Willow Sawfly Activity in Victoria
Final Report, June 2011

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Willow Sawfly Activity in Victoria: Final Report, June 2011

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Melbourne Water

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Executive Summary

Introduction

Willows (*Salix* spp.) are serious weeds of waterways and wetlands in many parts of Victoria and south eastern Australia due to their highly invasive nature and their numerous detrimental impacts on the physical and biological components of waterways.

Willow sawfly is an insect native to the Northern Hemisphere which has become invasive in Southern Hemisphere countries. The larval stage of the life cycle consumes willow leaves, and high populations can completely defoliate willow trees. Repeated, severe defoliation events have led to willow tree deaths in other countries.

Due to concerns from waterway managers about the potential impacts of willow sawfly on willows and their management in Victoria, a project was established in 2006 to monitor willow sawfly activity and impacts. This project concluded with the final monitoring of sites in the 2010/11 season. This report provides an analysis of the data collected this season and a synthesis of project findings over the lifetime of the project.

Monitoring Willow Sawfly Activity

Results from the 2010/11 Season

Four sites in north east Victoria were monitored by assessing willow sawfly population levels and tree defoliation levels three times during the season. Each site had been monitored since the 2006/07 season. At two sites, an estimate of the ratio of live:dead material was also carried out in spring.

Monitoring in the 2010/11 season found that:

- willow sawfly population levels were low at all four sites on all willow species;
- no tree defoliation occurred at the monitoring sites in 2010/11;
- low populations were possibly the result of flooding in early spring affecting the viability of over-wintering cocoons;
- the ratio of live:dead material changed little from the previous season at one site and increased in some trees at the second site due to the loss of dead material.

Few new willow sawfly sites were reported during the season and the current distribution of willow sawfly includes sites in south west Western Australia, eastern South Australia, northern Tasmania and an arc of sites from southern Victoria, through ACT and eastern NSW up to the Queensland border.

Outcomes of the Monitoring Program

Monitoring over five seasons has shown that willow sawfly will consume foliage from a range of willow species. Larvae have been found on leaves of poplar trees (*Populus* spp.) very occasionally, causing only on minor damage. It is extremely unlikely that willow sawfly larvae will consume leaves of any other species, including native species.

Given the host specificity of willow sawfly, its distribution across the landscape is limited to locations with suitable willow hosts. However there appear to be few other limitations, either environmental or biological, to its distribution and it is expected that willow sawfly will continue to expand its range across temperate Australia to all areas which have suitable willow hosts.

The monitoring program also found that:

- willow sawfly populations vary within a season, between seasons and between sites due to a range of environmental and biological factors;
- at some sites, willow sawfly has maintained low populations for 5 seasons;
- at other sites, populations have undergone a boom and bust cycle with high levels in consecutive seasons followed by a steep decline in subsequent seasons;
- high populations of willow sawfly generally result in tree defoliation and several defoliation events may occur during a season.

Impacts of Willow Sawfly

Impacts on Willows

Willow sawfly affects willow trees by causing:

- whole canopy defoliation, which is a short term impact of high willow sawfly populations; and
- the dieback of twigs, branches and stems, which is the only obvious longer term impact of repeated defoliation by willow sawfly on willows in Victoria.

Despite these impacts, repeated tree defoliation events over several seasons have not yet killed any trees at monitoring sites, and although high willow sawfly populations have been sustained in many locations, there have been no confirmed tree deaths in Victoria as a result of willow sawfly activity over the past five seasons.

This outcome was not predicted at the outset of the project. Based on international experience, at that time it was predicted that high willow sawfly populations across much of the landscape would lead to extensive willow tree deaths.

Impacts on Willow Management

As willow sawfly has not had any impact on willow populations, it is unlikely that the insect will affect any aspects of current or future willow management.

However, at sites with high willow sawfly populations where willow management is unlikely to be undertaken, a native-dominated riparian community can be established under defoliated willow trees, if other factors are not limiting. This outcome has been achieved at a trial site in north east Victoria where there has been very strong growth of a number of native tree and shrub species over the past three seasons.

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1. Introduction

1.1 Willows and Willow Sawfly

Willows (*Salix* spp.) are serious weeds of waterways and wetlands in many parts of Victoria and south eastern Australia. Both willow trees and shrubs can be highly invasive, spreading by seed and by vegetative means, such as stem fragments. Stem fragments tend to spread willows within water courses, whereas seed can be blown several kilometres across the landscape, with some seedlings being traced back to parent trees (through genetic fingerprinting) that are 50 km distant (Hopley pers. comm.).

Many species of willow have significant detrimental impacts on the structure and functioning of waterways, including altering stream hydrology, exacerbating bank erosion and affecting sedimentation processes. Willows also affect aquatic and terrestrial flora and fauna by changing food webs, decreasing the amount of suitable habitat and competing for resources, particularly light.

Due to their invasiveness and detrimental impacts, considerable resources have been invested in willow management over recent years. The ‘Willows Management Guide’ (Holland-Clift and Davies 2007) has been produced to provide managers with guidance on the most appropriate management techniques for willows growing in various situations. Despite the ready availability of management information and the significant level of resources that has been invested in willow management activities over the past decade or more, there are still many areas of the riverine landscape where willows dominate the vegetation.

Willow sawfly (*Nematus oligospilus* Förster (Hymenoptera: Tenthredinidae)) is an insect native to the Northern Hemisphere where it feeds on the leaves of various willow species. It has become invasive in a number of Southern Hemisphere countries, and where it has sustained high population levels over a number of seasons, willow sawfly has caused the death of willow trees.

It is during the larval stage of the life cycle (Fig. 1) that willow leaves are consumed and high numbers of larvae can defoliate entire trees within a few weeks. The insect completes several generations within a season, so although willow trees can regrow more foliage during the season, this new foliage is often consumed by a new generation of larvae. Details of the life cycle of willow sawfly are provided in Ede (2006).

1.2 Monitoring Willow Sawfly Activity and Impacts

The first verified observation of willow sawfly in Australia was made in Canberra in March 2004 (Bruzzese and McFadyen 2006), although it is likely that the insect was present in Australia prior to this but in such low numbers that it remained undetected. Since that time, willow sawfly has spread across the south east of Australia and parts of south west of Western Australia.

Due to concerns from waterway managers about the potential impacts of willow sawfly on willows and their management in Victoria, a project was established in 2006 to monitor willow sawfly activity and impacts. The first phase of this project was a review of the international literature about the insect and its affects on willows, particularly in the Southern Hemisphere, to gain a better understanding on the likely impacts of willow sawfly in the Victorian context (Ede 2006).

A long term monitoring program was then initiated in the 2006/07 season, with monitoring undertaken at sites in north east Victoria, where the first willow sawfly populations developed in the state, and in southern Victoria. At some of these sites, intensive monitoring of willow sawfly populations, extent of tree canopy and defoliation, leaf areas and light levels were undertaken at regular intervals over three seasons. Willow sawfly populations and tree defoliation levels were monitored at the remaining sites. Results from these activities are reported in Ede *et al*. 2007 and Ede *et al*. 2009.

The monitoring program was scaled back after three seasons, but assessment of willow sawfly populations and tree defoliation levels continued at a limited number of sites in 2009/10 (reported in Ede *et al*. 2010) and in 2010/11, reported here.

In addition, assessments of the amount of dead material were made over four seasons on selected trees at two sites with high willow sawfly populations, in order to determine if willow sawfly was likely to cause substantial numbers of tree deaths.

In parallel with this monitoring program, an experimental trial was designed to test whether it would be possible to establish native riparian species under defoliated willow canopies. It was envisaged that the information gained from this study would be applied to sites with active willow sawfly populations where willow management was unlikely to be undertaken. At these sites, the increased light available to the understorey as a result of tree defoliation could provide the opportunity to establish native-dominated riparian communities.

This trial was established at three sites in winter 2008 and involved planting nursery-raised tube stock and direct seeding. Plant survival and growth at all sites were monitored for three growing seasons. A full description of the trial is given in Ede *et al*. 2010, with initial results also presented in Ede *et al*. 2009. The final results from the trial are presented in this report.

As well as documenting the results of assessments undertaken in the 2010/11 season, this final report synthesises the findings of the project over the past five years and the outcomes of the overall project.

Figure 1: Willow sawfly larvae on a willow leaf and twig

2. Monitoring Willow Sawfly

2.1 Introduction

Monitoring of willow sawfly population levels and the extent of tree defoliation has been undertaken at a number of sites in north eastern and southern Victoria since the 2006/07 season. The extent of the monitoring program was scaled back in the 2010/11 season as the overall project came to an end.

The monitoring program was designed to determine the impact of willow sawfly on willows and their management. It included assessments of tree health and tree death, as well as collating all new records of willow sawfly locations.

2.2 Sites and Methods

Four sites were monitored in north east Victoria in the 2010/11 season (Table 1). All sites had been monitored each season since 2006/07.

Sites were monitored three times during the season, in late spring, summer and autumn. During each assessment two parameters were monitored:

1. willow sawfly population levels;
2. extent of tree defoliation.

Willow sawfly population levels were estimated by counting the number of larvae visible on all accessible foliage during a five minute period. All sizes of larvae were counted and other stages of the life cycle were noted if present.

The extent of defoliation of the tree canopy was estimated by one observer and recorded as percentage of total canopy defoliated by willow sawfly. Notes on tree health were also recorded where appropriate.

In addition to this regular monitoring, one brief visit was made to each of two sites in southern Victoria which had been included in the monitoring program in previous years.

Table 1: Site Locations and Willow Taxa Monitored at Sites in 2010/11 Season

Site	River	Willow Taxa Assessed
Everton	Ovens River	Black willow (*S. nigra*) Crack willow (*S. fragilis*) Golden upright (*S. alba* var. *vitellina*) Purple osier (*S. purpurea*)
Happy Valley	Happy Valley Creek	Crack willow (*S. fragilis*)
Kergunyah	Tributary to Kiewa River	*S.* x *rubens*
Kiewa	Kiewa River	Crack willow (*S. fragilis*) Weeping willow (*S. babylonica*)

At two sites (Kergunyah and Kiewa), assessments of the ratio of live:dead material had been made in three previous seasons and these assessments were repeated in spring 2010. These assessments were visual estimates of the ratio of live:dead material over the whole tree. As such, judgements were difficult to make, so the results are subjective and only give an indication of the extent of change over time rather than an absolute measure.

Details of new willow sawfly locations, reported by land holders and land management agency staff, were entered into the existing database. Maps of all known willow sawfly sites were then produced using these data.

2.3 Results

2.3.1 Willow Sawfly Population Levels

In comparison with previous seasons, population levels of willow sawfly were low at all monitored sites and did not increase to any significant extent during the season (Table 2). At Everton and Kergunyah, willow sawfly populations had been high for several seasons, as characterised by 5 minutes counts which found more than 50 larvae. However at Happy Valley, high populations had only developed in the 2009/10 season.

This was the second consecutive season with low population levels at Kiewa, after a number of seasons with high levels.

Table 2: Number of Willow Sawfly Larvae at Monitoring Sites Assessed During the 2010/11 Season

		Average Number of Willow Sawfly Larvae Found During a 5 Minute Count		
Site	**Willow Taxa**	**Oct 2010**	**Jan 2011**	**Mar 2011**
Everton	Black	0	3	0
	Crack	1	2	0
	Golden	0	0	0
	Purple	0	1	0
Happy Valley	Crack	3	3	12
Kergunyah	*S.* x *rubens*	4	8	12
Kiewa	Crack	2	5	17
	Weeping	0	3	11

2.3.2 Tree Defoliation and Tree Health

Due to low willow sawfly populations, no whole tree defoliation was observed at any site during the 2010/11 season and there was no evidence of defoliation of any extent during the season. The populations that did develop resulted in damage to individual leaves. Most commonly this damage was confined to the development of small to moderate sized holes in leaves, but occasionally larvae consumed the entire lamina, leaving only the midrib.

Overall tree health was good, and it is likely that trees at all sites responded to the increased available moisture throughout the season. Most trees monitored maintained healthy canopies all season, including those trees which had shown signs of stress in previous seasons, indicating a recovery of canopy health.

At the Happy Valley site in 2009/10, high population levels and tree defoliation were observed on two grey sallow (*S. cinerea*) plants. However, this was not repeated in 2010/11 and these plants were not defoliated by willow sawfly this season.

The very brief assessments of two additional sites, Healesville and Tarago River in southern Victoria, which had both been included in the monitoring program previously, indicated similar results to the sites in north east Victoria. No defoliation was obvious at either site and tree health was good, with fully canopy development. There was some limited leaf damage on some trees at the Tarago site and a number of larvae were observed, although 5 minute counts were not undertaken. Thus is appears that willow sawfly populations at both these sites were also very low during the 2010/11 season.

2.3.3 Tree Death

Although the health of trees monitored at sites has varied over the past five seasons, no overall tree death has been observed at any sites. There has been one unconfirmed report of tree death arising as a result of willow sawfly activity in West Gippsland, but it has not been possible to verify this report.

For those trees assessed for the ratio of live:dead material at the Kergunyah site, there was very little change in the estimates made in October 2010 compared with those made a year previously (Table 3). Over the four years of assessments, the greatest change in the ratio occurred between 2007 and 2008 when it increased for Trees 1, 2, 3 and 5, and decreased for Tree 4 (Table 3). No change in the ratio has been observed in Tree 6 over the four seasons.

Willow sawfly population levels were low at the Kiewa site during the 2009/10 season, and so any decrease in the proportion of live material between October 2009 and October 2010 would not have been expected. In general, there was an increase in the amount of live material (Table 3). In the case of Tree 2, this increase from an estimate of 70% live material in 2009 to 90% in 2010 resulted from the loss of a significant portion of the dead branches and large stems of this tree, which left behind predominantly live material. It is likely that similar losses of dead material from Trees 5 and 6 resulted in the change in ratios assessed for these trees, but the branches that had been lost were smaller and their loss was less obvious than was the case for Tree 2.

There had also been a dramatic increase in the amount of live material on Tree 4, the cause of which is unknown. This tree has been dominated by dead material through all assessments, but in the current season produced and retained healthy foliage across much of the tree. Because this tree is growing directly in the watercourse, this change is unlikely to be due to improved water availability.

Table 3: Change in Ratio of Live:Dead Material on Trees Between October 2007 and October 2010

Tree	October 2007	October 2008	October 2009	October 2010
Kergunyah				
Tree 1	40% live	60% live	60% live	60% live
Tree 2	50% live	80% live	70% live	80% live
Tree 3	80% live	90% live	90% live	80% live
Tree 4	30% live	20% live	Not assessed*	Not assessed*
Tree 5	80% live	90% live	90% live	90% live
Tree 6	70% live	70% live	70% live	70% live
Kiewa				
Tree 1	90% live	80% live	70% live	80% live
Tree 2	80% live	80% live	70% live	90% live
Tree 3	90% live	90% live	80% live	90% live
Tree 4	10% live	20% live	10% live	50% live
Tree 5	60% live	60% live	60% live	80% live
Tree 6	60% live	60% live	50% live	70% live
Tree 7	80% live	80% live	90% live	90% live

* A portion of this tree was still alive at the time of each assessment, but due to restricted access, it was extremely difficult to estimate the ratio of live to dead material

2.3.4 Willow Sawfly Activity at Other Sites

Across much of Victoria it appears that willow sawfly population levels were low in the 2010/11 season. Very few reports of new willow sawfly locations and/or tree defoliation were received during the season.

In north east Victoria, a new sighting was reported from Nariel Valley, south of Corryong, in January 2011, while in central Victoria some tree defoliation was reported in areas around Kyneton, Hepburn and Newstead with some activity occurring on Jim Crow Creek which runs between Hepburn and Newstead.

Tree defoliation was also observed on several trees at sites along the Lower Mitchell River, west of Bairnsdale in Gippsland, where willow sawfly had been active the previous season as well. In West Gippsland, between Heyfield and Maffra, some partial tree defoliation was observed on trees in March 2011.

Two reports of willow sawfly activity were also received from south west Western Australia, where willow sawfly has been active over the previous two seasons. At a site near Bridgetown, south east of Bunbury, very high willow sawfly populations were observed in December 2010 which caused the defoliation of several upright, weeping and tortured willow trees growing around a farm dam. The second report was from Denmark, which is west of Albany on the south coast, where willow sawfly populations were affecting Chilean pencil willows (*S. humboldtiana*).

2.4 Discussion

It is unclear why willow sawfly population levels were so low in 2010/11 but it may be due to a number of factors. Many insect populations experience boom and bust cycles in response to environmental and biological triggers. These factors include the development of strong predator or parasite populations that directly impact on the target insect, although evidence of predation or parasitism at levels that would impact on willow sawfly populations was not observed during the season.

It is also possible that willows trees affected by willow sawfly have begun to manufacture a range of chemicals that decrease the palatability of the leaves to willow sawfly, but without biochemical analysis it is not possible to test this hypothesis. It also seems unlikely that willows at Happy Valley would be producing such chemicals only one season after the first whole tree defoliation events, while at other monitoring sites whole tree defoliation has been occurring each season for 3 - 4 seasons.

It is more likely that the low population levels in the 2010/11 season relate to floods in early spring. Willow sawfly larvae over-winter in cocoons spun at the end of the season, in late autumn. It appears that many of these cocoons are located in the leaf litter and topsoil under and around willow trees. It is likely that prolonged inundation of these areas would affect the viability of larvae within the cocoons, potentially drowning many of them. All the monitoring sites experienced some level of flooding early in the season, with high water levels inundating areas directly under the monitored willows. It is also possible that the floods washed away cocoons which may not be sufficiently robust to withstand relocation in turbulent flood waters.

If indeed floods were the major factor resulting in the low willow sawfly population levels both at the monitoring sites and more generally across the landscape, it will be interesting to determine how quickly population levels rebuild. It may be 2 - 3 seasons before high populations and whole tree defoliation are commonly observed again. If however, other factors are impacting on population levels, then it may be several years before any noticeable increase in numbers occurs, if populations ever do recover to previous levels.

Key Points:

- Willow sawfly population levels and extent of tree defoliation were monitored at four sites in north east Victoria in the 2010/11 season;
- Willow sawfly populations remained low at all monitoring sites during the season;
- No tree defoliation occurred at monitoring sites during the season;
- Some defoliation of trees was reported from sites in central Victoria and Gippsland, as well as two sites in Western Australia;
- Low populations were possibly a result of flooding in early spring affecting the viability of over-wintering cocoons;
- The ratio of live:dead material monitored in trees at Kergunyah changed little from the previous season, while trees at Kiewa tended to have more live material;
- No whole tree death has been confirmed in Victoria as a result of willow sawfly activity.

3. Management Trials

3.1 Introduction

High populations of willow sawfly cause the defoliation of willow trees, increasing the light levels available to understorey species. This feature of the interaction between willows and willow sawfly formed the basis of a trial to determine whether or not it would be possible to establish native riparian species under willows defoliated by willow sawfly, either by planting or direct seeding.

It was envisaged that at sites with high willow sawfly populations where willow removal is impractical or which are of such low priority that willow control is unlikely to ever be undertaken, this approach of actively introducing native species would have the potential to establish native-dominated riparian vegetation communities. If successful, the development of these communities would also limit the establishment of riparian weeds which would otherwise flourish under more open willow canopies.

Details of this trial are provided in a report published previously (Ede *et al.* 2010, available from the authors), including a full description of the trial methods, results for the two years after trial establishment, and trial outcomes. The data presented in this report were collected in the 2010/11 season and a brief analysis of these data is provided here.

3.2 Methods

3.2.1 Trial Design

Three trial sites (Table 4) were established in winter/spring 2008. Tube stock of appropriate native species were planted in plots at all sites, and at the Happy Valley and Campaspe River sites, direct seeding was also undertaken in a number of plots (Table 4).

Table 4: Trial Sites and Treatments for Management Trial

Site	Location	Number of Replicates	Revegetation Treatments
Kiewa River	Kergunyah (NE Vic)	8	Planting of tube stock
Happy Valley	Ovens (NE Vic)	8 8	Planting of tube stock Direct seeding
Campaspe River	Kyneton (Central Vic)	8 8	Planting of tube stock Direct seeding

3.2.2 Monitoring

Plant health, survival and heights were assessed at all sites in autumn 2011, at the end of the third growing season. For trees taller than 3 m at the Kiewa River site, the diameter at breast height (dbh) was also measured as accurate tree heights were difficult to obtain. Assessments of willow sawfly populations and the extent of willow tree defoliation were made during the monitoring process.

3.3 Results

The defining feature of the 2010/11 season was the widespread and recurrent flooding which occurred across much of Victoria. All trial sites were affected by flooding to a greater or lesser extent, as outlined below.

3.3.1 Kiewa River Site

Plant Survival and Health

Plants at this site have established extremely well, with most making very strong growth over the three seasons since planting. Although the site was affected by flooding during spring and summer 2010/11, the floods had only limited impact on plant survival and growth due to the location of the trial site above the river.

The overall survival rate across all species at this site was 82%, and survival rates were high for all species except *Bursaria spinosa* (sweet bursaria) (Table 5). The causes of mortality for *B. spinosa* and for plants of the remaining species are unclear, although flood inundation is likely to have resulted in some deaths. At the time of site assessment, standing water was still present in some areas. In some plots, large willow limbs had fallen during the season, crushing and killing a small number of plants, while herbicide spraying appeared to have adversely affected plants in two plots, and may have caused plant deaths in those plots.

Competition with weeds also impacted on plant health and survival in some plots, with two plots particularly affected by bindweed (*Convolvulus* spp.), which is a climber. In these plots, the bindweed had formed dense infestations around several plants, climbing up to more than 3 m in some cases. The weight of the bindweed had bowed over some plants, and it is likely that the impact of the bindweed had resulted in the death of a small number of plants.

Leaf damage, including insect chewing, galls and rust affected the health of a number of *Eucalyptus camaldulensis* (river red gum) trees. Galls were also observed on one *Acacia dealbata* (silver wattle) tree.

Plant Growth

The tallest trees at this site are now more than 6 m tall. Despite the requirement to estimate the heights of the tallest trees due to the difficulty in obtaining accurate measurements, it is obvious that *A. dealbata* trees, particularly, are growing extremely well. Just over 50% of these trees are now more than 4 m in height, as are almost 30% of *E. camaldulensis* trees. *A. melanoxylon* (blackwood) trees are shorter on average (Table 5), with the tallest of these trees reaching 3.3 m.

The diameter (dbh) of trees greater than 3 m tall was also measured, with *A. dealbata* trees averaging 5.1 cm (Table 5) which is an increase of 2.1 cm since April 2010 for those trees measured on both occasions. The average diameters of *E. camaldulensis* and *A. melanoxylon* trees were similar to one another despite *E. camaldulensis* trees being 84 cm taller on average (Table 5).

The three shrub species, *Callistemon sieberi* (river bottlebrush), *Melicytus dentatus* (tree violet) and *B. spinosa* also grew strongly. At 207 cm the average height of the remaining *B. spinosa* plants (Table 5) was 63 cm taller than in April 2010. Annual height increments for the two other shrub species were lower at about 30 cm.

Table 5: Plant Survival, Average Height and Average Tree DBH at Kiewa River Trial Site

Species	% Survival over 3 Seasons	Plant Height (cm) in March 2011	Tree DBH[1] (cm) in Mar 2011
Acacia dealbata	81%	388	5.1
Acacia melanoxylon	93%	235	3.0
Eucalyptus camaldulensis	89%	319	3.2
Bursaria spinosa	41%	207	
Callistemon sieberi	96%	186	
Melicytus dentatus	79%	134	

[1] DBH = diameter at breast height (usually taken to be 1.3 m high) measured for trees taller than 3 m

Willow Sawfly Populations and Tree Defoliation Levels

When assessed in March 2011, willow sawfly population levels were quite low (19 larvae counted in a 5 minute period). Some relatively minor leaf damage as a result of willow sawfly activity was observed.

There was no evidence that whole tree defoliation had occurred at any stage during the season, and at the time of assessment willow canopies were in good health, although senescence was starting to occur.

Thus it is likely that in the 2010/11 season, willow sawfly had relatively limited impact on the willows at this site.

Figure 2: Growth of *Acacia dealbata* and other planted species at the Kiewa River trial site after three growing seasons (reference pole is 2 m high)

3.3.2 Happy Valley Site

Flood Impacts

Severe flooding in September 2010 destroyed several plots at this site. At the upstream end of the trial site, the river burst its banks and created a new channel through the first four plots (Fig. 3). In some areas plots were washed away, while silt and debris deposition across other plots killed plants. As well, several willows were toppled by the floods which also impacted on the growth of plants.

The impact of the flood on this site prevented any systematic assessment of plant growth. However, during a site visit in March, all plots were searched for plants and the heights and health of remaining plants were assessed. These results are presented here.

Tube Stock

Of the tube stock originally planted at this site, only 37 plants were found in March 2011 (Table 6). One unexpected outcome at the site is that the remaining plants do not seem to have been browsed as heavily as in previous seasons. As a result, the average plant heights were generally greater than in the 2010 assessment, particularly for *E. camaldulensis* and *A. dealbata* trees which were 82 cm and 64 cm taller respectively than when assessed in April 2010. The tallest trees of both these species were more than 3 m tall (Table 6). It is also likely that taller, better established plants were more able to survive the floods than smaller plants, which would contribute to an increase in average heights.

Table 6: Numbers and Heights of Surviving Plants at Happy Valley Trial Site

Species	**Number of Plants Found**	**Range of Heights (cm)**	**Average Height (cm)**
Acacia dealbata	9	41 - 383	138
Acacia melanoxylon	7	38 - 131	96
Eucalyptus camaldulensis	8	104 - 320	151
Callistemon sieberi	8	36 - 110	79
Kunzea ericoides	3	34 - 69	54
Melicytus dentatus	2	57 - 82	70

Plant health was generally good, although a number of trees were quite spindly and some plants were either partially buried in flood debris and sediment, or bowed over by fallen branches.

Direct Seeding

In the plots which had been sown, 16 live seedlings and one dead seedling were found in March 2011. The dead plant was an *A. dealbata* which measured 118 cm tall and it is unclear what caused its death.

Of the 16 live seedlings, 10 were *A. dealbata* seedlings, one was an *A. melanoxylon*, a further three were also *Acacia* spp. which could not be identified to species level, and two were *K. ericoides* (burgan) seedlings (Table 7). Most of the seedlings were healthy, although browsing was noted on two of them.

Table 7: Seedlings Found in Direct Seeded Plots at Happy Valley Trial Site in March 2011

Species	Number of Plants Found	Average Height (cm)
Acacia dealbata	10	99
Acacia melanoxylon	1	98
Acacia spp.	3	19
Kunzea ericoides	2	16

Willow Sawfly Populations and Tree Defoliation Levels

Although assessments of willow sawfly populations and tree defoliation were not done at the site this season, assessments were done in the adjacent monitoring site, just upstream, on three occasions during the season. These found an average of six larvae per tree in 5 minute counts (Table 2) and with such low populations, no tree defoliation occurred.

Figure 3: Flood damage in Plots 1 & 2 of Happy Valley trial site, showing some surviving plants

3.3.3 Campaspe River Site

Tube Stock

Floods, particularly in January 2011, inundated this site and damaged a number of plots. Several plants were killed by the floods – probably as a result of both the physical action of the high water and the extended periods of water-logging.

A. melanoxylon and *A. dealbata* plants had the highest survival rates, with most of the plants which were present in April 2010 still present 12 months later. However survival rates for the remaining species were low, particularly for the two *Eucalyptus* species (Table 8). Across all species, 57 of the 121 plants present in April 2010 survived until April 2011 and these represent a subset of the 166 plants planted initially.

A simple analysis of the relationship between plant height in April 2010 and plant survival until April 2011 indicated that these two factors may be correlated for *A. retinodes* (wirilda) plants, and also possibly for *A. melanoxylon* but it is unlikely they are correlated for *A. dealbata*. Too few plants of either *Eucalyptus* species survived to undertake the analysis.

Table 8: Numbers, Survival Rates and Average Height of Plants at Campaspe River Trial Site

Species	Number Remaining Plants, April 2011	Survival between 2010 and 2011	Average Height (cm)
Acacia dealbata	11	65%	44
Acacia melanoxylon	27	77%	53
Acacia retinodes	8	36%	73
Eucalyptus ovata	3	20%	60
Eucalyptus viminalis	4	18%	23
Carex appressa	4	40%	*

* Heights of *Carex appressa* plants have not been measured

Many of the surviving plants exhibited poor health. For a number of plants, the only live material was weak regrowth that had arisen after the plants were damaged by the floods. For example, the heights of three of the four remaining *E. viminalis* plants were less than that previously recorded, in April 2010, as the only live material was regrowth. This meant that the average height of *E. viminalis* was only 23 cm (Table 8), compared with 37 cm in April 2010.

A. retinodes plants were the tallest on average, at 73 cm tall (Table 8). In comparison, there were a number of plants which had been planted at the same time as the trial was established, but which were located outside the plots in areas with very limited weed control. The average heights of surviving plants, particularly the three *Acacia* species, were greater than those planted inside plots for species except *E. ovata*, which was only represented by one survivor outside the plots (Table 9). These plants surviving outside the plots had received a degree of protection from browsing by the dense weed growth around them, so those which overcame the weed competition in the first two seasons were well established and able to withstand the impacts of the flooding.

Table 9: Average Height in April 2010 and April 2011 of Additional Tube Stock Planted Outside Trial Plots in Spring 2008 at Campaspe River Trial Site

	April 2010		April 2011	
Species	**Height (cm)**	**Number of Plants**	**Height (cm)**	**Number of Plants**
Acacia dealbata	57	8	133	5
Acacia melanoxylon	70	6	95	17
Acacia retinodes	100	9	164	8
Eucalyptus ovata	38	2	45	1
Eucalyptus viminalis	74	3	51	3

Direct Seeding

No seedlings were found in any of the direct seeding plots.

Willow Sawfly Populations and Tree Defoliation Levels

There was very limited willow sawfly activity at this site in the 2010/11 season and no whole tree defoliation was observed. At the time of the assessments in April 2011, an average of 26 larvae was found in 5 minute counts. There was some damage to individual leaves in places, ranging from small holes to the loss of the entire lamina in some cases, but extensive leaf damage was very limited across the site.

3.4 Discussion

Plant growth continues to be strong at the Kiewa River site with high survival rates for five of the six planted species. Although competition from weeds and insect damage has impacted on some plants, overall plant health is good. At this site, a thriving community of native riparian species has been established under willows which were defoliated by willow sawfly in the first two seasons after planting. Despite the lack of willow defoliation in the 2010/11 season, most plants were sufficiently well established to continue their strong growth. It is expected that this growth will continue into the future regardless of the levels of willow sawfly activity, particularly as conditions at this site such as soil conditions and the lack of browsers, are highly favourable for plant growth.

However, one limitation of this approach of under-planting defoliated willows, which has been highlighted at the Kiewa River site, is the potential for developing plants to sustain damage as a result of the loss of willow limbs. As results from analysis of the dieback of willow trees affected by willow sawfly has shown, loss of large and small branches is common on willow trees affected by repeated, severe defoliation. Therefore planting directly under these trees needs to be undertaken in such a way as to recognise the reality of this risk and its potential impacts on under-plantings.

The flood damage at both the Happy Valley and Campaspe River sites has compounded the poor growth of the planted tube stock initially caused by ongoing browsing by a range of agents. It is possible that the plants remaining at these two sites will continue to grow, particularly at the Happy Valley site where browsing pressure appears to have eased and plant growth is stronger than in previous seasons. However the low numbers of surviving plants means that even if they all continue to survive and grow, the native riparian communities that eventually establish at these sites will be very sparse.

Direct seeding has not been successful at either the Happy Valley or Campaspe River sites. Initial seedling establishment was limited by drought and any subsequent establishment affected by floods. Only 16 live seedlings were found across the two sites, all of these at Happy Valley.

Key Points:

- A trial to test the establishment of native riparian species under willow canopies was established in 2008;
- Plant establishment and growth have been strong at the Kiewa River site with tree species now averaging 2 - 4 m tall;
- A thriving, native-dominated riparian community has established at this site where willows were defoliated for the first two growing seasons;
- Survival of planted tube stock at the Happy Valley and Campaspe River sites has been lower, with floods in 2010/11 causing further mortality;
- Some remaining plants have shown strong growth at these latter sites;
- Direct seeding at the Happy Valley and Campaspe River sites was not successful.

4. Synthesis

4.1 What is the Current Distribution of Willow Sawfly?

Since the first report of its presence in Canberra in 2004, willow sawfly has spread rapidly across south eastern Australia. Within two seasons, willow sawfly had been found in several sites in south west South Australia, central and north east Victoria, northern Tasmania, south eastern New South Wales and across the ACT.

Reports of willow sawfly during the past five seasons indicate that the insect has extended its distribution, particularly in NSW and in eastern and western parts of Victoria. In addition, numerous new sites within the initial range have been identified. As can be seen in the maps of current distribution (Figs. 4 and 5), willow sawfly has been found in locations that form an arc of sites from southern Victoria, up through ACT and eastern NSW, extending to the Queensland border, in addition to the sites in South Australia and Tasmania.

Willow sawfly is also now present in Western Australia (Fig. 4) where it has been active at some sites since the 2008/09 season. It appears to be confined to the south west corner of the state.

Given its host specificity, willow sawfly is limited to locations with suitable willow hosts. These hosts include most species of tree willows commonly found in Australia, although it is occasionally found on shrub willows such as grey sallow. A full list of willow species on which willow sawfly has been found is given in Table 10.

However, there appear to be few other limitations to its distribution and it is likely that willow sawfly will continue to expand its range to all areas across temperate Australia which have suitable willow hosts.

Table 10: Willow (*Salix*) Species on which Willow Sawfly have been Observed

Scientific Name	Common Name	Growth Form
S. alba var. *caerulea*	Cricket bat willow	Tree
S. alba var. *vitellina*	Golden willow	Tree
S. babylonica	Weeping willow	Tree
S. cinerea	Grey sallow	Shrub
S. fragilis	Crack willow	Tree
S. humboldtiana	Chilean pencil willow	Tree
S. matsudana hybrids	New Zealand hybrid willow	Tree
S. matsudana 'Tortuosa'	Tortured willow	Tree
S. nigra	Black willow	Tree
S. purpurea	Purple osier	Shrub
S. sepulcralis var. *chrysocoma*	Golden weeping willow	Tree
S. sepulcralis var. *sepulcralis*	Weeping willow	Tree
S. x *reichardtii*	Pussy willow	Shrub
S. x *rubens*	Crack x golden willow	Tree

-

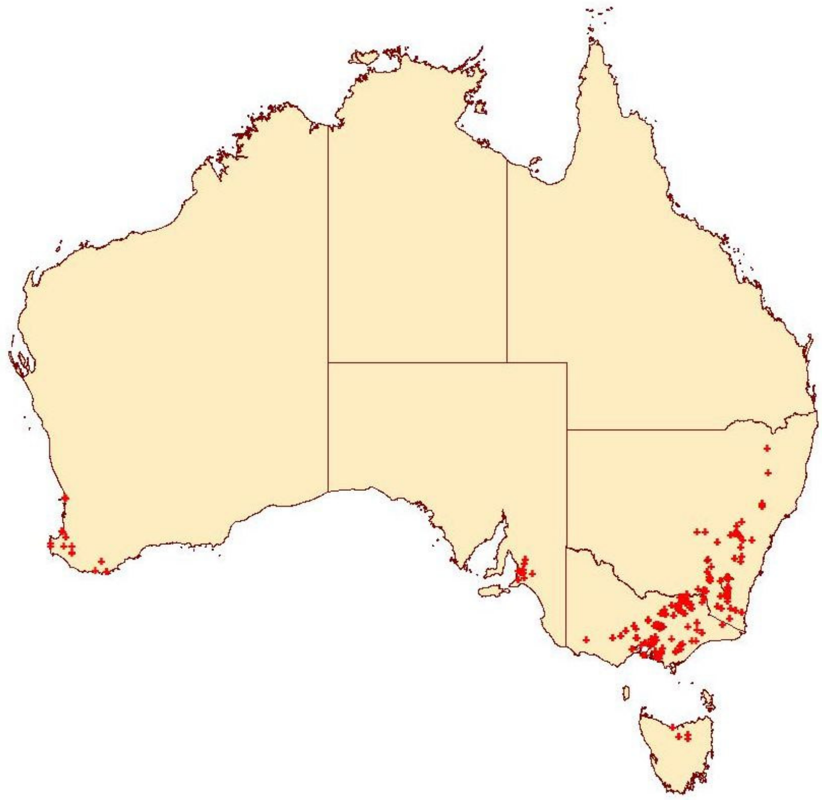

Figure 4: Map showing known distribution of willow sawfly across Australia at April 2011

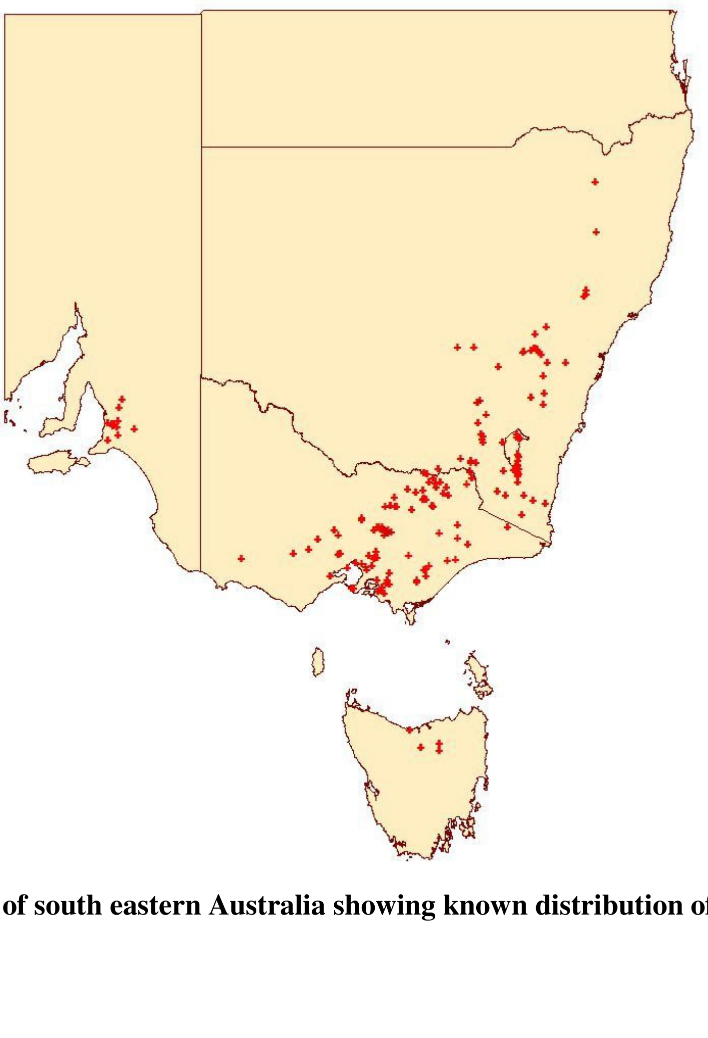

Figure 5: Map of south eastern Australia showing known distribution of willow sawfly at April 2011

4.2 Will Willow Sawfly Affect Other Plant Species?

Given the extensive damage willow sawfly populations can do to the foliage of willow trees, one legitimate question that is frequently raised by both waterway managers and members of the public is whether or not willow sawfly will affect other plant species.

During the course of this project, willow sawfly was only ever found either on willow (*Salix*) species or, very infrequently, on poplars (*Populus* spp.). At sites in north east Victoria which had very high populations of willow sawfly, larvae were occasionally observed on leaves of poplars growing in close proximity to willows. These larvae were able to consume some leaf material with the most extensive infestation observed causing partial defoliation to a small number of leaves. No whole tree defoliation of poplars was observed, or reported, during the project. However, overseas experience indicates that poplars may be susceptible to willow sawfly infestations (as reported in Ede 2006).

No reports of willow sawfly consuming leaves of other species have been received from anywhere in Australia. A laboratory trial undertaken as part of a PhD on the ecology and genetics of willow sawfly by Valerie Caron at Monash University tested the feeding behaviour of willow sawfly larvae on more than 30 species. This trial found that larvae did not consume leaves of any native species, including common riparian species such as river red gum, manna gum, paperbark species, blackwood, black wattle, river bottlebrush, burgan, woolly teatree, prickly currant bush, bidgee-widgee and spiny-headed mat-rush, even when this was the only food source offered to them (Caron *et al*. 2011).

These results indicate that it is extremely unlikely that willow sawfly larvae will consume foliage of any species other than willows or poplars. This situation reflects the taxonomy of the plant species, as both willows and poplars belong to the family Salicaceae, which is not closely related to the key families of Australian native species.

Key Points:

- ❖ Willow sawfly has spread rapidly across south eastern Australia;
- ❖ The current distribution of willow sawfly includes sites in eastern South Australia, northern Tasmania and an arc of sites from southern Victoria, through ACT and eastern NSW, as well as being found recently in south west Western Australia;
- ❖ Willow sawfly has been found on several different willows species and, very occasionally, on poplars;
- ❖ It is extremely unlikely that willow sawfly larvae will consume foliage of other species, including native species.

4.3 Willow Sawfly Population Levels

4.3.1 Variation in Population Levels During Seasons

Population levels of willow sawfly at sites vary both within seasons and between seasons. The adults that emerge from the over-wintering cocoons early in spring lay their eggs on willow leaves (one adult may lay 60 - 100 eggs). These eggs then hatch into larvae which consume the leaves, pupate and produce a new cohort of adults, which lay further batches of eggs. The full life cycle may take 4 - 6 weeks or more to complete, depending on conditions.

The likelihood of an egg completing the life cycle to adulthood is affected by both environmental conditions and predation by other insects or birds (particularly during the larvae stage) or parasitism. This project was not able to determine which factors had most influence on the build-up of willow sawfly numbers. However, it was obvious that at some sites conditions were favourable for the rapid development of willow sawfly populations relatively early in the season. For example, in November 2007 at the Everton and Kergunyah sites, 10 and 20 willow sawfly larvae were recorded per 5 minute count respectively. One month later, numbers of larvae had increased to 210 and 101 respectively, which resulted in whole tree defoliation. In the previous season, willow sawfly populations at Kergunyah had been sufficient to cause tree defoliation in late November.

Although it was generally found that high numbers of willow sawfly larvae found during the 5 minute count period resulted in tree defoliation at a later date, this was not always the case and it was not possible to determine a population threshold above which the numbers of willow sawfly larvae would always cause defoliation. In some case, high larvae numbers were not sustained for a long enough period to defoliate trees.

It was also not possible to predict larval numbers across a season as sites which had experienced significant tree defoliation often had very little remaining foliage on which larvae could feed. It generally took some weeks for new foliage to develop sufficiently to provide the food source for larvae. This lead to significant variation in population levels over the course of the season. The variation in larval numbers on the crack willows at the Everton site in 2008/09 provides a graphic illustration of this situation. The numbers of larvae found in 5 minute counts undertaken in October, December, January, March and April were 31, 138, 1, 44 and 1, respectively.

4.3.2 Variation in Population Levels Between Seasons and Between Sites

At some sites, such as Healesville, willow sawfly has maintained low population levels for several seasons. The average number of willow sawfly larvae found in 5 minute counts at the Healesville site over four seasons ranged from 0 - 6 larvae, with exception of March 2008 when 14 larvae were found on average per tree. Although counts were not undertaken during the 2010/11, there was no evidence of increased willow sawfly activity at this site in this season.

It is likely that low willow sawfly populations are being maintained on willows at many sites across the landscape and these populations are at such low levels that they remain undetected. Reports of willow sawfly activity tend to be received once population levels have reached the situation where they are causing observable defoliation. It is unclear what site factors influence the maintenance of low willow sawfly populations over several seasons and prevent populations from increasing.

In contrast, at the Happy Valley site willow sawfly populations were low during the first three seasons of the monitoring program, despite relatively high populations at nearby sites along the Ovens River. Then in 2009/10, the population increased dramatically, resulting in extensive tree defoliation along about 1 km of stream frontage. This situation is probably also relatively common, as sites maintain low population levels for a number of seasons before high levels develop. It is likely that the number of seasons where population levels are low varies between sites, and at some sites, populations may reach high levels within one or two seasons of the first arrival of willow sawfly, while for other sites it may take many seasons to develop high populations.

There is evidence for a boom and bust cycle in population levels, as is typical for many insect species. Population levels high enough to cause tree defoliation have been observed at a number of sites for one or more seasons, to be followed by a crash in population levels with limited numbers of willow sawfly found in subsequent seasons. This was first noticed at a site near Whitfield in north east Victoria where golden willows were defoliated in 2005/06 but willow sawfly numbers remained low in the 2006/07 season. Similarly at Tarago in southern Victoria, Campaspe River in central Victoria and Kiewa in the north east of the state, high population levels resulted in tree defoliation for between one and four seasons, before declining sharply. A redevelopment of high population levels has not yet been observed at any of these sites, but it is possible that willow sawfly numbers will increase again at these sites.

It is possible that this cyclic variation in population levels will become obvious in willow sawfly populations in Western Australia after a number of years. At this stage of the cycle, sites where there have been high willow sawfly numbers in one season have maintained those high population levels into a second season, but it is not yet clear whether high population levels are being maintained beyond two seasons. New sites are also still being found in WA where willow sawfly populations are sufficiently high as to cause tree defoliation.

In the 2010/11 season, willow sawfly population levels tended to be low at sites across much of Victoria, as discussed in Section 2, including sites such as Everton, Happy Valley and Kergunyah where populations had been high in 2009/10. The widespread decline in population numbers in the 2010/11 season may have been caused by a number of factors, the most likely being the widespread flooding in spring across much of the state. It is also possible that willow sawfly populations are becoming subject to increasing levels of predation or parasitism, although evidence for this is not obvious. Another possible factor limiting the development of willow sawfly populations is changes in the palatability of willow leaves as trees begin to manufacture chemicals which limit herbivory.

Much remains unknown about the environmental and biological factors that affect the development of willow sawfly populations and it is difficult to effectively explain the observed variation in population levels between sites and between seasons.

Key Points:

- Willow sawfly populations vary within a season, between seasons and between sites due to a range of environmental and biological factors;
- At some sites, willow sawfly has maintained low populations for 5 seasons;
- At other sites, populations have undergone a boom and bust cycle with high levels in consecutive seasons followed by a steep decline in subsequent seasons.

4.4 What Impact Does Willow Sawfly Have on Willows and Willow Management?

4.4.1 Short and Long Term Impacts

In the short term, the most obvious impact of willow sawfly on willows is damage to foliage which ranges from small holes in occasional leaves to complete canopy defoliation when population levels are high. Willow trees can recover from whole tree defoliation and regrow new foliage. If high willow sawfly populations are sustained at a site, this new foliage is likely to be consumed, and often trees continue to produce new foliage for the remainder of the season.

Apart from the very obvious impact of tree defoliation, there are no other visible or obvious signs that high willow sawfly populations affect willow tree health in the short term. The new foliage that regrows during the season is generally healthy, and at the outset of each new season, trees which had been defoliated the previous season develop full canopies that appear to be as healthy as those on trees unaffected by defoliation. It is possible that reproductive capacity, root health and overall growth are all compromised by repeated defoliation, but these factors have not been investigated.

What has been observed in the longer term is dieback of both large and small branches on willow trees which have been repeatedly defoliated. In some cases it is readily apparent that twig dieback is a direct response to repeated defoliation. It is less straightforward to ascribe the cause of death of larger branches and stems to willow sawfly defoliation, particularly in crack willow trees as there appears to be a constant cycle of dieback and regrowth in these trees.

Despite observations of dieback, it is not possible to categorically state that the activity of willow sawfly has caused the deaths of any willow trees in Victoria over the past five seasons, and widespread tree deaths have certainly not occurred.

Several trees have been monitored over this period and although the health of some trees has deteriorated at sites with high willow sawfly populations, all monitored trees remained alive throughout the monitoring period. Many trees which had shown some signs of stress after repeated defoliation events appeared to be in better health during the 2010/11 season than previously, indicating that drought stress may have also been contributing to their poor health. It is likely that the impacts of willow sawfly defoliation do interact with other stressors such as drought or disease in their overall affects on tree health.

At the two sites with high willow sawfly populations where estimates of the ratio of live to dead material have been undertaken over four seasons, trees have either changed little over that period or the proportion of live material has increased, primarily due to the loss of dead material from the trees.

One of the major concerns held by waterway managers at the outset of the willow sawfly program was that large numbers of willow trees across the landscape would be killed as a result of repeated defoliation by willow sawfly. This concern was based on the experience gained in other Southern Hemisphere countries, particularly Argentina, New Zealand and South Africa, where willow trees were killed by repeated defoliation events after two - three seasons of willow sawfly activity.

It is puzzling that despite several seasons of repeated defoliation, as has been seen elsewhere, willow trees in Victoria have not been killed by willow sawfly activity. It is unclear whether environmental or genetic factors, or a combination of both, are responsible for this outcome.

4.4.2 Willow Sawfly Impacts on Willow Management

The impacts of willow sawfly on willow trees are relatively short term and there has been no long term decline in willow populations in Victoria as a result of willow sawfly activity. Therefore there has been no impact of willow sawfly on overall willow management. As willow sawfly infestations are not likely to lead to any willow tree deaths, active management intervention is still required at sites where willow control is desirable.

Defoliation as a result of willow sawfly activity may provide the opportunity to establish native riparian species in areas where limited or no willow management is planned. Results from one trial site which was part of a study assessing the feasibility of establishing native species under defoliated willow canopies, showed that establishment was possible. However at the remaining two trial sites, plantings were severely affected by browsing and direct seeded plots were adversely affected by drought, with few seedlings establishing. The floods in 2010/11 had serious impacts on both these sites. These results show that several factors, including competition for light and other resources with willows, influence the successful establishment of native species in riparian areas.

It is possible that the cycle of defoliation and refoliation of willow trees may affect the efficacy of herbicide treatments when applied through a stem-injection technique. A small trial to test this was undertaken but its results were inconclusive due to the difficulty of timing stem injection activities within the defoliation/refoliation cycle. The theory being tested was that as trees regrow new foliage, a change in the direction of herbicide translocation from the roots to the canopy would result in poorer control. Despite the lack of conclusive trial results, it is recommended that if stem injection activities are planned for trees which have been defoliated by willow sawfly, that stem injection be delayed until the peak period of willow refoliation has passed.

4.5 Revisiting Predictions

At the outset of this project, analysis of the international literature and experience with willow sawfly led to the development of two possible outcomes for willow sawfly in Victoria (Ede 2006). Five seasons on, at the conclusion of the project, it is timely to revisit those predictions and determine their predictive power.

The first scenario envisaged was that willow sawfly populations would be sufficient in some places to cause tree defoliation but that high population levels would not be sustained over time or over large areas. This scenario predicted that willows may be moderately affected by willow sawfly, but that extensive tree deaths were unlikely and there would be little impact on willow management.

The second scenario predicted that large willow sawfly populations would develop in many locations. As a result, willow trees would be subjected to several defoliation events over successive seasons, resulting in widespread tree deaths. This scenario would result in significant impacts on willow populations and their management.

The limitations to willow sawfly impacts were seen at the time to relate to the factors that influence the development of willow sawfly populations. It was believed that sustained high populations would result in tree deaths through repeated defoliation events and the two scenarios differed in the extent to which willow sawfly populations established across the state.

In reality, the situation which has unfolded in Victoria over the past five seasons is a hybrid of these two scenarios. Willow sawfly has developed high population levels at many locations across the state for several seasons, as predicted in the second scenario. However, although the result of these high populations has been successive and severe tree defoliations, tree deaths have not occurred. Thus the outcomes predicted by the first scenario have come to pass.

The limitations to the impacts of willow sawfly on willows and their management relate not to the development of willow sawfly populations, but to the relationship between defoliation events and tree health and mortality. In this outcome, the situation in Victoria (and across south eastern Australia) is quite different from that seen in other parts of the world.

Key Points:

- Impacts of willow sawfly include short term foliar damage and longer term branch dieback;
- Willow sawfly has not caused any decline in willow populations in Victoria and therefore it is unlikely that the insect will affect current or future willow management;
- It was initially predicted that if willow sawfly populations were sustained at high levels, willow tree deaths would occur but this has not happened in Victoria to date.

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Other information pertaining to willow sawfly and willows in general can be found on the Weeds of National Significance (WoNS) website:

http://www.weeds.org.au/WoNS/willows/