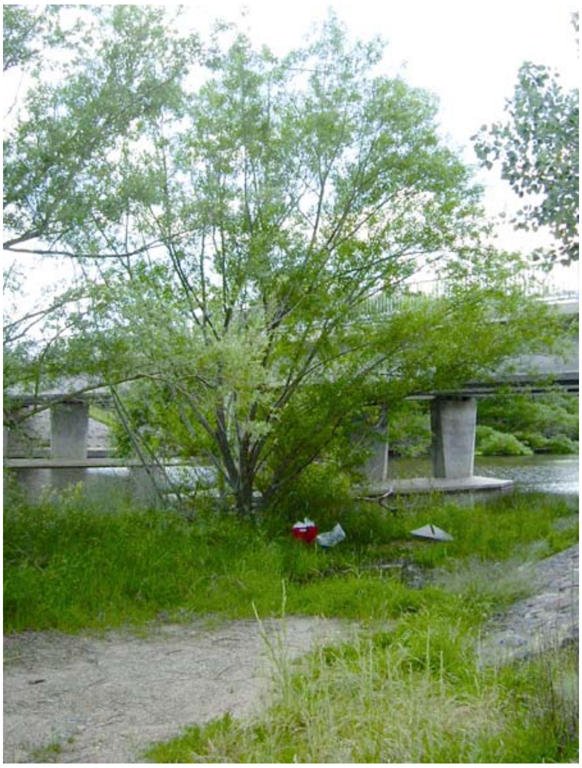

Fig. 17. *S. matsudana* (NZ hybrid?) tree, near Canberra on 14 Nov, 2005.
(Photo: K. Finlay)

Fig. 18. Same *S. matsudana* tree, on 8 March, 2006, after defoliation by willow sawfly.
(Photo: K. Finlay)

Fig. 19. Willows defoliated by willow sawfly at Meadow Flat, Great Western Highway, NSW, April, 2006.
(Photo: S. Holland-Clift)

Fig. 20. Defoliation of *S. alba* var. *vitellina* (golden upright willow), *S. babylonica* (weeping willow) still green. Near Canberra airport, Jan, 2005.
(Photo: L. Bond)

Section 7
Willow Sawfly Elsewhere in the World

Section 7.1: Native Range

Nematus oligospilus is native to the Northern Hemisphere where it is widespread, being found across Europe from Ireland to the Himalayas, and in North America from Alaska to Mexico (Bruzzese and McFadyen, 2006). There are no species of *Nematus* endemic to the Southern Hemisphere (Koch and Smith, 2000).

In its native range, the willow sawfly appears to do little damage, although outbreaks of nematine sawflies can cause repeated defoliation of host plants which impact on plant health (Urban and Eardley, 1995).

Carr *et al.* (1998) undertook a series of studies of *N. oligospilus* on *S. lasiolepis* (arroyo willow) in northern Arizona. In ten years of observations, this sawfly had been uncommon and never visibly damaged the host plant, suggesting that the sawfly maintains stable, low density populations in this area. Sawfly populations were most dense in autumn, when most willow shoot growth had ceased. The strong relationship between oviposition preference, larval performance and shoot vigour found in their studies indicated that in this system, food resources limit population growth in *N. oligospilus*.

One comment made by these authors was that willow sawfly larvae rarely devoured entire leaves, so the location of the initial hole chewed by the emerging larva was visible on leaves until leaf fall. This is in direct contrast to the situation in Southern Hemisphere populations where entire leaves are eaten by willow sawfly larvae.

Carr *et al.* (1998) also considered that although the larvae often moved between leaves on a plant, movement of larvae between plants would not be feasible as they are highly sedentary, and commented that willow sawflies have a low dispersal capability, which has not proved to be the case in the Southern Hemisphere.

Section 7.2: South America

A willow sawfly species arrived in Argentina in 1980/81 (Dapoto and Giganti, 1994), which Smith (1983) determined was a new species which he named *Nematus desantisi*. However, it is now recognised that this species is in fact *Nematus oligospilus* (Koch and Smith, 2000), which indicates that this was the first record of *N. oligospilus* in the Southern Hemisphere.

Willow sawfly spread quickly throughout Argentina and was found in Santiago, Chile in 1983/84. The rate of spread was 3,000 km in 9 - 10 years (Dapoto and Giganti, 1994).

Severe defoliations, repeated defoliation events and tree deaths have been reported in willows in Argentina (Dapoto and Giganti, 1994; Alderete and Liljesthröm, 2004), and damage to poplar species has also been noticed (Dapoto and Giganti, 1994). These impacts are of concern as both poplars and willows are important plantation species in a number of areas, and willows are also used extensively for control of erosion in river basins.

Willow sawfly can complete 4 - 5 generations per year in Argentina (Dapoto and Giganti, 1994), although Gonzalez *et al.*(1986) reported only two generations per year in Chile.

At one study site in Argentina, willow sawfly were found to emerge in early September and attack *S. babylonica* (weeping willow), while adults emerged in October at a second, cooler site, where they attacked *S. fragilis* (crack willow) and *S. elegantissima* (Thurlow weeping willow) (Dapoto and Giganti, 1994). These latter two species were found to be preferred hosts, but once these trees had been defoliated willow sawfly would move to *S. humboldtiana* (Chilean pencil willow), *S.*

matsudana (Peking willow) and *S. alba* (white willow), as well as *Populus* x *canadensis* and *P. alba* (white poplar). No details of the extent of defoliation on these species were reported in this paper, but all were considered host species by these authors. Willow sawfly entered diapause in mid-March at the cooler site, and in early April at the first, warmer site.

Gonzalez *et al.* (1986) reported willow sawfly on *S. babylonica* and *S. humboldtiana* in Chile, with severe defoliation occurring. Adults emerged in early October, with second generation adults emerging from mid-December onwards, and larvae entered diapause in mid to late summer.

Additional species on which willow sawfly has been reported in Argentina include *S. caprea* (goat willow), *S.* 'Erythroflexuosa' (golden tortured willow), *S. nigra* (black willow) and *Populus nigra* (black poplar) (Koch and Smith, 2000).

Section 7.3: Southern Africa

Severe defoliation by willow sawfly of willow trees was first reported in Lesotho, in southern Africa, in October 1993, although the sawfly was probably present in the area the previous summer (Urban and Eardley, 1995). This was the first record of any member of the subfamily Nematinae in southern Africa. It is not known how willow sawfly arrived in southern Africa, although it is believed that illegally imported willow material was a likely source of the insect (Urban and Eardley, 1997).

In southern Africa, exotic willows have been grown commercially, and also used in amenity and reclamation plantings, but are considered by many land managers to be weeds (Urban and Eardley, 1995). Poplars (*Populus deltoides*) have been grown commercially in Natal for the match industry. There is one species of willow indigenous to the area, *Salix mucronata* Thunb.

In their 1995 paper, Urban and Eardley described the cuurent distribution of willow sawfly, which coincided approximately with the Highveld Region of southern Africa. This area lies 2 - 3,000 m above sea level and has a rainfall above 450 mm in summer and a dry, cold winter. Willow sawfly was active from late October to late March, and with generation times of about one month, completed about four generations per year.

These authors reported that small willow trees may be totally defoliated by the sawfly, with larger willow trees defoliated more heavily in the lower canopy. Repeat defoliation events were observed, and defoliation was patchy in some areas. Tree deaths were reported in a later paper (Urban and Eardley, 1997).

Field observations indicated that willow sawfly had a strong preference for the exotic willow species, *S. fragilis* (crack willow) and *S. babylonica* (weeping willow), while adjacent poplars and *S. mucronata* trees were not attacked by sawfly. However, it was noted that willow sawfly larvae would colonise and feed on poplars when nearby willows were completely defoliated (Urban and Eardley, 1995). Experimental transfer of larvae from weeping willow to *P. deltoides* or *S. mucronata* were undertaken, and the larvae fed readily, but only about 10% completed their development. Results from glasshouse experiments indicated that although eggs were laid and hatched successfully on poplar leaves, larvae died within two days of hatching, having chewed a small hole in the leaf (Urban and Eardley, 1997). The authors concluded that willow sawfly posed no threat to the poplar plantation industry.

No analysis of the long term impact of willow sawfly on exotic willow populations in southern Africa appears to have been published.

Section 7.4: New Zealand

<u>Section 7.4.1.Initial Outbreak</u>

Willow sawfly was first recorded in New Zealand from an infestation on two *S. matsudana* trees in Onehunga, Auckland in February, 1997 (Berry, 1997). The defoliation of these trees was severe, with the lower foliage stripped almost bare, and large amounts of frass had accumulated under the tree (Berry, 1997). This suggests the insects had been present for some time before being reported. Larvae were also collected in early April from a *S. humboldtiana* (Chilean pencil willow) tree in Mt. Albert, Auckland (Berry, 1997) and a survey undertaken in late summer 1997, by the Ministry of Agriculture, found the sawfly throughout urban Auckland (van Kraayenoord, 1997).

In April, 1997, the sawfly was reported on golden willow (probably *S. alba* var. *vitellina*) in Rotorua (van Kraayenoord, 1997), which is 230 km south of Auckland. These sightings indicate that the sawfly was already well established in New Zealand by summer 1997, and suggest that the insect had probably been in the country for at least two years by that stage (van Kraayenoord, 1997).

It is believed that the sawfly possibly arrived in New Zealand from South Africa, as a diapausing, cocooned larvae on a shipping container (Charles *et al*., 2004).

Section 7.4.2: Willow Use in New Zealand

The arrival of European settlers in New Zealand in the 1800's led to the wide-spread clearing of forest to allow for the development of agriculture and horticulture. Lowland areas were cleared first, and many of these areas were alluvial floodplains, formed by the action of rivers over aeons. Due to the predominantly steep topography of much of New Zealand, over 50% of the population now live on floodplains (Cowie, 2006), and the high energy river systems that formed these areas are now constrained by man-made systems to limit the impact of flood events. Part of these flood mitigation systems are stopbanks planted with willows, as the extensive root systems of these willows provide stability in times of flood, preventing lateral channel erosion (Cowie, 2006). Native riparian species do not have the root morphology to provide sufficient stopbank stability. It has been estimated that if willows fail, the increase in economic damage to infrastructure and primary production land from flood events could be up to $NZ10 million per annum (Charles *et al*., 2004). Willows and poplars are also planted extensively as part of hill country stabilisation works in non-riparian areas. In some areas such as wetlands, land managers recognise willows as serious weeds, and some taxa are considered more weedy than others.

Because of the reliance on willows, particularly for river management purposes, the arrival of the willow sawfly in New Zealand was a significant cause for concern. A research program headed by HortResearch was initiated, in association with a number of Regional Councils. This program has investigated aspects of sawfly biology, such as diapause triggers; effect of different taxa on oviposition preference, fecundity, and larval development; impact of temperature, season and tree nutrition on development; leaf chemistry and palatability studies; and studies on the effect of defoliation on root biomass, which have all been described above.

Section 7.4.3: Impact of Willow Sawfly in Different Regions

After initially causing severe defoliation of willow trees in several regions in New Zealand, the impact of willow sawfly has diminished over time. Cowie (2006) conducted a survey of Regional Councils asking them to detail sawfly outbreaks and to estimate the damage caused by the sawfly.

The impact of willow sawfly was first noticed in Northland (north of Auckland) in 2000, with serious damage to crack and weeping willows at several sites. The resultant deaths of crack willow (*S. fragilis*) were welcomed as it is a weed species in that region. However, there have been no further reports of damage since that initial outbreak.

Similarly in the Waikato (south of Auckland), some damage was reported in 1998/99 through to 2000/01, particularly on old crack willows, some of which have died, but there has been little impact of willow sawfly since then.

In remaining regions in the west of the North Island and throughout the South Island, willow sawfly appears to have had little impact on willows, despite being present.

In eastern regions of the North Island, willow sawfly has had greater impacts. However, for all but one region (Hawke's Bay), outbreaks of severe defoliation have been sporadic. Riparian and hill country willow trees have been damaged, with some trees dying, particularly older trees. On-ground staff report that outbreaks of sawfly appear to be associated with warm weather, with little wind or rain. In some regions, sawfly population numbers have been high for two or three consecutive seasons which resulted in damage to willows, but ongoing problems with willow sawfly have not been observed.

It can be concluded that, apart from in the Hawke's Bay, the impact of willow sawfly on willow populations in New Zealand has not been as serious as first feared and that outbreaks which were initially very damaging have not been sustained over the medium to longer term in most regions.

<u>Section 7.4.4: Hawke's Bay - A Case Study</u>

Willows are used extensively in catchment management in Hawke's Bay (which is on the east coast of the southern North Island), with several rivers having tens of kilometres of riverbank planted in willows, with some plantings up to 80 m wide (G. Hansen, pers. comm.). Tree willows are used predominantly as their roots provide better erosion protection than roots of shrub willows.

Willow sawfly arrived in Hawke's Bay in 1999 (G. Hansen, pers. comm.) and has sustained high population levels for five of the past six seasons. As noted earlier, willows in this region have suffered multiple defoliation events per season. On-ground staff have observed that if a defoliation event occurs prior to Christmas, then several defoliation events are likely during the season due to the initial build-up of high sawfly population levels. Willow tree deaths have been widespread.

Trees in riparian plantings seem to be more susceptible to willow sawfly attack, with sawfly infestations able to move rapidly along river systems. Sawfly problems on soil conservation plantings in the hill country have been less severe and isolated trees do not appear to be as susceptible to sawfly attack (G. Eyles, pers. comm; I. McIvor, pers. comm.).

As population levels of willow sawfly build up over a season, larvae can defoliate all the available willow trees in an area. As food supplies diminish, larvae will move down their host tree and travel some distance across the ground to a new host. If larvae fall off a tree, they can climb back up (I. McIvor, pers. comm.). On-ground staff have observed dense swarms of green sawfly larvae travelling down the trunks of willow trees, across intervening areas and up other potential hosts, including fence posts and non-preferred tree species (G. Hansen, pers. comm.). Larvae can even re-infest trees they have already defoliated and attack emerging leaves (J. Charles, pers. comm.).

The appearance of sawfly larvae on poplar trees in Hawke's Bay is explained by this mass movement of larvae, as poplar trees are often planted in conjunction with willows in riparian and soil conservation areas. Willow sawfly has been found on poplars and caused some levels of defoliation, but it is likely that this was only noticeable due to the sheer volume of sawfly larvae and not because poplars are a potential food source in the field (G. Hansen, pers. comm.).

As a consequence of the death of willow trees due to willow sawfly, the Hawke's Bay Regional Council is having to undertake multi-million dollar remediation works for floodplain control in some locations. More details of this can be found on their website: http://www.hbrc.govt.nz/DesktopDefault.aspx?tabid=299

Section 8

Willow Sawfly in Australia

Section 8.1: Initial Observations: 2004 - 2005

The first reported observations of willow sawfly in Australia were made in summer, 2004, in the Canberra area. An infestation was noted on *S. babylonica* (weeping willow) in Telopea Park, Manuka, ACT on 3rd March, 2004, and defoliation of weeping and crack willows along the Molonglo River at Duntroon, ACT, was observed the following day (Bruzzese and McFadyen, 2006).

Queanbeyan Landcare members also observed defoliation at the Yass Road bridge over the Molonglo River in summer 2004 (Gaind, 2005). Further observations of defoliation of willows were made as far as 150 km south of Canberra in 2004 (Bruzzese and McFadyen, 2006).

Confirmation of the identity of the willow defoliating agent as *N. oligospilus* was made by CSIRO in February, 2005, from samples taken from around Lake Burley Griffin in Canberra (Rees *et al*., 2005). Confirmed reports of the sawfly were also made from the Adelaide Hills in South Australia and from one suburban backyard in East Keilor in Melbourne, Victoria (Bruzzese and McFadyen, 2006). There is anecdotal evidence that this infestation may have inadvertently arrived via a frequent visitor to the property who travels from Canberra by car (K. Finlay, pers. comm.).

Further anecdotal reports of willow sawfly were made throughout the 2004/05 season from the Queanbeyan River, ACT (Gaind, 2005); Braidwood, NSW (110 km east of Canberra) (Exon, 2005); and Cooma, SE NSW (Rees *et al*., 2005).

Fig. 21 shows the confirmed (verified) and anecdotal (unverified) sightings of willow sawfly reported during 2004 and 2005.

It is possible that willow sawfly actually arrived in Cooma in the 2003/04 season, with willow defoliation observed by willow management contractors (S. Lang, pers. comm.). Subsequent observations have noted that the sawfly tends to defoliate crack willows and hybrids, and *S. alba* hybrids, with *S. babylonica* not affected. Sawfly has not been observed on any shrub willows.

Willow sawfly appear in the Monaro area in late spring, with defoliation of trees becoming apparent over Christmas. However unlike willow trees in New Zealand, the defoliated trees in the Monaro area are not producing a second flush of leaves. This may be a consequence of the extremely hot, dry conditions over recent seasons (S. Lang, pers. comm.). Trees that are defoliated remain bare until the following spring, when strong new growth is observed, which is then attacked by sawfly. The same trees have being attacked for 2 - 3 seasons but are not showing any signs of ill-health yet (S. Lang, pers. comm.). This pattern of a single defoliation event leaving trees bare for the remainder of the season is similar to observations made in 2006 in some sites in north-east Victoria (see Section 8.3).

It will be interesting to monitor tree health over several years under these conditions and determine whether trees eventually recover or whether they die after some years in which they are foliated for only part of the season. It will also be important to understand if this pattern of defoliation is the normal pattern experienced in southern Australia, or whether several defoliation/refoliation events in a single season is more usual. It is possible that the combination of extreme environmental conditions (such as the drought conditions around Cooma) and the lack of willow foliage throughout an entire season prevents the build-up of sawfly population levels.

It is unclear how willow sawfly arrived in Australia. It is possible that it was brought into the country inadvertently via shipping containers or other contaminated material, potentially as cocoons containing diapausing larvae. It is also possible that adults were blown across from New Zealand via easterly wind systems that occur in late summer (Bruzzese and McFadyen, 2006).

Figure 21. Map of south-eastern Australia showing locations of willow sawfly reported in 2004/05, including verified reports (3 sites) and unverified reports (2 sites).

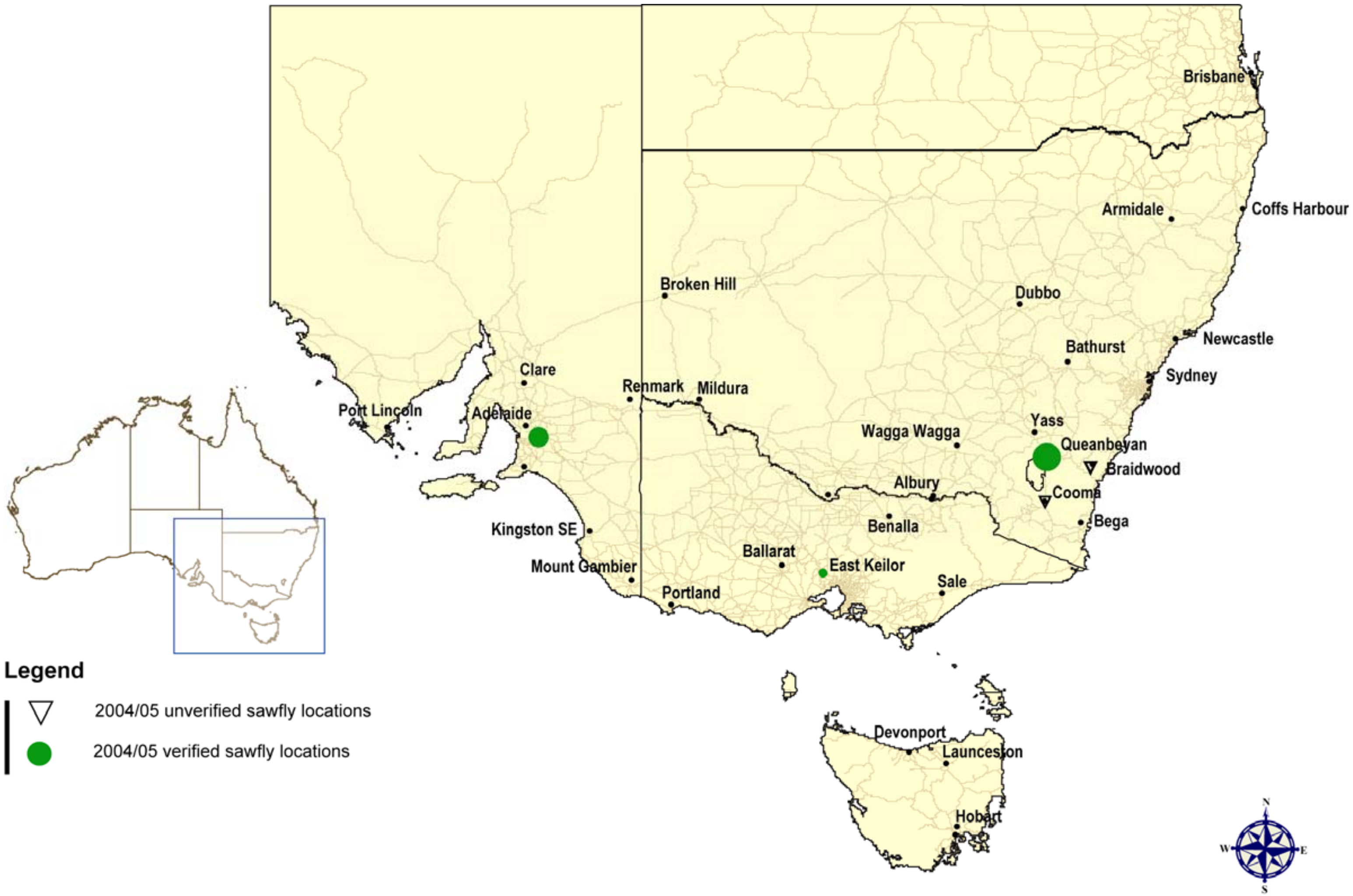

Figure 22. Map of south-eastern Australia showing locations of all willows assessed between October 2005 and March 2006 during field survey, highlighting sites where willow sawfly was found. (Data provided by K. Finlay, DPI)

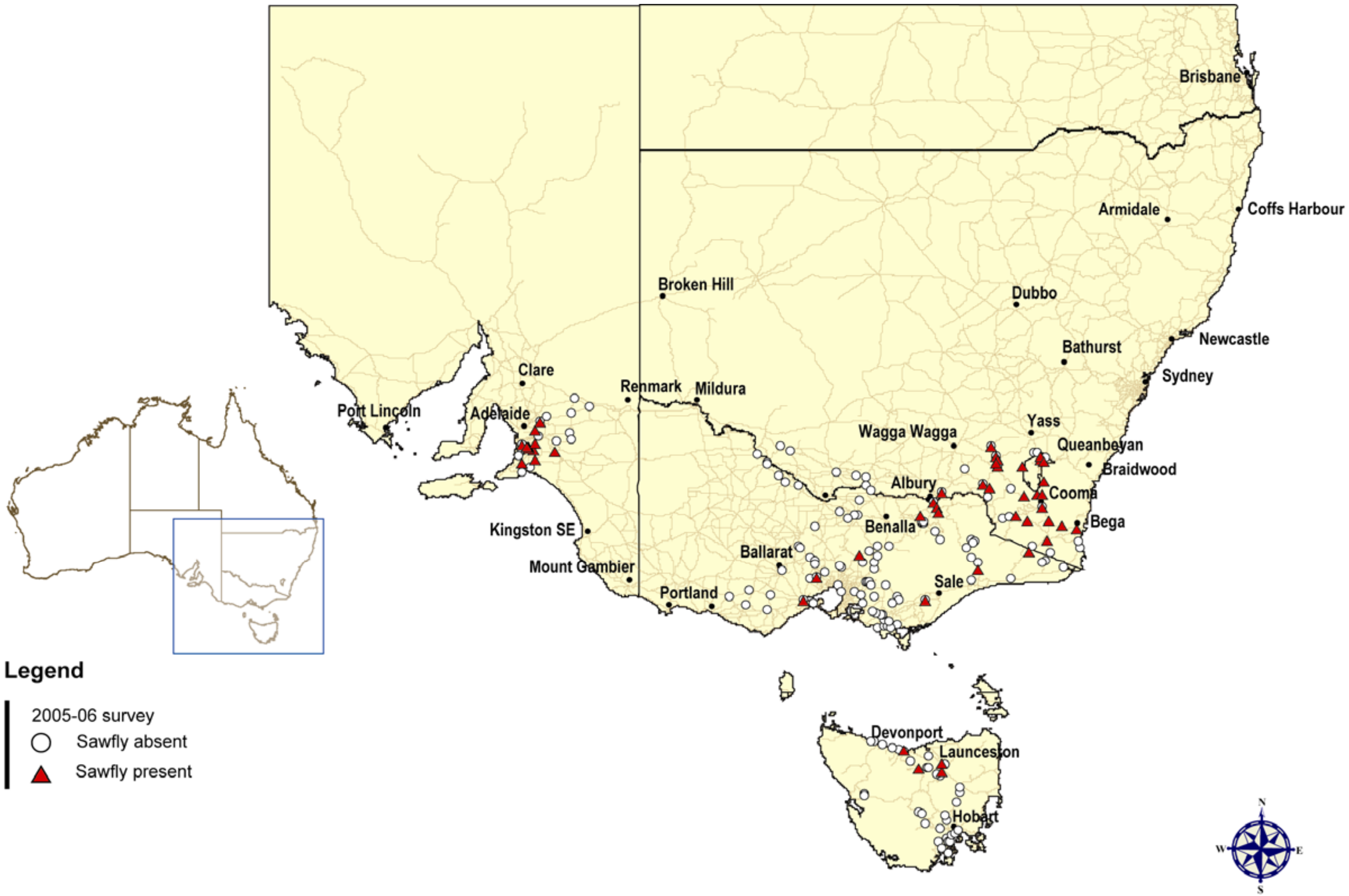

Figure 23. Map of south-eastern Australia showing location of all willow sawfly sightings reported as at April 2006.

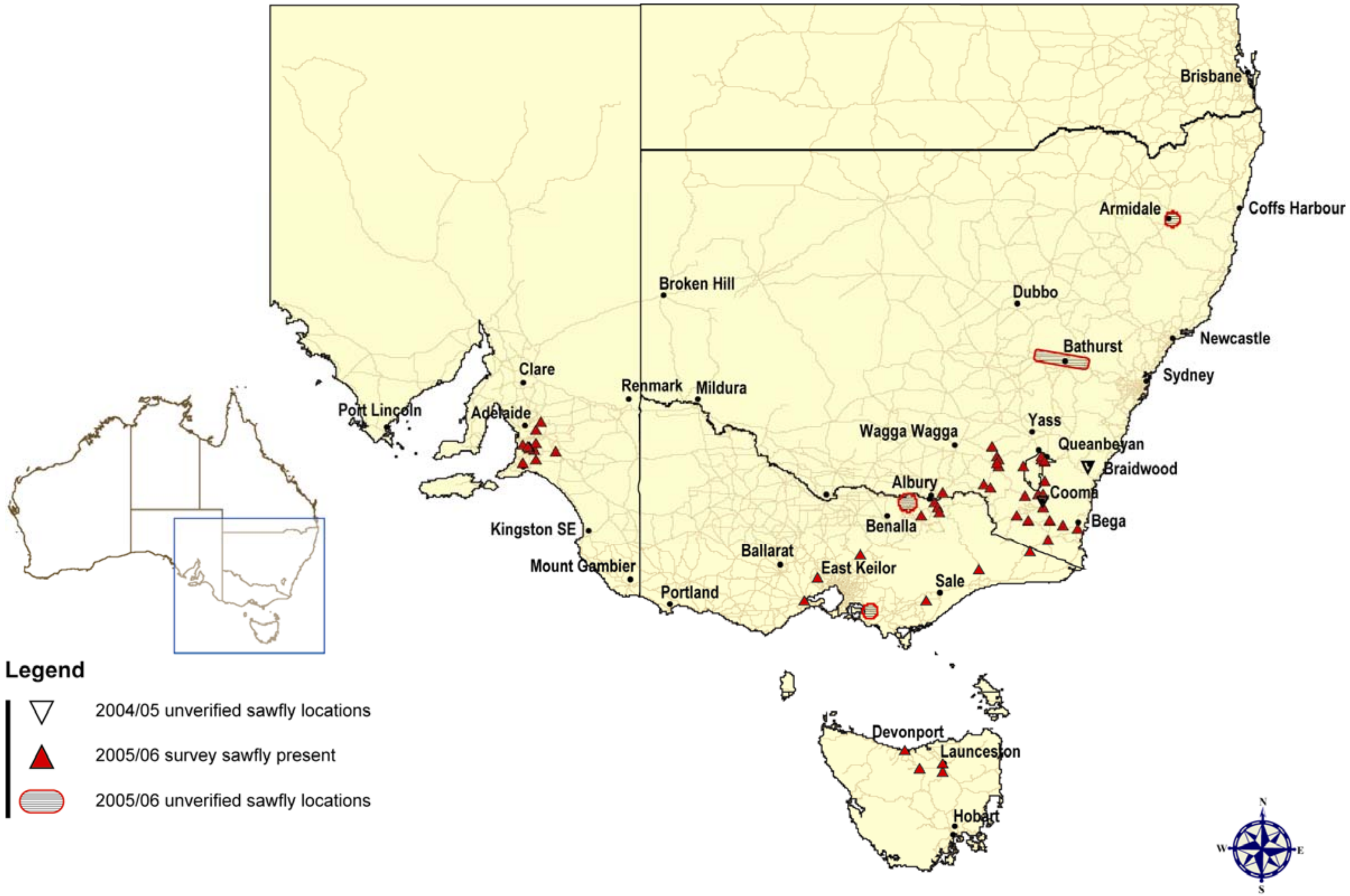

Figure 24: Defoliated crack willows (*S. fragilis*) along the Kiewa River, north-east Victoria, 16 Jan, 2006.
(Photo: S. Guinane)

Section 8.2: The 2005/06 Season

A field survey was undertaken by Dr Kyla Finlay of DPI Victoria in the 2005/06 season to assess the invertebrate and fungal taxa associated with willows in southern Australia (Finlay and Adair, 2006). As part of this survey, the presence of willow sawfly on willows was noted. The data presented on Fig. 22 include all the sites where willows were assessed, with those sites where willow sawfly was found highlighted.

Willow sawfly were found on 76 willows, out of a total sample of 336 willows. Almost half of these records were on *S. fragilis* (crack willow) or hybrids of crack willow. Sawfly were also recorded on several weeping willow taxa: *S. babylonica* (11 records), *S.* x *sepulcralis* var. *chrysocoma* (9 records), and *S.* x *sepulcralis* var. *sepulcralis* (8 records).

Other tree willow taxa on which sawfly was occasionally found were *S. alba* var. *vitellina* (golden upright willow), *S. humboldtiana* (Chilean pencil willow), *S. matsudana* 'Tortuosa' (tortured willow) and another *S. matsudana* hybrid. The only shrub willows on which sawfly were found were two *S. cinerea* (grey sallow) plants, which represents the first confirmed field sightings of willow sawfly on this species in the Southern Hemisphere (Finlay and Adair, 2006).

No attempt was made to quantify the sawfly populations or to assess extent of tree defoliation in this survey. However, it was noted that the level of defoliation was high on crack willow and its hybrids, in comparison with its occurrences on grey sallow which constituted only a few individual sawflies. Sawfly was found on grey sallow only at sites where crack willow was not present.

Sawfly were found from late October, 2005, right through the season until sampling ceased in late March, 2006.

This survey confirmed willow sawfly records from locations in previous seasons, with sawfly being found in the ACT; southern NSW; the Adelaide Hills; and East Keilor, Melbourne.

New records were obtained from South Australia around Murray Bridge; Victor Harbour; and the Barossa Valley, and from several areas in southern NSW (Fig. 22). Sawfly was also recorded for the first time in Tasmania, at four locations in the north of the state (Fig. 22) (Finlay and Adair, 2006).

In Victoria, new sawfly records were found in Geelong; Yea in central Victoria; at Rosedale, Tambo Crossing and Bendoc in Gippsland; and in a number of places in the north-east of the state (Fig. 22).

Anecdotal reports of willow sawfly increased in 2005/06 and the locations of these sightings are included in Fig. 23 as unverified sawfly locations. Sawfly was reported at several sites in NSW, including Armidale in the north of the state; from Lithgow to Orange; and from a site south of Holbrook in the south of the state (P. Ash, pers. comm.; S. Holland-Clift, pers. comm.). In Victoria, sawfly arrived at several sites in the north-east (see Section 8.3 below), and tentative sightings were also reported from the Bass and Powlett Rivers in West Gippsland (M. Gibson, pers. comm.).

Fig. 23 collates all the sightings (both verified and unverified) of willow sawfly reported as at April 2006, including sightings from previous years. It should be noted, however, that this map only records known sightings of willow sawfly, and it is highly likely that willow sawfly is already present in many locations where its presence has not been recognised. As more people become aware of willow sawfly and its effects on willow trees, it is expected that the number of sawfly sightings will increase.

Section 8.3: North-East Victoria - A Case Study (Andrew Briggs, NECMA)

An outbreak of willow sawfly was initially confirmed along the Kiewa River in north-east Victoria, in early summer 2005. The outbreak covered an expanse of river extending for approximately 10 km upstream and 5 km downstream of the township of Kiewa itself. The infestation was initially reported by land-holders concerned that unauthorised poisoning of willows was taking place. Most severely attacked were the extensive stands of crack willow (*S. fragilis*) along the river. Interestingly it appeared that weeping willow growing adjacent to the infested crack willow were not being attacked by the sawfly, until later in the summer when they too were defoliated as the availability of crack willow declined. This preference for crack willow over weeping willow was observed at other locations.

By autumn 2006 sawfly had been observed across most of the catchment area, including the following streams:

- Kiewa River
- Middle Creek
- Finns Creek
- Mitta Mitta River
- King River
- Ovens River
- Queens Creek

It can be assumed that the sawfly exists along many other waterways throughout the region and have not yet been identified or reported. With one exception, in all instances the sawfly was initially observed feeding on crack willow. The one exception is notable - it was black willow (*S. nigra*) along the Ovens River immediately upstream of the Hume Freeway bridge. In this reach of the Ovens River crack willow is relatively uncommon and the willows throughout this reach are almost exclusively black willow. Black willow was also attacked along the Kiewa River and Finns Creek, but in conjunction with crack willow. Damage to the black willow was every bit as severe as that seen on the crack willow, with most trees completely defoliated.

Observation of the crack willow behind the Authority’s works depot at Kiewa seemed to indicate that after the initial defoliation event there was some recovery made by the trees, however once this new growth had been removed there was little or no further regrowth, other than minor shoots from the bases of trees. It would appear that there has been some death in the tips of the canopy of these willow trees, although this will not be able to be measured until spring when the new season’s growth appears.

Section 9

Control of Willow Sawfly

In both Australia and New Zealand, initial recognition of the arrival of willow sawfly occurred at a stage of the incursion when it was already too late to attempt to eradicate the insect due to the widespread nature of its distribution (van Kraayenoord, 1997; Bruzzese and McFadyen, 2006). It does not appear that attempts to eradicate the insect from southern Africa or South America have been made.

Section 9.1: Biological Control

As mentioned in Section 5.3, *N. oligospilus* does have a range of natural enemies, some of which have been investigated for potential use as biological control agents in Argentina (Alderete and Fidalgo, 2004). A classical biocontrol program has also been proposed by HortResearch for control of willow sawfly in New Zealand (J. Charles, pers. comm.). However, at this stage it seems unlikely that either of these programs have yet proceeded to the point of testing potential agents.

It should be noted that if a successful biocontrol agent is introduced into New Zealand, there is a risk that that agent could make its way to Australia and affect willow sawfly populations here.

It is possible that natural enemies can have a significant impact on willow sawfly populations in the Southern Hemisphere, as shown by Alderete and Liljesthröm (2004). Declines in sawfly populations in some areas of New Zealand cannot be fully explained by climatic influences, and so these populations are possibly being kept in check by parasitism or predation. This possibility has not been investigated in the field in New Zealand to date (I. McIvor, pers. comm.). It is also possible that willow sawfly in Australia will be predated or parasitised by existing species in the invertebrate fauna, but no data exist to test this hypothesis at this stage.

Section 9.2: Chemical Control

Willow sawfly can be controlled with broad-spectrum insecticides, but there are currently no products registered in Australia for the control of *N. oligospilus* (Bruzzese and McFadyen, 2006). One of the problems with using broad-spectrum insecticides on this insect is the impact of the insecticide on other invertebrates and the limitations imposed on using such products in the riparian environment (Urban and Eardley, 1995).

There are some insecticides registered for use on “sawfly”, but none of these are registered for use in riparian situations. Further information can be obtained from the DPI Customer Service Centre (telephone: 136-186).

However, it has been recognised elsewhere that on a wide scale, chemical control of *N. oligospilus* is not environmentally or economically feasible, nor is it practical (Alderete *et al*., 2004; Charles *et al*., 2004).

The bacterial suspension Bt (*Bacillus thuringiensis*), which has been used successfully against a number of plant pests on a wide scale, is not effective against willow sawfly (Alderete and Fidalgo, 2004).

In some situations, small-scale chemical control of willow sawfly may be justifiable or desirable. Disbury *et al*. (2004) undertook a trial using the naturally-derived insecticide Spinosad on trees of *S. alba* var. *vitellina* (golden willow) in Hawkes Bay, New Zealand. Spinosad is derived from the fermentation of the bacterium *Saccharopolyspora spinosa* and is active against Hymenoptera but has a reduced risk profile for non-target species. However, this insecticide is highly toxic to aquatic invertebrates.

The number of sawfly larvae and pupae were counted on trees prior to spraying with Spinosad, and at regular intervals for 28 days after spraying. Larval numbers declined sharply immediately after spraying, and remaining larvae ceased feeding. A week after spraying, there were no live larvae on treated trees, but larval numbers had also declined on control trees, possibly due to the levels of defoliation of these trees. Defoliation continued to occur on control trees, with defoliation estimated at 65% on control trees at the end of the trial, compared with defoliation of 7% on treated trees. The insecticide treatment also reduced egg-laying and larval development on sprayed leaves for up to two weeks after spraying. These authors concluded that Spinosad had potential to provide good control of willow sawfly on individual trees for some weeks.

It is also possible to provide some protection to willow trees using stem-injected insecticides, and the Hawke’s Bay Regional Council have done some work with different chemicals. They found that it was important to inject the insecticide on all sides of the stem as leaves growing on a side that hadn’t been protected were defoliated by the sawfly, while remaining leaves were not attacked (D. Gorst, pers. comm.). However, this potential method of control is only feasible on a very localised scale (e.g. an iconic specimen tree) and could only be used in areas where willow leaves are not entering invertebrate food chains. Because willow leaves enter waterways and provide food for aquatic invertebrates, stem injection is not suitable for willow sawfly control in riparian areas.

Section 10

Interactions Between Willow Sawfly and Willow Taxa

One of the key concerns of river health managers is knowing which willow taxa are more susceptible to willow sawfly, and whether any taxa are resistant to the sawfly. It is possible to make some generalisations about taxa susceptibility, but there is conflicting evidence, and so it is likely that it will be some time before this issue can be clarified in the Australian context.

However, there is agreement that generally, tree willows (*Salix* subgenus *Salix*) are more susceptible to willow sawfly than shrub willows (*Salix* subgenus *Vetrix*).

Section 10.1: Tree Willows

Of the tree willows, the following species have a high potential to be seriously affected by willow sawfly:

S. alba and hybrids	(white willow)
S. alba var. *vitellina*	(golden upright willow)
S. fragilis and hybrids	(crack willow)
S. humboldtiana = *S. chilensis*	(Chilean pencil willow)
S. matsudana and hybrids	(Peking willow and the NZ hybrids)
S. nigra	(black willow)

S. babylonica (weeping willow) can also be defoliated by willow sawfly but appears to be a less preferred host, with sawfly feeding on other taxa if adjacent.

Willow sawfly has also been recorded on other tree willow taxa, but the extent of defoliation is unknown. These include:

S. elegantissima	(Thurlow weeping willow)
S. 'Erythroflexuosa'	(golden tortured willow)
S. matsudana 'Tortuosa'	(tortured or twisted willow)
S. x *sepulcralis* var. *chrysocoma*	(golden weeping willow)
S. x *sepulcralis* var. *sepulcralis*	(weeping willow)

Section 10.2: Shrub Willows

Although generally immune from willow sawfly attack, some shrub willow species have been affected by willow sawfly. Hawke's Bay Regional Council staff consider the following taxa to be susceptible to sawfly:

S. elaeagnos x *daphnoides* 'Tiritea'	(hoary x violet willow)
S. purpurea 'Booth'	(purple osier)
S. repens x *purpurea* 'Kumeti'	(creeping willow x purple osier)

Willow sawfly has also be recorded on the following shrub willow taxa, but extent of defoliation is unknown:

S. caprea	(goat willow)
S. cinerea	(grey sallow)

Section 10.3: Poplars

Willow sawfly has been recorded on a number of poplar taxa in other countries, but only appears to be problematic in the field in South America where it attacks *Populus alba* (white poplar) and *P.* x *canadensis* (Dapoto and Giganti, 1994). It is unlikely that willow sawfly will have a significant impact on poplars in Australia.

Section 10.4: Other Taxa

There are no reports in the literature of *N. oligospilus* being found on any taxa other than *Salix* and *Populus*, and there have been no observations of the sawfly appearing on any native species in

New Zealand. It is highly unlikely that the *N. oligospilus* will attack any taxa other than willows and poplars in Australia.

Section 11

Predictions of Possible Outcomes in Victoria

Synthesising all the preceding information about willow sawfly leads to two differing forecasts for possible outcomes of the impact of willow sawfly in the Victorian environment.

Firstly, it is possible that willow sawfly will establish in Victoria over the next two to three seasons, and cause some defoliation of willow trees, but that the population of willow sawfly does not build up to damaging levels. In this scenario, sawfly population levels are limited by environmental factors and possibly by predation. Willows may be moderately affected, but extensive tree death is unlikely. Cycles in population levels may be seen, with some years being more favourable for sawfly development, and other years less so. The impact of sawfly is likely to be greater initially, but the sustained impact is limited, as has happened in many regions of New Zealand. The outcome of this scenario is that, over time, willow sawfly has little impact on willow management and hence riparian management.

The second scenario involves the same dispersal of willow sawfly across the state, but with large populations developing in many locations. Under this scenario, willow trees are subjected to several, severe defoliation events over successive seasons, which result in widespread tree deaths (as has occurred in the Hawke's Bay in New Zealand). Sawfly populations build to damaging levels in most seasons, and in many locations. The outcome of this scenario is that, over time, willow sawfly has a major impact on willow management and hence riparian management.

A variation on this scenario is that willow trees are defoliated once, early in a season and remain bare until the following spring. If these same trees are defoliated over successive years, then it is likely that tree deaths will eventually occur, but it may take several years of annual defoliation events to kill trees.

All of these outcomes are predicated on the assumption that willow sawfly will disperse widely across Victoria in the near-term. The evidence suggests that this is highly likely to happen. The experience from other countries and from Australia to date suggests that the sawfly will disperse rapidly across the state. In both South America and New Zealand dispersal rates for willow sawfly were measured at about 300 km per year. As the sawfly is already present in the north-east of the state, in central Victoria, in three sites in Gippsland, in Melbourne and in Geelong, it is only a matter of time before sawfly populations establish in all areas of the state where there are significant numbers of willows.

It also seems likely that in localities with susceptible willow taxa and under environmental conditions conducive to willow sawfly, populations will build up and tree defoliation will occur. If defoliation events are frequent and serious, then there is a high likelihood of tree deaths.

What is less clear are the factors that influence the build-up of sawfly numbers. It seems that environmental factors, particularly temperature, are important in determining population levels. In conditions suited to the sawfly (warm spring conditions, for example), sawfly populations may increase to potentially damaging levels. Ideal environmental conditions combined with the increased egg-laying potential of females and the rapid development of sawfly in spring has the potential to lead to dramatic population increases, and to the maintenance of high population levels throughout the season, which then results in severe tree damage.

It is also currently unknown how willow sawfly populations cope with the higher temperatures common in summer in Victoria, particularly in the northern areas of the state. High temperatures may limit population development, and hence prevent damaging outbreaks of the insect. Or it is possible that high temperatures (perhaps coupled with very dry conditions) prevent willows redeveloping leaves after a defoliation event, limiting willow sawfly population development over a season.

It is possible that a mixture of outcomes will occur in Victoria, with some areas experiencing significant impacts from willow sawfly, and other areas not impacted to any significant extent. This patchiness in impact may relate to environmental conditions, and also the predominant willow taxa in an area.

It is generally agreed some of Victoria's worst willow species, particularly crack willow and black willow are likely to suffer severe willow sawfly infestations. However, grey sallow, which is also an extremely serious weed, is unlikely to be attacked by willow sawfly. If willow sawfly infestations do lead to extensive tree deaths in these susceptible willow species, it is likely that in the medium to long term, resource allocation to willow management may need to be refined. Overall riparian management, including replacement of willows with native species, will also need refinement under this scenario. In some situations where trees are defoliated but not killed, it is possible that recruitment of native species may be enhanced by the increased light levels under the defoliated willow canopy, particularly if willows remain bare for some months after defoliation.

There are many questions still unanswered about willow sawfly and the consequences of its arrival in Victoria. Over the coming three seasons, this project aims to gain a greater understanding of sawfly biology, environmental influences on the sawfly and the consequences for riparian management, particularly the re-introduction of native species into riparian areas.

Section 12

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Note: pers. comm. after a person’s name in the text is an abbreviation for Personal Communication and relates to information relayed by either conversation or unpublished text.