Willow seedlings establishing on a typical seedbed: bare, wet sediment beside water.

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Thickets of 15 year old *S. nigra* grown from airborne seed from Tumut 70 km away blocking a flood channel on the Murrumbidgee.

A 'gallery' of willows showing the multitude of stems causing sediments to build up.

WILLOW MANAGEMENT FOR AUSTRALIAN RIVERS

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ABSTRACT

Concern has grown over the past years about the natural spread of willows (*Salix*) in Australian rivers. This paper updates and extends an initial assessment (Cremer et al. 1995). Methods of control are considered. The spread and escalation of willow populations are illustrated. The following biological features help to explain the spread and to provide a basis for control:

- The original willow source has been through importation and planting, usually as cuttings of just one or two clones at a time.
- Most of the tree willows in Australia have branches with fragile bases and tend to spread by broken live branches taking root in wet areas. Shrub willows are less fragile.
- Male and female flowers usually occur on separate trees. Female trees will usually produce viable seed with pollen from a male of the same species or of any other species of its group (either tree willows or shrub willows), provided the trees are within pollinating distance of each other (up to at least 1 km) and flower at the same time.
- Seed is easily carried by wind for more than 1 km, and some travels for up to 50 km or even 100 km. Transport of seed and live branches by water also serves to spread willows, but is less effective.
- Seedlings are often hybrids and able to grow vigorously and to interbreed with each other and with their parents.
- Regeneration by seed of all but one willow species (*S. cinerea*) is virtually restricted to bare sediment that is wet for weeks or months following seed shed. Seed has a limited life and germinates in about one day when wet; seedlings need much light and have very slow root growth. The main barriers to the survival of seedlings are lack of suitable seed bed, rising or rapidly falling water levels, and floods that uproot or bury seedlings.
- Conditions suitable for the establishment of large numbers of seedlings probably occur in most southern streams at 5 to 20 year intervals.
- *S. cinerea* spreads by seed to riparian as well as other moist to wet habitats, and this is of special concern.

Only a few thousand kilometres of streams have been seriously infested with willows to date and—except for *S. cinerea* in eastern Victoria—it is still feasible and worthwhile to manage them.

National strategies for management should include restrictions on importation, sale and planting, and the total eradication of the most aggressive species (*S. nigra* and *S. cinerea*). A significant start has been made with the implementation of both national and regional management strategies. Regional strategies require an assessment of local conditions. They aim to eliminate feral willows and to reduce their sources to manageable levels by:

- eliminating fragile willows in situations where their broken branches are likely to take root;
- keeping males at least 2 km from compatible females;
- keeping seeding females to minimal numbers and at least 3 km from suitable seedbeds.

KEY WORDS

Willows, control, *Salix*, *Vetrix*, river management, willow ecology

INTRODUCTION

Introduced willows (*Salix* species) have been planted widely in the southern half of Australia for protection of river banks, beauty, shade and shelter. They are valuable where native species are difficult or impossible to grow satisfactorily. However, there is now a growing concern about willows becoming feral and spreading into rivers from broken branches taking root and the often explosive spread by seed. The main concern is that multitudes of willow stems will obstruct and divert floods to erodible river banks. Displacement of native vegetation and the resulting ecological changes are also of concern (Ladson et al. 1997) together with the additional water that willows may use in some situations.

An initial assessment of the spread of willows in Australia (Cremer et al. 1995) was followed by a major rise in awareness and control activity (e.g. Parker & Bower 1996, Ladson et al. 1997). This paper updates and extends that initial assessment. It focuses on the biological information needed to properly manage willows and deals with methods of control and national as well as locally adapted strategies.

New information that has emerged since 1995 includes:

- *S. babylonica* is now known to produce seedlings where suitable pollen sources and seedbeds exist;
- keeping seed producers at least 300 m from a seedbed is now known to be inadequate, as many seedlings have since been found at 1 km, and significant numbers even at 50 to 100 km downwind of the seed source;
- separating males from females by 300 m has also proved inadequate: ample pollination has been found at 1 km;
- new surveys have shown that breeding populations have built up in more locations, to greater numbers, in a greater variety of species and hybrids, and for a longer period of time than previously known;
- existing methods of control have sometimes proved disappointing;
- human obstacles (bureaucrats, landholders, institutions, laws) to willow management are greater.

The following paper is based on observations during 1993–98 in south-eastern Australia, including the Bellingen, Hunter, Bega, Snowy, Ovens, Murrumbidgee and Murray Rivers, and particularly in the Canberra, Cooma, Bega and Tumut regions. The work included intensive river surveys, constant monitoring of a small willow arboretum near Cooma and informal studies of seed distribution, seed longevity, germination, pollination, hybridisation, flowering times, and control by girdling. Willow names follow Cremer (1996) and Carr (1996), see Appendix 1.

ECOLOGY AND BREEDING

Flowering, pollination and seed production

Time of flowering

Most of the willows in Australia flower in spring, during September to October (Figure 1), with the male and female trees of any one species tending to flower simultaneously. Actual timing varies between species and clones, with climatic differences between years (up to two weeks at Canberra) and between regions (plus two weeks at the alpine tree line, minus two weeks at the coast of northern NSW). Most of the shrub willows (the exception is *S. aegyptiaca*) flower at about the same time and are thus all able to pollinate each other (Figure 1). However tree willow flowering times differ enough to make cross pollinations between a few of the species unlikely or impossible during the main flowering season.

The time of flowering is the period during which the stigmas of the female flowers are receptive (i.e. looking fresh and light yellow-green rather than withered) and the pollen of the male flowers is viable (i.e. the pollen sacks carried at the top the filaments are recently split open and fresh).

In addition to the above main flowering, four kinds of minor irregular flowering were observed and these could occasionally allow cross-pollination between species whose flowering times normally do not overlap. Such flowerings may be stimulated by physiological disturbances, especially when the willows grow in areas warmer than their native climate. Mosseler and Papadopol (1989) noted that:

- the time of flowering in willows is strongly controlled by temperature;
- the relative timing between species is reasonably constant;
- *S. exigua* tends to flower throughout the growing season from buds formed in the previous as well as in the current growing seasons. Willow flowers normally only develop from buds formed in the previous season.

The four kinds of minor flowering observed were:

- some catkins of the main crop developing relatively slowly and extending the main flowering by at least two weeks (common in *S. babylonica* and its hybrids in relatively warm areas of coastal NSW);
- some of the overwintered buds of *S. nigra* due to produce catkins in spring remaining closed until well after the main crop of catkins had matured;
- new flowering shoots emerging belatedly from apparently newly formed buds (*S. glaucophylloides*, hybrid *S. babylonica*);
- completely separate flowerings in January to March (observed mainly in coastal NSW, mainly in *S. babylonica* with new shoot growth following the loss of older leaves infected by rust disease).

Phenology

Sexual development, starting with emergence from the bud (in August/September) to shedding of seed (in October/November) occurs in four stages (enlarging of the catkin, flowering, ripening, and shedding of seed) each taking some two to three weeks in any one tree (Figure 1). The male catkins are shed soon after the pollen has ripened. The female catkins fall together with the last seed, or sometimes sooner if they were not fertilised. The first leaves of tree willows emerge at the same time as the catkins, but these early leaves do not develop fully and tend to shed around November. This is especially so for the leaves of the flowering short-shoots. With the exception of *S. purpurea*, the leaves of shrub willows do not emerge until flowering finishes. In weakly-growing shoots, growth tends to finish around January and the apical bud drops off, but in vigorous shoots, the apical bud continues to produce new leaves until autumn.

Pollination

Willows are pollinated by insects and possibly by wind (Argus 1986). In Australia, both male and female willow flowers are highly attractive to European (*Apis* spp.) as well as native bees.

Although the chance of cross-pollination was previously thought to be minimal at 200 m (Cremer et al. 1995), in two places pollination has now been observed to take place between individuals at least 1 km apart.

Seed production

Flowering and the production of viable seed may begin two to three years after germination, provided the plant is at least 1 m tall if it is a shrub willow, or 2 m tall if it is a tree willow. Where growth is slower, flowering begins later. In some taxa (e.g. *S. alba*) flowering tends to begin at larger sizes.

Flowering tends to be ample and to occur every year. Although seed potential could be as high as several million seeds per tree, actual observed seed production has usually been far less. It ranges from zero (catkins produce only fluff that does not shed) to ample (fluff extrudes readily and contains more than five seeds per catkin). If only 10 percent of ovules are fertilised, a large crown would produce over 500 000 seeds. Willow seed production in Australia is mainly from hybridisation and is considered further below.

Seed release and seed collection

Ripened fruit dries and opens. In warm, dry weather the seed is then levered out by the hygroscopic

	July / August / September / October / November
Tree willows	
S. babylonica	cccccccccXXXXXXXXXXXXXsssssssssooooooooo
S. x *chrysocoma*	XXXXXXXXXXXX
S.matsudana x alba	XXXXXXXXXXXX
S. alba	XXXXXXXXXXXX
S. fragilis	XXXXXXXXXX
S. matsudana 'Tortuosa'	XXXXXXXXX
S. x rubens	XXXXXXXXXX
S. alba var. *vitellina*	XXXXXXXXXX
S. nigra	XXXXXXXXXXX
S. humboldtiana 'Pyramidalis'	XXXXXXXXX
Shrub willows	
S. aegyptiaca	XXXXXXXXXX
S. x calodendron	XXXXXXXXXXXXXX
S. x reichardtii	XXXXXXXXXXXXXXXXX
S. viminalis	XXXXXXXXXXXXXXX
S. glaucophylloides	XXXXXXXXXXXXX
S. purpurea	XXXXXXXXXXX

The relativities shown here between species are roughly constant. However, actual flowering times may vary by as much as 3 weeks, depending on yearly and regional variations of temperature, and on genetic constitution, especially in hybrid swarms grown from seed.

c = catkins enlarging

X = flowering time

s = seed maturing

o = seed being shed

Figure 1. Flowering times of willows in Canberra (average of 1994–98 seasons)

movement of the hairs (or cotton) attached to its base (Lautenschlager 1985). Wind, although not necessary, accelerates that release. The abundance of seed is indicated by the extent to which the cotton is levered out of the fruit. When there is no seed, the fruit may open and show its cotton, but the hairs tend to remain straight and in the fruit.

Seed should not be collected from the ground, as it may be too old to germinate. It is preferable to collect branches with catkins holding fruits which have begun to open and to bring them indoors. If seeds are present, these catkins will extrude billows of cotton with attached seeds within hours or days.

Seed Quality

Germination can be tested by placing the cotton with attached seed in close contact with a wet surface (such as tissue paper on a dish) and kept in a plastic bag to admit light but reduce evaporation. Tested seed should be fresh and growth of resultant seedlings should continue for a week to see if they are healthy.

In more than 100 tests it was found that if seed production was ample (> 5 seeds/catkin) and if the seed was freshly collected, it was usual for 90 to 100 percent of seeds to germinate and for nearly all of the just-germinated seedlings to appear healthy. When few seeds were produced seedlings in some seed lots were stunted reflecting poor survival prospects possibly due to unfavourable parentage.

Sexuality and hybridisation

Sexuality

Willow trees are usually considered to be either wholly male or wholly female, with only rare exceptions. This would mean that (unless viable seed is produced without pollination—not yet reported for willows) willows could be prevented from spreading by seed by planting cuttings only from purely male trees, or only from purely female trees.

Unfortunately for willow management, bisexuality has proved to be quite widespread in Australia, especially in hybrids. When choosing to plant willows of only one sex, care should thus be taken to avoid bisexuals. Observed bisexuals produce mainly male flowers with the proportion of female flowers typically under 10 percent, but varying with clones and years. Male and female flowers usually occur on the same catkin.

Bisexuality occurs regularly and at all ages in *S.* × *chrysocoma* and two other hybrids of *S. babylonica*, in at least one clone of *S. matsudana* × *alba*, in *S. aegyptiaca*, and in some forms of *S.* '*alba*' (probably hybrids of *S. alba*). Neumann (1981) also noted that bisexuals occur mainly in hybrids. Mosseler and Zsuffa (1989) found bisexuals in hybrids as well as pure species, but noted that these bisexuals tended to become purely male in the second or third year of flowering. Viable seed (not necessarily the result of self-pollination) has been collected from most of the Australian bisexuals (especially *S. matsudana* × *alba*, but rarely from *S.* × *chrysocoma*).

A serial form of bisexuality had been observed in *S. nigra*, when an initially wholly female tree produced wholly male catkins from the tops of female catkins while these were still flowering. Another *S. nigra* produced abundant, viable seeds in February and without a then noticeable source of pollen, presumably due to 'serial bisexuality'.

In two seedling populations of *S. purpurea*, females were so common that males were hard to find. Such female-biased sex ratios are not rare (e.g. Mosseler & Zsuffa 1989).

Hybridisation

Many willows are known to hybridise. However, it has recently been suggested that breeding between different species is not as common as once thought. Neumann (1981) considers that hybrids in Europe constitute less than 5 percent of the total willow population. Nevertheless, he lists some 170 well documented different hybrid combinations among 34 species, with indications that some species cannot interbreed for genetic reasons. In their native habitats, the separate identities of species tend to be preserved by the existence of natural barriers to interbreeding (non-overlapping flowering times, non-overlapping ecological distributions) as well as genetic barriers, especially those between tree willows (subgenus *Salix*) and shrub willows (subgenus *Vetrix*) (Mosseler & Papadopul 1998). Hathaway (1987) was able to produce hybrids between *Vetrix* and *Salix* but only with special techniques to overcome incompatibility; and most of the offspring were unfit to live in the wild. He cites other workers with similar results. Numerous artificial interspecific crosses amongst shrub willows have produced viable seed. Although some of these produced poor offspring, a few were superior, even to their parents (Mosseler 1990).

Some of the barriers to hybridisation break down when willows are introduced to new environments, where flowering times may be altered or gaps in flowering bridged (over several generations) by other species flowering at intermediate times, and where species that were previously separated geographically are planted side by side. Many hybrids occur in the UK and this has raised concern that some of the native willows may loose their identity by breeding with introduced willows (White 1994). Meikle (1975) annotated 122 hybrid combinations formed by the 22 UK species, but stated that only three hybrids were both common and spontaneous, including *S. caprea* × *cinerea* (i.e. *S.* × *reichardtii*).

Willows introduced to Australia have proved to be especially promiscuous. Although only four of the taxa in Appendix 1 occur as both males and females (numbers 6, 7, 12, 13), all but two (1, 13d) are now known to have bred locally. *S. babylonica*, previously not seen to be seeding (Cremer et al. 1995), has certainly proved able to seed when a compatible male is nearby. The indications are that probably all fertile willows within each sub-genus in Australia will hybridise, provided their flowering times overlap. Although some of the resulting hybrids might not be fit, many certainly are and some are clearly superior to their parents (e.g. some hybrids of *S. babylonica*). These fit individuals may develop strains that are even better adapted than their parents to local conditions. A number of streams are now dominated by swarms of varied hybrids of unknown parentage.

Observations on breeding in Australia

Tree willows

S. humboldtiana 'Pyramidalis' (pencil willow)

In Argentina an early-flowering strain of *S. humboldtiana* breeds vigorously with *S. babylonica* (Hunziker 1962), but in Australia the local *S. humboldtiana* flowers after the local *S. babylonica.* No offspring have been noticed from this combination to date. *S. humboldtiana* can produce ample pollen but unlike most other willows, it tends to be evergreen and frost tender.

S. matsudana 'Tortuosa' (tortured willow)

The originally-planted clone is female. It has now bred with *S. fragilis*, with *S. matsudana* × *alba* and probably with others. Its 'tortured' offspring include both male and female trees. The 'tortured' form tends to be widespread in some hybrid groups but in the absence of a nearby tortured seed source it occurs at low frequencies (1–2 %) and with the colour of young bark ranging from grey-green to red or yellow suggesting a variety of parents.

S. × chrysocoma (golden weeping willow)

This mainly male bisexual has rarely produced seed from its own few female flowers. Its pollen seems to have caused *S. babylonica* to produce some viable seed but not significant numbers of seedlings.

S. babylonica (weeping willow)

This earliest-flowering of female tree willows has co-existed with the later-flowering *S. fragilis* in much of Australia for many decades without producing many offspring. Although its flowering only just failed to overlap at Canberra during 1994–98 (Figure 1) it may overlap elsewhere (e.g. coastal NSW). Such overlap and planting of early-flowering males (such as *S. alba*, *S. matsudana* × *alba* and other hybrids) has now seen *S. babylonica* produce ample seed and seedlings in various rivers. Some of the resulting hybrids are clearly more vigorous than their mother (possibly due to a higher resistance to the leaf-rust disease). Hybrid offspring include females, males and bisexuals with varying degrees of weep, some variety in times of flowering, and often vigorous seed and seedling production. Argus (1986) reported that both male and female trees of *S. babylonica* are widely naturalised in south-eastern USA.

S. alba var. vitellina (golden upright willow)

This female clone, breeding vigorously with *S. fragilis*, has been the major cause of seedlings in several rivers. It has probably also bred with *S.* × *rubens*, *S. alba* and *S. matsudana* × *alba*. Its offspring now include males that look similar to their mother.

S. nigra (black willow)

This is probably the only willow that was imported as seed into Australia. Thus both males and females were imported in this species and are breeding and spreading aggressively. Hybridisation with other species (e.g. *S. fragilis*, *S. humboldtiana*) is expected, but no clear evidence has been found.

S. matsudana × alba (matsudana hybrid willow, New Zealand hybrid willow, M×A)

S. matsudana × *alba* was bred in New Zealand for wind breaks and similar uses. Nine clones were imported to Australia in the 1980s: three female clones and six male clones, including at least one bisexual. They breed vigorously with each other and the bisexual clone produces viable seed after self-pollination. The males also pollinate *S. babylonica* so that it produces vigorous offspring.

S. fragilis (crack willow)

This originally male clone is one of the most common willows in Australia. It spreads vigorously from easily broken branches taking root in suitable streams. It pollinates other species (numbers 2, 4c, 5, 10) and enables them to produce viable seed. Some of these offspring are females which look like *S. fragilis*.

S. alba **(white willow)**

The identity of this variable set of willows is puzzling. It may be a range of *S.* × *rubens* (Cremer 1996). It has females, males and bisexuals and flowers almost as early as *S. babylonica*, sometimes produces viable seed and it probably breeds with other species. However it also sometimes fails to produce seedlings when expected.

S. × rubens **(white crack willow)**

S. × *rubens* is a variable group of hybrids (usually started locally from numbers 5, 8, 9) which is now proliferating of its own accord. Interbreeding (with numbers 2, 3, 4, 7) is producing an undefinable mix that might conveniently be called FAM willows, reflecting their parentage of *fragilis, alba,* and *matsudana/babylonica.*

Shrub willows

Fertile shrub willows

S. aegyptiaca is a planted bisexual which flowers very early (Figure 1). It produces vigorous seed by selfing but it has not yet been seen to spread to the rivers. With the exception of *S.* × *calodendron*, the females of all the shrub willows in Appendix 1 have been observed to produce healthy seed and seedlings. More specifically, the females of the following species were found to hybridise with other species (probably mainly with pollen from *S.* × *reichardtii*): *S. viminalis, S. purpurea, S. glaucophylloides, S. seringeana* and an unidentified 'K Clarke Willow'. Hybrid seed of the last four was used to raise many healthy seedlings in a nursery test. In some bushes of *S. purpurea* and *S. viminalis* growing far away from any male shrub willow only 1 or 2 percent of ovaries were found to swell and produce a few viable seed, perhaps because of seed production without fertilisation. The most considerable spread to date has been from *S. cinerea* and *S. purpurea*, each present as both sexes and thus able to spread as pure species. The spread of *S. cinerea* ssp *cinerea*—mainly in Victoria—has been most widespread because invasion has not been confined to the rivers, but has extended to several other habitats, including coastal wetlands, moist forests and alpine *Sphagnum* bogs.

Sterile shrub willows

S. purpurea 'Booth' is reported to be sterile (van Kraayenoord et al. 1995), but *S. purpurea* looking like 'Booth' are spreading by seed in Australia. Two clones of *S.* × *calodendron* ('Balana' and 'Hybrida') are considered to be sterile, but *S.* × *dasyclados* (a hybrid of similar parentage) is not (White 1994). The two sterile *S.* × *calodendron* are rarely planted in Australia and have not spread. Mosseler (pers. comm. 1995) found some hybrids of *S. exigua* to be sterile while observed for three years, but considered sterility in *Salix* might not be permanent. Even when a clone is reliably sterile, there can be room for error in identification it if there is a fertile lookalike.

Germination and seed longevity

Time and speed of germination

Although some subarctic dwarf willows are unusual amongst willows in not shedding their seed until autumn for germination in spring (Densmore & Zasada 1983), this paper deals only with the more usual pattern. Seed is shed when the fruit ripens during October/November, usually over a period of one or two weeks in any one tree. At room temperature the seed begins to germinate within one day (if it is kept moist) and it finishes germinating in two or three days. The germinating seed turns green within hours (if it is not already green, as is common in mature seed), elongates its stem, sheds its thin, transparent coat and spreads out its cotyledons. The fine cotton hairs originally attached to the base of the seed are soon shed and replaced by root hairs of similar appearance, but the actual root initially grows only very slowly (about 0.5 mm per day). The first true leaves begin to emerge about two weeks later.

Germination and survival under water

Willow seed will float on water only while it is attached to its cotton 'parachute'. Unless the water is very still this parachute soon falls off.

Three tests have shown that willow seed can easily germinate on and under water, and that the seedlings can survive (but not grow) while submerged for up to one month. Seedlings of two *S.* × *rubens* appeared healthy after 10 and 21 days' submergence, respectively. Seedlings of *S. babylonica* and *S. glaucophylloides* appeared less green after 34 days' submergence, but most of them grew healthily when exposed to air. Older willow seedlings have also proved quite tolerant of submergence—e.g. *S. nigra* to 30 days (Hosner 1960 cited by Noble 1979). Such tolerance permits recently germinated seeds and uprooted seedlings to remain viable while being transported by floods for many kilometres, but it should also be noted that willows can probably not *emerge* from under water, even though it is common to see them in later years with their roots and even their lower stems under water.

Seed longevity

With the exception of some subarctic dwarf species, willow seed is very short-lived, unless it is stored at subzero temperatures (McLeod & McPherson 1973). Figure 2 shows how the viability of seed of two willows stored dry in a room declined to zero in two to four weeks after shedding. Two other willows previously tested showed no seed viability at 17 or 19 days after shedding. With increasing seed age, germinations became not only fewer but also slower (by one or two days) and the seedlings less vigorous. The ungerminated seeds were infected with fungus and rotted within about a week while being kept moist. Note that the seed of *S. nigra* was slightly longer-lived and that McLeod and McPherson (1973) found that a few seeds of *S. nigra* even survived at 8 to 10 weeks.

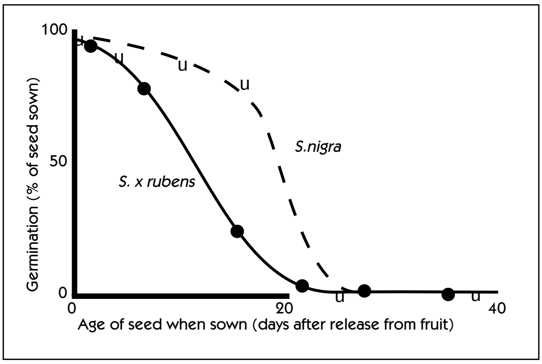

Figure 2. Longevity of willow seed

Seed collected from freshly opened fruit were stored in a room and placed on wet tissue paper in daylight 2 to 40 days after collection. The data points show healthy germinations only.

METHODS OF SPREAD

In the past the spread of willows in Australia has mainly been from importation and widespread planting. However, now natural spread predominates increasingly. Willows are spread by people through:

- intentional propagations, mainly due to the planting of cuttings with or without roots;
- unintentional propagation (e.g. when heavy machinery churns live branches into wet ground);

and by natural processes:

- seed transported by wind or water and then taking root on wet bare ground;
- detached branches taking root in shallow water or on wet ground;
- attached branches taking root in shallow water or on wet or relatively dry ground (i.e. layering);
- attached roots sprouting shoots on wet or dry ground (i.e. suckering—rare or absent in Australian willows).

Willow seeds are not adapted for natural dispersal by birds, animals or people: the seeds are not protected from digestion, and they have no means of hooking or gluing themselves to fur. Seed is short-lived and accidental transport by vehicles or soil is unlikely to result in its placement on suitably wet ground while it is still alive.

Seed and seedlings can be transported by water. When a seed lands on water it floats until agitation of the water causes its halo of hairs to drop off. Seed does germinate under water, but the resultant seedling will not grow unless it becomes exposed to air on moist ground. The seedling can survive under water for as long as a month and can thus be transported during that time. This may not result in many new seedlings quickly, but it could be important for distant dispersal in the long term.

Willow seed is superbly equipped for dispersal by air. The seed with its halo of delicate hairs can float on the slightest breeze for hundreds of metres. However wind is not essential to detach the seed from its fruit and dispersal over greater distances depends on winds of sufficient turbulence to sweep the seed into higher, faster air streams. Dispersal is reduced if the seed source is sheltered by trees or mountains. The probability of establishment from seed at a remote site also depends on the suitability of that site, the genetic constitution of the seed and the size of the seed supply.

Establishment by seed

Willow seedlings typically establish in swathes or 'galleries' along the wet edges of gravel bars or at the foot of river banks. Once sediments have accumulated to bury their bases, these willows appear as though they are growing from higher, dry ground.

Barriers to establishment vary between species and environments. The main limitations are lack of suitable seedbed, rising or rapidly falling water levels after germination, and occurrence of severe floods that wash seedlings away before they are sufficiently anchored.

Seedbed

With the exception of *S. cinerea* the establishment of willows from seed in Australia has been virtually restricted to riparian sites where bare sediments (mud, sand or gravel, the last being the least likely to provide favourable moisture and temperature conditions) are exposed and kept wet for weeks or months from the time of seed shed in October/November.

Seed attached to its parachute is likely to be blown from exposed, dry surfaces and to adhere to wet surfaces. If the ground is not largely bare, the willows cannot grow because of their high requirement for light. If the surface is not wet within about two weeks of seed shed, the seed dies before it can germinate.

Water level

Once seeds have germinated the surface needs to be kept moist. Cloudy weather can help prevent seedlings from being overheated or dehydrated on bare gravels. If the ground does not remain moist for weeks or months, the seedling dries out because root growth is initially very slow (< 1 mm/day). If the seedling is submerged by rising water, its growth is stopped while submerged, but growth can resume if the seedling is exposed to air within about 30 days. The importance of water levels is demonstrated when the seed of different species is shed at different times while the water level is falling slowly: this may result in the later seedling populations establishing on lower seedbeds. Such patterns were also observed by van Splunder et al. (1995).

Other (grazing, trampling, temperature)

Small seedlings are also readily killed through trampling by cattle and grazing by insects. Grazing at later stages is unlikely to kill the seedlings directly, but can greatly retard growth and thus increase the chance that the next flood will wash the seedlings away. Frost heave can uproot seedlings up to heights of at least 5 cm. Frost damage to shoots is probably rare, except in *S. humboltiana* 'Pyramidalis' in southern Australia and *S. nigra* near the alpine tree line. Niiyama (1990) reported some similar ecological features in Japan. He and others also reported that some willows seemed to have a preference for fine rather than coarse sediments. This could be explained by the timing of seed fall in relation to water levels and sediment size, and by the influence of texture on moisture content and hence surface temperature.

Potential for natural spread by seed

Indications from willow biology and a broad assessment of climate suggest that the establishment of riparian willows from seed may be restricted to the south-east (the region with fairly uniform and moderately summer-biased rainfall between Brisbane, Dubbo, Canberra, Bega, Melbourne and Hobart), plus any lakes and rivers in the southern half of the continent where water levels are fairly constant after seed germination (i.e. after October for most species).

Other areas are less likely candidates for willow spread:

- the northern half of the continent is probably too hot, except perhaps for the warmer-country species (*S. nigra*) growing in wetlands;
- the vast arid interior is too dry, except at regulated streams;
- the non-arid parts of South Australia and Western Australia are probably not suitable because their strong bias for winter rainfall probably nearly always causes rapidly falling water levels after willow germination in October/November, except in regulated streams.

However introduction of willows that seed at other times of the year could greatly extend the range of climates where willows may establish from seed (e.g. *S. exigua* imported to Victoria in 1995/96 is able to seed in summer and autumn, as well as in spring).

Most of the perennial streams of south-eastern Australia are probably suitable for the establishment of willows from seed from time to time. Some are less suitable because they provide little or no seed bed for germination (e.g. the highly regulated Tumut River below Blowering Dam and most alpine streams) because such streams are full at the time of seed shed and their banks are well vegetated. Some other streams are less suitable because they provide only negligible chances for survival due to the power and regularity of their floods, e.g. the Hunter River. Where floods are most limiting, only few seedlings can avoid being washed away, and these will be mainly at the very edges where flow is weakest and sediment is least mobile. The indications are that many willows can establish from seed in most streams at intervals of about 5 to 20 years, if seed is available. *S. nigra* may regenerate almost every year in some streams. Where its seed falls during a wet season it may regenerate in ditches and water courses that are dry most of the year (e.g. near Tumut). Where the seed falls during a dry season, its germination is restricted to the wettest places and its survival is threatened by submersion and floods in the following wet season (e.g. near Coffs Harbour). Much depends on the influence of climate and artificial stream regulation on flow regimes.

Vegetative spread

Suckering

Although *S. exigua* suckers vigorously most other willows do not sprout shoots from roots. *S. nigra* is an occasional exception to this rule. Willows tend to have many stems or low branches that sprout roots when they become buried by accumulating sediments. This means that they often appear as though they had grown from suckers.

Layering and rooting of detached branches

In Australia, the rooting of attached willow branches (layering) is significant. In some species (mainly *S. purpurea)* a single plant may develop hundreds of stems producing a thicket more than 10 m in diameter which is difficult to control. Layering may also assist modest advances into drier ground (e.g. when a branch from a willow grown at the base of a bank takes root at the top of the bank). Layering can result in major advances into still, shallow waters. Willow branches and stems tend to lean towards the water so much that they touch the ground and take root. Such rooting is usually only temporary where strong floods occur, but it can eventually result in extensive thickets in relatively still waters, such as the lower Murray River and at lake edges. Layering is also promoted when a tree growing in boggy ground at the edge of a forest develops its crown mainly towards the open water and eventually falls into the water. Some dwarf willows of alpine zones in other countries spread mainly by creeping stems taking root.

With the exception of *S. caprea* (Fjell 1987), willows are usually easily grown from cuttings. This assists their spread by both people and nature. Although such natural spread is only slight in species whose branches are not easily broken (e.g. most of the shrub willows), it can be important in most tree willows (numbers 4–10 in Appendix 1), especially in *S. fragilis* and its hybrids. Although the branchlets of these trees may be tough enough to make baskets, their bases tend to be so fragile that live branches can be broken by storms or floods. *S. fragilis* has thus come to dominate many kilometres of Australia's streams, especially where branches get caught on rocks (e.g. in eastern Tasmania).

Willows can spread through transport by water of broken branches. Spread by the rooting of attached and detached branches is much less restricted by climate and site conditions than spread by seed, and should be possible in wet places anywhere in the southern half of the continent.

Spread of willows in other countries

Willows introduced to other countries

Introduced willows are also spreading in other countries, but without so far causing major concern—e.g. in South Africa (Henderson 1991), in Canada (Mosseler pers. comm.) and New Zealand (van Kraayenoord et al. 1995). In New Zealand planting of willows is promoted (van Kraayenoord et al. 1995) while at the same time they are being cleared (Scholes 1996). In Colorado, USA introduced species (*S.* × *rubens* and *S. alba* var. *vitellina*) are spreading from rooted branches rather than from seed, even though they interbreed to produce many seeds able to grow seedlings in the nursery. Inability to establish in the rivers is probably due to the annual rise in water levels after the seed falls (Shafroth et al. 1994).

Willows may thrive in countries where they are not native because of a relative freedom from pests and diseases. However recently willows in Australia and New Zealand have lost some of this freedom (Spiers 1989). *S. babylonica* in coastal New South Wales is subject to a debilitating leafrust. In 1998 a voracious sawfly began defoliating various tree willows in New Zealand (van Kraayenoord pers. comm.).

Willows growing in their native countries

The spread of native willows does not seem to have caused real concern in their native countries. In Europe this is largely because there is little or no available seedbed (usually the streams are full and their banks densely vegetated) and the land is densely settled and carefully maintained. However the ecology of colonisation by riparian willows in their native lands is similar to that in Australia. In North America, Europe and Japan, the riparian willows and poplars regenerate from seed germinating on bare, wet sediments at the edges of rivers, especially where these form sand sheets or meander over flood plains. When the willows die of old age, these pioneers—unable to regenerate in their own shade—are succeeded by other hardwoods and by conifers that are able to regenerate in that shade (e.g. Hosner & Minckler 1963, Noble 1979, Niiyama 1990, van Splunder et al. 1995). In their native lands, shrub willows generally are not restricted to riparian habitats. Their regeneration in Europe and America extends also to wetlands and to open sites on mountains (Neumann 1981). In Alaska, establishment of shrub willows on uplands is favoured by hot burns (Zasada et al. 1983). Only *S. cinerea* has shown such versatility in Australia so far.

Willows in Australia may also eventually tend to give way in some situations to more shade tolerant exotic invaders, such as privet, lantana, blackberry, camphor laurel and box elder, as well as to native rainforest species, but probably not *Casuarina* or *Leptospermum* spp. as these are pioneers with ecologies similar to willow. Succession to more desirable species may need to be assisted.

BUILD-UP OF WILLOW POPULATIONS

The first willows in Australia were planted more than 150 years ago and were mainly *S. babylonica* and *S. fragilis*. These spread from broken branches taking root.

Once the planting of additional species had resulted in compatible male and female trees growing within pollinating distance of each other willows started to produce seed and seedlings where seedbed was available. These produced their own offspring beginning an exponential growth in willow numbers illustrated by recent surveys of four infested rivers in southeast Australia (Table 1).

For each tree that was planted 1.4 trees have since grown from rooted branches and about 300 trees from seed illustrating that where seeding occurs, it can be a far more important means of spread. Rooted trees too can become important in the long run (cf. *S. fragilis* where the overall ratio was 2.1 rooted trees for each planted tree). The highest numbers of rooted trees occur in rough streams where branches tend to become caught in rocks. *S. babylonica* rooted less frequently (0.7 rooted trees for each planted tree). Although their magnitude depends on time these figures are nonetheless an indication of the relative importance of seeding versus rooting, and of species and environment.

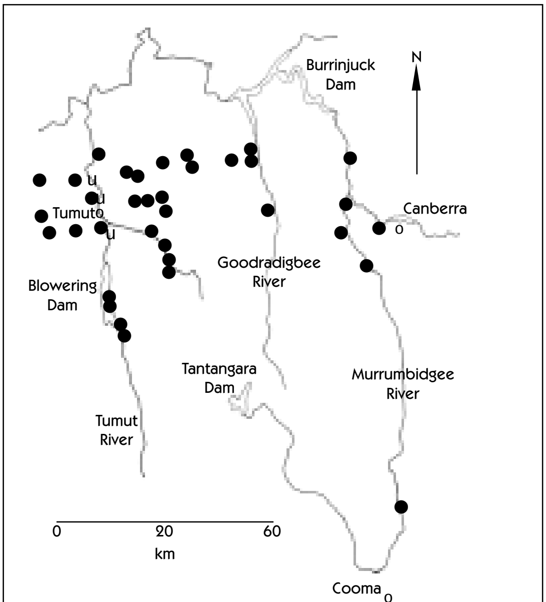

Figure 3. Dissemination of *S. nigra* by wind

Although 84 percent of the planted trees were *S. babylonica* and *S. fragilis*, seed production resulted from introduction of additional species able to breed both with these and with each other. In these surveys the main species providing seed were *S. alba* var. *vitellina* and *S. alba* (S. '*alba*'), and the resulting *S.* × *rubens*. Various other willows found in the survey areas had only recently found breeding partners (e.g. *S. matsudana* × *alba*, *S. purpurea*) or had yet to find them (e.g. *S. nigra*, *S. viminalis*). In general *S. purpurea*, although present in all four survey areas, were still too few and widely dispersed for females to have been pollinated by any compatible males. Most of the non-planted willows surveyed were a result of seed that had germinated in 1993. The frequency of major new seedling populations becoming established in these survey areas was around once in 5 to 20 years.

Case studies

<u>*S. nigra* spreading by windborne seed from Tumut, NSW</u>

S. nigra spreading from Tumut in Southern NSW provided an unusual opportunity for this study:

- it has a massive seed supply created by planting at a known time over a relatively small area;
- the seed has a high capability of growing into trees;
- trees of this species are easily recognised;
- very few other *S. nigra* had been planted in this region.

Field observations were made on a two-day survey of the Tumut region in March 1997, followed by shorter visits to the Tumut, Goodradigbee and Murrumbidgee Rivers.

The original plants were raised from seed collected in 1962 near the lower Mississippi River, USA. Cuttings were then propagated from both male and female seedlings for planting at three poplar plantations near Tumut. These plantings during 1964–77 covered between 10 and 20 ha and were largely at Gocup, but also at Cluny and at Tumut Plains, and possibly at the mouth of Gilmour Creek (Figure 3). By 1970 there was a massive and expanding seed supply in open terrain subject to moderate and largely westerly winds.

S. nigra have also since been planted 100 km south in a sheltered valley at Khancoban and in the Ovens Valley in Victoria. In about 1995 Landcare planted some *S. nigra* willows in Bombowlie Creek near Tumut and a gardener planted one at Wee Jasper. Two older trees planted at Canberra's Pialligo Nursery were prevented from seeding by complete pollarding every winter. Most or all of the self-sown seedling populations shown in Figure 3 probably grew from seed carried by wind directly from Tumut, rather than these other potential sources. However since the number of original trees has dwindled to around two hundred large individuals, seed supply from their offspring is now more important than from the original plantings. These offspring are now more numerous than their parents, are very widely distributed and are producing seed and offspring of their own.

The probability of a tree being established from seed blown directly from Tumut (circles Figure 3) was judged by two criteria:

- its situation (e.g. in the middle of a remote stream) indicated it had grown from seed rather than from planting or a rooted branch;
- its age—trees younger than 10 years were ignored as these could have established from seed of self-sown trees closer than Tumut.

River	**Species**	**Total trees planted**	**Number of trees to be removed**			
Length of survey (km)			planted	rooted	seeded before 1993	seeded in 1993–94
Snowy River	*S. babylonica*	231	0	365	0	0
(40)	*S. fragilis*	534	0	1 662	0	0
	Other*	146	146	255	10	700
Numeralla	*S. babylonica*	778	0	72	0	0
(44)	*S. fragilis*	1 110	0	495	0	0
	Other*	440	440	86	300	104 000
Murrumbidgee	*S. babylonica*	485	0	67	0	0
(30)	*S. fragilis*	586	0	128	0	0
	Other*	115	115	3	10	19 000
Bega	*S. babylonica*	900	0	1 100	0	0
(271)	*S. fragilis*	800	0	4 200	0	0
	Other*	300	300	700	1 600	1 800 000
Total	*S. babylonica*	2 394	0	1 604	0	0
(385)	*S. fragilis*	3 030	0	6 485	0	0
	Other*	1 001	1 001	1 044	16 320	1 923 700
Number of willows per km of river		**17**	**2**	**24**	**42**	**5 000**

* species found as follows:

	Snowy	**Numeralla**	**Murrumbidgee**	**Bega**
S. babylonica hybrids		X	X	X
S. humboldtiana 'Pyramidalis'				X
S. matsudana 'Tortuosa'	X	X		X
S. × *chrysocoma*			X	
S. alba var. *vitellina*	X	X	X	X
S. nigra			X	
S. matsudana × *alba*		X		
S. alba	X	X	X	X
S. × *rubens*	X	X	X	X
S. viminalis	X			
S. purpurea	X	X	X	X
S. × *reichardtii*	X	X		X

Table 1. Results of four willow surveys in southeast Australia made in 1995–1997

Most of the sites with self-sown *S. nigra* are streams in pastoral country, but some are in openings in pine and eucalypt forests. Of the 30 sites examined between the Tumut and Goodradigbee Rivers, four had only a single tree, six had more than one tree but no offspring of their own, and 20 sites had 'first-comers' (trees grown from seed that had blown directly from Tumut) as well as local offspring of their own. The first-comers amounted to only a few hundreds, but their offspring came to many hundreds, plus the much larger numbers at Walleroo on the Murrumbidgee River at 70 km east of Tumut, and those on the shores of Blowering Dam at 20 to 30 km south of Tumut. Seeds from maturing self-sown trees have, of course, been the cause of further seedling spread. However, the ages of those shown as circles in Figure 3 are such that most or all of these must have been due to seed blown directly from Tumut, and not from some older offspring downwind of Tumut.

It is hard to believe that the *S. nigra* growing in the Murrumbidgee, Queanbeyan and Molonglo Rivers also arrived as seed blown directly from Tumut, because these distances amount to some 100 km, and because of the height of the intervening mountains. No *S. nigra* was found in the mainly unfavourable country between the Goodradigbee and Murrumbidgee Rivers, nor at Burrinjuck Dam, except for a single tree where Mountain Creek runs into Burrinjuck, and that tree could have been planted. The several trees at 25 km north of Cooma are particularly remarkable, since no *S. nigra* could be found upwind on the extensive seedbeds on the shores of the Eucumbene and Tantangara Dams. This could be explained by indications from elsewhere that *S. nigra* cannot tolerate the severe frosts at those altitudes.

The sites invaded by *S. nigra* were all essentially riparian, but included spots in remote creeks that are only sometimes wet and were only briefly free of vegetation. The trees grew about 1 m per year and began to flower about 3 years after germination.

Although *S. nigra* is an aggressive willow that has spread 50–100 km in 30 years, it is still feasible to eradicate *S. nigra* from this region because:

- invasion of water courses in pastoral country is so far quite limited;
- invasion of heavily vegetated mountain streams by seed has been slow—it could later accelerate due to broken branches taking root;
- irrigation releases fill some rivers (e.g. the Tumut River) at the time of seed shed and such rivers are at little risk.

However other lowland rivers (e.g. the Murrumbidgee River) are under serious threat because of the extensive seedbeds they usually provide and the ability of *S. nigra* seedlings to establish vigorously on these almost every year.

The shores of pondages with fluctuating water levels are largely bare in the 'intertidal zone' because this is hostile to plants that cannot survive prolonged submersion and also hostile to water plants that cannot survive prolonged exposure to air. This opens opportunities for willows. At Blowering Dam, *S. nigra* has formed dense 'seepage galleries' 1–12 m in height, down to 15 m below top water level in areas kept moist by seepages or streams. Invasion is slower on drier parts of the shore and unlikely on steep, rocky, sunny slopes. Invasion downhill is limited by the regime of water levels.

S. nigra is present also in some other Australian catchments (e.g. Bellinger, Hawkesbury, Ovens) but its spread so far is minute, compared with its potential. Total eradication of this willow from Australia is no longer easy, but it is still possible, and it is almost certainly in the community's interest to do so.

The seeds of other willow species are presumably similarly mobile, but most other species seem to be less aggressive than *S. nigra*. The willows of the Bega Valley, for example, have so far spread to only a small proportion of available habitats in that catchment. The great mobility of willow seed makes it necessary to continue monitoring streams even after all seed producers have been removed.

A difficult species: *S. cinerea*

S. cinerea has spread at an alarming rate in Australia. It readily invades wet or moist habitats well beyond open riparian sites and is already entrenched in much of eastern Victoria. *S. cinerea* probably does not sucker and it rarely breaks off live branches that could then take root. Layering is rare until the trees are old and fall over to produce a great tangle. Rather it is spread by airborne distribution of its seed.

In New Zealand '*S. cinerea* has readily spread from seed and has invaded most swamp areas throughout the country' (van Kraayenoord et al. 1995). Thompson et al. (1994) recorded that *S. cinerea* in one wetland increased from a few bushes in the 1940s to 1243 ha some 50 years later. They state that this species will dominate wherever there is shallow permanent (or near-permanent) water, that it can tolerate acidity down to pH 3.0 and that it spreads faster in areas disturbed by clearing, draining or roading. Champion (1994) reported that *S. cinerea*:

- was present at the 38 Waikato Lakes he examined and that they dominate the shores of most;
- has a much wider ecological latitude than the native species;
- has invaded rapidly in the past 30–40 years;
- is especially adapted to water logging;
- become a sprouting tangle when old trees fall over;
- stands are mostly monocultures excluding 97 percent of sunlight and most other species;
- can invade undisturbed herbaceous wetlands (although favoured by prior disturbance);
- is itself relatively tolerant of grazing and other disturbances.

In Australia, *S. cinerea* has spread mainly in the lowland and mountain streams of eastern Victoria. In Victoria, it 'occurs along streams or near seasonal or permanent swamps and bogs, from sea level to above the treeline; invasive of both disturbed and undisturbed situations ...', especially '... in wetter parts of the Eastern Highlands and the Gippsland Plains'(Carr 1996). An April 1999 survey of the Ovens catchment above Myrtleford estimated that some 130 km of the water courses were infested by *S. cinerea* at light (2 plants/km) to high densities (> 100 per km). Using Carr's distribution map for extrapolation, the two dots assigned to the Ovens area (compared with 34 dots for all Victoria) would translate to some 2000 km of infestation in eastern Victoria. In NSW infestations are known at Tumbarumba (Cremer), near Leura in the Blue Mountains (Rodd pers. comm.), in the Wingecarribee Swamp near Moss Vale, in the Botany wetlands and at Limeburner's Creek in Hurstville (Jacobs & Sainty pers. comm.). The total spread in NSW is minute compared with that in Victoria. In Tasmania, *S. cinerea* is fairly common, but probably always male and nearly always planted (Parker pers. comm.). In South Australia *S. cinerea* is rare and not known to be spreading by seed (Cooke pers. comm.).

Regeneration of *S. cinerea* from seed in the Ovens area is mainly riparian; in and near the permanent, less steep streams. It is also found well above the usual water level in road ditches and in wet seepage areas. It generally prefers open sites, but also occurs extensively in permanent creeks even under fairly dense wet sclerophyll forest. However, it is rare or absent in steep native forests in or away from dry water courses. In the second rotation pines of the Ovens plantation it is widely but only sparsely distributed along more or less dry water courses. At Tumbarumba, however, with annual rainfalls also around 1000 mm, *S. cinerea* has invaded steeply sloping, mature pine forest, not just along water courses. Of special concern is the ability of *S. cinerea* to establish in undisturbed herbaceous communities above the treeline in National Parks (Carr 1996, Nicholas & Gillham pers. comm.).

The wide and mainly continuous distribution of *S. cinerea* within the Ovens catchment could be explained by transport of seed by air from just one or two local plantings of both sexes. The discontinuous distribution of *S. cinerea* on a much larger scale throughout much of eastern Victoria is more likely due mainly to widespread planting. With self seeded trees now over 50 years old, some original plantings must be older than 60 years.

Why *S. cinerea* can invade so extensively beyond the streams is not known. Such invasion can be aided by pasture improvement clearing (Jacobs pers. comm.), burning and soil disturbance, if the ground is wet. This invasiveness makes *S. cinerea* a particularly serious environmental threat.

Spread by layering

In the absence of a seed supply, willows self-propagate from rooted branches or layering. This can range from being a negligible problem in many situations (at least in the short term) to severe (in the longer term). *S. fragilis* and *S. babylonica* dominate many kilometres of the relatively still, shallow waters of the lower Murray River, for example. These have slowly spread—mainly by layering—after original plantings many decades ago. Such spread by layering is unlikely where floods are vigorous and dislodge the rooted branches.

Introduction of a breeding partner

Where one species (e.g. *S. babylonica*) has been the only willow for many decades (as is the case in many remote, outback rivers) the previously stable population is now ready to explode if a suitable breeding partner is introduced (e.g. by the planting of male *S. matsudana* × *alba* within 1 or 2 km of the *S. babylonica*). Most of the seed production in the Numeralla River in NSW, was started when *S. alba* var. *vitellina* was introduced. This newly introduced female was then fertilised by the already widespread male *S. fragilis*.

Willows near Bega, NSW

Willows in the Bega area are the result of a longer-term build-up. Early-flowering males able to pollinate the local *S. babylonica* were introduced more than 50 (up to 100) years ago. Some of these trees now have stems up to 2 m in diameter. The 271 km survey identified only about 2000 trees that had been planted, 6000 trees that had grown from rooted branches, 16 000 trees that had grown from seed germinated perhaps around 1950 to 1980, and 1 800 000 trees that had germinated in 1993 (Table 1). So, in a few decades, 2000 trees grew to about 20 000 and these to nearly two million.

CONTROL METHODS

The reliability of previous methods for control of willows (Trounce & Cremer 1997) are now in doubt following further research. Recent experience with extensive willow control operations and an experiment to assess the value of girdling (ringbarking) suggest improvements.

Mechanical control

Hand pulling

Willows less than 1 m tall and few in number are able to be pulled out by hand. Roots that remain do not sucker but buried portions of stems may take root and must also be pulled out. Seedlings that have been partly flattened and buried by floods are hard to pull out once additional roots have formed on the buried stem.

Use of heavy machinery

Use of heavy machinery can be effective but is not advisable on wet sites if the accidental incorporation of broken, live branches into the ground cannot be kept to a minimum.

Felling

Willows can be felled, but except for some large, old willows the remaining stump usually coppices (produces shoots). These shoots can sometimes be controlled through grazing by sheep or cattle; or their flowering prevented by regular lopping for fodder. The green crowns can be burnt immediately after felling (fire restrictions permitting).

Pollarding

Cutting the crown and all branches tends to invigorate trees rather than kill them and the original crown volume of a young tree can be regained in just three years after felling or pollarding. Such recovery is likely to be strongest after cutting in winter and weakest after cutting in summer (Kindschy 1989). Regular annual pollarding can however serve to prevent flowering as well as to produce fodder.

Burning

If a tree is completely girdled by fire at ground level it may die without coppicing, especially if it is old. However young trees tend to sprout from the buried portion of their stem. Burning of flood debris caught up against the stems will kill some of the bark and will also improve access for other treatments.

Grazing

Willows can certainly be retarded, but are probably rarely killed by grazing. Recently germinated willows can be effectively eliminated by trampling on sandy sites.

Flooding or droughting

Although floods and droughts are the main ways that germinating willows are prevented from establishing in rivers, this is not usually an option in deliberate willow control, except in some regulated rivers.

Girdling

A girdling experiment was conducted in the Canberra–Cooma region using self-regenerated trees of *S. nigra* (1 site), *S. fragilis* (1 site), and *S.* × *rubens* (3 sites). Girdling removed a 10 cm strip of bark from the entire circumference of the stem at about 1 m above the ground. Where a tree had more than one stem, all stems were girdled, except at one site. At some sites girdling was compared with other treatments including:

- felling;
- felling followed by immediate application of undiluted glyphosate to the cut surface of the stump;
- stem injection of glyphosate (Trounce & Cremer 1997).

Each treatment was applied to four trees at each of the five sites in each of four seasons: July 1997, October 1997, January 1998 and April 1998.

Girdling has proved to be of little practical value. It will kill the crown, unless the girdle is incomplete or becomes bridged (by a strip of new tissue regenerating from a thin layer of inner bark that is easily left behind unintentionally after girdling). However the crowns tend to take more than a year to die (typically 2 or 3 years) and thus produce at least one more crop of flowers. Crowns of *S. nigra* and any suppressed willow died relatively quickly (usually within a year). Nearly all stumps coppiced from below the girdle although coppicing after cutting in January or April was usually delayed until the following spring. Apart from timing of coppicing, there was no obvious effect of season on girdling. Only two trees failed to coppice; they died 10 and 15 months, respectively, after an earlier girdling in January 1997.

Under favourable conditions coppice arising from below a girdle should be able to grow indefinitely. However, given heavy shading from other vegetation and from the willow crowns remaining green for 1 to 3 years, and given the sometimes heavy grazing from livestock, much of the coppice (34 percent in this experiment) was dead at 13 to 16 months after girdling. Mortality would probably have been higher if the browsing pressure had been high on all sites and if the shoots had been made more accessible by making the girdle less than 1 m above the ground. There is thus some scope for eliminating willows by girdling, provided that the coppice is controlled by grazing or by 'sucker bashing' as was the practice with clearing eucalypts.

Chemical control

Glyphosate is the only weedicide currently registered for use on willows in Australia and is the only one referred to below. The biactive form is permissible near rivers. The best time for foliar spraying is believed to be December to April, but stem injection and cut stump painting have been successful in all seasons.

Foliar spray

Evidence suggests that foliar spray of willows is ineffective at 1 percent concentration but that 3 percent works well. Because glyphosate is absorbed by clay particles, only clean water should be used to dilute the glyphosate. If floods have covered the willow foliage with silt spraying should be delayed until rain has washed the silt off.

Stem injection

Death rates from stem injection have ranged from 10 to 99 percent at 1 year after treatment probably as a result of how well or poorly the treatment was carried out. Failures may be due to insufficient dosage and distribution of injection points. Stem injection usually does not result in coppice from the stump. The whole crown and trunk may be killed within 3 or 4 months; or some or all of the crown may survive indefinitely after recovering from the initial effects, with strips of bark remaining alive between injection points to connect crown and root.

Although the chemical does act systemically, a multi-stemmed tree will not be killed unless all its stems are injected. Similarly, cuts must be spaced closely so that the whole circumference of each stem is eventually killed. Die-back of bark from the injection site extends indefinitely along the grain, especially upwards, but its extension laterally across the grain tends to be limited to just 2 or 3 cm. The injection cuts can thus be staggered up and down the stem, but their lateral spacing should be no more than 4 cm. On the other hand, it may be important not to cut all of the bark and thus prevent the weedicide from travelling from the crown back to the roots.

As the chemical is to be injected into the sapstream, the axe should make a horizontal slit sloping 1 to 3 cm deep into the actual wood and capable of holding at least 1 ml of liquid per 3 cm of cut. The injection should be made as the cut is being levered open. Any delay will allow air to be sucked into the vessels, as the sapstream of trees is normally under tension all the year. Similarly, a second cut above or below the original is likely to make uptake of liquid into both cuts less effective. The injection should be below the lowest branch and preferably close to the ground.

Cut stump painting

Undiluted glyphosate is applied to the cut stump within a few minutes of felling. When this is not possible a fresh cut should be made just before painting the cut surface of the stump. Evidence suggests that the second cut should not be delayed much more than a day. Although 'flashback' (killing of untreated trees through translocation of weedicide via root grafts) does occur, every stem of each multi-stem tree should be cut and painted.

Incidence of coppice from the base of tall cut and painted stumps can be reduced by cutting the stumps low (under 50 cm). The cut surface should be horizontal so that the chemical does not run off.

Resistant species (such as *S. cinerea*) may need to be sprayed several times. Effectiveness is increased if the bark is also sprayed if it is thin or stripped if it is thick.

Follow-up

Regeneration from pieces of felled or trimmed trees should always be considered and can be reduced by painting their cut surfaces, burning or placing where they cannot take root. Failed or missed treatments nearly always need later attention.

MANAGEMENT STRATEGIES

Willows have now demonstrated their potential to spread along Australia's streams and cause environmental degradation. However, more than 95 percent of the habitat suitable for their invasion is still essentially free leaving opportunities for their proper management. Total eradication of willows would be excessively damaging and expensive. Willows should be managed for their benefits, while at the same time identifying and selectively controlling problem trees. Indiscriminate or poorly conceived control can do more harm than good and be expensive. Work on rivers should comply with the law and occur within a proper framework of river and vegetation management.

Although the simplest strategy would be to continue to only remove trees that grow where they are not wanted, this would result in escalating problems as willows continued their spread. An ideal strategy would be to eradicate all fertile females and bisexuals, and to retain only males, preferably sterile ones that do not have fragile branch bases and do not sucker. However, given that *S. babylonica* is a fertile female and widespread, this option is no longer realistic.

This leaves ad hoc strategies to at least minimise the spread by seed. To do this, we should keep males at least 2 km from compatible females and keep any females that are seeding at least 3 km from suitable seedbeds. It must be assumed that all tree willows can interbreed and that all shrub willows can interbreed, unless they flower at separate times. Both males and females of the most aggressive species (*S. nigra*, *S. matsudana* × *alba* and *S. cinerea*, and all shrub willows other than *S.* × *reichardtii* and *S.* × *calodendron*) should be eradicated everywhere, except perhaps for some of the *S. cinerea* in parts of eastern Victoria, where this species is already out of practical control.

Other more general strategies include:

- eliminate all feral willows—if they grew from seed, many will produce seed of their own—pull out all seedlings and rooted branches while this is easy to do and the seed rain is still modest;
- do not plant willows unless it is legal and reasonably safe to do so (i.e. do not plant fragile willows where their branches can take root and do not introduce any new willow that might start existing willows breeding).

The thoroughness with which any of these options is applied will vary with available knowledge and resources, severity of the threats seen in the given species and local situation, and feasibility of coping with continuing infestations.

National strategies

A comprehensive national strategy would address issues of funding, institutional arrangements, laws and regulations. Only some other matters are considered in the following discussion.

Importation, selling and planting

Willows have a very high capability to hybridise. Importing any willows is dangerous unless they are reliably sterile and have little potential to spread vegetatively. Several clones of *S. matsudana ′ alba* were imported in the 1980s. A further 46 species were imported in 1995/96. The Australian Quarantine and Inspection Service (AQIS) was aware of the weed potential of willows in Australia by early 1995 but restrictions on additional importations are not yet settled, because of Australia's international obligations on free trade. However there are now prospects for appropriate restrictions.

Since 1998, the selling and planting of willows in NSW has been restricted to just three permitted species: *S. babylonica*, *S.* × *reichardtii* and *S.* × *calodendron* (a hybrid shrub willow with two sterile female clones). This is a compromise to be used with caution. The *S. babylonica* must be purely female and early-flowering. In cool climates it can then be planted near the widespread, later-flowering *S. fragilis* but never within 2 km of any early-flowering male tree willow. The *S.* × *reichardtii* must be male and should not be planted within 2 km of any female shrub willow. Only reliably sterile clones of *S.* × *calodendron* should be used.

Since June 1999, all but the above three permitted species have been declared as 'weeds of national significance' with the intention of developing a national willow management strategy. Nurseries now have an important role in selling only reliably identified, permitted species together with the appropriate warnings. These national restrictions should also help AQIS with instituting its restrictions on imports.

Research, information, awareness

Further research is needed to:

- further verify current biological information;
- identify and develop safe clones;
- develop more reliable and efficient methods of control;
- determine environmental effects of willows, including water use;

- investigate biological control to prevent pollen production, pollination, or seed development.

A great deal of awareness has already been raised, but expertise to assess and develop control strategies adequately is yet to be developed by the river management authorities.

Local strategies

Strategic assessment

Willows need to be managed at a landscape or regional level. Reconnaissance of a region or catchment should identify approximate population sizes, species, genders, times of flowering and patterns of spread by seed and rooted branches.

Perhaps the biggest difficulty is to obtain the cooperation of people. When developing and implementing a local control program, the community generally needs to be aware and supportive. Landholders affected should be notified and proposals developed with their input. Where possible they should be visited and their support enlisted.

Observations needed for a strategic assessment as well as the strategies to be developed from them are illustrated in the decision chart (Figure 4).

The following examples of various situations may also assist in evaluation and consequent strategies:

- Willows are absent on the watercourse and not wanted.

Action: continue vigilance to keep all willows out.

- The willows present are all unwanted, such as in a National Park

Action: eliminate all willows.

- Planted willows are present but the site is unsuitable for their spread, such as a watercourse that is usually dry, especially during seed-shed.

Action: avoid very aggressive willows, including *S. nigra* and *S. cinerea*. Preferably avoid any seeding willows.

Figure 4. Decision chart to aid local willow management

1. Are willows present?
yes? **continue to number 2**
no? **decide on merit of keeping them out**

2. Are any of these willows acceptable?
yes? **continue to number 3**
no? (e.g. in a National Park)
remove them all

3. Are the willows spreading?
yes? **continue to number 4**
no? (e.g. one gender; not fragile; site not suitable for natural regeneration; site regularly weeded of unwanted willows)
keep it that way

4. Are they spreading from branches *and* seed?
yes? **continue to number 5**
no? (spreading from branches only)
remove unwanted trees (and their main sources)

5. Are there large numbers of more than two species?
yes? **continue to number 6**
no ? (one species predominates e.g. *S. babylonica* in most inland rivers of NSW)
remove and keep out all other species

6. Are there large numbers of both sexes?
yes? **continue to number 7**
no ? (one gender predominates, e.g. male)
remove all trees of the opposite sex and keep them at least 2 km away

7. You have a more complex problem of numerous willow species seeding and regenerating at or near your site. You could:

(a) decide you can live with the proliferation by dealing with limited clearing as and when needed

(b) decide you can reasonably stop the proliferation by pulling out seedlings and rooted branches as they appear, especially if the local seed rain and seedbed are limited

(c) remove only the most aggressive species (e.g. *S. nigra*, *S. cinerea*)

(d) tackle the problem fundamentally by removing all self-grown willows as well as their main sources

If (d) Do an intensive survey. Selectively remove all targeted trees.

- Only one willow species (e.g. *S. babylonica*) is wanted and this species predominates.

Action: remove and keep out all other species. Check existing willows to ensure all remaining trees are in fact the desired species. Propagate only from these trees.

- Unwanted willows appear to be spreading only by broken branches, such as when only male *S. fragilis* are present.

Action: eliminate all volunteer willows in the stream and remove any obvious sources; avoid introducing female tree willows.

- Areas where there is no suitable seedbed or where seedlings can be weeded out reliably, such as at lakes in towns (e.g. Lake Burley Griffin in Canberra).

Action: keep out the most aggressive species, such as *S. nigra*, and monitor potential seedbeds.

- Seedlings have been noticed or suspect trees have been planted.

Action: determine which parent is to be targeted for removal (e.g. in an area with many male *S. fragilis* pollinating just a few female *S. alba* var. *vitellina*, remove the latter). Carry out an intensive survey to identify every targeted planted tree. Also eliminate all suspected non-planted willows in the river channel, especially any suspected seedlings.

- Areas of extreme infestation that have reached an acceptable equilibrium. Clearing such sites may be very costly and may open the site to erosion and invasion by new weeds, including other willows.

Action: halt the extension of such areas and defer their treatment until more urgent problems have been solved.

Intensive survey

The aim of an intensive survey is to locate every individual of the specified target (e.g. late-flowering females, such as *S. alba* var. *vitellina*) and to look for any additional types of trees that should also be targeted.

Identifying the time of flowering and gender of target trees is possible only when the catkins are recognisable on or under the trees, around October/November. This is a narrow window of opportunity. If flowering occurs at very different times, more than one visit may be needed. Even then, some trees (especially when very young) may not show any flowers. These should also be removed.

Divide the stream to be surveyed into numbered 1 km segments on a 1:25 000 map. Make an enlarged sketch of each 1 km segment on a separate survey sheet which also contains a form to record the desired information. Identify each targeted tree on the ground by attaching conspicuous, plastic ribbons which are safe from floods and grazing animals and durable for 2–3 years (the usual spray paint is *not* satisfactory). Show the location of each seed tree (or group of trees) on the sketch map and record their numbers and species so that they can be found again by others. Indicate numbers, heights and location of seedling populations. State what work is needed on each l km segment. Sometimes more than one type of label may be needed (e.g. to indicate male, female and no-flower). Sometimes marking for retention is better than marking for removal, depending on relative numbers. Marking should be minimised also by specifying that all self-grown trees if they can be recognised should be removed even if not marked. Young seedlings can be recognised by their single, prominent, vertically descending taproot and from where they grow (i.e. at the edge of the water). Older seedlings may appear as if they grow from higher levels if their bases have been buried (up to 2 or 3 m deep) in sediments.

A stream that is easily crossed can be surveyed by a single observer, but it is usually safer and more efficient to have two persons with two cars, so that the same terrain does not have to be traversed repeatedly. Two people can survey about 1 to 6 km per day.

The most widespread female tree, the true, early-flowering, female *S. babylonica*, should usually not be marked for removal, unless there are good reasons (e.g. seed is seen and found to be viable, or hybrids seedlings of *S. babylonica* are present or a likely pollen source is present). Even when a pollen source is present, it usually is preferable to eliminate the responsible male. The true *S. babylonica* flowers early and therefore is usually not pollinated by *S. fragilis*, except perhaps in coastal areas. However some male and female hybrid *S. babylonica* that flower late can produce seed and these should be eliminated.

One should aim to find the source of seedlings. When looking for that source, it should be remembered that the seed tree could be several kilometres away. When seedling numbers are large (> 2 per m^2) the supply of seed must also be large and therefore probably within a few hundred metres.

In most situations an intensive survey is not warranted. However, where one is needed, it must be based on a defined strategy, such as situation 7(d) in Figure 4 plus any additional defined targets, such as the elimination of all shrub willows, all *S. nigra* and all *S. matsudana* × *alba*.

CONCLUSION

Most willow removal operations are inclined to take little account of the real problem and ways to prevent its recurrence. Strategies for and methods of control should take account of willow ecology and breeding. The recent growth in information, awareness and activity promises that willows will be more thoughtfully managed in the future and that their natural spread will be stopped or slowed in many areas. So far, although it is already serious, we have seen only the very beginnings of the potential natural spread of willows in this country. With the exception of some of the worst *S. cinerea* infestations in Victoria, it is still feasible and in the community's interest to actively manage willows.

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* These can be seen at http://www.ffp.csiro.au/publicat/articles/willows. Copies can be obtained by writing to Bob Trounce, NSW Agriculture, Locked Bag 21, Orange, NSW 2800, or by faxing him at (02) 6391 3605.

APPENDIX 1.

Botanical and common names (after Cremer 1996)

The following willow species are known to be found in rural areas in Australia.

Tree species

1.	*S. humboldtiana* 'Pyramidalis'	pencil willow
2.	*S. matsudana* 'Tortuosa'	tortured willow
3.	*S.* × *chrysocoma*	golden weeping willow
4.	*S. babylonica*	weeping willow
4c.	hybrids of *S. babylonica*	'weeping willow'
5.	*S. alba* var. *vitellina*	golden upright willow
6.	*S. nigra*	black willow
7.	*S. matsudana* × *alba*	matsudana hybrid willow, N.Z hybrid willow, MxA
8.	*S. fragilis*	crack willow*
9.	*S. alba*	white willow*
10.	*S.* × *rubens = S. alaba* × *fragilis*	white-crack willow*

Shrub species

11.	*S. viminalis*	common osier
12.	*S. purpurea*	purple osier
13.	*S. cinerea*	grey sallow, 'pussy willow'
13a.	S *cinerea* ssp. *cinerea*	grey sallow
13b.	S *cinerea* ssp. *oleifolia*	rusty willow
13c.	*S.* × *reichardtii = S. cinerea* × *caprea*	pussy willow
13d.	*S.* × *calodendron = cinerea* × *caprea* × *viminalis*	'pussy willow'
14.	*S. glaucophylloides*	broadleaf willow
15.	*S. aegyptiaca* (syn. *medemii)*	

* often incorrectly called basket willow;

'weeping willow' or 'WW' indicates strongly weeping hybrids of *S. babylonica*.

Willow infestation in the mid-Snowy river. The surrounding area is the Byadbo wilderness.

WAYWARD WILLOWS WEEP

cleaning up the Snowy catchment

Mike Gooey Executive officer
Snowy Genoa Catchment Management Committee
(02) 6452 1455

The Snowy Genoa Catchment Management Committee (CMC) is concerned about the spread of willows by both sexual and asexual reproduction in the Snowy River below Jindabyne, NSW (Figure 1). The potential for spread has occurred following the reduction of stream flow in the river (less than 1 per cent of the original flow is now being released below Lake Jindabyne) as a result of the Snowy Mountains Scheme. Current flows are insufficient to maintain the natural structure of the river, and pool infilling and exposure of prior riverbed has meant that extensive areas are ideal for establishment of willows both vegetatively and by seed (Environmental Protection Authority 1997).

The Snowy Genoa CMC is addressing the impact of willows on the Snowy River as a part of the broad Snowy River Restoration Plan (SRRP) which has been developed over the past two years. The SRRP involves the community in developing a Streamside Vegetation Plan and sets common objectives for weed control, revegetation and remnant vegetation management.

Objectives of the willow component of the SRRP are to:

- survey and map the numbers and extent of willows spreading by sexual reproduction in the Snowy River and in tributaries feeding in to the river;
- assess the risk that those willows pose and implement appropriate control programs;
- develop (in consultation with the Streamside Vegetation Plan) zones for willow management;
- liaise with the community to develop an increased understanding of the need for willow management in the Snowy River.

The threat of seeding willows was considered of primary importance in the short term, with the spread of other willows to be tackled once flows have been allocated.

Willow survey

In spring of 1996 and 1997 the Snowy Genoa CMC commissioned surveys to ascertain the extent of willow populations along the Snowy River. The aim of the survey was to determine the number and species present and identify 'problem' and seeding willows (Table 1). These surveys confirmed that willow seeding has been occurring in the Snowy for at least 20 years (Aveyard & Miners 1996).

Surveyors noted that willow management should focus on the prevention of willows spreading by seed and that 'seeding willow' populations were a manageable size, providing strategies were implemented now (Aveyard & Miners 1996, Miners & Miners 1997).

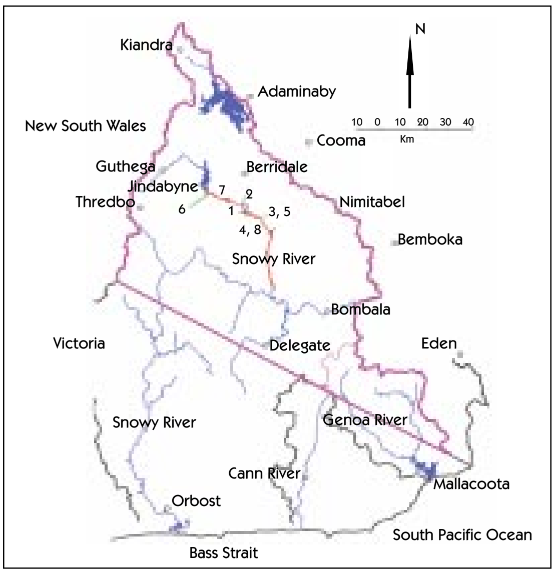

Figure 1. Snowy Genoa catchment.

Scientific Name	Common Name	Comments
Salix babylonica	weeping willow	Could provide a stable willow population
S. fragilis	crack willow	Main source of instream volunteers
S. alba var *vitellina*	golden upright willow	Few *S. vitellina* are evident; females cross with *S. fragilis* + *S. rubens* var. *vitellina*
S. rubens	basket hybrid willows	Hybrid of *S. alba* x *S. fragilis*; most aggressive seeding willow
S. x *rubens* var *vitellina*	golden crack willow	Differs from *S. rubens* as stems are golden to 2m from tip; differs from *S. vitellina* as are multi-stemmed
S. alba	white willow	Single stem *S. rubens* can be identified as *S. alba* (due to this variability)
S. babylonica x *S. rubens*	hybrid willow	Possibly *S. alba* or *S. babylonica* hybrid; highly variable: single to multi stemmed
S. matsudana 'Tortuosa'	tortured willow	Planted young trees marked for removal—can produce viable seed with *S. fragilis*
S. purpurea	purple osier	Difficult to control: labour intensive
S. cinerea	pussy willow	Can cross with *S. purpurea*, requires immediate removal

Table 1. Species of type of willows identified in the 1996 and 1997 willow surveys (Aveyard & Miners 1996; Miners & Miners 1997).

Willow control

Willow control activities have been carried out each autumn since 1997 with control works using a combined approach of hand pulling seedlings, cutting and painting stems, and stem injection (Table 2).

Experienced contractors are engaged for all control works. The Snowy Genoa CMC is conscious of the need to act with due diligence and care, and to respect the needs of individual land owners, community and legislation, in such a broad catchment activity.

The *Native Vegetation Conservation Act (NSW, 1997)* requires approval and consent for willow control works. This includes consent from land owners for access to properties and to control willows. Approximately 120 land owners have been involved in the three-year control program. The community's response to willow control has been positive and there have been no refusals to participate in the program.

Whilst the major focus of the SRRP is control of willows in the Snowy River itself, the Upper Snowy Landcare Committee and Snowy Genoa CMC are working together in a separate (but related) project focusing on the upper Snowy tributaries. Management of tributaries is dependent on the ability to provide buffer zones before joining the Snowy River.

Season	Aim of control works	Length of river (km)	Map key Fig.1
Autumn 1997	Selective treatment of all female willow trees, shrub willows and seeding populations identified in the spring 1996 survey on the Snowy River (Kara Creek to Dalgety)	17	1
Autumn 1998	Remove all in stream willows in the Wullwye Creek	5	2
	Start removal of shrub willows in the Bobundara Creek	3	3
	Selective control of seeding, immature and shrub willows on the Snowy River between Dalgety and Ironmungie	11	4
Autumn 1999	Continue removal of shrub willows in the Bobundara Creek	1	5
	Control all willows on the Mowamba River from the aqueduct to its confluence with the Snowy River	8	6
	Control all willows in the Snowy Gorge below Jindabyne	12	7
	Selective removal of shrub willows on the Snowy River at Ironmungie	1	8

Table 2. Summary of control works undertaken.

The future of willow management in the Snowy

The overall aim of the Snowy willow management program is to specify areas of river that should be willow-free and other areas where *Salix babylonica* (weeping willows) are present for amenity, aesthetic and stabilising reasons. Current estimates suggest this aim could be achieved over 10–20 years at a cost of $7m.

Initial aims of the Snowy willow program were to identify and control 'problem' instream and seeding willows, but the SRRP steering committee and Snowy Genoa CMC have assessed the surveys and agreed to a 'control from the top-of-the-catchment' approach. Individual and community needs and the desire for a strategic approach to some complex, highly infested areas moderate this principle.

Community commitment to the willow control program is exceptional and has been funded to date by Department of Land and Water, NSW Rivercare, NSW Total Catchment Management and the Natural Heritage Trust.

Challenges for the future include the need to:

- build on the current success;
- secure a long term funding source for the control program;
- institute approval and consent procedures that are robust and timely, and that satisfy the needs of community and government.

On the basis of the success of the Snowy willow control program, a partnership between the Snowy Genoa CMC, and NSW and Victorian agencies and authorities will commence a willow control program for the Genoa catchment in 2000. Given the environmental qualities of the Genoa catchment the control program will work from the top of the catchment and aims to have it willow-free in five to ten years.

The overwhelming message from the experiences of the Snowy Genoa CMC willow control program is the need for long term commitment, enthusiasm and constructive partnerships.

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S P O N S O R S H I P

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Total Catchment Management — *Community And Government Working Together* — TCM

Land & Water Conservation

Snowy Genoa Catchment Management Committee — Healthy landscapes, sustainable communities

NSW WILLOW-CLEARING GUIDELINES

best management principles at work

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New South Wales has introduced easy-to-follow guidelines for landholders wishing to clear willows from State-protected, riparian land*. The guidelines clarify the clearing process and are aimed at streamlining applications for clearing. The best management principles described in the document are widely used across the State by individuals, community groups and public authorities. These guidelines are only applicable to NSW. People contemplating any disturbance to the riverine environment should seek guidance from their relevant department/ government authority.

Where the principles apply

The best management principles for willow clearing apply when applicants wish to clear all or some willows for a distance of up to 500 metres along a stream, and where additional consents or approvals have been obtained where necessary (e.g. tree preservation orders in Council local environment plans).

Best management principles do not cover situations where track construction or significant soil disturbance is necessary, or where willow removal affects streambank stability; water quality; visual amenity and privacy; threatened species habitat; or a known Aboriginal site. Willows that have a significant heritage or historical value are also not covered by the best management principles. In these situations applicants would need to submit an application which cosiders the relevent issue.

Best management principles

The NSW Department of Land and Water Conservation's best management principles require:

- minimisation of damage to existing vegetation (other than willows and other noxious weeds) and streambanks;
- killing of willows by hand removal, cut and paint stump, foliar spraying or stem injection;
- revegetation of the site if necessary;
- protection of wildlife corridors;
- management of debris;
- use of herbicide;
- removal of dead willows.

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* State-protected, riparian land is land that is situated within, or within 20 metres of, the bed or bank of any a prescribed stream or lake, including major watercourses.

Process for removal of willows

Initial application for removal of willows on protected land involves a pre-application site visit by a local Department of Land and Water Conservation officer. Where it is confirmed that the proposal meets the requirements of willow-clearing guidelines, and that removal will be carried out following best management principles, the Department undertakes to process the application within five days of its lodgement.

In some situations (e.g. where large numbers of willows are to be cleared) land management issues may require more detailed consideration. Problem areas are identified and discussed during the pre-application visit.

The Department of Land and Water Conservation recognises the damage that willows can cause to State-protected, riparian land, but must ensure the protection of streambanks and water quality during the transition to a more natural riparian zone.

The involvement of local departmental officers from the start of the clearing process can be of great assistance to applicants. Prior to the first visit, the officer contacts the local council to find out whether any environmental planning instruments or development control plans apply to the proposal; conducts a search of the National Parks and Wildlife Services Aboriginal sites database; and researches whether any threatened species may be present in the proposed area of clearing.

The NSW Department of Land and Water Conservation's *Willow clearing guidelines for applicants* simplifies and streamlines the approval process to remove willows from State-protected riparian land, while protecting the fragile riparian environment.

Australian Association of Natural Resource Management Inc. (AANRM)

Leadership in natural resource management.

Facilitating networking between natural resource managers.

Focusing on all aspects of our natural resources.

Practical information in a user friendly format.

Attractive to all natural resource managers and concerned individuals.

AANRM provides an independent stimulating forum for debating and sharing ideas about natural resource management. It encourages adoption of management systems in accord with natural resources capabilities.

AANRM members are part of a professional body dedicated to education, practical solutions and sound natural resource management policies.

AANRM provides opportunities for promotion through a national network of farmers, researchers, Government employees, Landcare groups and individuals. Members are able to participate in State workshops and training.

All members receive and are invited to contribute to their own professional journal thereby keeping in touch with research. AANRM's website provides an active forum for discussion and promoting new ideas.

Membership is open at three levels:

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- *Individual*—including private individuals, community based organisations and libraries.
- *Student*—people undertaking full time study acceptable to the AANRM Council.

Branches currently operate in Queensland, New South Wales, Victoria and South Australia.

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Please send appropriate amount.

Membership	Corporate	Individual	Student*
Australia	$168	$58	$48
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*Student status to be confirmed by head of faculty of principal of college or school.

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Application Form

I hereby apply to join AANRM. My membership is for one year beginning on the first of the month in which my application and fee are received. Post form and payment to Baden Willians, P.O. Box 173, Lyneham, ACT 2602.

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Extensive wet sand banks of the Bega River allowed the establishment of huge seedling populations when germinations that occurred in 1993 were able to survive in the absence of floods over the following two years.