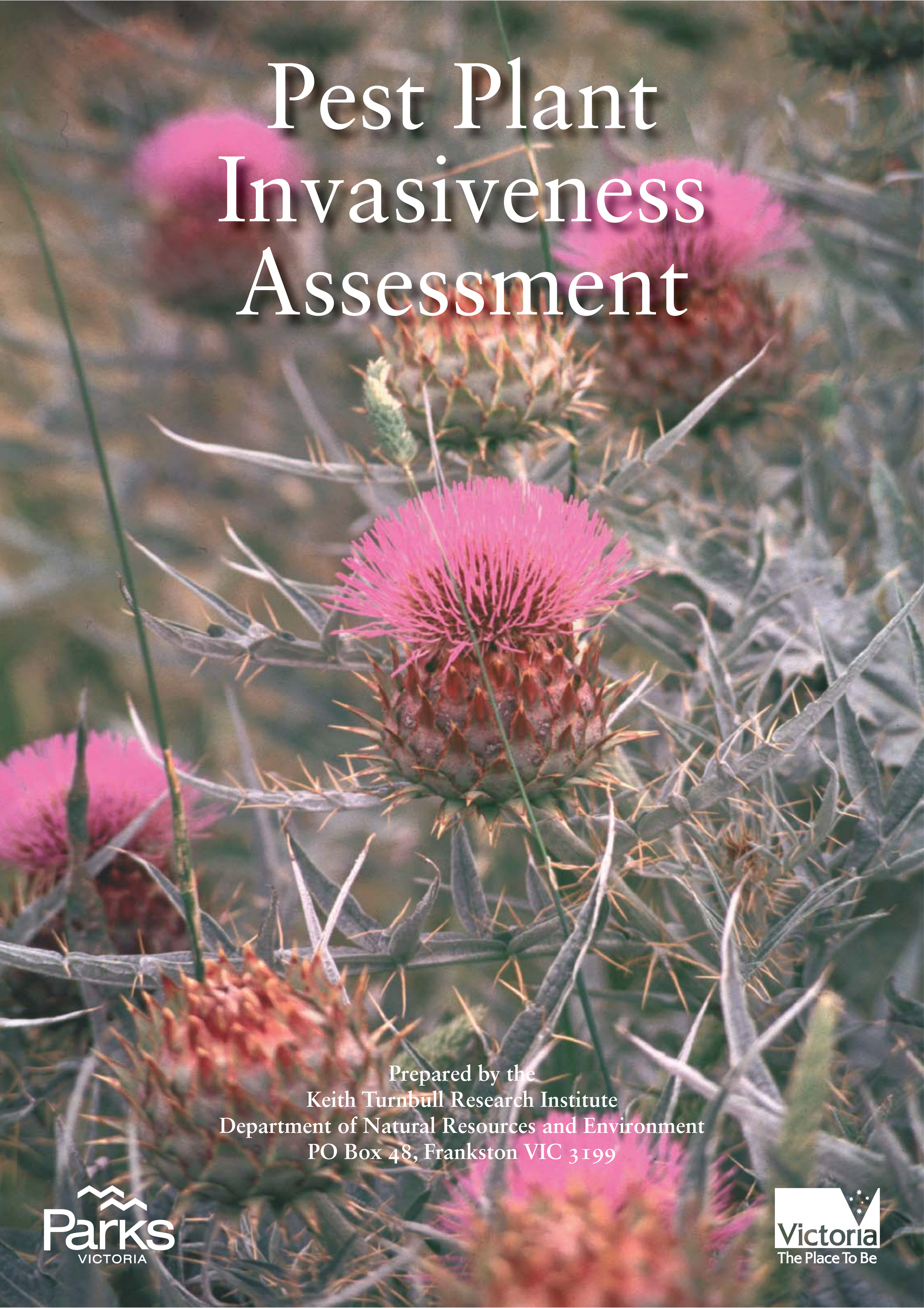
Pest Plant Invasiveness Assessment



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Parks Victoria

Victoria The Place To Be

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Acronyms

AHP	Analytical Hierarchal Process
ARI	Arthur Rylah Institute
BVTs	Broad Vegetation Types
CMA	Catchment Management Authority
EVCs	Ecological Vegetation Classes
FIS	Flora Information System (Viridans 1999)
GIS	Geographic Information System
KTRI	Keith Turnbull Research Institute
IPMS	Integrated Pest Management System (previously known as PMIS)
PMIS	Pest Management Information System
PV	Parks Victoria

1. Project Background

1.1 Weed Management Within Parks Victoria

Parks Victoria (PV) is responsible for the management of 16 percent of the State and has a critical role as the custodian of natural values and for the development of high quality and innovative environmental management in the State's parks and reserves. PV is required to conduct its management to achieve the objectives of a range of treaties, conventions, Acts, regulations and policies, including:

- ensuring that threats to all indigenous flora and fauna occurring in the parks and reserves system are managed, in accordance with the *Flora and Fauna Guarantee Act (1988)*; and
- the eradication or control of exotic flora and fauna in the parks and reserves is in line with the *National Parks Act (1975)* and the *Catchment and Land Protection Act (1994)*.

In 2000/2001, PV's Environmental Management Program included 402 pest plant management projects across the State accounting for 28 percent of PV's natural values management budget. To ensure PV directs its resources to weed species of highest risk potential to particular environmental values, an assessment of the invasive potential of pest plant species is required.

1.2 The Pest Plant Assessment System

In Victoria, there are over 1200 plant species reported in literature as weeds (Ross 2000). It has been estimated that only approximately ten percent of naturalised plant species become weeds of significant economic and ecological impact (Williamson and Fitter 1995). It is therefore unrealistic and unnecessary to expect that all weeds can and should be controlled.

To make informed decisions about the best way to control weeds on public land, it is necessary that the relative importance and potential impact of each weed be determined. It is essential that this is done prior to the allocation of priority works or funding. Decisions based on limited factual data and emotional reactions, will almost certainly result in unnecessary expenditure of resources and damage to the environment through inappropriate use of control measures.

The Pest Plant Assessment System, developed for Victoria by the KTRI, is a risk assessment process that allows for the prioritisation of weeds based on a combination of the following factors:

(1) Assessing the plant's invasiveness;

(2) Comparing the plant's present and potential distribution; and

(3) Determining the impacts of the plant on social, environmental and agricultural values.

1.3 Project Objectives

The objective of this project is to determine the invasive and current and potential distribution of 112 pest plant species using the method already established by KTRI (factors (1) and (2) above). The species were selected by PV on the basis of:

- risk rating for environmental weeds (Carr *et al* 1992);
- pest plant species new to a district, park or area of the park;
- number of hectares per pest plant species proposed to be controlled in 2001/02; and
- number of parks in which each pest plant species occurs.

The selected species are listed alphabetically, with some updates to the nomenclature used in the report, at the start of Appendix 3.

This report documents:

1. The method, results and discussion of the invasiveness score and current and potential distribution for the 112 environmental weeds selected by PV (Section 2);
2. Tabulated data for the 112 weed species including environmental risk rating (according to Carr *et al* 1992), national status, and invasiveness score (Appendix 2); and
3. Present and potential distribution maps for the 112 weeds (Appendix 3), which have also been provided in digital format.

The data compiled in this report on the invasive potential of pest plants will assist with the development of a pest plant risk assessment method. This method will be consistent with Victoria's Pest Plant Assessment System, incorporating additional measures of impact on environmental, social and economic values, and is being developed under a separate, but related project.

2. Method, Results and Discussion of the Pest Plant Invasiveness Assessment

2.1 Invasiveness Potential of Pest Plants

2.1.1 Introduction

Many researchers have focused on the relative invasiveness of species as an indicator of potential spread rate. Invasiveness can be defined as the ability to establish, reproduce, and disperse within an ecosystem. Plant propagules arrive at a new site with certain inherent characteristics that previously enabled their successful survival and continued reproduction throughout their evolutionary history. There is no single suite of characteristics which make a plant invasive, rather there are several predisposing factors that act either alone or together to increase the chance of a plant becoming invasive.

Many researchers have also agreed that the following biological attributes of a plant species are associated with invasiveness.

- *Ecological status; a generalist or specialist plant.*
  Most common and noxious weeds in southern Australia are generalist and opportunistic rather than requiring specific niches or special habitat requirements.
- *'Weedy' phenology and biology; such as competitive growth, seed dispersal mechanisms, seed dormancy and propagule production.*
  Major weeds can have attributes such as high seed production, rapid vegetative spread, long-lived seeds, staggered germination, competitive growth and long-distance seed dispersal. However, there is no defined group of ecological and biological attributes that can be used to identify all major weeds. Different attributes may be important for different plant families and different ecosystems.
- *Wide native range.*
  Within a genus the more important weeds may have a wider native range.
- *Taxonomic position; members of generally 'weedy' plant families.*
  Certain plant families such as Poaceae (grasses), Asteraceae (eg. daisies, thistles), Iridaceae (irises) and Brassicaceae (eg. mustards, turnips) are noted for having many 'weedy' species.
- *Effective modes of reproduction and genetic variation.*
  Plant species that vegetatively reproduce or self-pollinate have the potential to start new populations from a single, isolated plant. However, high levels of inbreeding in self-pollinators may limit their adaptability compared to cross-pollinators.

2.1.2 Invasiveness Criteria

Criteria for a generic model to assess the potential invasiveness of weeds were determined at workshops by national participants at the Arthur Rylah Institute (ARI), in June 1998 (Table 1). A working group at the Keith Turnbull Research Institute (KTRI) then used an expert system, relying on multi-criteria analysis/analytical hierarchical process (AHP) (Saaty 1995), to develop a decision tree that allows for groups and criteria to be weighted according to importance (Table 1). Basically, the AHP is a method of breaking down a complex unstructured situation into its component parts; arranging these parts into a hierarchical order; and assigning numerical values to subjective judgements to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation. AHP also facilitates effective decisions on complex issues by simplifying and expending the intuitive decision making process.

Table 1: Group and criteria weightings for determining invasive potential.

GROUP	CRITERIA	GROUP & CRITERIA WEIGHTINGS
Establishment		**0.5**
	Germination requirements?	0.085
	Establishment requirements?	0.671
	Disturbance requirements?	0.244
Growth/competitive ability		**0.096**
	Life form?	0.06
	Allelopathic properties?	0.09
	Tolerates herbivory pressure?	0.472
	Normal growth rate?	0.192
	Stress tolerances?	0.185
Reproduction		**0.119**
	Reproductive system?	0.047
	Propagule production?	0.46
	Seed longevity?	0.256
	Reproductive period?	0.101
	Time to reproductive maturity?	0.136
Dispersal		**0.284**
	Number of mechanisms?	0.333
	How far do propagules disperse?	0.667

Comparing the major groups (*i.e.* establishment, growth/competitive ability, reproduction and dispersal), the working group indicated that the ability of a plant to establish in an ecosystem was by far the most important indicator of its invasiveness, followed by the plant's ability to disperse, then its reproduction strategy, and finally its growth/competitive ability. Some of the reasons (and comments made during the weighting process) for this ranking are mentioned below:

- "It doesn't matter how many seeds/propagules the plant produces, if they can not establish themselves they are not going to be invasive."
- "The ability to disperse great distances, no matter how they reproduce, gives the plant a better chance of finding a suitable location for it to establish."
- "The more locations it establishes in, (*i.e.* multi loci), the quicker the plant will invade an area."

These group weightings can be expressed graphically as shown below in Figure 1.

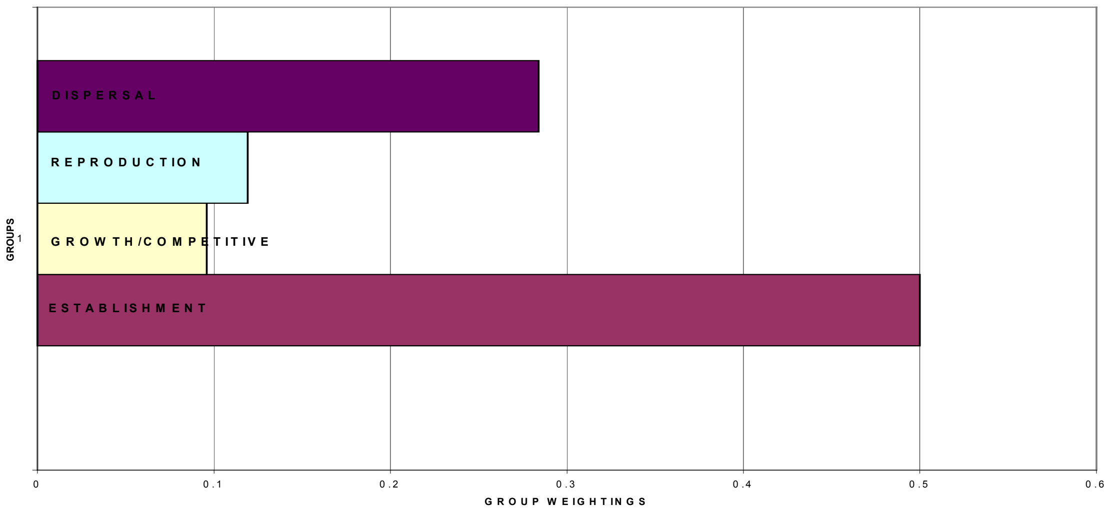

Figure 1: Group weightings of invasiveness.

Within each group, the individual criterion (Appendix 1) were compared and weighted against each other. For instance, within the dispersal group, the working group decided that the distance propagules disperse was twice as important as the mechanisms for dispersal. The results of the intra-group criteria weightings are illustrated in Figure 2.

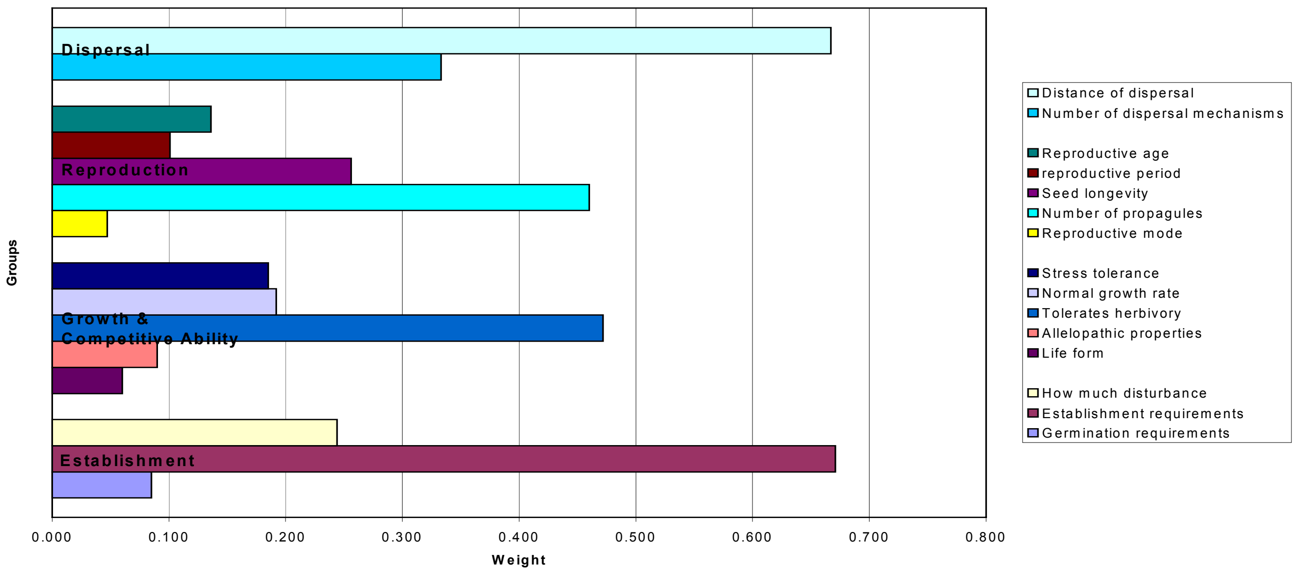

Figure 2: Criterion weightings of invasiveness.

Within the invasiveness hierarchy, the weightings of individual criterion are multiplied by the groups weight (eg. distance of dispersal x dispersal $\Rightarrow$ 0.667 x 0.284 = 0.189). The total weightings for individual criterion are illustrated in Figure 3.

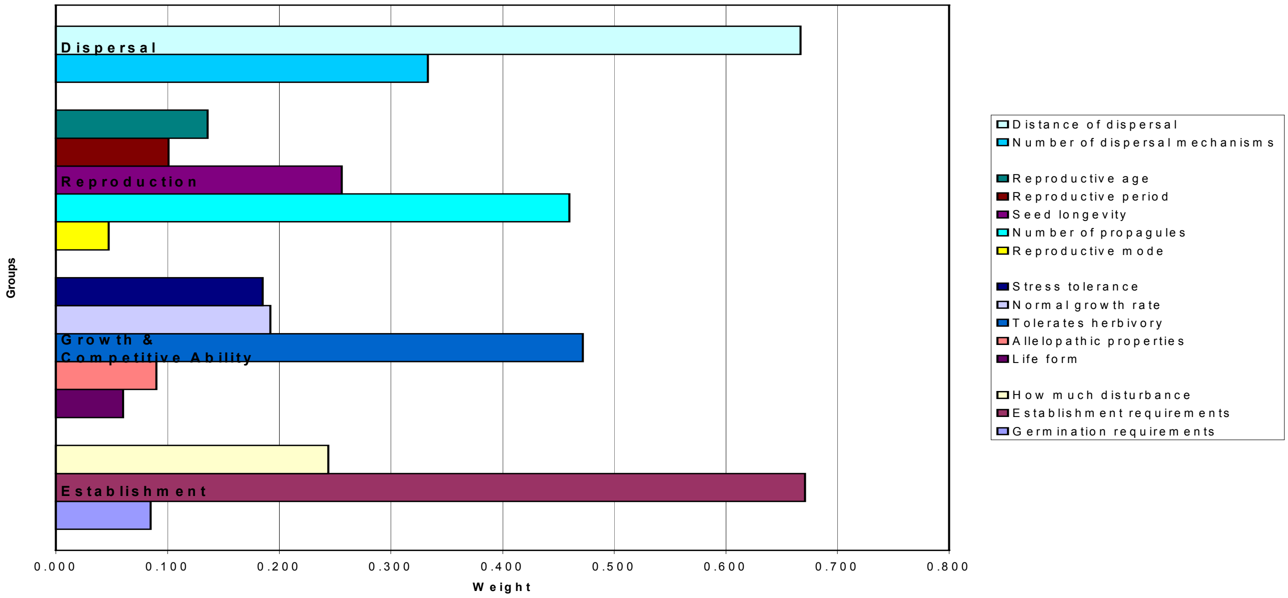

Figure 3: Individual criterion total weightings expressed in groups.

The invasive hierarchy and weightings indicate that the most important invasive biological features of a plant is its' ability to establish and disperse widely. The plant's ability to withstand herbivore pressure, number of propagules produced and seed longevity are of lesser importance. Other biological features such as its life form and reproductive strategies are of much less importance. This was acknowledged during the workshops at ARI, where serious weeds from a wide range of life forms (grasses, shrubs, trees, climbers etc) and reproductive systems (vegetative, asexual, self pollinating, cross pollinating etc) were identified.

The criteria are assigned intensity ratings or definitions of 'high', 'medium-high', 'medium', 'medium-low' and 'low' (Appendix 1), which are used to score each species. The scores for each criterion and weightings are then tallied and calculated to produce a final 'invasiveness index' for each species. An example of this process is shown below; a summary of biological data was collated to determine the 'invasiveness index' of *Spartina anglica* and *S. x townsendii* (Table 2). The overall score is only relative to scores of other plants run through the same process, but can be used to rank species as to their potential invasiveness or rate of spread.

The information to rate each criterion is sourced from databases, journal articles, flora's of the world (books or articles describing the species of a particular country or region), online information, and any other sources. There is much available information on some species (eg. declared noxious species), and very scant information for others (eg. grasses and new and emerging weed species). Where there is an information 'gap' for a particular criterion, a 'medium' (M) ranking is given to indicate 'unknown'. Although the invasiveness assessments are undertaken using the best available information, they are only as accurate as the information that is used. Therefore, as we become more informed about a species, reassessment may be necessary.

Table 2: Summary of the biological data used to determine the intensity rankings for each criterion and the overall invasiveness index of *Spartina anglica* and *S. x townsendii*. Comments relate to intensity rakings shown in Appendix 1 and apply to both species unless otherwise stated.

QUESTION	COMMENTS	INTENSITY RANKING	
Establishment		***S. anglica***	***S. x townsendii***
Germination requirements?	Only requires water (an aquatic environment) for vegetative propagules to germinate.	H	H
Establishment requirements?	Occurs in 'open' areas where light and space are not limiting (eg. saltmarsh and mangrove communities).	ML	ML
Disturbance requirements?	Able to invade existing saltmarsh and mangrove communities to form extensive meadows.	H	H
Growth/competitive ability			
Life form?	Aquatic grass.	H	H
Allelopathic properties?	None described or known.	L	L
Tolerates herbivory pressure?	Palatable to stock. Could produce vegetative propagules under moderate herbivory.	MH	MH
Normal growth rate?	Forms extensive colonies in a relatively short period of time that excludes other plants.	H	H
Stress tolerances?	Tolerant of salinity, waterlogging and fire.	MH	MH
Reproduction			
Reproductive system?	Both species are capable of vegetative reproduction, however only *S. anglica* is able to produce viable seeds.	H	MH
Propagule production?	*S.* x *townsendii* does not produce seeds. *S. anglica* is a prolific seeder with inflorescences exceeding 90 per square metre in mature and transitional zones.	M	L
Seed longevity?	*S. anglica* seeds germinate within the year and no seed bank exists. *S.* x *townsendii* does not produce seeds.	M	M
Reproductive period?	Forms self -sustaining extensive meadows (*i.e.* dense monocultures that can be tens or hundreds of hectares in area).	H	H
Time to reproductive maturity?	Forms extensive meadows over a relatively short period, Fast growing grass species. Rhizomes send up new shoots that quickly grow into a large clump (assumed to be 1-2 years).	H	H
Dispersal			
Number of mechanisms?	Distributed widely by water-borne dispersal, seeds also carried by wind. Fragments of the rhizome may break loose and drift in currents.	MH	MH
How far do they disperse?	Sea currents likely to disperse some propagules >1 kilometre however in estuaries most likely to be dispersed between 200-1000 metres.	MH	MH
	INVASIVENESS INDEX (Maximum=1, Minimum=0)	**0.61**	**0.58**

2.1.3 Results and Discussion of the Invasiveness Index

The invasiveness scores, as well as risk rating according to Carr *et al* (1992) and national status, for all 112 species are given in Appendix 2. The closer the invasiveness index to the maximum score of one, the more invasive a species is. To give the score some perspective, a comparison can be made with the 'non-weedy' plant Red or Chinese Hibiscus (*Hibiscus rosa-sinensis*). A common plant grown throughout southern Australia, it scored 0.43 but only because it has such a high chance of dispersal by deliberate transport of cuttings/seeds greater than one kilometre. When humans were excluded from dispersal, the invasiveness score dropped to 0.31.

Spartina anglica scored 0.61 and *S. x townsendii* 0.58. In relation to the other assessed weeds, both Spartina species scored less than the mean invasive index of the 112 species assessed, which was 0.69. *S. anglica* scored an equivalent rank to plants such as Angled onion (*Allium triquetrum*), Slender thistle (*Carduus tenuiflorus*), and Stinkwort (*Dittrichia graveolens*), while *S.* x *townsendii* scored equivalent to Arrowhead (*Sagittaria graminea*). Many species are considerably more invasive than *Spartina*, such as Pampas grass (*Cortaderia selloana*) with a score of 0.95, White willow (*Salix alba*) with a score of 0.93, and Grey sallow and Crack willow (*Salix babylonica* and *S. cinerea* respectively) which both scored 0.92 (Appendix 2).

As demonstrated above, an expert system, such as the Pest Plant Assessment System, provides a ranking of plants from most invasive to least. The invasiveness indices are not meant to be an absolute number relating to distance, but to give a relative indication of rate of spread of a plant in its preferred habitat. To make the invasiveness scores more useful, one can group the resulting indices of the 112 assessed species into categories (eg. 'very high', 'high', 'medium' invasiveness, etc). Such a process can assist land managers to determine which species, or groups of species, to target management efforts and resources at for maximum gain. There are several methods of breaking the score range of zero to one to form 'invasiveness categories', with some more relevant than others.

One method is to group the species, ordered from lowest to highest invasiveness index, according to percentile rankings. For instance, using 25 percentiles to break the species into four groups (*i.e.* indices between the 0-25, 25-50, 50-75 and 75-100 percentiles respectively). Such an approach results in an even number of species in each category, however did not well reflect the range or 'natural groupings' of indices when applied to the 112 assessed species. As the majority of assessed species have indices in the mid range (*i.e.* between the 25-75 percentiles), species at the lower and higher ends of this mid range were dispersed into the lower and high groups (*ie.* 0-25 and 75-100 percentiles respectively) to allow for an even distribution of the scores. This elevated the cut-off score for the lowest group and reduced the cut-off score for the highest group to accommodate the extra species falling either side of this mid group. Furthermore, if subsequent species are assessed and grouped with the 112 species, the 25 percentiles are likely to change. Therefore, a method which arbitrarily fixed the 'cut off' points is required.

A frequency distribution graph of the scores of all 200 species that have been assessed to date by KTRI was produced (Figure 4). Evaluation of the figure shows indications of some natural breaks in the data. These 'natural groupings' produced the five groups used to categorise the 112 species considered in this report (Table 3): ***moderately invasive*** (species with scores <0.5), ***moderately-highly invasive*** (species with scores between 0.5-0.59), ***highly invasive*** (species with scores between 0.6-0.79), ***very highly invasive*** (species with scores between 0.8-0.89), and ***extremely invasive*** (species with scores >0.9). As expected, few species occur in the ***moderately*** and ***extremely invasive*** categories, while the vast majority (73 of the 112 assessed species) occur in the middle ***highly invasive category*** (Table 3).

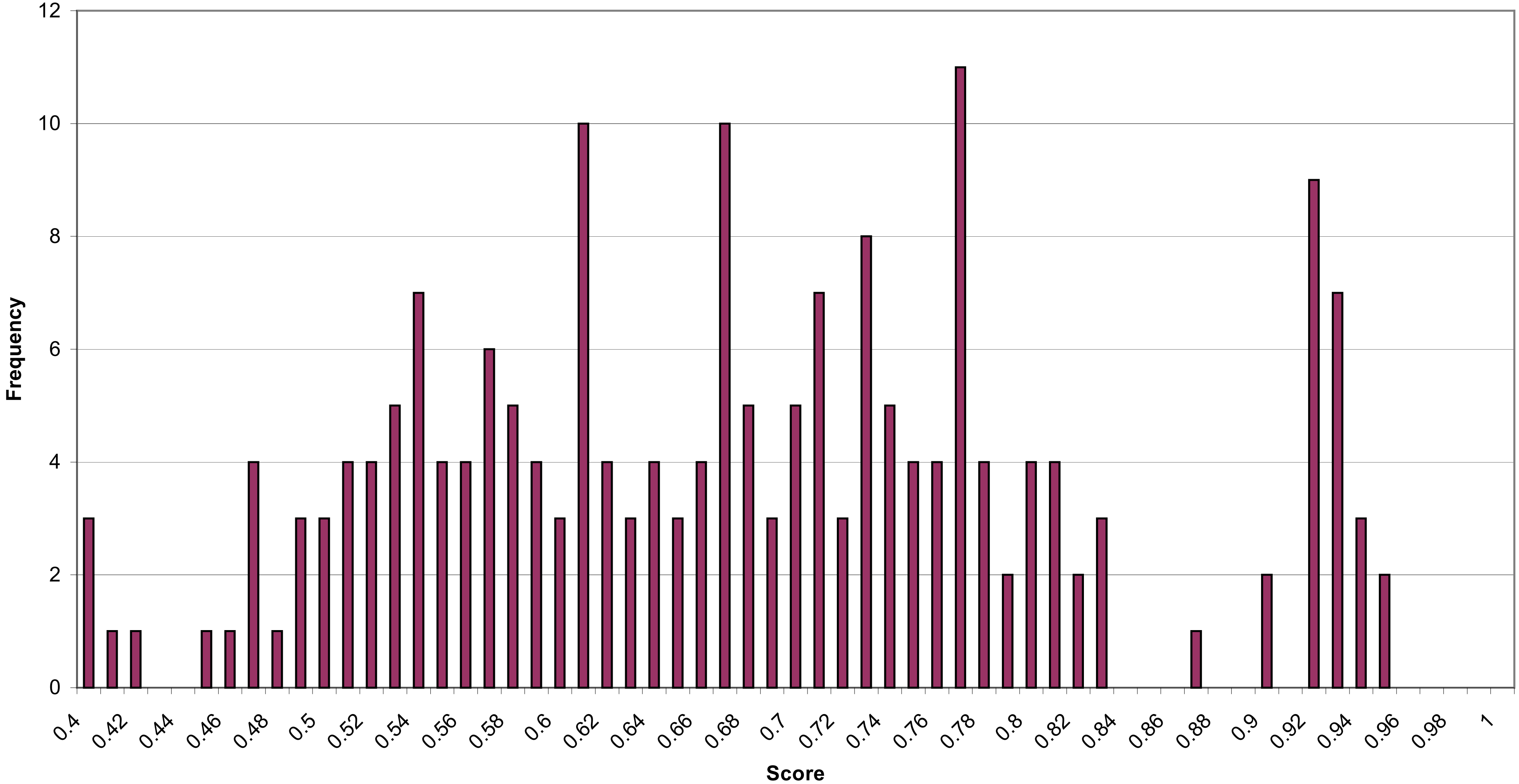

Figure 4: Frequency graph of invasiveness indices.

Table 3: Assessed species, grouped according to their invasiveness indices.

Moderately Invasive Score (<0.5)	**Moderately/Highly Invasive Score (0.5-0.59)**	**Highly Invasive Score (0.6-0.79)**	**Highly Invasive Score (0.6-0.79)**	**Very Highly Invasive Score (0.8-0.89)**	**Extremely Invasive Score (>0.9)**
Centaurea calcitrapa	*Asphodelus fistulosus*	*Acacia baileyana*	*Ligustrum vulgare*	*Ailanthus altissima*	*Cortaderia selloana*
Melianthus comosus	*Carthamus lanatus*	*Acer pseudoplatanus*	*Lycium ferocissimum*	*Chrysanthemoides monilifera*	*Salix alba*
Nassella hyalina	*Cirsium acarna*	*Agrostis capillaris*	*Marrubium vulgare*	*Cotoneaster glaucophyllus*	*Salix cinerea*
Scolymus hispanicus	*Dipsacus fullonum*	*Allium triquestrum*	*Myriophyllum aquaticum*	*Coprosma repens*	*Salix babylonica*
Solanum linnaeanum	*Diplotaxis tenuifolia*	*Aloe saponaria*	*Mysiphyllum asparagoides*	*Dipogon lignosus*	*Salix x rubens*
Verbascum thapsus	*Emex australis*	*Alternanthera philoxeroides*	*Nassella neesiana*	*Hypericum androsaemum*	
Watsonia meriana	*Foeniculum vulgare*	*Anthoxanthum odoratum*	*Nassella trichotoma*	*Leycesteria formosa*	
	Hypericum tetrapterum	*Briza maxima*	*Opuntia ficus-indica*	*Lonicera japonica*	
	Juncus acutus	*Carduus pycnocephalus*	*Opuntia robusta*	*Rhamnus alaternus*	
	Onopordum acanthium	*Carduus tenuiflorus*	*Opuntia stricta*	*Sollya heterophylla*	
	Onopordum acaulon	*Cestrum parqui*	*Oxalis pes-caprae*	*Ulex europaeus*	
	Reseda luteola	*Cirsium arvense*	*Oxylobium lanceolatum*		
	Sagittaria graminea	*Cirsium vulgare*	*Paspalum dilatatum*		
	Spartina x townsendii	*Convolvulus arvensis*	*Pennisetum clandestinum*		
	Tradescantia albiflora	*Crataegus monogyna*	*Phalaris aquatica*		
	Xanthium spinosum	*Cuscuta campestris*	*Physalis viscosa*		
		Cynara cardunculus	*Pinus pinaster*		
		Cytisus scoparius	*Pinus radiata*		
		Datura stramonium	*Pittosporum undulatum*		
		Delairea odorata	*Polygala myrtifolia*		
		Dittrichia graveolens	*Populus alba*		
		Echium plantagineum	*Prunus lusitanica*		
		Echium vulgare	*Rosa rubiginosa*		
		Ehrharta erecta	*Rubus fruticosus agg.*		
		Eragrostis curvula	*Salpichroa origanifolia*		
		Erica lusitanica	*Senecio jacobaea*		
		Galenia pubescens	*Senecio pterophorus*		
		Genista linifolia	*Silybum marianum*		
		Genista monspessulana	*Solanum elaegnifolium*		
		Hedera helix	*Spartina anglica*		
		Hieracium aurantiacum	*Sporobolus indicus*		
		Homeria flaccida	*Tribulus terrestris*		
		Hypericum perforatum	*Verbascum virgatum*		
		Ilex aquifolium	*Vinca major*		
		Juncus effusus	*Vulpia bromoides*		
		Lavandula stoechas	*Xanthium strumarium*		
		Leucanthemum vulgare			

2.2 Present and Potential Distribution of Pest Plants

2.2.1 Introduction

Current and potential distributions are another major component required in the decision support system and AHP, to predict the status of a weed. The greater the potential distribution of a weed, the greater the potential impact and management costs. To ensure the most cost-effective use of resources, invasive species that have the greatest potential range should be targeted. Prioritisation is also important, as it is unrealistic to expect that all weeds can be controlled with limited available resources. Knowledge of potential distribution is furthermore important for devising management programs. Land managers can be alerted to the risk of weed invasion and measures can be enforced to prevent the introduction of weed propagules into new areas. Low priority can be given to areas where the weed might fail to persist, or be of little economic, environmental or social importance.

Two of the major factors influencing weed distribution are climate and land use. Weed species are typically more invasive in regions that are climatically similar to their native environment. Climate limits distribution according to how temperature and moisture stresses affect the weed's life cycle. Different land uses (eg. cropping, perennial pasture and forestry) have different disturbance regimes that favour different groups of weeds. Having determined the climatic preferences of a weed it is necessary to overlay these on a map of the weed’s associated land use in Victoria. The areas of the state that are potentially at risk from this weed can then be identified.

2.2.2 Present Distribution

Information on the weed's present distribution, both overseas and in Australia, is collected from databases, journal articles, flora's of the world (books or articles describing the species of a particular country or region), online information, and any other sources. Spartina is used herein as an example to highlight the variety of sources and process used to determine a weed's present. The information was sourced from books, conference proceedings, online databases, and a CD database.

Spartina anglica and *S.* x *townsendii* were first collected at Lymington Hampshire, United Kingdom in 1892, and then in the Isle of Wight in 1893 (Hubbard 1974). By 1900 it occurred in scattered patches from Chichester Harbour to Poole Harbour (Hubbard 1974). By 1907 many thousands of tidal mud-flats from Sussex to East Dorset were infested (Hubbard 1974). It also appeared on the north coast of France (Hubbard 1974), and has spread through marshes in Germany, Denmark, the Netherlands, New Zealand, China, and the west coast states of the United States of America (Figure 4) (Wu *et al* 1999).

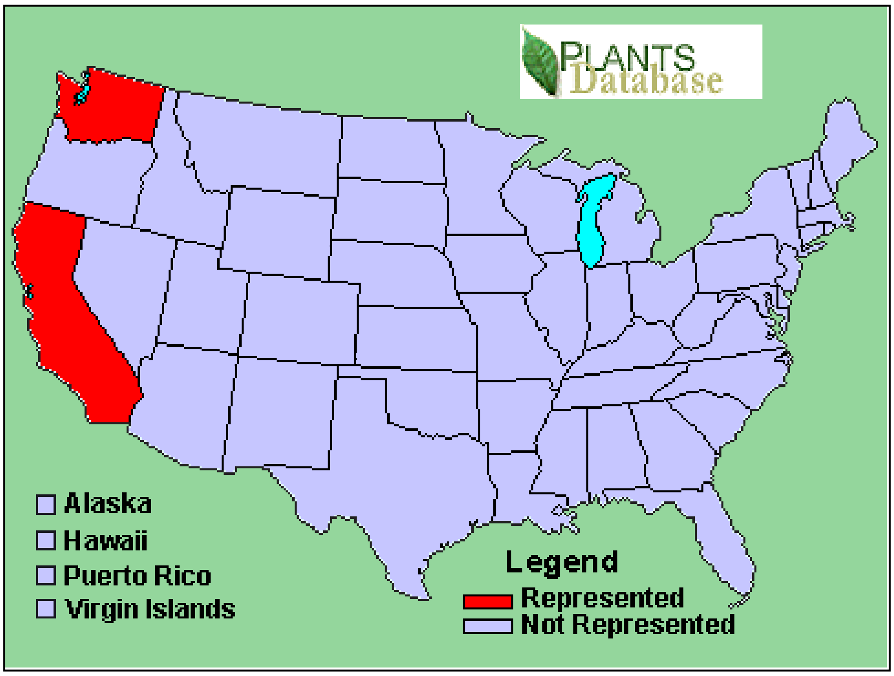

Figure 5: Distribution of *Spartina anglica* in the United States of America.
(From USDA Plant Database http://plants.usda.gov/plantproj/plants/index.html).

Spartina is widely distributed in New Zealand, with *S. anglica* occurring from latitudes $35^0$25'S to near 47^0S (Shaw and Gosling 1996).

In Australia, Spartina appears to be restricted to Tasmania, Victoria and South Australia (Bridgewater 1996). In Tasmania it is widespread in estuaries, river mouths and especially along the north coast (Wells 1996). The worst affected areas of Tasmania are Port Sorell and the Tamar River (Wells 1996). In Victoria, Spartina is found along the Gippsland coast in Corner Inlet, Waratah Bay and Andersons Inlet, on the eastern side of Westernport Bay and near the heads of Port Phillip Bay (Williamson 1996) (Figure 5).

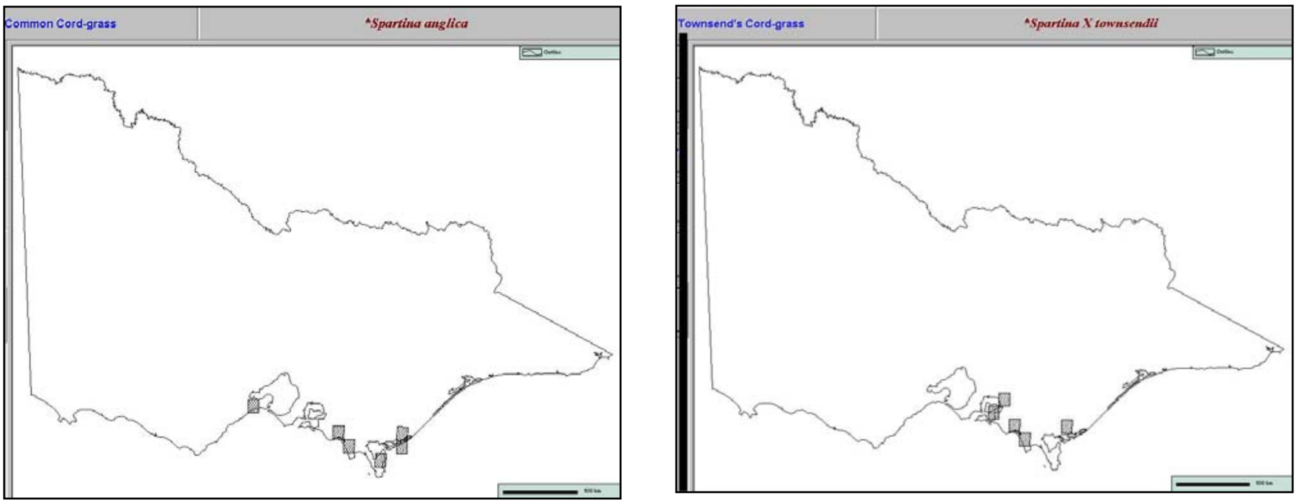

Figure 6: Distribution of *Spartina anglica* (left) and *S. x townsendii* (right) in Victoria. (Shaded squares indicate quadrats in which one or more plants of a particular species have been recorded. The species does not necessarily occupy the entire shaded area). *(From Wild Plants of Victoria, Viridans).*

2.2.3 Potential Distribution

Information on Australian and overseas distributions were imported into a climate matching program, CLIMATE®, to predict potential distribution in Australia. Using the localities where a species occurs overseas and within Australia, the potential climatic range of any species can be overlaid upon Australia's climatic regions. The maps below illustrate the climatic regions most suitable for Spartina in Australia and Victoria (Figures 6 and 7).

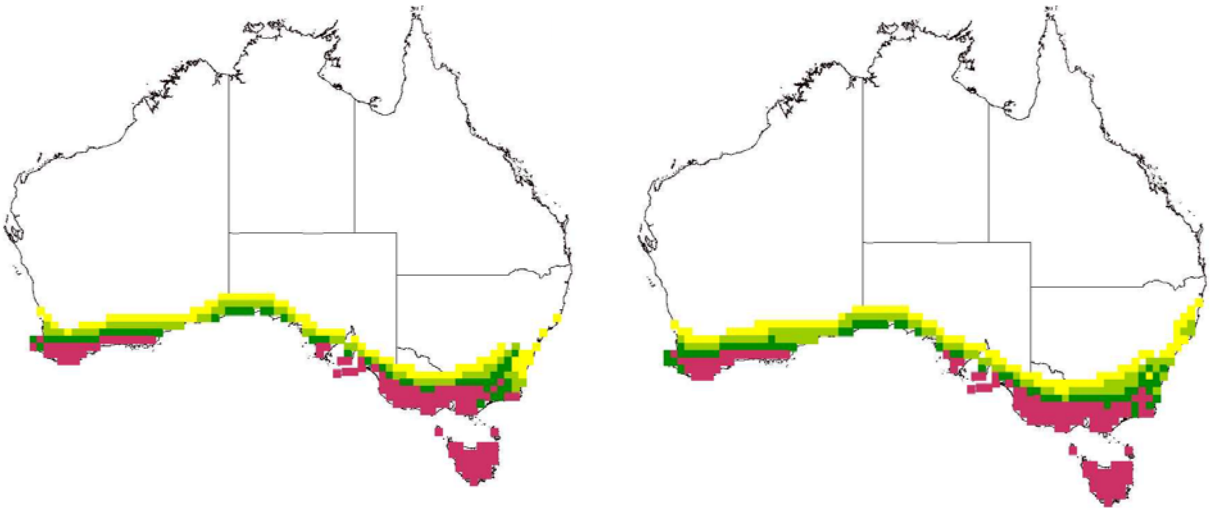

Figure 7: Potential distribution of *Spartina anglica* (left) and *S.* x *townsendii* (right) and in Australia, according to climatic parameters. (Areas in red indicate a 80%+ match with the preferred climate of the plant species, dark green 70%, light green 60% and yellow 50%).

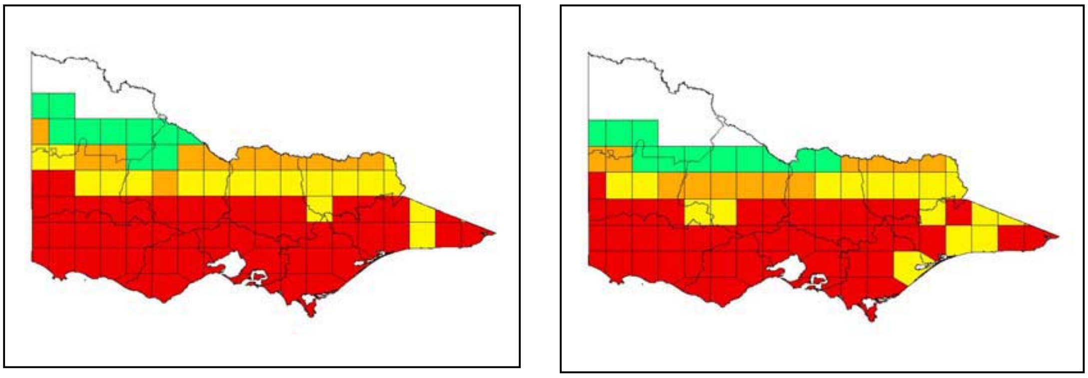

Figure 8: Potential distribution of *Spartina anglica* (left) and *S.* x *townsendii* (right) in Victoria, according to climatic parameters. (Areas in red indicate a 80%+ match with the preferred climate of the plant species, yellow 70%, orange 60% and green 50%).

The 16 climatic parameters that are used to determine potential distribution can be grouped into temperature or rainfall parameters (Figure 8).

Aquatic weeds are modeled for potential climatic range slightly differently than terrestrial species. Rainfall is obviously not a major criterion for determining the potential range of aquatic species, especially submergents, although it may play a key role in triggering certain biological properties (eg. freshwater flood events appear to stimulate flowering in Spartina) (Strong pers. comm.). Thus rainfall parameters are excluded when predicting the climatic range. Water temperature is generally more moderate and has fewer fluctuations than air temperature and provides a more accurate prediction for modeling aquatic species. However, the required data is usually unknown. Therefore, modeling the climatic range of aquatic species has included eight air temperature parameters that provide at least some indication of potential range. The process is, consequently, more uncertain and likely to overestimate the species' actual potential range.

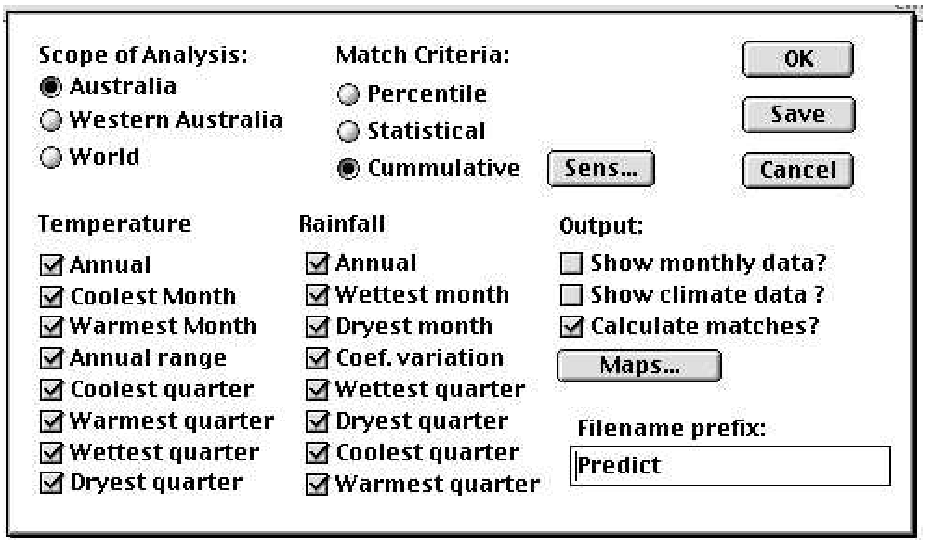

Figure 9: Dialogue box from CLIMATE® showing the climatic parameters used in terrestrial weed modeling. The eight rainfall parameters are not included when modeling the potential climatic range of aquatic weeds.

The climatic overlays are then used to determine the potential range of the plant species by linking or intersecting them with susceptible land uses and broad vegetation types (BVTs) or wetlands using the ArcView Geographic Information System (GIS) program. This refines the potential distribution maps produced using the climate matching program, as plants are limited by other factors, such as disturbance regimes associated with land uses. The resulting maps (Figures 9 and 10) illustrate the potential range of Spartina in Victoria.

Figure 10: Potential distribution of *Spartina anglica* (left) *and S.* x *townsendii* (right) in Victoria, according to climatic parameters, susceptible land uses and BVTs.

Areas in red indicate a very high probability that Spartina could establish in watercourses and wetlands within this region, yellow a high, and orange a medium probability of establishment.

Figure 11: Potential distribution of *Spartina anglica* and *S.* x *townsendii* in Eastern Victoria, according to climatic parameters, susceptible land uses and BVTs.

The potential distribution maps are estimates and are only as reliable as the data they are based on. As more records are collected on where the plants occur, the predictions will become more accurate. It is expected, consequently, that there are potential distribution maps that do not yet fully represent existing or potential distribution. Also, for some species there may be insufficient data to undertake potential distribution mapping. For instance, only a small number of current distribution records were found for *Salix* x *rubens*; too few to produce a meaningful potential distribution map. For these species, a provisional coarse climate map is produced but the next stage of matching onto susceptible land types is not completed.

2.2.4 Results and Discussion of the Present and Potential Distribution Maps

Present and potential distribution maps for each of the 112 species assessed are given in Appendix 3. These have also been provided to PV in digital format. As 74 of the species had already been assessed by KTRI, these maps include Catchment Management Authority (CMA) boundaries. The 38 species assessed as part of this project have been mapped using PV district boundaries.

The present distribution of weeds is generally underrepresented in the databases used (*i.e.* herbarium records, *Wild Plants of Victoria* (Viridans 1999), and to a lesser extent IPMS/PMIS), with the exception of priority weeds such as Serrated tussock (*Nassella trichotoma*). Conversely, the modeled potential distribution of weeds is likely to be overestimated. This occurs as the broad scale (*i.e.* 1:250,000) of the statewide databases used, merges minor differences into the larger BVTs or land uses for each grid. Microhabitats within a vegetation or land use type maybe unsuitable for the particular weed species, and microhabitats outside the identified susceptible land use or vegetation type may be suitable but not recognised (eg. roadsides, small riparian or vegetation corridors). More detailed map layers, such as the soon to be introduced Ecological Vegetation Classes (EVCs), will produce better quality predictions.

The many weeds recorded as occurring along roadsides presents another major limitation when predicting potential distribution. Victoria has over 170,000 kilometres of roads, however to include all these roads within the image would not be suitable, as it would be too cluttered and meaningless. Thus, some potential distribution images may not include the occurrence of weeds within a region, if they only occur along roadsides. For example, Horehound (*Marrubium vulgare*) can occur along roadsides within cropping regions, but is unable to withstand cultivation. Similarly, some riparian weeds may occur along small rivers, streams and water channels, but are not included in the riparian or riverine vegetation classes of the BVT GIS layer, as they are too small or scattered to be detected, and so don't appear on the predicted potential distribution maps.

The above limitations highlight the need for suitable actions to be undertaken. Where information on a weeds present distribution is known but not recorded, records need to be updated to ensure management and monitoring are effectively undertaken. An accurate comparison of a weeds present distribution with its potential distribution allows managers to make decisions on the course of actions to take. The ratio of present and potential distribution provides an indication as to what stage the weed is at. Another way of expressing this is the relative position of the species on its invasion graph (Figure 11).

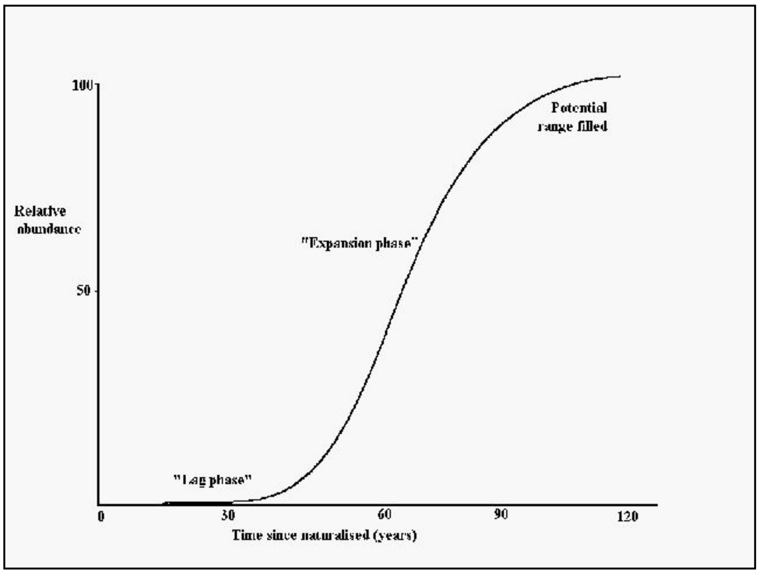

Figure 12: Invasion graph indicating stages of expansion of a new species into a habitat. *(Adapted from Groves (1992) and Hobbs (1991)).*

Weeds that have reached or nearly reached the full limits of their distribution, are not a major concern in terms of potential spread and impacts. Whereas, weeds currently occupying a small area of their potential range, or in the 'lag or sleeper' phase, should become a management priority. Indeed, a powerful weapon against weed invasions arising from existing infestations is early intervention (Figure 12). Early intervention not only achieves better in government/land manager investment, but also reduces costs of control and impact on the triple bottom line (social, environmental and agricultural values).

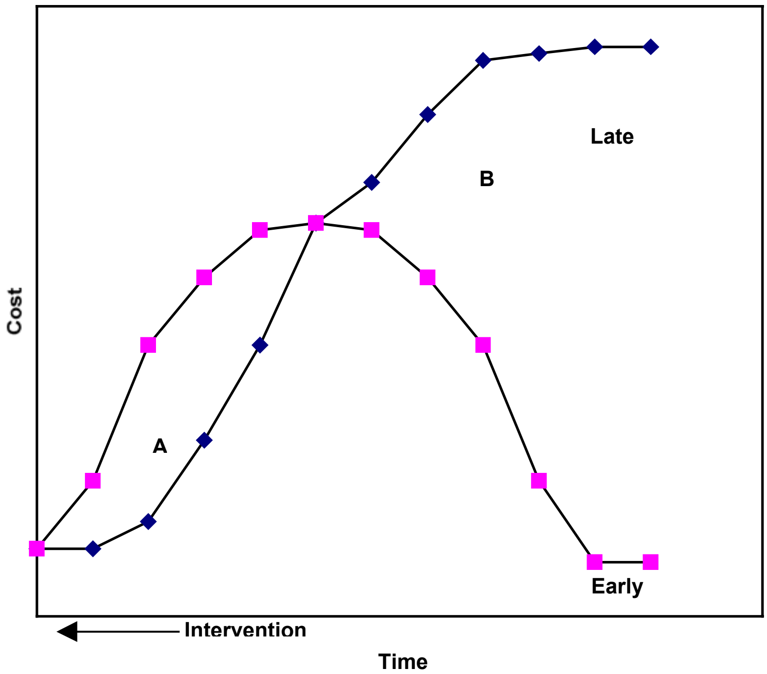

Figure 13: Total cost of plant invasions. Costs of early expenditure (Area A) and the resulting benefit (Area B) *(Adapted from Hobbs and Humphries (1995)).*

Two parts of the Pest Plant Invasiveness Assessment process have been finalised, the invasiveness assessments and the current and potential distributions within Victoria. The results of this project will provide a valuable tool for determining the risks that pest plants pose to environmental values and for prioritising weed management activities within PV.

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Appendix 1:

Invasive Potential Criteria and Intensity Ratings

Criteria	Rank	Intensity Rating	Weight
Establishment			
Germination /propagule requirements?	H	Opportunistic germinator, can germinate or strike/ set root at any time whenever water is available.	1.00
	MH	Requires natural seasonal disturbances such as seasonal rainfall, spring/summer temperatures for germination.	0.67
	M	Unknown.	0.50
	ML	Requires unseasonal or uncommon natural events for germination (eg. flooding, fire).	0.33
	L	Requires specific environmental factors that are not part of an annual cycle to germinate (eg. specific temperatures, floods, fire OR human caused disturbance such as ploughing).	0
Seedling/ propagule establishment requirements (*i.e.* light, water, nutrients)?	H	Can establish without additional factors.	1.00
	MH	Can establish under moderate canopy/litter cover	0.67
	M	Unknown.	0.50
	ML	Requires more specific requirements to establish (eg. open space or bare ground with access to light and direct rainfall).	0.33
	L	Requires additional and very specific factors such as nutrients and water that are deliberately added or highly eutrophic conditions.	0
How much disturbance is required for seedling establishment to occur?	H	Establishes in healthy and undisturbed natural ecosystems (eg. mallee, alpine, heathlands).	1.00
	MH	Establishes in relatively intact or only minor disturbed natural ecosystems (eg. wetlands, riparian, riverine, grasslands, open woodlands); in vigorously growing crops OR in well established pastures.	0.67
	M	Unknown.	0.50
	ML	Establishes in highly disturbed natural ecosystems (eg. roadsides, wildlife corridors, or areas which have a greater impact by humans such as tourist areas or campsites) OR in overgrazed pastures/poorly growing or patchy crops.	0.33
	L	Major disturbance required with little OR no competition from other plant species.	0
Growth/ Competitive Ability			
Life form?	H	Aquatic (submerged, emergent, floating) and semi aquatic.	1.00
	MH	Grass, leguminous plant.	0.67
	M	Unknown.	0.50
	ML	Geophyte, climber or creeper.	0.33
	L	Other.	0

Criteria	Rank	Intensity Rating	Weight
Allelopathic properties?	H	Major allelopathic properties inhibiting all other plants.	1.00
	MH	Allelopathic properties seriously affecting some plants.	0.67
	M	Unknown.	0.50
	ML	Minor properties.	0.33
	L	None.	0
Ability to tolerate herbivory pressure and produce propagules?	H	Favoured by heavy grazing pressure as **not eaten** by animals/insects and not under a biocontrol program in Australia/New Zealand.	1.00
	MH	Consumed but non-preferred or consumed but recovers quickly; capable of flowering /seed production under moderate herbivory pressure (where moderate = normal; not overstocking or heavy grazing).	0.67
	M	Unknown.	0.50
	ML	Consumed and recovers slowly. Reproduction strongly inhibited by herbivory but still capable of vegetative propagule production (by rhizomes or tubers); weed may still persist.	0.33
	L	Preferred food of herbivores. Eliminated by moderate herbivory or reproduction entirely prevented.	0
Normal growth rate?	H	Rapid growth rate that will exceed most other species of the same life form.	1.00
	MH	Moderately rapid growth that will equal competitive species of the same life form.	0.67
	M	Unknown.	0.50
	ML	Maximum growth rate less than many species of the same life form.	0.33
	L	Slow growth, will be exceeded by many other species.	0
Stress tolerance of established plants to	H	Highly resistant to at least two of (drought, frost, waterlogging, fire and salinity) not susceptible to more than one (cannot be drought or waterlogging).	1.00
frost, drought, water logging, salinity, fire?	MH	Highly tolerant of at least two of (drought, frost, waterlogging, fire and salinity) and maybe tolerant of another. Susceptible to at least one.	0.67
	M	Unknown.	0.50
	ML	Tolerant to at least two and susceptible to at least one.	0.33
	L	Maybe tolerant of one stress, susceptible to at least two.	0

Criteria	Rank	Intensity Rating	Weight
Reproduction			
Reproductive system?	H	Both vegetative and sexual reproduction.	1.00
	MH	Vegetative reproduction.	0.67
	M	Unknown.	0.50
	ML	Sexual (self and cross pollination).	0.33
	L	Sexual but either cross or self pollination.	0
Number of propagules produced per flowering event?	H	Above 2000.	1.00
	MH	1000-2000.	0.67
	M	Unknown.	0.50
	ML	50-1000.	0.33
	L	Less than 50.	0
Propagule longevity?	H	Greater than 25% of seeds can survive over 20 years in the soil.	1.00
	MH	Greater than 25% of seeds survive 10-20 years in the soil, OR lower viability but survives over 20 years.	0.67
	M	Unknown.	0.50
	ML	Greater than 25% of seeds survive 5-10 years in the soil, OR lower viability but survive 10-20 years.	0.33
	L	Greater than 25% of seeds survive 5 years, OR vegetatively reproduces.	0
Reproductive period?	H	Mature plant produces viable propagules for 10 years or more, OR species forms self-sustaining monocultures.	1.00
	MH	Mature plant produces viable propagules for 3–10 years.	0.67
	M	Unknown.	0.50
	ML	Mature plant produces viable propagules for only 1–2 years.	0.33
	L	Mature plant produces viable propagules for only 1 year.	0
Time to reach reproductive maturity?	H	Reaches maturity and produces viable propagules in under a year.	1.00
	MH	Produces propagules between 1-2 years after germination.	0.67
	M	Unknown.	0.50
	ML	2-5 years.	0.33
	L	Greater than 5 years to reach sexual maturity.	0

Criteria	Rank	Intensity Rating	Weight
Dispersal			
Number of dispersal mechanisms?	H	Very light, wind dispersed seeds, OR bird dispersed seeds OR has edible fruit that is readily eaten by highly mobile animals.	1.00
	MH	Propagules spread by wind, water, animals (not birds), light vehicular traffic.	0.67
	M	Unknown.	0.50
	ML	Propagules spread by attaching to humans or animals.	0.33
	L	Propagules mainly spread by gravity.	0
Probability (or chance) that propagules will disperse to a distance greater than one kilometre?	H	Very likely that some propagules will disperse greater one kilometre.	1.00
	MH	Few propagules will disperse greater than one kilometre but many will reach 200-1000 metres.	0.67
	M	Unknown.	0.50
	ML	Very few to none will disperse to one kilometre, most 20-200 metres.	0.33
	L	Very unlikely to disperse greater than 200 metres, most less than 20 metres.	0

Appendix 2:

Table of Risk Ratings, National Status and Invasiveness Indices

Scientific Name	**Common Name**	**Risk Rating**	**National Status**	**Invasive Index**
Acacia baileyana	Cootamundra wattle	V	None	0.79
Acer pseudoplatanus	Sycamore maple	V	None	0.72
Agrostis capillaris	Brown-top bent	V	None	0.65
Ailanthus altissima	Tree-of-heaven	P	Vic, NSW, WA	0.89
Allium triquetrum	Angled onion	V	Vic, SA, Tas	0.61
Aloe saponaria	Aloe	S	None	0.63
Alternanthera philoxeroides	Alligator weed	None	Vic, NSW, QLD, ACT, SA, NT, WA, Tas	0.69
Anthoxanthum odoratum	Sweet vernal-grass	V	None	0.66
Asphodelus fistulosus	Onion-weed	S	Vic, NSW, SA, NT, Tas	0.54
Briza maxima	Large quaking-grass	V	None	0.74
Carduus pycnocephalus	Slender thistle	S	Vic, Tas	0.72
Carduus tenuiflorus	Slender thistle	P	Vic, SA, Tas	0.61
Carthamus lanatus	Saffron thistle	P	Vic, NSW, QLD, NT, WA, Tas	0.51
Centaurea calcitrapa	Star thistle	S	Vic, NSW	0.41
Cestrum parqui	Green poisonberry	None	Vic, NSW, QLD	0.73
Chrysanthemoides monilifera ssp. monilifera	Boneseed	V	Vic, NSW, QLD, SA, WA	0.80
Cirsium acarna	Soldier thistle	None	Vic, SA	0.52
Cirsium arvense	Californian thistle	None	Vic, NSW, SA, WA, Tas	0.70
Cirsium vulgare	Spear thistle	S	Vic, SA, Tas	0.69
Convolvulus arvensis	Common bindweed	None	Vic, SA, WA	0.78
Coprosma repens	New Zealand mirror-bush	V	None	0.82
Cortaderia selloana	Pampas grass	V	NSW, WA, Tas	0.95
Cotoneaster glaucophyllus	Cotoneaster	V	NSW	0.81
Crataegus monogyna	Hawthorn	V	Vic, SA	0.70
Cuscuta campestris	Golden dodder	S	Vic, NSW, SA, WA, Tas	0.73
Cynara cardunculus	Artichoke thistle	V	Vic, SA, WA, Tas	0.66
Cytisus scoparius	English broom	V	Vic, NSW, SA, ACT, Tas	0.73

Scientific Name	Common Name	Risk Rating	National Status	Invasive Index
Datura stramonium	Common thorn-apple	S	Vic, QLD, WA, NT, Tas	0.61
Delairea odorata	Cape ivy	V	NSW	0.72
Diplotaxis tenuifolia	Sand mustard	P	Vic, SA	0.57
Dipogon lignosus	Dipogon	V	WA	0.82
Dipsacus fullonum	Wild teasel	P	Vic	0.55
Dittrichia graveolens	Stinkwort	P	Vic	0.61
Echium plantagineum	Paterson's curse	S	Vic, NSW, SA, WA, NT, Tas	0.66
Echium vulgare	Viper's bugloss	P	Vic, NSW, Tas	0.66
Ehrharta erecta	Panic veldt grass	V	None	0.77
Emex australis	Spiny emex	S	Vic, NSW, QLD, SA, WA, NT, Tas	0.53
Eragrostis curvula	African love-grass	V	Vic, NSW, SA, WA, ACT, Tas	0.71
Erica lusitanica	Spanish heath	V	None	0.77
Foeniculum vulgare	Fennel	V	Vic, Tas	0.57
Galenia pubescens	Galenia	S	NSW	0.61
Genista linifolia	Flax-leaf broom	V	Vic	0.70
Genista monspessulana	Montpellier broom	V	Vic, NSW, SA, ACT, Tas	0.70
Hedera helix	Ivy	V	None	0.76
Hieracium aurantiacum	Orange hawkweed	None	None	0.62
Homeria flaccida	Cape tulip (one-leaf)	V	Vic, NSW, SA, WA, Tas	0.74
Hypericum androsaemum	Tutsan	V	Vic, WA	0.81
Hypericum perforatum	St John's wort	V	Vic, NSW, WA, Tas	0.66
Hypericum tetrapterum	Square-stem St John's wort	P	Vic	0.55
Ilex aquifolium	Holly	V	None	0.75
Juncus acutus	Sharp rush	V	Vic	0.52
Juncus effusus	Soft rush	V	None	0.69
Lavandula stoechas	Topped lavender	S	Vic	0.68
Leucanthemum vulgare	Ox-eye daisy	P	Vic	0.72

Scientific Name	Common Name	Risk Rating	National Status	Invasive Index
Leycesteria formosa	Himalayan honeysuckle	V	None	0.80
Ligustrum vulgare	European pivet	S	None	0.75
Lonicera japonica	Japanese honeysuckle	V	None	0.83
Lycium ferocissimum	African box-thorn	V	Vic, NSW, QLD, SA, WA, NT, Tas	0.67
Marrubium vulgare	Horehound	V	Vic, NSW, SA, WA, Tas	0.77
Melianthus comosus	Tufted honeyflower	None	Vic	0.49
Myriophyllum aquaticum	Parrot's feather	P	WA, Tas	0.63
Myrsiphyllum asparagoides	Bridal creeper	V	NSW, SA, WA, Tas	0.79
Nassella hyalina	Fine needle-grass	S	None	0.48
Nassella neesiana	Chilean spear-grass	V	NSW	0.69
Nassella trichotoma	Serrated tussock	V	Vic, NSW, SA, ACT, Tas	0.76
Onopordum acanthium	Heraldic thistle	None	Vic, NSW, Tas	0.57
Onopordum acaulon	Stemless onopordon	S	Vic, NSW, WA, Tas	0.53
Opuntia ficus-indica	Prickly-pear	P	None	0.76
Opuntia robusta	Wheel cactus	S	Vic, NSW, QLD, SA, WA, NT	0.66
Opuntia stricta	Common prickly pear	S	Vic, NSW, QLD, SA, WA, NT	0.76
Oxalis pes-caprae	Soursob	V	Vic, SA, Tas	0.74
Oxylobium lanceolatum	Oxylobium	S	None	0.62
Paspalum dilatatum	Paspalum	V	None	0.73
Pennisetum clandestinum	Kikuyu	V	None	0.67
Phalaris aquatica	Toowoomba canary-grass	V	None	0.73
Physalis viscosa	Prairie ground cherry	None	Vic, NSW	0.73
Pinus pinaster	Cluster pine	V	None	0.79
Pinus radiata	Monterey pine	V	None	0.78
Pittosporum undulatum	Sweet pittosporum	V	NSW, WA	0.79
Polygala myrtifolia	Myrtle-leaf milkwort	V	None	0.76
Populus alba	White poplar	P	None	0.66

Scientific Name	Common Name	Risk Rating	National Status	Invasive Index
Prunus lusitanica	Portugal laurel	S	None	0.77
Reseda luteola	Weld	None	Vic, Tas	0.54
Rhamnus alaternus	Italian buckthorn	V	None	0.82
Rosa rubiginosa	Sweet briar	V	Vic, NSW, SA, Tas	0.79
Rubus fruticosus agg.	Blackberry	None	Vic, NSW, QLD, SA, WA, ACT, Tas	0.77
Sagittaria graminea	Arrowhead	S	SA, WA, Tas	0.58
Salix alba	White willow	S	NSW, SA, ACT	0.93
Salix babylonica	Weeping willow	S	None	0.93
Salix cinerea	Grey sallow	V	NSW, SA, ACT	0.92
Salix x rubens	Crack willow	V	NSW, SA, ACT	0.92
Salpichroa origanifolia	Pampas lily-of-the-valley	V	Vic, Tas	0.76
Scolymus hispanicus	Golden thistle	None	Vic	0.50
Senecio jacobaea	Ragwort	P	Vic, NSW, SA, WA, Tas	0.66
Senecio pterophorus	Winged groundsel	P	Vic	0.68
Silybum marianum	Variegated thistle	S	Vic, SA, WA, Tas	0.76
Solanum elaeagnifolium	Silverleaf nightshade	None	Vic, NSW, SA, Tas	0.67
Solanum linnaeanum	Apple of Sodom	S	Vic, WA, Tas	0.36
Sollya heterophylla	Bluebell creeper	V	None	0.81
Spartina anglica	Spartina	V	None	0.61
Spartina x townsendii	Spartina	V	None	0.58
Sporobolis indicus	Rat-tail grass	S	NSW	0.71
Tradescantia albiflora	Wandering creeper	V	NSW	0.59
Tribulus terrestris	Caltrop	None	Vic, SA, WA, NT, Tas	0.61
Ulex europaeus	Gorse	V	Vic, NSW, SA, WA, ACT, Tas	0.83
Verbascum thapsus	Great mullein	S	Vic	0.47
Verbascum virgatum	Twiggy mullein	S	None	0.64
Vinca major	Blue periwinkle	V	None	0.67

Scientific Name	Common Name	Risk Rating	National Status	Invasive Index
Vulpia bromoides	Squirrel-tail fescue	V	None	0.67
Watsonia meriana	Wild watsonia	S	Vic, SA, WA	0.40
Xanthium spinosum	Bathurst burr	S	Vic, NSW, QLD, SA, WA, NT, Tas	0.58
Xanthium strumarium	Noogoora burr	None	Vic, NSW, QLD, SA, WA, NT, ACT, Tas	0.62

Legend

Risk Rating (according to Carr *et al* 1992):
V - very serious threat to one or more vegetation formation in Victoria
S - serious threat to one or more vegetation formation in Victoria
P - potential threat to one or more vegetation formation in Victoria
None - Not present in risk assessment

National Status:
Vic - Noxious in Victoria
NSW - Noxious in New South Wales
Tas - Noxious in Tasmania
SA - Noxious in South Australia
WA - Noxious in Western Australia
QLD - Noxious in Queensland
NT - Noxious in Northern Territory
ACT - Noxious in Australian Capital Territory

Appendix 3:

Examples of Present and Potential Distribution Maps

List of species with present and potential distribution maps in the order they occur in Appendix 3. Updates to names are indicated.

Botanical name:

*Acacia baileyana**
*Acer pseudoplatanus**
*Agrostis capillaris**
Ailanthus altissima
Allium triquetrum
Aloe saponaria = A. maculata*
Alternanthera philoxeroides
*Anthoxanthum odoratum**
*Asphodelus fistulosus**
*Briza maxima**
Carduus pycnocephalus
Carduus tenuiflorus
*Carthamus lanatus**
Centaurea calcitrapa
Cestrum parqui
Chrysanthemoides monilifera ssp. *monilifera*
Cirsium acarna = Picnomon acarna
*Cirsium arvense**
Cirsium vulgare
Convolvulus arvensis
*Coprosma repens**
Cortaderia selloana
*Cotoneaster glaucophyllus**
Crataegus monogyna
Cuscuta campestris
Cynara cardunculus
Cytisus scoparius
Datura stramonium
*Delairea odorata**
Diplotaxis tenuifolia
*Dipogon lignosus**
Dipsacus fullonum
Dittrichia graveolens
Echium plantagineum
Echium vulgare
*Ehrharta erecta**
Emex australis
Eragrostis curvula
*Erica lusitanica**
Foeniculum vulgare
Galenia pubescens
Genista linifolia
Genista monspessulana
*Hedera helix**
Hieracium aurantiacum

Homeria flaccida = Moraea flaccida
Hypericum androsaemum
Hypericum perforatum
*Hypericum tetrapterum**
*Ilex aquifolium**
Juncus acutus
*Juncus effusus**
Lavandula stoechas
Leucanthemum vulgare
Leycesteria formosa
*Ligustrum vulgare**
*Lonicera japonica**
Lycium ferocissimum
Marrubium vulgare
Melianthus comosus
*Myriophyllum aquaticum**
Myrsiphyllum asparagoides = Asparagus asparagoides
Nassella hyalina
Nassella neesiana
Nassella trichotoma
Onopordum acanthium
Onopordum acaulon
Opuntia ficus-indica
Opuntia robusta
Opuntia stricta
Oxalis pes-caprae
Oxylobium lanceolatum = Callistachys lanceolata*
*Paspalum dilatatum**
*Pennisetum clandestinum**
*Phalaris aquatica**
Physalis viscosa
*Pinus pinaster**
*Pinus radiata**
*Pittosporum undulatum**
*Polygala myrtifolia**
*Populus alba**
*Prunus lusitanica**
Reseda luteola
*Rhamnus alaternus**
Rosa rubiginosa
Rubus fruticosus agg.
Sagittaria graminea
Salix alba
Salix babylonica
Salix cinerea
Salix x rubens
Salpichroa origanifolia
Scolymus hispanicus
Senecio jacobaea

Senecio pterophorus
Silybum marianum
Solanum elaeagnifolium
Solanum linnaeanum
*Sollya heterophylla**
Spartina anglica
Spartina x townsendii
Sporobolus indicus = S. africanus
Tradescantia albiflora = T. fluminensis*
Tribulus terrestris
Ulex europaeus
Verbascum thapsus
*Verbascum virgatum**
*Vinca major**
*Vulpia bromoides**
Watsonia meriana
Xanthium spinosum
Xanthium strumarium = X. occidentale; X. orientale

* Indicates a species with PV district boundaries on the potential distribution maps; the others species, previously assessed by KTRI, have the CMA boundaries overlayed onto the potential distribution maps.

Maps in Appendix 3 are located in a separate document.