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A review of recent weed research and management relevant to Australian livestock industries and proposals for future investments

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Abstract

Weeds are important for most agricultural industries and many native and introduced species are problematic for Australian livestock industries (also referred to as grazing industries). This project reviews relevant scientific and management literature published since 2003. Data from 17 independent sources were used to identify 71 species that are already widespread and abundant ("prominent weeds") and 18 that are still relatively restricted ("emerging weeds"). We prioritised species using a decision tree that required assessments of each species' distribution and abundance, current and potential impacts, the availability of effective control measures and prospects for improved management through cost-effective research, development and extension (RD&E). Such assessments, however, are necessarily based on imperfect knowledge. Literature on the economic costs of weeds to livestock industries was also reviewed. We identified only five studies conducted since 2003 that focus on economic impacts of weeds on Australian livestock industries. Future RD&E on weeds of Australian livestock industries require fundamental studies of important aspects of basic biology of species that are currently poorly known, development of systems approaches to addressing weed issues, promotion of measures and strategies that are currently available, development of cost-effective solutions for priority prominent and emerging weeds and studies to test and demonstrate the benefits of weed management at an enterprise level.

Executive Summary

Weeds are an important issue for most agricultural industries including Australian livestock (grazing) industries. This report reviews for Meat & Livestock Australia (MLA) relevant scientific and management literature published since 2003 and identifies priorities for research, development and extension (RD&E) investments.

A large number of native and introduced plant species are problematic for Australian livestock industries. The species of concern vary greatly from region to region and also in terms of the magnitude of impacts that they have and the measures that are available for dealing with them.

We reviewed the refereed and non-refereed literature published since the report by Grice (2003) that deals with weeds of Australian livestock industries. At least 23 of the 32 Australia's Weeds of National Significance are relevant to livestock industries. Over 25% of papers published in the proceedings of the five Australian Weeds Conferences (AWC) since 2003 covered grazing-relevant weeds. The many (170) journal papers recorded in the Web of Science addressed 65 grazing-relevant weed species, the most studied species being *Cenchrus ciliaris*, *Nassella neesiana*, *N. trichotoma*, *Vulpia* spp., *Parthenium hysterophorus, Phyla canescens*, and *Carduus nutans*.

While the number of grazing-relevant papers dealing with weeds declined between 2004 and 2012, this was associated with a proportional decline in total AWC publications and simply reflected a decline in weeds RD&E in general. The number of weed-related PhD thesis completions also declined despite a national increase in total PhD completions over the same period.

A discussion paper, including the above review and preliminary analyses to identify grazing-relevant weeds, was widely circulated to stakeholders with an interest in livestock industries. The final analyses presented in this report were adjusted to take into account feedback from this consultation process.They covered 17 independent data sources to identify which weed species are most important to livestock industries. Seventy-one species were identified as already widespread and abundant; these are described as "prominent weeds" of livestock industries. An additional 18 species that have the potential to become major weeds of livestock industries, but that are currently restricted relative to their potential distributions; were also identified; these are described as "emerging weeds". These lists exclude native plants and strictly aquatic species.

We prioritised species using a decision tree that required assessments of each species' distribution and abundance, current and potential impacts, the availability of effective control measures and prospects for the development of improved management through cost-effective research, development and extension. Such assessments, however, are necessarily based on imperfect knowledge.

Of the 71 prominent weeds, 20 were determined to be higher priority for RD&E. These included: *Cylindropuntia* spp., *Euphorbia terracina, Hyparrhenia hirta, Hyparrhenia rufa, Lantana montevidensis, Lycium ferocissimum, Moraea flaccida, Moraea miniata, Nassella neesiana, Nassella trichotoma, Opuntia spp., Parthenium hysterophorus, Phyla canescens, Prosopis* spp*., Rubus fruticosus* agg*., Senna obtusifolia, Sporobolus fertilis, Themeda quadrivalvis, Vachellia nilotica* (syn. *Acacia nilotica*) and *Ziziphus mauritiana.*

Of the 18 emerging weeds, 5 were determined to be of higher priority (*Chromolaena odorata*, *Clidemia hirta*, *Gomphocarpus fruticosus*, *Physalis viscosa* and *Praxelis clematidea*) and 1 (*Cascabela thevetia)* of medium priority.

Two major issues hampered the analysis of relative importance of these weed species:

- there has been little current research examining the agronomic impacts of weeds on grazing lands, and
- only five studies conducted since 2003 focussed on economic impacts of weeds.

We conclude that future RD&E on weeds of Australian livestock industries requires:

- fundamental studies of important aspects of the basic biology of species that are currently poorly known,
- studies to test and demonstrate the benefits of weed management at an enterprise level, including economic studies,
- development of systems approaches to addressing weed issues,
- development of cost-effective solutions to priority prominent and emerging weeds including in particular:
    - containment strategies for emerging weeds
    - biological control of appropriate weed targets
- promotion of measures and strategies that are currently available.

The future of RD&E on weeds of livestock industries in Australia also depends on having the scientific capacity to undertake research. Capacity needs require urgent assessment, starting with the need for training of PhD level graduates in issues related to management of weeds in the livestock industries.

In general, research on weeds of the livestock industries in Australia has remained at the same level or declined since the last review in 2003. This report attempts to show a way forward to address this ecologically, economically and socially important issue.

Summary of recommendations

1. Develop a collaborative approach to weed RD&E and promote it at the operational level.
2. Livestock industries, through MLA and other representative organisations, should participate in national programs for the management of relevant weed species, most notably the Weeds of National Significance program.
3. Develop and promote realistic perspectives on weeds RD&E and weed management.
4. Take and promote a long-term view.
5. Build capacity.
6. Development of research capacity should be encouraged by providing financial and other incentives to attract postgraduate students into research of relevance to the grazing industries, including weed research. Potential university supervisors should also be made aware of industry needs.
7. Focus on likely winners.
8. Take a holistic approach to address the problems of weeds in livestock grazing systems across a range of scales: farm, catchment, landscape and regional.
9. Conduct RD&E to provide and promote the application of a better understanding of the links between grazing management and invasion and proliferation of species favoured by the types of disturbance typically associated with livestock enterprises.
10. Baseline studies and reassessments of the economic and other impacts of priority weed species and groups of co-occurring weeds should be given priority.
11. The prioritisation of weed species relevant to grazing industries should be refined using a consistent and cost-efficient methodology across all regions of Australia.
12. Weeds relevant to grazing industries should be prioritised as targets for biological control on the basis of their impact as well as the feasibility and likelihood of success of biological control, prior to the initiation of new programs.
13. Develop cost-effective management solutions for priority prominent and emerging weed species.
14. Fundamental studies of the biology and ecology of priority prominent and emerging weeds, for which major knowledge gaps exist, should be conducted to provide a basis for understanding invasion processes and impacts and the development of management measures and strategies.
15. Biological control programs should be established for priority species for which there are good prospects of success.
16. Contribute to development of improved means for managing unpalatable, high biomass grasses, including measures for containing their spread.
17. The potential distributions of emerging weeds of livestock industries should be determined under both current and future climates, with development of appropriate adaptation responses.

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Introduction

Weeds pose significant threats to Australian industries and environments. Most land-uses in Australia are subject to the prospect of negative impacts from weeds. Australian livestock industries and enterprises, like other primary industries, are subject to the direct effects of a wide variety of weeds and expend considerable amounts of money addressing weed problems. However, resources to address weed problems are inevitably limited. This applies to both management activities designed to directly reduce the impacts and costs of weeds and to RD&E activities conducted to develop new weed management tools or improve the effectiveness and efficiency of the weed management measures that are available.

Many dozens of weed species have some bearing on livestock production, the efficiency of animal husbandry, the quality of livestock produce and so on the economic viability of livestock industries and the individual enterprises of which they are comprised. Some weeds are widely distributed and have been recognised as significant for livestock industries for a long time. Others, even some that have been present in Australia for years, are more restricted by bioclimatic factors. A third group are restricted because they are in relatively early stages of invasion, but have potential to expand their distributions and increase their impacts on industries.

The situation is complex. There are many weed species, varying in their current and potential impacts. There are limited resources available for either practical weed management and weeds RD&E, and the productivity of livestock enterprises, driven in part by heterogeneity of the underlying bioclimatic potential, varies greatly. This complexity means there is a need to direct both property and industry level resources as efficiently as possible.

This report is the final product of a project commissioned by MLA to assess the current situation in relation to weeds that are a problem for Australian livestock industries. It presents a synopsis of work undertaken since 2003 when the report “Weeds of Significance to the Grazing Industries of Australia” (Grice 2003) was published. The current report includes recommendations for RD&E activities to which MLA might contribute resources. In particular it identifies priority weeds, whether they are already widespread and abundant or present emerging problems. It also proposes RD&E priorities that are not species-specific.

Project objectives

General aim of the project

This report examines developments in weed research and management that has been carried out since 2003 (see Grice 2003) and is relevant to Australian livestock industries. It assesses which weeds are important to livestock industries and enterprises whether because they are already problematic or because there is evidence that they are emerging or could emerge to be so. On the basis of this analysis of recent weeds RD&E we propose an investment strategy, with recommendations for specific RD&E project areas, to address the problems of current and emerging grazing-relevant weeds. This investment strategy is conceived to address RD&E priorities over the next ten years. Work toward this report included preparation of a discussion paper that was widely circulated to relevant researchers, managers, policy makers and individuals in Australian livestock industries in order to draw on a broad range of interest and expertise in the fields of weed science and management that are relevant to Australian livestock industries.

Specific objectives

The specific objectives of this project were to:

1. provide an inventory of investments in weed research and management in Australia that has been conducted since 2003 and is relevant to livestock industries
2. update information on the general importance of weeds to Australian livestock industries
3. recommend priority RD&E project areas
4. propose a weed RD&E investment strategy for MLA.

Background

Livestock industries in Australia

Grazing of livestock is a major land-use in Australia, being the predominant land-use on around 4.3 million square kilometres of land or 56% of the continent. Livestock enterprises contribute significantly to the economic outputs of all states and territories, across all bioclimatic zones, exploiting pastures that range from highly modified, fertilised pastures of sown exotic species to natural and semi-natural pastures in extensive rangeland situations (Anon. 2013a).

Australian livestock enterprises are based mainly on the grazing of cattle and sheep. In 2011-2012, there were around 28 million cattle and 73 million sheep in Australia. However, these animals are very unevenly distributed across the continent. Considered in terms of Natural Resource Management (NRM) Regions, the Fitzroy NRM region and the Northern Territory have the largest cattle herds with over 2 million head each. Other regions with large cattle numbers are the Desert Channels, Southern Gulf, Burdekin and Border Rivers/Maranoa Balonne NRM regions, all of which are in Queensland, and each of which typically carry over 1 million cattle. The Rangelands NRM region in Western Australia also supported over 1 million cattle in 2011-2012. However, cattle densities tell a somewhat different story: the highest densities of cattle are in five NRM regions in Victoria, the South East NRM region in South Australia and the Condamine NRM region in Queensland. NRM regions with both high cattle densities and large total herds include: West Gippsland, Glenelg Hopkins and Goulburn (all in Victoria), South East (South Australia), Namoi and the Northern Rivers in NSW, Condamine and South East (Queensland), Fitzroy and Burnett Mary in Queensland.

The national sheep flock is also very unevenly spread. The NRM regions with the greatest numbers of sheep are in NSW (Lachlan, Central West, Murrumbidgee, Murray), South Australia (South East), Victoria (Glenelg Hopkins, North Central) or southern Western Australia (South West, Avon, South Coast). Most of these also support high densities of cattle. Many of the sheep in some of these and other regions are grown primarily for wool production rather than for meat.

Cattle and sheep densities are generally inversely correlated with property size which has a bearing on weeds RD&E in terms of the numbers of producers likely to benefit from an effective investment in a region's weed issues.

Weeds and livestock industries

Many factors influence the viability of livestock enterprises and industries: climate, markets, livestock genetics, infrastructure, animal diseases, pest animals and plants and so on. However, given that there are so few data on the costs of weeds to Australian livestock enterprises, it is difficult to assess the economic impacts of weeds on enterprise productivity and profitability relative to the influence of other factors. Importantly, the relative impact of weeds versus other factors will vary spatially at geographic scales as well as from enterprise to enterprise within the same region.

The most comprehensive analysis of the economic impact of weeds in Australia was that conducted in 2004 (Sinden *et al.* 2004). That report estimated that the economic impacts of weeds on the natural environment and agricultural industries in the period 1997-2002 was approximately $4 billion per year. The cost to livestock industries was estimated at $2.2 billion per year, including costs of control and yield losses.

Weeds, pest animals and diseases each have direct and indirect effects on enterprise and industry economics. Direct effects are in the form of lost production (e.g. livestock poisoning, reduced forage supply) while indirect effects relate to the costs of measures imposed in order to reduce those production losses. At an enterprise level, a manager must decide

where the greatest gains are to be made in addressing the limits to profitability. Weed management comes with direct economic costs but there are also transaction costs – other property management options will be reduced if money and time are spent on weed management. Decisions about expenditure on weed management must consider the impact of weeds relative to other factors affecting enterprise viability as well as the relative gains from applying particular weed management measures versus other types of expenditures.

Synopsis of Grice (2003)

In 2003, in collaboration with the Co-operative Research Centre for Australian Weed Management (Weeds CRC), MLA commissioned a review of weeds of significance to Australian grazing industries (Grice 2003). By drawing on relevant expertise from across Australia, the review identified plant taxa that were or could have become problematic for grazing industries. It provided an assessment of the relative importance of different weed species and identified R&D needs on the basis of the significance of the weed and the feasibility of successful control.

The final report included regional reviews separately covering northern Queensland, southern Queensland, inland NSW, coastal NSW, Victoria, southern Western Australia, northern Western Australia and the Northern Territory. Weeds were also analysed in terms of their relevance to six bioclimatic zones that together covered the whole of Australia: monsoon tropics, tropical rangelands, tropical and subtropical east coast, temperate rangelands, the perennial pasture zone and the cropping/pasture zone. South Australia and Tasmania were not covered in the review though many of the species and issues that were identified would have been relevant to those states too.

The review was based on expert opinion and results of some surveys and assessments conducted in the period just prior to 2003. Different approaches were applied to different states and territories, or parts thereof. The coverage of northern Queensland (Vitelli 2003) drew on the assessments of Weeds of National Significance (WoNS) (which covered 71 species) (Thorp and Lynch 2000), and a list, prepared in 2002, of important weeds and research priorities for the wet- and dry-tropics of Queensland (Bebawi *et al.* 2002). The latter was derived from pest management plans prepared for 47 northern Queensland local government areas. The list of species relevant to southern Queensland was compiled following discussions with relevant officers of the then Queensland Department of Primary Industries and some producers. The review of grazing-relevant weeds in inland NSW was based on several surveys: (i) of the temperate perennial pasture zone covering the northern, central and southern tablelands and slopes (Dellow *et al.* 2002); (ii) of particular species in various sub-regions (see Dellow 2003). The conclusions for coastal NSW were based on the assessment of an individual familiar with the region, emphasising those species given formal noxious plant status (Officer 2003). For Victoria, a formal pest plant prioritisation process was applied to plants deemed to be significant to grazing industries in that state (McLaren *et al.* 2003). Separate prioritisations were provided for grasses, broadleaf weeds and bulbous weeds (McLaren *et al.* 2003). The approach taken for southern Western Australia was similar to that used to cover Victoria except that a formal prioritisation process was not applied due to a deficiency of information (Revell 2003). The evaluation for northern Western Australia was based on a review prepared for the Department Agriculture and Food Western Australia (DAFWA) and identified five species that were subjectively assessed to be "highest priority", plus one (*Hyptis suaveolens*), which was the subject of research that was underway (Julien and van Klinken 2003). Finally, for the Northern Territory, expert opinion was used to identify a relatively small number of grazing-relevant weeds for four broad bioclimatic zones (Wingrave 2003).

The final report of the review listed 142 species as being weeds or potential weeds of Australian grazing industries (Appendix 1). Among these were annual grasses, annual forbs, perennial grasses, perennial forbs, aquatic plants, climbers, shrubs and trees. Many of the listed species were also problematic for sectors other than livestock industries, notably crop-

based agriculture and conservation/environmental management. The listed weed species varied greatly in how important they were deemed to be for livestock industries. Forty eight taxa were identified as being of greatest significance to livestock industries (Appendix 2), an assessment based on literature, pre-existing reports and the expert opinion of a relatively small number of weed specialists and livestock producers. Finally, there was a great deal of regional differentiation in terms of which weeds were most important.

The species identified in the 2003 review cannot be taken as a comprehensive list of grazing-relevant species. The compilation is based quite strongly on subjective information, there is a great deal of variation between regions in the approaches taken to assemble the information and South Australia and Tasmania were not explicitly included, although geographically and climatically similar regions were. The review identified R&D priorities for six bioclimatic regions. These priorities were largely species-based and are summarised in Appendix 3.

Change in weed prevalence over the last 10 years

There has not been a comprehensive national analysis of trends in abundance and distribution of weeds in Australia though several states maintain databases of weed occurrence. Borger *et al.* (2012) compared the results of two field surveys covering 478 sites in the south-west of Western Australia, the first conducted in 1997 and the second, using the same methodology, in 2008. One hundred and ninety-four weed species were recorded during the surveys. The incidence of a number of important species was lower in 2008 than in 1997 and only two species showed significant increases. A large proportion of the sites surveyed were in cropped fields rather than pastures. However, there were significant decreases in the incidence of several species in the pasture sites including *Vulpia* spp., *Aira caryophyllea*, *Bromus diandrus*, *B. hordeaceus*, *Romulea rosea* and native grass *Austrostipa* spp. and increases for *Raphanus rhapanistrum*, *Hypochaeris* spp., *Crassula* spp., *Erodium cicutarium* and *Arctotheca calendula.* For only a few species is much more detailed information available on distribution and abundance and how these have changed over time. Possibly the best examples are from national eradication programs. The National Siam Weed (*Chromolaena odorata*) Eradication Program carefully documented all known occurrences of the species, which is currently restricted to north Queensland and one location in central Queensland. It is a challenge to distinguish between genuinely new infestations and newly discovered infestations that have been there for some time and this makes it difficult to analyse the data in terms of time trends in prevalence (Jeffery 2012). Following abandonment of the eradication effort in 2012, data collection has been far more sporadic. There has also been valuable quantification of the distribution of at least some WoNS in relation to national strategic goals (e.g. *Vachellia nilotica*[1] ; March 2009) Quality distribution and abundance data are also available for species targeted by the National Four Tropical Weeds Eradication Program (*Clidemia hirta*, *Limnocharis flava*, *Miconia* spp., *Mikania micrantha*). New infestations of each have been detected in recent years though many known infestations have been reduced or extirpated by control efforts (Anon. 2011).

[1] Formerly *Acacia nilotica*

Methodology

Outline of approach

This project provides an inventory of investments in weed research and management for the last ten years (2003-2013) and an up-to-date statement on weeds relevant to Australian livestock industries following that produced by Grice (2003). The 2003 review was based on regional/state level reports prepared by a small number of individuals with expertise and experience in those particular regions. It did not effectively cover either South Australia or Tasmania though many of the weed species identified in adjacent states/regions were relevant to them. Preparation of the current report took a different approach. The available literature was reviewed and used to prepare a discussion paper that was widely circulated for feedback. The review material and feedback received were then used to formulate this report. This report also identifies priority work areas and priority species for future RD&E that we propose should be part of an investment strategy for MLA. The time-frame for the investment strategy is 10 years.

Literature reviewed and investment inventory

Readily available publications and reports on weeds research and management projects undertaken since 2003 were reviewed[2]. We considered:

i. Information contained in Grice (2003).
ii. Strategy documents prepared for the original 20 WoNS (Thorp and Lynch 2000; AWC 2007) and reviews of those strategies (Anon. 2013b).
iii. Strategies or draft strategies prepared for the additional 12 WoNS declared in 2012–13 (Anon. 2013b).
Strategy and review documents were downloaded and examined for evidence of relevance to livestock industries. A word search was done using keywords, pasture and/or grazing, in addition to reading relevant parts of the documents.
iv. NRM regions' weed and pest plans.
The websites of NRM regions were searched for strategies, plans and documents on weeds. These were examined for relevance to livestock industries.
v. The Weeds Research Database of the Australian Weeds Committee that covers the period 2006–12 (Anon. 2013c).
vi. Publications of the Weeds CRC.
vii. Proceedings of the five Australian Weeds Conferences since 2003 (2004, 2006, 2008, 2010, 2012).
viii. Publications in Web of Science database:
Web of Science was searched for all references since 2003 with an address in Australia and using the key words pasture or graz* and weed. References were downloaded into Endnote. Titles and abstracts were scanned to identify references relevant to the livestock industries in Australia.
ix. PhD and MSc theses completed since 2003, including the highly relevant PhD thesis of Trotter (2007).
The library catalogues of 21 universities, including all major universities and universities known to teach subjects possibly related to weeds in pastures were accessed via the internet by using the search term "digital thesis". Key word searches of the library catalogues were restricted to PhD and MSc thesis and used the key words "weed", "pasture" or "grazing". Searches were restricted to theses from 2003 up to May 2013. The search engines differ between universities so each search was structured to ensure that all keywords were accessed. "Invasive plant" was used as a check if no results were obtained. Details of each relevant thesis were copied

[2] A complete list of the references used to compile this report is available from the authors upon request.

into an Endnote file. Universities differ in the availability of pdfs of theses. Attempts to standardise and make available digital thesis were abandoned in 2010 and now each university maintains independent digital thesis access. In general the earliest digital theses date from 2003, but some, including recent theses, are only of restricted internal university access or not digitised. When available they were downloaded from each university library site and examined for details to add to the Endnote file. A second search was made using trove.nla.gov.au using various combinations of the keywords. This found further theses not previously detected, and did not detect others, using the same keywords that were used at university library sites. In all, 19 of the 32 theses were available for downloading.

x. Reports of projects conducted under the Defeating the Weed Menace program (2004–08), with on-ground projects managed by the Australian Department of Agriculture, Forestry and Fisheries (DAFF, now known as the Department of Agriculture) and R&D projects by the now defunct Land and Water Australia.

xi. Reports of relevant projects funded through the Australian Weed Research Centre and National Weeds and Productivity Research Program (managed by Rural Industries Research and Development Corporation–RIRDC) in 2008–12.

xii. Final reports of relevant projects funded by MLA since 2003. These reports were obtained from the MLA website and do not cover projects in progress that are funded by MLA.

Discussion paper

The findings from this review and preliminary analyses to identify grazing-relevant weeds (see Definitions in following section) were presented in a discussion paper that was widely circulated to stakeholders with an interest in weeds relevant to livestock industries. These stakeholders included industry representatives, representatives of relevant state government departments, including those working in the policy arena, and weed scientists. A list of individuals to whom the Discussion Paper was circulated for feedback is provided in Appendix 4.

Determination of grazing-relevant weeds and RD&E priorities

DEFINITIONS

Grice (2003) used the expressions “weeds of significance to Australian grazing industries”, “priority weeds”, “important weeds” and “emerging weeds” without providing definitions. A “weed” can be “significant” to grazing industries because it has strictly negative impacts on grazing enterprises. However, any species may have both positive and negative impacts on grazing enterprises, perhaps depending on circumstances such as the mix of forage species generally available, the time of year or the seasonal conditions. Moreover, different pastoralists may have different perspectives on whether a species is an asset or a liability. There are some species that are “weeds” for some non-pastoral land-users but are either benign or beneficial from a pastoral perspective. Some species, for instance, are crop weeds or environmental weeds but are palatable to livestock and provide useful forage, at least at particular times. In this report we have tried to consistently use a minimum set of terms and expressions relating to weed impacts and priorities for livestock industries.

Weed: A plant species is a weed if it is problematic for or deemed to be problematic for any land-users or stakeholders. A species may be problematic for any of a large number of reasons.

Grazing-relevant weed: A plant that has positive or negative consequences for livestock producers but which is regarded as a weed by some stakeholders in livestock industries or by other sectors. Under this definition a plant that has or is perceived to have benefits for livestock industries and enterprises but which is a weed for other sectors would be regarded as a grazing-relevant weed.

Prominent weed: A prominent weed is a species that already occupies a large proportion of its potential Australian range and has real or perceived negative impacts **on livestock industries**. This does not preclude the possibility that some land-users, including some livestock producers, regard the species as providing benefits.

Emerging weed: A species is regarded as emerging as a weed if:

(i) it is naturalised in Australia;
(ii) its distribution and/or abundance are restricted relative to its estimated potential distribution and/or abundance in Australia;
(iii) there are only relatively few infestations, whether broadly scattered or all within one district or region;
(iv) it has significant negative impacts on only a small proportion (perhaps none) of the livestock producers who could potentially be affected by it **or** it has the potential to have significant negative impacts on livestock industries.

Significant weed: A significant weed is any species that currently has or could in the future have important negative impacts on Australian livestock enterprises. This category incorporates both prominent and emerging weeds.

Priority weed: A priority weed is a taxon that is a priority for investment by MLA. This relates specifically to this project's recommendations. It does not simply infer that a weed has or could have high impact but also that there is perceived scope for the development of solutions within an affordable budget and a reasonable (10-year) time-frame.

The sources of information used to determine grazing-relevant weeds, and how that information was used to determine prominent and emerging weeds and prioritise them for RD&E, are summarised in Table 1. Information used and the outputs and outcomes of the analysis are compared with that compiled by Grice (2003).

Table 1. Summary of sources of information and results derived for prominent and emerging weeds (this report) compared with results of "significant" and emerging weeds listed by Grice (2003). References to outputs relate to Grice (2003), the Discussion Paper circulated during this project and the Tables and Appendices in this report.

Grice (2003)			Grice *et al.* (2014) (this report)				
Information source	**Outcome**	**Output**	**Information source**	**Changes**	**Outcome**		**Output**
All weeds listed			**Prominent weeds**				
Reviews by regional experts	142 taxa	"Weeds of significance to grazing industries" Appendix 1	Up to top 10 spp. from each of 13 regional sources [a]		66 taxa		Discussion Paper Table 2
Distilled from reviews by regional experts	48 taxa	"Weeds of greatest significance" (Grice 2003: Table 21)	Up to top 10 spp. from each of 4 additional data sources [b]	+7 spp.	73 taxa.		Important weeds Appendix 8
			Feedback on Discussion Paper	-16 spp. +14 spp.	71 taxa		Prominent weeds Table 2
			Processed through decision tree		Higher priority 20 spp.	Lower priority 51 spp.	Prominent weeds priorities Table 4
Emerging weeds			**Emerging weeds**				
Reviews by regional experts	24 taxa	"Emerging weeds" (Grice 2003: Table 23)	Grice (2003); Other publications [c]		73 taxa		Preliminary list of potential emerging weeds Appendix 11
			Removed native, aquatic and valuable pasture spp.	-21 spp.	52 taxa		Removed spp. Appendix 12
			Applied selection criteria for emerging weeds	-34 spp.	18 spp.		Emerging weeds Table 3
			Processed through decision tree		Higher priority 5 spp.	Medium priority 1 spp. / Lower priority 12 spp.	Emerging weeds priorities Table 5

[a] Sources comprised reviews, surveys and prioritisation exercises (WRM assessments) conducted by various organisations/jurisdictions.

[b] Additional sources added following feedback on Discussion Paper.

[c] See Appendix 11.

DETERMINING PROMINENT WEEDS

To identify prominent weeds for the current report we analysed a series of 17 reviews, surveys and prioritisation exercises conducted by various organisations/jurisdictions since 2002. Four of these sources were accessed following receipt of feedback on the Discussion Paper. This material is detailed in Appendix 5.

Data from the 17 sources consulted provided a measure of the comparative importance of grazing-relevant weed species in Australia. These assessments are variously based on the perceptions of primary producers, field surveys or other processes. Details on data used from each source are summarised in Appendix 6. Data extracted from each source were compiled in a single spreadsheet (Appendix 7). The most important/impactful 10 species (or fewer depending on data available) from each of the 17 sources consulted (data in red in Appendix 7) were determined and compiled into a list of 73 species (Appendix 8)[3]. This list was compared with the list of species covered in Grice (2003), and consideration given to individual species that has not previously been considered as significant to determine whether their status had changed since 2003. This, along with feedback on the Discussion Paper, prompted consideration of some changes to the list: 16 species were removed; 6 species that were reconsidered were retained (Appendix 9) and 14 species were added (Appendix 10). Aquatic and semi-aquatic WoNS that were identified by Grice (2003) as affecting grazing industries, primarily by altering the quality of water used by livestock, are not covered by this report. The final list of prominent weeds consists of 71 species.

DETERMINING EMERGING WEEDS

A preliminary 'long' list of emerging weeds that are potentially relevant to livestock industries was compiled using Grice (2003), the National Alert List for Environmental Weeds (Anon. 2013d), species for which the Weeds CRC had prepared management guides and species specifically identified in recent literature as emerging (see Results – Literature review and RD&E investment inventory). To these were added any additional species identified by stakeholders who provided feedback on the Discussion Paper.

Our preliminary list of potential emerging weeds included 73 species (Appendix 11). This was refined by first removing species that fell in any of four categories:

(i) Already included in prominent weed list following the process outlined above.

(ii) Native to Australia.

(iii) Solely aquatic.

(iv) Primarily valued for the forage they produce.

Twenty one species fell into one of these categories (Appendix 12) and they were not assessed any further.

For each of the remaining species we then addressed a set of questions that relate to the criteria used to define emerging weeds. The questions were:

(i) Is it already widespread in Australia relative to its potential distribution? A species did not have to have occupied its entire potential Australian range in order to be regarded as widespread. A species could be widespread but still classified as emerging if it was perceived or documented to be increasing in density so that its impacts were likely to be increasing from negligible levels.

(ii) Are there many infestations?

(iii) Are many livestock producers already being negatively affected by infestations?

[3] Results in the Discussion Paper were based on 13 sources which yielded a list of 66 species (Table 2 of the Discussion Paper).

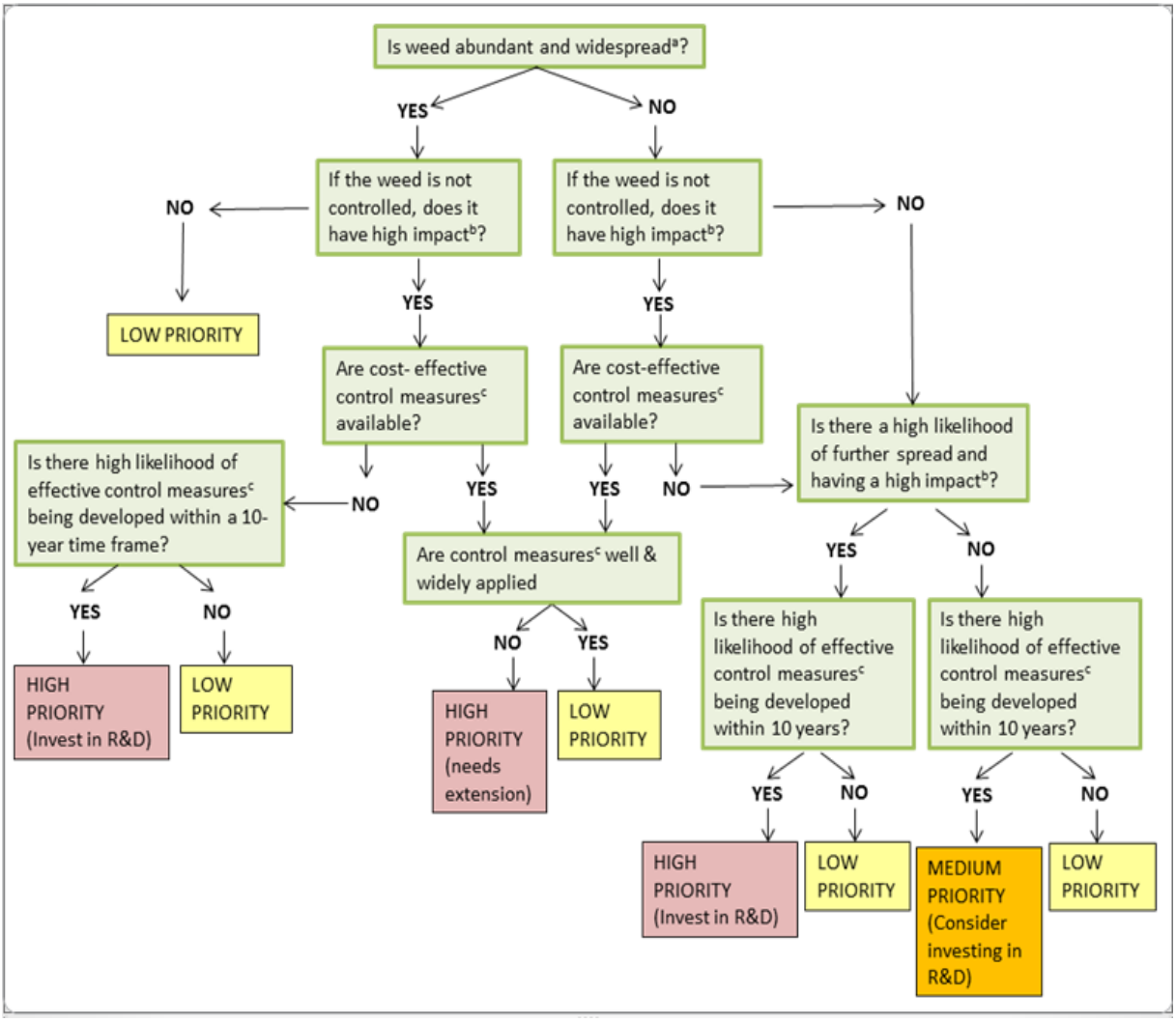
(iv) Does it have the potential to have significant negative impacts on livestock production enterprises?

Species that were judged to be not yet widespread (relatively to their potential distribution); exist as few infestations; and not currently affecting many livestock producers; but which have the potential to have significant negative impacts on livestock enterprises were assigned as emerging (Appendix 13). A literature search was then undertaken on each individual emerging weed species that was identified and brief descriptions of their situation was prepared.

DETERMINING PRIORITY WEEDS FOR RD&E

To help decide species-specific RD&E priorities, we developed and applied a simple decision-tree (Figure 1). This decision tree required assessments of each species' distribution and abundance, current and potential impacts, the availability of effective control measures, and prospect of improved control measures being developed. These assessments were made by members of the project team with input from others through feedback on the Discussion Paper (see p32); assessments were inevitably based on imperfect knowledge. Maps of the distributions of herbarium specimens available through Australia's Virtual Herbarium (Anon. 2013e) were used to classify species on the basis of their distribution and abundance. Species were judged to either occupy a large proportion of their potential Australian range (="abundant and widespread") or be restricted to a small part of their potential Australian range and present at few locations. Judgements were made in the absence of formal assessments of potential distributions for most species though for some species, such formal assessments have been made. For most species there are no quantitative data on their impacts on livestock enterprises and industries.

At the same time as this work was being undertaken, a parallel MLA-funded project was assessing prospects and priorities for the biological control of weeds of livestock industries. The two teams sought to develop consistent analysis of available information and complementary recommendations.



[a] This refers to weed abundance and extent relative to potential abundance and distribution respectively.
[b] In this diagram, "impact" refers to impact on livestock industries.
[c] Our use of the term control measures encompasses any methods used to reduce weed spread, abundance and/or impacts including grazing management strategies, pasture improvement and fertiliser application.

Figure 1. Schematic of decision tree used to prioritise weed species.

Assessment of economic impacts

In order to assess the economic impacts of weeds on Australian livestock industries, we consulted both the peer reviewed and non-peer reviewed literature. We found over 200 journal articles, project reports and dissertations by searching the ISI Web of Science and the World Wide Web in September 2013. We combined several groups of key words — weed, Australia, pasture OR grazing, economic OR cost OR $, and cattle OR beef OR sheep OR goat in various patterns to elicit studies that might be relevant. We selected those publications that met the following criteria:

(i) The study was published during or after 2003.

(ii) The study was not a review article, or purely theoretical, and it includes dollar estimates of the economic impacts of individual weed species or multiple species on industry.

(iii) The publications had a major focus on Australian livestock industries. Those with a more general focus on weed management or weeds' impacts on other industries were rejected from this screening step.

(iv) The study was conducted at either the national or State/Territory level.

Results

Literature review and investment inventory

WEEDS OF NATIONAL SIGNIFICANCE

The critical criterion for selection as a WoNS is that national coordination is required to improve management of the weed species. Consequently the WoNS are not necessarily the weeds that cost the most to agriculture in situations where there is a readily available management solution (e.g. herbicide). The inaugural 20 and now additional 12 species (or species groups) of WoNS are a major part of the Australian Weeds Strategy and have been a major target for research projects (Thorp and Lynch 2000, Mewett *et al.* 2011). Of the 32 species, the strategic plans and reviews mention the relevance to livestock industries in 23 cases (with a surprising lack of mention for *Rubus fruticosus* agg.). Some WoNS are primarily problems of livestock industries e.g. *Nassella neesiana* and *N. trichotoma.* Despite other weeds having clearly identified costs to livestock industries (e.g. *Lantana camara*), some WoNS strategies do not specifically identify outcomes specific to the livestock industries. Other weeds (e.g. *Parkinsonia aculeata*) do not have economic assessments of their impact on grazing industries. However, overall the WoNS program has made a major contribution over the last decade to the management of weeds of relevance to the livestock industries.

Martin and van Klinken (2006) point to the investment of almost AU$25 million of Australian Government funding in projects specifically targeting WoNS that occur in rangelands (14 species) and a further AU$56 million on projects conducted in rangelands that included a weed management component. There have been two more recent assessments. A study by Raphael and Baker (2010) included 208 telephone interviews and 75 questionnaires, primarily of people involved in coordination, policy or on-the-ground weed management. There was a high awareness of the WoNS program and all except one WoNS (*Vachellia nilotica*[4]) were mentioned. Telephone interviews of landholders (150) found that 60% were not aware of the WoNS program. A recent national survey (Ecker *et al.* 2012) of change management in Australian agriculture found that 50% of 1329 farm managers surveyed in 2010-2011 had adopted management of WoNS (broadscale 49%, dairy 59% and horticulture 51%). This was primarily for the financial benefits and to a lesser extent, the environmental benefits of controlling WoNS.

A major factor in the success of the WoNS program has been the role of WoNS coordinators. These positions have been funded by Federal and State agencies, with the arrangement ceasing in July 2013. The coordinators have provided the link between stakeholders and enabling research to flow through to adoption.

A major output of the development of management strategies for WoNS is the defining of containment zones. Most of the WoNS strategies have maps that identify containment zones. A successful example is the containment of *Parthenium hysterophorus* within Queensland. These containment zones complement the state declared status of certain weeds (e.g. P2 in Western Australia), and together they form the major national strategy to prevent the spread of weeds. Containment is difficult because it is effectively a localised eradication that never stops because there is a constant source of reinfestation (Grice *et al.* 2012). Movement and transport of livestock are major vectors of weeds and this has prompted the establishment of wash down stations on major routes (e.g. for *Vachellia nilotica*[5]). This management strategy, especially containment, needs testing and quantification of its effectiveness for weeds of livestock industries. This is because most

[4] Fomerly *Acacia nilotica.*

[5] Formerly *Acacia nilotica.*

dispersal vectors, dispersal distances, survival through time and establishment success are unknown for most species.

Most of the original WoNS have been targeted for biological control with some notable successes (e.g. *Asparagus asparagoides*) and future work in this area is needed, especially because of the high return on investment (Page and Lacey 2006). The 12 new WoNS taxa also present opportunities for biological control.

NRM REGION WEED AND PEST PLANS

As a means of approaching natural resources issues on a regional basis, Australia is divided into 56 NRM regions. The organisations responsible for each of these regions (NRM bodies or Catchment Management Authorities) address a wide variety of natural resource issues across their jurisdictions, each of which encompasses varied land types and land uses. Weeds are one of the issues on which NRM bodies have significant input with development of strategies, regional weed and pest plans being an important activity that they undertake. Only a few NRM regions have developed prioritisation processes for weeds (e.g. Adelaide and Mt Lofty Ranges in South Australia), although all regions have some focus on WoNS or sleeper and alert weed species. Most NRM regions incorporate areas of grazing lands so that their weed and pest plans consider weeds of relevance to livestock industries (e.g. Northern Territory NRM region). However any grazing-relevant weeds that are present within a NRM region are considered in the context of a cross-sectoral, regional approach. Consequently, in this report we have not attempted to extract information on grazing-relevant weeds from the weed and pest plans of the large number of NRM regions that encompass grazing lands.

WEEDS RESEARCH DATABASE OF THE AUSTRALIAN WEEDS COMMITTEE

We consulted the database of Australian research and development projects related to weeds compiled by the Australian Weeds Committee, for the period 2007 to September 2012, to evaluate the overall trend in funding of R&D relating to livestock industries. The database contains 402 records of R&D projects, some initiated before 2002 and others recorded as continuing beyond 2012.

Dates in the database were standardised and projects with no start or finish dates were excluded from the summary, unless it was possible to deduct the timeframe using other information provided, such as funding body/sponsor of the project. Projects with only a finish date recorded were assumed to have been performed over a 2-year period, and a corresponding start date was added. Projects thought to be related in some way to pasture or grazing were identified. The number of pasture/grazing-related projects was then compared with the total number of active projects in the database for each year (Figure 2). A peak of weeds R&D activity occurred between 2007 and 2010 at the time of the Australian Government Defeating the Weed Menace program, the Australian Weed Research Centre and the National Weeds and Productivity Research Program. R&D projects related to pasture/grazing followed a similar trend.

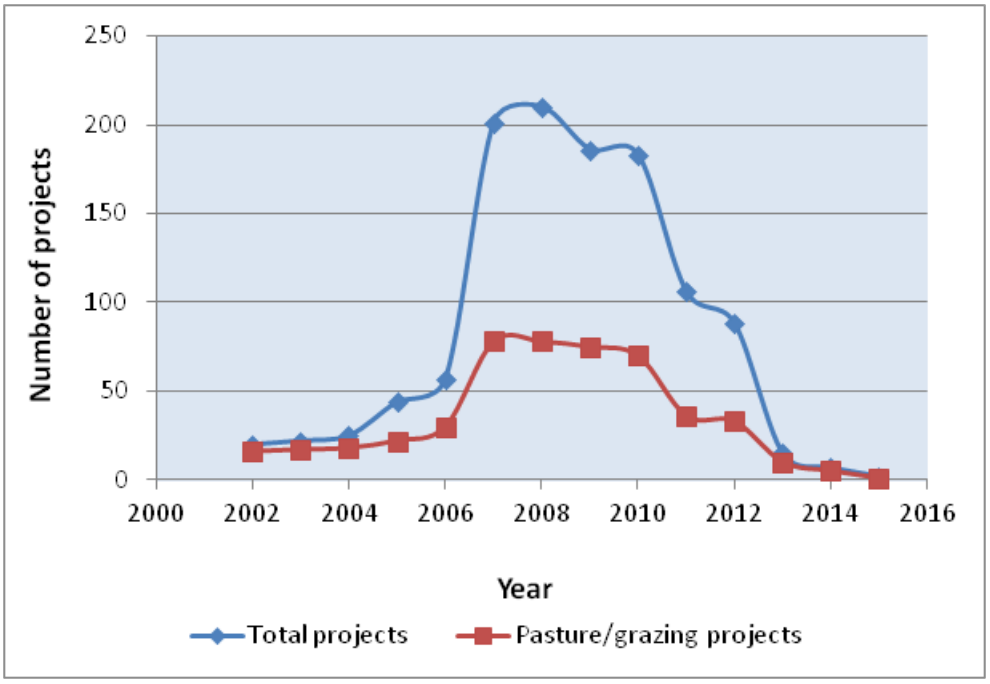


Figure 2. Total number of weeds R&D active projects compared with the number of projects that were relevant to weeds of livestock industries in each year, based on the database compiled by the Australian Weeds Committee.

PUBLICATIONS OF THE WEEDS CRC 2004–08

We compiled a list of the journal papers published from the work of the Weeds CRC. This list was based on the organisation's annual reports for 2003–04 through to 2007–08 inclusive. From these we identified 98 papers in refereed journals that addressed specific weeds relevant to livestock industries. Collectively they considered 32 different species of grazing-relevant weeds, around half of which were WoNS. All but one (*Chromolaena odorata*) of the 32 species were identified as being significant to Australian grazing industries in 2003 (Grice 2003). This coverage of weeds relevant to livestock industries should be considered in light of the fact that a large proportion of the Weeds CRC's research was not species specific.

Over 50% of the 98 grazing-relevant journal papers published by the Weeds CRC between 2003 and 2008 related to biological control. Another 15% related to other control methods and 16% reported studies of the biology and ecology of particular species.

In addition to refereed journal papers, the Weeds CRC also published species-specific management guides as well as more general extension material. Some of the species-specific guides cover grazing-relevant species. They included the 20 inaugural WoNS, species on the National Environmental Alert List (Anon. 2013f) and other emerging or widespread, important weeds. Other relevant extension material produced by the Weeds CRC includes best practice guides relating to the release, establishment and evaluation of biological control agents (Weeds CRC 2008a,b) and a set of ecological principles for the strategic management of weeds in rangelands (Grice *et al.* 2008a).

The 2004 report by the Weeds CRC still provides the most up-to-date national estimates of the economic impacts of weeds in Australia (Sinden *et al.* 2004). The report covered costs to agriculture, the natural environment, Commonwealth and State authorities and Indigenous land managers. It did not attempt to incorporate costs associated with the loss of ecological services, impacts on human health or the value of the large amount of volunteer weed management that takes place.

PROCEEDINGS OF AUSTRALIAN WEEDS CONFERENCES 2004–12

Five biennial Australian Weeds Conferences (AWC) have been held since publication of Grice (2003). These conferences provide a periodic summary of research and other work relating to weeds in Australia. We reviewed the Proceedings of these five conferences (2004, 2006, 2008, 2010, 2012), searching for publications relating to weeds relevant to Australian livestock industries. Two hundred and fifty three of the 958 papers presented at the conferences were assessed as dealing with specific weeds that are relevant to livestock industries. The number of grazing-related papers declined sharply after 2008. The average numbers of grazing-related papers per conference for the periods 2004–08 and 2010–12 were 62 and 33, respectively. This was however, paralleled by a decline in the overall number of papers from between 220 and 256 per conference prior to 2010, to only 144 and 111 for the 2010 and 2012 conferences, respectively (Figure 3). This is perhaps indicative of a general decline in weed-related research after the Weeds CRC was wound up in 2007–08. Over the nine year period there was no apparent trend in the percentage of AWC papers that addressed grazing-related weeds; it varied between 19% and 34%.

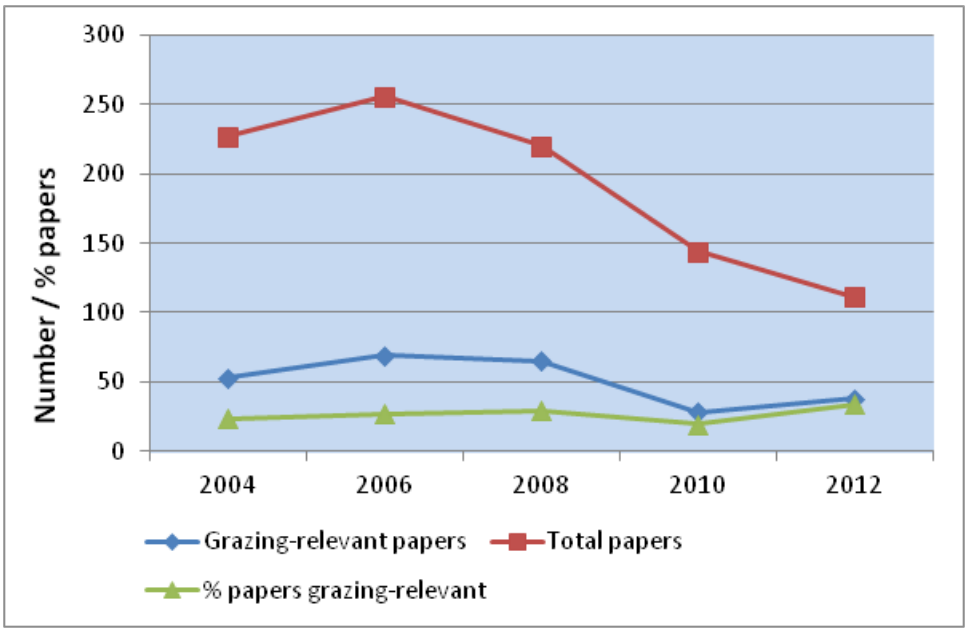


Figure 3. Total number of papers, number of grazing-relevant papers and percentage of papers that were grazing-relevant at each of the five Australian Weed Conferences held since 2003.

Papers delivered at the post-2003 AWC collectively covered 85 plant taxa, most identified to species level. These 85 taxa included 17 of the original 20 WoNS and 8 of the additional 12 WoNS that were newly listed in 2012–13 (Appendix 14). Eighty-two species that were identified in Grice (2003) as weeds of significance to Australian grazing industries received no coverage in the AWC Proceedings, but an additional 27 species were the focus of at least one AWC publication.

There was a great deal of variation in the amount of attention given to the various taxa as expressed in terms of the numbers of papers addressing them. A large proportion of taxa were addressed by only one or two papers over the nine year period. On the other hand, a small group of nine species were addressed by a relatively large number of papers. Species that received the most attention (nine or more papers each) were *Nassella neesiana* (19 papers), *N. trichotoma* (17), *Lantana camara* (13), *Parthenium hysterophorus* (13), *Parkinsonia aculeata* (11), *Rubus fruticosus* agg. (10), *Alternanthera phileroxoides* (10), *Orobanche* spp. (9), and *Ulex europaeus* (9). Together, these species accounted for 40.3% (n=102) of the grazing-relevant papers at the AWC Proceedings. All but two of these were

among those identified as being of "greatest significance to Australian grazing industries" in Grice (2003). The exceptions were *Orobanche* spp. and *Alternanthera phileroxoides.* The former is largely a weed of southern Australian cropping systems; both were listed among weeds of significance (though not those of greatest significance) to livestock industries in Grice (2003). Seventeen species listed as being of "greatest significance" in 2003 had no coverage by papers published in subsequent AWC Proceedings. This list included one of the additional WoNS declared in 2012–13 (*Lycium ferocissimum*).

Two species identified as grazing-relevant are deliberately introduced grasses that have, at least in the past been promoted as useful pasture species. They are *Hymenachne amplexicaulis* and *Andropogon gayanus*, both listed as WoNS. While they are broadly "grazing-relevant", they are not generally seen as problematic for livestock industries.

Twenty-seven species that were the focus of at least one paper each in the AWC Proceedings and that are grazing-relevant were not mentioned in Grice 2003.

Papers in AWC Proceedings covered a wide variety of topics. We classified them into 12 categories (Appendix 15). Well over 40% of papers dealt with control methods and 50% of those addressed biological control. A relatively large proportion of papers also fell into the category of ecology. Together, ecology and control methods accounted for almost 64% of papers. Communications and extension, policy and economics each accounted for less than 6% of the papers published.

AWC papers specifically addressed biological control of 35 plant species (Appendix 16). They include general assessments of the prospects of biological control, either on the basis of a single potential agent or more comprehensive native range surveys; evaluations of the impacts that agents have under controlled or field conditions, investigations of aspects of the biology of prospective or released agents; and a few methodological studies. Sixteen of the species listed in Appendix 16 as biological control targets are WoNS (though these 16 represent only 13 WoNS as two of the 14 WoNS incorporate multiple species in the listing). All but seven of the AWC referenced biological control targets were identified as weeds of significance to Australian grazing industries in 2003 (Grice 2003).

PUBLICATIONS IN WEB OF SCIENCE

Of the 292 publications recorded in the Web of Science database for 2003 to 2013, 170 were journal articles, 83 were papers in the AWC Proceedings and the remaining articles (39) were other conference papers and reports (Figure 4). Note that the Web of Science search yielded far fewer (n=83) grazing/pasture-related weeds papers from the AWC Proceedings than did direct inspection of the Proceedings themselves (n = 253).

Only journal articles are considered in this section. The 170 papers concern some 63 weed species (Appendix 17), with the most studied species (judged in terms of the number of papers) being *Cenchrus ciliaris* (12), *Nassella neesiana* (11), *N. trichotoma* (11), *Vulpia* spp. (10), *Parthenium hysterophorus* (6), *Phyla canescens* (6), and *Carduus nutans* (4); three of which are WoNS.

Review papers included the transport of seeds by livestock and reviews of the introduction of new pasture species as an outcome of the Future Farm Industries CRC and their consideration of the weed risk of these new introductions. Other major subject areas (as measured by the number of papers) included biological control (17), fire (14), herbicides (31) and poisonous plants (11). The large number of weeds studied points to a lack of overall research strategy and an *ad hoc* approach, all within a declining output (Figure 4). In contrast, most areas of scientific research have increasing numbers of papers over the same period.

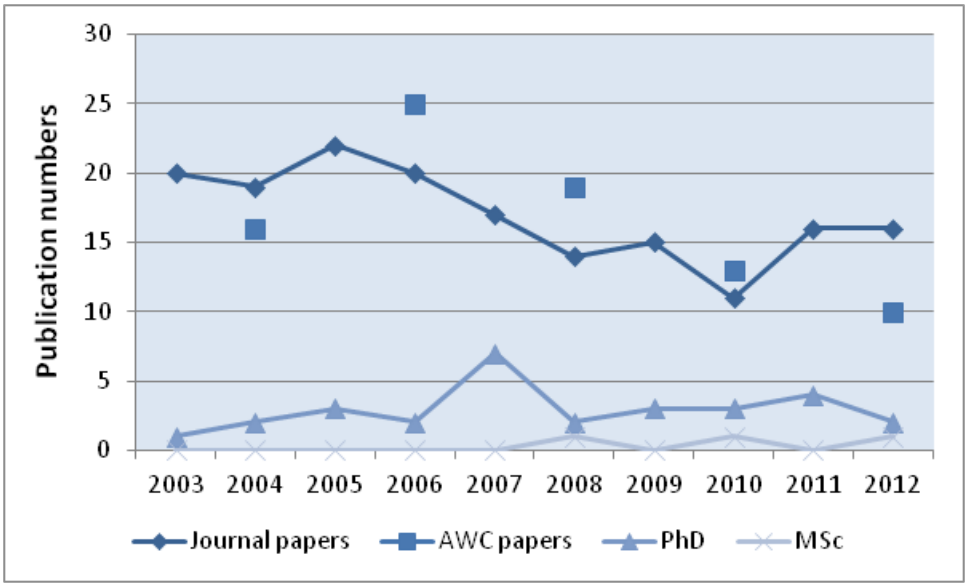


Figure 4. Numbers of publications in Proceedings of the Australian Weeds Conferences (AWC papers) and scientific journal papers (Journal papers), for the period 2003 to 2013 that relate to grazing or pasture weeds in Australia, which are reported in Web of Science. Numbers of PhD and MSc theses completed in the same period are also included.

PHD AND MSC THESES

Most years, including each of the last five, saw the awarding of three or four PhDs of relevance to weeds of livestock industries in Australia. The only peak in output over the ten years under consideration was in 2007, with seven theses being completed (Figure 4). This corresponds to the end of the Weeds CRC and the winding up of its activities, including support for students. In contrast to livestock industry focused studies, the number of PhDs across all subjects nationally continues to increase each year, even if the rate of increase has slowed in recent times (Dobson 2012).

Twenty-seven weed species were studied over a wide range of topics (Appendix 18). The most studied species was *Parthenium hysterophorus* (3) and studies included 14 species from the Grice (2003) list of 47 species of greatest importance to livestock industries (Appendix 2). Most of these (21 out of 27) were species-focused studies, or concerned with pasture management (6). Likewise the studies were widely dispersed across locations (Appendix 18) and Universities (Appendix 19), with the main centres of study being the Universities of New England, Queensland and Western Australia.

Synopsis of Trotter (2007)

Trotter's (2007) PhD thesis is highly relevant to this review as it examined livestock producers' perspectives and perceptions about weeds on grazing lands in southern Australia, using a combination of interviews, a postal survey and focus group discussions. The work targeted beef, wool and mixed grazing enterprises in south-east Queensland, inland NSW, most of Victoria, south-eastern South Australia, south-western Western Australia and northern Tasmania. Producers who responded to the postal survey identified approximately 328 plant species that they regarded as problematic, though only 107 species were reported by more than 0.5% (n = 924) of respondents. This suggests that there may be a "long tail" of non-native plants that are of limited significance or restricted distribution. Trotter's list includes four native genera, the trees *Eucalyptus* and *Leptospermum*, the shrub *Cassinia* and the grasses *Stipa* spp. The majority of the 20 most frequently reported weed species were broad-leaved plants, mostly annuals, with only three grass species. The most commonly reported weeds overall were *Arctotheca calendula*, *Echium plantagineum*, *Hordeum* spp., *Carthamus lanatus* and *Rubus fruticosus* agg. There was some agreement

between the five regions, for which data were analysed separately, in terms of the most commonly reported weeds. In addition to the five most commonly reported taxa overall, *Marrubium vulgare*, "thistles", *Vulpia* spp. and *Xanthium spinosum*, among others, were frequently reported. Trotter conducted more detailed analyses on four species, one from each of four functional groups: *Arctotheca calendula* (annual broadleaf), *Rubus fruticosus* agg. (perennial broadleaf), *Hordeum* spp. (annual grass) and *Nassella trichotoma* (perennial grass).

DEFEATING THE WEED MENACE PROGRAM

The Australian Government, through DAFF (now known as the Department of Agriculture) and the Department of the Environment & Heritage (formerly known as SEWPaC and now Department of Environment), initiated the Defeating the Weed Menace (DWM) program in 2004, with a commitment of $40 million over four years to tackle Australia's most significant weeds. This initiative expanded activities on weeds, which had previously been funded under the Natural Heritage Trust (2002–08) that focused on biodiversity conservation, sustainable use of natural resources and community capacity building at the local (Envirofund), regional and national levels.

Through a competitive grant process, the DWM program provided funding for on-ground actions and awareness, and also included a R&D component that began in 2006 and was administered by the now defunct Land and Water Australia.

Of the 120 on-ground/awareness projects, 68 targeted weeds of relevance to livestock industries: the WoNS – *Vachellia nilotica*[6] (3), *Alternanthera phileroxoides* (3), *Cabomba caroliniana* (3), *Cryptostegia grandiflora* (8), *Lantana camara* (13), *Mimosa pigra* (5), *Nassella neesiana* (7), *N. trichotoma* (4), *Parkinsonia aculeata* (5), *Parthenium hysterophorus* (5), *Prosopis* spp. (3)*, Rubus fruticosus* agg. (4), *Salvinia molesta* (2), *Tamarix aphylla* (3) and *Ulex europaeus* (6), and two priority 'sleeper weeds' – *Hieracium aurantiacum* (1) and *Cynoglossum creticum* (1). Of the projects directly or indirectly related to livestock industries, 29% were actively involved with the on-ground control of the target weeds to eradicate localised infestations, maintain containment lines or continue general control activities within specific regions. Another 26% of projects were concerned with biological control, including both research on new agents and on-ground delivery, while 19% concentrated on developing, demonstrating and/or implementing best practice integrated management. The latter grouping comprised projects in which a survey of flupropanate resistance in *Nassella trichotoma* was performed and the benefits of grazing management for *Nassella neesiana* demonstrated. Education and awareness activities were the key focus of 16% of projects, with four of those specifically designed to develop Best Management Practice manuals. The remaining projects were supported to develop national strategic actions (e.g. national strategy to prevent weed spread) or provide funding for activities of specific WoNS Management Groups and Coordinators.

Four additional projects not included in the above grazing-related 68 projects, focused on the WoNS *Hymenachne amplexicaulis*, a ponded pasture species that provides forage for cattle, but also causes major problems in native wetland habitat. These projects aimed at (i) developing practical approaches for the management of the species considering both ecological and economic factors; (ii) controlling the weed in high priority catchments; and (iii) increasing stakeholder awareness.

The R&D component of the DWM program had the following three overarching goals:

(i) to generate new knowledge to prevent the development of new weed problems
(ii) to reduce the impacts of existing weeds of national priority

[6] Formerly *Acacia nilotica.*

(iii) to build the capacity for their management into the future.

The program funded 27 R&D projects from 2006–08, with 8 focusing on weed species relevant to the livestock industries. Five of these concentrated solely on biological control (*Cytisus scoparius*, *Genista monspessulana*, *Parkinsonia aculeata*, *Salvinia molesta*, *Xanthium occidentale*) and two involved biological control within the broader management context of the weed (*Alternanthera phileroxoides*, *Prosopis* spp.). One other project targeted *Nassella trichotoma* and identified that the key to preventing establishment was the constant and diligent use of control techniques that minimise disturbance. Three generic projects on pathway risk analysis for weed spread, best practice for on-ground weed detection and climate change impacts modelling "sleeper" and alert list weed species were carried out and have relevance to the industry. It is noteworthy that the R&D program also invested in three projects that investigated the environmental impacts of tropical pasture grasses (*Andropogon gayanus*, *Cenchrus ciliaris, Hymenachne amplexicaulis*) and the benefits and costs of different approaches to manage them.

AUSTRALIAN WEED RESEARCH CENTRE & NATIONAL WEEDS AND PRODUCTIVITY RESEARCH PROGRAM

In 2008, the Australia Government allocated $15.3 million over four years to support research on weeds in light of the unsuccessful rebid for a Weeds CRC and the end of the DWM program. A small proportion of the funds ($0.3 million) was earmarked at the very beginning for a research project on the management of *Senecio madagascariensis*. In the first year the initiative was referred to as the Australian Weed Research Centre, and allocated nearly $3.6 million to 39 projects. In 2009–2010, RIRDC was asked to develop a five year strategic plan for weed research and manage the second stage of the program (NWPRP 2010). By then the program was referred to as the National Weeds and Productivity Research Program (NWPRP), which was overseen by a Weeds R&D Advisory Committee. The program goal was to improve the management of weeds in agriculture, forests, pastures and native vegetation. It funded a total of 56 R&D projects up to June 2012.

Slightly more than 26% of the 95 projects undertaken targeted specific weeds of direct relevance to livestock industries. Twelve projects investigated, implemented and/or assessed classical biological control for the WoNS *Vachellia nilotica*[7], *Alternanthera phileroxoides*, *Cylindropuntia* spp. including *C. rosea*, *Cytisus scoparius*, *Genista monspessulana*, *Nassella neesiana*, *N. trichotoma*, *Parkinsonia aculeata*, *Rubus fruticosus* agg., *Ulex europaeus* and three other species; *Echium plantagineum*, *Phyla canescens* and *Sporobolus* spp. Two other projects investigated dieback that is naturally-occurring in six grazing-relevant WoNS in Australia (*Vachellia nilotica*, *Jatropha gossypiifolia*, *Mimosa pigra*, *Parkinsonia aculeata*, *Rubus fruticosus* agg. and *Tamarix aphylla*) and phytotoxins produced by a potential bioherbicide candidate (*Phomopsis* spp.) for *Carthamus lanatus*.

Nassella trichotoma was the focus of four other projects that investigated motivation to control and adoption of control practices, landscape scale management and extent of herbicide-resistance to flupropanate. The use of suppressive/competitive pasture species for weed management was assessed in two projects focusing on *Lantana montevidensis* and *Parthenium hysterophorus*, while other projects developed a Best Practice Manual for *Jatropha gossypiifolia* and assessed the effectiveness of different control options for *Parthenium hysterophorus* and *Bryophyllum* spp. The remaining three projects: (i) modelled the risk of invasions in the Murray Darling Basin by *Parthenium hysterophorus*, *Phyla canescens* and *Nassella neesiana*; (ii) developed a second generation dispersal model of *Hieracium* spp. to improve detection and eradication; and (iii) demonstrated the use of unmanned aerial vehicles for the detection of *Opuntia robusta*.

[7] Formerly *Acacia nilotica.*

Another 38% of the total projects undertaken either focused on generic issues of some relevance to livestock industries or on specific weeds that do affect these industries but within a different context. Seven projects were concerned with herbicide-resistance, five of which specifically investigated *Lolium rigidum*, an important crop weed, but also found in pastures. Two other projects carried out research into the development of a novel control method to reduce seed production in *Raphanus raphanistrum*, another crop weed of some grazing relevance. Commercially valued grasses that cause problems outside of agriculture, such as *Andropogon gayanus* and *Hymenachne amplexicaulis*, were investigated in five projects, and the ecology and impact of the aquatic weeds *Cabomba caroliniana* and *Alternanthera phileroxoides*, that are sometimes considered a problem for livestock industries, in two projects. Three projects explored the potential impact of climate change on the distribution of agricultural weeds or herbicide efficiency under elevated CO_2. Novel technologies were the focus of four additional projects: (i) assessment of novel molecular diagnostics and genetic diversity methods for rapid and accurate identification of weed species and biotypes; (ii) hyperspectral remote sensing for enhanced weed detection and (iii) the development of a biodegradable mat and (iv) a microwave system for weed control. The remaining projects addressed other generic issues of relevance to the livestock industries, which ranged from weed threat identification, weed seed persistence, containment, eradication, surveillance, livestock grazing in native areas and information systems.

The remaining 36% of projects targeted environmental or cropping weeds and issues of broader governance, social and communication matters relating to weed management.

MEAT AND LIVESTOCK AUSTRALIA

In the period post-2003, MLA also invested in projects on weed issues relevant to livestock industries (Appendix 20). In addition to a range of research projects covering aspects such as biological control, adoption of weed management, novel surveillance systems and integrated management, MLA supported the development of resources to enhance the delivery of technical weed management information to producers. Guidelines and case study reports cover specific weeds including *Solanum elaeagnifolium*, *Nassella trichotoma*, *N. neesiana*, *Echium plantagineum*, *Eragrostis curvula* and *Onopordum* spp.

Of particular interest is the report by Barker *et al.* (2006) that considered threats to Australian livestock industries from plants currently being cultivated as garden plants. This review examined the DAFWA Plant Database (Randall 2006) to identify plants currently available from Australian nurseries that could naturalise and pose a threat to livestock industries. It identified 1081 species that present some risk, and, of these, 281 had “foremost potential to threaten Australia’s livestock industries”. This potential was determined on the basis of whether the species had been recorded as “weedy” overseas, declared as “noxious” overseas and/or have the capacity to harm livestock. Generally, the species listed by Barker *et al.* (2006) do not occur in lists of weeds relevant to Australian livestock industries, though *Nassella tenuissima* was listed in Grice (2003) and *Equisetum* spp. were the subject of a conference paper published since 2003 (Ainsworth *et al.* 2006).

A draft discussion paper and final report prepared for MLA (Mason 2012a, b) proposed a RD&E investment framework relating to weeds of livestock industries. It argued for two approaches. The first was to involve a focus on the most important weeds, an understanding of their ecology and the development and delivery of biological, chemical and other control options. The second was to be a focus on grazed ecosystems in which “multiple weed challenges” are addressed in a holistic manner including giving consideration to the attitudes and motivations of livestock producers. Three outcomes were to be pursued:

(i) increased capacity of livestock producers to incorporate weed management into multi-purpose pasture management;
(ii) increased profit from livestock enterprises through reduced weed impacts;
(iii) reduced risk of new weeds or of increased weed burdens in grazed systems.

Five strategies to achieve these outcomes were proposed:

(i) contributions to major/national weed strategies relevant to livestock industries;
(ii) development of a system so that weed R&D addressed the paddock-level needs of individual producers;
(iii) support to develop and improve delivery of the outputs of R&D at the paddock level;
(iv) producer-initiated R&D involving "weed-management-within-production-systems" to involve producers and demonstrate effective weed management;
(v) industry-specific R&D on surveillance of "sleeper" or "emerging" weeds likely to impact on livestock industries.

Feedback on Discussion Paper

Feedback on the Discussion Paper that was any earlier output of this project was received from a wide variety of sources including weed scientists and various groups and individuals with knowledge of weed issues that are relevant to livestock industries and enterprises. Among other things it pointed to a number of species that either had not been listed in the Discussion Paper or were deemed by respondents to be worthy of greater emphasis (see Appendices 10, 11). Some of the other important issues raised by respondents were:

- terms used to describe grazing-related weed issues and priorities should be expressly defined;
- the relative importance of weed versus other issues impacting livestock enterprises and industries should be explored;
- important geographical variation in the identification and description of weed issues and in the prioritisation of RD&E should be recognised;
- the process used to prioritise weed issues for Australian livestock industries should be clearly described;
- it should be recognised that some "weeds", even species that might be regarded as weeds of livestock industries, may also provide useful forage resources so the definition of a "weed" of livestock industries is not as clear cut as a weed of, for, example, cropping industries where, generally, weed species provide no benefit. This also relates to the prospect that some weeds of livestock industries can actually be managed by livestock grazing regimes;
- prevention of weed problems is critical for livestock industries, particularly given the costs of weed management versus returns from livestock enterprises.

This report has attempted to reasonably take account of this feedback.

Grazing-relevant weeds and RD&E priorities

PROMINENT WEEDS

Our review of the literature produced since 2003 yielded a long list of weeds that are broadly grazing-relevant. One of the literature sources consulted (Sindel *et al.* 2008), was not set up as a prioritisation exercise for weeds of livestock industries but it was the only source that was national in scope and it provided valuable information for identifying important grazing-relevant weeds. The national landholder survey they carried out gathered relevant data on weeds that were of most concern to grazing and mixed cropping and livestock enterprises.

Each of the other sources we used provided information on important weeds within smaller (i.e. not national) jurisdictions. They covered either entire states (e.g. Biosecurity SA 2011; NSW DPI 2013; S. Johnson *pers. comm.*) or parts of states (e.g. Trotter 2007). For example, the PhD work of Trotter (2007) surveyed southern Australian graziers and identified a larger number of species, higher taxa and broad groups of plants that some considered important. Our searches indicated that since 2002 southern Australia has received a lot more attention

than northern Australia in terms of studies that can be used to identify important weed species. In fact we included Bebawi *et al*. (2002) because it was the sole relevant study that covered northern Queensland. We considered seven sources covering southern Australia but found only one covering the north (van Klinken *et al.* 2013), though we recognise that further prioritisation efforts are currently underway in Queensland (T. Pople, S. Campbell, O. Osunkoya, *pers. comm.*) [8]. This involves a survey of stakeholders (local government, biosecurity officers, NRM bodies) and targeted workshops; the survey asked participants to identify the five top priority weeds or weed issues that should be the target of research to improve management. The geographical bias we observed in pre-existing information that can be mined for identifying important weeds for the industry, inevitably translates into bias in any synthesis designed to provide an up-to-date national list of grazing-relevant weeds for Australia. We found no source that specifically covered Western Australia, except Borger *et al.* (2012) which focused on the south-western Australian wheat belt. We were not able to obtain recent Weed Risk Management (WRM) assessment material from NT government departments.

Our final list of prominent weeds affecting livestock industries consists of 71 taxa (Table 2), following removal of species that are grazing-relevant but not problematic for livestock industries, native species, and species that are often present on grazing lands but really only problematic for cropping enterprises.

[8] The results of this Queensland-wide survey are currently being analysed by Biosecurity Queensland but they were not available for use at the time of preparation of this report (Olusegun Osunkoya, pers. comm. 17 October 2013)

Table 2. Prominent weed species currently affecting Australian grazing industries. Species are ascribed to the climatic zone where most herbarium records are from (based on the Australian Virtual Herbarium): N = northern Australia (north of the Tropic of Capricorn); S = southern Australia; W = widespread (i.e. neither mainly N nor mainly S). Note that species are arranged in alphabetical order – numbering **DOES NOT** indicate priority ranking.

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM	CLIMATIC ZONE
1	*Andropogon gayanus*	Gamba grass	perennial grass	N
2	*Arctotheca calendula*	Capeweed	annual forb	S
3	*Asphodelus fistulosus*	Onion weed	annual/perennial forb	S
4	*Bryophyllum delagoense*	Mother-of-millions	succulent	W
5	*Calotropis procera*	Calotrope	shrub	N
6	*Carduus* spp. *(*include *C. tenuiflorus)*	Slender thistles	annual forb	S
7	*Carthamus lanatus*	Saffron thistle	annual forb	S
8	*Cenchrus incertus*	Innocent weed	annual grass	S
9	*Cenchrus longispinus*	Innocent weed	annual grass	S
10	*Cenchrus pedicellatus*	Annual mission grass	annual grass	N
11	*Cenchrus polystachios*	Perennial mission grass	perennial grass	N
12	*Cirsium arvense*	Californian thistle	perennial forb	S
13	*Cirsium vulgare*	Spear thistle	annual forb	S
14	*Cryptostegia grandiflora*	Rubber vine	shrub/vine	N
15	*Cylindropuntia* spp.	Hudson pear	succulent	W
16	*Cytisus scoparius*	Broom	shrub	S
17	*Diplotaxis tenuifolia*	Lincoln weed	annual forb	S
18	*Echium plantagineum*	Paterson’s curse	annual forb	S
19	*Emex australis*	Spiny emex	annual forb	S
20	*Eragrostis curvula*	African love grass	perennial grass	S
21	*Erodium cicutarium*	Common storksbill	annual forb	S
22	*Euphorbia terracina*	False caper	perennial forb	S
23	*Galium tricornutum*	Three-horned bedstraw	annual forb	S
24	*Harrisia martinii*	Harrisia cactus	succulent	N
25	*Hordeum* spp.	Barley grass	annual grass	S
26	*Hyparrhenia hirta*	Coolatai grass	perennial grass	W
27	*Hyparrhenia rufa*	Thatch grass	perenial grass	W
28	*Hypericum perforatum*	St. John's wort	annual forb	S
29	*Hypochaeris* spp.	Cat's ear	annual forb	S
30	*Hyptis suaveolens*	Hyptis	annual forb	N
31	*Jatropha gossypiifolia*	Bellyache bush	shrub	N
32	*Lantana camara*	Lantana	shrub	W
33	*Lantana montevidensis*	Creeping lantana	shrub	W
34	*Lycium ferocissimum*	African boxthorn	shrub	S
35	*Marrubium vulgare*	Horehound	annual forb	S
36	*Mimosa diplotricha*	Giant sensitive plant	shrub	N

Table 2 (Continued)

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM	CLIMATIC ZONE
37	*Mimosa pigra*	Giant sensitive plant	shrub	N
38	*Moraea flaccida* (syn. *Homeria flaccida*)	One-leaf Cape tulip	perennial forb	S
39	*Moraea miniata* (syn. *Homeria miniata*)	Two-leaf Cape tulip	perennial forb	S
40	*Nassella neesiana*	Chilean needle grass	perennial grass	S
41	*Nassella trichotoma*	Serrated tussock	perennial grass	S
42	*Onopordum* spp.	Onopordum thistles	annual forb	S
43	*Opuntia* spp.	Opuntioid cacti	succulent	W
44	*Parkinsonia aculeata*	Parkinsonia	shrub	W
45	*Parthenium hysterophorus*	Parthenium weed	annual forb	N
46	*Phyla canescens*	Lippia	perennial forb	S
47	*Prosopis* spp.	Mesquite	tree/shrub	W
48	*Raphanus raphanistrum*	Wild radish	annual forb	S
49	*Reseda lutea*	Cutleaf mignonette	annual forb	S
50	*Romulea rosea*	Guildford grass (=onion grass)	perennial forb	S
51	*Rosa rubiginosa*	Sweet briar	shrub	S
52	*Rubus fruticosus* agg.[9]	Blackberry	shrub	W
53	*Rumex* spp.	Dock	perennial forb	S
54	*Senecio jacobaea*	Ragwort	perennial forb	S
55	*Senecio madagascariensis*	Fireweed	perennial forb	S
56	*Senna obtusifolia*	Sicklepod	shrub	N
57	*Solanum elaeagnifolium*	Silverleaf nightshade	perennial forb	S
58	*Sporobolus africanus*	Parramatta grass	perennial grass	W
59	*Sporobolus fertilis (*syn *S. indicus* var. *major*)	Giant Parramatta grass	perennial grass	W
60	*Sporobolus jacquemontii*	American rat's tail grass	perennial grass	N
61	*Sporobolus natalensis*	Giant rat's tail grass	perennial grass	W
62	*Sporobolus pyramidalis*	Giant rat's tail grass	perennial grass	W
63	*Tamarix aphylla*	Athel pine	tree	W
64	*Themeda quadrivalvis*	Grader grass	annual grass	N
65	*Tribulus terrestris*	Caltrop	annual forb	W
66	*Ulex europaeus*	Gorse	shrub	S
67	*Vachellia nilotica* ssp. *indica*[10]	Prickly acacia	tree/shrub	N
68	*Vulpia* spp.	Vulpia or silvergrass	annual grass	S
69	*Xanthium occidentale* (syn. *X. strumarium*)	Noogoora burr	annual forb	W
70	*Xanthium spinosum*	Bathurst burr	annual forb	W
71	*Ziziphus mauritiana*	Chinee apple	tree/shrub	N

[9] Mainly *Rubus anglocandicans*
[10] Formerly *Acacia nilotica.*

EMERGING WEEDS

Our final list of emerging weeds with potential to affect grazing industries is comprised of 18 taxa (Table 3). Here we provide brief accounts of each of these emerging weed species:

Acaciella angustissima (Fabaceae)

Acaciella angustissima (syn. *Acacia angustissima*) (White ball acacia) was identified as being a potential weed during field trials to select suitable pasture species. The weed produces prolific amounts of hard seed, is adapted to a wide range of climates and is relatively unpalatable. It is now targeted for control at old pasture trial sites across Queensland.

Key references:

Gardiner C, Chanclud N, Clouten B, Cox K (2008) Acaciella angustissima: a soil seed bank study. Proceedings of the 16th Australian Weeds Conference, Cairns Convention Centre, North Queensland, Australia, 18-22 May, 2008, pp 187-188.

Gardiner C, Cox K, Wright C, Keating M (2010) Passage and survival of *Acaciella angustissima* (Mill.) Britton & Rose and *Aeschynomene paniculata* Willd. ex Vogel seed through the sheep gut. Proceedings of the 17th Australasian Weeds Conference. New frontiers in New Zealand: together we can beat the weeds. Christchurch, New Zealand, 26-30 September, 2010, pp. 418-420

Aeschynomene paniculata (Fabaceae)

Aeschynomene paniculata (Panicle jointvetch) is a shrubby legume native to Central and South America. In its native habitat, *A. paniculata* grows on rocky vegetated slopes, in meadows, open woods and savannahs at elevations up to 1,500m. In Brazil it is found in open pasture, secondary succession and disturbed vegetation. There appears to be no noticeable soil or habitat association. It has been considered as a prospective forage species for northern Australia. It has been recorded from relatively few sites but these are widely spread, including Cape York Peninsula and Cairns regions in Queensland and around Darwin in the Northern Territory. It has been listed as a sleeper species because of its potential threat to agriculture.

Key reference:

Cameron AG (1996) Evaluation of tropical pasture species as leys in the semi-arid tropics of northern Australia. Australian Journal of Experimental Agriculture 36:929-935.

Cascabela thevetia (Apocynaceae)

Cascabela thevetia (Yellow oleander) is a shrub that is native to tropical parts of South America but is now naturalised in Asia, some Pacific Islands and in Australia where it is widely distributed in coastal and sub-coastal parts of the tropics and subtropics in Western Australia, the Northern Territory and as far south as south-east Queensland, though currently mostly close to settlements, often along creek lines. It is recognised as an environmental weed, as well as a weed of pasture, and is a Class 3 Declared Plant in Queensland.

Key reference:

http://www.daff.qld.gov.au/plants/weeds-pest-animals-ants/weeds/a-z-listing-of-weeds/photo-guide-to-weeds/captain-cook-tree-or-yellow-oleander (Accessed 14 October 2013)

Table 3. Emerging weed species with potential to affect Australian grazing industries. Species are ascribed to the climatic zone where most herbarium records are from (based on the Australian Virtual Herbarium): N = northern Australia (north of the Tropic of Capricorn); S = southern Australia; W = widespread (i.e. neither mainly N nor mainly S). Note that species are arranged in alphabetical order – numbering **DOES NOT** indicate priority ranking.

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM	CLIMATIC ZONE
1	*Acaciella angustissima*	White ball acacia	shrub	dry tropics
2	*Aeschynomene paniculata*	Panicle joint vetch	perennial shrub	dry tropics
3	*Cascabela thevetia*	Yellow oleander	shrub	wet tropics
4	*Chromolaena odorata*	Siam weed	shrub	tropics & subtropics
5	*Clidemia hirta*	Koster's curse	shrub	tropics
6	*Cyperus aromaticus*	Navua sedge	perennial sedge	tropics
7	*Elephantopus mollis*	Tobacco weed	forb	tropics
8	*Florestina tripteris*	Florestina	forb	tropics
9	*Gmelina elliptica*	Badhara bush	shrub/small tree	tropics
10	*Gomphocarpus fruticosus*	Cottonbush	shrub	temperate
11	*Hieracium* spp., especially *H. aurantiacum*	Hawkweeds	forb	temperate
12	*Lavandula stoechas*	Topped lavender = Spanish lavender	shrub	warm temperate
13	*Nassella charruana*	Lobed needle-grass	perennial grass	temperate
14	*Nassella hyalina*	Cane needle-grass	perennial grass	temperate
15	*Physalis viscosa*	Prairie ground cherry	forb	warm temperate
16	*Praxelis clematidea*	Praxelis	forb	tropics & subtropics
17	*Rubus alceifolius*	Giant bramble	shrub	wet tropics
18	*Solanum viarum*	Tropical soda apple	tree	tropics & subtropics

***Chromolaena odorata* (Asteraceae)**

Chromolaena odorata (Siam weed) is a scrambling shrub that is regarded as one of the world's worst invasive plants. It is now widespread in the world's tropics and a serious weed of agriculture (livestock industries, horticulture, forestry and natural environments). Although it has probably been in Australia since the 1960s it was not discovered until 1994 after which it became a national eradication target. Since the eradication program was abandoned in 2012, the continued spread, including into grazing lands, is all but inevitable. The potential range of *Chromolaena odorata* in Australia is predicted to extend across coastal and sub-coastal areas from near Broome (Western Australia) to far northern NSW. There has been some success with biological control overseas and it is now a biocontrol target in Australia. It will be important to continue to raise awareness of this weed amongst land-holders and promote use of available control and containment measures.

Key references:

Jeffrey M (2012) Eradication: lessons learnt from 17 years of the National Siam Weed Eradication Program. In Eldershaw, V (ed.) Proceedings of the 18th Australian Weeds Conference, Weed Society of Victoria, Melbourne, Australia, 8-11 October 2012,. pp. 92-95.

Kriticos DJ, Yonow T, McFadyen RE (2005) The potential distribution of *Chromolaena odorata* (Siam weed) in relation to climate. Weed Research 45:246-254.

***Clidemia hirta* (Melastomataceae)**

Clidemia hirta (Koster's curse) is a perennial shrub (up to 3m in height) native to the tropical Americas (humid, tropical lowlands of Central and South America) and the Caribbean Islands. The seed is bird dispersed with seed longevity probably in excess of ten years. Plants arrive at reproductive maturity in one year. It is considered a weed in 18 countries, where it forms dense thickets that smothers young plantations of cocoa, tea, coconut and oil palm, pastures and native vegetation. *Clidemia hirta* has been subjected to an eradication program since 2004 following its discovery at Julatten, north Queensland in 2001 and currently is only known from one infestation at this location.

Key reference:

Breaden RC, Brooks SJ, Murphy HT (2012) The biology of Australia weeds: 59. *Clidemia hirta* (L.) D. Don. Plant Protection Quarterly 27:3-18.

***Cyperus aromaticus* (Cyperaceae)**

Following the discovery of *Cyperus aromaticus* (Navua sedge) in 1979 in Cairns, the weed has spread, mainly in northern Queensland. It is an aggressive weed of pastures in Fiji, Sri Lanka, the Malay Peninsula, Vanuatu, Samoa, the Solomon Islands, and Tahiti and is now a weed of pastures and roadsides in north Queensland, Australia. Navua sedge is capable of forming dense stands, smothering many tropical pasture species. Herbicide treatments have been investigated and were more effective than slashing or cultivation treatments which could prolong seed persistence.

Key reference:

Vitelli JS, Madigan BA, van Haaren PE (2010) Control techniques and management strategies for the problematic Navua sedge (*Cyperus aromaticus*). Invasive Plant Science and Management 3:315-326.

***Elephantopus mollis* (Asteraceae)**

Elephantopus mollis (Tobacco weed) is a vigorous and aggressive weed and is regarded as a serious weed of agriculture in many wet tropical or subtropical countries. It is found in Queensland where it is a major threat to beef and diary industries.

Key reference:

Queensland Department of Employment Economic Development and Innovation (2009) Fact sheet DECLARED CLASS 2 Pest plant Tobacco weed *Elephantopus mollis*. Retrieved from http://www.daff.qld.gov.au/plants/weeds-pest-animals-ants/weeds/a-z-listing-of-weeds/photo-guide-to-weeds/tobacco-weed/?a=68451. Accessed 14 October 2013.

***Florestina tripteris* (Asteraceae)**
Florestina tripteris (Florestina) is an annual exotic weed native to south-central Texas and Mexico and is believed to have been accidentally introduced to Australia in 1964.It grows mostly along roadsides and in disturbed fields, occurring on various soils from near sea level to about 900 m. It was first collected from Tambo and more recently from Barcaldine in Queensland. Florestina seeds are easily spread by stock and vehicles. Florestina closely resembles *Parthenium hysterophorus* in flower structure and growth form.

Key reference:
Brazier D, McKenzie J, Owen A, Campbell S, Vitelli J, Reid A, Mayer R (2010) Evaluating herbicides for the control of the invasive weed florestina (*Florestina tripteris* DC.). Proceedings of the 17th Australasian Weeds Conference. New frontiers in New Zealand: together we can beat the weeds. Christchurch, New Zealand, 26-30 September, 2010:421-423.

***Gmelina elliptica* (Lamiaceae)**
Gmelina elliptica (Badhara bush) is a small shrub or tree that is native to a range covering the continent and islands of southern and south-eastern Asia through to the Pacific. Almost nothing has been published on this species according to scientific databases, whereas there is an extensive literature on its congener *Gmelina arborea*, which is a large tree extensively used in plantations. *Gmelina elliptica* forms secondary regrowth including dense thickets, especially along roads and other open sites in coastal regions up to 100 m altitude or to 500 m altitude in Java. It occurs in forest on limestone in Palau. *Gmelina elliptica* has been naturalised in Queensland around Rockhampton and Yeppoon since at least 1972. It is listed as a sleeper weed because of its potential threat to agriculture.

Key reference:
Munir A (1984) A taxonomic revision of the genus *Gmelina* L. (Verbenaceae) in Australia. Journal of the Adelaide Botanical Gardens 7:91-116.

***Gomphocarpus fruticosus* (Asclepiadaceae)**
Gomphocarpus fruiticosus (Narrow-leaf cotton bush) is a perennial shrub of South African origin that is widely naturalised but with a scattered distribution in Australia. It spreads by wind dispersed seeds. It is an emerging weed in the sense that it is increasing in abundance and invading new areas of pasture in south west Australia, especially between Perth and Bunbury. In unmanaged land it can form dense thickets covering many hectares. While highly toxic, it is not normally eaten by livestock. This lack of palatability enables it to invade and replace pasture.

Key reference:
Lloyd S and Rayner B (2012) Narrow-leaf cotton bush and its control. Western Australia Department of Agriculture and Food Farmnote 498:http://www.agric.wa.gov.au/PC_95260.html

***Hieracium* spp., especially *Hieracium aurantiacum* (Asteraceae)**
Four *Hieraceum* spp. have been recorded in Australia: *H. aurantiacum*, *H. praealtum*, *H. mucrorum* and *H. pilosella*. *Hieracium aurantiacum* (Orange hawkweed) is considered a potential threat since it was first reported as naturalised in alpine country and temperate tablelands of eastern Australia. *Hieracium aurantiacum* is found at disjunct locations in the Australian Alps and has proved difficult to control and prevent from spreading. *Hieracium aurantiacum* is considered a typical alpine species being found to 2800 m altitude in its native habitat, Europe. In introduced areas it invades a wide range of soils and altitudes. It is listed as both an alert and sleeper species because of its potential threat to the environment and agriculture.

Key reference:

McDougall KL, Morgan JW, Walsh NG, Williams RJ (2005) Plant invasions in treeless vegetation of the Australian Alps. Perspectives in Plant Ecology, Evolution and Systematics 7, 159-171.

Williams NSG and Holland KD (2007) The ecology and invasion history of hawkweeds (*Hieraceum* species) in Australia. Plant Protection Quarterly 22:76-80.

***Lavandula stoechas* (Lamiaceae)**
Lavandula stoechas (Topped lavender) is established in the Care Valley, South Australia following its introduction possibly as early as the 1800s. It is a weed of grassy woodlands and neighbouring pasture. It is also found in Western Australia as an environmental weed often on road verges. It is also a garden plant and is used for its essential oils and as a source of honey.

Key reference:
Nicholson H (2006) Conflicting values of topped lavender *Lavandula stoechas* L.: the essential oil on a complex issue. In: Preston C, Watts JH, Crossman ND (eds) Proceedings of the 15th Australian Weeds Conference, Managing Weeds in a Changing Climate. Adelaide, South Australia, 24-28 September 2006, pp 191-194

***Nassella charruana* (Poaceae)**
Nassella charruana is a grass native to South America. In its native distribution the plant is found in Rio Grande do Sul (Brazil), Buenos Aires, Corrientes, Entre Rios and Santa Fe (Argentina) and Uruguay. It is established in Victoria and assessed to be an environmental and agricultural threat to Australia. *Nassella charruana* is found on fertile shallow soils over limestone or “limy” soil layers in Uruguay. This soil association would considerably restrict the distribution in Australia. It is listed as both an alert and sleeper species.

Key references:
McLaren DA, Stajsic V and Gardener MR. (1998) The distribution and impact of South/North American stipoid grasses (Poaceae: Stipeae) in Australia. Plant Protection Quarterly 13:62-70.

McLaren DA, Stajsic V and Iaconis L. 2004. The distribution, impacts and identification of exotic stipoid grasses in Australia. Plant Protection Quarterly 19:59-66.

***Nassella hyalina* (Poaceae)**
Nassella hyalina is a grass native to South America. In its native distribution the plant is found in Rio Grande do Sul (Brazil), Buenos Aires, Corrientes, Entre Rios, Federal District, La Pampa, Mendoza, Santa Fe, Santiago del Estero and Tucuman (Argentina) and Uruguay. It is established in New South Wales and Victoria. It is listed as an Alert species and presents an environmental threat to Australia, as well as having potential as a weed of livestock industries.

Key references:
McLaren DA, Stajsic V and Gardener MR (1998) The distribution and impact of South/North American stipoid grasses (Poaceae: Stipeae) in Australia. Plant Protection Quarterly 13:62-70.

McLaren DA, Stajsic V & Iaconis L. (2004) The distribution, impacts and identification of exotic stipoid grasses in Australia. Plant Protection Quarterly 19:59-66.

***Physalis viscosa* (Solanaceae)**
Physalis viscosa (prairie ground cherry) is widespread but patchily distributed in Australia, being found in most states (except Northern Territory and Tasmania). This perennial herb, reproducing by creeping roots and by seed, was first recorded in Australia in 1909. Subsequently it invaded the Goulburn Valley where it remains a problem pasture weed along with other areas in northern Victoria and southern NSW. Its origins are in South America.

Key reference:

Sagliocco JL, Kwong RM, McLaren D, Weiss J, Morfe T and Hunt T (2008) Prairie ground cherry: what should be done before it is too late? Proceedings of the 16th Australian Weeds Conference, Cairns Convention Centre, North Queensland, Australia, 18-22 May, 2008, pp 268-270.

***Praxelis clematidea* (Asteraceae)**

Praxelis clematidea (praxelis) is an annual or short-lived herb from South America (Argentina, Brazil, Bolivia, Paraguay) that was first detected in the Innisfail and Tully regions, northern Queensland in 1993. In northern Queensland it is a weed of roadsides, stream banks and pastures and invades relatively undisturbed woodlands. In the Upper Herbert and Upper Burdekin River catchments of far north Queensland, *Praxelis clematidea* is the major weed nutrient-poor, sandy soils of grazed pastures and ungrazed areas in this seasonally dry tropical environment. It is listed as an Alert species.

Key reference:

Shaw KA and Kernot JC (2004) Extent of dense native woodland and exotic weed infestation in the extensive grazing lands of the Upper Herbert and Upper Burdekin River Catchments of far north Queensland: results of a producer survey. Tropical Grasslands 38, 112-116.

***Rubus alceifolius* (Rosaceae)**

Rubus alceifolius (Giant bramble) was introduced to Queensland, principally near Cairns but gradually spreading. Its history of arrival in Australia is unknown but it was present by at least 1943. It is native to south-eastern Asia and is also introduced to Indian Ocean islands where it is a major invader in natural and pasture ecosystems. It is a scrambling shrub with canes up to 5 m in length, and can form dense impenetrable thickets in developing pastures, blocking access to water, invading roadways and impeding farm management.

Key reference:

Queensland Department of Employment Economic Development and Innovation (2010) Fact sheet Pest plant Giant bramble *Rubus alceifolius*. Retrieved from http://www.daff.qld.gov.au/__data/assets/pdf_file/0003/50727/IPA-Giant-Bramble-PP24.pdf. Access date 14 October 2013.

***Solanum viarum* (Solanaceae)**

Solanum viarum (Tropical soda apple) is the most common pasture weed in Florida and throughout south east USA. It is managed by herbicides, mowing and reduced stocking rate with an annual cost (2006, in Florida) of $US15 million per year. Biological control has had some recent success against this weed in Florida. Tropical soda apple was probably present in Australia for some years before its discovery on the mid-north coast of NSW. Subsequent surveys found the weed had spread, possibly via movement of cattle (the seed passes through the digestive system) to as far away as Queensland. It was considered to be not feasible to eradicate. Control options should be applied because tropical soda apple is a serious potential threat to pasture and other agricultural activities.

Key references:

Charlton S, Henderson R, Michelmore M (2012) In the footsteps of cows. Using technology to predict new weed incursions. Developing solutions to evolving weed problems. Proceedings of the 18th Australasian Weeds Conference, Melbourne, Victoria, Australia, 8-11 October 2012, pp.1-4.

Mullahey JJ (2011) Biology, ecology, and control of tropical soda apple (*Solanum viarum*). Proceedings of the 23rd Asian-Pacific Weed Science Society Conference. Volume 1: weed management in a changing world. Cairns, Queensland, Australia, 26-29 September 2011, pp 382-390.

PRIORITY WEEDS FOR RD&E

The 71 prominent weeds were categorised into groups of higher and lower priority (Table 4) based on responses to a series of questions that were comprised in the decision tree (Figure 1; Appendix 21). Twenty taxa were categorised as being of higher priority (Table 4).

The 18 emerging weed species identified were also prioritised using the same decision tree as for prominent weeds (Table 5). Five species were categorised as being of higher priority; one species was categorised as being of intermediate priority.

Table 4. Prioritisation of prominent weeds of Australian livestock industries. (See Methodology section for more detail on the questions used in this table.)

If the weed is not controlled does it have high impact?				
NO	YES			
LOWER priority	**Are cost-effective control measures available?**			
	NO		YES	
	Is there a high likelihood of effective control measures being developed in the next 10 yr?		**Are control measures well and widely applied?**	
	YES	NO	NO	YES
	HIGHER priority	LOWER priority	HIGHER priority	LOWER priority
Andropogon gayanus	*Cylindropuntia* spp.	*Carduus* spp.	*Nassella neesiana*	*Cirsium arvense*
Arctotheca calendula	*Euphorbia terracina*	*Carthamus lanatus*	*Nassella trichotoma*	*Cirsium vulgare*
Asphodelus fistulosus	*Hyparrhenia hirta*	*Hordeum* spp.	*Parthenium hysterophorus*	*Cryptostegia grandiflora*
Bryophyllum delagoense	*Hyparrhenia rufa*	*Hypericum perforatum*	*Ziziphus mauritiana*	*Echium plantagineum*
Calotropis procera	*Lantana montevidensis*	*Jatropha gossypiifolia*		*Eragrostis curvula*
Cenchrus incertus	*Lycium ferocissimum*	*Lantana camara*		*Harrisia martinii*
Cenchrus longispinus	*Moraea flaccida*	*Raphanus raphanistrum*		*Mimosa pigra*
Cenchrus pedicellatus	*Moraea miniata*	*Romulea rosea*		*Onopordum* spp.
Cenchrus polystachios	*Opuntia spp.*	*Senecio madagascariensis*		*Senecio jacobaea*
Cytisus scoparius	*Phyla canescens*	*Solanum elaeagnifolium*		*Ulex europaeus*
Diplotaxis tenuifolia	*Prosopis* spp.	*Sporobolus jacquemontii*		*Xanthium occidentale*
Emex australis	*Rubus fruticosus* agg.	*Sporobolus natalensis*		
Erodium cicutarium	*Senna obtusifolia*	*Sporobolus pyramidalis*		
Galium tricornutum	*Sporobolus fertilis*	*Vulpia* spp.		
Hypochaeris spp.	*Themeda quadrivalvis*	*Xanthium spinosum*		
Hyptis suaveolens	*Vachellia nilotica*			

Table 4 (Continued)

If the weed is not controlled does it have high impact?				
NO	YES			
LOWER priority	**Are cost-effective control measures available?**			
	NO		YES	
	Is there a high likelihood of effective control measures being developed in the next 10 yr?		**Are control measures well and widely applied?**	
	YES	NO	NO	YES
	HIGHER priority	LOWER priority	HIGHER priority	LOWER priority
Marrubium vulgare *Mimosa diplotricha* *Parkinsonia aculeata* *Reseda lutea* *Rosa rubiginosa* *Rumex* spp. *Sporobolus africanus* *Tamarix aphylla* *Tribulus terrestris*				

Table 5. Prioritisation of emerging weeds of Australian livestock industries. (See Methodology section for more detail on the questions used in this table.)

If the weed is not controlled, does it have high impact?							
YES				NO			
Are cost-effective control measures available				**Is there a high likelihood of further spread and having high impact**			
YES		NO		YES		NO	
Are control measures well and widely applied		**Is there a high likelihood of effective control measures being developed in the next 10 years**		**Is there a high likelihood of effective control measures being developed in the next 10 years**		**Is there a high likelihood of effective control measures being developed in the next 10 years**	
NO	YES	YES	NO	YES	NO	YES	NO
HIGHER priority	LOWER priority	HIGHER priority	LOWER priority	MEDIUM priority	LOWER priority	MEDIUM priority	LOWER priority
Gomphocarpus fruticosus		*Chromolaena odorata* *Physalis viscosa* *Clidemia hirta* *Praxelis clematidea*	*Cyperus aromaticus* *Hieracium* spp. *Nassella hyalina*		*Rubus alceifolius* *Gmelina elliptica* *Solanum viarum* *Nassella charruana*	*Cascabela thevetia*	*Acaciella angustissima* *Aeschynomene paniculata* *Elephantopus mollis* *Florestina tripteris* *Lavandula stoechas*

Economic impacts

The screening of the 200 studies found during literature searches resulted in elimination of the majority. Only five studies meet all of the criteria we set for inclusion in the analysis (see Methodology section; Commonwealth Department of Environment and Heritage 2003, Sinden *et al.* 2004, Lloyd 2005, Page and Lacey 2006, AEC Group 2007). Using the benefit-cost analysis (BCA) framework, these studies identify and assess the benefits and costs associated with weed management alternatives. Two of them went one step further by comparing alternatives in terms of net present value and benefit-cost ratios (BCR) (AEC group 2007, Page and Lacey 2006).

Among these five studies, one applied a 'top down' approach to estimate the impacts of weeds on livestock industries (Sinden *et al.* 2004) and the others used a 'bottom up' approach by assessing the impacts of individual weeds.

Sinden *et al.* (2004) estimated the total impact of weeds on the livestock industries nationwide in terms of lost production and control costs as $ 2,862 million to $2,902 million per year (in 2012 AUD)[11]. The authors believe that even the upper end of this range is an underestimate because it includes only the cost of weed control and the value of lost production where estimation has been possible. The financial costs of weed control are estimated as the costs of chemicals, costs such as fuel for vehicles, and the cost of hired and contract labour. The annual control cost for the industry has a lower bound value of $413 million and an upper bound of $452 million. The range of estimates allows for low and high estimates of the costs of herbicides, and for geographic, seasonal and commodity variations in chemical use and other costs of weed control. The yield loss in livestock industries is estimated from the percentage losses and the existing average gross margin in the industry. The cost due to lost production is calculated to be $2,459 million per year.

Instead of estimating the financial impact of weeds on the whole industry, the remainder of the four studies that met our criteria applied a 'bottom up' approach and calculated the market costs of individual weed species. Table 6 documents, for each species, their costs to livestock industries at either national or State level (including cost due to production, control cost and other market costs as specified in the column headed "Note"), and the source of these impact estimates. For the purpose of easy comparison, all the cost figures are converted to 2012 dollars using Reserve Bank of Australia's inflation calculator.

[11] These figures include the costs to dairy cattle, beef cattle, grain-sheep, grain-beef, sheep-beef and sheep industries.

Table 6. The economic impacts of individual weed species on livestock industries (in 2012 AUD).

SCIENTIFIC NAME (COMMON NAME)	COST DUE TO LOST PRODUCTION ($M/YEAR)	CONTROL COST ($M/YEAR)	OTHER MARKET COSTS ($M/YEAR)	NOTES	SOURCE
National level					
Lantana camara (lantana)		20.1	122.6	Other costs = cost of lost production + increased management expenses	(AEC group 2007)
Cryptostegia grandiflora (rubber vine)			24.8	Other cost = cost of reduced carrying capacity of pasture.	(Page and Lacey 2006)
Echium plantagineum (Paterson's curse)			304.4	Other costs = lost productivity in pastures + control costs + wool contamination	(Lloyd 2005)
State level					
Parthenium hysterophorus (parthenium)			28.1	Other costs = reduced stocking rates + reduction in daily live weight gain + additional production and control costs in NSW	(Page and Lacey 2006)
Vacchelia nilotica (syn. *Acacia nilotica*) (prickly acacia)		3.7	11	Other costs = reduced beef and wool production + control costs + increased mustering costs + repairs to tyres in Queensland	(Page and Lacey 2006)
Hypericum perforatum (St John's wort)			34.5	Other costs = losses on infested pastures in NSW.	(Page and Lacey 2006)
Nassella trichotoma (serrated tussock	51.2			Cost figure is for NSW grazing industry.	(Barker *et al.* 2006; Lloyd 2005)

Discussion

This report has attempted to identify the species present in Australia that have or are likely to have significant negative impacts on livestock enterprises and industries and then to identify RD&E priorities relating to individual weed species, groups of species or non-species specific weed issues.

Weeds do not exist in isolation or independence from other components of agro-ecological systems. Weed management must take place within a complex of interacting ecological, economic and social factors. In virtually any Australian animal production system there are multiple weeds and these interact with one another. Weeds are just one component of the pasture system and they interact with other plant species. They are also influenced by the grazing regime and ecological factors such as fire and climatic patterns. Economic factors dictate what weed management measures are applicable in a given situation and weed management must compete with other demands on an enterprise's resources. Finally, weeds exist within a human social system in which there are varied perspectives about particular weed species, their importance and how to most effectively deal with them. All of this makes decisions about weed management rather complex. What is more, those decisions must generally be based on imperfect knowledge about the biology/ecology of weeds, the best management options for particular situations and their production and economic impacts. In this report we have proposed RD&E priorities in the face of this complexity.

Inventory of past investments in weed research and management

Since 2003 there has been considerable investment in weeds RD&E as well as on-ground activity. The period 2003-2013 included five years during the life of the Weeds CRC which oversaw a wide range of activities including research, technology development and communication that targeted a wide range of stakeholders. There was also a strong focus on Australia's Weeds of National Significance including, in 2012, the declaration of 12 new WoNS. NRM regional bodies have been active players in the weed arena, particularly in the area of strategic planning on a regional basis. Commonwealth programs such as Defeating the Weed Menace focused on awareness activities, on-ground works and R&D. There is evidence that since 2008 there has been a decline in terms of both Australia's weeds RD&E capacity and outputs, though this is a general trend in relation to weed work rather than one focused just on grazing-relevant weeds.

Grazing-relevant weeds

Other than the WoNS program, there has been no systematic and comprehensive process to identify the most significant weeds at a national scale in Australia. The WoNS program "attempt[ed] to draw together meaningful indicators on which to base future weed decision-making" and provided "a framework for prioritising weeds at the state, regional and local level". In 1999–2000 it identified 20 species that were regarded as being of national significance (Thorp and Lynch 2000). These priorities were derived from a longer list of 73 species (subsequently reduced to 71 by merging *Sporobolus natalensis* with *S. pyramidalis* and *Senna obtusifolia* with *S. tora*) that had been nominated by "States and Territories". Using the nomination process, a questionnaire and three reference panels, invasiveness, impacts, observed distribution and available economic and environmental data were used to derive a ranking of the 71 species with the top 20 species being ascribed WoNS status. An analogous process was used to identify an additional 12 species as WoNS in 2012 (Mewett *et al.* 2011).

Thorp (2011) considered whether the process for determining Australia's WoNS (Thorp and Lynch 2000) could be used to devise a national prioritisation of weeds of significance to grazing enterprises. The species covered by this analysis were 25 agricultural weeds from the WoNS assessment that impact on livestock industries and they were ranked based on their economic impact. This list of 25 species is broadly consistent with those identified in

Grice (2003), the top ranked 10 being *Rubus fruticosus* agg.*, Senecio jacobaea, Ulex europaeus, Echium plantagineum, Nassella trichotoma, Senna obtusifolia, Parthenium hysterophorus, Acacia nilotica*[12]*, Cryptostegia grandiflora* and *Prosopis* spp. The first five of these species are temperate weeds; the second five are tropical/sub-tropical. Thorp (2011) points out that reliable data for making such assessments are lacking. It assumes that high impact justifies high priority, though "prevention" is highlighted as the most cost-effective action that can be taken. It can be presumed that the cost:benefit ratio of prevention is lowest when a plant is most restricted in its distribution.

In this report we have not attempted to present a comprehensive list of all weeds that are relevant to Australian livestock industries. Such a list would include species that are more weeds of cropping systems rather than pastures, but which may have both positive and negative consequences for livestock industries. It would also include many native species. Our review of the literature and consultation with stakeholders identified a small number of problematic native species for livestock industries, but we deliberately did not explore the considerable literature dealing with them and made no attempt to cover them. It is noteworthy that weeds such as *Cylindropuntia* spp., which was not included as an "emerging or recently emerged" weed of livestock industries in Grice (2003), has made it to the list of prominent species compiled in this project. *Cylindropunita rosea* has recently been declared a WoNS and is now considered a prospective target for biological control, although it is still relatively restricted in distribution in Australia (Holtkamp 2008). In addition, under the definition we have applied, some "grazing-relevant weeds" are associated with livestock industries but not problematic for them; rather they are problematic for other land-uses. These are generally pasture grasses or legumes. Examples that were either listed in Grice (2003) or identified during this project include *Cenchrus ciliaris* (buffel grass), *Hymenachne amplexicaulis* (Olive hymenachne), *Urochloa mutica* (syn. *Brachiaria mutica*) (para grass) and *Leucaena leucocephala* (leucaena). Only one pasture species, *Andropogon gayanus* (gamba grass), is included in our list of prominent weeds. While this species is valued by some northern livestock producers as a pasture grass, it is also problematic for livestock enterprises because of its effects on fuel loads and, consequently, fire intensity, in pastoral lands of the northern woodlands.

Prominent weeds of Australian livestock industries

Our list of prominent weeds is NOT intended to be a comprehensive list of all weeds that might be regarded as currently having negative impacts on Australian livestock industries. However, we consider that it does capture the most important weed species that are broadly influential. The 71 species we have identified vary greatly in terms of:

- mode of influence upon livestock industries
- degree of influence on livestock production and operation of livestock enterprises
- current and potential distributions
- extend to which potential distribution has been reached
- impact in different parts of current range
- whether the species also possesses positive attributes for livestock enterprises
- knowledge of their ecology and biology
- effectiveness of current measures for managing them.

There are several intuitive groupings of the prominent species listed. Members of each group share some morphological and functional characters.

[12] Now formally *Vachellia nilotica*

(i) High biomass perennial grasses that have value as forage species but which, when not heavily grazed, can produce high fuel loads that increase the risk of destructive high intensity fires. The outstanding example is *Andropogon gayanus*.

(ii) High biomass perennial grasses of low forage value that compete with more productive forage species. Examples include various members of the genera *Cenchrus*, *Sporobolus* and *Nassella.*

(iii) Annual grasses that have some forage value but may be detrimental in terms of vegetable fault in wool and animal health problems (southern Australia) or compete with more palatable forage species. Examples include *Vulpia* spp., *Hordeum* spp., *Cenchrus pedicellatus* and *Themeda quadrivalvis*. Some of these are also crops weeds in southern Australia.

(iv) Annual and short-lived perennial forbs such as *Arctotheca calendula*, thistles (*Carduus* spp., *Carthamus lanatus, Cirsium* spp.), *Echium plantagineum*, *Emex australis*, *Erodium cicutarium, Galium tricornutum, Hyptis suaveolens*, *Phyla canescens* etc. These species vary in the quality of forage they provide.

(v) Succulents such as *Bryopyhyllum delagoense*, *Harrisia martinii*, *Opuntia* spp.and *Cylindropuntia* spp.

(vi) Unpalatable shrubs, some of which are spiny and/or toxic. Examples include *Jatropha gossypiifolia*, *Lantana camara*, *L. montevidensis*, *Lycium ferrocissimum*, *Mimosa pigra* and *Parkinsonia aculeata*.

(vii) Vines such as *Cryptostegia grandiflora*.

(viii) Trees, including *Vachellia nilotica*[13], *Tamarix aphylla* and *Ziziphus mauritiana*.

There is likely to be value in developing understanding of key processes of invasion and impact shared by members of these groups and, in some cases, seeking shared solutions.

The priorities amongst prominent weeds that we have provided must be considered in the light of the process used to establish them. First, the process used does not set priorities simply on the basis of the severity or spatial extent of problems caused by individual weed species. Rather it integrates the severity and extent of problems caused with an evaluation of the probability of providing cost-effective solutions within an acceptable time-frame. Second, responses to individual questions of our decision tree were made on the basis of imperfect knowledge of each species' ecology, current impacts and the effectiveness and efficiency of current management techniques. Assessments of the likelihood of further spread of a species, of its future impacts and of developing and applying more effective and efficient management measures are also based on imperfect knowledge.

Accepting that decisions about priorities must be based on imperfect knowledge, we have not attempted to rank species beyond classifying them as being of lower, intermediate or higher priority. We contend that the precision of knowledge of grazing-relevant weeds, particularly their impacts, is such that a greater precision in prioritising cannot be justified. This is consistent with our identification of all the species listed as "prominent weeds", that is, each already has "important negative impacts on livestock industries" throughout a "large proportion of its potential Australian range" (see Definitions in Methodology section). The prominent weeds vary greatly in their bioclimatic preference and so in their distributions.

Emerging weeds of Australian livestock industries

As with the prominent weeds, the emerging weeds we have identified vary greatly in terms of factors such as:

- apparent mode of influence upon livestock industries

[13] Formerly *Acacia nilotica*.

- current and potential distributions
- whether the species also possesses positive attributes for livestock enterprises
- knowledge of their ecology and biology
- attention given to them as invasive species.

Not surprisingly, knowledge of the biology and ecology of apparently emerging species is not as good as knowledge of more widely established prominent weeds of livestock industries. Some species that are emerging as weeds of Australian livestock industries are much better known overseas where they are already widely established and have high impact. This is the case, for example, with *Hieracium* spp. which are well known as weeds of livestock industries in New Zealand. This knowledge is valuable for assessing the risks that a potentially emerging weed poses in Australia, although caution should be used in applying this information to the very different climatic, grazing and management environments in Australia. Furthermore, as the report of Barker *et al.* (2006) points out there are many potentially emerging weeds relevant to Australian livestock industries. We have not attempted to be comprehensive in this regard but have sought to identify the taxa that should be regarded as posing the greatest threats in the foreseeable future.

Some of the same intuitive groupings of species as are found in prominent weeds occur among the emerging weeds.

(i) High biomass perennial grasses of low forage value such as *Nassella charruana* and *N. hyalina*
(ii) Annual and short-lived perennial forbs such as *Hieracium* spp.
(iii) Unpalatable shrubs such as *Chromolaena odorata* and *Cascabela thevetia*

The same uncertainties as associated with decisions about prominent weeds apply to the emerging weeds though the latter are, if anything, less well known than the prominent weeds because they have, in the main, had less exposure to Australian grazing environments than is the case overseas. Land managers, weed scientists and policy makers have also had less experience with the emerging weeds than with the prominent weeds. Our decisions are based on imperfect knowledge. Thus, the same caveats apply to our prioritisation of emerging weeds.

Economic impacts

Weeds pose a significant problem for grazing industries. In a recent national survey of the agricultural businesses comprising the beef cattle and sheep farming industries, 69.1% of respondents report weed-related problems (Australian Bureau of Statistics 2008). The nationwide economic costs to livestock industries of weeds in terms of production losses and control costs is estimated to range from $ 2,862 million to $2,902 million a year (in 2012 AUD) (Sinden *et al.* 2004). This is an equivalent of about 36% of the gross value of Australian cattle and calf production (estimated at $7.9 billion in year 2011-12) (Meat and Livestock Australia Limited 2012). The loss of economic surplus is estimated at $3,156 million. Even though about a quarter of the loss is borne by consumers, the loss in producer surplus alone ($2,358 million per annum) is equivalent to around 30% of the gross value. When compared with other environmental problems facing agricultural industries, weeds have a higher impact at the farm gate than at least salinity, acidity and sodicity, and the lowest estimate of the net impact of weeds is an order of magnitude higher than the gross estimates at farm gate given for the other three problems (Sinden *et al.* 2004)[14].

Based on our extensive review of the more than 200 studies relating to the economics of management of grazing-relevant weeds, we can draw two major conclusions. First,

[14] This result is based on the calculations for three agricultural businesses, including crops, livestock and horticulture.

monetary estimates in the literature provide lower-bound values of the economic impacts of weeds on livestock industries, considering most of them include direct market costs only. Second, there is a high level of uncertainty associated with the estimates. The numbers generated by such exercises do not mean much by themselves but only indicate the scale of the problem and the degree of uncertainty (Perrings *et al.* 2005). Even from these baseline estimates, however, a picture emerges of current and impending problems that require action.

As with economic analysis of other invasive species (Colautti *et al.* 2006), indirect and non-market impacts (e.g. costs in terms of decreased land value, higher risk of fire and social and environmental perspectives) of weeds are often omitted from studies because of a dearth of data. Indeed, we found little information about the costs related to land value and fire risk in our search, even though nationally, decreased value of holdings (34.3%) and increased fire risk (32.0%) were ranked the second and third most common weed-related problems (after decreased value of production 76.1%) for agricultural businesses in a recent survey (Australian Bureau of Statistics 2008). In spite of the difficulty in quantifying these impacts, where they have been quantified, they constitute significant impacts in terms of lost production and increased management costs (AEC group 2007).

A shortcoming of these economic analyses is that they only consider the financial impacts of weeds and largely ignore the industry-wide supply, demand and price effects of both the presence and control of weeds (Jones *et al.* 2005). This is why some economists tend to prefer change in welfare to the concept of an impact and use the notion of economic surplus to measure it (Sinden *et al.* 2004). Weeds restrict meat production and so impose opportunity costs on producers and consumers. Such costs could translate into higher meat prices to consumers.

Weeds impact livestock industries in multiple ways, and they impose substantial economic costs on them (DiTomaso 2000). Economic evaluations of weed problems usually provide two levels of information (Vere *et al.* 2004). The first relates to the costs of weeds in terms of decreased yield. Because pasture weeds are widespread, an opportunity cost of foregone production is imposed on the industries. The second level of information concerns the costs in terms of increased management efforts (or the benefits to producers of improved weed control) in grazing systems. Producers control weeds to maintain production from pastures (e.g. by applying herbicides) and may be legally required to do so[15].

The impacts of invasive species in general are idiosyncratic and often unpredictable (Mack *et al.* 2000). The same species may cause quite different impacts on ecosystem processes at different sites or at different times (Ehrenfeld 2010). The uncertainty associated with the impacts of pasture weeds is likely to be even higher for at least two reasons. The first relates to the long time horizon over which weed management programs usually operate, and the second involves the difficulty of assessing the economic impacts of pasture weeds.

A high level of uncertainty prevails concerning each step in the invasion process and about how human actions can alter the process of invasion (Liu *et al.* 2011). This is particularly true when the potential impacts of invasion are of a long-term and large-scale nature (Strayer 2009, Strayer *et al.* 2006). When a weed has been newly discovered, there is often little information about its behaviour in its new environment. This creates a challenge for weed management in the face of limited knowledge (Hester *et al.* 2013). In the longer term, on one hand there is time for the development of new technologies (e.g. the testing and release of

[15] For example, in Queensland landowners have legal responsibilities under the *Land Protection (Pest and Stock Route Management) Act 2002* to control declared pest plants. The Victorian government is responsible for taking all reasonable steps to eradicate State prohibited weeds under the *Catchment and Land Protection Act 1994*. In New South Wales the *Noxious Weeds Act 1993* requires that some serious weeds are controlled. Under the Weed Management Act 1999 in Tasmania, weed management plans have been prepared for all declared weeds

new biocontrol agents) to significantly reduce the economic costs of weeds. On the other hand, external factors such as climate change could accelerate or slow the spread of weeds and magnify or reduce their impacts (Taylor *et al.* 2012). As a result, the longer the time horizon, the more difficult it is to predict the impacts of weeds. Because weed management programs are generally protracted, and benefit-cost analysis (BCA) is not well suited to deal with decisions that require flexibility as uncertainty unfolds through time (Hester *et al.* 2013), the results of economic analyses based on the BCA framework become less relevant as time goes by[16].

In addition, pasture weeds tend to be more difficult to evaluate economically than crop weeds for a number of reasons, including the complex interactions between livestock and weed species, lack of consistent biological properties that distinguish weeds from other pasture plants, and producers' failure in identifying some as weeds due to their seasonal grazing value (Vere *et al.* 2004). For these reasons, there is usually a considerable level of uncertainty in quantifying the parameters (e.g. population density, impact on production, spread potential and life-cycle) that relate to weeds' economic impacts, and again, the level of uncertainty is even more substantial when the potential consequences of invasion are of a long-term and large-scale nature.

To conclude, there is a significant research gap in conducting economic analyses to estimate the impacts of weeds on livestock industries. Although detailed quantitative information has been published about the economic impacts of weeds on livestock industries overall (Sinden *et al.* 2004) and by several individual important weed species (AEC group 2007, Page and Lacey 2006), for the majority of the species on our list of prominent weeds, quantitative information is limited and references to impacts are mainly anecdotal and poorly documented (e.g. Australian Department of the Environment & Heritage 2003; Lloyd 2005). Furthermore, the existing information mainly focuses on decreased production costs and control costs instead of the loss of economic surplus. Last, it pays little attention to the indirect and non-market costs of the weeds.

Combined with the inherent deep uncertainty associated with the economic analyses of pasture weeds, these information gaps result in a highly fragmented picture of weeds' true costs to livestock industries. Even from these baseline estimates, however, the picture also emerges of current and impending problems that require action.

[16] This is why we exclude pre-2003 studies from our review of cost figures.

Prioritising investments in RD&E

Prioritisation of RD&E needs is a major challenge. The complexity of the prioritisation issue is such that there can be no single "correct solution". Many factors, including subjective ones, might justifiably be considered when making decisions about resource allocations. The information on which decisions should be based is imperfect and not all stakeholders will hold the same views or interpret the available information in the same way. This report is designed to help guide MLA in relation to investments in weeds RD&E, given that the organisation must consider the investments made by other players with common interests. Priorities relate to either species or topics that are not species-specific.

It is relevant to elaborate on two sets of considerations in prioritising species for RD&E for livestock industries or individual livestock enterprises. One relates to the impacts that that species (or group of species) has and the other to the scope for addressing those impacts.

The current importance of a weed is a function of its current distribution and the severity of the impact that it has in places where it occurs. Likewise, though it is the subject of prediction rather than estimation, potential importance is a function of potential distribution and its prospective impact in places where it might occur. The paucity of relevant data on current distributions and impact where weeds are present, and the uncertainty of predictions about potential distributions and prospective impacts, increases the challenge of prioritising between species. Species could be given priority because:

(i) They are currently widespread and so have an impact across a large area.
(ii) They are restricted in distribution relative to their potential with the assumption, that a species might be contained and its impacts limited accordingly.
(iii) They have a high impact where they occur locally even though they are not currently widespread relative to their potential distribution.
(iv) They are a prospective weed of livestock industries even though they are not currently having an impact. Early intervention, based on well-targeted RD&E may circumvent or minimise future impacts.

Species could also be given priority on the basis of currently available control measures and strategies because:

(v) There are no cost-effective control measures currently available.
(vi) The currently available control measures are ineffective.
(vii) The currently available control measures are not being applied.
(viii) There is a high prospect of cost-effective management measures and strategies being developed and applied.

Finally, species could be priority RD&E targets because:

(ix) Their biology and ecology are poorly known.

It is important to emphasise that these nine broad reasons that might influence priorities do not all drive consistently to the same set of priorities. Prioritisation involves a trade-off that rationalises across the influence of these different driving forces. For example, priority could be given to large problems simply because there is currently no effective solution or to lesser problems because it is judged that a solution is within reach given a realistic level of investment. Prioritisation should involve some analysis of the likely returns on RD&E investment and this requires some judgement of the likelihood of achieving a particular result.

There are two further considerations for prioritisation of RD&E effort relating to weeds of livestock industries that were outside the scope of this report. They should be at the forefront of future investment decisions by MLA. One concerns how RD&E investments might be distributed geographically. Neither the productive capacities of livestock industries nor the weeds that impinge on that productive capacity are homogeneously distributed across Australia. This further complicates RD&E prioritisation; investment decisions might consider

where, geographically, the greatest industry-level impacts are likely to be, the greatest industry-level gains might be made, as well as sources of the resources to be applied to the RD&E. The other consideration is that some species that we have identified as weeds of livestock industries are also weeds of other sectors, including cropping systems or natural ecosystem. These cases give scope for inter-sectoral collaborative RD&E.

This report has placed a strong emphasis on species-specific priorities in line with the fact that much weed research and management must be species specific. However, it also provides a list of non-species-specific priorities. These were included in the Discussion Paper that was circulated to a wide range of stakeholders and feedback incorporated to derive a final set of recommendations that address broader issues in relation to weeds of Australian livestock industries.

Recommendations for future RD&E

The following recommendations are based on (1) general issues that if addressed with RD&E could greatly enhance the ability of Australian livestock industries to deal with weed problems; and (2) the RD&E prioritisation process undertaken for individual weed species identified as prominent or emerging.

STRATEGIC INVESTMENT

Recommendation 1. Develop a collaborative approach to weed RD&E and promote it at the operational level.

MLA is only one player in a complex community of stakeholders that includes other funding organisations, Commonwealth agencies, state government departments, local governments, non-government organisations, universities, NRM bodies and land-managers and land-users with a wide variety of interests in grazing. Weeds RD&E is poorly co-ordinated across these many interest groups and, while no doubt some industry-specific weed problems could be addressed "in-house", many weed problems involve more than one sector of the economy and often also affect environmental assets. RD&E on grazing-relevant weeds and the systems of which they are a part will be more effective and efficient if MLA works with other stakeholders to address common problems and resolve issues where there are contrasting perspectives. MLA's focus within such a collaborative approach should remain on grazing-relevant weeds.

Recommendation 2. Livestock industries, through MLA and other representative organisations, should participate in national programs for the management of relevant weed species, most notably the Weeds of National Significance program.

There is demonstrated benefit in the co-ordination of responses to prominent and emerging weeds at catchment, regional, state and national levels. One of the most important attempts to devise and implement strategic weed management at a national scale has been the Weeds of National Significance program. At least 25 WoNS (mostly species but some are listed at genus level) are relevant to livestock industries. Other species that are or recently were the targets of national eradication efforts, including *Chromolaena odorata* and *Clidemia hirta*, are also relevant to livestock industries. While WoNS are still recognised under Australia's national Weeds Strategy, there is currently a lack of support for strategic co-ordination of efforts to counter these important weeds. MLA and other bodies that operate in support of livestock industries should collaborate with other stakeholders to support these and other national programs through research, development and communication and to co-ordinate state and national programs for species such as *Nassella* spp., *Senecio madagascariensis*, *Vachellia nilotica*[17] and *Parkinsonia aculeata*.

[17] Formerly *Acacia nilotica.*

Recommendation 3. Develop and promote realistic perspectives on weeds RD&E and weed management.

There is a view that investment in weeds RD&E is a "bottomless pit". There is more than an element of truth in this in that, for many weed problems, there is no final solution. In reality, weeds RD&E might expect to provide cost-effective management systems that reduce weed-related production losses. Rarely will it be possible to totally remove a weed from a grazing land system once it has been introduced. More thorough investigations on the costs and benefits of both weeds RD&E and weed management are going to be important to facilitate sensible decisions about RD&E by funding organisations and policies developed by government agencies and weed management by land-users. Better documentation of weed distribution and abundance, including more effective use of currently available information, would help generate realistic perspectives.

Recommendation 4. Take and promote a long-term view.

Development and implementation of the means to effectively address weed problems usually take a number of years. For example, a biological control program starting from scratch may take more than ten years. Funding commitments for RD&E reflect these time-lines. Weed management must also be promoted as an on-going component of property management.

Recommendation 5. Build capacity.

Australia's capacity in weeds RD&E has been declining in recent years. This is, perhaps, most notable in the area of weed biological control and ecology (e.g. many scientists in state departments not being replaced). MLA has a vested interest in maintaining and building this capacity though, obviously, is not primarily responsible for it.

Recommendation 6. Development of research capacity should be encouraged by providing financial and other incentives (e.g. top-up scholarships in addition to those awarded by universities) to attract postgraduate students into research of relevance to the grazing industries, including weed research. Potential university supervisors should also be made aware of industry needs.

The declining research output in the field of weed science, as shown by the number of post graduate students, the declining number of publications both in the formal scientific literature and in the proceedings of conferences such as the Australian Weeds Conference, points to an urgent need to enhance research capacity in Australia and put in place incentives for researchers to address the problems encountered by livestock industries. PhD and MSc theses addressing particular weed species will remain an important conduit for weed R&D in Australia.

Recommendation 7. Focus on likely winners.

This project, and the parallel MLA-funded project on biological control of weeds of Australian livestock industries (Morin *et al.* 2013), propose a focus not simply on the most serious weed problems (however they are defined) but on the problems that are both tractable and serious enough to be concerned about. Of course, evaluating the prospects of devising and applying measures to address weed problems is not an exact science. This report has endeavoured to provide guidance on which problems may be more tractable, considering both feasibility and likelihood of success.

Recommendation 8. Take a holistic approach to address the problems of weeds in livestock grazing systems across a range of scales: farm, catchment, landscape and regional.

Much weed RD&E activity is species-specific. Species specific work is important and, in areas such as biological control, a species-specific focus is essential. However, there is also a need to develop system-based, multi-species approaches to both understanding weeds within pasture environments and devising and implementing effective management measures and strategies. Solutions that consider the complex ecological, economic and social context within which weeds exist should be developed. Particularly important is the relationship between weed management and pasture management in general. This opens the issue of weeds as the cause of problems themselves versus symptoms of other problems in particular grazing land management systems (Grice and Campbell 2000). An important overall question concerns the extent to which good pasture management suppresses problem species; the answers will likely be different for different weed species and groups of weeds and with different management situations and geographical regions. Some species on the prominent (Table 2) and emerging (Table 3) weed lists may well be suppressed by vigorous perennial pastures grasses. Examples include *Cyperus aromaticus, Emex australis, Themeda quadrivalvis* and *Echium plantagineum.* Pasture species may even suppress recruitment of woody perennial weeds. Good grazing management should be promoted on-property as an important component of a weed control strategy. It should not be assumed, however, that weed problems will vanish provided appropriate grazing management is in place.

MLA should explore, encourage and support RD&E that incorporates the need to address weed problems in the context of the whole property, the enterprise, the region and even higher scales. Perhaps the most obvious connection is with grazing and pasture management, but other aspects of property management that have a bearing on weed management include movement of livestock, machinery and fodder; fire regimes, disturbances associated with access roads, construction of fences and watering points; and management of waterways and wetlands. Biosecurity planning will be important at property to national scales.

Recommendation 9. Conduct RD&E to provide and promote the application of a better understanding of the links between grazing management and invasion and proliferation of species favoured by the types of disturbance typically associated with livestock enterprises.

There is a suite of annual and short-lived species that are more likely than longer-lived species to be advantaged by high levels of disturbance that are often associated with commercial livestock grazing. Research should aim to describe the relationships between grazing management and weed abundance and impact. These relationships may be different for different species and grazing systems but common principles should be pursued. A systems approach to weed management in general should be encouraged, both in research and pasture management.

Recommendation 10. Baseline studies and reassessments of the economic and other impacts of priority weed species and groups of co-occurring weeds should be given priority.

The review, conducted as a component of this project, of the literature relating to the economic impacts of weeds of Australian livestock industries, clearly indicates that there is a paucity of quantitative information in this field. Sound economic data on the impacts of weeds in different grazing systems should be acquired to better inform weed management decisions and to assess the likely benefits of proposed RD&E investments. This report is based on inadequate information regarding weed impacts, including their economic impacts. Quantitative information would allow managers to more effectively ascertain the costs and benefits of different weed management strategies and decide which species should be the focus of attention, which control measures are most cost-effective and whether and when

doing nothing is an economic optimum. The costs of weed management must be weighed up against the costs and benefits of investment in other aspects of grazing property management or, for that matter, off-property investments. The assumptions and calculations in the existing economic assessments, for example those done through the former Co-operative Research Centre for Australian Weed Management (Weeds CRC), should be revisited to see what changes have taken place over the last decade. A variety of approaches to economic assessments should be explored.

Recommendation 11. The prioritisation of weed species relevant to grazing industries should be refined using a consistent and cost-efficient methodology across all regions of Australia.

The data from which weeds that are important to livestock industries were determined and prioritised for this report were: (i) gathered using very different sources, which were mostly based on subjective rather than objective approaches, (ii) not necessarily collected specifically for the purpose, and (iii) geographically limited in most instances. The fact that the sources we used were disparate may explain why some weed species on the priority list appear more prominent than would have been expected (for example *Hypochaeris* spp.). Further, there are large areas for which data are not currently available or could not be sourced, for example, south-western Western Australia, northern Western Australia and the Northern Territory. Considering these limitations, it is therefore most likely that some key species have been omitted from lists of prominent and emerging weeds. Notwithstanding this, it is important to realise that weed prioritisation exercises will always involve some subjectivity. For this reason it is important that stakeholders, including MLA, do not over-invest in determining weed RD&E priorities.

Recommendation 12. Weeds relevant to grazing industries should be prioritised as targets for biological control on the basis of their impact as well as the feasibility and likelihood of success of biological control, prior to the initiation of new programs.[18]

Biological control has been highly successful and provides excellent investment return for agricultural industries. Not all grazing-relevant weeds are equally valid as biological control targets and, while the outcomes of biological control programs are obviously variable in terms of their effectiveness, there is a demonstrated high benefit:cost ratio of biological control RD&E overall (Page and Lacey 2006). There has been a long history of biological control of weeds in pasture and rangeland, but Australia's capacity in this area has been steadily declining. In particular, investment in overseas exploration, an essential initial step to source candidate agents, has seen a greatly diminished effort. See Recommendation 15.

Recommendation 13. Develop cost-effective management solutions for priority prominent and emerging weed species.

Cost-effective weed control solutions should be developed or refined for the important weed problems of livestock industries, emphasising species for which there are currently no established management measures or for which there is scope for more cost-effective measures compared with those currently available. Further, representatives of livestock industries and enterprises should engage with other interest groups to address the problems of weed species and functional groups over which there is common interest as well as in cases where commercially valued pasture species are problematic for non-pastoral land-

[18] In parallel to this project, MLA resourced another to develop a prioritised and justified listing of target weed species for biological control, including an assessment of likelihood of success, and make recommendations for investment in weed biological control. Consultation between the two teams has provided a co-ordinated approach to determining overall species priorities, devising RD&E strategic directions and identifying biocontrol targets (Morin *et al.* 2013).

users. Examples of these contentious species (Grice *et al.* 2008b) include the WoNS *Andropogon gayanus* and *Hymenachne amplexicaulis*. Generally, "solutions" that integrate multiple measures will be most effective.

SPECIES-SPECIFIC RECOMMENDATIONS

Recommendation 14. Fundamental studies of the biology and ecology of priority prominent and emerging weeds, for which major knowledge gaps exist, should be conducted to provide a basis for understanding invasion processes and impacts and the development of management measures and strategies.

The declining weed science research base in Australia means that we know very little about the biology and ecology of some well-established weeds and newly invading species that affect grazing industries. For example, species such as *Lycium ferocissimum* are declared WoNS despite a lack of basic knowledge of them (e.g. there were no scientific publications on *L. ferocissimum* in the last ten years). It is not possible to develop effective control techniques without an understanding of a weed's ecology, particularly how it interacts with different environmental variables. In general terms, key practical ecological questions in research on any weed are:

1. How long do plants live?
2. How long does it take young plants to become reproductive?
3. How long will it take for the seed-bank to be depleted in the absence of seed-rain?
4. How much, how far and by what means are seeds (or other propagules) dispersed?
5. What is the frequency and scale of seedling recruitment? (Campbell and Grice 2000)

There has been some recent work on *Calotropis procera, Moraea* spp. (genetic studies) and *Phyla canescens.* Research associated with the eradication programs for *Chromolaena odorata* and *Clidemia hirta* has been valuable in understanding those species (Anon. 2011). More in-depth consultation with the researchers and other staff associated with the National Four Tropical Weeds Eradication Program and those who were responsible for the now defunct Siam Weed (*Chromolaena odorata*) Eradication Program (e.g. Mick Jeffrey and Simon Brooks, Biosecurity Queensland) is essential prior to finalising additional RD&E on these species. PhD and other student projects are one cost-effective means of acquiring important biological, ecological and genetic information on particular species or species groups. One of the species groups for which further basic research would be useful are the high biomass grasses, including both annual and perennial species.

Knowledge of the basic biology and ecology of most of the emerging weed species (Table 3) is poor, particularly when it comes to the species' performance in Australian livestock grazing environments. Priority in filling knowledge gaps relating to both prominent and emerging weeds should be given to those listed as being of higher priority in Tables 4 and 5. Some species for which more basic biological/ecological information may be helpful are: *Chromolaena odorata, Clidemia hirta, Diplotaxis tenuifolia, Euphorbia terracina, Gomphocarpus fruticosus, Hyparrhenia* spp.*, Lantana montevidensis, Lycium ferrocissimum, Physalis viscosa* and *Praxelis clematidea.*

Recommendation 15. Biological control programs should be established for species for priority which there are good prospects of success.

Morin *et al.* (2013) provides a detailed, up-to-date analysis of biological control priorities relating to weeds of Australian livestock industries. These are based on expert consideration current and potential impacts and the prospects for implementing successful biological control programs. Species short-listed by that project are:

High prospects of biocontrol:

Chromolaena odorata

Moderate-high prospects of biocontrol:

Cirsium vulgare
Marrubium vulgare
Moraea flaccida
Moraea miniata
Opuntia spp.
Cylindropuntia spp.
Prosopis spp.

Moderate prospects of biocontrol:

Carduus tenuiflorus
Carduus pycnocephalus
Euphorbia terracina
Lantana camara
Lycium ferocissimum

Low-moderate prospects of biocontrol:

Bryophyllum delagoense
Jatropha gossypiifolia
Nassella neesiana
Physalis viscosa
Romulea rosea
Solanum elaeagnifolium
Vachellia nilotica[19]
Ziziphus mauritiana

Recommendation 16. Contribute to development of improved means for managing unpalatable, high biomass grasses, including measures for containing their spread.

This is probably one of the more intractable groups of weeds associated with Australian livestock industries. Many of Australia's grazing systems are threatened by one or more unpalatable, high biomass grasses. At least some of these grasses also affect other sectors, particularly those involved in maintaining environmental values. RD&E effort designed to raise awareness of these weeds and devise and apply measures to at least minimise their spread are important. Species that fall into this group are *Andropogon gayanus, Cenchrus pedicellatus, Cenchrus polystachios, Hyparrhenia* spp.,*Nassella* spp., *Sporobolus* spp. and *Themeda quadrivalvis*

Recommendation 17: The potential distributions of emerging weeds of livestock industries should be determined under both current and future climates, with development of appropriate adaptation responses.

Early responses to emerging weeds that are or could be problematic for grazing industries, are an important means of minimising longer-term impacts on livestock industries, including restricting spread. The development of reliable predictions of trends in distribution, abundance and impact of emerging weeds, would enable the determination of weed species early in the invasion process, which would make biosecurity measures, including control, more effective and considerably reduce costs. To date the livestock industries have not considered climate change, which is likely to be an increasingly significant driver of change in species distributions. Critical assessment of potential weeds, on a regional basis, could be done in conjunction with priority setting.

[19] Formerly *Acacia nilotica.*

GENERALISED ECONOMIC ANALYSIS OF RECOMMENDED INVESTMENT AREAS

The limited amount of quantitative data that are available on economic costs of weeds in Australian livestock production systems and uncertainties surrounding the prospects for devising new measures to deal with them and the likelihood that those measures will be taken up by managers of livestock enterprises, largely precludes undertaking worthwhile cost-benefit analysis to guide decisions about RD&E priorities.

Investments in weed RD&E come with transaction costs and must be justified in terms of the forecasted benefits. Decisions must consider the importance of weeds relative to other factors, and so the transaction costs involved, as well as expected returns on investments. Also, in deciding on the priorities for investment in RD&E, it is important to recognise that weed problems are not spatially homogeneous at local, regional or national scales. Hypothetically, there will need to be trade-offs, for example, between RD&E on weed species that are relatively geographically restricted but in highly productive areas, and much more widespread species that occur in areas of relatively low productivity. This makes the geographical distributions of livestock production and productivity important factors to be considered in deciding where the best returns on RD&E investment might be.

Economists have much to offer on the subject of pasture weeds and identifying their economic costs is only a small part of their potential contribution. More important is the design of policy instruments for managing invasive species (Perrings *et al.* 2005). At the project level, the economic approach to the allocation of investment funds is to compare benefits with costs and to allocate first to the project with the highest ratio of benefits to costs, second to the project with the next highest ratio, etc, until the funds are exhausted; At the broader program or sector level, the same principles of BCA apply (Sinden *et al.* 2004).

Numerous control options have been developed to manage pasture weeds, with herbicides as the primary method in most pasture systems (DiTomaso 2000). In Australia, almost two thirds of the total expenditure on weed related management was spent on herbicides across all agricultural businesses nationwide (Australian Bureau of Statistics 2008). However, chemical control might not be the most economically efficient control method, as suggested by one economic study on the impacts of *Lantana camara* on Australian livestock industries. The study shows that the current control initiatives have a benefit:cost ratios (BCR) of 0.11, or a return of $0.11 for every dollar invested. By comparison, a successful biological control program has the potential to return up to and over $90 of benefit for every dollar invested (AEC group 2007).

A survey of 29 BCAs of weed biocontrol programs also found overall such efforts provide a strongly positive return on investment (Page and Lacey 2006). The aggregate results of the individual BCA programs indicate an overall BCR of 23.1, which implies that, for every dollar invested in weed biocontrol effort, a benefit of $23.10 is generated (Page and Lacey 2006).

We must treat these seemingly optimistic results with caution because considerable uncertainty is often attached to estimates and very few economic analyses have attempted to estimate the variability surrounding point-estimates of BCRs (Hill and Greathead 2000). Prudent decision-making requires tools that are explicit about uncertainty and management options that are both precautionary and adaptive (Doak *et al.* 2008). Yet such a strategy is hardly the norm in today's practice (Simberloff 2005). As BCA is not well suited to dealing with uncertainty and the inherent high level of uncertainties involved in weed management, decision analysis has been proposed as a complementary tool to provide useful insights into decision-making processes (Hester *et al.* 2013, Liu *et al.* 2012).

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Appendices

Appendix 1. The 142 weed species referred to by Grice (2003) as significant to Australian grazing industries.

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
1	*Acacia farnesiana*[20]	Mimosa bush	shrub
2	*Acacia nilotica*[21]	Prickly acacia	tree/shrub
3	*Acetosella vulgaris*	Sorrel	annual forb
4	*Achnatherum caudatum*	Espartillo or puna grass	perennial grass
5	*Agave sisalana*	Sisal hemp	perennial forb
6	*Ageratina adenophora*	Crofton weed	perennial forb
7	*Ageratina riparia*	Mistflower	perennial forb
8	*Agrostis capillaris*	Browntop bent grass	perennial grass
9	*Alternanthera philoxeroides*	Alligator weed	aquatic
10	*Amaranthus albus*	Tumbleweed	annual forb
11	*Andropogon gayanus*	Gamba grass	perennial grass
12	*Arctotheca calendula*	Capeweed	annual forb
13	*Asphodelus fistulosus*	Onion weed (= wild onion)	perennial forb
14	*Azadirachta indica*	Neem	tree
15	*Baccharis halimifolia*	Groundsel bush	shrub
16	*Brassica tournefortii*	Asian mustard	annual forb
17	*Bryophyllum delagoense*	Mother-of-millions	perennial forb
18	*Cabomba caroliniana*	Cabomba	aquatic
19	*Calotropis procera*	Calotrope	shrub
20	*Carduus nutans*	Thistles	annual forbs
21	*Carduus pycnocephalus*	Italian thistle	annual forb
22	*Carrichtera annua*	Ward's weed	annual forb
23	*Carthamus lanatus*	Saffron thistle	annual forb
24	*Cascabela thevetia*	Yellow oleander	shrub
25	*Celtis sinensis*	Chinese celtis	tree
26	*Centaurea calcitrapa*	Purple star-thistle	annual/biennial
27	*Centaurea maculosa*	Spotted knapweed	annual forb
28	*Centaurea nigra*	Black knapweed	perennial forb

[20] Now formally *Vachellia farnesiana*
[21] Now formally *Vachellia nilotica*

APPENDIX 1 (CONTINUED)

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
29	*Centaurea solstitialis*	Yellow star-thistle	annual forb
30	*Cerastium glomeratum*	Mouse-eared chickweed	annual forb
31	*Cestrum parqui*	Green cestrum	shrub
32	*Chenopodium pumilio*	Small crumbweed (= goosefoot)	annual forb
33	*Cinnamomum camphora*	Camphor laurel	tree
34	*Cirsium arvense*	Creeping thistle	perennial forb
35	*Cirsium vulgare*	Spear thistle	biennial forb
36	*Citrullus lanatus*	Afghan melon	annual forb
37	*Coronopus didymus*	Lesser swinecress	annual forb
38	*Cotula* spp.	Cotula	annual forb
39	*Cryptostegia grandiflora*	Rubbervine	climber/shrub
40	*Cucumis myriocarpus*	Paddy melon	annual forb
41	*Cuscuta planiflora*	Small-seeded dodder	annual forb
42	*Cynara cardunculus*	Artichoke thistle	perennial forb
43	*Cytisus scoparius*	Broom	shrub
44	*Diplotaxis tenuifolia*	Lincoln weed (= sand rocket)	perennial forb
45	*Dittrichia graveolens*	Stinkwort	annual forb
46	*Ecballium elaterium*	Squirting cucumber	perennial forb
47	*Echinochloa polystachya*	Aleman grass	perennial grass
48	*Echium plantagineum*	Paterson’s curse	annual forb
49	*Eichhornia crassipes*	Water hyacinth	aquatic
50	*Elephantopus mollis*	Tobacco weed	perennial forb
51	*Emex australis*	Spiny emex	annual forb
52	*Eragrostis curvula*	African lovegrass	perennial grass
53	*Eriocereus martini* (= *Harrissia martini*)	Harrissia cactus	Shrub
54	*Erodium* spp.	Storksbill	annual forb
55	*Fumaria* spp.	Fumatory	anual forbs
56	*Galium tricornutum*	Three-horned bedstraw	annual forb
57	*Heliotropium amplexicaule*	Blue heliotrope	perennial forb
58	*Heliotropium europaeum*	Common heliotrope	annual forb
59	*Hieracium* spp.	Hawkweeds	Perennial forb

APPENDIX 1 (CONTINUED)

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
60	*Holcus lanatus*	Yorkshire fog	annual grass
61	*Hordeum* spp.	Barley grass	annual grass
62	*Hyparrhenia hirta*	Coolatai grass	perennial grass
63	*Hypericum perforatum*	St John's wort	perennial forb
64	*Hypochaeris radicata*	Cat's ear	annual forb
65	*Hyptis suaveolens*	Hyptis	annual forb
66	*Ibicella lutea,*	Devil's claw	annual forb
67	*Jatropha gossypiifolia*	Bellyache bush	shrub
68	*Juncus* spp.	Rushes	perennial forb
69	*Lantana camara*	Lantana	shrub
70	*Lantana montevidensis*	Creeping lantana	shrub
71	*Ligustrum lucidum*	Large-leaved privet	tree
72	*Ligustrum sinense*	Small-leaved privet	tree
73	*Lycium ferocissimum*	African boxthorn	shrub
74	*Macfadyena unguis-cati*	Cat's claw creeper	climber
75	*Malva parviflora*	Small-flowered mallow	annual forb
76	*Marrubium vulgare*	Horehound	perennial forb
77	*Martynia annua*	Devil's claw	annual forb
78	*Mentha pulegium*	Pennyroyal	perennial forb
79	*Mesembryanthemum crystallinum*	Ice plant	perennial forb
80	*Mimosa invisa*	Creeping sensitive plant	shrub
81	*Mimosa pigra*	Giant sensitive plant	shrub
82	*Moraea flaccida* (=*Homeria flaccida*)	One-leaf Cape tulip	perennial forb
83	*Moraea miniata* (=*Homeria miniata*)	Two-leaf Cape tulip	perennial forb
84	*Nassella charruana*	Lobed needle grass	perennial grass
85	*Nassella neesiana*	Chilean needle grass	perennial grass
86	*Nassella tenuissima*	Mexican feather grass	perennial grass
87	*Nassella trichotoma*	Serrated tussock	perennial grass
88	*Olea europaea*	Olive	tree
89	*Onopordum acanthium*	Thistle	annual forb
90	*Onopordum illyricum*	Thistle	annual forb

APPENDIX 1 (CONTINUED)

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
91	*Onopordum. acaulon*	Thistle	annual forb
92	*Opuntia* spp.	Prickly pear	shrub
93	*Ornithogalum thyrsoides*	Chincherinchee	perennial forb
94	*Orobanche* spp.	Branched broom rape	perennial forb
95	*Parkinsonia aculeata*	Parkinsonia	shrub
96	*Parthenium hysterophorus*	Parthenium	annual forb
97	*Paspalum notatum*	Bahia grass	perennial grass
98	*Passiflora foetida*	Stinking passion flower	climber
99	*Pennisetum pedicellatum*[22]	Annual mission grass	annual grass
100	*Pennisetum polystachion*[23]	Perennial mission grass	perennial grass
101	*Pennisetum setaceum*[24]	Fountain grass	perennial grass
102	*Phyla canescens*	Lippia	aquatic, perennial forb
103	*Physalis viscosa*	Prairie ground cherry	perennial forb
104	*Praxelis clematidea*	Praxelis	perennial forb
105	*Proboscidea louisianica*	Devil's claw	annual forb
106	*Prosopis glandulosa*	Mesquite	shrub/tree
107	*Prosopis juliflora*	Mesquite	shrub/tree
108	*Prosopis pallida*	Mesquite	shrub/tree
109	*Pteridium aquilinum*	Bracken fern	perennial forb
110	*Raphanus raphanistrum*	Wild radish	annual forb
111	*Rapistrum rugosum*	Brassicas	annual forbs
112	*Romulea rosea*	Guildford grass (=onion grass)	perennial forb
113	*Rosa rubiginosa*	Sweet briar	shrub
114	*Rubus fruticosus* agg.	Blackberry	shrub
115	*Salvinia molesta*	Salvinia	aquatic
116	*Schinus terebinthifolius*	Broad-leaved pepper tree	tree
117	*Scolymus maculatus*	Spotted golden thistle	annual forb
118	*Senecio jacobaea*	Ragwort	perennial forb

[22] Now formally *Cenchrus pedicellatus*
[23] Now formally *Cenchrus polystachios*
[24] Now formally *Cenchrus setaceus*

APPENDIX 1 (CONTINUED)

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
119	*Senecio madagascariensis*	Fireweed	annual or perennial forb
120	*Senna obtusifolia*	Sicklepod	shrub
121	*Senna occidentalis*	Coffee bush	shrub
122	*Sida acuta*	Sida	perennial forb
123	*Silybum marianum*	Milk thistle	annual forb
124	*Sisymbrium* spp.	Mustard	annual forb
125	*Solanum elaeagnifolium*	Silverleaf nightshade	perennial forb
126	*Solanum hoplopetalum*	Afghan thistle	perennial forb
127	*Sporobolus africanus*	Parramatta grass	perennial grass
128	*Sporobolus fertilis*	Giant Parramatta grass	perennial grass
129	*Sporobolus jacquemontii*	American rat's tail grass	perennial grass
130	*Sporobolus natalensis*	Giant rat's tail grass	perennial grass
131	*Sporobolus pyramidalis*	Giant rat's tail grass	perennial grass
132	*Stachytarpheta* spp.	Snakeweed	shrub/perennial forb
133	*Tamarix aphylla*	Athel pine	tree
134	*Themeda quadrivalvis*	Grader grass	annual grass
135	*Tribulus terrestris*	Caltrop	annual forb
136	*Typha* spp.	Typha	aquatic
137	*Ulex europaeus*	Gorse	shrub
138	*Vulpia* spp.	Vulpia	annual grass
139	*Xanthium occidentale*	Noogoora burr	annual forb
140	*Xanthium orientale*	Bathurst burr	annual forb
141	*Zantedeschia aethiopica*	Arum lily	perennial forb
142	*Ziziphus mauritiana*	Indian jujube (= chinee apple)	shrub/tree

Appendix 2. Species determined by Grice (2003) to be of greatest significance to Australian grazing industries in each of nine regions.

NQ northern Queensland, NT Northern Territory, nWA northern Western Australia, sWA southern Western Australia, Tas Tasmania, iNSW inland New South Wales, cNSW coastal New South Wales, Vic Victoria, SQ southern Queensland.

	SPECIES	NQ	NT	NWA	SWA	TAS	VIC	INSW	CNSW	SQ
1	*Acacia nilotica*[25]	■	■							
2	*Agrostis capillaris*						■	■		
3	Annual grasses					■	■	■	■	
4	*Arctotheca calendula*				■		■	■		
5	*Asphodelus fistulosus*							■		
6	*Bryophyllum delagoense*	■						■		■
7	*Calotropis procera*	■	■	■						
8	*Cryptostegia grandiflora*	■								
9	*Echium plantagineum*				■			■		
10	*Elephantopus mollis*	■								
11	*Emex australis*				■		■	■	■	■
12	*Eragrostis curvula*				■		■	■		■
13	*Erodium* spp.					■				
14	*Fumaria* spp.					■				
15	*Heliotropium amplexicaule*							■		
16	*Heliotropium europaeum*				■			■		
17	*Hyparrhenia hirta*						■	■		
18	*Hypericum perforatum*							■		
19	*Hyptis suaveolens*	■								
20	*Jatropha gossypiifolia*	■	■	■						
21	*Lantana camara*	■							■	■
22	*Lantana montevidensis*									■
23	*Lycium ferrocissimum*							■		

[25] Now formally *Vachellia nilotica*

APPENDIX 2 (CONTINUED)

	SPECIES	NQ	NT	NWA	SWA	TAS	VIC	INSW	CNSW	SQ
24	*Mimosa pigra*	■	■							
25	*Moraea miniata*				■		■			
26	*Nassella neesiana*							■		
27	*Nassella trichotoma*						■	■		■
28	*Parkinsonia aculeata*	■	■	■						
29	*Parthenium hysterophorus*	■						■		■
30	*Pennisetum polystachion*[26]		■	■						
31	*Phyla canescens*							■		■
32	*Physalis viscosa*						■	■		
33	*Prosopis* spp.	■	■	■				■		■
34	*Pteridium aquilinum*				■					
35	*Raphanus raphanistrum*				■					
36	*Rubus fruticosus* agg.				■		■	■		
37	*Senecio madagascariensis*								■	
38	*Senna obtusifolia*	■	■							
39	*Senna occidentalis*		■							
40	*Sida acutifolia*	■	■							
41	*Solanum elaeagnifolium*				■		■	■		■
42	*Sporobolus* spp.	■					■		■	■
43	*Themeda quadrivalvis*	■								
44	Thistles				■	■	■	■		
45	*Ulex europaeus*							■		
46	*Xanthium occidentale*		■					■		
47	*Xanthium orientale*		■					■		

[26] Now formally *Cenchrus polystachios*

Appendix 3. Research and development priorities identified by Grice (2003) for each of six bioclimatic zones.

BIOCLIMATIC ZONE	PRIORITY SPECIES	R&D NEEDS
Monsoon tropics	*Andropogon gayanus* *Calotropis procera* *Hyptis suaveolens* *Pennisetum polystachion*[27] *Sporobolus pyramidalis*	1. fill critical knowledge gaps 2. develop systems approaches 3. develop extension material
Tropical rangelands	*Acacia nilotica*[28] *Jatropha gossypiifolia* *Lantana camara* *Parkinsonia aculeata* *Parthenium hysterophorus* *Prosopis* spp. *Sporobolus pyramidalis* *Xanthium occidentale* *Ziziphus mauritiana* Native woody species	1. fill knowledge gaps relating species' ecology 2. relate to grazing management 3. develop control measures for *L. camara* 4. biological control of *A. nilotica, Prosopis* spp. and *X. occidentale* 5. implement containment measures for aquatic weeds
Tropical and sub-tropical east coast	*Elephantopus mollis* *Lantana camara* *Lantana montevidensis* *Parkinsonia aculeata* *Phyla canescens* *Senna obtusifolia* *Sporobolus* spp.	1. fill knowledge gaps relating species' ecology 2. develop herbicides suitable for use in pastures 3. management options for extensive grazing systems
Temperate rangelands	*Asphodelus fistulosus* *Bryophyllum delagoense* *Carthamus lanatus* *Lycium ferocissimum* Native woody species	1. fill knowledge gaps relating ecology of *L. ferocissimum* 2. management strategies for *L. ferrocissimum* 3. biocontrol of *L. ferocissimum* 4. education and extension for native woody species 5. management strategies and biocontrol of *P. canescens* 6. biocontrol of *C. lanatus*
Perennial pasture zone	*Agrostis capillaris* *Eragrostis curvula* *Nassella neesiana* *Nassella trichotoma* *Physalis viscosa* *Solanum elaeagnifolium* *Sporobolus africanus*	1. development of systems approaches for management of multiple species of perennial grass 2. develop better management packages and extension material
Cropping/pasture zone	Annual and perennial forbs *Physalis viscosa* *Solanum elaeagnifolium*	1. management strategies and education 2. fill ecological knowledge gaps for *S. elaeagnifolium* and *P. viscosa*

[27] Now formally *Cenchrus polystachios*
[28] Now formally *Vachellia nilotica*

Appendix 4. Stakeholders invited to provide feedback on the Discussion Paper.

Grazing industry bodies

Australian Wool Innovation Ltd	Rory Coffey (Pastures Australia Co-ordinator)
Cattle Council of Australia	cca@cattlecouncil.com.au
Future Farm Industries	John McGrath (Research Director)
MLA More beef from pasture	Dougal Purcell
MLA More beef from pasture	Fiona Jones
MLA More beef from pasture	Peter Ball
MLA More beef from pasture	Sally Duff
MLA More beef from pasture	Simon Vogt
North Australia Beef Research Council	Jackie Kyte (Secretariat)
North Australia Beef Research Council	Ralph Shannon (Chairman)
Northern Territory Cattlemen's Association	Tracey Page (Secretariat)
Sheepmeat Council of Australia	sca@sheepmeatcouncil.com.au
Southern Australia Beef Research Council	Chris Prideaux (CSIRO representative)

Weeds RD&E

ABARES	Bertie Hennecke
Biosecurity South Australia	David Cooke
Biosecurity South Australia	John Heap
Biosecurity South Australia	John Virtue
Biosecurity South Australia	Michaela Heinson
Charles Sturt University	Ian Lunt
Charles Sturt University	Leslie Weston
Charles Sturt University/NSW DPI	Deirdre Lemerle
Charles Sturt University/NSW DPI	Hanwen Wu
CSIRO	Andy Sheppard
CSIRO	Bob Godfrey
CSIRO	Rieks van Klinken
CSIRO	Tim Heard
Curtin University	Pippa Michael
DAFF Australian Government	Jeanine Baker
DAFF Australian Government	Peter Langdon
DAFF QLD	Joseph Vitelli
DAFF QLD	Kunjithapatham Dhileepan
DAFF QLD	Nathan March
DAFF QLD	Olusegun Osunkoya
DAFF QLD	Shane Campbell
DAFF QLD	Tony Pople
DAFF QLD	Wayne Vogler
Darwin University	Samantha Setterfield
NSW DPI	David Officer

APPENDIX 4 (CONTINUED)

NSW DPI	Michael Michelmore
NSW DPI	Philip Blackmore
NSW DPI	Rod Ensbey
NSW DPI	Royce Holtkamp
NSW DPI	Scott Charlton
NSW DPI	Stephen Johnson
NSW DPI	Sydney Lisle
NSW Far North Coast Weeds	Phil Courtney
NSW Mid North Coast Weeds Co-ordinating Committee	Terry Schmitzer
NT Department of Natural Resources, Environment, the Arts and Sport	Chris Brown
NT Department of Natural Resources, Environment, the Arts and Sport	Keith Ferdinands
NT Department of Natural Resources, Environment, the Arts and Sport	Piers Barrow
TAS Department of Primary Industries, Parks, Water and Environment	Michael Askey-Doran
TAS Department of Primary Industries, Parks, Water and Environment	Michael Noble
TIAR/University of Tasmania	John Ireson
University of Melbourne	Roger Cousens
University of New England	Brian Sindel
University of New England	Michael Coleman
University of New England	Ralph (Wal) Walley
University of Queensland	Stephen Adkins
VIC Department of Environment and Primary Industries	David McLaren
VIC Department of Environment and Primary Industries	Greg Lefoe
VIC Department of Environment and Primary Industries	Jackie Steel
VIC Department of Environment and Primary Industries	Michael Moerkerk
VIC Department of Environment and Primary Industries	Nigel Ainsworth
VIC Department of Environment and Primary Industries	Raelene Kwong
Western Australia Department of Agriculture and Food	Alex Douglas
Western Australia Department of Agriculture and Food	Andrew Reeves
Western Australia Department of Agriculture and Food	Catherine Borger
Western Australia Department of Agriculture and Food	John Moore
Western Australia Department of Agriculture and Food	Jon Dodd
Western Australia Department of Agriculture and Food	Noel Wilson
Western Australia Department of Agriculture and Food	Richard Watkins
Western Australia Department of Agriculture and Food	Rod Randall
Western Australia Department of Agriculture and Food	Sally Peltzer
Western Australia Department of Agriculture and Food	Sandy Lloyd
Western Australia Department of Agriculture and Food	Viv Read

Appendix 5. Reviews, surveys and prioritisation exercises consulted for the compilation of lists of weeds important to livestock industries.

1. Alam (2012) MSc Thesis on how interactions between bio-physical and socio-political drivers influence weed awareness and management efforts. Included a postal survey of land holders and interviews with the local weed officer.
2. Bebawi *et al.* (2002) Scientific paper reporting on a participatory decision making approach involving a range of stakeholders to prioritise weed research for the wet- and dry-tropics of north Queensland.
3. Biosecurity South Australia (2011) Weed Risk Management (WRM) assessments of weeds associated with crop-pasture rotation, rangeland, irrigated pastures and souther grazing land uses in South Australia.
4. Biosecurity South Australia (pers. comm.). Weed Risk Management (WRM) assessments of weeds associated with rangeland land uses in South Australia.
5. Biosecurity South Australia (pers. comm.). Weed Risk Management (WRM) assessments of weeds associated with irrigated pastures land uses in South Australia.
6. Biosecurity South Australia (pers. comm.). Weed Risk Management (WRM) assessments of weeds associated with southern grazing land uses in South Australia.
7. Borger *et al.* (2012) Scientific paper reporting on research that identified changes to weed incidence and distribution over the past decade in the south-western Australian wheat belt in Western Australia. Included a comparison of results from weed field surveys and postal surveys of farmers' perceptions of their worst weeds performed in 1997 and again in 2008.
8. Department of Environment and Primary Industries, Victoria (pers. comm.). Weed Risk Assessments of weeds that affect grazing industries in Victoria.
9. Green *et al.* (2011) MLA report on a scoping study that assessed the need and benefits of having a pasture weed impact calculator for southern Australia temperate grazing systems.
10. Ireson *et al.* (2007) Technical Bulletin of the Weeds CRC that provided an assessment of the cost of weeds and species that have the most significant impact on Tasmanian pastures and field crops, and reviewed current status of weed biological control programs in that state.
11. Mewett *et al.* (2011) ABARES report that outlined the process undertaken to rank 16 weed species nominated as potential new WoNS.
12. NSW Department of Primary Industries (2013) and S Johnson, *personal communication*. WRM assessments of weeds associated with grazing natural areas and grazing modified pastures land uses.
13. Sindel *et al.* (2008) Report on research funded by the Defeating the Weed Menace program. Two national surveys of landholders and weeds inspectors were undertaken to develop and extend more widely efficient methods for surveying and eradicating emerging weeds on farms.
14. Thorpe (2011) MLA report that ranked 25 weed species, which impact on grazing industries, on the basis of cost of control (considered a surrogate for pasture production losses, cost of other management practices to reduce spread and product sale losses resulting from weed contamination), which was estimated during the process of identifying WoNS in 1998.
15. Trotter (2007) PhD Thesis on best practice management of pasture weeds in southern Australia. Research activities included interviews with key informants, postal survey of graziers, on-farm validation study, telephone interviews and producer focus groups. (summarised in the MLA report by Trotter and Sindel (2007)).
16. Van Klinken *et al.* (in press) Scientific paper that used data and expert opinion on tropical and subtropical grasses naturalised in Australia since European settlement to identify high-impact species of the environment, pastoral and agriculture sectors.
17. Weston (2011) MLA report summarising the recent history and status of current efforts in weed research and extension in Australia, especially for pasture and rangelands.

Appendix 6. Source and type of data used to compile the list of important weeds of livestock industries.

SOURCE	REGION	DATA TYPE	SAMPLE SIZE
Alam (2012)	Kiama Local Government Area, Illawara region, NSW	Levels of concern by farmers for particular species (highest rank=highest concern) (data extracted from Table 8 of Alam (2012)) [a]	n = 85
Bebawi *et al.* (2002)	Northern Queensland	Species with scores > 0.1 for current economic impact out of 50 species shortlisted as being of most concern to stakeholders across the region (data extracted from Table 2 of Bebawi *et al.* (2002))	n/a
Biosecurity SA (2011 & pers. comm.)	South Australia	Comparative weed risk score from each WRM assessment of weeds associated with crop-pasture rotation, rangeland, irrigated pastures and southern grazing land uses (18, 6, 13 and 26 species respectively). Only species with a current distribution categorised as 'widespread' or 'evenly scattered' in the region were included.	n/a
Borger *et al.* (2012)	South-western Australian wheat belt, WA	Weed incidence (%) in pastures recorded during a field survey in 2008 (>5% included) (data extracted from Table S1 of Borger *et al.* (2012)).	478 fields surveyed
Department of Environment and Primary Industries (pers. comm.)	Victoria	Invasiveness and impact scores (weighted and added) for the top 10 weeds. Only species with a high or moderately high score for impact on yield that relate to grazing and have a statewide distribution that is at least “several or widely scattered small infestations or one large infestation" or more were considered.	n/a
Green *et al.* (2011)	Southern regions [b]	Number of participants in a telephone survey who considered a weed in their top three problem weeds, on which they would like impact data collected (data extracted from Table 9 of Green *et al.* (2011)).	n = 56 (40 graziers and 16 advisors)

APPENDIX 6 (CONTINUED)

SOURCE	REGION	DATA TYPE	SAMPLE SIZE
Ireson *et al.* (2007)	Tasmania	Total number of respondents in dairy, beef and sheep enterprises who listed the weed as a problem on their property (data extracted from Table 2.1 of Ireson *et al.* (2007)).	n = 990
Mewett *et al.* (2011)	National	Total number of livestock-related industries (cattle and calves, and sheep and lambs slaughtered and wool) that the new WoNS is affecting (data extracted from Appendix 5 of Mewett *et al.* (2011)).	n/a
NSW DPI (2013) & S. Johnson, *pers. comm.*	NSW (whole state or subregions within)	Comparative weed risk score from each WRM assessment of weeds associated with grazing natural areas and grazing modified pastures land uses. Only species with a current distribution categorised as 'widespread' or 'evenly scattered' in the region were included (29 species).	n/a
Sindel *et al.* (2008)	National	Proportion of interviewees (%) in property type (grazing or mixed cropping and livestock) mentioning various weed species as being of most concern to them (data extracted from Table 4.7 of Sindel *et al.* (2008)).	n = 568 (86 to 89 respondents in each state; 41 in the NT)
Thorp (2011)	National	Ranking of 25 weed species, which impact on grazing industries, using economic impact data[c] estimated during the process of identifying WoNS in 1998 (rank 1=most costly; data extracted from Table 5 of Thorp (2011)).	n/a
Trotter (2007)	Southern regions [d]	Occurrence (%) of the most commonly reported weeds of all respondents across all regions (> 10% included) (data extracted from Table 5.6 of Trotter (2007)).	n = 934
Van Klinken *et al.* (in press)	Northern regions	Seven subtropical and tropical grass species determined as having a high impact on pastoral industries using pre-defined criteria. No ranking provided by authors.	n/a
Weston (2011)	National	Producer priority weeds (Section 5.1 of Weston 2011) based on a national survey of graziers undertaken in 2008 by Brian Sindel's group (although not specifically cited we assumed these priorities were based on Sindel *et al.* (2008)).	n/a

Footnotes to Appendix 6.

[a] Only the four species with statistically significant mean rank above 170 were considered. All others (47 spp.) had similar ranks lower than 170, with the majority statistically insignificant.
[b] Regions within southern Australia, comprising both high rainfall and cereal zones and temperate and Mediterranean climatic regions (northern NSW, southern NSW, north-east Vic, Central and western Vic, Tas, SA, WA).
[c] As there was no readily available economic data at a national level during the WoNS determination process, the costs to control each weed was used as it was considered a surrogate for pasture production losses, cost of other management practices to reduce spread and product sale losses resulting from weed contamination
[d] Respondents predominantly distributed across the eastern inland (non coastal) areas of NSW throughout Victoria (excluding the north western districts, south eastern South Australia, south western WA and Northern Tasmania. These areas were identified as prominent sheep meat and particularly prime lamb production areas

Appendix 7. Data extracted from the 17 sources as part of the compilation process of important weeds of livestock industries.

		SOUTHERN REGIONS											NORTHERN REGIONS		NATIONAL				
Weed-common name	**Weed-scientific name**	Ireson et al. 2007	Trotter 2007	Green et al. 2011	Biosecurity SA 2011 - crop-pasture rotation	Biosecurity SA *pers. comm.* - rangeland	Biosecurity SA *pers. comm.* - irrigated pasture	Biosecurity SA *pers. comm.* - southern grazing	Alam 2012	Borger et al. 2012	NSW DPI 2013	Vic DEPI 2013	van Klinken et al. *in press*	Bebawi et al. 2002	Sindel et al. 2008 - Grazing	Sindel et al. 2008 - Mixed cropping and livestock	Mewett et al. 2011	Thorpe 2011	Weston 2011
Mimosa bush	*Acacia farnesiana*			1															
Prickly acacia	*Acacia nilotica* spp. *indica*													0.5				8	
Pheasant's eye	*Adonis microcarpa*				17														
Silvery hairgrass	*Aira caryophyllea*									14.9									
Khaki weed	*Alternanthera pungens*													0.3					
Amaranthus	*Amaranthus* spp.	8																	
Yellow burrweed	*Amsinckia* spp.							88											
Gamba grass	*Andropogon gayanus*																1		
Capeweed	*Arctotheca calendula*	234	40.8	9						90.1					11.8	7.5			7
Onion weed	*Asphodelus fistulosus*					45		38											
	Austrostipa spp.									10.6									
Wild oats	*Avena fatua*									30.5									
Groundsel bush	*Baccharis halimifolia*										108								
Cobbler's peg	*Bidens pilosa*			1															
Bifora	*Bifora testiculata*				22														
Wild turnip	*Brassica rapa* ssp. silvestris	20																	
Great brome	*Bromus diandrus*									34.8									
Soft brome	*Bromus hordeaceus*									12.8									
Red brome	*Bromus rubens*									29.8									
Mother of millions	*Bryophyllum spp.*										69			0.2					
Cabomba	*Cabomba caroliniana*													0.2					
Hoary cress	*Cardaria draba*				22														
Slender thistles	*Carduus* spp. (include *C. tenuiflorus*)	136					63	45											
Bergalia	*Carex longebrachiata*								180.48										
Saffron thistle	*Carthamus lanatus*		28.4																
Sifton bush	*Cassinia arcuata*										15								
Innocent weed	*Cenchrus longispinus* & *C. incertus*						112	76											
Green cestrum	*Cestrum parqui*										82								
Fat hen	*Chenopodium album*	30																	
Skeleton weed	*Chondrilla juncea*				116		105	31											

Californian thistle	*Cirsium arvense*	66									0.66							
Spear thistle	*Cirsium vulgare*	169	12.8		25		59	88										
Field bindweed	*Convolvulus arvensis*				46			63										
Fleabane	*Conyza* spp.			6														
	Crassula spp.									20.6								
Rubber vine	*Cryptostegia grandiflora*													0.6			9	
Paddy melon	*Cucumis myriocarpus*			2														
Hudson pear	*Cylindropunita rosea*										126						3	
Opuntioid cacti	*Cylindropuntia* spp.										188							
Wild artichoke	*Cynara cardunculus*							69										
Navua sedge	*Cyperus aromaticus*													0.2				
Scoth broom	*Cytisus scoparius*											0.7					1	
Thornapple	*Datura stramonium*													0.2				
Lincoln weed	*Diplotaxis tenuifolia*				56		95	57										
Paterson's curse	*Echium plantagineum*		34.9	16	74	114	88	278		7.1					21.1	10.9	4	4
Water hyacinth	*Eichhornia crassipes*													0.2				
Spiny emex, three corne	*Emex australis*				135	39	49	135		12.8					2.6	3.1		
Stink grass	*Eragrostis cilianensis*									5								
African love grass	*Eragrostis curvula*			4				59			39		X					
Long storksbill	*Erodium botrys*		10.3							8.5								
Common storksbill	*Erodium cicutarium*		10.3							19.1								
False caper	*Euphorbia terracina*							101										
Fumitory	*Fumaria muralis*	10																
Three-horned bedstraw	*Galium tricornutum*				95													
Montpellier broom	*Genista monspessulana*										69							
Narrowleaf cotton bush	*Gomphocarpus fruticosus*			1													24	
Harrisia cacti	*Harrisia* spp.										63							
Blue heliotrope	*Heliotropium amplexicaule*			4														
Buchan weed	*Hirschfeldia incana*						67											
Barley grass	*Hordeum* spp.	48	28.9	6						56								
Coolatai grass	*Hyparrhenia hirta*			4							170		X					
St. John's wort	*Hypericum perforatum*		13.2	9							164-199						15	
Cat's ear	*Hypochaeris* spp.	41								37.6								
Hyptis	*Hyptis suaveolens*																23	
Bellyache bush	*Jatropha gossypiifolia*													0.3			1	25
Rushes	*Juncus* spp. (including *J. acutus*)	52						39										
Lantana	*Lantana camara*										84			0.4				14
	Lantana spp.										63							
Annual ryegrass	*Lolium rigidum*														21.1	20.1		
African boxthorn	*Lycium ferocissimum*					25		88			213	0.66					2	17
Small-flowered mallow	*Malva parviflora*									8.5								
Horehound	*Marrubium vulgare*	45	18	5	17	35		147				0.67						
	Mesembryanthemum spp.									7.1								
Giant sensitive plant	*Mimosa invisa*													0.4				

Mimosa	*Mimosa pigra*																18	
Cape tulip	*Moraea* spp. (syn *Homeria* spp.)			1														
Chilean needle grass	*Nassella neesiana*			7						126								
Serrated tussock	*Nassella trichotoma*		14.6	9						189	0.76						5	
Onopordum thistles	*Onopordum* spp.		25.8														11	
Opuntioid cacti	*Opuntia* spp.									309						3		
Clover broomrape	*Orobanche minor*				42		63											
Soursob	*Oxalis pes-caprae*				17			90										
Parkinsonia	*Parkinsonia aculeata*												0.4				21	
Parthenium weed	*Parthenium hysterophorus*												0.8	8.5	13.3		7	9
Lippia	*Phyla canescens*			1						337	0.8							
Ink weed	*Phytolacca octandra*			2														
Soldier thistle	*Picnomon acarna*				29			114										
Wireweed	*Polygonum aviculare*	16							5									
Mesquite	*Prosopis* spp.									262			0.4				10	
Guava	*Psidium guajava*												0.2					
Bracken	*Pteridium* spp.	103																
Longtails	*Ptilotus polystachyus*								10.6									
Wild radish	*Raphanus raphanistrum*	36	11.3	2					28.4					1.2	1.9			
Cutleaf mignonette	*Reseda lutea*				162		29	29										
Onion grass	*Romulea rosea*			3					6.4									
Sweet briar	*Rosa rubiginosa*							25			0.7							
Blackberry	*Rubus fruticosus* agg.	282	26.1	5				278	190.65		0.82			19.5	7.6		1	5
Dock	*Rumex* spp.	60	16.3															
Galvanised burr	*Sclerolaena birchii*			1						211								
Spotted golden thistle	*Scolymus maculatus*									79								
Ragwort	*Senecio jacobaea*	251		6										8.7	11.6		2	8
Fireweed	*Senecio madagascariensis*			1					219.79	239						1	20	
Sicklepod	*Senna obtusifolia*												0.2				6	
Bladder campion	*Silene vulgaris*							63										
Variegated thistle	*Silybum marianum*		16.4					59										
Indian hedge mustard	*Sisymbrium orientale*								8.5									
Giant devils thorn	*Solanum chrysotrichum*									365								
Silverleaf nightshade	*Solanum elaeagnifolium*			2	152		101			216						3	12	
Nightshade	*Solanum nigrum*	12																
Sowthistle	*Sonchus oleraceus*								5									
Parramatta grass	*Sporobolus africanus*								175.6			X	0.2					
Giant Parramatta grass	*Sporobolus fertilis* (syn *S. indicus* var. *major)*			1						154		X	0.2				13	
American rat's tail grass	*Sporobolus jacquemontii*											X	0.2					
Giant rat's tail grass	*Sporobolus natalensis*											X	0.2				16	
Giant rat's tail grass	*Sporobolus pyramidalis*									152		X	0.2			2		
	Stachytarpheta spp.												0.2					
Caltrop	*Tribulus terrestris*				140	98	98	126					0.2	1	23.1			
Gorse	*Ulex europaeus*	234		5						157	0.74			5.7	2.2		3	10

Vulpia or silvergrass	*Vulpia* spp.		23.1	3						34.8								
Noogoora burr	*Xanthium occidentale* (syn *X. strumarium*)			1				118			367	0.67					22	
Bathurst burr	*Xanthium spinosum*		24.4	17	56		172	112			289				12.5	9	19	6
Chinee apple	*Ziziphus mauritiana*													0.3				
Thistles			22.7	20											30.8	29.8		1
Other perennial broadleaf weeds															27.9	29.5		
Others															25.2	19.2		
Perennial grasses															23.2	20.2		2
Woody weeds															21.2	13		3
Other annual broadleaf weeds															18.7	10.5		
Other annual grasses															6.9	11.6		
Vines															4.5	7.1		

Appendix 8. The most important ten weed species (or fewer depending on data available) for each of the sources consulted.

These data are marked in red in Appendix 7. Note that species are arranged in alphabetical order – numbering DOES NOT indicate priority ranking. * Species that were not listed in Grice (2003).

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
1	*Vachellia nilotica* ssp. *indica*	Prickly acacia	tree/shrub
2	*Alternanthera pungens* *	Khaki weed	annual forb
3	*Andropogon gayanus*	Gamba grass	perennial grass
4	*Arctotheca calendula*	Capeweed	annual forb
5	*Asphodelus fistulosus*	Onion weed	annual/perennial forb
6	*Avena fatua* *	Wild oats	annual grass
7	*Bromus diandrus* *	Great brome	annual grass
8	*Bromus rubens* *	Red brome	annual grass
9	*Carduus* spp. (include *C. tenuiflorus*)	Slender thistles	annual forb
10	*Carex longebrachiata* *	Bergalia	perennial grass
11	*Carthamus lanatus* *	Saffron thistle	annual forb
12	*Cenchrus longispinus* & *C. incertus* *	Innocent weed	annual grass
13	*Chondrilla juncea* *	Skeleton weed	annual forb
14	*Cirsium arvense*	Californian thistle	perennial forb
15	*Cirsium vulgare*	Spear thistle	annual forb
16	*Convolvulus arvensis* *	Field bindweed	annual forb
17	*Conyza* spp. *	Fleabane	annual forb
18	*Crassula* spp. *		succulent
19	*Cryptostegia grandiflora*	Rubber vine	shrub/vine
20	*Cylindropuntia rosea* *	Hudson pear	succulent
21	*Cytisus scoparius*	Broom	shrub
22	*Diplotaxis tenuifolia*	Lincoln weed	annual forb
23	*Echium plantagineum*	Paterson's curse	annual forb
24	*Emex australis*	Spiny emex	annual forb
25	*Eragrostis curvula*	African love grass	perennial grass

APPENDIX 8 (CONTINUED)

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
26	*Erodium cicutarium*	Common storksbill	annual forb
27	*Euphorbia terracina* *	False caper	perennial forb
28	*Galium tricornutum*	Three-horned bedstraw	annual forb
29	*Hirschfeldia incana* *	Buchan weed	annual forb
30	*Hordeum* spp.	Barley grass	annual grass
31	*Hyparrhenia hirta*	Coolatai grass	perennial grass
32	*Hypericum perforatum*	St. John's wort	annual forb
33	*Hypochaeris* spp.	Cat's ear	annual forb
34	*Jatropha gossypiifolia*	Bellyache bush	shrub
35	*Juncus* spp.	Rushes	perennial grass
36	*Lantana camara*	Lantana	shrub
37	*Lolium rigidum* *	Annual ryegrass	annual grass
38	*Lycium ferocissimum*	African boxthorn	shrub
39	*Marrubium vulgare*	Horehound	annual forb
40	*Mimosa invisa*	Giant sensitive plant	shrub
41	*Nassella neesiana*	Chilean needle grass	perennial grass
42	*Nassella trichotoma*	Serrated tussock	perennial grass
43	*Onopordum* spp.	Onopordum thistles	annual forb
44	*Opuntia* spp.	Opuntioid cacti	succulent
45	*Oxalis pes-caprae* *	Soursob	perennial forb
46	*Parkinsonia aculeata*	Parkinsonia	shrub
47	*Parthenium hysterophorus*	Parthenium weed	annual forb
48	*Phyla canescens*	Lippia	perennial forb
49	*Picnomon acarna* *	Soldier thistle	annual forb
50	*Prosopis* spp.	Mesquite	tree/shrub
51	*Pteridium* spp.	Bracken	fern
52	*Raphanus raphanistrum*	Wild radish	annual forb
53	*Reseda lutea* *	Cutleaf mignonette	annual forb
54	*Rosa rubiginosa*	Sweet briar	shrub
55	*Rubus fruticosus* agg.	Blackberry	shrub
56	*Rumex* spp. *	Dock	perennial forb
57	*Sclerolaena birchii* *	Galvanised burr	shrub

APPENDIX 8 (CONTINUED)

	SCIENTIFIC NAME	COMMON NAME	GROWTH FORM
58	*Senecio jacobaea*	Ragwort	perennial forb
59	*Senecio madagascariensis*	Fireweed	perennial forb
60	*Senna obtusifolia*	Sicklepod	shrub
61	*Solanum chrysotrichum* *	Giant devils thorn	shrub
62	*Solanum elaeagnifolium*	Silverleaf nightshade	perennial forb
63	*Sporobolus africanus*	Parramatta grass	perennial grass
64	*Sporobolus fertilis* (syn *S. indicus* var. *major)*	Giant Parramatta grass	perennial grass
65	*Sporobolus jacquemontii*	American rat's tail grass	perennial grass
66	*Sporobolus natalensis*	Giant rat's tail grass	perennial grass
67	*Sporobolus pyramidalis*	Giant rat's tail grass	perennial grass
68	*Tribulus terrestris*	Caltrop	annual forb
69	*Ulex europaeus*	Gorse	shrub
70	*Vulpia* spp.	Vulpia or silvergrass	annual grass
71	*Xanthium occidentale* (syn *X. strumarium*)	Noogoora burr	annual forb
72	*Xanthium spinosum*	Bathurst burr	annual forb
73	*Ziziphus mauritiana*	Chinee apple	tree/shrub

Appendix 9. Species reconsidered for inclusion in the list of prominent weeds and explanations for retaining or removing them.

Most of these were species which had not been included in the Grice's (2003) review.

	SCIENTIFIC NAME	EXPLANATION
1	*Alternanthera pungens*	Removed: Weed of disturbed ground and a problem because it is a nuisance due to its prickly fruits.
2	*Avena fatua*	Removed: Palatable species; weed in crop phase of crop/pasture rotation system; not a problem in pasture.
3	*Bromus diandrus*	Removed: Palatable species; provide early season forage for livestock.
4	*Bromus rubens*	Removed: Palatable species; provide early season forage for livestock.
5	*Carex longebrachiata*	Removed: Raised as a concern in a limited area (South Coast NSW).
6	*Carthamus lanatus*	Retained: Widespread and with potential to spread further into drier areas.
7	*Cenchrus longispinus* & *C. incertus*	Retained: Widespread and specifically identified as a weed of irrigated pastures and grazing systems in South Australia. Burrs can reduce the value of wool.
8	*Chondrilla juncea*	Removed: Primarily a weed in crop phase of crop/pasture rotation system.
9	*Convolvulus arvensis*	Removed: Primarily a weed in crop phase of crop/pasture rotation system.
10	*Conyza* spp.	Removed: Important weed of fallows as part of cropping systems. Apparently not a significant weed in pasture
11	*Crassula* spp.	Removed: Weed of disturbed water logged areas in cropping systems; disappears during pasture phase.
12	*Cylindropuntia rosea*	Retained: Change to *Cylindropuntia* spp. to cover all species as identified in the final list of new WoNS.
13	*Euphorbia terracina*	Retained: Unpalatable weed found in SA and WA pastures. Occurs inland as well as on the coast.
14	*Hirschfeldia incana*	Removed: Only mentioned as a weed of irrigated pasture in SA. Not one of the highest priorities for this system.

APPENDIX 9 (CONTINUED)

	SCIENTIFIC NAME	EXPLANATION
15	*Lolium rigidum*	Removed: Palatable species; weed in crop phase of crop/pasture rotation system; not a problem in pasture.
16	*Oxalis pes-caprae*	Removed: Primarily a crop weed, but sometimes found in pasture and as an environmental weed.
17	*Picnomon acarna*	Removed: Predominant where it is not controlled in crops and is allowed to dominate regenerated pastures. It is not a major weed of permanent pastures.
18	*Pteridium* spp.	Removed: Native species
19	*Reseda lutea*	Retained: Important in crop/pasture rotation and to a lesser degree in rangelands but only in S. Aust.
20	*Rumex* spp.	Retained: Widespread in southern Australia and present in the north. Crop/pasture rotation encourages this species.
21	*Sclerolaena birchii*	Removed: Known as a pioneer species. Weed of overgrazed or disturbed areas. Included because a WRM assessment was done by NSW DPI.
22	*Solanum chrysotrichum*	Removed: Assessment made for only a small region of NSW (Far North Coast), where its current distribution is scattered. Not believed to be important for the rest of NSW and Australia.

Appendix 10. Species added to list of prominent weeds and explanations for their inclusion.

	SCIENTIFIC NAME	COMMON NAME	INFORMATION SOURCE
1	*Bryophyllum delagoense*	Mother-of-millions	Consultation process
2	*Calotropis procera*	Calotropis	Consultation process
3	*Cenchrus pedicellatus*	Annual mission grass	Consultation process
4	*Cenchrus polystachios*	Perennial mission grass	Consultation process
5	*Harrsia martinii*	Harrisia cactus	Consultation process
6	*Hyparrhenia rufa*	Thatch gras	Consultation process
7	*Hyptis suaveolens*	Hyptis	Consultation process
8	*Lantana montevidensis*	Creeping lantana	Consultation process
9	*Mimosa pigra*	Mimosa	Consultation process
10	*Moraea flaccida* (syn. *Homeria flaccida)*	One-leaf Cape tulip	Toxic species that are a concern for SA and WA. High impact where abundant, but distribution patchy.
11	*Moraea miniata (*syn. *Homeria miniata)*	Two-leaf Cape tulip	Toxic species that are a concern for SA and WA. High impact where abundant, but distribution patchy.
12	*Romulea rosea*	Guildford grass (=onion grass)	Consultation process; has negative effects on pasture performance
13	*Tamarix aphylla*	Athel pine	Included because it is a WoNS, not captured by review process, but which adversely affects livestock industries
14	*Themeda quadrivalvis*	Grader grass	Consultation process

Appendix 11. Species assessed for inclusion in the final list of emerging weeds relevant to livestock industries.

	SCIENTIFIC NAME	COMMON NAME	INFORMATION SOURCE
1	*Acaciella angustissima*	White ball acacia	Gardiner *et al.* (2008, 2010) – few locations in north Queensland; MLA funded control program underway
2	*Aeschynomene paniculata*	Panicle joint vetch	Gardiner *et al.* (2008, 2010) – few locations in north Queensland; MLA funded control program underway
3	*Agave sisalana*	Sisal hemp	Grice (2003)
4	*Andropogon gayanus*		Consultation process
5	*Azadirachta indica*	Neem	Grice (2003)
6	*Barleria prionitis*	Barleria	Alert List for Environmental Weeds; Weeds CRC Management Guide series
7	*Bassia scoparia*	Kochia	Alert List for Environmental Weeds; Weeds CRC Management Guide series
8	*Bryophyllum delagoense*	Mother-of-millions	Grice (2003)
9	*Carrisa ovata*	currant bush	Consultation process
10	*Cascabela thevetia*	Yellow oleander	Grice (2003); consultation process
11	*Celtis sinensis*	Chinese celtis	Grice (2003)
12	*Cenchrus basedowii*	asbestos grass	Consultation process
13	*Cenchrus ciliaris*	Buffel grass	Weeds CRC Management Guide series
14	*Cenchrus macrourus* (syn. *Pennisetum macrourum*)	African feathergrass	Weeds CRC Management Guide series
15	*Cenchrus pedicellatus*	Annual mission grass	Weeds CRC Management Guide series
16	*Cenchrus polystachios*	Perennial mission grass	Grice (2003); Weeds CRC Management Guide series
17	*Cenchrus setaceus*	Fountain grass	Grice (2003)
18	*Cenchrus villosus*	Feathertop	Weeds CRC Management Guide series

APPENDIX 11 (CONTINUED)

	SCIENTIFIC NAME	COMMON NAME	INFORMATION SOURCE
19	*Centaurea maculosa*	Spotted knapweed	Grice (2003)
20	*Centaurea nigra*	Black knapweed	Grice (2003)
21	*Cestrum parqui*	Green cestrum	Grice (2003)
22	*Chromolaena odorata*	Siam weed	Alert List for Environmental Weeds; Jeffrey (2012) – Recently abandoned eradication program means further range expansion highly likely
23	*Clidemia hirta*	Koster's curse	Graham *et al.* (2008) – prospective weed of pastures and other systems in humid tropics
24	*Crotalaria* spp.	crotalaria	Consultation process
25	*Cuscuta planiflora*	Small-seeded dodder	Grice (2003)
26	*Cynoglossum creticum*	Blue hound's tongue	Alert List for Environmental Weeds; Weeds CRC Management Guide series
27	*Cyperus aromaticus*	Navua sedge	Consultation process
28	*Cyperus teneristolon*	Cyperus	Alert List for Environmental Weeds; Weeds CRC Management Guide series
29	*Cytisus multiflorus*	White Spanish broom	Alert List for Environmental Weeds; Weeds CRC Management Guide series
30	*Cytisus scoparius*	Scotch broom	Weeds CRC Management Guide series
31	*Diplotaxis tenuifolia*	Lincoln weed = sand rocket	Grice (2003)
32	*Dittrichia viscosa*	False yellowhead	Alert List for Environmental Weeds; Weeds CRC Management Guide series
33	*Elephantopus mollis*	Tobacco weed	Grice (2003)
34	*Equisetum* spp.	Horsetails	Alert List for Environmental Weeds; Weeds CRC Management Guide series; Ainsworth et al. (2006) – present in Australia; weed of pastures overseas, including New Zealand
35	*Eragrostis curvula*	African love grass	Consultation process

APPENDIX 11 (CONTINUED)

	SCIENTIFIC NAME	COMMON NAME	INFORMATION SOURCE
36	*Erica lusitanica*	Spanish heath	Alert List for Environmental Weeds; Weeds CRC Management Guide series
37	*Florestina tripteris*	Florestina	Brazier *et al.* (2010) – locally naturalised in central Queensland
38	*Galium tricornutum*	Three-horned bedstraw	Grice (2003)
39	*Gastrolobium grandiflorum*	heartleaf poison bush	Consultation process
40	*Gleditsia triacanthos*	Honey locust	Csurhes (2004) – eradication program progressing well in Queensland
41	*Gmelina elliptica*	Badhara bush	Baker (2010) – a prospective environmental weed but also occurs in rangelands; subject of a control program
42	*Gomphocarpus fruticosus*	Cottonbush	Lloyd and Rayner (2012) – increasing pasture weed south-west WA
43	*Hieracium aurantiacum*	Orange hawkweed	Alert List for Environmental Weeds; Weeds CRC Management Guide series; Baker (2010) – expanding range
44	*Hieracium* spp.	Hawkweeds	Grice (2003)
45	*Hygrophila polysperma*	Indian Swampweed	Consultation process
46	*Hymenachne amplexicaulis*	Olive hymenachne	Consultation process
47	*Hypharrhenia hirta*	Coolatai grass	Weeds CRC Management Guide series
48	*Lachnagrostis filiformis*	Fairy grass	Gosney *et al.* (2006) – native grass “recently become a major concern”; Warnock *et al.* (2008) – western Victoria
49	*Lavandula stoechas*	Topped lavender = Spanish lavender	Nicholson (2006) – limited current distribution; invades unimproved pastures
50	*Lycium ferocissimum*	African boxthorn	Weeds CRC Management Guide series
51	*Macfadyena unguis-cati*	Cat's claw creeper	Weeds CRC Management Guide series
52	*Moraea flaccidea (=Homeria flaccida)*	One-leaf Cape tulip	Grice (2003)

APPENDIX 11 (CONTINUED)

	SCIENTIFIC NAME	COMMON NAME	INFORMATION SOURCE
53	*Moraea miniata (=Homeria miniata)*	Two-leaf Cape tulip	Grice (2003)
54	*Nassella charruana*	Lobed needle-grass	Alert List for Environmental Weeds; Weeds CRC Management Guide series
55	*Nassella hyalina*	Cane needle-grass	Alert List for Environmental Weeds; Weeds CRC Management Guide series
56	*Nassella neesiana*	Chilean needle grass	Grice (2003)
57	*Ocium tenuiflorum*	native thyme	Consultation process
58	*Ornithogalum thyrsoides*	Chincherinchee	Grice (2003)
59	*Orobanche* spp.	Branched broom rape	Grice (2003)
60	*Paspalum notatum*	Bahia grass	Grice (2003)
61	*Pelargonium alchemilloides*	Garden geranium	Alert List for Environmental Weeds; Weeds CRC Management Guide series
62	*Phyla canescens*	Lippia	Grice (2003)
63	*Physalis viscosa*	Prairie ground cherry	Grice (2003)
64	*Pimelea* spp.	pimelea	Consultation process
65	*Piptochaetium montevidense*	Uruguayan rice grass	Alert List for Environmental Weeds; Weeds CRC Management Guide series
66	*Praxelis clematidea*	Praxelis	Grice (2003) Consultation process
67	*Rubus alceifolius*	Giant bramble	Consultation process
68	*Rubus niveus*	Hill raspberry	Consultation process
69	*Senna obtusifolia*	Sicklepod	Consultation process
70	*Solanum viarum*	Tropical soda apple	Consultation process
71	*Stevia ovata*	Candyleaf	Consultation process
72	*Striga asiatica*	Striga	Consultation process
73	*Vachellia farnesiana* (syn. *Acacia farnesiana*)	Mimosa bush	Consultation process

Appendix 12. Species excluded from the preliminary list of potentially emerging weeds.

SCIENTIFIC NAME	COMMON NAME
Species already included in list of prominent weeds	
Andropogon gayanus	Gamba grass
Cytisus scoparius	Broom
Diplotaxis tenuifolia	Lincoln weed
Eragrostis curvula	African lovegrass
Galium tricornutum	Three-horned bedstraw
Harissia spp.	Harissia cactus
Hyparrhenia hirta	Coolatai grass
Lycium ferocissimum	African boxthorn
Moraea flaccida	One-leaf Cape tulip
Moraea miniata	Two-leaf Cape tulip
Nassella neesiana	Chilean needlegrass
Phyla canescens	Lippia
Species native to Australia	
Carissa ovata	Currant bush
Crotalaria spp. (some species are native)	Rattlepods
Ocimum tenuiflorum	Native thyme
Vachellia farnesiana (syn. *Acacia farnesiana*)	Mimosa bush
Gastrolobium grandiflorum	Heart-leaf poison bush
Pimelea spp.	Riceflowers
Species that are entirely aquatic	
Hygrophilia polysperma	East Indian hygrophylla
Species that are valued for the forage they produce	
Cenchrus ciliaris	Buffel grass
Hymenachne amplexicaulis	Olive hymenachne

Appendix 13. Responses to four questions used to evaluate whether species meet criteria for emerging weeds of livestock industries.

Q1. Is it already widespread in Australia relative to its potential distribution?
Q2. Are there many infestations?
Q3. Are many livestock producers already being negatively affected by infestations?
Q4. Does it have the potential to have significant negative impacts?

SCIENTIFIC NAME	Q1	Q2	Q3	Q4
Species that did not meet criteria for being emerging weeds of livestock industries				
Agave sisilana	Y	N	N	N
Azadirachta indica	Y	N	N	N
Barleria prionitis	N	N	N	N
Bassia scoparia	Y	N	N	N
Bryophyllum delagoense	Y	Y	N	N
Celtis sinensis	Y	N	?	N
Cenchrus basedowii	Y	Y	?	N
Cenchrus macrourus	Y	Y	N	N
Cenchrus pedicellatus	Y	Y	?	N
Cenchrus polystachios	Y	Y	Y	N
Cenchrus setaceus	Y	?	?	N
Cenchrus villosus[29]	Y	Y	N	N
Centaurea nigra	N	N	N	?
Cestrum parqui	Y	Y	?	?
Cuscuta planiflora	Y	Y	?	N
Cynoglossum creticum	N	N	N	?
Cyperus teneristolon	N	N	N	?
Cytisus multiflorus	N	N	N	N
Dittrichia viscosa	N	N	N	N
Equisetum spp.	N	Y	?	N
Erica lusitanica	Y	Y	?	N
Gleditsia triacanthos	Y	Y	?	N
Lachnagrostis filiformis	Y	Y	?	N
Macfadyena unguis-cati	Y	N	N	Y
Ornithogalum thyrsoides	Y	N	N	N
Orobanche spp.	Y	Y	?	N
Paspalum notatum	Y	Y	?	N
Pelargonium alchemilloides	?	?	N	?
Piptochaetium montevidense	N	N	N	N

[29] Formerly named *Pennisetum villosum*

APPENDIX 13 (CONTINUED)

SCIENTIFIC NAME	Q1	Q2	Q3	Q4
Rubus niveus	N	N	N	N
Senna obtusifolia	Y	Y	Y	N
Stevia ovata	N	N	N	N
Striga asiatica.	N	N	N	N
Species that met criteria for being emerging weeds of livestock industries				
Acaciella angustissima	N	N	N	Y
Aeschynomene paniculata	N	N	N	Y
Cascabela thevetia	N	N	N	Y
Centaurea maculosa	N	N	N	Y
Chromolaena odorata	N	N	N	Y
Clidemia hirta	N	N	N	Y
Cyperus aromaticus	N	N	N	Y
Elephantopus mollis	N	N	N	Y
Florestina tripteris	N	N	N	Y
Gmelina elliptica	N	N	N	Y
Gomphocarpus fruticosus	N	N	N	Y
Hieraceum spp. esp. *H aurantiacum*	N	N	N	Y
Lavandula stoechas	N	N	N	Y
Nassella charruana	N	N	N	Y
Nassella hyalina	N	N	N	Y
Physalis viscosa	N	N	N	Y
Praxelis clematidea	N	N	N	Y
Rubus alceifolius	N	N	N	Y
Solanum viarum	N	N	N	Y

Appendix 14. Grazing-relevant Weeds of National Significance that were the specific subjects of papers presented at the five Australian Weeds Conferences held since 2003.

INAUGURAL WoNS		ADDITIONAL WoNS	
SCIENTIFIC NAME	**COMMON NAME**	**SCIENTIFIC NAME**	**COMMON NAME**
Acacia nilotica[30]	Prickly acacia	*Andropogon gayanus*	Gamba grass
Alternanthera phileroxoides	Alligator weed	*Austrocylindropuntia, Cylindropuntia, Opuntia*	Opuntioid cacti
Cabomba caroliniana	Cabomba	*Cytisus scoparius*	Scotch broom
Cryptostegia grandiflora	Rubber vine	*Jatropha gossypiifolia*	Bellyache bush
Eichhornia crassipes	Water hyacinth	*Lycium ferocissimum*	African boxthorn
Hymenachne amplexicaulis	Olive hymenachne	*Macfadyena unguis-cati*	Cat's claw creeper
Lantana camara	Lantana	*Senecio madagascariensis*	Fireweed
Mimosa pigra	Giant sensitive plant (Mimosa)	*Solanum elaeagnifolium*	Silverleaf nightshade
Nassella neesiana	Chilean needle grass		
Nassella trichotoma	Serrated tussock		
Parkinsonia aculeata	Parkinsonia		
Parthenium hysterophorus	Parthenium		
Prosopis spp.	Mesquite		
Rubus fruticosus agg.	Blackberry		
Salvinia molesta	Salvinia		
Tamarix aphylla	Athel pine		
Ulex europaeus	Gorse		

[30] Now formally *Vachellia nilotica*

Appendix 15. Topics addressed in papers published in the Proceedings of the five Australian Weeds Conferences held since 2003.

TOPIC	DESCRIPTION	NO. PAPERS	% OF PAPERS
General	General introduction to specific weeds; awareness raising	11	4.3
Ecology	Any aspect of a species' ecology	50	19.8
Biological control	Prospects, progress and outcomes of biological control research	57	22.5
Other control methods	Development and testing of control methods other than biocontrol	56	22.1
Management	Reports on specific management efforts	23	9.1
Management plans	Development and assessment of management plans	13	5.1
Surveys and delimitation methodology	Development of delimitation methodology and reports on specific delimitation exercises	18	7.1
Communication and extension	Extension related to weed awareness and management methods	5	2.0
Policy	Weed-related policy and its effects	3	1.2
Economics	Economic analysis of the costs of weeds and benefits of control actions	3	1.2
Impact	Documenting/quantifying the impacts of specific weeds	11	4.4
Climate change	Predicting the impacts of climate change on the distribution, abundance and impacts of weeds	3	1.2
TOTAL		253	100

Appendix 16. Species that are the subjects of publications on biological control published in the Proceedings of Australian Weeds Conferences 2004-2012.

* indicates WoNS.

SCIENTIFIC NAME	COMMON NAME	NOTES
**Acacia nilotica*[31]	Prickly acacia	Demonstration of agent establishment in field; report on agent search in India; preliminary investigation of dieback phenomenon
Ageratina adenophora	Crofton weed	Investigation of prospective fungi
**Alternanthera phileroxoides*	Alligator weed	Preliminary evaluation of pathogens; two prospective agents rejected, another still being tested
**Cabomba caroliniana*	Cabomba	Two prospective agents identified
Cirsium arvense	California thistle	Synopsis of biocontrol in New Zealand
Cirsium vulgare	Spear thistle	Research on bioherbicides; assessment of distribution of biocontrol agent in Victoria
**Cylindropuntia rosea*	Hudson pear	General assessment of prospects for biocontrol
**Cytisus scoparius*	Scotch broom	Surveys for rust in Australia; update of progress
Echium plantagineum	Paterson's curse	Impact of biocontrol agents in the field; methodological development; biology of an agent; study of interactions between agents; assessment of biocontrol agents in the field
Emex australis	Spiny emex	Biology of biocontrol agent
**Lantana camara*	Lantana	Non-target damage; retrospective host-specificity testing; monitoring agent establishment and spread; assessment of impact of rust biocontrol agent
**Macfadyena unguis-cati*	Cat's claw creeper	Two prospective agents identified
Marrubium vulgare	Horehound	Preliminary evaluation of establishment and impact of biocontrol agents; agent release and assessment of establishment
**Mimosa pigra*	Giant sensitive plant Mimosa	Field evaluation of current agents; two agents assessed in the field; assessment of dieback phenomenon
**Nassella neesiana*	Chilean needle grass	Update on current research; host-specificity testing and culture of prospective agents; search for fungal agents in Argentina

[31] Now formally *Vachellia nilotica*

APPENDIX 16 (Continued)

SCIENTIFIC NAME	COMMON NAME	NOTES
**Nassella trichotoma*	Serrated tussock	Prospective fungal agents affect on seed germination; update on current research; assessment of dieback phenomenon
**Opuntia robusta*	Wheel cactus	Assessment of a prospective biocontrol agent
**Parkinsonia aculeata*	Parkinsonia	Update on native range surveys and prospective agents; preliminary investigation of dieback; evaluation of prospective mycoherbicides; study of dieback
**Parthenium hysterophorus*	Parthenium	Assessment of biocontrol rust in field
Rubus anglocandicans	English blackberry	Assessment of dieback phenomenon in SW Western Austalia
**Rubus fruticosus* agg.	Blackberry	Taxonomy of *Rubus* spp. has implications for biocontrol; general analysis of biocontrol situation; report on release of new rust strains; study of prospective fungal agent; report on prospective biocontrol agent
Rumex brownii	Docks	Establishment of biocontrol agent on various *Rumex* spp.
Rumex conglomeratus		
Rumex crispus		
Rumex obtusifolius		
Rumex pulcher		
**Salvinia molesta*	Salvinia	Account of biocontrol success; general assessment of biocontrol against nine weed spp. in NT including *S. molesta*; biodiversity impacts of biocontrol; description of successful control
Senecio jacobaea	Ragwort	Methodological research
**Solanum elaeagnifolium*	Silverleaf nightshade	Review of natural enemies
Sporobolus africanus	Parramatta grass	Analysis of prospects for biocontrol; inoculation by prospective fungal biocontrol agent
Sporobolus fertilis	Giant Parramatta grass	
Sporobolus jacquemontii	American rat's tail grass	
Sporobolus natalensis		
Sporobolus pyramidalis	Giant rat's tail grass	
Xanthium occidentale	Noogoora burr	Surveys for agents in native range

Appendix 17. Weed species of grazing lands that were the subject of journal articles between 2003 and 2013.
* indicates native species

SCIENTIFIC NAME	COMMON NAME	SCIENTIFIC NAME	COMMON NAME
Acacia nilotica[32]	Prickly acacia	*Hieracium* spp.	Hawkweeds
Alternanthera philoxeroides	Alligator weed	*Hordeum murinum* ssp. *Glaucum*	Barley grass
Andropogon gayanus	Gamba grass	*Hordeum murinum* ssp. *Leporinum*	Barley grass
Arctotheca calendula	Cape weed	*Hymenachne amplexicaulis*	Olive hymenachne
Artemisia verlotiorum	Chinese mugwort	*Hyparrhenia hirta*	Coolatai grass
Bothriochloa pertusa	Indian couch	*Hypericum perforatum*	St John's wort
Calotropis procera	Calotrope	*Hypochaeris radicata*	Cat's ear
Capsella bursa-pastoris	Shepherd's purse, locowort	*Jatropha gossypiifolia*	Bellyache bush
Carduus nutans	Musk thistle	*Lachnagrostis filiformis*	Blown grass
Carissa ovata *	Conkerberry	*Lantana camara*	Lantana
Carrichtera annua	Ward's weed	*Leucaena leucocephala*	Leucaena
Carthamus lanatus	Saffron thistle	*Lolium rigidum*	Annual ryegrass
Cenchrus ciliaris	Buffel grass	*Mimosa pigra*	Mimosa
*Chloris truncata**	Windmill grass	*Nassella neesiana*	Chilean needle grass
Crotalaria medicaginea	Trefoil rattlepod	*Nassella trichotoma*	Serrated tussock
Crotalaria spp	Rattlepods	*Onopordum* ssp.	Onoportum thistles
Cynosurus echinatus	Rough dog's tail	*Onopordum illyricum*	Illyrian thistle
Cyperus aromaticus	Navua sedge	*Parkinsonia aculeata*	Parkinsonia
Cytisus scoparius	Scotch broom	*Parthenium hysterophorus*	Parthenium

[32] Now formally *Vachellia nilotica*

APPENDIX 17 (Continued)

SCIENTIFIC NAME	COMMON NAME	SCIENTIFIC NAME	COMMON NAME
Dactyloctenium radulans *	Button grass	*Pennisetum clandestinum*[33]	Kikuyu grass
Echium plantagineum	Paterson's curse	*Phalaris aquatica*	Australian phalaris
Emex australis	Spiny emex	*Phyla canescens*	Lippia
Emex spinosa	Lesser Jack	*Pimelea* ssp.[34]	Riceflowers
Enteropogon ramosus	Curly windmill grass	*Pimelea trichostachya*	Annual rice-flower
Eragrostis curvula	African love grass	*Praxelis clematidia*	Praxelis
Prosopis spp.	Mesquite	*Sporobolus* spp.	Rat's tail grasses
Raphanus raphanistrum	Wild radish	*Sporobolus fertilis*	Giant Parramatta grass
Romulea rosea	Onion grass	*Sporobolus pyramidalis*	Giant rat's tail grass
Rubus anglocandicans	English blackberry	*Ulex europaeus*	Gorse
Salsola australis	Russian tumbleweed	*Urochloa mutica*	Para grass
Sclerolaena birchii	Galvanised burr	*Vulpia bromoides*	Brome fescue
Senecio jacobaea	Ragwort	*Vulpia myuros*	Fox tail fescue
Sisymbrium irio	London rocket	*Vulpia* spp.	Fescues
Solanum elaeagnifolium	Silverleaf nightshade		

[33] Now formally *Cenchrus clandestinus*
[34] Native species

Appendix 18. Key words in 32 PhD (30) and MSc (3) theses completed between 2003 and May 2013 at Australian universities with a subject matter relevant to weeds in pastures.

SCIENTIFIC NAME	STUDY LOCATION	TOPIC
Allium triquetrum	Border Rivers Catchment	annual pasture
Andropogon gayanus	Brigalow	biodiversity impacts
Anredera cordifolia	Cape York Peninsula	biological control
Aristida latifolia	Cobar	climate change
Cenchrus ciliaris	Dalrymple	CLIMEX
Cirsium vulgare	Glen Innes	crop-pasture rotation
Eragrostis curvula	Greenvale	dairy pastures
Heliotropium europaeum	Kiama LGA in the Illawarra Region	decision modelling
Hypericum perforatum	Kings Plain Subcatchment	dieback
Lantana camara	Mallee	distribution modelling
Lotus corniculatus	Mary River catchment	economic impact
Malva parviflora	New South Wales	genetic variability
Mimosa pigra	Northern Territory	herbicide resistance
Nassella neesiana	Queensland	landscape modelling
Nassella trichotoma	semi-arid	pasture ecology
Olea europea	Tasmania	pasture legumes
Panicum maximum[35]	temperate Australia	perennial pasture
Parkinsonia aculeata	Victoria	questionnaire
Parthenium hysterophorus	Western Australia	weed competition
Senecio madagascariensis	Wheat belt of south west Australia	weed ecology
Senna obtusifolia		weed ranks
Sporobolus africanus		weed risk assessment
Sporobolus fertilis		weed survey
Sporobolus pyramidalis		woody encroachment
Trifolium subterraneum		
Ulex europaeus		
Urochloa mutica		

[35] Now formally *Megathyrsus maximus*

Appendix 19. Sources of PhD and MSc theses on weeds of grazing lands completed since 2003.

UNIVERSITY	NO. PhD THESES (MSc THESES)
Charles Darwin University	2
Curtin University	1
James Cook University	1
Monash University	(1)
Queensland University of Technology	1
RMIT University	2
University of Adelaide	2
University of Melbourne	1
University of New England	6
University of Queensland	6
University of Tasmania	1
University of Western Australia	4 (1)
University of Western Sydney	1
University of Wollongong	(1)

Appendix 20. Completed RD&E projects relating to weeds funded by MLA post-2003.
Information extracted in June 2013 from http://www.mla.com.au/Research-and-development

PROJECT TITLE	END DATE	ORGANISATION OR RESEARCHER
Delivery of Biological Control Agents for Paterson's Curse [and thistles]	30/06/2005	CSIRO Entomology, Department of Agriculture WA, Department Primary Industries Victoria, NSW Department of Primary Industries, South Australian Research & Development Institute (with co-funding from Australian Wool Innovation)
Protecting North Australian Grasslands from Rejected Forage Plants of High Weed Potential	31/01/2006	Queensland Department of Primary Industries & Fisheries
Analysis of threats to grazing industries by invasive garden plants	28/04/2006	Weeds CRC
Paterson's Curse CD Workshop (CMA)	26/05/2006	Ellis Farm Consultancy Pty Ltd
The Sociology of Weeds - Motivating, Building Capacity and Educating Graziers who Fail to Control Weeds	30/06/2006	University of New England
New approaches to weed management extension - Southern Australia	30/06/2006	Meat and Livestock Australia, in partnership with Australian Wool Innovation
Feasibility of biological control of solanaceous weeds of temperate Australia	31/08/2006	Victorian Department of Primary Industries
Blue Heliotrope Biological Control	1/10/2006	Blue Heliotrope Action Committee (Qld), Ian Crosthwaite
Delivery of best weed management practices for meat sheep producers	11/11/2006	University of New England

APPENDIX 20 (Continued)

PROJECT TITLE	END DATE	ORGANISATION OR RESEARCHER
The Biological Control of Paterson's Curse and Scotch Thistles. A long-term investment by grazing industries, State and Federal Governments	30/11/2006	CSIRO Entomology, Department of Agriculture WA, NSW Department of Primary Industries, South Australian Research and Development Institute (with co-funding from Australian Wool Innovation)
Strategic management of weedy sporobolus grasses	30/11/2006	New South Wales Department of Primary Industries
Biological control of Paterson's curse - an interactive guide	1/03/2007	CSIRO Entomology, Department of Agriculture WA, Department Primary Industries Victoria, NSW Department of Primary Industries, South Australian Research & Development Institute (with co-funding from Australian Wool Innovation)
Weed Research Delivery	30/06/2007	Stuart Burge
Scoping a management program for Fireweed on the South Coast of NSW	30/08/2007	Ellis Farm Consultancy Pty Ltd

Appendix 21. Responses to questions used to prioritise weed species from the prominent and emerging lists for RD&E.

Prominent weeds

Scientific name	Abundant and widespread (Y/N)	High impact (Y/N)	Effective control measure (including management strategies) available (Y/N)	Control measures (including management strategies) well & widely applied (Y/N)	High likelihood of effective control measures (including management strategies) being developed in the next 10 years (Y/N)
Andropogon gayanus	Y	N	-	-	-
Arctotheca calendula	Y	N	-	-	-
Asphodelus fistulosus	Y	N	-	-	-
Bryophyllum delagoense	Y	N	-	-	-
Calotropis procera	Y	N	-	-	-
Carduus spp. (include *C. tenuiflorus*)	Y	Y	N	-	N
Carthamus lanatus	Y	Y	N	-	N
Cenchrus incertus	Y	N	-	-	-
Cenchrus longispinus	Y	N	-	-	-
Cenchrus pedicellatus	Y	N	-	-	-
Cenchrus polystachios	Y	N	-	-	-
Cirsium arvense	Y	Y	Y	Y	-
Cirsium vulgare	Y	Y	Y	Y	-
Cryptostegia grandiflora	Y	Y	Y	Y	-
Cylindropuntia spp.	Y	Y	N	-	Y
Cytisus scoparius	Y	N	-	-	-
Diplotaxis tenuifolia	Y	N	-	-	-
Echium plantagineum	Y	Y	Y	Y	-
Emex australis	Y	N	-	-	-
Eragrostis curvula	Y	Y	Y	Y	-
Erodium cicutarium	Y	N	-	-	-
Euphorbia terracina	Y	Y	N	-	Y
Galium tricornutum	Y	N	-	-	-
Harrisia martinii	Y	Y	Y	Y	-
Hordeum spp.	Y	Y	N	-	N
Hyparrhenia hirta	Y	Y	N	-	Y
Hyparrhenia rufa	Y	Y	N	-	Y
Hypericum perforatum	Y	Y	N	-	N
Hypochaeris spp.	Y	N	-	-	-
Hyptis suaveolons	Y	N	-	-	-
Jatropha gossypifolia	Y	Y	N	-	N
Lantana camara	Y	Y	N	-	N

Appendix 21. (Prominent weeds) (Continued)

Scientific name	Abundant and widespread (Y/N)	High impact (Y/N)	Effective control measure (including management	Control measures (including management strategies) well &	High likelihood of effective control measures (including management strategies)

			strategies) available (Y/N)	widely applied (Y/N)	being developed in the next 10 years (Y/N)
Lantana montevidensis	Y	Y	N	-	Y
Lycium ferocissimum	Y	Y	N	-	Y
Marrubium vulgare	Y	N	-	-	-
Mimosa diplotricha	Y	N	-	-	-
Mimosa pigra	Y	Y	Y	Y	-
Moraea flaccida	Y	Y	N	-	Y
Moraea miniata	Y	Y	N	-	Y
Nassella neesiana	Y	Y	Y	N	-
Nassella trichotoma	Y	Y	Y	N	-
Onopordum spp.	Y	Y	Y	Y	-
Opuntia spp.	Y	Y	N	-	Y
Parkinsonia aculeata	Y	N	-	-	-
Parthenium hysterophorus	Y	Y	Y	N	-
Phyla canescens	Y	Y	N	-	Y
Prosopis spp.	Y	Y	N	-	Y
Raphanus raphanistrum	Y	Y	N	-	N
Reseda lutea	Y	N	-	-	-
Romulea rosea	Y	Y	N	-	N
Rosa rubiginosa	Y	N	-	-	-
Rubus fruticosus agg.	Y	Y	N	-	Y
Rumex spp.	Y	N	-	-	-
Senecio jacobaea	Y	Y	Y	Y	-
Senecio madagascariensis	Y	Y	N	-	N
Senna obtusifolia	Y	Y	N	-	Y
Solanum elaeagnifolium	Y	Y	N	-	N
Sporobolus africanus	Y	N	-	-	-
Sporobolus fertilis	Y	Y	N	-	Y
Sporobolus jacquemontii	Y	Y	N	-	N
Sporobolus natalensis	Y	Y	N	-	N
Sporobolus pyramidalis	Y	Y	N	-	N
Tamarix aphylla	Y	N	-	-	-
Themeda quadrivalvis	Y	Y	N	-	Y
Tribulus terrestris	Y	N	-	-	-
Ulex europaeus	Y	Y	Y	Y	-
Vachellia nilotica ssp. *indica*	Y	Y	N	-	Y
Vulpia spp.	Y	Y	N	-	N
Xanthium occidentale	Y	Y	Y	Y	-
Xanthium spinosum	Y	Y	N	-	N
Ziziphus mauritiana	Y	Y	Y	N	-

Emerging weeds

Scientific name	Abundant and widespread (Y/N)	High impact (Y/N)	Effective control measure (including management strategies) available (Y/N)	High likelihood of further spread and having a high impact (Y/N)	Control measures (including management strategies) well & widely applied (Y/N)	High likelihood of effective control measures (including management strategies) being developed in the next 10 years (Y/N)
Acaciella angustissima	N	N	-	N	-	N
Aeschynomene paniculata	N	N	-	N	-	N
Cascabela thevetia	N	N	-	Y	-	Y
Chromolaena odorata	N	Y	N	Y	-	Y
Clidemia hirta	N	Y	N	-	-	Y
Cyperus aromaticus	N	Y	N	N	-	N
Elephantopus mollis	N	N	-	N	-	N
Florestina tripteris	N	N	-	N	-	N
Gmelina elliptica	N	Y	-	N	-	N
Gomphocarpus fruticosus	N	Y	Y	-	N	-
Hieracium spp., especially *H. aurantiacum*	N	Y	N	-	-	N
Lavandula stoechas	N	N	-	N	-	N
Nassella charruana	N	Y	-	Y	-	N
Nassella hyaline	N	N	N	-	-	N
Physalis viscose	N	Y	N	-	-	Y
Praxelis clematidea	N	Y	N	-	-	Y
Rubus alceifolius	N	Y	-	N	-	N
Solanum viarum	N	N	N	Y	-	-