2.0 How willow management priorities were developed

'You can't manage what you don't know'

2.1 Determining the extent of willows

Collate existing information

The first major step was to collate all available mapping information on willows across Australia. Comprehensive surveys of willows managers and mapping databases were conducted, in conjunction with workshops to fill the gaps in existing willow mapping data.

Surveys

A standard mapping template was developed and distributed via the National Willows Network e-group to over 300 people nationwide, with a request for all available mapping information for willows. This template was also placed on the Weeds Australia website (www.weeds.org.au/WoNS/willows) to reach an even greater audience. The template included information regarding data collection and a list of mapping attributes that, if available, was the preferred means of data collection. The mapping attributes incorporated a national list of core attributes for mapping WoNS, and several willow-specific attributes to assist in prioritising management efforts (see mapping tools in supplementary information, Section 5).

The NWT located and procured several willow mapping data sets which were incorporated in larger Arcview / ArcGIS database. These included data sources such as the Australian Virtual Herbarium (Council of the Heads of Australian Herbaria), Flora Information System (Department of Sustainability and Environment, Victoria), Environmental Information System (Parks Victoria) and Integrated Pest Management System (Department of Primary Industries, Victoria), and other sources hosted by specific CMA/NRM regions/organisations.

Participants registering for workshops were asked on their registration forms if they had access to any willow mapping data. All who indicated that they did were systematically contacted to request access to this information. Where data was freely available, it was forwarded to us and immediately incorporated in the database. Where permission for use was required, it was sought and, following approval, this data was also included in the database.

Workshops

A series of workshops was organised and delivered to all willow affected regions across south eastern Australia in conjunction with surveys. Anyone involved in willow management, or with an interest in willows within a region, was invited to attend a workshop; including contractors, regional catchment management/river health officers, Landcare and 'Friends of…' groups, state and local government weeds and native vegetation officers, and park rangers.

At each workshop, participants were requested to mark on maps where they knew willows occurred in their region, using a methodology and classification system adapted from **Strategic Planning for Willow Management in Tasmania** (Farrell, 2003).

In total, twenty-nine willow workshops, attended by a total of 576 people, were held across twenty-nine CMA or NRM regions in Victoria, New South Wales, Tasmania, South Australia and the Australian Capital Territory between September 2006 and March 2007 (see Figure 1). The workshops were used to collate and update mapping information (including information derived from the surveys) and to educate willow managers in the topics of willow identification, willow sawfly, willow mapping and setting priorities for willow management. This phase of the project was delivered by a team of staff from the Department of Primary Industries (DPI), Victoria.

Figure 1: Locations of the twenty-nine willow workshops conducted across Australia

All of the data collected during the survey period was used to generate a map for workshop participants. This map indicated which parts of the region had already been mapped for willows, and so where participants should focus their efforts in filling the gaps. Requests for any available mapping data was repeated at workshops and additional data sourced as a result.

Additional data was sourced at the workshops, and acetate sheets containing current known infestations of willows in each region were obtained. The maps then formed the basis for current distribution of willows, and provided input for the weed risk assessment. The maps also formed a base for the on-ground mapping and ground truthing to update and include more data on willow distribution. The final result, "interactive maps" displaying the current known extent of willows in Australia, is presented and discussed below, under "interactive maps".

In addition to the workshops, presentations were given in Queensland and Western Australia to raise awareness of the potential threat of willows, and the need for more detailed mapping data. Two presentations were given in southeast Queensland, and six in southwest Western Australia over April and May 2007. An additional presentation was given in Western Australia in October 2007.

Further detail on this component can be found in Wadley & Holland Clift (2007) "Developing willow management priorities from the local to the national level: Report on phase three – delivery of willows workshops & collation of willow distribution data September 06 – March 07."

On-ground mapping & ground truthing

Further detailed mapping on outlying regions and states was required to update and confirm data collected during workshops.

Regional data

GIS and local weeds officers were requested to practice their identification skills and conduct on-ground identification and mapping over spring 2007 to add data in their region. This included utilising aerial photography or *Landsat* imagery where available and relevant. It was emphasised this was most important for areas where information was scant, such as in lower order streams (e.g. headwaters).

A mapping brief, excel spreadsheet with mapping attributes for additional data collection (see mapping tools in supplementary information) and regional map was provided to workshop participants from each region as the means for collecting new data. Regional maps were developed using information collected on acetate sheets during workshops.

There were two processes for additional information collated from GIS and local weeds officers:

- If adding further detail to data already on maps (from workshops), a printout of existing map with new detail written on it was requested.
- If providing new data the excel spreadsheet was filled out and either GPS coordinates, shape files or other GIS format were requested.

Local weeds officers collected data for their regions over the spring period and sent collated information (on maps, or in the spreadsheet) to the DPI Victoria project team for inclusion in weed risk assessment and final distribution maps.

Outlying regions and states

Western Australia, Queensland and South Australia are considered as outlying areas for willow distribution, or areas with little willow distribution knowledge. In Western Australia, for example, prior to this project there was only one record of willows lodged in the Western Australian Herbarium (a weeping willow, *Salix babylonica* specimen). Regions within these three states were chosen for detailed investigation and mapping to improve knowledge of willow distribution in outlying areas. This was particularly important for Western Australia and Queensland as they were not participants in the detailed workshops phase, instead receiving abridged 'awareness raising' presentations.

Initial scoping was conducted in Queensland and Western Australia in April and May 2007. On-ground mapping was conducted by a willows mapping project officer over the spring flowering period, October and November 2007. Local government and weeds officers were contacted in Western Australia and Queensland, and mapping field trips were arranged. The mapping database was used along with experience of these local weeds officers to determine where to focus mapping efforts. Samples were taken of willows identified in the field and submitted for formal identification to the Western Australian and Queensland Herbariums. A second set of samples were also formally identified by Ecology Australia. Records from the on-ground mapping were incorporated into mapping database and weed risk assessment.

Areas mapped in Queensland were across the south east and included Warwick, Gladstone, Brisbane, Stanthorpe, Tenterfield, and south of the NSW border at Casino, Spring Grove, Lismore and Bonalbo.

Areas mapped in Western Australia were across the south west and included from Gin Gin in the north to Perth and Albany, Augusta and Esperance in the south.

Prior to this project, our understanding of ***willow distribution in South Australia*** was primarily confined to the River Murray. It was also thought that there were very few, if any, seeding willows found in South Australia, and they were not recognised as a great threat. Following the workshop held at Renmark in November 2006, the Murray Darling NRM Board mapped all willows along their section of the River Murray in conjunction with a weed survey that had already been planned.

Through funding from the South Australian Government, a partnership was developed between Rural Solutions South Australia and the National Willows Program, which led to the engagement and collation of willow mapping information in regions not targeted through workshops.

Rural Solutions South Australia was contracted by South Australian DWLBC to collate all South Australian willow mapping information. Their primary role was to assist in further updating the distribution data on willows in South Australia, by:

- liaising with people in regions where willows may exist that were not targeted through workshops,
- liaising with people from regions where workshops were held who did not attend a workshop, but have knowledge of where willows exist, and
- collating all maps and acetate sheets, and sending to the project team.

Rural Solutions South Australia also mapped the distribution of seeding willows *S. cinerea* and *S. reichardtii* in the southern Fleurieu Peninsula, after South Australia was alerted to its presence during one of the workshops.

National Case Study

A national-level case study was conducted to prioritise willow management based on asset protection. This case study can be used as an example of how and where to direct on ground mapping resources in order to protect highest priority assets first (see "National Case Study: Prioritising willow management based on asset protection", Section Four).

Interactive maps: current and potential distribution of willows

The data collected from the initial collation, workshop surveys, mapping workshops, regional mapping exercises and by the mapping project officers were incorporated into a GIS database. The distribution data for each willow taxon was used to supplement world-wide data to determine the potential distribution of the thirty-five assessed willow taxa. These potential distribution maps were also incorporated into the GIS database, along with geospatial references such as towns, roads and waterways. This database can be used in a GIS environment to determine the current and potential distribution of willows that have been mapped, and areas where willow management has occurred across Australia from the local to the national level.

This GIS data was also used to produce a set of layered PDFs that enable the same data to be displayed at several scales and in detail appropriate to the national, state or NRM/CMA level. The layers of the PDF can be turned on or off to allow the display of a combination of present and potential distributions of one, several or all willow taxa, as well as locations where willow management has occurred.

These two methods of presenting mapping data were chosen to allow flexible use of the data, for land managers regardless of their GIS capabilities. Whilst the PDFs were limited to a useful size by providing the data in a set number of ways, the GIS database can be used to manipulate the data for more specific purposes. Land managers with *ArcGIS 9* can use the project that was developed for the database. Others, with different versions of this software, or other brands of software, such as *MapInfo*, can use the data that is contained in the project either directly or by converting it to compatible file types.

2.2 Weed risk assessment

Introduction

The genus *Salix* (willows) is a taxonomically complex genus comprising more than 400 taxa worldwide (van Kraayenoord *et al.* 1995). More than 100 willow taxa have been introduced to Australia. Of these, eleven species, at least twenty-five subspecies and numerous hybrid combinations are known to be naturalised (ARMCANZ 2001; APC 2007; APNI 2007).

Willows were nominated, assessed and listed at the genus level for classification as WoNS (Thorp & Lynch 2000). However three *Salix* taxa were excluded from the WoNS list, and a further six were exempt from declaration in Victoria.

Willow infestations are targets for either eradication or containment in Australia (ARMCANZ, 1999; also see Appendix 1). However, determining appropriate control strategies is complicated due to the large number of taxa involved and the variation amongst these taxa in their distribution, invasiveness and impacts. Furthermore, to ensure that willow management strategies are cost efficient, it is important to decide which willows require control, and which can be considered safe enough to leave *in situ*, or even continue to be planted.

The weed risk assessment process is a standard process that seeks to obtain relative rankings on weed risk and control feasibility, as a decision support tool for allocating resources in weed management. Weeds are prioritised based on their intrinsic abilities to invade suitable ecosystems, and their present and potential impacts on social, environmental or agricultural values.

A weed risk assessment of willows was required to inform the prioritisation of willow management in Australia from the local to the national scale. As described below, a risk assessment tailored to willows was required to achieve this aim.

The Victorian Weed Risk Assessment

In 2006, the Victorian Weed Risk Assessment was used to assess sixteen willow taxa (DPI Victoria 2006 list of taxa, see Appendix 2). This method complies with the *Australian Standard for National Post-Border Weed Risk Management Protocol* (AS/NZS HB 294:2006 Standards Australia/Standards New Zealand, 2006), and as such includes consideration of each plant's:

1. invasiveness (or biological traits);
2. potential for spread (by comparing current and potential distributions); and
3. impacts on land use and ecosystems (or ecology).

The invasiveness and impacts components of the Victorian Weed Risk Assessment (VWRA) comprises a list of questions (or criteria), and a descriptive rating that relates to each question (listed in Appendix 3). Literature and expert opinion was used to determine whether each willow taxon should be given a rating of high (H), medium high (MH), medium (M), medium low (ML), or low (L) for each question.

Many of the criteria used to assess the *impacts* of willows were not able to discriminate between different willow taxa (Figure 2). In thirteen of the twenty-six questions, all willows achieved the same score. Furthermore, in question 11 all the willows rated either H or MH; and in question 19, either L or ML. For more than half of the impacts assessment there was very little separation in the scores attained by each willow taxon. Figure 2 represents the spread of scores that resulted from the application of the assessment process.

The impacts of willows

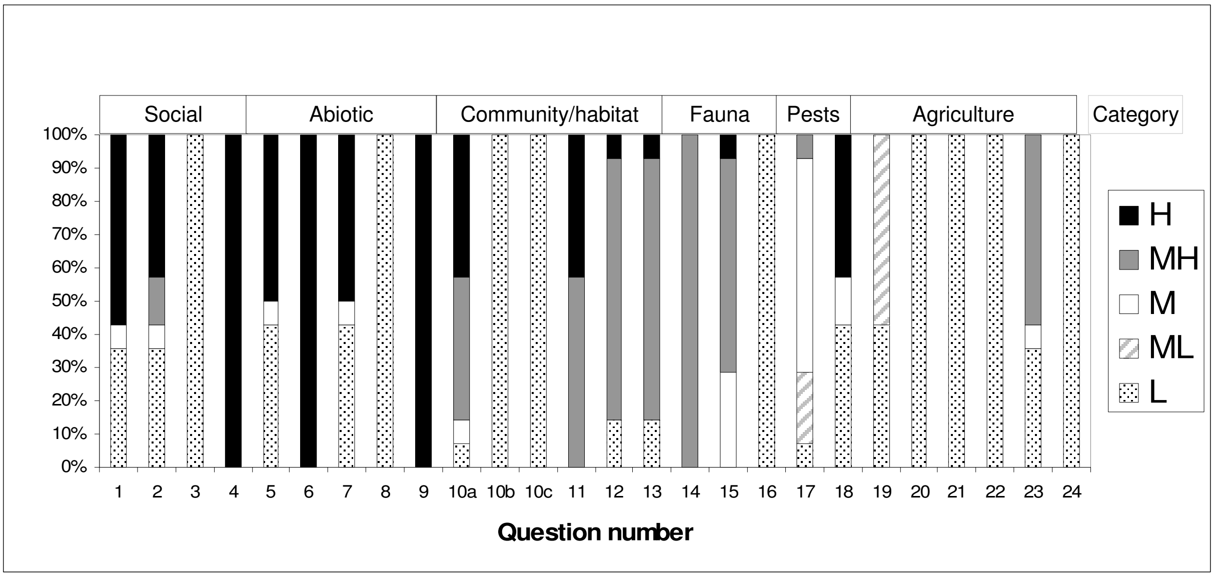

Figure 2: Spread of scores from the VWRA for the impacts of willows. Proportion of willows that scored H, MH,M, ML, or L for each question.

Below is a summary of willow impacts found during the Victorian Weed Risk Assessment of willows. Notes:

- A numbered list of the impacts criteria used in the Victorian Weed Risk Assessment can be found in Appendix 3.
- These numbers appear in brackets in the text to indicate which criterion was being addressed.
- The criteria were broadly categorised according to the types of values that may be impacted by weeds: *social, abiotic, community/habitat, fauna, pest animals and agricultural values*.
- Full assessments for all of the plants that have been assessed using Victoria's Weed Risk Assessment can be found at www.dpi.vic.gov.au/vro/weeds.

Social impacts (questions 1-4)

Only two social impacts criteria provided any separation value between the willow taxa: restricting access (1) and reducing tourism (2). All willows attained a low score for ability to injure to people (3) and high for ability to cause major damage to cultural sites or infrastructure (4).

Certain willows form thickets as well as grow in-stream, which gives them the capacity to significantly restrict human access to watercourses, as well as restricting access by boats. Taxa with these characteristics include *S. cinereea, S. exigua* and *S. fragilis;* and, combined with their ability to reduce channel capacity (Cremer 1995, Purtle *et al.* 2001) this can lead to a reduction in tourism. Activities potentially affected include boating, fishing, swimming, canoeing and bird watching. Single-trunked taxa and those valued aesthetically such as *Salix matsudana* and *S. glaucophylloides* [incorrectly identified as *S. myricoides*] (Ladson *et al.* 1997) were not considered to significantly reduce tourism.

No reference to willows being directly injurious to people was found, therefore all taxa attained a low score for this criterion. Damage to buildings may occur when stream channel routes are altered as a result of blockage by willow roots, (Sarah Holland-Clift pers. comm. 2006) and during flooding episodes the build up of woody material from willows in rivers can destroy bridges (ARMCANZ 2001). Thus, willows generically were considered to have the potential to cause major damage to cultural sites or infrastructure and all taxa scored high for the criterion addressing this impact.

Abiotic impacts (questions 5-9)

Whilst some willows scored higher than others for impacts on water flow (5) and soil erosion (7), the other three questions relating to abiotic impacts did not differentiate between the willow taxa assessed. All willows assessed were considered to have a high impact on water quality (6); to be capable of increasing vegetative biomass (8); and the potential to greatly reduce the frequency and intensity of fire risk (9) in the habitats in which they occurred.

Willows were considered to have a high impact on water flow, if they had the capacity to grow within streambeds, therefore interrupting the flow of water (Purtle *et al.* 2001), or if their roots intruded extensively into stream beds (Ladson *et al.* 1997). Taxa confined to riverbanks were considered less likely to impact on flow. All willows assessed were considered to have a high impact on water quality because, as deciduous plants (Carr 1996), mass leaf fall in autumn can decrease dissolved oxygen levels, and willows can also cause intense shading as their canopies tend to be denser than native taxa (Ladson *et al.* 1997). Willows that encroach into the centre of streams interrupt water flow, which is then directed into banks causing erosion. In severe cases, extreme blockages can occur, causing streams to change course (Purtle *et al.* 2001). Therefore, taxa that encroach into streams have a high probability of increasing soil erosion.

As woody shrubs or trees with the capacity to form dense thickets, (Carr 1996) all willows assessed were capable of increasing the vegetative biomass where they replaced lower or less dense vegetation, a regular occurrence on disturbed sites (Cremer 1999). Willows have low combustibility and flammability (Carcallet *et al.* 2001), and all taxa have the potential to greatly reduce the frequency and intensity of fire risk in the habitats in which they occurred.

Community/habitat impacts (questions 10-13)

All assessed taxa were considered to have a high, or moderately high, impact on the structure of vegetation communities (11). There was some variation in the impacts on high value Ecological Vegetation Classes (EVCs) (10a), however, willows were not considered to impact on any low or medium value EVCs (10b & c).

Impacts on threatened flora (12) and fauna (13) were considered high for one taxon (*S. cinerea*), medium high for most, and medium (which is the score for 'unknown') for a couple of the willow taxa.

The formation of dense thickets, intense canopy shade, and mat-forming roots of willows, can suppress and exclude indigenous understorey (Cremer 1999, Purtle *et al.* 2001), with the result that all assessed taxa were considered to have a high, or moderately high, impact on the structure of vegetation communities. They would consequently have a similarly high impact on invaded EVCs, however, the degree of impact was considered dependant on the suitability of the climatic match for the taxa. Climatic modelling showed that some taxa are not likely to occur as invasive plants in Victoria, giving these taxa a low score both for this criterion, and also for impact on threatened flora. The vegetation communities of all water bodies in Victoria were considered to comprise high value EVCs, therefore willows were not considered to impact on any low or medium value EVCs.

Although willows are well documented as having a significant impact on vegetation communities, little information was found in regard to their impact on threatened flora. Only *S. cinerea* was specifically identified, being described as the most serious willow preventing the recruitment of *Eucalyptus camphora*, a dominant component of the rare sedge-rich *E. camphora* swamp community, listed under the *Flora and Fauna Guarantee Act 1988* (Ladson *et al.* 1997).

Climatic suitability was the main factor separating willows in the two questions that showed much variability in the community/habitat section of the impact assessments.

Impacts on fauna (questions 14-16)

All willows were documented as having a moderately high impact on native fauna (14). The ability of willows to provide some assistance in shelter to desirable taxa (15) was considered high for one taxon (*S. glaucophylloides* [incorrectly identified as *S. myricoides*]), medium high for most, and medium (which is the score for 'unknown') for three of the willow taxa. No willow taxa were found to possess properties injurious to fauna (16).

Willows are documented as having a significant impact on native fauna, with the ability to decrease available habitat and reduce population numbers. For example, shading from willows decreases primary production and impacts on aquatic invertebrates and fish (Ladson *et al* .1997). Willows suppress and kill indigenous vegetation that would otherwise provide valuable habitat and food for insects, birds and other vertebrates, and bare banks beneath willows provide little protection for fauna such as frogs, water rats, snakes and lizards. Willows do not provide nectar for birds, have few hollows (Purtle *et al.* 2001) and provide less large woody debris in stream than native tree species, important habitat for aquatic fauna (Ladson *et al.* 1997).

Again, no information was found specifically documenting the impact of particular willow taxa on threatened fauna, except for *S. cinerea*, which is described as having the potential to destroy important habitat of the endangered Leadbeaters possum (*Gymnobelideus leadbeateri*) and helmeted honeyeater (*Lichenostomus melanops cassidix*), as well as the rare broad toothed rat (*Mastocomys fuscus*) (Ladson *et al.* 1997).

Possums are known to graze and defoliate willows (ARMCANZ 2001). Thicket forming willows provide cover for wildlife in the USA (Uchytil 2006); therefore willows are likely to provide some assistance in shelter to desirable species (15). *S. glaucophylloides* [incorrectly identified as *S. myricoides*] is unpalatable (Webb, *et al.* 1998) and as having a single trunk (Haines 2003), so it was considered to provide very little benefit to fauna. No reference was found in the literature to suggest that any willow taxa possess properties injurious to fauna, and consequently all taxa attained a low score for the criterion associated with this impact.

Pest animal impacts (questions 17 & 18)

There was some variation in the willows' potential to provide a food source to minor pest species (17) and capacity to provide harbour to pest animals (18).

Only *S. purpurea* was documented as providing a food source to rabbits, a serious pest (Dickerson 2002). *Salix alba* and *S. exigua* were described as being palatable (Uchytil 2006), and rodents are documented as eating the buds of *S. nigra*, therefore, these willows have potential to provide a food source to minor pest species.

Willow stands are described as providing excellent cover for wildlife in the United States of America (Uchytil 2006), therefore, thicket forming taxa, such as *S. exigua, S. cinerea, S. fragilis, S. purpurea, S. x rubens* and *S. viminalis* (Uchytil 2006; Cremer 1995, 1999 & 2001; Webb *et al.* 1988) are likely to have the capacity to provide harbour and permanent warrens to rabbits and foxes. Non-thicket forming willows are unlikely to provide harbour.

Agricultural impacts (questions 19-24)

The Victorian Weed Risk Assessment of willows indicated that willows generally have few impacts on agriculture. There was no information in the literature to indicate that any of the willow taxa have: affected agricultural quality (20) or land value (21), caused a change in land use (22), or provided a host to pests or diseases of agriculture (24), hence all taxa attained low scores for the criteria addressing these impacts. Impact on agricultural yield (19) varied from low to medium low, and there was varying ability of willows to increase in harvest costs (23).

Several species were described as agricultural weeds in the United States of America and New Zealand, including *S.alba*, *S. babylonica*, *S. cinerea*, *S. exigua*, *S fragilis* and *S nigra* (Holm *et al.* 1979), but as they are not recorded as invaders of pasture or crops, their impacts are likely to be associated with waterways. Their ability to form dense thickets restricting access for irrigation is likely to be the only impact they have on agriculture, and willow root mats are described as reducing access to flowing water (Sarah Holland-Clift pers. comm. 2006). This may have a minor impact on agricultural yield, as well as cause a minor increase in harvest costs due to the requirement to maintain waterways for irrigation purposes.

Summary of impacts

Willows are clearly able to seriously impact many of our social and environmental values, mostly confined to habitat niches in riparian and wetland areas (Richardson & Richardson 2006) and largely affecting abiotic components of aquatic systems and biodiversity. Many similarities exist between different willows because they are a closely related group of taxa that grow in similar habitats, and the minor variation was not adequately captured by the Victorian Weed Risk Assessment. Another factor that reduced the separation value of the Victorian Weed Risk Assessment of willows was that many of the criteria are not particularly applicable to willows. Consequently, a Weed Risk Assessment method was developed specifically for willows.

The Willows Weed Risk Assessment

A standard risk assessment process was adopted, in accordance with the *National Post-Border Weed Risk Management Protocol*, in order to objectively rank the weediness of willow taxa more specifically than the Victorian Weed Risk Assessment had done previously. Data collated for the Willows Weed Risk Assessment was used for the prioritisation of willow taxa and for identifying priority locations for coordinated control programs at the regional and national levels.

In addition to assessing the weed risk posed by willow taxa, the relative feasibility of reducing or minimising each of these risks through coordinated control programs was examined. Coordinated control programs aim to achieve eradication or containment of a weed within the geographic area of interest, through locating and treating infestations and restricting movement of propagules. In simple economic terms, the total cost of a successful coordinated control program will be a function of three components:

1. total area infested;
2. annual control cost per unit area; and
3. number of years required to achieve the desired level of control.

To a large degree, the feasibility of control for willows, which have similar control costs (per unit area and years of treatment required) can be determined by the total area infested. A high impact taxon with a smaller area of infestation in a region, has a higher cost:benefit ratio than one that has already spread a long way. Early intervention at these sites can prevent serious willow taxa from becoming widespread. On the other hand, large infestations may currently be impacting on the environment, and management to reduce these impacts is also a relatively high priority. This is a site-led approach to weed control, rather than a weed-led approach like the weed risk assessment.

By comparing weed risk and feasibility of coordinated control, willow taxa can be categorised and prioritised for various treatment actions in each region. Treatment actions can include preventing entry, eradication, containment, protecting priority sites/assets, targeted control, research, improve general weed management practices, as well as no action.

The desired outcome of this process is the efficient use of resources for willow management through targeting investment to those taxa and areas that pose high risks and have a high feasibility of coordinated control.

How the Willows Weed Risk Assessment was conducted

General

A generic weed risk assessment tool needs to be suitable to assess a large number of different taxa, and the Victorian Weed Risk Assessment was developed to achieve this aim. However, it was not designed to detect the differences between similar, or closely related, taxa, such as the willows. Aquatic plants also tended to attain similar scores using this Victorian Weed Risk Assessment, so an aquatic weed risk assessment was also developed for Victoria (Weiss 2007). New Zealand also has a weed risk assessment tailored to aquatic plants (Champion & Clayton 2001).

The impacts of willows are largely related to several main characteristics; such as, the ability to form dense thickets, grow within streams, undertake mass autumn leaf drop and develop large, invasive root systems. Impact assessment criteria for willows therefore needed to utilise these characteristics. However, the impact criteria needed to discriminate between different willow taxa.

The aim of the willow risk assessment was to determine ***which are the worst willows in Australia***; which should be the focus of our management efforts. The weed risk of different willow taxa was assessed based on three major components:

- invasiveness, or potential rate of spread;
- current and potential distribution; and
- the current and potential impacts of the plant on land use and ecosystems.

The invasiveness criteria from the Victorian Weed Risk Assessment (see Appendix 3) were more successful for differentiating between the willow taxa, than the impacts assessment discussed above. The results of the Victorian Weed Risk Assessment *invasiveness* questions are displayed in Figure 3. All willow taxa achieved the same score for only two questions (4 and 7). Some questions showed little variation, including questions 11 and 12, which were replaced by new questions in the Willow Weed Risk Assessment. This enabled the Willow Weed Risk Assessment to consider the risks of hybridisation and the propagule pressure associated with planting willows *en masse*, as a single specimen, or somewhere in between.

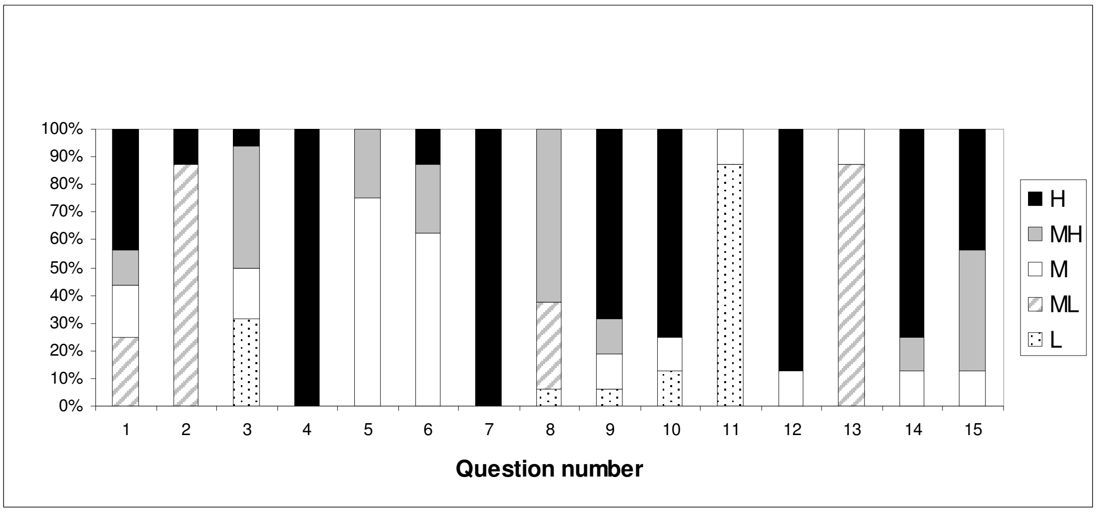

Figure 3: Spread of scores from the Victorian Weed Risk Assessment. Proportion of willows that scored H, MH, M, ML, or L for each question.

Developing the criteria for assessing the impacts of willows

In February, 2007, criteria were developed to assess the relative impacts of a range of willow taxa. Criteria were developed that would be used to assess the degree of impact that each willow taxon might have on social, economic and environmental values. These criteria needed to differentiate between willow taxa, and provide evidence for their impact on social, environmental or economic values.

As was the case with the Victorian Weed Risk Assessment, it was recognised that some criteria were more important in determining the impacts of willows than others. These questions were given more weight than questions that were considered less important. The weightings were determined using Analytical Hierarchal Process, as described in the Victorian Weed Risk Assessment methodology (DPI Victoria 2006). The hierarchy and weightings for the invasiveness and impact questions are presented in Figures 4 and 5.

The willow impact and invasiveness criteria are presented in Tables 1(a-d) and 2(a-c). As with the Victorian Weed Risk Assessment method, each criterion was addressed with a multiple-choice question, and scored either as “high impact,” “moderately high impact,” “moderately low impact” or “low impact,” according to the descriptors that were developed for each intensity rating (or choice).

For each willow taxon that was assessed, a literature search was performed, and expert opinion sought, to find the answers to the ten impacts questions and fifteen invasiveness questions. In all cases, the ‘worst-case scenario’ was used. If there was evidence that a willow was capable of having a large impact in a particular environment, it scored highly, even if its impact was lower in other types of environments.

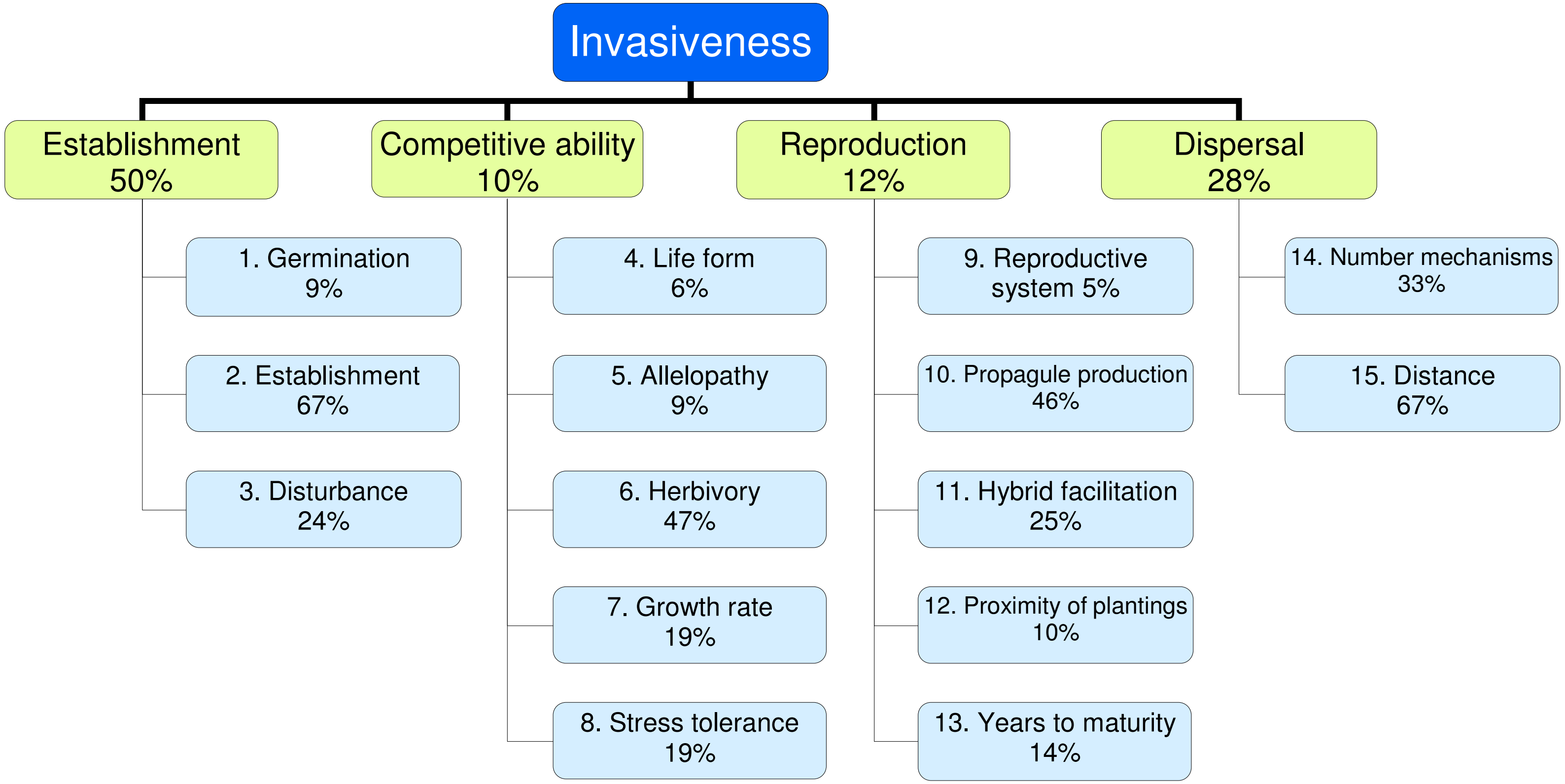

Figure 4: Hierarchy and weightings of the willow invasiveness criteria

Table 1(a): Willow *invasiveness* criteria (establishment)

Criteria	Intensity Rating			
	Low	Medium Low	Medium High	High
Establishment				
1. Germination /propagule requirements?	Requires specific environmental factors that are not part of an annual cycle to germinate (eg. specific temperatures, or human caused disturbance, such as ploughing).	Requires unseasonal or uncommon natural events for germination (eg. flooding, fire).	Requires natural seasonal disturbances such as seasonal rainfall, spring/summer temperatures for germination.	Opportunistic germinator, can germinate or strike/set root at any time whenever water is available.
2. Seedling/ propagule establishment requirements (*i.e.* light, water, nutrients)?	Requires additional and very specific factors, such as nutrients and water, that are deliberately added **OR** highly eutrophic conditions.	Requires more specific requirements to establish (eg. open space or bare ground with access to light and direct rainfall).	Can establish under moderate canopy/litter cover.	Can establish without additional factors.
3. How much disturbance is required for seedling establishment to occur?	Major disturbance required with little **OR** no competition from other plant species.	Establishes in highly disturbed natural ecosystems (eg. roadsides, wildlife corridors, or areas which have a greater impact by humans such as tourist areas or campsites) **OR** in overgrazed pastures/poorly growing or patchy crops.	Establishes in relatively intact **OR** only minor disturbed, natural ecosystems (eg. wetlands, riparian, riverine, grasslands, open woodlands); in vigorously growing crops **OR** in well-established pastures.	Establishes in healthy **AND** undisturbed natural ecosystems (eg. mallee, alpine, heathland).

Table 1(b): Willow *invasiveness* criteria (lifeform and competitive ability)

<table>
<tr><th rowspan="2">Criteria</th><th colspan="4">Intensity Rating</th></tr>
<tr><th>Low</th><th>Medium Low</th><th>Medium High</th><th>High</th></tr>
<tr><td colspan="5">Lifeform and competitive ability</td></tr>
<tr><td>4. Life form?</td><td>Other.</td><td>Geophyte, climber or creeper.</td><td>Grass, leguminous plant.</td><td>Aquatic (submerged, emergent, floating for ALL of life, including germination), and semi aquatic (some plant parts always in water).</td></tr>
<tr><td>6. Ability to tolerate herbivory pressure and produce propagules?</td><td>Preferred food of herbivores. Eliminated by moderate herbivory OR reproduction entirely prevented.</td><td>Consumed and recovers slowly. Reproduction strongly inhibited by herbivory but still capable of vegetative propagule production (by rhizomes or tubers); weed may still persist.</td><td>Consumed but non-preferred OR consumed but recovers quickly; capable of flowering /seed production under moderate herbivory pressure (where moderate = normal; not overstocking or heavy grazing).</td><td>Favoured by heavy grazing pressure as not eaten by animals/insects and not under a biological control program in Australia/New Zealand.</td></tr>
<tr><td rowspan="2">7. Normal growth rate?</td><td rowspan="2">Slow growth; will be exceeded by many other species.</td><td>Maximum growth rate less than, many species of the same life form.</td><td>Moderately rapid growth that will equal competitive species of the same life form.</td><td rowspan="2">Rapid growth rate that will exceed most other species of the same life form.</td></tr>
<tr><td colspan="2">Medium
Growth rate equal to the same life form, OR there is widely conflicting evidence.</td></tr>
<tr><td>8. Stress tolerance of established plants to frost, drought, water logging, salinity, fire?</td><td>Maybe tolerant of one stress, susceptible to at least two.</td><td>Tolerant to at least two AND susceptible to at least one.</td><td>Highly tolerant of at least two of drought, frost, fire, waterlogging, and salinity, AND MAY be tolerant of another. Susceptible to at least one.</td><td>Highly resistant to at least two of drought, frost, fire, waterlogging, and salinity.
Not susceptible to more than one (cannot be drought or waterlogging).</td></tr>
</table>

Table 1(c): Willow *invasiveness* criteria (reproduction)

Criteria	Intensity Rating			
	Low	Medium Low	Medium High	High
Reproduction				
9. Reproductive system? How does the taxon spread?	Sexual (either cross **OR** self-pollination).	Sexual (self **AND** cross-pollination).	Vegetative reproduction (may be via cultivation, but not propagation).	**Both** vegetative **AND** sexual reproduction (vegetative reproduction may be via cultivation, but not propagation).
10. Number of propagules produced per flowering event?	Less than 50.	50 - 1,000.	1,000 – 2,000.	Above 2,000.
11. Hybrid facilitation. Hybridisation is assessed based on taxa that have been introduced to Australia. Ability to produce viable propagules.	Very unlikely to hybridise with a naturalised willow.	Cultivation has produced hybrids between this taxa and a naturalised willow taxon.	Able to hybridise with a naturalised willow in the wild. Enables a cultivated willow to produce viable offspring (by providing a pollen or egg source).	Evidence that the taxon is the parent of a naturalised hybrid
12. Proximity of plantings.	Willow grown only in floriculture for foliage/catkins/stems.	Specimen tree or shrub, usually only planted as a single specimen.	Fodder or shade tree that may be planted in larger numbers.	Willow commonly used as a windbreak, erosion control or avenue tree. Large scale plantings.
13. Time to reach reproductive maturity?	Greater than 5 years to reach sexual maturity, **OR** for vegetative propagules to become separate individuals.	2-5 years to reach sexual maturity, **OR** for vegetative propagules to become separate individuals.	Produces propagules between 1-2 years after germination, **OR** vegetative propagules become separate individuals between 1-2 years.	Reaches maturity and produces viable propagules, **OR** vegetative propagules become separate individuals, in under a year.

Table 1(d): Willow *invasiveness* criteria (dispersal)

Criteria	Intensity Rating			
	Low	Medium Low	Medium High	High
Dispersal				
14. Number of dispersal mechanisms?	Propagules mainly spread by gravity.	Deliberate human dispersal (propagation or planting).	Propagules spread by wind, water, attachment (humans, animals, or vehicles), **OR** accidental human dispersal (ploughing).	Very light, wind dispersed seeds, **OR** bird dispersed seeds, **OR** has edible fruit that is readily eaten by highly mobile animals.
15. Probability (or chance) that propagules will disperse to a distance greater than one kilometre?	Very unlikely to disperse greater than 200 metres, most less than 20 metres.	Very few to none will disperse to one kilometre, most 20-200 metres.	Few propagules will disperse greater than one kilometre but many will reach 200-1000 metres.	Very likely that at least one propagule will disperse greater one kilometre.

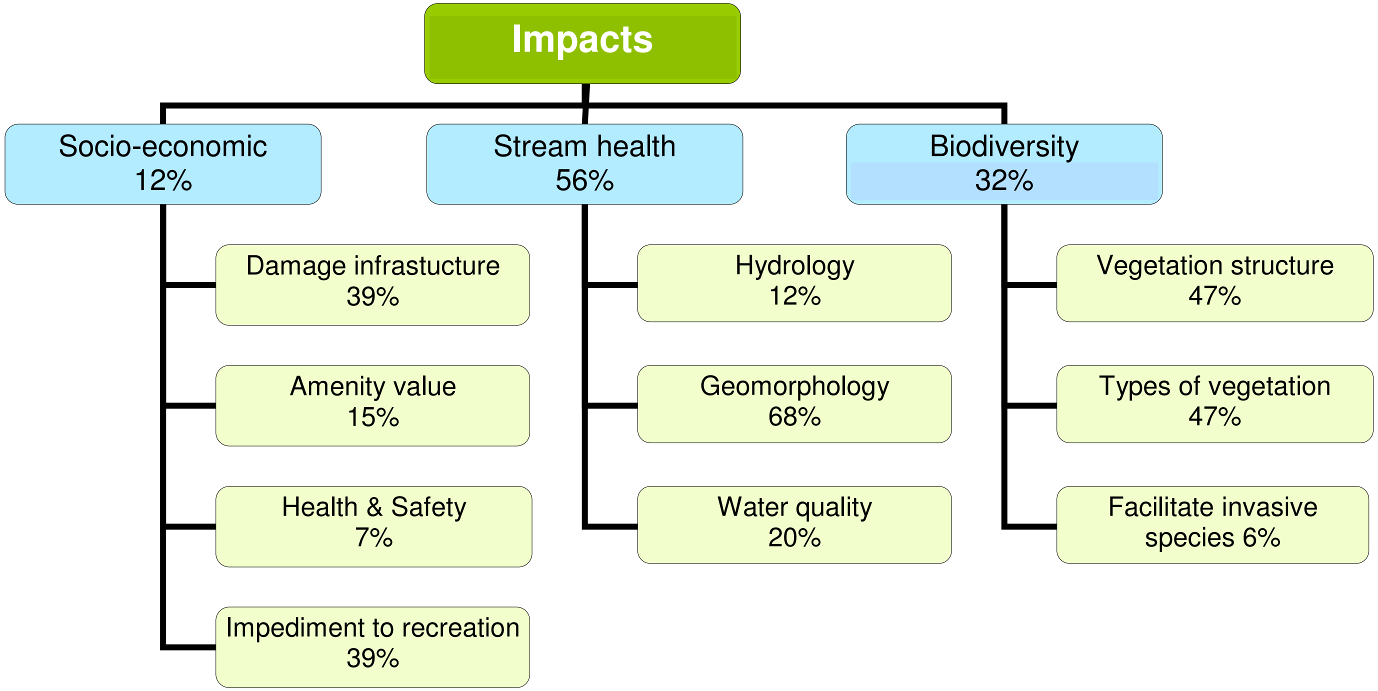

Figure 5: Hierarchy and weightings of the willow impact criteria

Table 2(a): Willow *impact* criteria (socio-economic)

Criteria	Intensity Ratings			
	Lowest Threat L	ML	MH	Highest Threat H
Socio-Economic				
1. How much damage could be caused to human-built infrastructure?	Visual effect; little to negligible structural damage.	Able to be remedied as a normal part of everyday maintenance (eg. pruning).	Maintenance requires specialised equipment, such as for clearing drains or drainage channels.	Major damage to bridges, culverts, weirs, dams, etc. requiring repair.
2. How much amenity value does the willow have?	Attractive/useful foliage/catkins/stems; **OR** valued as a fodder, shade, wood, windbreak or avenue tree; **AND** require knowledge to propagate, **AND** are single-sex clones	Attractive/useful foliage/catkins/stems; **OR** valued as a fodder, shade, wood, windbreak or avenue tree; **AND** require knowledge to propagate.	Some horticultural/ agricultural value, but easy to propagate, bisexual or male and female, naturalised in Australia	No aesthetic value, easy to propagate, bisexual or male and female, naturalised in Australia
3. To what extent could the willow impact on the health and safety of waterway/riparian users?	Little to no impact on public safety. Willow is low-growing and/or has branches that are too thin to cause serious health damage.		Moderately likely to cause serious injury or death of waterway/riparian users (eg. tree willow/tall shrub with large, but flexible branches).	Most likely to cause serious injury or death of waterway/riparian users. Eg. Tree willow with brittle branches. Risk of death to water skiers.
4. To what extent could the taxon impact on recreation in/on waterways? (eg. swimming, boating (including canoeing, skiing, rafting), fishing, bird watching, passive enjoyment (eg. picnics)	Little to no impact on activities. Weeds not obvious to average visitors.	<4 activities affected. Minor effects (eg. willows able to form monocultures that reduce bird life and impede river views for passive enjoyment, but access for swimming, boating and fishing is still possible)..	4+ activities impeded (eg. stream deep enough to boat/swim, but access impeded by willows on the bank).	4+ activities prohibited (eg. willows encroach into stream, making it too shallow to swim/boat).

Table 2(b): Willow *impact* criteria (stream health)

Criteria	Intensity Ratings			
	Lowest Threat L	ML	MH	Highest Threat H
Stream Health (water quality and aquatic biodiversity)				
5. To what extent could the willow impact on the hydrology- flow of water in streams, and on water availability?	Little or negligible impact on flow capacity or water availability. Willow grows offstream with no root or stem growth in stream.	Minor impact of flow by roots or foliage. Roots sometimes grow instream. Capable of removing more water than vegetation lacking instream root systems.	Major impact on flow by roots and foliage including major root structure. Roots and stems often grow instream. Capable of using large quantities of water.	Always extensive roots and stems growing in stream, making them capable of using the most water.
6. To what degree could the willow cause bank erosion (changes to geomorphology)?	Low probability of large scale soil movement. Does not grow in riparian areas.	Moderate probability of large scale soil movement. Terrestrial species that suppresses the understorey and lacks extensive root system, allowing erosion of the banks by overland runoff.	High probability of large scale soil movement, but effects remain in stream. Willow roots and stems encroach instream to create a wider, shallower stream.	High probability of large scale soil movement and major off site implications and bank failure. Willows are confined to the banks, but under flood conditions the stream is diverted behind the willows, scouring out large areas of land.
7. To what extent could the willow affect water quality (and consequently, instream native biodiversity) as measured by potential leaf fall?	Plant is low growing and unlikely to affect the shading of waterways or to drop many leaves into the stream **AND/OR** doesn't grow near waterways.		Grows along the bank to 4+m tall such that large amounts of leaf litter will fall into the stream and/or has the ability to cause unseasonal opening in the canopy by significantly outcompeting native vegetation.	Plant overhangs stream, or encroaches into stream such that most of its foliage will fall into the water. Weeping tree or prostrate form.

Table 2(c): Willow *impact* criteria (biodiversity)

Criteria	Intensity Ratings			
	Lowest Threat L	ML	MH	Highest Threat H
Biodiversity (aquatic and terrestrial)				
8. To what extent could this willow affect riparian/wetland habitat structure/layers? *i.e.* ground layer (forbs, grasses, herbs) shrub layer, tree layers within an environment.	Minor or negligible effect on <20% of the floral strata/layers present; usually only affecting one of the strata **OR** not known as a weed anywhere in the world.	Minor effect on 20-60% of the floral strata. Does not form large thickets.	Minor effect on>60% of the layers **OR** major effect on <60% of the floral strata. Large thickets interspersed with other vegetation.	Major effect on all layers. Able to form monocultures; no other intact strata/layers present.
9. How many riparian habitats (in-stream, margins, banks, floodplain, wetlands) could be impacted by this willow?	Coexists with other vegetation in any of the riparian niches and is not dominant **OR** does not grow in riparian environments.	Occurs as the dominant species in any one of the riparian niches.	Occurs as the dominant species in any two of the riparian niches.	Occurs as the dominant species in any three of the riparian niches, **AND**/**OR** is capable of invading wetlands.
10. To what extent could this willow affect other invasive species (flora and fauna)?	Suppresses (eg. *Glyceria* sp.) No associations formed with other invasive species.	May occur in association with minor pests, such as blackbirds or non-declared weeds.		May occur in association with serious (declared) pests, such as rabbits, foxes or blackberry

How willows were assessed

A range of literature was used to perform the assessments, from journals, books and internet sites, to expert opinion. A confidence score was attributed to each questions answered to give an indication of the quality of the data used to assess each taxon, according to the descriptions in Table 3.

Table 3. Confidence scores for information sources.

Document Type Or Information Source	Rating	Score
• Peer-reviewed scientific paper	**H**	1
• High quality science or plant specific books (eg. floras), • Non-peer reviewed scientific paper (eg. conference proceedings), • Personal communications from expert (eg. PhD, or higher degree on species being assessed), • Unpublished reports from highly reliable source (eg. commercial reports or honours theses, etc.), • Internet information from Herbaria data, or • Internet information that cites sources from MH category, as listed above.	**MH**	0.75
• Personal communications from people with experience with the species under assessment, • Information from general plant books (eg. *Encyclopaedia Botanica,* etc.), • Unpublished reports from uncertain sources, • Internet information that cites sources from M category, or • Internet information from government or university websites (eg. Australian state governments, or USDA)	**M**	0.5
• Anecdotal data from non-experts, • Internet information that cites anecdotal non-expert sources, • Internet information from uncertain/uncited sources, or • Horticultural, nursery notes or general web pages.	**ML**	0.25
• No data or reference material available.	**L**	0

If there was insufficient evidence available to answer a question for a particular taxon, a score of medium (M) was chosen, with a value of 0.5; likely to cause the least amount of error, as it could only be inaccurate by +/-0.5. In such a case as this, a confidence score of L was chosen.

Once all the questions had been answered for a willow taxon, the descriptive scores were converted to numerical scores. The descriptive scores of high (H), medium high (MH), medium low (ML) and low (L) were converted into the following numerical scores: H=1, MH=0.67, ML=0.33 & L=0 for the invasiveness and impacts; and H=1, MH=0.75, M=0.5, ML=0.25 & L=0 for the confidence scores. Each numerical score was multiplied by its relevant weighting (see Figures 4 & 5), so that when a taxon's scores for each question were added together, the score would fall between the values of 0 and 1. The higher the score, the greater was degree of impact and/or invasiveness that the willow could have.

Similarly, confidence scores for each assessment were converted to a numerical value from 0 to 1, but these scores were not weighted.

Which willows to assess?

Given that there are over 400 willow taxa world wide, with a complex variety of species, subspecies, varieties, hybrids and cultivars, it was not feasible to assess the weed risk of all willow taxa individually. We therefore adopted an objective process to determine which taxa, or groupings of willows, would be assessed.

The sixteen willow taxa assessed using the Victorian Weed Risk Assessment were chosen because they are declared noxious in Victoria, and are naturalised in Australia. However, to determine which taxa should be national priorities for management, we assessed a larger list that included non-declared taxa, potentially low risk candidates, and also tried to identify willow taxa that might become weedy in Australia in the future. We limited the assessment list to taxa that have been introduced to Australia, including taxa that have naturalised in Australia; or have the potential to naturalise in Australia, either due to a history of naturalising overseas or because they exhibited invasive traits; or that appeared unlikely to become serious weeds in Australia.

We also assessed individually the three major groups of willows, the subgenera *Salix, Vetrix* and *Chamaetia* (Skvortsov 1999). , within each subgenus *Salix* taxa often share many biological and ecological traits.

A recent modelling exercise highlighted the weed risk associated with some exempt taxa (Stokes & Cunningham 2006), so willows that were exempted from noxious weed legislation in any Australian state were also assessed.

Assessments were made of the following *Salix* taxa (willows) that are present in Australia; either naturalised or in cultivation, listed in Table 4 (below):

1. Each of the three *Salix* subgenera: *Salix, Vetrix* & *Chamaetia* (according to the taxonomy of Skvortsov, 1999); the tree, shrub and alpine willows.

Species within a subgenus, and the hybrids that form between them (within that subgenus) often share many biological and ecological traits. The assessment of each subgenus used high quality data to give a broad picture of the invasiveness of whole groups of willows. This enabled us to make predictions about the invasiveness of those willows that we have very little information about. It will also assist land managers to make decisions about willow management where there is uncertainty about the identification of the willows in the field. It is often easier to identify the subgenus that a willow specimen belongs to, than to work out exactly which species, or hybrid, the plant is.

2. All naturalised species and named hybrids

Willows have naturalised in Australia, both as recognised species, and as hybrids between those species. To confidently assess these willows it is important that the data used can be attributed to a particular type of willow. Most willows were assessed at the species level with notes about the subspecies, varieties, etc. if they differed significantly from each other.

It is difficult enough to identify individual willow *species* and even harder with *hybrids*. We assessed only hybrid willows that have been named according to the *Code of Botanical Nomenclature* (see Lumley & Spencer (1991) for further explanation) as literature describing these “named” hybrids was more likely to be consistently referring to the same plant. Hybrids that have been named according to the *Code* can be identified in the literature, because they are written with a cross between the genus and the species names, eg. *Salix* x *reichardtii*.

3. Willows not naturalised in Australia that have become naturalised far beyond their native range, especially those that are naturalising in New Zealand and Oceania, where *Salix* is absent from the native flora (Skvortsov, 1999).

One of the best indicators that a plant may naturalise in Australia is its ability to naturalise elsewhere in the world.

4. Willows not naturalised in Australia that exhibit invasive traits such as forming dense thickets.

If these willows were to naturalise in Australia, they may have the potential for major adverse impacts on environmental, agricultural and social values in Australia. A weed risk assessment can determine whether a particular willow poses a low or high weed risk.

5. Willows not naturalised in Australia and suspected of having a low weed risk.

Willows have social and economic value as cultivated plants. It would be useful to know which ones might be suitable for cultivation from a risk management perspective. These might include single-sex sterile clones with flexible (not brittle) stems. We used input from the nursery and garden industry on which plants we should assess in this category.

6. Willows exempt from noxious weed legislation

A recent modelling exercise highlighted the weed risk associated with some exempt taxa (Stokes & Cunningham 2006), so willows that were exempted from noxious weed legislation in any Australian state were also assessed. *Salix babylonica, Salix* x *calodendron,* and *Salix* x *reichardtii* (exempt everywhere in Australia); and *Salix caprea* 'Pendula', *Salix alba* x *matsudana, Salix matsudana* 'Aurea', *Salix matsudana* 'Tortuosa', *Salix myrsinifolia* and *Salix alba* var. *caerulea* (exempt in Victoria) (Faithfull, 2006). Although these willows are not covered by noxious weed legislation in every state, some have naturalised and some have the potential to naturalise, so it is useful to know how they compare to other willows from a weed risk perspective.

In total thirty-five willows were assessed as part of the weed risk assessment, this comprised three sub-groups and a further thirty-two taxa (Table 4).

Table 4. Willows that were assessed.
Numerals in the last column relate to the reasons for assessment outlined above.

	Willow	Common name	Notes	Subgenus	Reason for assessment
1	*S.* subg. *Chamaetia* (Dum.) Nasarov	Alpine/Arctic/Mountain willows			1. Subgenus
2	*S.* subg. *Salix* Dum.	Tree willows			1. Subgenus
3	*S.* subg. *Vetrix* Dum.	Shrub willows			1. Subgenus
4	*S. aegyptiaca* L.	Egyptian willow	Syn. *S. medemii*	*Vetrix*	2. Naturalised
5	*S. alba* L.	White willow	Including vars. *alba*, *sericea* & *vitellina*	*Salix*	2. Naturalised
6	*S. alba* var. *caerulea* (Sm.) Rech. f.	Cricket Bat willow		*Salix*	6. Exempt in Vic
7	*S. babylonica* L.	Weeping willow		*Salix*	2. & 6. Naturalised & exempt
8	*S. caprea* L.	Goat willow (Pussy willow/Great allow)		*Vetrix*	6. 'Pendulina' exempt in Vic
9	*S. cinerea* L.	Grey sallow	Incl. ssp. *oleofolia* & *cinerea*	*Vetrix*	2. Naturalised
10	*S. daphnoides* Vill.	Violet willow		*Vetrix*	3. Naturalised in NZ
11	*S. elaeagnos* Scop.	Hoary willow (Bitter willow)		*Vetrix*	3. Naturalised in NZ
12	*S. eriocephala* Michx.		Rhizomatous	*Vetrix*	3. Introduced & naturalised in England
13	*S. exigua* Nutt.	Sandbar willow	Thicket-forming (unlike others in subgenus *Salix*)	*Salix*	4. Invasive traits
14	*S. fragilis* L.	Crack willow		*Salix*	2. Naturalised
15	*S. glauca* L.	Arctic Grey willow	Grows fast and forms thickets on subalpine slopes, creeks and rivers	*Chamaetia*	4. Invasive traits
16	*S. gracilistyla* Miq.		Can spread to form dense thickets	*Vetrix*	4. Invasive traits
17	*S. chilensis* Molina. 'Fastigiata'	Chilean Pencil willow	Syn. *S .humboldtiana* 'Pyramidalis'	*Salix*	2. Naturalised
18	*S. integra* Thunb. 'Hakuro-nishiki'	Nishiki willow		*Vetrix*	5. Possibly low weed risk

	Willow	Common name	Notes	Subgenus	Reason for assessment
19	*S. matsudana* Koidz.	Tortured willow	Incl. *S. matsudana* 'Aurea' & *S. matsudana* 'Tortuosa'	*Salix*	2. Naturalised
20	*S. myricoides* Muhl.	Bayberry willow	*S. glaucophylloides* was misapplied to this sp. in Australia	*Vetrix*	2. Naturalised
21	*S. myrsinifolia* Salisb.	Dark-leaved willow	Syn. *S. nigricans*	*Vetrix*	6. Exempt in Vic
22	*S. nigra* Marshall	Black willow		*Salix*	2. Naturalised
23	*S. pentandra* L.	Bay willow		*Salix*	3. Naturalised in USA
24	*S. purpurea* L.	Purple osier		*Vetrix*	2. Naturalised
25	*S. triandra* L.	Almond willow		*Salix*	2. Naturalised
26	*S. viminalis* L.	Common osier		*Vetrix*	2. Naturalised
27	*S. alba* L. x matsudana Koidz.	New Zealand hybrid		*Salix*	2. Naturalised
28	*S.* x 'Boydii' E.F. Linton	Boyd's willow	*S. lapponum* x *S. herbacea* (x? *S. lanata*?)	*Vetrix* x *Chamaetia* x ?	5. Possibly low weed risk
29	*S.* x *calodendron* Wimm.	Pussy willow	*S. caprea* x *S. cinerea* x *S. viminalis*	*Vetrix*	2. & 6. Naturalised & exempt
30	*S.* x *mollissima* Ehrh.		*S. triandra* x *S. viminalis*	*Salix* x *Vetrix*	2. Naturalised
31	*S.* x *pendulina* Wender.	Wisconsin Weeping willow	*S. babylonica* x *S. fragilis*	*Salix*	2. Naturalised
32	*S.* x *reichardtii* A. Kern.	Pussy willow	*S. caprea* x *S. cinerea*	*Vetrix*	2. & 6. Naturalised & exempt
33	*S.* x *rubens* Schrank	Gold-crack willow	*S. alba* x *S. fragilis*	*Salix*	2. Naturalised
34	*S.* x *sepulcralis* Simonk.	Weeping willow	*S. alba* x *S. babylonica* (Incl. vars. sepulcralis & chrysocoma)	*Salix*	2. Naturalised
35	*S.* x *sericans* Tausch ex A. Kern.	Pussy willow	*S. caprea* x *S. viminalis*	*Vetrix*	2. Naturalised