South Australia's Weed Risk Management System

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Summary

The South Australian Weed Risk Management System (SAWRMS) is a relatively simple and transparent scoring system to prioritize weed species for strategic management at a range of spatial scales. There are two key considerations in prioritizing weeds for coordinated control programs; weed risk and feasibility of control. A score for 'Comparative Weed Risk' (CWR) is generated from multiplying separate scores (each ranging between 0 and 10) for the three criteria of 'Invasiveness', 'Impacts' and 'Potential Distribution'. A score for 'Feasibility of Containment' (FoC) is generated by multiplying separate scores (again, each ranging between 0 and 10) for the three criteria of 'Control Costs', 'Current Distribution' and 'Persistence'. Scores for each of the six criteria are generated from a series of multiple-choice questions (e.g. high/medium/low), with definitions to aid in the consistency of assessments. Weeds are assessed within land uses (e.g. crop/pasture rotation, native vegetation, forestry, urban) as this avoids contention over the relative values of land uses in a region of interest. CWR and FoC scores have been categorized into five levels (ranging from negligible to very high), which enables weed species to be placed on a simple prioritization matrix for each land use. The matrix indicates the most appropriate management action (e.g. prevention, eradication, containment, integrated weed management).

Keywords: Weed risk management, priority setting, feasibility of control.

Introduction

The State of South Australia (SA) covers 983 482 km^2 of southern, central Australia. It is mostly arid, temperate rangelands, with the southern third of the state having a Mediterranean climate. This southern agricultural zone mainly consists of dryland cropping (cereals, canola, pulses) and grazing (sheep, cattle) farms, aligned to a winter-dominant rainfall pattern. Perennial (wine grapes, pome fruits, citrus, stone fruits) and annual (potatoes, onions, cucurbits) horticulture crops are concentrated in areas with access to irrigation from ground water or the River Murray, as are irrigated pastures for hay production and dairies. Forestry (*Pinus radiata* and *Eucalyptus globulus*) plantations are common in the lower south-east of SA and the Mt Lofty Ranges in the centre of the state, where annual rainfall is higher. Large and small remnants of native vegetation occur in the southern agricultural zone, often as public or private conservation reserves. The northern rangelands are predominantly native vegetation (although often with weed invasion) and have mixed pastoral (sheep, cattle), conservation and indigenous (i.e. Aboriginal) use. SA has an extensive southern coastline but few permanent, freshwater rivers, lakes and swamps other than those of the River Murray. SA's human population of 1.5 million people is mainly concentrated around Adelaide, the State's capital, with smaller regional centres based around mining, forestry and agricultural industries.

Weeds occur in all of the aforementioned land uses in SA, which presents a challenge in determining priorities for government investment in weed management. SA has over 1100 naturalized plant species (Barker *et al.* 2005), mostly exotic species but also including plants native to eastern and western Australia. The *Natural Resources Management Act, 2004* is the basis for regulation of pest plants (i.e. noxious weeds) in SA. Approximately 110 species or genera are declared under the Act, with legal provisions restricting sale and movement of these plants and their propagules and requiring their control by landholders (whether private or government). The State Minister responsible for the Act makes plant declarations and eight regional Natural Resource Management Boards (NRMBs) across SA enact these through compliance and education programs. Weeds declared in SA vary in the types and degree of their current and potential impacts (i.e. economic, environmental and/or social effects), life forms (e.g. parasites, annual and perennial herbs and grasses, geophytes, obligate aquatics, vines, shrubs and trees) and invasion status (i.e. not present, recent incursion, spreading, widely established).

There are insufficient resources to enable every declared plant to be effectively contained and eventually eradicated in SA. Hence there is an ongoing need to prioritize species for coordinated control programs. Such prioritization of weeds needs to be based on two, separate considerations; does the weed pose a significant risk and can the weed be feasibly controlled? Whilst prevention and early intervention are frequently espoused as the most cost-effective actions in weed management (NRMMC 2007) there has been a historical propensity to keep targeting widespread noxious species, in SA and elsewhere. Various reasons for this include a long history of enforced control, visually obvious weeds that attract political pressure, perceived rather than actual impacts, familiarity with particular weeds and their control and a community attitude of accepting a shared burden of control costs. Conversely there can be a hesitancy to enforce control of a new weed incursion in a region, due to the community seeing it as an unfair cost burden on a few landholders, doubt over the species' potential threat, the weed posing a predominantly environmental threat and/or the weed being currently restricted to a land use where it poses a minimal threat. These are valid considerations in determining what actions, if any, should be taken against a particular weed. However, decisions need to be primarily informed by a formal comparison of the risk imposed by, and feasibility of control of, various weed species.

This paper describes the development, structure, and use of a scoring system to compare the risk and feasibility of control of different weed species in SA.

Development of the SA WRM System

The South Australian Weed Risk Management System (hereafter SAWRMS) has its origins in a research project to develop a draft ranking system to determine Weeds of National Significance (WoNS) for Australia (Virtue *et al.* 2001), presented at the 1st International Workshop on Weed Risk Assessment (WRA) in 1999. This was thought to be the first attempt at devising a generic scoring system to rank the national importance of established weeds, with the final version of the system (Thorp and Lynch 2000) determining 20 WoNS. However, there were important prioritizing WRA predecessors overseas that had provided sound direction, particularly Hiebert and Stubbendieck (1993) and Owen *et al.* (1996).

The draft ranking system from the WoNS research project (Virtue *et al.* 2001) became the basis for further development into the SAWRMS. A series of regional consultation workshops were held from 1998–2000 with Animal and Plant Control Boards (precursors to NRMBs) on prioritizing weed species for regional control programs and state declarations. Testing successive versions of the SAWRMS in a workshop setting allowed incremental improvement in criteria, definitions and logic so that the system could be readily understood and used by regional weeds staff. An important advance was

adopting the Australian state of Victoria's approach for their WRA system (Weiss and McLaren 2002), of multiple choice options (e.g. high, medium, low) being given clearly worded definitions to increase consistency in scoring between assessors.

By 2000 an MS-Excel score sheet and MS-Word guide were available to assess weed risk, but subsequent uptake by Animal and Plant Control Boards for local prioritization of weeds was patchy. In hindsight this was because the system was only half complete. Adoption improved considerably when the second component required for effective prioritization, feasibility of control, was developed. Criteria for feasibility of control were derived from a national workshop on post-border weed risk assessment, organized by the Cooperative Research Centre for Australian Weed Management (Weeds CRC) in 2002, and the subsequent development of a national post-border weed risk management protocol (Anon. 2006). A study by Panetta and Timmins (2004) on feasibility of weed eradication was another key source of criteria for the SAWRMS.

The SAWRMS, with weed risk and feasibility of control components, was completed in 2004. Its first major use was for regional weed prioritization in SA's South East (Anderson *et al.* 2005) and it has since been applied at various levels in SA and beyond.

Structure of the SA WRM system

The basic requirements guiding the development of the SAWRMS were:

- Generic questions that can be applied to any weed at any scale for any land use;
- Simple mathematics in a logical framework;
- Questions readily understood and terms commonly used by weed managers;
- As few questions as possible whilst still enabling robust species comparisons;
- Low subjectivity and not value-driven; and
- Able to use knowledge and observations.

The SAWRMS generates two scores for a weed in a particular context (pre-selected land use and geographic/management area); Comparative Weed Risk (CWR) and Feasibility of Containment (FoC). CWR and FoC scores are then compared in a matrix to identify the most appropriate management action.

Comparative weed risk

A score for CWR is generated from multiplying separate scores (each ranging between 0 and 10) for the three criteria of 'Invasiveness', 'Impacts' and 'Potential Distribution'. Hence CWR has a minimum of 0 and a maximum of 1000. Invasiveness considers the establishment, reproductive and dispersal abilities of weed species, providing an indicator for rate of spread. Impacts considers the types and magnitude of economic, environmental and social effects that the weeds can have. Potential distribution considers the geographic area that could be invaded by the weed.

Questions for the three CWR criteria are listed in Table 1. For the Invasiveness and Impacts criteria, scores are generated from a series of multiple-choice questions (e.g. high/medium/low), with clear definitions for each of the multiple answer options to aid in consistency of assessments (Virtue 2008). These criteria were tested in the development of the draft WoNS system (Virtue *et al.* 2001) and were also found to be robust in the selection of the WoNS themselves (Thorp and Lynch 2000). The Potential Distribution criterion has a score based on a percentage of a land use suitable for invasion of the weed (regardless of the weed's current distribution). The computer program CLIMATE (Pheloung 1996), now revised as CLIMATCH (Crombie *et al.* 2008), has been used to predict species' distributions in SA, based on temperature and rainfall parameters derived from the species' native and invasive ranges outside SA (overseas and within Australia). This climate match is then overlaid with soil tolerances and land use distribution using ArcGIS to quantify an area at risk. The Potential Distribution criterion is scored in broad increments of land use at risk (e.g. 20–40%), in recognition of uncertainties in the modelling.

Prior to assessing CWR it is important to define the land use for which the assessment is being undertaken, including what are the outputs of the land use and what are the existing, typical weed management practices (e.g. physical control, herbicides, soil cultivation). Risk is assessed as the potential threat a weed poses if it is not specifically targeted for a control program. Weed species will differ in their tolerance to existing weed management practices, with those poorly controlled likely to reach higher densities and subsequently have greater spread and impacts. Land uses that have intensive weed control practices tend to score lower average weed risk in the SAWRMS.

It is logical to multiply the three criteria for CWR. If it were possible to do a quantitative, economically-based, weed risk assessment then the units used in the formula in Figure 1 would apply. However, such data are rarely available for short-term decision-making and instead scores for each criteria are used as surrogate indices.

Feasibility of containment

A score for FoC is generated by multiplying separate scores (again, each ranging between 0 and 10) for the three criteria of 'Control Costs', 'Current Distribution' and 'Persistence'. Control Costs considers the weed management costs of detection, onground control and enforcement/education needs. Current Distribution considers how widespread the weed is at present.

Table 1. CWR criteria and questions (see Virtue 2008 for further detail on multiple choices, their definitions and scoring).

INVASIVENESS
What is the weed's ability to establish amongst existing plants?
What is the weed's tolerance to average weed management practices in the land use?
What is the reproductive ability of the weed in the land use? (a) time to seeding (b) seed set (c) vegetative reproduction
How likely is long-distance dispersal (>100m) by natural means? (a) flying birds (b) other wild animals (c) water (d) wind
How likely is long-distance dispersal (>100m) by human means? (a) deliberate spread by people (b) accidentally by people and vehicles (c) contaminate produce (d) domesticated/farm animals
IMPACTS
Does the weed reduce the establishment of desired plants?
Does the weed reduce the yield or amount of desired vegetation?
Does the weed reduce the quality of products or services obtained from the land use?
Does the weed restrict the physical movement of people, animals, vehicles, machinery and/or water?
Does the weed affect the health of animals and/or people?
Does the weed have major, positive or negative effects on environmental health? (a) food/shelter (b) fire regime (c) increase nutrient levels (d) soil salinity (e) soil stability (f) soil water table
POTENTIAL DISTRIBUTION
In the Management Area, what percentage area of the land use is suitable for the weed?

Persistence refers to the expected duration of a control program. Questions for FoC are presented in Table 2. The logic behind the multiplication of the three criteria for FoC is shown in Figure 1.

Whereas CWR considered a weed species' potential under current routine management, for FoC one now consider how the weed species performs under targeted weed practices. Such practices need to be defined (e.g. additional herbicide treatments, physical controls).

The FoC criteria have not been subject to the same statistical scrutiny as the invasiveness and impacts criteria. However, all six CWR and FoC criteria (and their component questions) are largely equivalent to those in the nationally agreed post-border WRM protocol (Anon. 2006).

Land uses

In the SAWRMS weeds are assessed separately within land uses as this avoids contention over the relative values of land uses in a region of interest. The eight main land uses used are aquatic, non-arable grazing, crop/pasture rotation, irrigated crops/pastures, perennial horticulture, forestry, urban and native vegetation. These land uses can be defined at finer or coarser scales, taking account of variations within the geographic area (e.g. climate, topography, industries). A weed only needs to be assessed in a certain land use if it is likely to invade and have a significant impact in that land use. As yet there is no readily accepted methodology to equitably value the economic, environmental and social values of these land uses in SA to come up with one weed list.

Management action matrix

CWR and FoC scores have been categorized into five levels (ranging from negligible to very high), which enables weed species to be placed on a simple prioritization matrix for each land use (Figure 2). Cut-off scores for these levels were determined by calculating every possible scoring combination (excluding 'don't know' answers) and splitting the resultant frequency distribution of scores into 20% percentile bands.

The matrix indicates the most appropriate management action for a weed species in that land use (Figure 2). Appendix 1 gives guiding principles for each of the management actions in the matrix. However, a final decision on what level of regional control is required for a particular species needs to weigh up its allocated management actions across different land use matrices. For example, a weed may rank as 'destroy infestations' in one land use and 'limited action' in others. In this case coordinated control may still be required in the latter land uses to enable prevention of spread to the former land use.

Use of the SA WRM system

The SAWRMS has been used for regional weed prioritization in SA's eight NRMBs, with the outcomes directing resources to high risk / high feasibility species in each region. The process has highlighted species that are not currently declared for which coordinated control is warranted. A major benefit of the SAWRMS has been to provide a basis for informed debate on weed policies and programs. It has enabled a greater understanding of the diversity of weed threats in a region and has fostered a culture shift towards prevention and early intervention. There is still

Figure 1. Logic of the CWR and FoC formulae.

Comparative Weed Risk \$ y^{-1}
=
Invasiveness hectares (y_{i+1})/hectares (y_i)
×
Impacts \$ hectare^{-1} y^{-1}
×
Potential Distribution hectares

Feasibility of Containment \$
=
Control Costs \$ hectare^{-1} y^{-1}
×
Current Distribution hectares
×
Persistence y

Table 2. FoC criteria and questions (Virtue 2008).

CONTROL COSTS
How detectable is the weed? (a) height at maturity (b) shoot growth present (c) distinguishing features (d) pre-reproductive height in relation to other vegetation
What is general accessibility of known infestations?
How expensive is control of the weed, using techniques which both maximize efficacy and minimize off-target damage? (a) chemicals, fuel and equipment operating costs (b) labour costs
What is the likely level of cooperation from landholders within the land use at risk?
CURRENT DISTRIBUTION
What percentage area of the land use is currently infested by the weed?
What is the pattern of the weed's distribution across the Management Area?
PERSISTENCE
How effective are targeted control treatments applied to infestations of the weed?
What is the minimum time period for reproduction of sexual or vegetative propagules?
What is the maximum longevity of sexual or vegetative propagules?
How likely are new propagules to continue to arrive at control sites, or start new infestations? (a) long-distance dispersal by natural means (b) grown

Figure 2. Weed management action matrix.

WEED RISK	FEASIBILITY OF CONTAINMENT					
	Negligible >113	Low >56	Medium >31	High >14	Very high <14	
Negligible <13	LIMITED ACTION	LIMITED ACTION	LIMITED ACTION	LIMITED ACTION	MONITOR	
Low <39	LIMITED ACTION	LIMITED ACTION	LIMITED ACTION	MONITOR	MONITOR	
Medium <101	MANAGE SITES	MANAGE SITES	MANAGE SITES	PROTECT SITES	CONTAIN SPREAD	ALERT
High <192	MANAGE WEED	MANAGE WEED	PROTECT SITES	CONTAIN SPREAD	DESTROY INFESTATIONS	ALERT
Very high >192	MANAGE WEED	PROTECT SITES	CONTAIN SPREAD	DESTROY INFESTATIONS	**ERADICATE**	ALERT

a hesitancy to cut back on coordinated control of more widespread species, but decision makers are now more aware that priority weeds need not be those that are most visible.

The SAWRMS has been used at various scales, from coastal management plans (Cordingly and Petherick 2005) to assessing the risks of new species for revegetation and farm forestry in SA (Virtue and Melland 2003), to informing state policies on declared plants. Beyond SA, the SAWRMS has been adapted for use in the Northern Territory and New South Wales. It has also been an effective training tool in post-border WRM workshops run by the Food and Agriculture Organization in Panama, India and Uruguay.

Issues and future development

The strength of the SAWRMS lies in its relative simplicity. A logical decision framework can be applied to any weed in any land use, presented in terms of a mathematical structure that is readily comprehended by regional weed managers. The SAWRMS also plays an educational role in natural resource management, providing a means to explain and justify weed priorities to people with limited weed knowledge. However, there is room for improvement in the SAWRMS to address various weaknesses.

The SAWRMS lacks consideration of relative values within and between land uses. The original intent was to avoid the contentious debate about economic versus environmental versus social values that would occur if a single prioritized list of weeds was to be generated for a region. Yet even this debate may be simplistic, with Wallace (2006) listing eight types of values for natural resource management. If a single measure of value was obtained for each land use in a region then this could be incorporated as a weighting for the potential distribution score (e.g. a range of 0–1 in 0.1 increments). Even better would be a GIS-based dataset to compare values between and within land uses, which would enable weighting of land use polygons in calculating potential distribution. A weed species' total risk across land uses could then be determined as the sum of its CWR scores in individual land uses (to be compared with a similar sum of FoC scores across land uses). At present the SAWRMS is criticized when weeds of significant impact, but restricted to uncommon habitats, get lower CWR scores due to low potential distribution scores. Where such habitats are perceived to be of higher value due to rarity or greater productivity then formal inclusion of value in the CWR formula would help address this criticism.

At present the SAWRMS runs counter to the precautionary principle in handling uncertainty, with 'don't know' scored to lower both a species' risk and feasibility of containment. This is to avoid the most unknown species ranking as the highest priorities. Rather, a species with many 'don't knows' should be a focus for greater research to then enable an informed WRM decision. Other prioritizing WRM systems include an uncertainty score (e.g. Robertson *et al.* 2003). A straightforward approach for the SAWRMS could be to allow a lower and upper bound in answering individual questions (P. Keese personal communication), such as selecting 'low' and 'high' options where there is considerable uncertainty. The end result would be weed species falling within bands of CWR and FoC scores, the range of which would be in proportion to the level of uncertainty for a species.

Related to uncertainty is the prospect for assessor bias. It is recommended that an expert panel approach be used, at least for an initial small group of species to establish a common expectation in how assessments will be done. It is vital to have consensus in defining the geographical and land use context in which species are assessed, including the typical weed management practices. An individual can conduct a large number of species assessments quicker than a group, but still needs to consult on the scoring outcomes. Literature often does not sufficiently cover information required for species assessments, and personal observations and opinions from a range of experts (both scientific and operational) become important in order to make timely comparisons between species. In this regard, local knowledge from within the region of interest is valuable, and also fosters ownership of the scoring outcomes. The MS-Excel version of the SAWRMS has limited capability for recording justifications for scoring species and a MS-Access database version in development offers better recording of assumptions, literature references and observations.

The mathematics of the SAWRMS, whilst based in logic (Figure 1), is unsophisticated. The trend in pest risk analysis is towards multi-criteria decision analysis (MCDA) and WRM systems are likely to evolve in this direction. However, the needs of end users need to be kept in mind. A key component of risk management is effective communication (AS/NZS 4360:2004) and a system that is readily understood by regional weed managers (who generally have limited mathematical modelling expertise) will garner trust and foster ongoing use.

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Appendix 1. Guiding principles for weed management actions in the SAWRMS matrix.

Alert Aims to prevent the species arriving and establishing in the management area. Species that are not known to be present in the management area and which represent a significant threat. Such species would score '0' in FoC due to their absence.

- Prevention of entry to management area.
- Ongoing surveillance for incursions of the species (e.g. nursery inspections).
- Training and awareness activities for the community to enable early detection.

Eradicate Aims to remove the weed species from the management area.

- Detailed surveillance and mapping to locate all infestations.
- Destruction of all infestations including seedbanks.
- Prevention of entry to management area and movement and sale within.
- Must not grow and all cultivated plants to be removed.
- Monitor progress towards eradication.

Destroy infestations Aims to significantly reduce the extent of the weed species in the management area.

- Detailed surveillance and mapping to locate all infestations.
- Destruction of all infestations, aiming for local eradication at feasible sites.
- Prevention of entry to management area and movement and sale within.
- Must not grow.
- Monitor progress towards reduction.

Contain spread Aims to prevent the ongoing spread of the weed species in the management area.

- Surveillance and mapping to locate all infested properties.
- Control of all infestations, aiming for a significant reduction in weed density.
- Prevention of entry to management area and movement and sale within.
- Must not allow to spread from cultivated plants (if grown).
- Monitor change in current distribution.

Protect sites Aims to prevent spread of the weed species to key sites/assets of high economic, environmental and/or social value. Weed species may be of limited current distribution but only threatens limited industries/habitats (lower weed risk). Or the weed may be more widespread but is yet to invade/impact upon many key industries/habitats (higher weed risk).

- Surveillance and mapping to locate all infested areas.
- Identification of key sites/assets in the management area.
- Control of infestations in close proximity to key sites/assets, aiming for a significant reduction in weed density.
- Limits on movement and sale of species within management area.
- Must not allow to spread from cultivated plants (if grown) in close proximity to key sites/assets.
- Monitor change in current distribution within and in close proximity to key sites/assets.

Manage weed Aims to reduce the overall economic, environmental and/or social impacts of the weed species through targeted management.

- Research and develop integrated weed management (IWM) packages for the species, including herbicides and biological control where feasible.
- Promote IWM packages to landholders.
- Monitor decrease in weed impacts with improved management.
- Identify key sites/assets in the management area and ensure adequate resourcing to manage the weed species.

Manage sites Aims to maintain the overall economic, environmental and/or social value of key sites/assets through improved general weed management.

- Promote general IWM principles to landholders, including the range of control techniques, maintaining competitive vegetation/crops/pastures, hygiene and property management plans.
- Identify key sites/assets in the management area and ensure adequate resourcing to manage these to maintain their values.
- Broaden focus beyond weeds to all threatening processes.

Monitor Aims to detect any significant changes in the species' weed risk.
Monitor the spread of the species and review any perceived changes in weediness.

Limited action The weed species would only be targeted for coordinated control in the management area if its local presence makes it likely to spread to land uses where it ranks as a higher priority.

- Undertake control measures if required for the benefit of other land uses at risk.
- Otherwise, limited advice to land managers if required.