



Willow Sawfly Activity in Victoria

The 2006/07 Season

Willow Sawfly Activity in Victoria: The 2006/07 Season

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Executive Summary

Willows (*Salix* spp.) are serious weeds of waterways and wetlands in Victoria. The recent arrival of willow sawfly is of interest to river health managers. A project to investigate the distribution and impacts of willow sawfly in Victoria was established, with field monitoring commencing in spring 2006.

Regular assessments of willow sawfly population levels, tree defoliation, tree canopy density, leaf area, light levels and riparian vegetation were made at four sites in north east Victoria and four sites in southern Victoria. Several additional sites containing a wide range of willow taxa were surveyed periodically for willow sawfly numbers and tree defoliation.

Willow Sawfly Distribution

The known distribution of willow sawfly in Victoria increased in the 2006/07 season and the number of locations where willow sawfly activity resulted in tree defoliation also increased.

Tree defoliation was recorded at:

- Kiewa Valley (north east Victoria)
- Murray River (north east Victoria)
- Broken River and tributaries (central Victoria)
- Goulburn River (central Victoria)
- Campaspe River (central Victoria)
- Tarago River (southern Victoria)
- Pheasant Creek (southern Victoria)
- Fosters Creek (southern Victoria)
- Boneo, Mornington Peninsula (southern Victoria).

Mapping of potential distribution and impacts indicates that willow sawfly has the potential to spread across all of Victoria and to cause tree defoliation in all areas of the state where suitable host trees are available.

Willow Sawfly Populations

At the sites monitored, population levels of willow sawfly tended to be either very low at sites where it is in the establishment phase, or very high, resulting in tree defoliation. Sites with intermediate numbers of willow sawfly were not found.

The first willow sawfly larvae for the season were observed in mid-October and all stages of the life cycle were present all through the season. The season ended abruptly in early May when all remaining larvae spun cocoons in which they over-winter.

High summer temperatures did not appear to affect willow sawfly numbers and no parasites or predators were observed which would have the potential to have a major impact on willow sawfly population levels.

Impacts of Willow Sawfly

Complete defoliation of trees was common when willow sawfly numbers were high.

The first severe tree defoliation was observed in late November, in the Kiewa Valley. Discrete defoliation/refoliation cycles were not observed as high larval numbers throughout the season resulted in ongoing defoliation.

In defoliated trees, tree canopy density and leaf area were lower than in trees unaffected by willow sawfly, and light levels were higher. In intact willows, tree canopy densities were highest in early summer. These intact canopies allowed about a third or less of the available ambient light through to understorey vegetation.

Willow sawfly has not yet caused any tree deaths in Victoria. However branches on severely defoliated trees have suffered from dieback.

Willow Sawfly on Various Willow Taxa

In Victoria, willow sawfly has defoliated willow trees of the following taxa:

- crack willow (*Salix fragilis*)
- golden willow (*S. alba* var. *vitellina*)
- crack x golden willow (*S. x rubens*)
- black willow (*S. nigra*)
- Chilean pencil willow (*S. humboldtiana*)
- tortured willow (*S. matsudana* ‘Tortuosa’)
- weeping willow (*S. babylonica*)
- golden weeping willow (*S. sepulcralis* var. *chrysocoma*).

In addition, willow sawfly has been found on the following taxa:

- New Zealand hybrid willow (*S. matsudana* hybrids)
- purple osier (*S. purpurea*)
- grey sallow (*S. cinerea*).

Further monitoring of sites with active willow sawfly populations over coming seasons will increase our understanding of the potential impacts of this insect on willow populations in Victoria.

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Introduction

Willows are serious weeds along waterways and in wetland areas in many parts of Victoria, due to their highly invasive nature and impacts on river health. Significant resources are invested annually in willow control and management, particularly by public land managers.

Willow sawfly (*Nematus oligospilus* Förster (Hymenoptera: Tenthredinidae)) has recently been found in Australia, with the first official sighting reported from Canberra in March 2004 (Bruzese and McFadyen 2006). In Victoria, willow sawfly was first reported from an isolated suburban willow tree in East Keilor, Melbourne in April, 2005. In the following season, willow sawfly was found at several locations across the state during a survey of invertebrates and pathogens on willows in south eastern Australia (Finlay and Adair 2006). Significant tree defoliation occurred at sites in north east Victoria in 2005/06 (Ede 2006).

A full analysis of the known distribution and impact of willow sawfly in Victoria up until the end of the 2005/06 season is presented in Ede (2006). This report also provides a description of the insect and analysis of the international experience of the impact of willow sawfly on willow populations in the southern hemisphere, particularly New Zealand.

The larval stage of willow sawfly consumes leaves of willow trees. When willow sawfly populations increase to high levels, the larvae can defoliate entire trees. As the insect goes through several generations each season, trees can be defoliated several times, resulting in tree death in some cases (Ede 2006).

As there is a strong possibility that willow sawfly could have significant impacts on some willow populations in Victoria, a research project was commissioned, commencing in early 2006. The first phase of this study was a review of all known information about willow sawfly, both from the literature and from anecdotal sources (Ede 2006).

In the 2006/07 financial year, the project had the following objectives:

- Monitor spread and impacts of willow sawfly in Victoria;
- Collate reports of willow sawfly infestations and willow defoliation;
- Map spatial and temporal variations in willow sawfly effects, and develop potential willow sawfly distribution and impact maps using climate overlays;
- Determine consequences of willow defoliation for native riparian vegetation;
- Train public and private land managers in assessment of willow sawfly effects.

Analysis of the impacts of willow sawfly were made in the 2006/07 season at a number of field sites in north east Victoria and in southern Victoria, east of Melbourne. This report describes the results from the field assessments undertaken from September 2006 until May 2007. It also includes maps outlining the current known distribution of willow sawfly in Victoria and across Australia. Maps of the areas in Victoria and Australia where willow sawfly is predicted to have a significant impact on willows, based on current Australian and overseas experience, are also included.

Methods

Site Selection

Two levels of monitoring were undertaken in the 2006/07 season. Intensive monitoring was carried out at four sites in north east Victoria and four sites in southern Victoria (Table 1, Fig. 1). These two study areas were selected to provide contrasting conditions. North east Victoria was the only area in the state where major outbreaks of willow sawfly were confirmed at several locations in the 2005/06 season, with the most significant of these being in the Kiewa Valley. This part of the state has extensive willow populations, of several different willow taxa, and generally experiences hot, dry summers.

The second study area, east of Melbourne, included sites near Healesville and in West Gippsland which were all within catchment areas managed by Melbourne Water. This part of the state also has extensive willow populations, but summer temperatures are more variable and generally cooler than those found in north east Victoria. There were two unconfirmed, isolated reports of willow sawfly in this study area in 2005/06.

Site selection criteria included the requirement for a linear stand of willows, at least 100 m long, on relatively flat ground with easy access. Sites with crack willow (*Salix fragilis*) were preferentially selected. However, the only available site where defoliation had been known to occur in the 2005/06 season, the Kergunyah site, contained *S. x rubens* (a hybrid between crack willow and golden willow). In addition, the site at Poowong North was included despite containing golden willow (*S. alba* var. *vitellina*), but tree canopy density and riparian vegetation measurements were not undertaken at this site.

To determine the impact of willow sawfly on different willow taxa, a number of other sites were visited at regular intervals throughout the season to assess population levels of willow sawfly and the extent of tree defoliation. These sites were selected to include a wide range of willow taxa and were all within the vicinity of sites undergoing intensive monitoring. Poplar trees were also assessed at some sites.

Intensive Monitoring

Intensive monitoring of eight sites was undertaken from late September 2006 until early May 2007. Six trees were assessed at all sites except the Poowong North site where only five suitable trees were identified.

Assessments

Assessments of the following parameters occurred at approximately six weekly intervals:

- population levels of willow sawfly;
- tree defoliation levels;
- tree canopy density;
- leaf area of selected shoots;
- light levels under the willow canopy;
- riparian understorey vegetation.

In addition, temperature loggers (Tinytag, Gemini Data Loggers UK Ltd.) were installed during site establishment at the four sites in north east Victoria. Each logger was attached to the most southerly side of a willow tree, about 1.8 m above the ground. These data-loggers recorded the maximum temperature at 15 minute intervals throughout the season, and were removed and downloaded at the end of the season.

Willow sawfly population levels

The population levels of willow sawfly were assessed by visual inspection of willow leaves in the lower canopy and by taking beat samples. Each stage of the life-cycle was recorded separately, with larvae recorded as either small (<10 mm) or large (≥ 10 mm).

Beat sampling involved beating a sturdy branch on the tree 20 times with a strong pole and collecting the fall-out from the tree on a sheet of canvas (1 m²). The material collected on the sheet was inspected and the number of willow sawfly individuals of each life stage (as above) was recorded.

Tree defoliation

The extent of whole tree defoliation was assessed visually and scored as either nil, very low, low, moderate or severe.

Tree canopy density

As the main impact of willow sawfly on willows is defoliation, analysis of canopy density can provide quantification of the extent of defoliation. The density of the tree canopy was measured using digital images. Two photo points were established under each tree at the beginning of the season. A digital camera was mounted on a tripod and oriented vertically to capture an image of the canopy. The position of the tripod and the position of the camera on the tripod (height and orientation) were identical at each monitoring event, as were the camera settings. Multiple images were recorded to ensure at least one useable image was captured, particularly on windy days. Two examples of canopy images are shown in Fig. 2.

To calculate the amount of foliage present, each original digital colour image was converted into a HSB (Hue Saturation Brightness) colour space and the threshold within this image was adjusted to highlight foliage only. The area of the image occupied by foliage was then calculated. This processing was undertaken using Image J v. 1.38, a freeware image processing and analysis program (<http://rsb.info.nih.gov/ij/index.html>).

Leaf area

The leaf area of two shoots per tree was measured at each sampling event to determine the impact of willow sawfly on individual shoots. These shoots were selected from different heights on the tree - a lower sample that could be reached unaided, and an upper sample taken with a pair of telescopic pruners. The shoots were approximately one metre long, but only leaves from the youngest 50 cm were assessed for leaf area. The older 50 cm of shoot was examined to determine the extent of defoliation to ensure that defoliation which had occurred in this part of the stem was recorded, even if the shoot had 50 cm or more of intact new growth.

Table 1: Location of intensive monitoring sites

Site	River	Adjacent Land	Willow Taxa	Establishment Date
North east Victoria				
Cheshunt	King River	Public land	Crack willow ¹	29 Sep 2006
Everton	Ovens River	Pasture	Crack willow	27 Sep 2006
Happy Valley	Happy Valley Creek	Pasture	Crack willow	26 Sep 2006
Kergunyah	Trib to Kiewa River	Pasture	<i>S. x rubens</i>	28 Sep 2006
Southern Victoria				
Healesville	Trib to Yarra River	Pasture	Crack willow	11 Oct 2006
Glen Forbes	Bass River	Pasture	Crack willow	03 Oct 2006
Loch	Bass River	Public land	Crack willow	03 Oct 2006
Poowong	Lang Lang River	Pasture	Golden willow ¹	05 Oct 2006

¹ Crack willow is *Salix fragilis*; Golden willow is *S. alba* var. *vitellina*

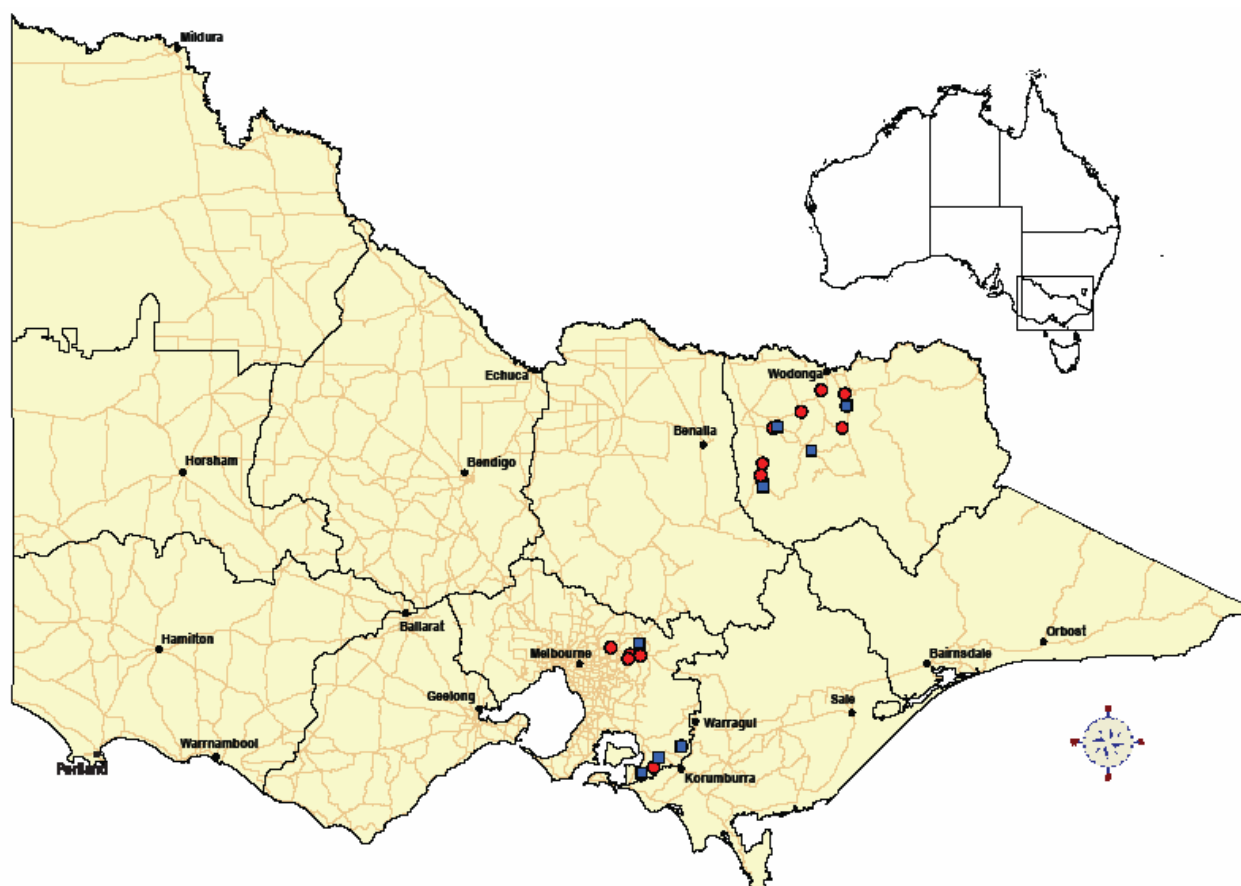
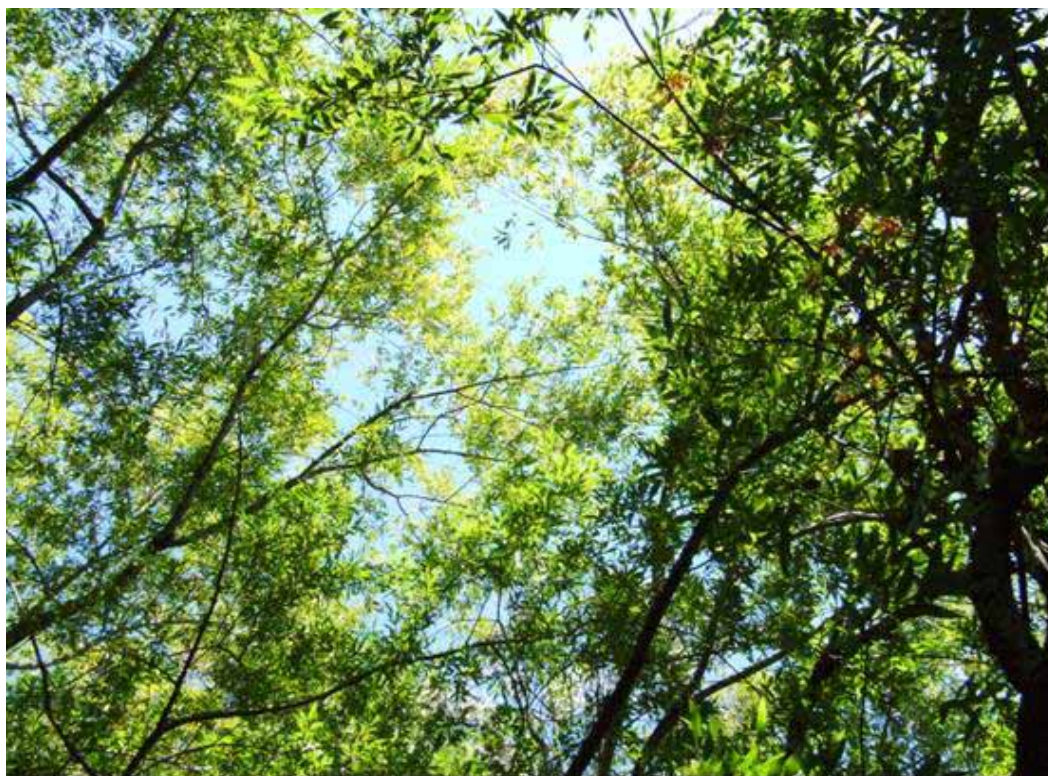


Figure 1: Location of willow sawfly monitoring sites in Victoria, 2006/07 season. Blue squares indicate the location of intensive monitoring sites; red circles indicate the location of sites monitored for various willow taxa

a)



b)

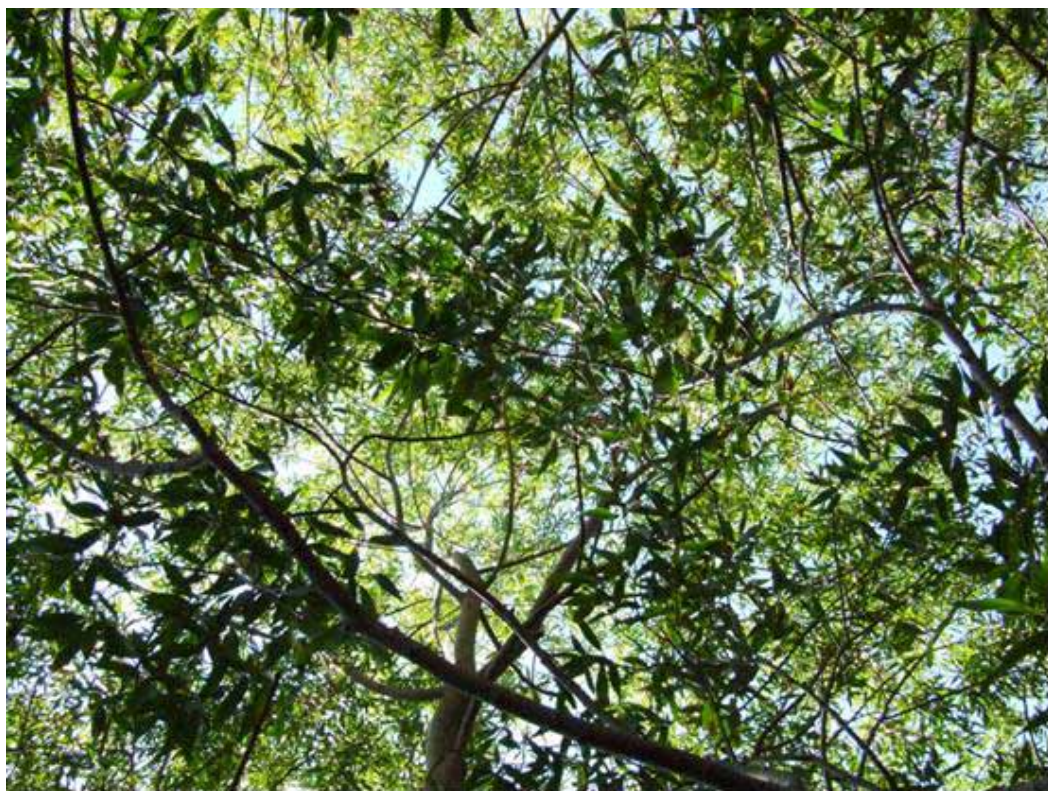


Figure 2: Examples of willow tree canopy density images at a) Cheshunt, March 2007; b) Glen Forbes, February 2007

Only the area of leaves attached directly to the main shoot and on first order branches were measured. First order branches were defined as those which were attached directly to the shoot but which did not branch themselves. Early in the season, these branches were herbaceous, but increased in woody content as the season progressed.

The leaves to be measured were removed from the shoot and placed on a flat-bed scanner. A colour digital image of the scan was recorded on a laptop computer for later analysis (Fig. 3). This analysis involved converting the image to black and white, and then counting the number of black pixels to calculate the area occupied by the leaves, using MVHimage PC v. 8 (<http://mvh.sr.unh.edu/software/software.htm>).



Figure 3: Example of leaf area scan (colour image) of leaves from a 50 cm length of willow shoot

Light levels

Incident light was measured under the willow canopy and outside the canopy in full light. A line quantum sensor calculated Photosynthetic Photon Flux Density (PPFD) from 10 sensors measuring PAR (Photosynthetically Active Radiation) over a 70 cm length. This instrument recorded the number of photons in the 400 – 700 nm range of the spectrum in units of $\mu\text{mol photons per metre}^2 \text{ per second}$. The range of the instrument was 0 - 2,000 $\mu\text{mol m}^{-2} \text{ s}^{-1}$.

Light levels were measured at each of the 12 photo points per site, at a height of approximately 1.4 m, in a northerly direction. Measurements were taken as close to midday as possible. At the Poowong site, where photo points were not established, two random points under the canopy on the northern side of tree, were selected.

The PPFD readings taken from under the willow trees at the photo point positions were converted to proportion of full light available at the time of measurement by comparison

with the PPFD measurements made outside the canopy. This allowed for comparison between dates and between sites by removing the requirement for identical light conditions at each time of measurement, which is particularly important as cloud cover has a significant impact on PPFD levels.

The light levels measured in these assessments were instantaneous measures of PPFD integrated over a 70 cm length. The measurements were influenced by the time of day, and by the date during the season, which affected the angle of incident light. Hence the measurements made were indicative of the proportion of light being intercepted by the willow canopy at that particular time, rather than being exact measures of the light environment of the understorey vegetation. Because of these limitations, these data were not subjected to statistical analysis.

Riparian understorey vegetation

One or two permanent transects were established at each site under the willow canopy to assess the presence/absence of understorey vegetation. The total length of transects was between 30 and 40 m, depending on the site conditions. A 30 x 30 cm quadrat was placed at one metre intervals along the transect and all species within the quadrat recorded.

Analysis of this dataset was limited because at several of the sites, cattle grazing during the season resulted in significant disturbance of the vegetation.

Data Analysis

Analysis of variance (ANOVA) analyses were undertaken on the tree canopy density data and the leaf area data using GenStat (GenStat 9.1, 2006; Lawes Agricultural Trust, UK). Fisher's Protected Least Significant Difference tests (LSD tests) were used to identify individual site means that were different from one another, within each sampling date.

The leaf area data were log transformed before analysis to improve normality, but the data presented here are back-transformed means.

To analyse the tree canopy density data across the season, it was necessary to undertake a repeated measures ANOVA as the canopy measures were not independent of one another through time (i.e. canopy density of a tree at one point in time influences the canopy density at subsequent sampling times). This analysis was performed in JMPIN 4.0 (JMPIN v. 4.0.3, 2000; SAS Institute Inc., Cary, NC, USA).

Monitoring Various Willow Taxa

Three weeks after each intensive monitoring event, all eight sites were assessed for willow sawfly population levels and extent of tree defoliation only, using the methods described above.

At the same time as these less intensive assessments, a number of additional sites (Table 2) were assessed for the same two parameters, although not all sites were assessed each time. These additional sites provided data on willow sawfly activity on a range of willow taxa.

Table 2: Location of monitoring sites with various willow taxa

Site	River/Location	Adjacent Land	Willow Taxa
North East Vic			
Whitfield	Roadside ditch	Public land	Crack willow (<i>S. fragilis</i>)
King Valley	Roadside ditch	Public land	Golden willow (<i>S. alba</i> var. <i>vitellina</i>) Lombardy poplar (<i>Populus nigra</i> 'Italica')
Edi Cutting, Edi	King River	Public camp ground	Crack willow (<i>S. fragilis</i>) Grey sallow (<i>S. cinerea</i>) Weeping willow (<i>S. babylonica</i>)
Markwood	Tea Garden Creek	Cultivated	Crack willow (<i>S. fragilis</i>)
Everton	Ovens River	Pasture	Black willow (<i>S. nigra</i>) Golden willow (<i>S. alba</i> var. <i>vitellina</i>) Purple osier (<i>S. purpurea</i>) Weeping willow (<i>S. babylonica</i>)
Beechworth Camping Ground	Spring Creek	Public camp ground	Crack willow (<i>S. fragilis</i>) Grey sallow (<i>S. cinerea</i>) Lombardy poplar (<i>P. nigra</i> 'Italica')
Leneva West	Middle Creek	Public land	Crack willow (<i>S. fragilis</i>) Grey sallow hybrid (<i>S. cinerea</i>) Weeping willow (<i>S. babylonica</i>)
Dederang	Glen Creek	Public land	Golden willow (<i>S. alba</i> var. <i>vitellina</i>)
Kergunyah	Kiewa River	Public land	Weeping willow Lombardy poplar (<i>P. nigra</i> 'Italica')
Kiewa	Kiewa River	Pasture	Chilean pencil (<i>S. humboldtiana</i>) Crack willow (<i>S. fragilis</i>) Weeping willow (<i>S. babylonica</i>)
Southern Vic			
Chirnside Park	Chirnside Park Drain	Public land	Crack willow (<i>S. fragilis</i>) Grey sallow hybrid (<i>S. cinerea</i> hybrid)
Wandin North	Roadside	Public land	Crack willow (<i>S. fragilis</i>) Grey sallow (<i>S. cinerea</i>)
Seville	Wandin Yallock Creek	Public land	Crack willow (<i>S. fragilis</i>) Grey sallow (<i>S. cinerea</i>)
Woori Yallock	Roadside	Public land	Crack willow (<i>S. fragilis</i>) Grey sallow (<i>S. cinerea</i>)
Woodleigh	Roadside ditch	Pasture	NZ hybrid (<i>S. matsudana</i> x <i>alba</i>)
Poowong North	Roadside	Pasture	Weeping willow (<i>S. babylonica</i>)

At three of the intensively monitored sites additional willow taxa were assessed in this monitoring cycle – at Everton there are four additional taxa, while one additional taxon was assessed at both Kergunyah and Poowong North.

Other Sightings

In addition to this field program of regular monitoring, reports of willow sawfly from local observers were followed up in almost all cases. These reports primarily related to defoliation events. Reports from other states were noted, but with one exception, could not be followed up with site visits.

Additional Data Collection

At two of these sites additional data were collected. At the Fosters Creek site near Kongwak, a number of leaves were sampled to determine the number of eggs and larvae on each leaf.

At the Boneo site on the Mornington Peninsula, a comprehensive search was made in mid May for the cocoons in which the larvae over-winter. Litter and soil samples were collected from a series of quadrats (approximately 60 cm²). All the litter within the quadrat formed one sample, while the soil under the litter, to a depth of 10 cm, formed the second sample. These samples were sorted in the laboratory and cocoons were separated into those which appeared to have intact larvae inside and those which were empty of larvae (possibly left over from the previous season).

Maps

Maps of the current known distribution of willow sawfly in Australia and in Victoria, as reported at the end of the 2006/07 season, were prepared. In addition, predictive maps were developed which plot the likelihood of both willow sawfly occurrence and tree defoliation as a consequence of willow sawfly. These predictive maps extrapolate data based on climate matches, using existing data from Australia and from the Hawkes Bay region of New Zealand, where willow sawfly has defoliated significant numbers of willow trees over a period of some years (Ede 2006). The climate data were sourced from the nearest meteorological stations to the willow sawfly sites. These data are mapped on the relatively coarse scale of 50 km x 50 km grid squares.

Results

General Observations

Evidence of Willow Sawfly Activity

Activity of willow sawfly on willow trees can be readily confirmed, even if live specimens are not present at the time of observation and even if willow sawfly population levels are too low to cause significant tree defoliation.

Hatched eggs of willow sawfly and the holes made by early instar larvae form a very distinctive distinguishing feature (Fig. 4). The hatched egg remains on the leaf for several weeks, as a small opaque kidney-shaped fleck, about 1-2 mm long. The newly hatched larva eats a small hole next to the egg, with the size of the hole increasing as the larva grows. If the larva does not survive for whatever reason, the hatched egg and nearby hole remain as evidence. It is straightforward to quickly search trees for this evidence to determine if willow sawfly has been active. Observation of live larvae or other stages of the life cycle, although desirable, is thus not required to confirm willow sawfly activity.

The fact that the adults prefer to lay their eggs in the lower parts of the tree first (G. Eyles, pers. comm.) assists the process of determining if willow sawfly is active on a tree. So, if a thorough search of easily accessible leaves does not prove fruitful, it is unlikely that willow sawfly has been active on that tree.

It is possible to determine the relative age of holes made by willow sawfly larvae, as a layer of necrotic (brown) tissue forms around the edge of older holes. This does not occur if the larvae continues to enlarge the hole, but without further study it is not possible to determine the length of time between the damage to the leaf and the appearance of necrotic tissue.

Defoliation

When willow sawfly populations increase, the feeding activity of the larvae results in whole tree defoliation. At the scale of an individual leaf, all the green material (lamina) is eaten by the larva, and the midrib (central vein of the leaf) remains (Figs. 5 and 6). However early in the season even the midribs of many leaves were consumed by the larvae. It is possible that in these young leaves that the midribs are easily digestible, but as the leaves age through the season, this part of the leaf becomes unpalatable and so is left uneaten.

On heavily defoliated trees, shoots which are bare except for these denuded midribs are common (Fig. 6). Generally, several leaves along a shoot will be consumed, rather than each shoot having only one or two eaten leaves. New foliage is produced at the end of defoliated shoots (Fig. 5) and on shoots that arise from epicormic buds further down branches, but where numbers of willow sawfly larvae are high, these new leaves are quickly eaten. Larvae will travel some distance along branches to find new food material.

The pattern of willow sawfly damage on willow leaves is different to that caused by possums, which frequently browse the upper branches of willow trees. Possums rip the upper part of each leaf off, leaving the lower part mostly intact. The damage is characterised



Figure 4: Hatched willow sawfly eggs and characteristic holes formed by young larvae



Figure 5: Willow shoots defoliated by willow sawfly with only midribs remaining at base and new leaves developing at tips



Figure 6: Scan of willow twig after consumption by willow sawfly larvae, with only midribs of leaves remaining

by shoots containing several half chewed leaves, predominantly in the upper crown of the tree. The effects of drought are also distinguishable from willow sawfly damage, as the leaf tips die and turn brown on droughted trees, but the leaves remain intact.

Larval Preferences

In the initial stages of population development, larvae are more frequently found on leaves closer to the tree trunk, rather than on those of outer branches. They particularly inhabit leaves on epicormic shoots, which arise directly on larger branches or the tree trunk. The leaves on these shoots are often larger, thinner and less robust than leaves on other branches, and so may be more palatable for the larvae. Given that the consequence of severe defoliation is the development of large numbers of epicormic shoots, it is possible that willow sawfly makes conditions even more favourable for itself in this defoliation/refoliation pattern.

Seasonality

In the 2006/07 season, willow sawfly was first observed in mid October, at the Kergunyah site. Low numbers of predominantly small larvae were observed at this time. By 8th November, large numbers of larvae of all sizes were present at the site, and by late November all stages of the life cycle were present.

From these observations and those made in New Zealand (Ede 2006), it is likely that the emergence of adults occurs over a period of several weeks in spring. This means that all stages of the life cycle can be present at any point through the season at a site.

However, the willow sawfly season appears to end very abruptly. At the Boneo site, on the Mornington Peninsula, large numbers of large willow sawfly larvae were discovered defoliating golden weeping willow trees on 30th April 2007 (Fig. 7). A further check was made on these trees five days later, on 4th May and no larvae could be found. Similarly, larvae (predominantly large) were present in large numbers at the Kiewa site on 2nd May, but no larvae could be found on 14th May. And at a site on the Tarago River, larvae were plentiful in mid April and absent by early May.

This sudden disappearance of larvae is probably a result of the adults ceasing to lay eggs at some point in April, possibly in response to a day-length trigger (Ede 2006). However, it is also possible that any eggs laid later than a certain time in the season fail to develop. The last cohort of larvae develops at about the same rate through to the stage where, within a few days of one other, they all spin cocoons in which they over-winter. Hence the transition from willows being overrun with willow sawfly larvae to being devoid of them occurs quite suddenly.

Stages of the Life Cycle

Eggs and larvae are commonly observed on trees where willow sawfly is or has been active, while pupae and adults are found less frequently. Eggs are laid on the upper leaf surface more commonly than on the lower surface (Table 3).



Figure 7: Golden weeping willow tree defoliated by willow sawfly, April 2007, Boneo, Mornington Peninsula

In areas where willow sawfly populations are high, multiple eggs are laid on leaves and multiple larvae have been observed on individual leaves (Figs. 8 and 9). At a heavily infested site on Foster Creek in Gippsland, the number of eggs per leaf was counted for nine large leaves collected from epicormic shoots in early March 2007 (Table 3). The highest total number of eggs per leaf was 171 and this leaf was already supporting six larvae! This site illustrates an extreme case but is indicative of the level to which willow sawfly numbers can build up.

Table 3: Number of willow sawfly eggs and larvae per leaf at a heavily infested site (Fosters Creek, Kongwak, West Gippsland)

	Average (s.e.) ¹	Range
Eggs on upper leaf surface	87 (12.5)	36 - 138
Eggs on lower leaf surface	18 (7.5)	0 - 57
Larvae	12 (5.5)	0 - 47

¹ s.e. is the standard error of the mean

The cocoons in which the larvae pupate during the growing season are yellow-green in colour, while those in which they over-winter are dark brown, making them very difficult to find.



Figure 8: Willow leaves with multiple willow sawfly eggs



Figure 9: Multiple willow sawfly larvae of various sizes on individual willow leaves

During the season, cocoons were found in various locations at sites with high willow sawfly population levels – on leaves and branches, tree trunks, other vegetation below trees, and man-made surfaces.

A comprehensive search was made for the cocoons in which the larvae over-winter at the Boneo site in mid May. No over-wintering cocoons were found on tree trunks or branches. Litter and soil samples were analysed for intact and empty over-wintering cocoons, with two to three times more empty cocoons found than intact cocoons. A similar number of cocoons were present in the soil samples as in the litter samples.

Parasites and Predators

No formal analysis of potential parasites or predators of willow sawfly was made in the 2006/07 season, but some observations of predation were noted.

At some sites with high willow sawfly populations, spiders and a hemipteran (family: Pentatomidae) were observed feeding on small larvae. At the end of the season, European wasps were observed looking for prey on willows, spending time around leaves with feeding holes. European wasps are efficient predators, especially at the end of summer when they are looking for protein source, so it is possible that they have an impact on willow sawfly populations. Small ants were also found on willow trees, but their role in willow sawfly predation is unknown.

Various species of birds, such as fantails and magpies, were seen eating larvae at a number of sites with high willow sawfly populations.

However when willow sawfly populations are high, it is unlikely that either bird or insect predators have any significant impact on the numbers of willow sawfly larvae.

Intensive Monitoring Sites

Willow Sawfly Population Levels and Tree Defoliation

Kergunyah

Willow sawfly was first reported in the Kiewa Valley, particularly around Kergunyah, in December 2005 when locals noticed tree defoliation and larvae falling out of trees. Defoliation of willows, especially of the locally dominant species *S. x rubens*, was widespread through the valley for the remainder of the 2005/06 season, with dieback of branches on some trees noted at the end of the season (A. Briggs, pers. comm.).

The *S. x rubens* trees in this study, which are on a small creek that runs into the Kiewa River, had been defoliated in the 2005/06 season. No willow sawfly were observed on any trees during site establishment in late September 2006, but a few willow sawfly larvae were found on several trees at the first return visit, on 18th October 2006. Willow sawfly larvae were present right through the season, including at the final assessment on 2nd May 2007.

Population levels increased rapidly; by 8th November larvae of all sizes were abundant on all trees. Some leaves had multiple larvae feeding on them. However although larval numbers were high and leaves had been eaten, overall tree defoliation levels were low or very low (Table 4). Defoliation was not evident from a distance.

By 28th November, tree defoliation was obvious and severe in some cases (Table 4, Figs. 10 and 11), with only about 10% of foliage remaining on Tree 1. The abundance of pupae and adults was much higher on this occasion than at any other time during the season. Cocoons formed by pupating willow sawfly thickly covered every available surface – branches, tree trunks, grass leaves, thistle leaves, the back of the temperature logger and flagging tape (Fig. 12). Adults were also extremely numerous.

Severe tree defoliation was still evident on the study trees in mid December and on many other willow trees in the vicinity. The trees had regrown some new leaves, but as willow sawfly population levels were so high, these new leaves all supported at least one and often multiple larvae.

Table 4: Defoliation of individual trees at Kergunyah site, September 2006 – May 2007

Date	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5	Tree 6
28/09/06	Nil	Nil	Nil	Nil	Nil	Nil
18/10/06	Nil	Nil	Nil	Nil	Nil	Nil
08/11/06	Low	Very low	Low	Low	Very low	Low
28/11/06	Severe	Severe	Moderate	Severe	Moderate	Severe
18/12/06	Severe	Severe	Severe	Severe	Severe	Severe
09/01/07	Severe	Moderate	Moderate	Severe	Moderate	Moderate
31/01/07	Moderate	Moderate	Moderate	Severe	Moderate	Moderate
20/02/07	Severe	Severe	Moderate	Severe	Moderate	Moderate
13/03/07	Severe	Severe	Mod-severe	Severe	Mod-severe	Mod-severe
04/04/07	Severe	Very severe	Severe	Severe	Severe	Severe
02/05/07	Severe	Severe	Severe	Severe	Severe	Severe

Tree defoliation was less severe in January, with some trees producing sufficient new foliage that not all leaves were immediately eaten by the larvae. In late January, a reasonable proportion of regrowth was still intact, and overall tree defoliation was rated as moderate for five trees (Table 4). Larvae numbers were still high, but no pupae or adults were observed.

The severity of tree defoliation increased for Trees 1 and 2 in mid February (Table 4), while Tree 4 continued to have severe defoliation. On this tree, few larvae were found in the latter part of the season because there were so few leaves on the tree. On the remaining trees, some regrowth was relatively intact and some had been eaten by larvae. Larval numbers continued to be high for the remainder of the season, leading to increased severity of defoliation across the site (Table 4). The majority of larvae observed in early May were large.



Figure 10: *S. x rubens* tree severely defoliated by willow sawfly, Kergunyah, Dec 2006



Figure 11: Canopy of severely defoliated *S. x rubens* tree, Kergunyah, Nov 2006

a)



b)



Figure 12: Willow sawfly cocoons crowded onto a) flagging tape; and b) a thistle leaf

Few adults or new cocoons were observed in the latter part of the season, but in early April, an adult was observed laying an egg on a leaf. There were already some eggs and a small larva on this leaf. This observation indicates that adults were still laying eggs in early April.

Tree dieback

Dieback of small twigs was noticed early in the season at this site, with a small number of shoots sampled for leaf area analysis in early November having dead tips. The frequency of shoots where the apex had died increased through the season. In many shoots, buds further down the shoot sprouted to form a new leader, but sometimes these also died (Fig. 13). In some instances, shoots had long bare areas where there were no leaves or buds, or the whole shoot died. The death of shoots and shoot tips lead to a mass of new twigs developing, some of which remained alive and some of which subsequently died.



Figure 13: Dieback of tips of small twigs, with new shoots developing further down branch

As the season progressed, dieback of larger branches and whole portions of trees became apparent. By February, branches on Tree 6 appeared to have died, while much of Tree 4 had died back and there were few parts of the tree still producing new foliage. This tree was severely defoliated from late November until the end of the season (Table 4), by which stage it was in very poor health.

The remaining five trees all showed signs of branch dieback by mid March to a greater or lesser extent, as did other willow trees in the vicinity. It is not yet known if these branches retain the capacity to regrow new foliage in spring, or whether they are indeed dead.

Remaining sites

No evidence of willow sawfly had been reported at the remaining seven sites prior to the commencement of this study. During the site establishment process, willow sawfly was not found on any trees or in beat samples.

Willow sawfly did arrive at each of these sites early in the 2006/07 season (Table 5). Confirmed observations of willow sawfly were first made in early-mid November at Cheshunt, Everton, Healesville and Glen Forbes, and in late November at Happy Valley. In mid-December, willow sawfly was observed at Loch and Poowong.

However, at these sites willow sawfly populations maintained very low levels throughout the season (Table 5). The maximum number of live larvae found across all trees at sites during any sampling occasion ranged from 2-6 at the Gippsland sites, through to more than 60 at Everton in December.

This result at Everton was primarily a consequence of Tree 6 having higher numbers of willow sawfly than other trees at this site or at other sites. Leaves on several epicormic shoots growing from the main trunk were defoliated back to the midrib in the latter half of the season. It is unclear why this particular tree was more heavily infested with willow sawfly than its neighbours.

Table 5: Willow sawfly populations and tree defoliation at intensively monitored sites, September 2006 – May 2007

Site	Date Sawfly First Observed	Willow Sawfly Population ¹	Tree Defoliation
Cheshunt	07/11/06	Low, 12	Nil
Everton	07/11/06	Low, >60	Very low
Happy Valley	28/11/06	Low, 16	Nil
Kergunyah	Dec 2005 (18/10/06) ²	High, numerous	Moderate to severe
Healesville	15/11/06	Low, >40	Nil
Glen Forbes	16/11/06	Low, 5	Nil
Loch	21/12/06	Low, 2	Nil
Poowong	22/12/06	Low, 6	Nil

¹ Population levels, classified as low, medium or high, are followed by an estimate of the maximum total number of live larvae found across the site during any one sampling occasion

² In the 2006/07 season, willow sawfly larvae were first observed at this site on 18th October 2006

Population levels of willow sawfly at Healesville were similar to those at the other southern Victoria sites until March, when about 40 live larvae were found on the trees. The majority of these larvae were found on branches immediately above the creek bed, rather than on branches further out in the paddock. These parts of the trees were closer to the main tree trunks which arise in the creek bed, and were accessible in March due to low water levels in

the creek. On this occasion, a very small number of leaves on Tree 1 had been defoliated back to the midrib.

Generally the limited numbers of willow sawfly at these seven sites were insufficient to cause any tree defoliation (Table 5). The only exception to this is Tree 6 at Everton, described above, where one small portion of the inner tree canopy was defoliated by willow sawfly.

Willow sawfly larvae and eggs were found at all sites, with occasional pupae observed at Cheshunt, Everton, Healesville and Poowong. Adults were observed at Everton, early in the season, but were not observed at the other sites at any stage during the season.

Tree Canopy Density

Tree canopy density was determined as the percentage of foliage cover assessed from digital photos taken at photo points under the willow canopies. Photos were not taken at the Everton site in November as it was not possible to locate the photo point markers from the previous sampling. A new set of photo points was used from December onwards at this site. At Cheshunt, the fall of a major tree branch in January lead to the loss of one photo point.

The ANOVA undertaken on the dataset of canopy densities pooled across the season indicated that the effect of site on tree canopy density was significant ($F_{6,75} = 20.50$, $p < 0.001$), with Kergunyah having a lower tree canopy density than the remaining sites. However, there was a significant interaction between time of sampling and site ($F_{20,323} = 14.10$, $p < 0.001$), which meant that seasonal changes in tree canopy density were different at the different sites, as illustrated in the Table 6 and Fig. 14.

Table 6: Tree canopy density (% foliage) of willow trees at intensively monitored sites, September 2006 – May 2007

Site	Sep/Oct	Nov	Dec	Jan/Feb	Mar
Cheshunt	49 c ¹	72 a	69 b	63 ab	67 a
Everton	34 d	-	75 ab	66 ab	62 ab
Happy Valley	48 c	78 a	81 a	68 ab	68 a
Kergunyah	28 d	76 a	4 c	36 c	32 d
Healesville	74 a	77 a	71 b	64 ab	56 abc
Glen Forbes	60 b	76 a	73 b	58 b	43 cd
Loch	57 b	74 a	73 b	71 a	49 bc

¹ Within sampling dates, values in each column followed by the same letter do not differ significantly from one another at the 5% level of probability (Fisher's Protected Least Significant Difference test)

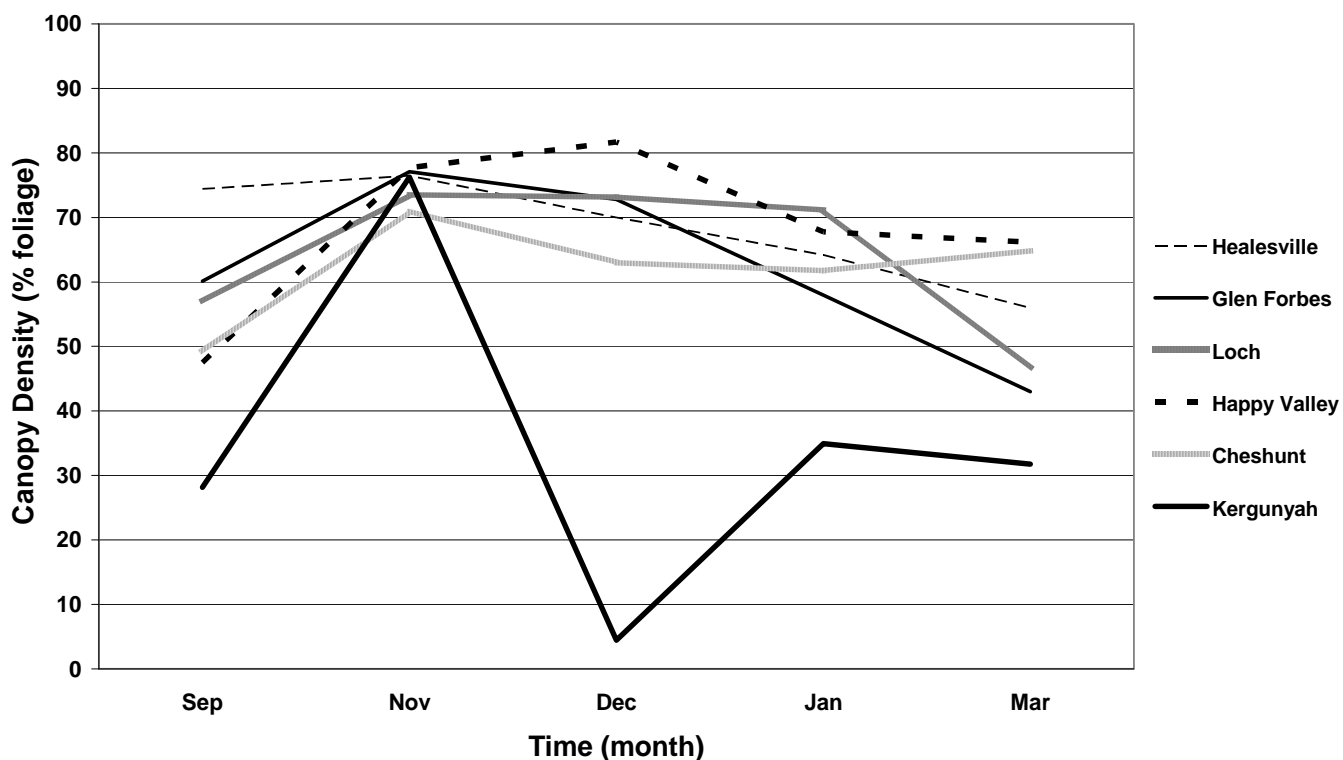


Figure 14: Willow tree canopy density at six sites, measured from September 2006 to March 2007

To explore the effect of site on tree canopy density within each sampling time, a series of separate one way ANOVAs were undertaken, and means of tree canopy density at the sites were compared within sampling times. There were significant differences in tree canopy density between sites for all sampling times except November (Table 7), when tree canopy density ranged from 72% at Cheshunt to 78% at Happy Valley. This non-significant result indicates that the potential density of tree canopy was not different between the crack willows present at the majority of the sites and *S. x rubens* at the Kergunyah site.

In September/October, tree canopy densities were greatest at the southern sites (Table 6) as these were assessed later than the sites in the north east. By November, tree canopies were fully developed at all sites. In December and January/February, Kergunyah had significantly lower tree canopy density than the other sites (Table 6), due to the activity of willow sawfly. In fact in December, canopy densities for this site ranged from 0.4% to 19.3%, with only one tree having a canopy density greater than 5%. Figure 15 illustrates the impact of willow sawfly on tree canopy at this site, contrasting the image captured at Position 2 of Tree 6 in November with that taken at the same position in December.

In March, Kergunyah and Glen Forbes had the lowest tree canopy densities, but all the southern sites had lower densities (Table 6), as a consequence of drought-induced leaf fall, which was most noticeable at Glen Forbes.

a)



b)



Figure 15: Tree canopy density of Tree 6 at Kergunyah in a) Nov 2006; and b) Dec 2006

Table 7: One way analysis of variance (ANOVA) of tree canopy density at dates of sampling for sites

Date	df ¹	Error df	F ratio	p ¹
Sep/Oct	6	75	34.92	<0.001
Nov	5	65	0.95	0.453
Dec	6	75	120.93	<0.001
Jan/Feb	6	74	10.49	<0.001
Mar	6	74	8.33	<0.001

¹ df are the degrees of freedom associated with the statistic; p is the probability

Leaf Area

The leaf areas of both upper and lower shoot samples were pooled across sites and dates for analysis. There was high variability between leaf areas on individual shoots within each site at each sampling occasion, which was not related to the position of shoot on the tree.

As for tree canopy density above, a two way factorial ANOVA indicated that although the effects of both time of sampling ($F_{4,411} = 21.66$, $p < 0.001$) and site ($F_{7,411} = 9.49$, $p < 0.001$) on leaf area were significant, there was also a significant interaction between time of sampling and site ($F_{28,411} = 2.94$, $p < 0.001$). This indicates that leaf area did not show the same pattern of change through the season at each of the sites, as can be seen in Table 8 and Fig. 16. However, the effect of sampling time was of less interest than the difference between sites, so a series of one way ANOVAs were undertaken for each sampling time (Table 9).

There were significant differences between sites in September/October, December and March but not in November or January/February (Table 9), which indicates that there was no inherent difference in potential leaf area from shoots from the three different willow taxa sampled. At the time of site establishment (September/October) Healesville had the highest leaf area (Table 8), possibly because it was the last site to be established, and so the trees were more advanced than those sampled earlier at the remaining sites. In December, leaf area from shoots sampled from Kergunyah was significantly lower than leaf area from all other sites except Happy Valley, while there was no difference in leaf area of shoots from the remaining sites. Again in March, shoots from Kergunyah had significantly lower leaf area than shoots from the other sites (Table 8). Examples of leaf scans from Kergunyah in December (Fig. 17) show partially and completely defoliated leaves.

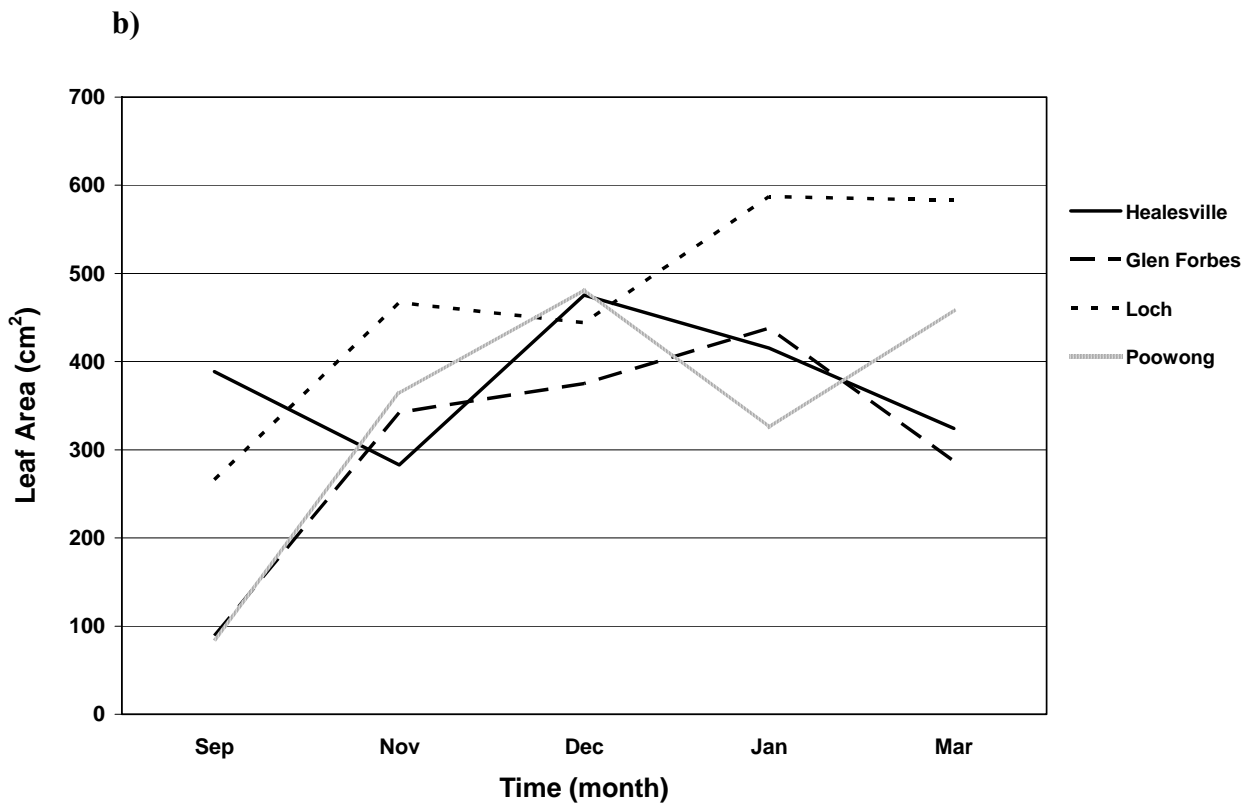
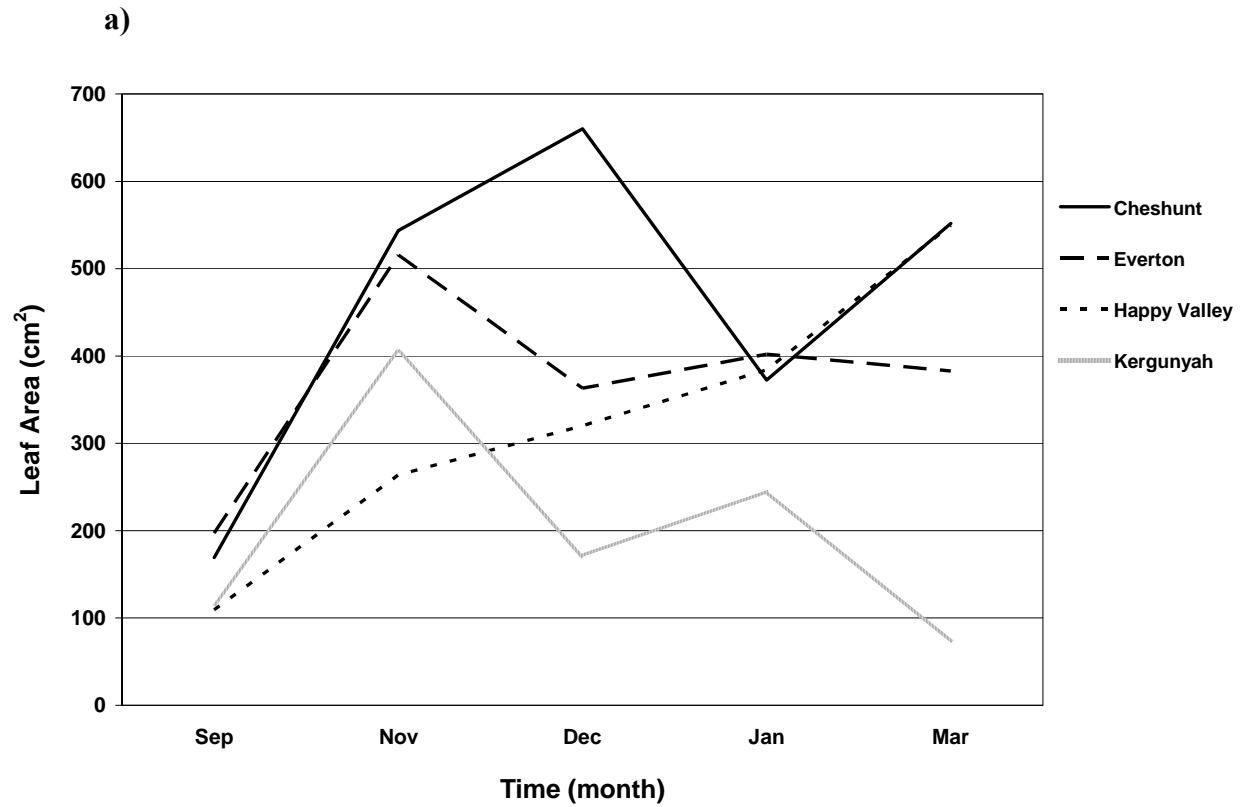


Figure 16: Leaf area of leaves sampled from willow shoots from September 2006 to March 2007 at sites in a) north east Victoria; and b) southern Victoria

Table 8: Average leaf area (cm²) of leaves from 50 cm long shoots collected from willow trees at intensively monitored sites, September 2006 – May 2007

Site	Sept/Oct	Nov	Dec	Jan/Feb	Mar
Cheshunt	169 bcd ¹	544 a	660 a	373 a	552 ab
Everton	197 bc	516 a	363 ab	402 a	383 ab
Happy Valley	109 de	264 a	320 bc	384 a	550 ab
Kergunyah	116 cde	405 a	171 c	245 a	73 d
Healesville	389 a	283 a	476 a	415 a	324 bc
Glen Forbes	89 e	343 a	375 ab	438 a	287 c
Loch	266 b	467 a	444 ab	587 a	583 a
Poowong	86 e	364 a	482 ab	325 a	459 abc

¹ Within sampling dates, values in each column followed by the same letter do not differ significantly from one another at the 5% level of probability (Fisher's Protected Least Significant Difference test)

Table 9: One way analysis of variance (ANOVA) of leaf area at dates of sampling for sites

Date	df	Error df	F ratio	p
Sep/Oct	7	78	7.89	<0.001
Nov	7	85	2.02	0.062
Dec	7	86	3.10	0.006
Jan/Feb	7	82	1.04	0.412
Mar	7	79	9.27	<0.001

Light Levels

Light levels (measured as Photosynthetic Photon Flux Density – PPFD) under the canopies of each of the study trees at the eight field sites were lower than light levels in open areas.

Although there was considerable variation throughout the season, tree canopies at the sites with low willow sawfly populations generally intercepted at least 70% of the available light when in full leaf, resulting in light levels under the canopy of 30% of ambient or less (Table 10). Canopy thinning later in the season increased the light levels at some sites, and due to drought this thinning process occurred as early as February for the two sites on the Bass River (Glen Forbes and Loch, Table 10).

Light levels under the crack willows at Cheshunt and Happy Valley were extremely low in the latter half of the season, dropping to 4 - 8%, and were below 20% all season at Happy Valley. In November very low light levels were also recorded at the Everton site, but this site had extremely variable light levels across the season (Table 10). There was also considerable variation between points at this site each assessment time. For example, in

a)



b)

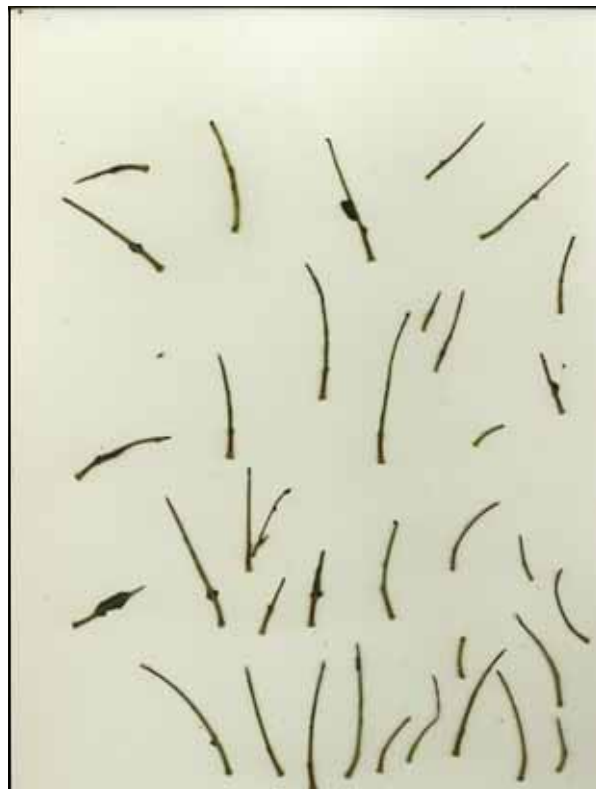


Figure 17: Scans of willow leaves from Kergunyah in December, 2006, which were a) partially; or b) completely consumed by willow sawfly

Table 10: Percentage of ambient light (as PPF) measured under willow canopies at intensively monitored sites, September 2006 – May 2007

Site	Sept/Oct	Nov	Dec	Jan/Feb	Mar
Cheshunt	28%	23%	17%	8%	8%
Everton	12%	2%	24%	27%	43%
Happy Valley	19%	9%	11%	4%	8%
Kergunyah	47%	20%	47%	43%	57%
Healesville	11%	8%	22%	27%	19%
Glen Forbes	22%	15%	19%	33%	32%
Loch	23%	27%	16%	31%	22%
Poowong	31%	25%	29%	22%	31%

March, the light levels at three points was only 4%, while at four points light levels were 70% or greater.

The canopies of the willow trees (*S. x rubens*) at the Kergunyah site were less developed at the time of site establishment in late September than those at most other sites, which may explain the higher light levels under these canopies (47%, Table 10). In early November, there was a very limited amount of defoliation from the activities of willow sawfly. The tree canopies had more foliage than at any other time during the season, hence the light levels recorded were similar to those at the other sites. As the season progressed, ongoing defoliation from willow sawfly meant that there was no stage when the tree canopies had a high cover of foliage. With only limited amounts of foliage and branches to intercept the light, light levels under these canopies were high (43 - 57%, Table 10). In fact, the light levels in March at the two positions under Tree 4, which was virtually bereft of leaves in the latter part of the season, were 100%.

Riparian Understorey Vegetation

The major impact on understorey vegetation at four of the seven sites assessed (Everton, Kergunyah, Healesville and Glen Forbes) was grazing by cattle. Cattle also browsed the lower shoots of the willows, decreasing the number of branches available for visual inspection and beat sampling.

At the Kergunyah site, the riparian area was crash grazed on one occasion which had a significant impact on vegetation. At the remaining sites grazing was more or less intensive at different times through the season. Riparian understorey vegetation at these sites, and at the Happy Valley site, was dominated by exotic pasture grasses such as ryegrass, Yorkshire fog, cocksfoot, phalaris, brome and poa species (Appendices 1 and 2).

Grasses were less dominant at Cheshunt and were not found on transects at Loch (Appendix 1). Both of these sites were on public land, with a mixture of willows and native tree species in the overstorey. At Cheshunt, blackberry (*Rubus fruticosus* agg.) dominated the understorey vegetation, while tradescantia (*Tradescantia fluminensis*) was the dominant

understorey species at Loch. There was also a dense infestation of tradescantia in one section of the Glen Forbes site (Appendix 1). At this site, the riparian weed caper spurge (*Euphorbia lathyris*) was found in 26-40% of quadrats throughout the season, while at Loch native nettles (*Urtica incisa*) were common, occurring in 30-40% of quadrats.

The frequency of some species varied across the season, with cleavers (*Galium aparine*) showing the strongest example of this trend (Appendix 1). At several sites, cleavers occurred with high frequency in quadrats in the first part of the season and then declined to very low levels, or nil, in the latter part of the season. It is unclear how much this pattern was influenced by the dry summer. It is likely that, at some sites at least, that understorey vegetation patterns were affected by drought conditions.

What is clearer is that at Kergunyah, the one site where willow sawfly defoliated willow trees, there was no discernible impact of tree defoliation on understorey vegetation during this season. The density and orientation of willows at this site is such that sufficient light is probably available to understorey vegetation to facilitate growth, even under an intact canopy. However, over time it is possible that if willow defoliation continues at this site, changes will be observed in riparian vegetation.

Temperature

The data collected by the temperature loggers at the sites in north east Victoria confirm that the 06/07 summer was hot! The highest temperature recorded at any site was 43.1°C on the 11th January at Kergunyah. Sub-zero temperatures were recorded at all sites early in the season. The highest and lowest monthly maximum and minimum temperatures are presented in Table 11, as is the number of days when the maximum temperature was 30°C or higher. Figures 18-21 show the daily maximum and minimum temperatures at each site throughout the season.

The highest monthly maximum temperature tended to be higher at Kergunyah which had 115 days where the maximum temperature reached 30°C or more, compared with approximately 80 days of $\geq 30^\circ\text{C}$ at the remaining three sites (Table 11). This may have been partly a consequence of the defoliation of trees removing shade from above the temperature logger. Minimum temperatures were similar across all sites.

Table 11: Minimum and maximum temperatures, and number of days with maxima $\geq 30^{\circ}\text{C}$, at sites in north east Victoria, October 2006 – April 2007

Month	Cheshunt		Everton		Happy Valley		Kergunyah	
	Min	Max	Min	Max	Min	Max	Min	Max
Oct: lowest	-0.2	16.8	-1.1	16.4	-3.2	16.2	-1.1	16.9
Oct: highest	10.6	32.3	20.9	32.5	12.3	32.4	14.0	34.0
Days $\geq 30^{\circ}\text{C}$		2		2		2		2
Nov: lowest	0.3	13.4	1.0	14.1	0.2	14.0	0.5	15.6
Nov: highest	14.5	35.2	17.5	35.0	14.6	35.4	15.8	38.5
Days $\geq 30^{\circ}\text{C}$		14		9		8		13
Dec: lowest	3.8	16.3	5.3	18.8	3.3	18.4	3.6	22.7
Dec: highest	20.0	39.1	20.5	39.3	20.3	38.5	22.0	42.7
Days $\geq 30^{\circ}\text{C}$		13		16		14		25
Jan: lowest	10.1	20.9	9.1	23.9	8.4	23.3	7.2	26.0
Jan: highest	23.1	38.7	25.1	42.0	22.0	40.8	25.1	43.1
Days $\geq 30^{\circ}\text{C}$		21		25		23		28
Feb: lowest	12.7	23.6	15.1	26.2	9.9	25.4	12.3	24.4
Feb: highest	20.1	37.9	20.8	39.5	21.5	38.0	21.0	40.7
Days $\geq 30^{\circ}\text{C}$		23		25		24		26
Mar: lowest	5.5	15.6	6.7	17.5	5.2	17.1	5.6	19.9
Mar: highest	18.8	33.9	21.2	36.4	19.6	36.0	19.5	37.0
Days $\geq 30^{\circ}\text{C}$		7		10		8		20
Apr: lowest	6.4	15.9	6.9	16.4	2.4	16.3	3.6	18.3
Apr: highest	12.7	27.1	13.6	26.9	12.7	26.7	13.2	30.4
Days $\geq 30^{\circ}\text{C}$		0		0		0		1

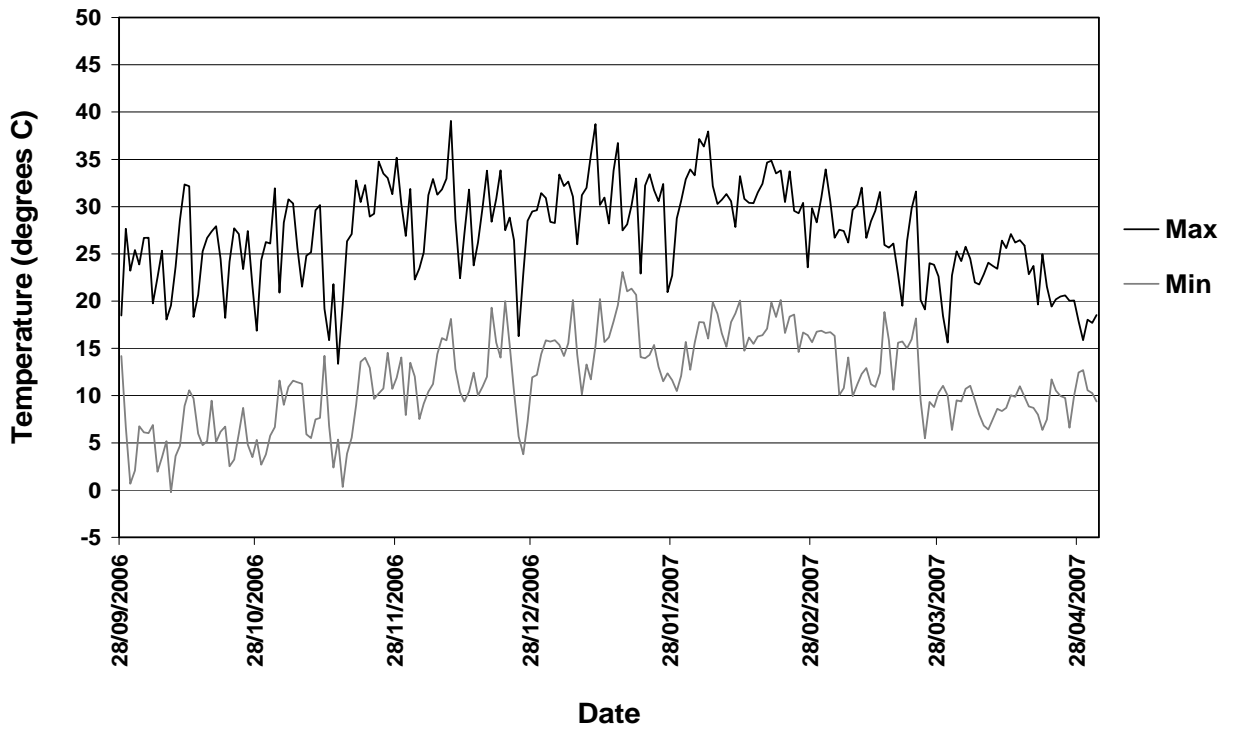


Figure 18: Daily maximum and minimum temperatures at Cheshunt site, from September 2006 to April 2007

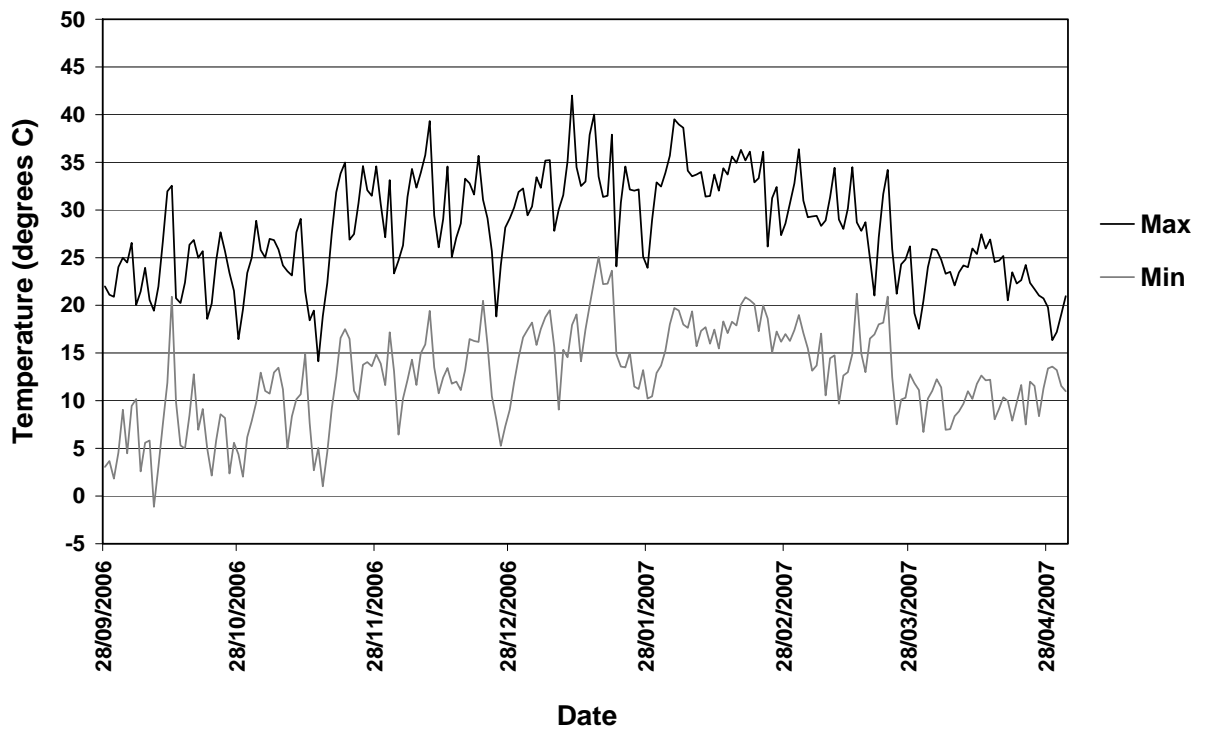


Figure 19: Daily maximum and minimum temperatures at Everton site, from September 2006 to April 2007

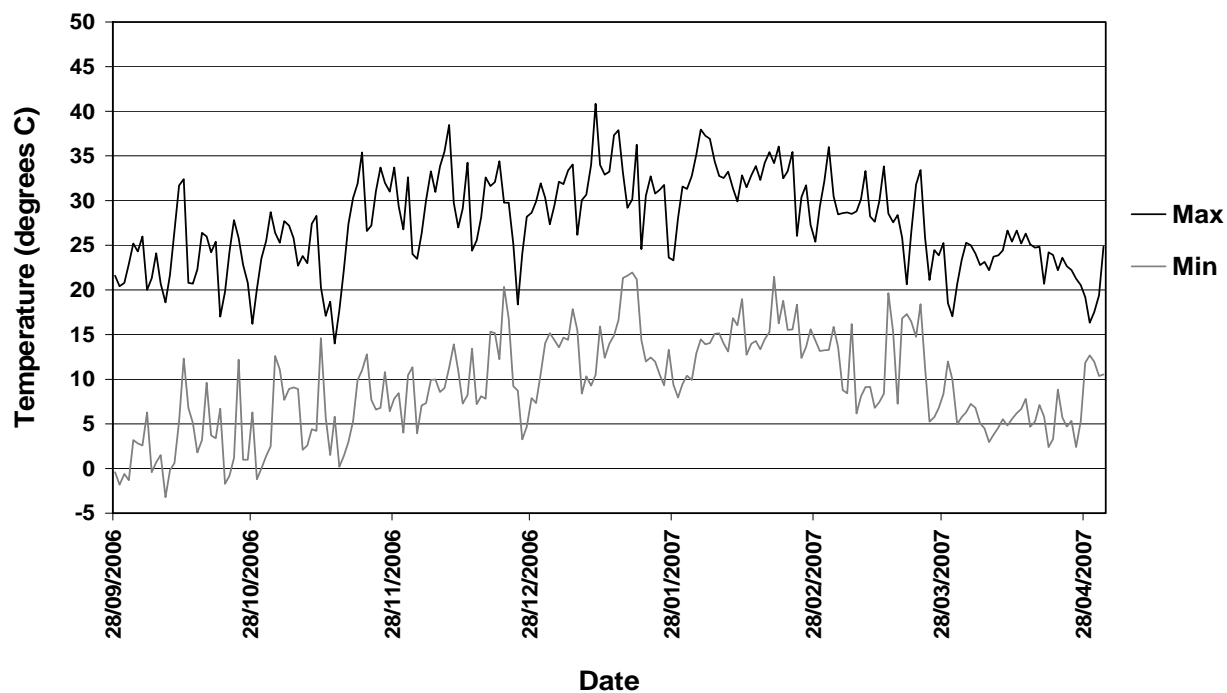


Figure 20: Daily maximum and minimum temperatures at Happy Valley site, from September 2006 to April 2007

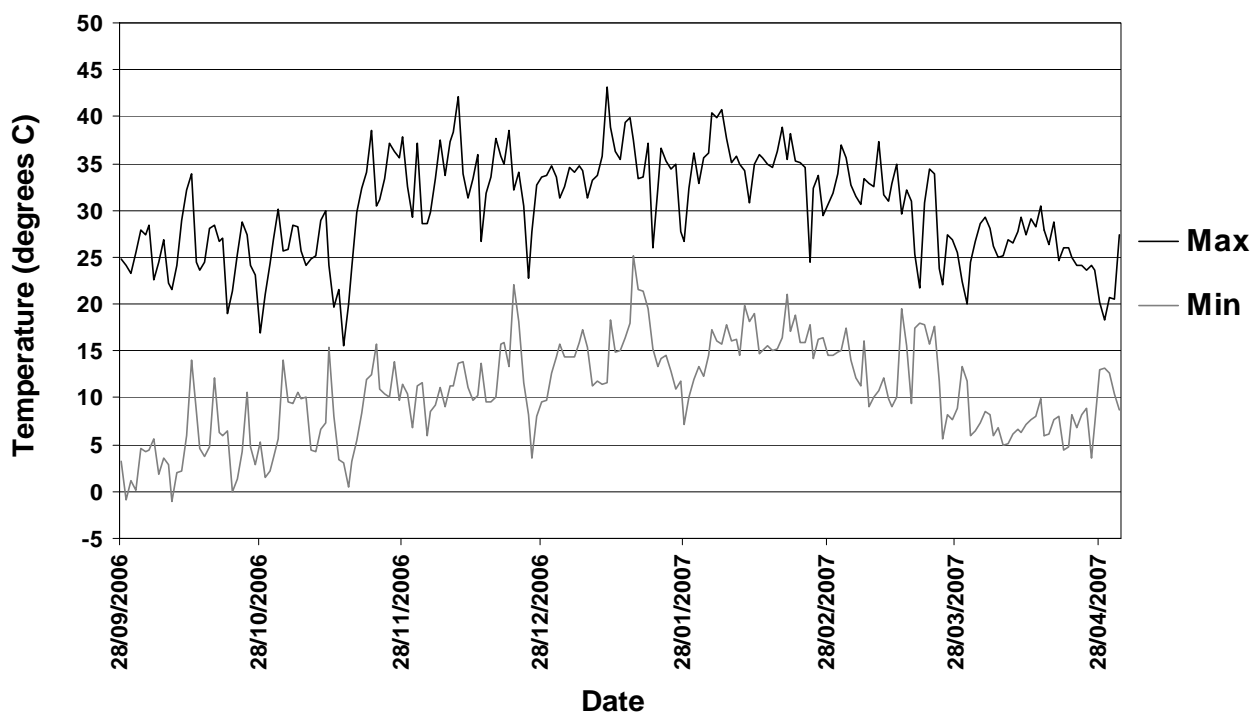


Figure 21: Daily maximum and minimum temperatures at Kergunyah site, from September 2006 to April 2007

Monitoring Various Willow Taxa

Nine additional willow taxa at 10 sites in north east Victoria and six sites in southern Victoria were assessed at intervals through the season for willow sawfly and tree defoliation. Willow sawfly was found at all sites during the season although not on all taxa (Table 12), but defoliation of trees only occurred at Kiewa and Kergunyah, both of which are in the Kiewa Valley in north east Victoria.

Crack Willow (*S. fragilis*)

At eight of the ten sites with crack willow, populations of willow sawfly remained low across the season, with only a few larvae found at any one time. Later in the season, larvae were often not found, but old eggs and holes characteristic of willow sawfly were observed. No tree defoliation was noted at any of these sites, although at the Markwood site, some individual leaves had been extensively eaten by willow sawfly larvae at different times in the season.

The remaining sites were Kiewa and Leneva West. The Kiewa site is about 10 km north of the intensively monitored site at Kergunyah and willow sawfly was active at this site in the 2005/06 season, as it was in much of the Kiewa Valley.

In the 2006/07 season, willow sawfly was first found on crack willows at Kiewa in mid October and population levels remained high throughout the season. On trees some distance from the river, defoliation was severe throughout the season and tree dieback extensive. However, the drought conditions through the season probably contributed to the poor health of these trees, so it is unclear if these trees will regrow in the coming spring. On those trees next to the river, defoliation was severe at times through the season, but in February, a reasonable amount of regrowth was still intact, despite high larval numbers. There was dieback of groups of smaller branches on some of these trees.

At the Leneva West site, willow sawfly population levels on crack willow remained low throughout the season. However, in February, a number of leaves had been damaged, with some small areas of twigs being completely defoliated by willow sawfly.

In December it was noticed that willow trees in an area close to this site were defoliated, but it was not possible to gain access to these trees to verify the activity of willow sawfly. This is consistent with observations in March 2006, when crack willows along a 2 km stretch of Middle Creek were defoliated by willow sawfly (A. Briggs, pers. comm.). At the time of this observation it was noticed that the willow sawfly were consuming regrowth, indicating that the trees had been defoliated earlier in the season. Weeping willows in the vicinity appeared to be untroubled by willow sawfly at this time.

Golden Willow (*S. alba* var. *vitellina*)

The golden willows in the King Valley (about 3 km north of Whitfield) had been defoliated by willow sawfly in the 2005/06 season (A. Briggs, pers. comm.). However in 2006/07, although willow sawfly larvae were present from the beginning of the season, no tree

Table 12: Willow sawfly activity at sites with various willow taxa

Willow Taxon	Site	Date First Observed Willow Sawfly	Willow Sawfly Population	Tree Defoliation
Crack willow (<i>S. fragilis</i>)	Whitfield	29/11/06	Low	Nil
	Edi Cutting	17/10/06	Low	Nil
	Markwood	29/11/06	Low	Nil
	Beechworth	29/11/06	Low	Nil
	Leneva West	18/10/06	Low	Very low
	Kiewa	18/10/06	High	Severe
	Chirnside Park	18/01/07	Low	Nil
	Wandin North	05/12/06	Low	Nil
	Seville	05/12/06	Low	Nil
	Woori Yallock	05/12/06	Low	Nil
Golden willow (<i>S. alba</i> var. <i>vitellina</i>)	King Valley	17/10/06	Low	Nil
	Everton	29/11/06	Low	Nil
	Dederang	28/11/06	Low	Nil
Weeping willow (<i>S. babylonica</i> ; <i>S. x sepulcralis</i> var. <i>chrysocoma</i>)	Edi Cutting	10/01/07	Low	Nil
	Everton	29/11/06	Low	Nil
	Leneva West	28/11/06	Low	Nil
	Kergunyah	28/11/06	High	Mod - severe
	Kiewa	28/11/06	High	Mod - severe
	Poowong North	01/03/07	Very low	Nil
Chilean pencil (<i>S. humboldtiana</i>)	Kiewa	28/11/06	Medium	Moderate
Black willow (<i>S. nigra</i>)	Everton	29/11/06	Low	Nil
NZ hybrid (<i>S. matsudana</i> x <i>alba</i>)	Woodleigh	04/12/06	Low	Nil
Grey sallow (<i>S. cinerea</i> and hybrids)	Edi Cutting	-	Nil	Nil
	Beechworth	21/02/07	Low	Nil
	Leneva West	09/01/07	Very low	Nil
	Chirnside Park	-	Nil	Nil
	Wandin North	-	Nil	Nil
	Seville	-	Nil	Nil
	Woori Yallock	18/01/07	Low	Nil
Purple osier (<i>S. purpurea</i>)	Everton	29/11/06	Very low	Nil
Lombardy poplar (<i>Populus nigra</i> 'Italica')	King Valley	-	Nil	Nil
	Beechworth	-	Nil	Nil
	Kergunyah	18/12/06	Very low	Nil
	Kiewa	-	Nil	Nil

defoliation occurred at this site. Population levels of willow sawfly larvae were not high at any stage through the season. There was evidence of some moderate level of activity, as the number of hatched eggs and holes was high at times, particularly in the latter half of the season, and multiple eggs were present on some leaves. But this was not reflected in overall damage to the trees.

At Everton and Dederang, willow sawfly was first observed on golden willow trees in late November. Although at some times throughout the season, large numbers of hatched eggs and holes were found, including multiple eggs per leaf, willow sawfly larvae numbers did not build up through the season. No tree defoliation occurred as a result of willow sawfly activity.

Weeping Willow (*S. babylonica*, *S. x sepulcralis* var. *chrysocoma*)

Willow sawfly populations were low or very low at four sites with weeping willows – Edi Cutting, Everton, Leneva West and Poowong North (Table 12). No live larvae were found on the trees at Poowong North during the season. No tree defoliation occurred at these sites. Although unconfirmed, it is likely that the trees are all *S. babylonica*. Despite the lack of willow sawfly activity, rust was common on these trees.

At both Kergunyah and Kiewa, willow sawfly populations built up to high numbers through the season, resulting in moderate to severe tree defoliation. At Kergunyah, where the dominant species of weeping willow is probably *S. x sepulcralis* var. *chrysocoma*, tree defoliation was moderate in the early part of the season, severe in January and February, and moderate for the remainder of the season. Defoliation on these trees tended to be patchy with foliage on some areas of the trees remaining intact, while other branches were completely defoliated.

In the early part of the season, the weeping willows (taxa unclear) at Kiewa had low willow sawfly numbers and little defoliation. However, by January population numbers had increased to the point where severe defoliation was occurring. By the end of the season, the internal branches of a number of weeping willows situated some distance from the river were completely defoliated, with leaves only present on a few external branches.

Chilean Pencil Willow (*S. humboldtiana*)

The population of willow sawfly on Chilean pencil willow at Kiewa varied through the season, with the lowest number of larvae being found in February. However, population levels were sufficiently high to cause some defoliation, which was severe at the end of the season. The leaves on this willow are smaller than those on other tree willows, and very narrow. It was interesting to note that the willow sawfly cocoons found on these leaves in November were smaller than those found on nearby crack willow leaves.

Black Willow (*S. nigra*)

Willow sawfly has defoliated black willow trees at sites in north east Victoria, particularly in the 2005/06 season (Ede 2006). However, no defoliation occurred on the black willows at the Everton site monitored during the 2006/07 season. Willow sawfly was first found at this site in spring 2006 and maintained low population levels on all willow species present

through the season. The low numbers of larvae found on the black willows were insufficient to cause any damage of note.

New Zealand Hybrid Willow (*S. matsudana* x *alba*)

Willow sawfly were present on the New Zealand hybrid willows at the Woodleigh site in West Gippsland through the season, but numbers were too low to have any impact on the trees beyond very occasional leaf damage.

Grey Sallow (*S. cinerea*)

Willow sawfly was not found on grey sallow at four sites - Edi Cutting, Chirnside Park, Wandin North and Seville (Table 12).

At Leneva West, an adult willow sawfly was observed on a grey sallow leaf in late November and hatched eggs and characteristic holes were present from January onwards. No larvae were found on grey sallow at this site, but they were observed at two other sites. At Woori Yallock, small numbers of larvae were found in mid January and late February, while at Beechworth several larvae were found on grey sallow shrubs in the latter half of the season.

At the Beechworth site, some leaves had holes which could have been caused by willow sawfly larvae early in the season, but confirmation of willow sawfly was not possible until February, when hatched eggs and holes, and several small larvae were found. Some of the holes adjacent to the hatched eggs were of a reasonable size, indicating that the larvae had survived for some days. In April, both small and large larvae were observed (Fig. 22), as were leaves that had been almost entirely eaten by willow sawfly.



Figure 22: Willow sawfly larva on grey sallow leaf, Beechworth, April 2007

A number of larvae were removed for rearing from the Beechworth grey sallow shrubs in February, along with quantities of fresh foliage. These larvae were grown on in the laboratory, fed only on grey sallow leaves. The larvae pupated and produced adults which laid fresh eggs, confirming the observations from New Zealand that willow sawfly can complete its life cycle on grey sallow (J. Charles, pers. comm.).

Purple Osier (*S. purpurea*)

Only one live larva was found on the purple osier willows at Everton at any stage during the season, and that was in late November. Hatched eggs and small holes were observed throughout the season but willow sawfly did not have an impact on these shrub willows.

Lombardy Poplar (*Populus nigra* 'Italica')

No sign of willow sawfly was found on Lombardy poplars at three sites (King Valley, Beechworth, Kiewa, Table 12). At Kergunyah, where willow sawfly were abundant in the local area which is heavily populated with willows (predominantly *S. x rubens*), a small number of adults were observed on the leaves of the poplars in mid December. One hatched egg plus a characteristic hole was found on a leaf at this time, but no larvae were observed, and no other eggs and holes were observed later in the season.

Tree Defoliation at Other Sites

Defoliation of willow trees at a number of sites in Victoria were reported by local field staff in 2006/07. All but one of these reports (a site on the Goulburn River at Seymour) were followed up by site visits.

Barnawartha North, North East CMA

Crack willows have been defoliated on two farms bordering the Murray River around Barnawartha North. At the first site, tree defoliation was first noticed in October 2005 (J. Terrill, pers. comm.). Defoliation was again evident in December 2006, in an increased number of trees. At the time of the site visit in February the new foliage on the trees was reasonably intact, despite the presence of some small willow sawfly larvae.

Severe defoliation of trees on the second farm had occurred, but the history of willow sawfly infestations and defoliation was unclear. At the time of the site visit, numerous larvae of all sizes were observed, but the newly developed leaves were still mostly intact.

Swanpool, Goulburn Broken CMA

Crack willows on a property on the Broken River near Swanpool were defoliated in the 2005/06 season (B. Whitten, pers. comm.). They were again severely defoliated in November 2006, and at that time numerous adults were evident. At the time of the site visit in February, there were moderate levels of defoliation, with some new foliage still intact and some completely eaten. Multiple eggs per leaf were observed.

Another willow sawfly outbreak has occurred a few kilometres to the west on Warrenbayne Creek. As reported for the site on the Broken River, willow sawfly defoliation was first

noticed in the 2005/06 season, followed by severe defoliation in November 2006 (G. Brennan, pers. comm.). It is possible that willow sawfly is also affecting willow trees on nearby Baddaginnie Creek but the extent of this infestation has not been ascertained.

Kyneton, North Central CMA

The Campaspe River crosses the Calder Highway at Kyneton and is lined with crack willows for some kilometres in both directions. Defoliation of willows was first noticed in mid January 2007, although it is likely that it had been occurring for some time prior to this. In January, adults laying eggs were observed, as were numerous larvae and pupae (M. Jackson, pers. comm.). It was estimated at that time that about 2 km of willows along the river were affected by willow sawfly.

A site just off the Calder Highway was visited in late March, at which time tree defoliation was very severe, with only about 1% of foliage remaining on the trees. Numerous larvae and some adults were observed. The extent of trees defoliated by willow sawfly at this time was estimated to be 4 km.

At a second site about 7-8 km south east, at Carlsruhe, tree defoliation was not as severe on all trees in the area, although some trees had been seriously affected by willow sawfly. Numerous larvae were observed at this site.

Willow sawfly has also been found on sites on other rivers in the local area, particularly the Little Coliban River, south of Kyneton.

Poowong North, Melbourne Water

Severe tree defoliation was noticed on willow trees along Pheasant Creek, near Poowong North, in March, extending for about 150 m along the creek. Numerous larvae were found eating regrowing foliage. It is unclear whether the willows at this site are crack willows or *S. x rubens*.

Robin Hood, Melbourne Water

An outbreak of willow sawfly in *S. x rubens* trees was first noticed on the Tarago River at Robin Hood in early February 2007 (M. Brown, pers. comm.). Few larvae were found at this time because of the paucity of leaves. During a site visit in late February, severe defoliation was observed on trees for 200 m or more along the river (Fig. 23). New foliage had developed in the lower parts of trees, but the high numbers of larvae meant that this foliage was rapidly being eaten. Multiple larvae per leaf were observed, as were larvae moving along branches and tree trunks in search of new foliage.

This site was visited again in mid April and then three weeks later, in early May. In April, tree defoliation was still severe and larvae were numerous. The defoliation was still evident in May, including recent defoliation of individual leaves, but despite an intensive search effort, no larvae were found. This sudden disappearance of larvae has also been observed at some other sites.



Figure 23: Defoliation of *S. x rubens* trees along the Tarago River, February 2007

Kongwak, West Gippsland CMA

Defoliation of willows by willow sawfly was first observed in February 2006 at a site on Fosters Creek, Kongwak, with larvae found at that time. In the current season, numerous larvae and tree defoliation were noticed in early January 2007 (G. Charman, pers. comm.). A site visit in early March found high population levels of all stages of the life cycle, and numerous eggs on several leaves (see Table 3 above). The trees were severely defoliated at this time. As for the Poowong North site above, the identity of the willow taxon present at this site is unclear.

Boneo, Mornington Peninsula, Melbourne Water

At the very end of the season, a new defoliation site was discovered on the Mornington Peninsula at Boneo. Several golden weeping willows (*S. x sepulcralis* var. *chrysocoma*) (Fig. 24) and weeping willows (*S. babylonica*) were severely defoliated in late April. Dieback was evident on some trees. Numerous large larvae were observed at the time of the first site visit, including several on tree trunks and fence posts. However a return visit five days later failed to find any larvae, as discussed above.

Golden willows and golden weeping willows across the road from the severely defoliated trees had also been affected by willow sawfly, but defoliation was less severe on these trees.



Figure 24: Defoliation of golden weeping willow at Boneo, April 2007

Willow Sawfly in New South Wales

Willow sawfly has been present in some parts of New South Wales for some years, and a field visit was made to an area with high willow sawfly activity around Bathurst (west of Sydney) in March. The predominant willow taxon in this area is crack willow.

Tree defoliations have been noted in crack willows between Bathurst and Oberon to the south, along Fish River, for the past three seasons (C. Miller, pers. comm.). Initially, only about 5% of trees were affected in a patchy distribution along the river, with stretches of tree defoliation interspersed by reaches containing unaffected trees.

In the 2006/07 season, a dry spring was followed by a large increase in the number of defoliated trees in November and December, with about 80% of the trees between Bathurst and Oberon affected. The patchiness of tree defoliation observed in previous seasons did not occur this season. Instead, defoliation was first noted at the top of the catchment, and moved downstream in solid wave, affecting the majority of the trees.

Trees remained defoliated through January, but significant rain in February promoted the development of new leaves which remained intact for some time. However, high willow sawfly populations resulted in this flush of new growth being consumed, giving rise to the second complete defoliation event of the season.

Sites in the affected area were visited in mid March. At this time, crack willows at several locations were severely defoliated, with some stands completely defoliated by willow sawfly. Larvae of all sizes were observed and a number of adults were found at one site. Dieback was also noted.

Willow sawfly was also found on a number of other willow taxa at this time, including golden willow, tortured willow and weeping willow, with defoliation affecting some of these trees.

Tree death has been observed in this area, but it is unclear whether the main causal factor is willow sawfly or drought, or a fatal combination of these, and potentially other, factors. It will be interesting to see how many trees produce new foliage in the coming spring.

Reports of willow sawfly and of tree defoliation from other locations in NSW are included on Fig. 26. One of these reports indicates that willow sawfly defoliation has occurred for the past two seasons at Evans Plains and Kings Plains, which are both west of Bathurst. The first defoliation event was noticed in February 2006, with defoliation again occurring in mid December 2006. A second defoliation event was observed in the Kings Plain trees in March 2007 (J. Gordon, pers. comm.).

Maps

Current Distribution

The current known distribution of willow sawfly is presented in Figures 25 and 26, for Victoria and for south eastern Australia. The points mapped relate only to sites where the

location data are known, either from GPS or map references. However, it is highly likely that willow sawfly is more widespread than is shown by these maps and that additional search effort would be rewarded with increased sightings.

These maps differentiate between sightings of willow sawfly and reports of tree defoliation. In the case of the Victorian map (Fig. 25) all known sites of defoliation are illustrated. However, much of the data used to populate the map for south eastern Australia (Fig. 26) do not differentiate between willow sawfly sightings and tree defoliation. For example, the majority of sites in the area around ACT and southern NSW, and in South Australia are sites where tree defoliation has occurred, but as it was not possible to confirm which points relate to sites of tree defoliation, all these sites were depicted as sightings.

Potential Distribution and Impact

The potential distribution of willow sawfly across Victoria and across Australia is presented in Figures 27 and 28, while the areas where willow sawfly has the potential to significantly impact of willow trees (causing defoliation) are presented in Figures 29 and 30. These maps have been prepared by matching the climate of areas in Australia and New Zealand where willow sawfly is currently found and is currently causing tree defoliation. The maps do not screen out areas which do not contain willows, so in the north west of Victoria, for example, where the distribution of willows is limited, conditions are such that willow sawfly would not be limited by climate.

The scale used on the maps describes the likelihood of the outcome occurring:

- White (uncoloured) – low likelihood of occurrence, < 50% likelihood
- Green – likely to occur, 50-60% likelihood
- Orange – moderately likely to occur, 60-70% likelihood
- Yellow – highly likely to occur, 70-80% likelihood
- Red – very highly likely to occur, >80% likelihood

This analysis of potential willow sawfly distribution and impact shows that in Victoria, there is a moderate to very high likelihood that willow sawfly can occur across all areas of the state (Fig. 27), with most areas of the state except for the north west and alpine areas scoring a very high likelihood rating. The likelihood that willow sawfly will cause tree defoliation is also moderate to very high across the state, although fewer areas have a score of very high likelihood (Fig. 29). However, these predictive maps do illustrate that willow sawfly does have the potential to spread right across the state and to defoliate willow trees in all areas of the state where suitable host trees are available.

Across Australia, willow sawfly has the potential to spread across much of the southern part of the continent, as far as southern Queensland in the east, as well as into eastern Tasmania (Fig. 28). The likelihood of defoliation follows a similar pattern (Fig. 30), with areas of highest likelihood occurring in South Australia, Victoria, NSW, ACT and Tasmania. However it should be noted that the techniques used to develop these predictive maps do not preclude the occurrence of willow sawfly and of tree defoliation in areas of the country which are uncoloured (white) on the maps. It is only possible to conclude that the likelihood of willow sawfly occurrence and tree defoliation is lower in these areas.

As additional data are collected for both willow sawfly sightings and tree defoliation events, it will be possible to further refine these potential distribution and impacts maps.

Training

Training of Victorian public and private land managers in willow sawfly identification and assessment was carried out as a component of Willow Identification and Mapping Workshops. These workshops were run by the National Willows program of WoNS (Weeds of National Significance) at more than 30 sites nationally. Ten workshops were held in Victoria, which were attended by more than 200 people. At these workshops, participants were given information about willow sawfly and its impacts, including techniques to identify the insect. Where possible, live specimens were included in the presentation. Participants were asked to report any willow sawfly sightings to the project team. A full report of these workshops and their outcomes (Wadley and Holland Clift 2007) is available at <http://www.weeds.org.au/WoNS/willows/>.

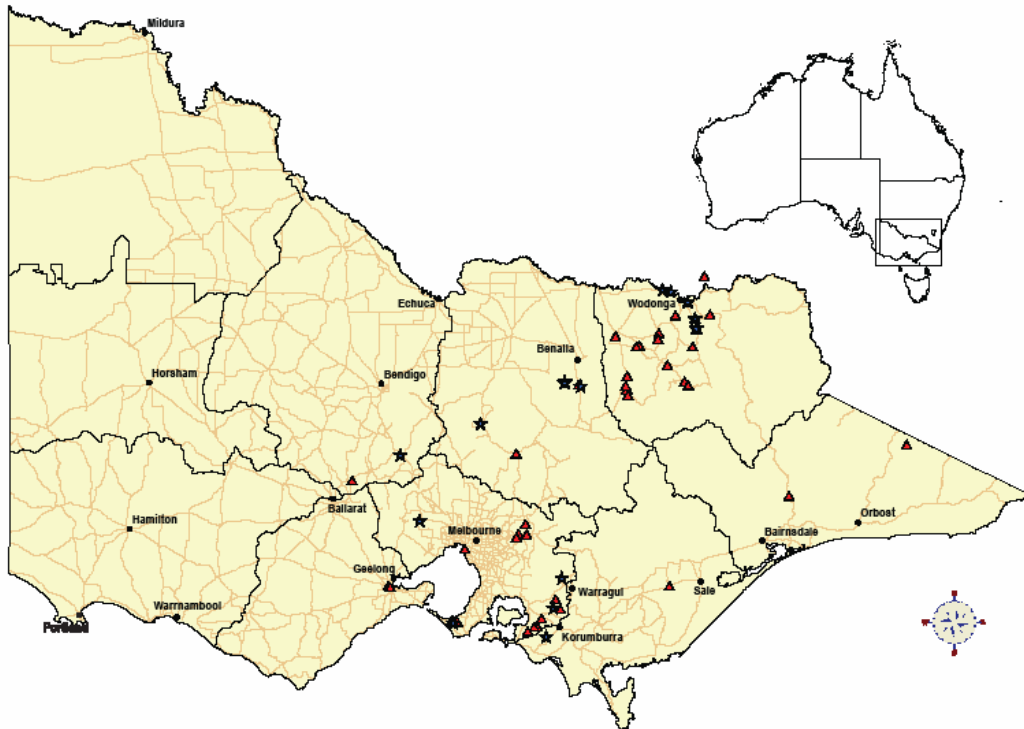


Figure 25: Sightings of willow sawfly (red triangles) and locations of tree defoliation (blue stars) across Victoria, as at May 2007

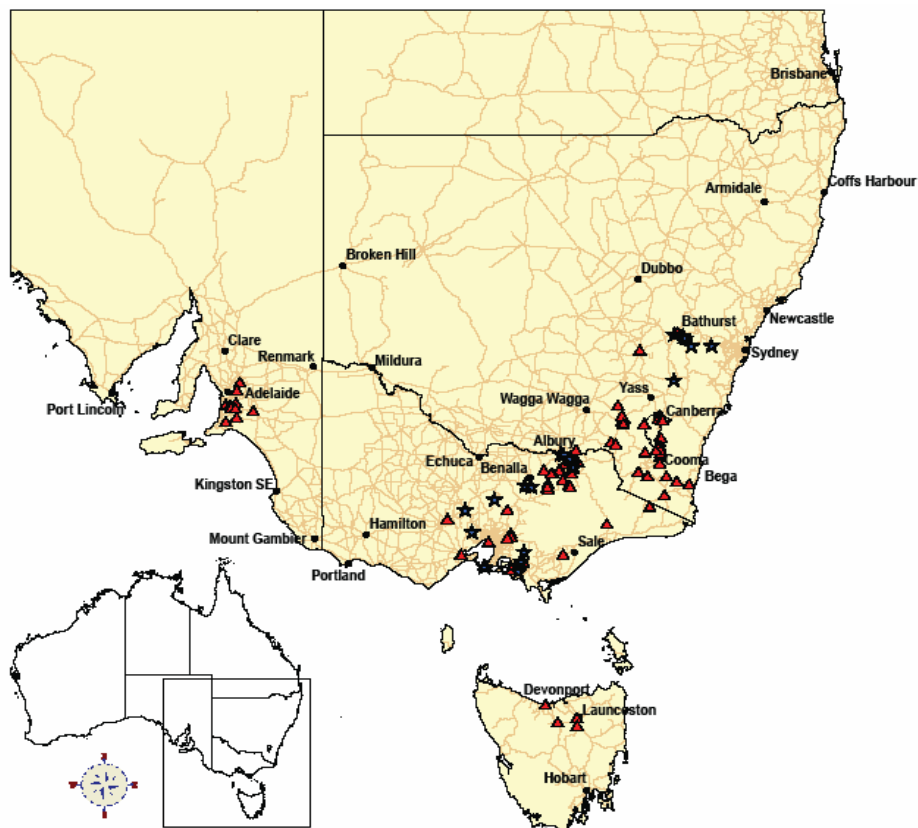


Figure 26: Sightings of willow sawfly (red triangles) and locations of tree defoliation (blue stars) across south east Australia, as at May 2007

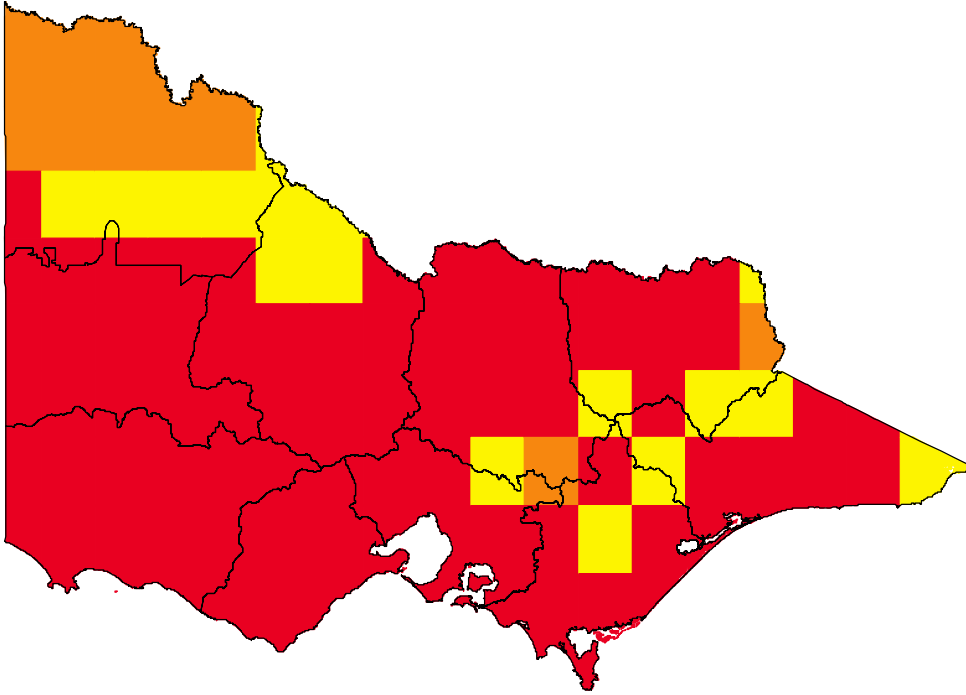


Figure 27: Likelihood of willow sawfly occurring across Victoria

Scale: Orange – moderately likely; yellow – highly likely; red – very highly likely

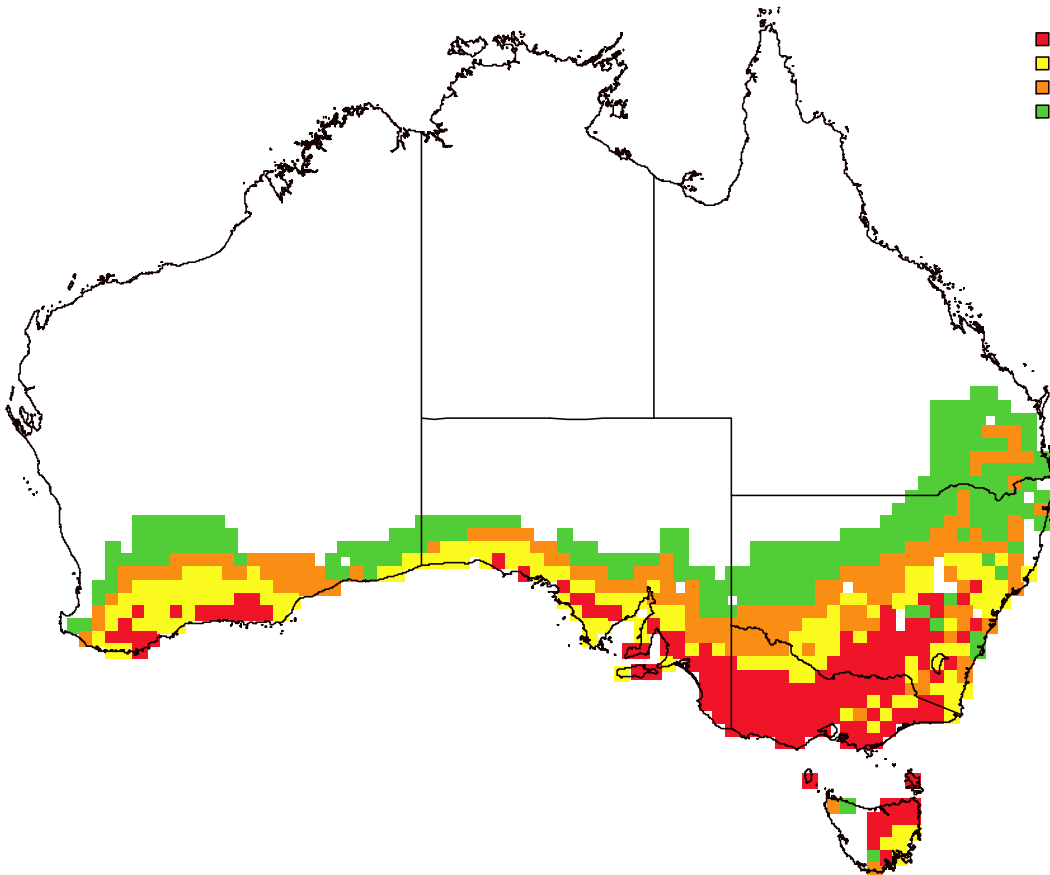


Figure 28: Likelihood of willow sawfly occurring across Australia

Scale: White – less likely; Green – likely; Orange – moderately likely; yellow – highly likely; red – very highly likely

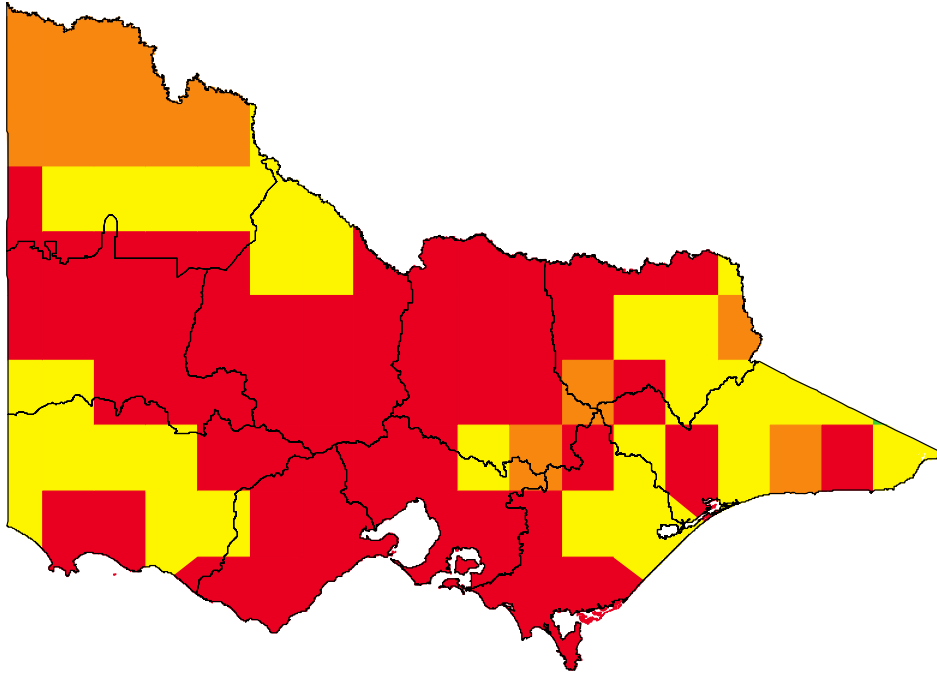


Figure 29: Likelihood of tree defoliation occurring across Victoria

Scale: Green – likely; Orange – moderately likely; yellow – highly likely; red – very highly likely

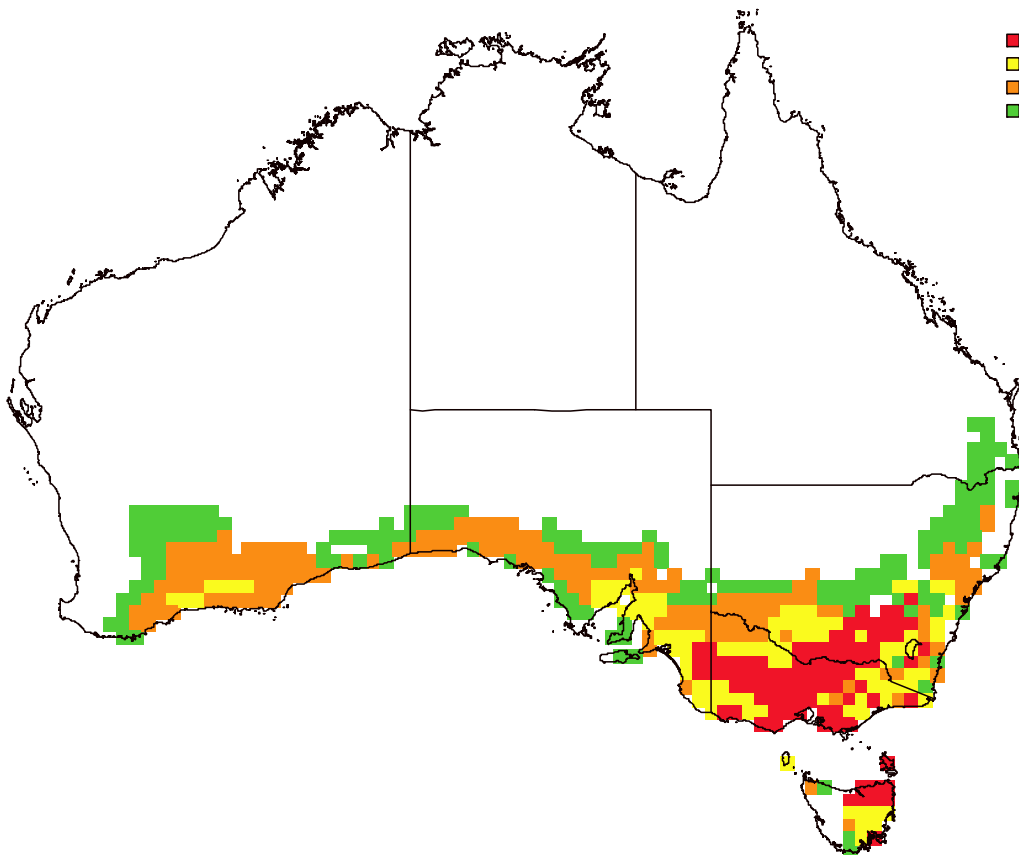


Figure 30: Likelihood of tree defoliation occurring across Australia

Scale: White – less likely; Green – likely; Orange – moderately likely; yellow – highly likely; red – very highly likely

Discussion

Willow Sawfly Population Levels

During the 2006/07 season, the number of sites in Victoria where willow sawfly occurred increased from the previous season, as did the number of locations where population levels were high enough to cause tree defoliation. Severe defoliation of stands of willows trees have now been reported from several sites in north east Victoria, the Goulburn-Broken system, the Campaspe River around Kyneton, and a small number of sites to the east and south east of Melbourne, including Boneo on the Mornington Peninsula.

From observations made during the monitoring process and from analysis of the reports received from field staff, it appears that population levels of willow sawfly operate in a binary fashion. If willow sawfly is present at a site, the population is either very low or extremely high. If low, some search effort is required to find eggs, larvae and/or characteristic holes, but this evidence can be readily found within a few minutes of searching. High population levels manifest in tree defoliation, and this may be obvious from quite some distance away.

Monitoring during the 2006/07 has found no evidence of intermediate population levels of willow sawfly, which would result in partial tree defoliation. At some sites, population levels did increase to the extent that very small areas of foliage were defoliated (e.g. Everton), but this level of defoliation was not obvious without some search effort.

The reports of willow sawfly received from field staff in Victoria all related to significant tree defoliation and in some cases, the 2006/07 season was the second season in which this defoliation had been observed. No reports of very low levels of willow sawfly were received from field staff, probably because a level of search effort was required to make such a finding, and because they were unaware of the evidence for which they could search to confirm willow sawfly presence.

If the populations of willow sawfly do indeed exist in only either very low levels or very high levels, it raises the very interesting question of how long does the population take to increase from this low baseline to a level high enough to cause tree defoliation? At the sites where defoliation has occurred, it is likely that low levels of willow sawfly existed for a number of seasons before building up to the level sufficient to cause noticeable defoliation. If only one season is required for numbers to build up to this level, then defoliation of trees at sites where willow sawfly arrived in 2006/07 will occur in 2007/08. However, it is more likely that two or more seasons are required for population numbers to increase to high levels. Ongoing monitoring of sites will increase our understanding of these population dynamics.

In the context of this question, it is interesting to consider the extensive defoliation of willow trees on the Campaspe River around Kyneton. The extent and intensity of defoliation is a consequence of very high willow sawfly numbers, indicating that it is highly likely that willow sawfly has been in the area for some time prior to the 2006/07 season. However, no evidence of willow sawfly was found on nearby crack willows during a comprehensive

willow survey undertaken by DPI staff in 2005/06 (K. Finlay, pers. comm.). The site surveyed is about 4 km south of the site of severe defoliation visited in March 2007. It is possible that as this site was surveyed in mid October 2005, it was prior to the commencement of willow sawfly activity in the area for that season, and so none were observed. However, no anecdotal reports of willow sawfly activity from the 2005/06 season have come to light as a consequence of the very obvious defoliation in 2006/07.

A second question that then arises relates to the factors that influence this population growth. Experience in New Zealand suggested that warm, dry spring conditions favoured population development (Ede 2006), and although the results from this season do not disprove that theory, it is too early to determine how important spring conditions are in the Australian context.

It had been hypothesised that high summer temperatures may be detrimental to willow sawfly, given that its native range is the more northern latitudes of the northern hemisphere (Ede 2006). However, the evidence from the 2006/07 season indicates that the insect can thrive in conditions where daily maximum temperatures are regularly above 30°C and occasionally more than 40°C. Relatively high night temperatures also occurred during the 2006/07 season, with no apparent detrimental impact on willow sawfly activity.

There seem to be few natural enemies of the willow sawfly in Australia. Although some limited predation of larvae by birds and other insects was observed under high population densities, at this stage it appears unlikely that either predation or parasitism affect willow sawfly numbers. Further work is required to see if natural enemies will accumulate through time and suppress willow sawfly population outbreaks.

There is one site where willow sawfly population numbers appear to have decreased in the 2006/07 season in comparison with the 2005/06 season. The stand of golden willows just north of Whitfield in the King Valley in north east Victoria were defoliated by willow sawfly in 2005/06 (A. Briggs, pers. comm.), but population levels in 2006/07 were too low to cause any tree defoliation at any stage through the season. No explanation for this decline in willow sawfly numbers is readily apparent.

Cycles of Defoliation

Anecdotal evidence from New Zealand suggested that a series of discrete defoliation events were readily observed in willow populations affected by willow sawfly (Ede 2006) as willows were defoliated, grew new leaves, and then were defoliated again. At some sites, up to four such cycles were observed. However, this cyclical pattern of defoliation, refoliation and subsequent defoliation was not readily observed in trees monitored at Kergunyah and Kiewa during the 2006/07 season. Instead, as larvae were present all through the season, new foliage was consumed by existing larvae as soon as it developed, and there was very little time during the season when trees had any appreciable foliar cover.

However, there was some limited recovery of foliage in January at Kergunyah, after particularly severe defoliation in December. Tree canopy densities and leaf areas were

higher in January than in December, but then declined again as the severity of defoliation increased later in the season. It is possible that these observations reflect a discrete cycle of defoliation/refoliation but the overall seasonal pattern is not strongly cyclical. At both Kergunyah and Kiewa, willow trees maintained a full canopy of leaves for probably less than two months of the entire season.

There appears to be no relationship between the partial recovery of foliage at Kergunyah in January and the temperature conditions in the preceding weeks. Maximum daily temperatures were generally above 35°C from mid November to mid December, decreasing slightly in late December and early January. The maximum temperature then peaked on 11th January (43.1°C). However, as there were days in both early December and late February with maxima above 40°C, which were followed by high willow sawfly activity and severe tree defoliation, it is unlikely that the 11th January temperature spike impacted on willow sawfly numbers. Daily minima were higher in January than December, but were even higher in February (generally ranging from 15°C to 20°C).

A second observation from willow populations in New Zealand was that if willow sawfly population levels built up to high numbers in late spring or early summer, with defoliation occurring before Christmas, then numbers would remain high all season and several defoliation events would occur (G. Hansen, pers. comm.). Warm dry spring conditions seemed to favour population development. Although Kergunyah and Kiewa were the only monitoring sites with high willow sawfly populations in 2006/07, at both sites population levels were high in spring and remained high all season. In addition, at sites along the Murray and in the Goulburn-Broken catchment where tree defoliations were reported, the first defoliations were noted in November or December. This limited evidence does suggest that in Victoria, willow sawfly populations can quickly develop early in the season, causing tree defoliations as early as November. However, at other sites the first defoliation events were not observed until later in the season, indicating that population numbers can still increase sufficiently to cause defoliation in summer and autumn.

Willow Sawfly on Different Willow Taxa

Defoliation

In Victoria, defoliation of willow trees of the following taxa has been observed at sites in the past two seasons:

Crack willow	<i>S. fragilis</i>
Golden willow	<i>S. alba</i> var. <i>vitellina</i>
Crack x golden	<i>S. x rubens</i>
Black willow	<i>S. nigra</i>
Chilean pencil willow	<i>S. humboldtiana</i>
Tortured willow	<i>S. matsudana</i> ‘Tortuosa’
Weeping willow	<i>S. babylonica</i>
Golden weeping willow	<i>S. x sepulcralis</i> var. <i>chrysocoma</i>

At sites where weeping willows are present in conjunction with other willow taxa, they tend to be defoliated later than other willows, indicating that weeping willows are not preferred

hosts. However, severe defoliation of several weeping willows trees was observed at the Kiewa, Kergunyah, Tarago and Boneo sites this season.

Chilean pencil willow (*S. humboldtiana*) was only present at the Kiewa site, where there were two trees. Severe defoliation was observed on these trees only in the latter part of the season, indicating that this species, like the weeping willows, may not be a preferred host species.

Presence

In addition to the taxa noted above, willow sawfly was found in low numbers on the following species in the 2006/7 season:

New Zealand hybrid	<i>S. matsudana x alba</i>
Purple osier	<i>S. purpurea</i>
Grey sallow	<i>S. cinerea</i>

The New Zealand experience (Ede 2006) and one report from NSW (J. Gordon, pers. comm.) suggest that the NZ hybrids are susceptible to willow sawfly, as is the shrub willow, purple osier. However, although under laboratory condition willow sawfly has been found to complete its lifecycle on grey sallow (J. Charles, pers. comm.), this shrub is generally not regarded as a preferred host for willow sawfly. There are no reports from the field of willow sawfly impacting on grey sallow.

Grey sallow

The evidence of willow sawfly activity on grey sallow at two of the monitoring sites, Leneva West and Woori Yallock, is indicative of an opportunistic occurrence whereby adults laid eggs on a small number of leaves of grey sallow, which were growing next to crack willow trees. Some of these eggs hatched to produce larvae that lived for a short time, but did not appear to live through to maturity, given the small size of the holes created.

However, at the Beechworth site, several larvae of all sizes were observed during site visits in the latter part of the season. In addition, the leaf damage caused by the larvae ranged from very small holes through to almost complete destruction of the leaf, indicating larvae were reaching maturity. This evidence points to the sustained development of a willow sawfly population in this stand of grey sallow, which is about 300 m from the crack willows at this site.

The extent of initial development of the willow sawfly population in the grey sallow shrubs at Beechworth is similar to that of populations on other taxa at sites where willow sawfly first appeared in 2006/07. In fact, total larval numbers at this site were higher than at some other sites. Ongoing monitoring of this site will contribute to determining whether populations of willow sawfly on grey sallow can develop to levels that lead to defoliation, or whether field populations will remain at low levels and have no significant impact on this serious weed.

Tree Deaths

At the end of the 2006/07 season, it is not possible to attribute any willow tree deaths in Victoria to willow sawfly activity. However, dieback of small and large branches is evident on a number of willow trees which have been severely defoliated by willow sawfly, particularly at the Kergunyah and Kiewa sites, where trees have now been defoliated over two seasons. It is possible that some of these trees will fail to produce new foliage in this coming spring, indicating that the tree as a whole has died. However, given the propensity of willows to resprout from seemingly inert wood, it can be difficult to determine the point at which a willow tree is dead.

In NSW it is possible that willow sawfly has led to tree deaths in the Bathurst area (C. Miller, pers. comm.), particularly in conjunction with recent drought conditions, but until the coming spring this cannot be confirmed. Dieback of large parts of trees has certainly been observed in a number of trees in that area, especially at sites where defoliation has occurred over the past two to three seasons.

Willow sawfly has caused tree deaths in New Zealand and elsewhere, and deaths can occur in the second season of severe willow sawfly infestations (Ede 2006). Thus it is possible that trees in north east Victoria will die as a result of willow sawfly in the coming season. However, until more evidence is available, it is not possible to draw any conclusions as to the likely speed and extent of tree deaths from willow sawfly in Victoria.

Drought

The 2006/07 season was particularly dry across the whole of Victoria. In north east Victoria, spring is generally the wettest part of the year, but in 2006 little rain fell over this period and the summer was hot and dry. The area around Melbourne also experienced drought. Willow trees across the landscape showed signs of drought, with burnt foliage and early leaf loss, with those furthest from permanent water sources being most affected.

Nothing is known about the interaction between willow sawfly and drought, but tree health will suffer more from the application of two stressors than from a single stressor. In some areas, the drought alone may have been severe enough to kill susceptible willow trees. The additional stress of defoliation from willow sawfly could contribute to the demise of willows that would otherwise have survived the drought.

It is possible that drought stressed leaves are less palatable to willow sawfly than non-stressed leaves, but no evidence to either substantiate or disprove this hypothesis was found this season.

Tree Canopies and Light Levels

The major impact of willow sawfly on willow trees is loss of foliage, which in the short term changes the light environment under willows, and in the longer term deprives the trees of photosynthates and hence food resources, compromising tree survival.

At the sites monitored in this study, light levels under intact willow canopies were only up to 30% of levels in the open, and in some cases were much lower. If willows are able to remove 70% or more of the available light, then understorey plants need to be relatively shade tolerant to survive. This is particularly the case when ambient light levels are low as a result of cloud cover, causing light levels under the canopies to drop to levels which are below those required for net photosynthesis for many species. Loss of foliar cover as a result of willow sawfly activity will affect understorey species and may result in a change in understorey species and/or abundances.

Although there is not a strong relationship between light levels under willow canopies and tree canopy densities in the data presented here, there is a trend of decreasing light levels with increasing tree canopy density, as would be expected. The lack of strength in the relationship is probably driven mostly by the high variability in light levels due to cloud cover, time of day and time of year of measurement. Tree canopy densities are more stable over time and change less quickly.

The relationship between tree canopy density and leaf areas is also not particularly strong, but in general the two sets of data do exhibit similar trends. Leaf areas do not decline as steeply as tree canopy densities at the end of the season at the southern sites. Leaf areas are a measure of a small sample of the overall canopy and so are more likely to be variable than overall canopy density.

However, it can be concluded from the tree canopy density, leaf area and light level data that defoliation as a result of willow sawfly activity does decrease both overall canopy density and leaf area on individual shoots, resulting in higher light levels under willow canopies.

Potential Distribution and Impacts

Modelling has shown that in all areas of Victoria with suitable willow hosts, the likelihood that willow sawfly will occur is moderate to very high, and in fact is very high for much of the state. The likelihood of willow sawfly occurring is also high or very high in much of NSW, ACT, eastern Tasmania, and southern South Australia and Western Australia. At this stage, there are no known limitations to the spread and establishment of willow sawfly, either from environmental conditions or the activity of predators or parasites. Thus, it is highly likely that willow sawfly will continue to spread across Victoria and the country, as a consequence of both independent spread (adults flying to new sites) and through inadvertent human activity.

The likelihood of willow sawfly establishing population levels sufficient to result in tree defoliation is high to very high across much of Victoria. Tree defoliation is also highly likely in southern NSW and ACT, eastern Tasmania and limited areas of South Australia and Western Australia.

The number of sites in Victoria where tree defoliation occurred increased in the 2006/07 season in comparison with the 2005/06 season, and it is expected that this trend will continue into the 2007/08 season and beyond. In the coming season defoliation of trees

which were defoliated in previous seasons is expected to occur, but as the example of the golden willows site near Whitfield shows, this outcome is not guaranteed. It is also possible in the coming season that tree deaths will become evident at some sites as a consequence of defoliation by willow sawfly.

It should be noted, however, that although it is theoretically possible that willow sawfly will establish across much of the state and potentially impact on willow populations, it is also possible that environmental or biotic factors will limit the spread and impacts of willow sawfly at some time in the future.

Further Research

Willow sawfly spread across Victoria in the 2006/07 season, with severe tree defoliation occurring at several sites in northern, central and southern Victoria. Monitoring of sites over coming seasons will determine how quickly willow sawfly populations build up to levels which can cause tree defoliation, and the rate and extent of willow tree death from ongoing defoliation. It will be particularly interesting to monitor the activity of willow sawfly on grey sallow at the Beechworth site to determine if the insect can establish a population that has a measurable impact on these willows.

In addition, further research to study the interaction between willow sawfly and willow management in riparian zones will commence in the 2007/08 season, to identify changes to willow management techniques that may be required in areas where large populations of willow sawfly establish.

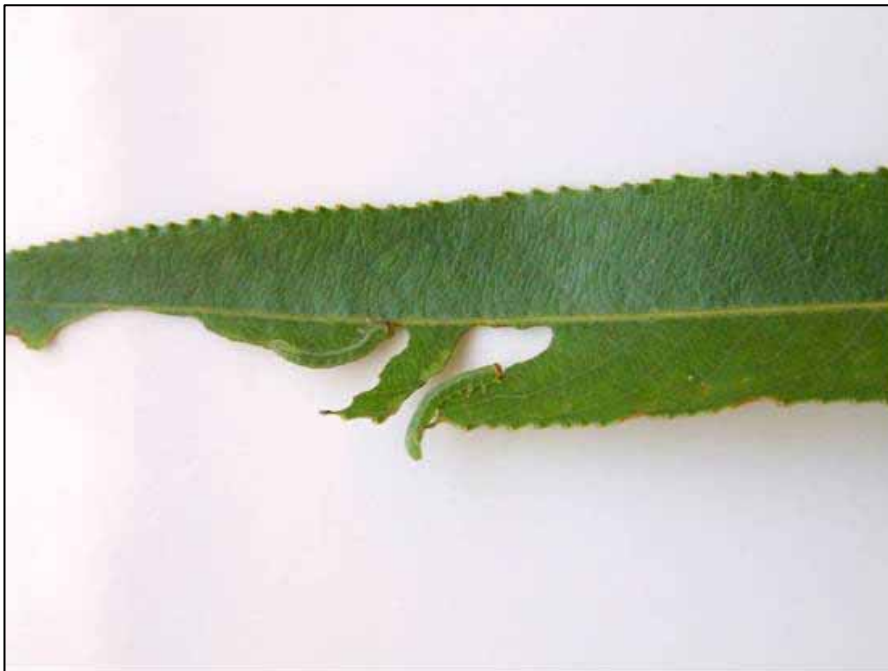


Figure 31: Two willow sawfly larvae on a willow leaf

Appendix 1: Percent of total quadrats containing understorey species commonly found on transects at intensively monitored sites, September 2006 – March 2007

Site	Date	Bbl ¹	Cle	Clo	Con	Doc	Fla	Ger	Gra ²	Hem	Ran	Sed	Thi	Tra
Cheshunt	Sep	93	36		0		4		25			18	4	
	Nov	100	46		25		0		29			11	7	
	Dec	97	18		25		0		4			4	0	
	Jan	100	0		25		0		4			7	0	
	Mar	100	0		29		0		7			7	0	
Everton	Sep		27			37		13	100	67	0	23	17	
	Nov		7			10		0	97	73	13	17	10	
	Dec		0			0		0	80	37	0	3	0	
	Feb		0			0		0	63	10	0	3	0	
	Mar		0			0		0	73	17	0	7	0	
Happy Valley	Sep	0	18	3		38	10	5	88			33	5	
	Nov	3	18	3		43	18	5	95			28	13	
	Dec	0	3	0		30	10	0	90			33	13	
	Jan	3	0	0		18	10	0	88			35	3	
	Mar	3	0	0		15	0	0	73			40	0	
Kergunyah	Sep	11	11	34	0	11	5	5	97			11	37	
	Dec ³	37	3	13	11	0	3	3	84			42	5	
	Jan	37	0	0	8	3	3	0	84			26	8	
	Mar	37	0	0	21	0	3	0	95			24	8	
Healesville	Oct			3		30	7		100		27			
	Nov			3		43	3		100		37			
	Dec ³			7		33	13		100		20			
Glen Forbes	Oct	9	97			19	3		81	19	3		6	66
	Nov	21	76			21	7		66	21	7		3	55
	Dec ³	30	57			10	0		67	20	0		3	67
Loch	Oct	3	56				0			3	22		0	88
	Nov	3	75				3			0	19		0	84
	Dec	3	78				0			0	16		0	91
	Feb	6	3				3			3	16		3	91
	Mar	9	9				3			3	6		3	88

¹ Full explanations of codes and plants are given in Appendix 2

² Gra = grasses, several species are identified in Appendix 2

³ Due to trampling by cattle at these sites, assessments of transects were not undertaken at each sampling time

Appendix 2: Names and codes of species found on transects

Common Name	Code¹	Scientific Name	Present²
Angled onion		<i>Allium triquetrum</i>	GF
Annual poa ³		<i>Poa annua</i>	E, H, HV, K
Barley grass ³		<i>Hordeum murinum</i>	GF, H, K
Bindweed	Con	<i>Convolvulus arvensis</i>	C, K
Blackberry	Bbl	<i>Rubus fruticosus</i> agg.	C, GF, HV, K, L
Boxthorn		<i>Lycium ferocissimum</i>	HV
Bromes ³		<i>Bromus catharticus</i> ; <i>B. diandrus</i>	E, GF, H, HV, K
Buttercup	Ran	<i>Ranunculus</i> spp.	E, GF, H, L
Calla lily, Arum lily		<i>Zantedeschia aethiopica</i>	C
Canary grass ³		<i>Phalaris</i> spp.	E, K
Caper spurge		<i>Euphorbia lathyris</i>	GF
Chickweed		<i>Stellaria media</i>	H, K
Cleavers	Cle	<i>Galium aparine</i>	C, E, GF, HV, L, K
Clover	Clo	<i>Trifolium</i> spp.	HV, K
Cocksfoot ³		<i>Dactylis glomerata</i>	GF, H
Common reed		<i>Phragmites australis</i>	C
Dandelion		<i>Taraxacum officinale</i>	H, HV
Dock	Doc	<i>Rumex obtusifolius</i>	E, GF, H, HV, K
Exotic sedge		<i>Cyperus</i> spp.	E, HV, K
Flatweeds	Fla	<i>Hypochaeris radicata</i> ; <i>Leontodon taraxacoides</i> ; <i>Crepis</i> spp.	C, GF, H, K, L
Fleabane		<i>Conyza</i> spp.	K
Geranium	Ger	<i>Geranium molle</i>	E, HV, K
Hemlock	Hem	<i>Conium maculatum</i>	E, GF, L
Japanese honeysuckle		<i>Lonicera japonica</i>	K
Kangaroo apple		<i>Solanum aviculare</i>	C
Liverwort		<i>Marchantia</i> spp.	HV
Lotus		<i>Lotus pedunculatus</i>	H, K
Nettle		<i>Urtica incisa</i>	E, L
Mint species		<i>Mentha</i> spp.	K
Paspalum ³		<i>Paspalum dilatatum</i>	K
Perennial ryegrass ³		<i>Lolium perenne</i>	E, GF, H, HV, K
Plantain		<i>Plantago</i> spp.	HV
Rush		<i>Juncus</i> spp.	C, HV, K
Sedge	Sed	<i>Gahnia</i> spp.	K
Selfheal		<i>Prunella vulgaris</i>	HV, K
Shepherds purse		<i>Capsella bursa-pastoris</i>	E, K
Solanum		<i>Solanum</i> spp.	E, GF
Sweet bursaria		<i>Bursaria spinosa</i>	C, HV
Thistle	Thi	<i>Carduus</i> spp; <i>Cirsium</i> spp.	C, E, GF, HV, K, L
Tradescantia	Tra	<i>Tradescantia fluminensis</i>	GF, L
Variegated thistle		<i>Silybum marianum</i>	GF, K
Willow		<i>Salix</i> spp.	C, HV, K
Willow weed		<i>Polygonum persicaria</i>	K
Yorkshire fog ³		<i>Holcus lanatus</i>	C, E, GF, H, HV, K

¹ Species code used in Appendix 1² Site where species found: C – Cheshunt; E – Everton; GF – Glen Forbes; H – Healesville;

HV – Happy Valley; K – Kergunyah; L - Loch

³ Grass species combined in Appendix 1 in column headed Gra

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