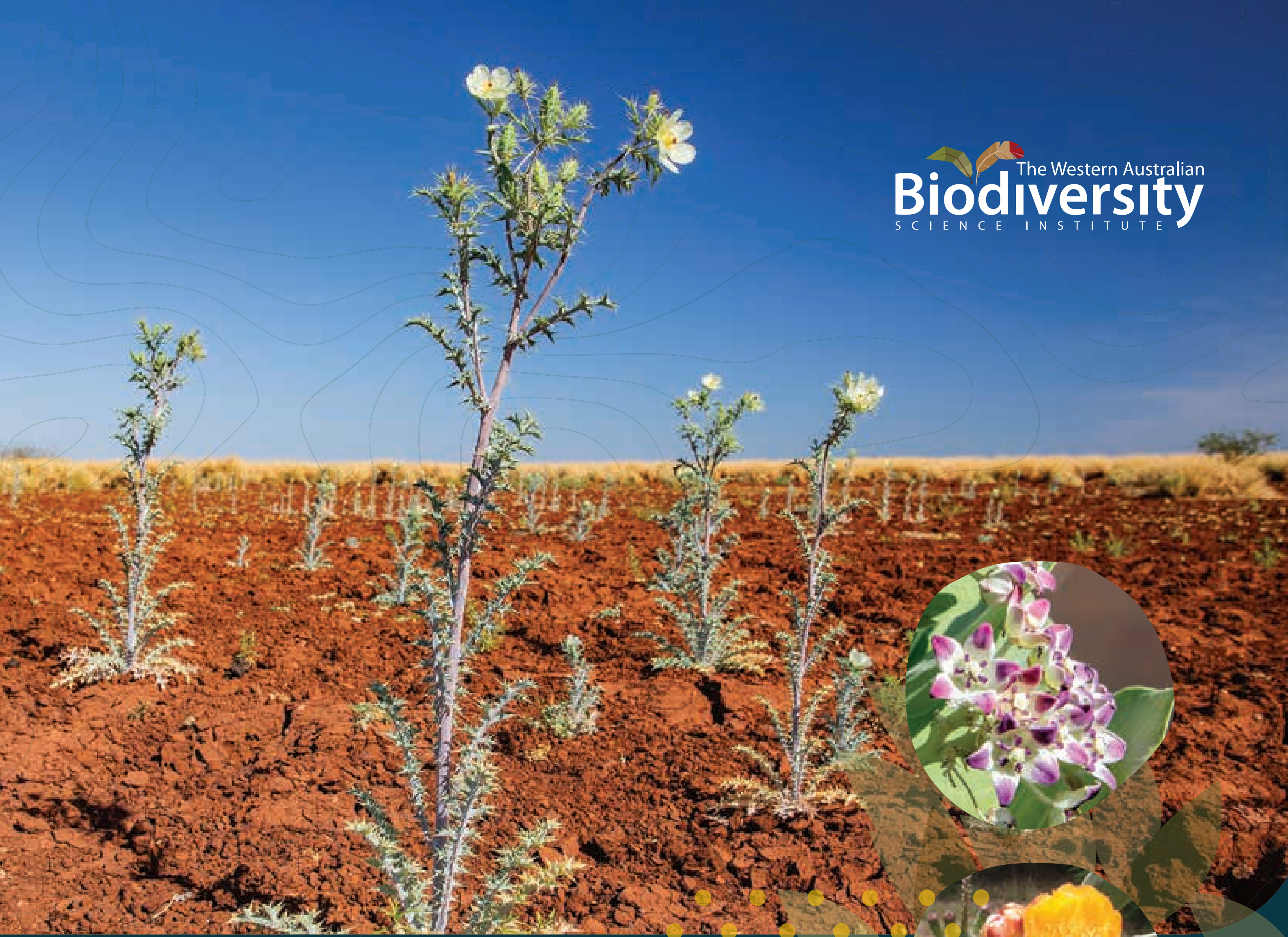

The Western Australian Biodiversity Science Institute

Addressing weed threats to biodiversity

The Western Australian Biodiversity Science Institute is to be congratulated for its efforts to raise awareness about the threat weeds pose to biodiversity.

HON. AMBER-JADE SANDERSON, MINISTER FOR ENVIRONMENT AND CLIMATE ACTION

We need a better understanding of all measures of weed impacts, so we can be more proactive with weed control. A deeper knowledge of weed ecology and impacts, through research, will enable us to target how we deliver weed control methods.

To address this knowledge gap, The Western Australian Biodiversity Science Institute (WABSI) has brought together community groups, science experts, government and industry to establish what we currently know about impacts and weed control and where we need greater knowledge. This stakeholder consultation guided the development of WABSI's research program, Addressing Weeds Threats to Biodiversity. *I am delighted to launch this really important initiative.*

PROFESSOR PETER KLINKEN, CHIEF SCIENTIST, WESTERN AUSTRALIA

The South Coast of Western Australia is an international biodiversity hotspot due to the sheer number of plant species here as well as the threats they face. Weeds are a key component of these threats, impacting directly and indirectly to displace our native species. This work by WABSI will help greatly by increasing our understanding of where we, both researchers and community end users, should be focused to maximise the outcomes for the environment.

JUSTIN BELLANGER, CEO, SOUTH COAST NATURAL RESOURCE MANAGEMENT INC.

During my 36 years of living and working in the Pilbara I have witnessed firsthand the loss of flora and original vegetation types and the degradation of landscapes due to the continual introduction and spread of weeds. I continue to watch as weeds such as stinking passionfruit and kapok invade the world renowned Murujuga (Burrup Peninsula). A lack of responsibility for this biodiversity loss, public ignorance and indifference, and ineffective or insufficient action are just some of the many challenges I deal with. This WABSI program will tackle these complex issues to help deliver effective weed management and positive outcomes.

VICKI LONG, ECOLOGIST

COVER PHOTO ACKNOWLEDGEMENTS:

MAIN IMAGE: Mexican poppy (*Argemone ochroleuca*), Photo: Bruce Webber

INSETS (from top): Calotropis (*Calotropis procera*), Photo: Bruce Webber; Riverina pear (*Opuntia elata*), Photo: Bob Chinnock, DPIRD Agpix; Blackberry (*Rubus anglocandicans*), Photo: Bronwen & Greg Keighery.

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Addressing weed threats to biodiversity

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The Western Australian Biodiversity Science Institute

Contents

1. Executive summary

Non-native invasive plants in Australia are currently among the greatest threats to native biological diversity and a significant cost to agriculture, costing the nation between A$3 to 5 billion annually.

Australia has a long history of some 26,000 plant species introductions and around 2,700 established non-native plant species. Approximately 30% of these potential invaders are now of serious economic and environmental concern.

The prevention of further invasions through weed risk assessment and the management of existing weeds has been the focus of considerable policy, research and management effort. Yet despite these efforts, there remains a mismatch between the magnitude of the threat to biodiversity from weeds in Australia and the resourcing invested to address the problems. Central to this need is a better understanding of, and ability to quantify, all measures of weed impacts. There is also increasing recognition of the benefits of proactive weed control when new introductions are not as widespread or threatening, improving the likelihood of acceptable outcomes and dramatically reducing the required resources to achieve management goals.

In many cases weeds are currently prioritised and managed based not on an objective assessment of their impact, but rather on their presence, abundance, or occurrence within political or land tenure boundaries. The impact of weeds is also significantly influenced by local context; interactions between weeds can also influence a given control outcome, requiring a management approach that can consider impacts at an ecosystem level. At a very basic level, weed impacts are, by their very nature, subjective with a diversity of views from positive to negative put forward on certain species. In particular, 'conflict species', which have contrasting impact determinations depending on the stakeholder viewpoint, can be mismanaged without cross-tenure assessment and broad stakeholder engagement. Moreover, new conflict species are still being brought into Western Australia for horticultural and agricultural purposes.

MAIN IMAGE: Dune onion weed (*Trachyandra divaricata*), Photo: Bruce Webber
INSETS (from left): Stinking passionflower (*Passiflora foetida*) seedlings, Photo: Bruce Webber;
Riverina pear (*Opuntia elata*), Photo: Bob Chinnock, DPIRD Agpix;
Blackberry (*Rubus anglocandicans*), Photo: Bronwen & Greg Keighery

Western Australia spans considerable variation in ecosystems, with associated variation in the weeds that are causing, or are likely to cause, negative impacts to natural ecosystems. The south west region is a global biodiversity hotspot with considerable weed threats compounding the impacts of past habitat loss. The State also has specific biosecurity advantages, relative to other states, which presents both challenges and opportunities from a weed management perspective. Western Australia has a long history of successful weed control and management. However, like all states, consistent and long-term funding to underpin effective weed management programs has been lacking. Moreover, while a number of 'priority lists' of target weeds have been produced in recent times, consistency across the State and broader stakeholder consultation would greatly enhance their relevance to help improve outcomes. Of increasing concern is the significant number of personnel with expertise on weeds in Western Australia that have recently retired or are likely to retire in the next five years. There is, therefore, a need to ensure proactive succession planning so that the State does not lose the knowledge held by these individuals or their organisations.

There are clear opportunities for Western Australia to improve outcomes from managing weeds more effectively. Weed spread and impacts span political and land tenure boundaries, meaning that significant gains in management effectiveness in Western Australia could be achieved via cross-tenure and multi-organisation collaboration. Weed impacts significantly affect a broad range of stakeholders in the State, and many land managers have policy-driven obligations to control weeds. This means there is a broad range of interested parties who would find value in a weeds research program. While improved collaboration between key stakeholders in the State would improve management outcomes utilising existing knowledge, addressing research knowledge gaps remains a priority for achieving greater impact with mitigating weed impacts on biodiversity.

Identification of knowledge gaps

The Western Australian Biodiversity Science Institute (WABSI) provides a coordinated, tenure blind opportunity for addressing knowledge gaps that will improve weed management outcomes for biodiversity in Western Australia. Following the Intergovernmental Agreement on Biosecurity (IGAB) review, the WA Department for Primary Industries and Regional Development (DPIRD) has signalled the need for a stronger focus on environmental biosecurity as part of its recent restructure. Regular stakeholder consultation by WABSI saw mitigating weed threats raised consistently as a challenge for land managers. Yet even with a step change in available funding, using existing techniques, there would not be enough resources available to manage all weeds across the State. Moreover, there is a real need to better prioritise resource investment to target those weeds where control (and the type of control) will most effectively deliver outcomes, and to develop more effective management programs.

Recognising the importance of mitigating weed impacts for the conservation of biodiversity in Western Australia, and the need to address knowledge gaps as a critical component of this desired outcome, WABSI led the development of a prioritised research programs. A series of workshops were held with end users and research providers representing many of the organisations at the forefront of research and management on weeds in Australia. A virtual format enabled engagement from stakeholders right across the state, with robust discussions producing a clear consensus on the work that needs to be done to close the most important knowledge gaps. These engagements identified, scoped and prioritised the most important research topics across eight focal areas: benefits, social licence, ecology, impacts, control, detection, prioritisation and implementation.

INSETS (from left): One-leaf Cape tulip (*Moraea flaccida*), Photo: DPIRD Agpix; *Carpobrotus glaucescens* cv Aussie Rambler naturalised near Bunbury, Photo: Bronwen & Greg Keighery

A prioritised research framework

The objective of this research program is to provide a prioritised framework for identifying knowledge gaps for mitigating weed threats to biodiversity in Western Australia. By identifying a clear pathway from knowledge generation to on-ground uptake, this program is relevant to a broad range of stakeholders including research providers, funding bodies, regulatory authorities, the broad range of land managers in the state, as well as members of the general public with an interest in biodiversity threats and weed management. The program is designed to encourage complementarity and collaboration, identify potential targets for resourcing and funding the work, and provide clarity on how best to translate research findings into improved outcomes for end users. When delivered, the program will facilitate a step change in our understanding of weeds, their impacts, and their control options, leading to improved weed management programs in Western Australia and resulting in tangible on-ground improvements in the mitigation of weed threats on native biological diversity.

Next steps

The implementation of this research program will require an effective governance structure and significant resources. A dedicated steering committee would provide the required oversight to facilitate the delivery of this program, a model that works successfully with WABSI research programs. Strong alignment with research initiatives underway nationally and in other states, and with relevant regulatory and policy bodies will enhance outcomes and reduce the risk of overlapping effort. Multiple sources of funding, including Commonwealth and State Government funding schemes, Lotterywest, Natural Resource Management grants, industry associations and philanthropic sources, are all realistic options that support end user driven research. We encourage land managers and the research community working on weed management in Western Australia to share and discuss their interests, management challenges and opportunities with us and engage with the delivery of this program as we seek to transform this document into tangible on ground impact.

MAIN IMAGE: Gazania hybrid (*Gazania linearis*), Photo: Kathryn Batchelor

ABOVE: Non-native Geraldton wax (*Chamelaucium uncinatum*) invading heath at Gingin, Photo: Bronwen & Greg Keighery

Key benefits

Environmental

- Deeper knowledge of weed ecology and impacts to better target the application and delivery of current and future weed control methods.
- Reduced threat to native biodiversity from improved weed control, leading to enhanced conservation outcomes.

Economic

- Improved efficiency for weed control programs, ensuring greater impact from available resources.
- Earlier stage management of weed populations before they become threatening, avoiding considerable control costs and delivering an improved return on investment.

Social

- Greater public awareness of the need for impact driven prioritisation and collaborative cross-tenure control programs.
- Stronger alignment of weed control expectations with available resourcing to deliver more effective, enduring weed management outcomes.

Stakeholder values

A range of stakeholders will benefit from the outcomes of this research program, including:

Researchers

- A roadmap of priority issues is clearly articulated as well as a pathway to ensure these challenges are turned into research findings to drive on-ground change.

Local, State and Commonwealth Government organisations

- A clearer case for investing in more efficient and effective weed management programs that deliver enduring improvements for biodiversity conservation, and the means with which to deliver that outcome.

Regulators

- More effective and relevant policy to guide the control, prioritisation and regulation of weeds to mitigate their impacts.

Conservation organisations

- More efficient use of resources and more appropriate targeting of efforts, including enhanced collaboration and knowledge sharing and opportunities.

Indigenous land owners and managers

- Better outcomes for managing the conservation of biodiversity and the relationship between these biodiversity assets and cultural values in the landscape, including culturally significant species.

Horticultural sector

- More opportunities for reducing risk of new weeds via improved awareness, detection and early phase mitigation of new or future weed threats, and a greater ability to deliver alternative solutions for preventing conflict species becoming problematic.

Agricultural and forestry sectors

- A reduced risk of conflict species becoming problematic with a greater focus on prioritising and informing weed management programs based on evidence-based impact mitigation.

Consulting industry

- Refined weed management programs based on mitigating impact and with more appropriate choice and implementation of deployed control methods.

Tourism sector

- More effective management solutions deliver improved natural ecosystem amenity in areas of high tourism value, improving the appeal and quality of experience for visitors.

Mining industry

- Enhanced outcomes for weed control on tenements improves restoration outcomes and makes offset conditions more achievable and enduring while minimising resources required.

Community

- A clearer case for the value of weed management and improved confidence that investment in these programs is delivering optimal outcomes for biodiversity conservation.

2. Abbreviations

ARC	Australian Research Council
AQIS	Australian Quarantine & Inspection Service
BAM Act	*Biosecurity and Agricultural Management Act 2007*
BC Act	*Biodiversity Conservation Act 2016*
CISS	Centre for Invasive Species Solutions
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWE	Department of Agriculture, Water and the Environment
DBCA	Department of Biodiversity, Conservation and Attractions
DPIRD	Department of Primary Industries and Regional Development
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
GRDC	Grains Research and Development Council
ISC	Invasive Species Council
IUCN	International Union for Conservation of Nature
LCDC	Land Conservation District Committee
NESP	National Environmental Science Program
NGO	Non-government organisation
NRM	Natural Resource Management
PHA	Plant Health Australia
RBG	Recognised Biosecurity Group
UWA	The University of Western Australia
WABSI	The Western Australian Biodiversity Science Institute
WONS	Weeds of National Significance
WAOL	Western Australian Organism List
WAQIS	Western Australian Quarantine & Inspection Service

IMAGE: Sea spurge (*Euphorbia paralias*), Photo: Bruce Webber

3.

Introduction

Native biological diversity is coming under increasing pressure from global environmental change.

In addition to climate change and land use change, non-native invasive species represent one of the biggest threats to terrestrial biodiversity globally (that is, a change in extent over time; Walther et al. 2009, Butchart et al. 2010) and are the biggest threat to Australia's threatened taxa (Kearney et al. 2019). A total of 207 non-native plants are listed as causing direct impacts on threatened native species, and these taxa are major indirect contributors to ecosystem change in degraded habitats. Non-native plants have the ability to transform the landscape, changing soil conditions and fire regimes, resulting in long term (sometimes permanent) changes in the environment that can facilitate further plant invasions.

Australia has a long history of non-native plant introductions from overseas, with some 26,000 non-native species occurring in Australia today, compared with just 20,000 native vascular plants that have evolved and radiated over the past 100 million years of evolution (Chapman 2009). Of these introduced plants, about 2,700 are established in the wild (Groves et al. 2003, Randall 2007) and, in turn, approximately 30% of these naturalised non-native species impact on environmental, economic and social values (Groves et al. 2003). Australia is a large land mass and plant taxa have been moved by humans well beyond their native range to become non-native populations, threatening their recipient communities. In Western Australia as of 2004 there were 1,233 naturalised vascular plant species (Keighery and Longman 2004). Of these, 676 are naturalised in reasonably intact native vegetation, and 94 are recognised as escapees from garden plantings. By 2021, the total of non-native plant taxa had increased to 1348 (Florabase 2021), an increase of nearly 10% over 15 years.

Many of these non-native plants are harmful weeds that are the focus of management programs for their control across Australia. Furthermore, while we already have a great number of problematic weeds to manage, many of our future problem plants may already be here yet not a current problem. For this program we have chosen to use the term 'weed' over other terms because a weed is simply a plant that

MAIN IMAGE: Blackberry (*Rubus anglocandicans*), Photo: Bruce Webber
INSETS (from left): Patersons Curse (*Echium plantagineum*), Photo: Preeti Castle; Buffel grass (*Cenchrus ciliaris*), Photo: Louise Beames; Ruby dock (*Rumex vesicarius*), Photo: Bruce Webber

is not wanted by a given stakeholder where it is found, and therefore management to control negative impacts is a reasonable response (see Terminology Matters section). We also recognise that while weeds can impact on a variety of different environmental, economic, social and cultural values, often together, this weeds program is focused primarily on threats where there is a clear impact on biological diversity.

The prevention of further weed impacts on biodiversity has been achieved through tight border biosecurity, weed risk assessment and the management of existing invaders. Improving these processes has been the focus of considerable policy, research and management effort. Yet despite these efforts, there remains a mismatch between the magnitude of the threat to biodiversity from weeds in Australia and the resourcing invested to address the problems (Webber et al. 2014).

The most effective way to manage impacts from weeds is to prevent their entry in the first place. Of concern, however, is that global trade and other human behaviours are facilitating a rate of introduction and establishment for non-native species that continues to rise globally (Seebens et al. 2017). Once introduced, the subsequent increase in range and abundance influences the options available for control and the magnitude of resources required for this management effort. This relationship is known as the invasion curve (Figure 1; Blackburn et al. 2011). It is becoming increasingly clear that the relationship between range, abundance and impact is a complicated one (Simberloff et al. 2013, Latombe et al. 2017). Some species may spread rapidly and become abundant, but nonetheless have relatively low impacts on biodiversity values, whereas others may have large negative impacts at relatively low abundance. There is a far greater need to manage weeds based on their impacts (either current or likely future), rather than abundance, and to ideally undertake this threat mitigation proactively before the invasion progresses too far along the invasion curve. Yet for most weeds there is a fundamental lack of information on their basic ecology, let alone impacts.

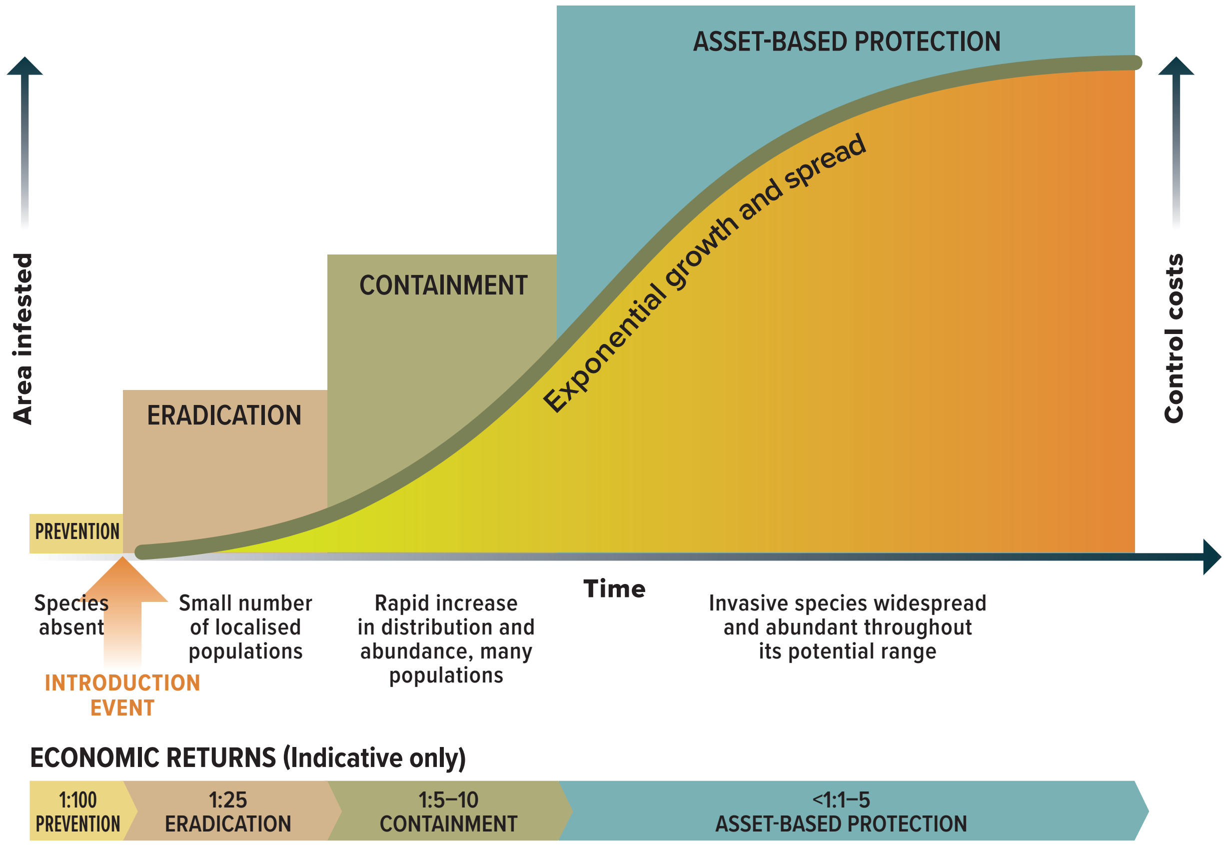


FIGURE 1. The invasion curve for introduced species shows the relationship between presence and abundance and the options for control of that species, as well as the likely costs associated with that control.

Adapted from Invasive Plants and Animals Policy Framework, Victorian Government, 2010.

BELOW: Date palm (*Phoenix dactylifera*) invading Millstream Chichester National Park, Photo: Bruce Webber.

The impacts of weeds on socio-economic values can be challenging to quantify (Diagne et al. 2020). While some values can be objective and quantified in a transparent way, such as the economic impact on agricultural production, other impacts such as social, environmental and cultural values are notoriously hard to capture (Hoffmann and Broadhurst 2016). Moreover, because of subjectivity in how impacts are defined, impacts are necessarily value judgements made within an anthropogenic framework. 'Conflict species' result when different stakeholders view impacts in very different ways. Buffel grass (*Cenchrus ciliaris*), for example, is an introduced pasture grass that has significant value as a perennial fodder crop, but is also listed as a 'transformer' species with the ability to significantly degrade the character or condition of natural ecosystems (Grice 2006, Friedel et al. 2011).

The direct economic cost of weeds is arguably the most effective way to communicate impacts to the general public. However, the quality and coverage of available data mean that estimates of the economic costs of weeds are conservative. A recent global analysis of non-native invasive species concluded that the cost of their impacts could be more than 30 times higher than the A$1.7 trillion lost or spent between 1970 and 2017 (Diagne et al. 2021). The estimated annual costs of invasive species today are 20 times higher than the combined budgets of the World Health Organisation and the United Nations (Bradshaw et al. 2021b). The financial burden of weeds in Australia is estimated to be in excess of A$5 billion per year (McLeod 2018), most of this relating to chemical control in agricultural crops and production loss costs. More recent values place this amount at A$2.97 billion with a more conservative approach to inclusion of costs (Bradshaw et al. 2021a). These are incredibly high numbers, and yet all of these values largely exclude the cost of weed impacts on natural ecosystems, cultural heritage and native biodiversity. Such impacts remain particularly challenging to monetise. Moreover, many financial estimates include significant funds that are spent on 'mis-management', where priorities are driven by meeting compliance requirements or to achieve outcomes that do not relate to biodiversity conservation.

There are further challenges that remain in regard to implementing more effective action against weeds. At a fundamental level, there is limited knowledge amongst the general public, particularly in urban Australia, as to which plants are native where, the risks associated with using weedy plants in horticulture and agriculture, and the increasing return on investment when acting early on new weed introductions. Limited knowledge on weed impacts is often matched by a limited understanding of the most effective control solutions. Like many non-native invasive species, an understanding of species- and context-specific attributes of the focal weed can transform the effectiveness of management. For example, the likelihood of achieving eradication as the end goal of a management program is significantly influenced by not only the size and age of the infestation, but also the longevity of a viable soil seedbank (Cacho et al. 2006, Panetta 2009). If more detailed ecological insight can be assembled for more widespread weeds, then the feasibility of classical biological control can be considered (Van Driesche et al. 2010). This level of detail, however, is lacking for many of the most threatening weeds in Australia. Even for more easily deployed control solutions, such as herbicides, an improved knowledge of weed ecology and efficacy of different control regimes can lead to significant improvements in control outcomes (Jucker et al. 2020).

It is extremely important to act upon the widespread threat of weeds to biodiversity in a more comprehensive manner. Unfortunately, an apparent apathy towards weed impacts is a global trend, with both the general public and decision makers generally disregarding or deprioritising what is one of the biggest drivers of the current biodiversity crisis (Courchamp et al. 2017). Moreover, the threats driven by weeds are likely to interact with other global change drivers threatening biodiversity, such as climate change and land-use change, making impacts even harder to predict and mitigate into the future. This inaction highlights the importance of more clearly and convincingly articulating the value proposition of addressing weed threats as central to any land management program. Despite these challenges, an opportunity to address knowledge gaps on weed impacts will bring considerable benefits in terms of outcomes for biodiversity conservation.

Terminology matters: the weed status triplet

What is a weed? What is an invasive species, if indeed it exists? Can natives be invasive and are all weeds aliens? Terminology matters for plants that have been introduced well beyond their native range!

Prioritising the management of plants that threaten biodiversity is a big enough challenge without also having confusion or misunderstanding around what exactly is being discussed. Here we provide clarity on the terminology used in this program, including how alternative terminology creates confusion and management risk.

While we are using the term ‘weed’ in this program, we also recognise that weed management needs to be prioritised by an assessment of impact. We therefore emphasise that the use of the weed-status triplet (sensu Scott et al. 2014) be applied where decisions around control are being made. That is, clarify where possible (a) the native status (native or non-native), (b) if the population is rapidly expanding or not (i.e. invasive or non-invasive), and (c) the known impacts (negative or positive) on defined values.

Invasion science terminology relevant to this program includes:

Impact:

A measurable change in the region of introduction that can be attributed, either directly or indirectly, to the addition of non-native plant(s). The assessment of impact can be based on one or more measures and the same measure may be viewed subjectively as positive or negative by different managers. Impact can be assessed using the Australian Weed Risk Assessment protocol (Parker et al. 1999, Wilson et al. 2014).

Invasive:

A subset of naturalised plants that are undergoing or have the potential for rapid range expansion (i.e. change in extent over time; Richardson et al. 2000, Wilson et al. 2014). Range expansion rates can be clearly quantified (Wilson et al. 2014), but what is deemed rapid or not remains a subjective decision (perhaps influenced by what is normal for the plant in question in its native range or what might be average range change in the recipient community). No implication of impact or a requirement for change in abundance is associated with this term (Valéry et al. 2008, Wilson et al. 2014). May or may not be a weed or non-native.

Native:

Occurring within an appropriate distance from the species region of origin, allowing for natural dispersal potential within a given time frame as defined by the Projected Dispersal Envelope (Webber and Scott 2012).

Naturalised (established):

Introduced and self-sustaining over multiple generations without human assistance or intervention (Richardson et al. 2000, Pyšek et al. 2004).

Non-native (alien, exotic, introduced):

Occurring outside its natural past or present range and dispersal potential in the timeframe under consideration, its presence being due to deliberate or accidental human actions (Pyšek et al. 2004, Richardson et al. 2011, Webber and Scott 2012).

Sleeper weeds (alert weeds):

A subset of plants that have naturalised populations in a region that have not yet rapidly increased their range and/or abundance. Evidence (or risk assessment) indicates, however, that they may become invasive or have negative impacts in that given area in the future (Groves 1999), implying that they may well be simply at an early stage on the invasion curve.

Transformers:

A subset of invasive plants that have negative impact to the extent that they change the character, condition, form or nature of ecosystems over a substantial area relative to the extent of that ecosystem (Richardson et al. 2000).

Weed:

A plant not wanted where it is found. An entirely subjective determination based on value systems within a human context. Weeds usually have detectable economic or environmental effects and are often both non-native and invasive, but this is not always the case (Richardson et al. 2000).

MAIN IMAGE: Neem (*Azadirachta indica*), Photo: Louise Beames

INSETS (from left): Tambookie grass (*Hyparrhenia hirta*), Photo: Bronwen & Greg Keighery; Rose pelargonium (*Pelargonium capitatum*), Photo: John Huisman; Pink gladiolus (*Gladiolus caryophyllaceus*), Photo: John Huisman

What does it take to eradicate a weed?

The ideal goal of any weed control program would be complete eradication, but there are very few examples of success. In most cases eradication is not a feasible prospect, as the size of infestation is too extensive, and the soil seedbank longevity is likely to outlast any resources available to deliver eradication as an outcome.

In Western Australia, the largest successful weed eradication delivered was for kochia (*Bassia scoparia* syn *Kochia scoparia*). Introduced in May 1990 as a forage plant and for revegetation of salt-affected land, it soon spread from introduction sites (Dodd 2004). An eradication campaign led by DPIRD started in 1992 with most infestations eradicated within a few years. Surveillance continued until 2004, five years after the last kochia was found. Key to success of this program was delimitation of the weed population (the plant was known from 81 planting sites), research into seedbank longevity (1-3 years), and a long-term commitment to surveillance by a stable workforce.

Bitou bush (*Chrysanthemoides monilifera* subsp. *rotunda*), a native of southern Africa and one of eastern Australia's worst environmental weeds, is currently it its ninth year of a WA eradication program led by CSIRO (Scott et al. 2019). Initially discovered by coast care staff in 2012 on Kwinana Bulk Terminal, a port and industrial area south of Perth, surveys in 2012-2013 discovered and removed 1268 plants over an area of 2.5 km^2. As of 2020, 1,789 plants have been removed. Bitou bush can only be locally eradicated if annual surveys continue for at least two years after no new plants are found and no new inputs into the soil seedbank have occurred for seven years. A significant factor in the success of the program to date has been a stable workforce, with the same survey staff involved every year since 2012.

Eradication projects tied to short term funding or staffing are almost certain to fail. A missed survey year essentially resets the seedbank. Loss of knowledge from staff or project turnover increases the risk that weed spread is missed through the loss of essential landscape knowledge and community networks.

Kochia (*Bassia scoparia* syn *Kochia scoparia*), Photo: DPIRD Agpix

Bitou bush (*Chrysanthemoides monilifera* subsp. *rotunda*), Photo: DPIRD Agpix

Existing management solutions

A range of weed management solutions exist for deploying against weeds and managing weed impacts on biodiversity and other assets. Just how successful each approach is depends on the stage the incursion is at along the invasion curve (Figure 1) as well as the traits of the target weed, the available control techniques, and the local context of the invasion.

Exclusion (border biosecurity, quarantine, property biosecurity)

Keeping a weed out of a given area can consume significant resources, but multiple weeds can be targeted at once and these costs are far smaller than the resources required to manage a weed once it has naturalised and started to invade. The Commonwealth Department of Agriculture, Water and the Environment (DAWE) applies import restrictions on many items coming from overseas to prevent pests and diseases entering Australia. An additional layer of biosecurity is applied for the State by the Western Australian Quarantine Inspection Service (WAQIS) to prevent pests and diseases present in other states and territories from entering Western Australia. Both organisations use a range of X-ray, surveillance, inspections, and detector animals to identify entry points for exotic organisms. Emerging technologies, such as eDNA, are being trialled to identify other pathways of incursion. Despite these existing and emerging tools and processes being in place, a notable proportion of incoming goods are not subject to assessment, creating a significant risk factor for the State.

Risk assessments have been completed for thousands of plant species, and DAWE and WAQIS use these to determine if species are safe to import into Western Australia. Under the *Biosecurity and Agricultural Management Act 2007* (BAM Act), every plant species is given a legal status under the Western Australian Organism List (WAOL) as either permitted, prohibited or unlisted. If unlisted, the plant species cannot be imported without a permit, which will only be issued after a disease and weed risk assessment. Controlled biosecurity facilities are used to contain potential weed risks for biosecurity research in the State, and are widely adopted by the transport, mining, forestry and conservation industry, as well as on farms, in sale yards and at port facilities.

BELOW: Narrow leaf cotton bush (*Gomphocarpus fruticosus*), Photo: DPIRD Agpix

Manual and chemical control

The vast majority of practiced weed control in the State, on a resource expenditure basis, is done using manual and/or chemical control. At small scales (and in agricultural settings), methods including herbicide applications, hand weeding, grazing/mowing, and heat and microwave treatments are used to reduce weed presence and abundance. Chemical control is the most extensively used at larger scales and is broadly effective, particularly on species where more detailed trials have been undertaken. However, herbicide programs are too often applied in a sub-optimal way (e.g. wrong timing, lacking adjuvants). Problems with herbicide resistance are ongoing and their application in certain environments, such as waterways and wetlands, is limited by a lack of understanding of off-target impacts and dosage rates. Furthermore, the important issue of social licence relating to the public perception and awareness of the health risks associated with herbicides, as well as their impacts on broader ecosystem resilience, is becoming an increasing challenge.

At even larger scales, fire can be used as part of broader landscape management plans to control weeds, although fire in certain contexts can also lead to greater weed problems, particularly if additional weed management is not planned either before or after the burn. Many of these control techniques are successful at managing weeds and are more likely to be effective if applied in the early stages of an outbreak or infestation. However, as infestations age and become more widespread these methods can often become incredibly resource intensive, need to be deployed indefinitely if extirpation (i.e. localised eradication, including the seedbank) or eradication is not an option, and can sometimes have off-target impacts that directly threaten native biodiversity. Manual and chemical control can be used to achieve a range of outcomes for weed populations, including eradication, extirpation, containment and abundance reduction.

LEFT: Targeted fire management can improve landscape level weed control, Photo: Judy Dunlop

RIGHT: Rubber vine (*Cryptostegia grandiflora*) herbicide control on Willare station, Photo: Tracey Vinnicombe, DPIRD

Holding back the mesquite tide

Mesquite (*Prosopis* sp.) is a Weed of National Significance declared C2 (eradication) species under the BAM Act. The weed is one of the greatest threats to biodiversity in the Pilbara region. Native to North and South America, the world's largest infestation of Mesquite occupies two-thirds of Mardie Station, at the mouths of the Fortescue and Robe Rivers, and covers 150,000 ha, a quarter of which is described as dense. Four species of *Prosopis* are in Australia, the infestation at Mardie Station is *Prosopis pallida*, and a hybrid swarm of *P. glandulosa* and *P. velutina*. Currently, the Pilbara Mesquite Management Committee coordinates the herbicide control of mesquite in the Pilbara, spending over A$300,000 per year of Pilbara Environmental Offset funds just holding the current infestation in place at Mardie Station.

Research toward mesquite biological control began in 1994 by CSIRO Entomology and the Queensland Department of Natural Resources. Four insect species were approved for release in Australia but only a leaf-tying moth (*Evippe* sp. #1) is confirmed as established at Mardie station. It has been over 20 years since the progress of biocontrol agents against mesquite on Mardie Station has been measured. There is currently no active research into controlling mesquite, despite the weed being climatically suitable to occupy the entire Pilbara region. As such, mesquite represents a priority for proactive investment in research to generate more effective control solutions.

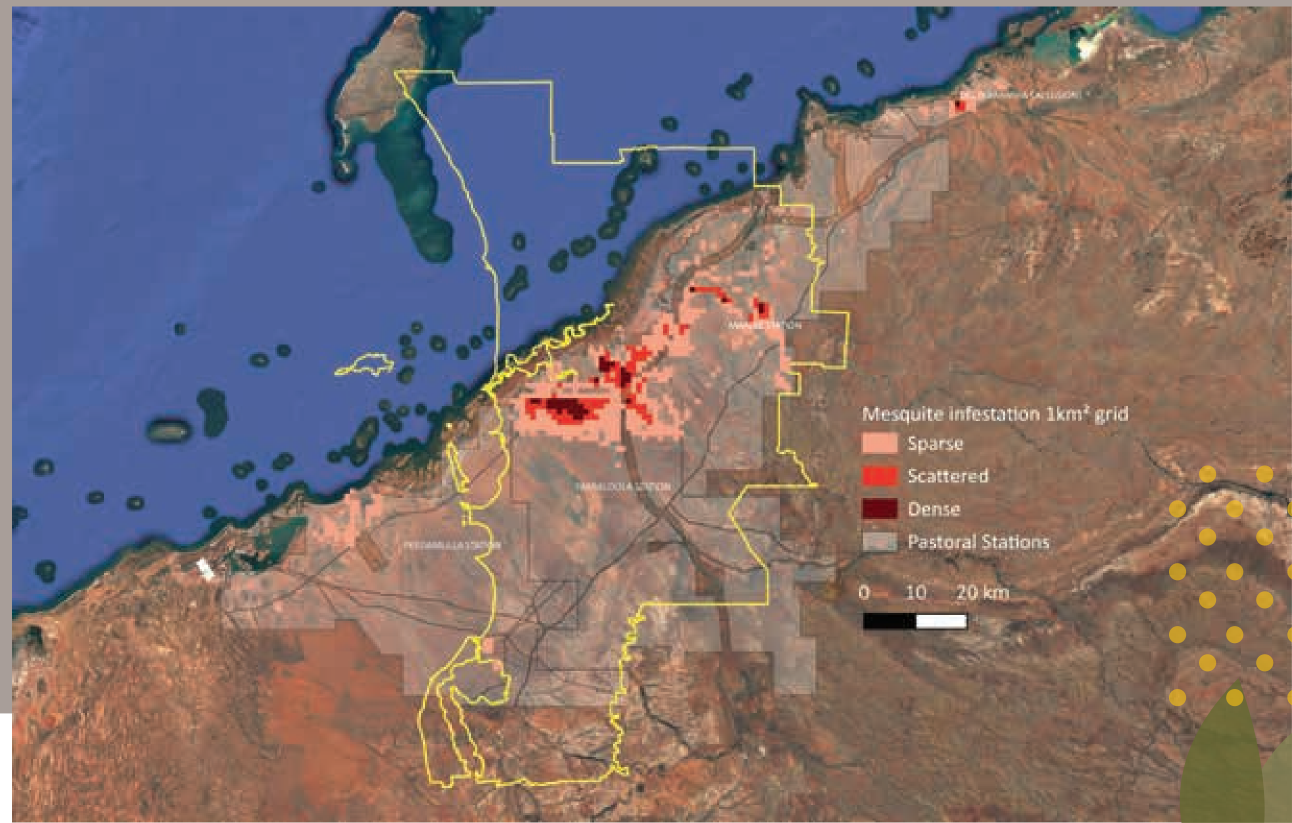


FIGURE 2. Mesquite control work at Mardie, Yarraloola and Peedamulla Station. Overlay of Perth metro area to demonstrate scale of infestation.

Biological control

Most plant species are not problematic in their native range because populations are kept in check by natural enemies, including fungi and insects. Some of these natural enemies are co-evolved specialists and can only sustain themselves on the target plant or closely related plant taxa, whereas other natural enemies will have a wide host range (generalists). Classical biological control for weeds seeks to unite the target weed species in their introduced range with host-specific natural enemies from the native range. Biocontrol programs do not have eradication as their end goal, but rather seek to reduce the impact of weeds to a point where they have negligible impacts and to sustain this suppression indefinitely. When successful, the benefits of biological control far-outweigh the initial investment and provide an enduring control solution.

No management

Doing nothing is often the default position for many weed management programs that simply do not have the resources or effective means to manage every weed. However, the active decision to do nothing to mitigate the impacts of a weed is also a viable management option in some instances. Many weed management programs do not clearly define their end goal or fail to adequately resource their control requirements. If this is the case, then it could be argued that any resources spent were wasted from the perspective of reducing impacts. It may also be that a weed has been carefully assessed and any likely negative impacts do not justify the resources that would be required to deploy effective control for mitigating the threat. Such a decision could equally apply to weeds where effective control is particularly costly or time consuming, where the threat is relatively minor, or where limited resources could be better allocated to more threatening weeds. Actively choosing to not manage a weed problem can also help to highlight the subsequent impacts that flow from inaction or from inappropriate control, in order to achieve support for resourcing management or developing a more robust method.

TOP LEFT: Flea beetle (*Longitarsus echii*), a biocontrol for Paterson's curse (*Echium plantagineum*), Photo: DPIRD Agpix

BELOW LEFT: Bridal creeper rust fungus (*Puccinia myrsiphylli*), a biocontrol for bridal creeper (*Asparagus asparagoides*), Photo: CSIRO Science Image

RIGHT: Gorse spider mite (*Tetranychus lintearius*), a biological control for gorse (*Ulex europaeus*). Photo: John Moore, DPIRD

Emerging management solutions

Improving existing solutions

Agricultural weed management is often an innovation pathway for methods that can be adopted for weed management in natural ecosystems. However, tools such as herbicide and integrated weed management programs developed for agriculture do not always translate as well as they could. There is simply not the financial imperative to drive research into herbicides that are better suited to natural ecosystems. The rising number of herbicide resistant species in agriculture is driving research into new chemicals that have different modes of action, and natural chemicals that have phytotoxic effects. Better application technology is also being developed to reduce off-target effects of herbicide in natural ecosystems (for example, 'drill and pill' applications of herbicide for woody weeds). New biological control solutions are being investigated for new target species, but local (Palmer et al. 2014) and global (Moran and Hoffmann 2015) reductions in biological control capability and expertise threatens the supply of new agents to target additional weed species.

Developing novel solutions

Novel solutions for weed control are again dominated by innovations coming out of the agricultural sector. Here industries are investing in artificial intelligence and machine learning to allow farmers to apply herbicide more selectively and deliver precision weed control. While research is looking at ways to adapt this technology to work in natural ecosystems, development is still in its infancy. New molecular tools for weed control, including gene technologies, are well behind those being developed for the control of non-native rodents. Even so, the technological challenges of gene technology are sometimes common to all platforms, and ways to progress this line of research are already being explored (Kumaran et al. 2020). From a weed detection and delimitation perspective, remote sensing technology (often via drones) is increasingly being used as a method to survey weeds in difficult terrain. Moreover, payload carrying drones are being developed to selectively apply follow-up herbicide in areas difficult to access on the ground.

BELOW: Victorian tea tree (*Leptospermum laevigatum*), manual removal of an infestation near Windy Harbour, Photo: Lee Fontanini

ABOVE: Blackberry (*Rubus anglocandicans*) invasion of karri forest, Photo: Paul Yeoh, CSIRO

Optimising weed management

Tools or their application?

Land managers have a variety of tools for controlling weeds that are theoretically available should resourcing be adequate. What is lacking, however, is the optimisation of these tools to the target weed, the context of the location and a realistic timeframe ideally focused on the early stages of introductions. Inevitably the deployment of these tools is then suboptimal in terms of results and resources consumed for a given outcome. For challenging environmental weeds with biodiversity impacts, is it a question of needing more tools or improving the application of existing tools? The short term and small budget nature of the majority of environmental weed resourcing means that 'tool optimisation' is potentially a more likely scenario for investment. This does not take away the rationale that a more strategic, longer-term vision and larger and longer-term funding opportunities could enable a suite of new tools, such as new biocontrol agents, for addressing weed impacts on biodiversity.

Are weeds the passengers or drivers of change?

Factoring in the ecological context of weed management can provide further opportunities for refining control programs. Weeds are just one of a number of threats impacting on biodiversity values, alongside factors such as climate change, landscape fragmentation and destruction, and altered natural disturbance regimes (e.g. fire, floods). Considering multiple weed impacts in a given area, as well as the diverse web of other interacting ecosystem threats, can provide a different perspective to control options. It may be that certain communities are more vulnerable to weed impacts. For example, already disturbed or degraded ecosystems may be particularly susceptible to invasion from early successional weeds, which if allowed to persist, could permanently change ecosystem trajectories. Quantifying weed impacts in such ecosystems is far harder than in more intact communities. On the other hand, weeds that can invade and dominate less degraded communities are likely to represent a greater threat to biodiversity (and therefore a management priority). In many situations it may be that simultaneously building ecosystem resilience via re-establishing natural processes (e.g. fire, flooding) in concert with active restoration and cultural management might lessen the overall impact of weeds on biodiversity, or make a given weed control more effective. Prioritising activity towards more vulnerable ecosystems as well as on more threatening weeds allows for management to improve biodiversity values with both a top-down and bottom-up approach. Such a strategy, however, requires robust knowledge of weeds and their recipient ecosystems so that sites with the potential to be impacted can be appropriately assessed within an appropriate risk-analysis framework.

Eastern weedy wattles invade western bush

ABOVE: Sydney golden wattle (*Acacia longifolia*), Photot: DPIRD Agpix

Sydney golden wattle (*Acacia longifolia*), is one of the weediest trees in the great southern region of Western Australia. It is an Australian species native to north-east NSW and has naturalised widely in south eastern Australia. Moore (2012) predicted that these non-native *A. longifolia* infestations would double in extent every five years in Western Australia and could occupy 18% of the local native bushland by 2020. Based on field observations in 2021, the invasion is likely to have met or already exceeded this prediction.

Acacia longifolia is spread mainly by birds transporting seeds, which makes containment difficult. Water flows and insects such as ants contribute local spread, while enthusiastic gardeners and revegetators have spread it from one district to the next. Occasionally when people buy sandalwood seedlings the host plant is indeed an unlabelled weedy wattle, creating another pathway for introduction to new regions and likely subsequent invasion. Current management of this species in Western Australia has an asset-protection focus, channelling on-ground resources into keeping Torndirrup National Park, Porongurup National Park and Mt Manypeaks Reserve free of *A. longifolia*.

A range of new control tools are being trialled to assist in protecting these areas. As *A. longifolia* flowers 3-6 weeks before local native acacias, it can be easily detected in remote stands using aerial photography. Research using microwaves to kill seeds in the seedbank has led to a DPRID and University of Melbourne collaboration to design a machine suitable for research use. More work is needed to understand seedbanks, particularly germination stimulants so that long-term control efforts don't exceed community capacity. There are future opportunities to consider biocontrol agents for *A. longifolia* that have been released in South Africa, where it is also a major weed in Mediterranean environments. These agents from the native range in NSW could be useful in Western Australia if they pass the various screening tests to ensure they have no off-target effects.

Acacia longifolia is not the only problem non-native wattle in the State — a range of other wattles that are native to the eastern states are serious environmental weed in various ecosystems around Western Australia. Each species seems to have a niche of climate and soil types where it can take over and out compete most of the local flora. More needs to be done to tackle the threat of Australian species that have been introduced well beyond their native range and are threatening native flora and fauna.

Relevant policy and legislation

Commonwealth

The *Biosecurity Act 2015* is administered by the Commonwealth Department of Agriculture and Water Resources and primarily addresses the biosecurity risk to Australia of international imports of goods and people entering Australia. Earlier this year the Auditor General's office conducted an audit and found six deficiencies with how the Department responds to non-compliance with the Act. The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is administered by the Commonwealth Department of Agriculture, Water and the Environment. Five weed species are listed as key threatening processes under the EPBC Act:

1. Gamba grass (*Andropogon gayanus*)
2. Para grass (*Urochloa mutica*)
3. Olive hymenachne (*Hymenachne amplexicaulis*)
4. Mission grass (*Cenchrus polystachios* syn. *Pennisetum polystachion*)
5. Annual mission grass (*Cenchrus pedicellatus* syn. *Pennisetum pedicellatum*)

Native species that are listed as Vulnerable to Critically Endangered that are threatened by these non-native grass species include 12 birds, five mammals, two reptiles, one invertebrate and seven plant species. Also directly threatened are two Ramsar wetlands and two world heritage areas and one ecological community. There are also 23 EPBC-listed communities in Western Australia and 11 of these identify weeds as a key threat. Threat abatement plans exist to reduce the impacts of these species on threatened species and ecological communities.

State

There are four main pieces of legislation in Western Australia that are relevant to the management of weeds and mitigation of their impacts. The *Biosecurity and Agriculture Management Act 2007* (BAM Act) is administered by the Department of Primary Industries and Regional Development (DPIRD) and manages new plants entering the State and the control of weeds within the State. The BAM Act protects Western Australia from new weed risks as species unknown to the State are deemed prohibited, until a risk assessment profile is undertaken. The BAM Act also imposes obligations on landholders to manage declared weeds on their properties. A 2020 audit by the Auditor General's office found that DPIRD and DBCA had not effectively addressed the findings from an earlier 2013 report on delivering against the BAM Act requirements. Communities concerned about declared weeds can form a Recognised Biosecurity Group (RBG) under the BAM Act, which then enables a Declared Pest Rate to be imposed on all landholders within the group area resulting in a source of funds to manage weeds.

The *Biodiversity Conservation Act 2016* (BC Act) is administered by the Department of Biodiversity, Conservation and Attractions (DBCA). The BC Act can impose obligations on landholders to protect threatened species or threatened ecological communities from weeds. The *Land Administration Act 1997* is administered by the Department of Planning Lands and Heritage and oversees the operation of pastoral leases in WA. Under the Act there are conditions on pastoral leases to control weeds and protect native vegetation.

Finally, the *Environmental Protection Act 1986* (EP Act), is administered by the Department of Water and Environmental Regulation. The EP Act can require a proponent (for example, a mining company) to undertake weed management or the monitoring of potential spread if it forms part of the Ministerial statements attached to a proposal.

MAIN IMAGE: Annual mission grass (*Cenchrus pedicellatus*) invades Bandilngan (Windjana Gorge), Photo: Louise Beames

INSETS (from left): Calotropis (*Calotropis procera*), Photo: Louise Beames; Narrow leaf cotton bush (*Gomphocarpus fruticosus*), Photo: DPIRD Agpix; Hottentot fig (*Carpobrotus edulis*), Photo: John Huisman

Relevant strategies and plans

Commonwealth

The Invasive Plants and Animals Committee (now the Environment and Invasives Committee) compiled the National Weed Strategy (2017–2027) that provides a framework for the strategic management of weeds in Australia. It follows on from previous strategies to minimise the impact of established weeds in Australia. It supports and guides the co-ordination of best practice weed management across state and territory jurisdiction with a focus on prevention, detection and early intervention. The National Environment and Community Biosecurity Research, Development and Extension Strategy (2021–2026) will add further guidance for targeted investment in biosecurity research, development and extension. Other strategies that are relevant to the management of weeds, primarily through mitigating threats to biodiversity, include Australia's Strategy for Nature (2019–2030), the Threatened Species Strategy (2021–2031) and the CSIRO's Australia's Biosecurity Future report (CSIRO 2020).

Weeds of National Significance (WoNS) were identified in the National Weed Strategy Executive Committee (1999). An agreed list of 20 weeds was determined for all states and territories to prioritise for national action, to overcome the state-based and often short-term approach to control. This list was expanded to 32 in 2012 and included listings of entire genera. However, formal national coordination of WoNS ceased in 2013 and many end users consider the current WONS program ineffective when considering current weed management needs. It is notable that the WoNS framework is currently being revised to benefit from alignment with the National Biosecurity Committee's Established Pests and Diseases of National Significance Framework (National Biosecurity Committee 2016, Wild Matters 2020).

At least 21 of the new WoNS are naturalised in Western Australia, with another three present but not invasive or problematic. Other WoNS have been detected in Western Australia but have either been successfully eradicated from the State or are part of an ongoing eradication program (*Salvinia molesta*, Parthenium weed). Mapping efforts for WoNS in recent years has been limited, particularly in the remote regions of northern Western Australia, with national maps often showing species as not being present when in fact they are.

State

Western Australia has an Environmental Weed Strategy (1999), a State Weed Plan (2001), and the Western Australian Biosecurity Strategy (2016–2025). All were compiled by experienced staff across multiple agencies and community Landcare groups to achieve a co-ordinated, effective weed management strategy to address the growing impact of weeds in the environment. In addition, a number of community-based organisations have developed regional or sub-regional weed management plans that complement these higher-level plans.

The Department of Biodiversity, Conservation and Attractions manages 31.6 million ha of conservation estate and has some responsibilities for management of 89.5 million ha of unallocated Crown land and reserves. Weed management in the Department's Parks and Wildlife Service has adopted a regional weed prioritisation process, where priorities are species-led (populations deemed highly invasive, and with high ecological impact but manageable) as well as focused on asset-based protection (protecting high value assets from weeds) and determined by those with knowledge in the region (Passeretto 2018). From this framework, weed prioritisation lists have been produced for many regions in the State. This approach means that the most widespread species might not be a priority for weed control resources, unless they are a threat to social, cultural or ecological assets. The process is also heavily reliant on the opinions of those with expertise on the weeds in question given that most species are data deficient.

LEFT: Bulbil watsonia (*Watsonia meriana* var. *bulbillifera*) spread by roadworks, Photo: Bruce Webber

INSETS (from left): Golden crownbeard (*Verbesina encelioides*), Photo: Bronwen & Greg Keighery; Spiked malvastrum (*Malvastrum americanum*), Photo: Vicki Long

TABLE 1. Weeds of National Significance known to occur in Western Australia

Common name	Scientific name
African boxthorn	*Lycium ferocissimum*
Alligator weed*	*Alternanthera philoxeroides*
Asparagus ferns	*Asparagus asparagoides, Asparagus declinatus, Asparagus scandens*
Asparagus ferns**	*Asparagus africanus, A. plumosus, A. aethiopicus*
Athel pine	*Tamarix aphylla*
Bellyache bush	*Jatropha gossypifolia*
Bitou bush, boneseed	*Chrysanthemoides monilifera* subsp. *monilifera* and *rotundata*
Blackberry	*Rubus fruticosus* agg.
Cats claw creeper	*Dolichandra unguis-cati*
Gamba grass	*Andropogon gayanus*
Gorse	*Ulex europaeus*
Hymenachne*	*Hymenachne amplexicaulis*
Lantana**	*Lantana camara*
Madiera vine	*Anredera cordifolia*
Mesquite	*Prosopis* spp.
Mimosa	*Mimosa pigra*
Brooms	*Genista monspessulana, G. linifolia* and *Cytisus scoparius*
Parkinsonia	*Parkinsonia aculeata*
Prickly acacia	*Vachellia nilotica* ssp. *indica*
Prickly pear, Opuntoid cacti	*Austrocylindropuntia* spp., *Cylindropuntia* spp., *Opuntia* spp.
Rubbervine	*Cryptostegia grandiflora*
Water hyacinths*	*Salvinia molesta & Eichhornia crassipes*
Sagittaria*	*Sagittaria platyphylla*
Silver nightshade	*Solanum elaeagnifolium*
Willows (except weeping willows, pussy willow and sterile pussy willow**)	*Salix* spp. except *S. babylonica, S.* X *calodendron* and *S.* X *reichardtiji*

** Aquatic species ** Present but not problematic where currently found*

MAIN IMAGE: Hottentot fig (*Carpobrotus edulis*), Photo: Bruce Webber

INSETS (from left): Bridal creeper (*Asparagus asparagoides*), Photo: DPIRD Agpix; Morea (*Morea setifolia*), Photo: Bronwen & Greg Keighery; Onion grass (*Romulea rosea*), Photo: John Huisman

ABOVE: Controlling rubber vine (*Cryptostegia grandiflora*), Photo: John Szymanski

Resourcing weed research

Commonwealth

Investment in weed research has declined since the end of the Cooperative Research Centre (CRC) weed research programs. Between 1995-2001 the CRC for Australian Weed Management coordinated A$18.45 million in Commonwealth and private grants, and A$34.92 million in in-kind support from nine government agencies (CRC, 2001). Approximately 23.5% of the grant resource of the CRC was allocated to research on weeds affecting natural ecosystems. The second iteration of the CRC for Weed Management Systems between 2001-2008 received up to A$26.5 million in grants and A$55 million in in-kind support, with 26% spent on weed problems in extensive land systems and natural vegetation (CRC, 2006). The CRC for Weeds was discontinued in 2008.

The national science agency, CSIRO, delivers a range of weed related research of direct relevance to biodiversity conservation in Western Australia. Investment nationally in weed research capability by CSIRO, however, has fluctuated over time. For example, between 1999–2018, average annual external revenue received by CSIRO for biocontrol was A$2.5 million, peaking at nearly A$7 million in 2002 but was less than A$1.7 million by 2018 (CSIRO, 2017). Biological control capability within CSIRO was falling up to 2015 (Palmer et al. 2014), but in recent years has seen a change in investment to retain and engage expertise. A significant component of the current CSIRO weed research capability is located in Western Australia.

State

In Western Australia, the two main government agencies currently involved in weed research are DPIRD and DBCA, with the former having more of a focus on agricultural weeds. In the past, the Agricultural Protection Board (APB) was a force in weed control regulation and research in the 1950s to the early 2000s. The APB was abolished in 2010 with the repeal of the *Agriculture Protection Board Act 1950* and amendments to the *Agriculture and Related Resources Protection Act 1976* (ARRPA). This legislation was replaced by the BAM Act.

Both DPIRD and DBCA have undergone considerable structural change and downward pressure on overall staffing numbers for well over a decade. The Department of Primary Industries and Regional Development (and its earlier naming iterations) saw workforce numbers decrease by 37% during 2007–2017 and by another 9% in 2017 following additional departmental mergers. With a current focus primarily on management and regulatory response, the capacity for undertaking weed research in DPIRD is now severely constrained and largely restricted to a single person for the whole State.

ABOVE: Undertaking Bolivian rosewood (*Tipuana tipu*) growth trials across broad climatic gradients, Photo: Bruce Webber
RIGHT: Mapping the control of mesquite (*Prosopis* sp.) on Mardie station, Photo: Bruce Webber, CSIRO

The Department of Biodiversity, Conservation and Attractions (and its earlier naming iterations) has seen resources directed to weed research vary over time. In recent years dedicated weed research capability in DBCA has not been replaced after natural attrition and retirements. Strategic collaborations with other research providers, particularly CSIRO, are providing an effective way to maintain research impact. At the same time there has been a strategic shift within DBCA from a species-led focus to a biodiversity asset-led approach, in which knowledge gaps in weed impacts and management options are considered in the context of multiple, often interacting, threats to biodiversity conservation.

Why Western Australia?

Western Australia has a globally unique biodiversity characterised by significant regional endemism, meaning that we have plants and animals that only live in a particular location. This is due to the State's vast geographical expanse, climatic diversity, areas of relative wilderness, regions with extremely nutrient-impoverished soils, and the fact that significant areas of Western Australia have not been covered by sea or glaciated over geological time. There are more species of flowering plants in the Fitzgerald River National Park, for example, than in the entire United Kingdom. Such diversity combined with significant threats to its ongoing existence combine to make the south west of Western Australia one of only *36 Global Biodiversity Hotspots*. Western Australia is also home to 8 of the 15 National biodiversity hotspots.

With considerable variation in ecosystems comes associated diversity in the weeds that cause, or are likely to cause, negative impacts on natural ecosystems. Weeds in the northwest remain disproportionately understudied relative to work in southern Western Australia, yet this area is considered a future location for agricultural expansion. If this expansion in the north is to be pursued, research will need to focus on invasion pathways, containment and dispersal mechanisms, as well as risk assessments for new potential invaders, including both novel incursions and existing species responding to climate change.

Western Australia has a long list of past examples of weed control and management programs that have been successful. However, like all states, consistent funding to underpin effective weed management programs has been lacking. The national weed lists (such as the Weeds of National Significance) have a history of being somewhat more East coast focused, despite 21 of the 32 WoNS being present in Western Australia combined with deficient mapping, making it harder to attract federal funding into the State. Moreover, while a number of 'priority lists' of target weeds have been produced in recent times, these have rarely involved broad stakeholder consultation, nor have they been done at a state level, and they have frequently relied on expert elicitation from a small number of experts.

Weed impacts significantly affect a broad range of stakeholders in Western Australia, and many land managers have policy-driven obligations to control weeds. Weed spread and impacts span political and land tenure boundaries. A diverse range of organisations manage natural landscapes in the State, meaning that significant gains in management effectiveness in Western Australia could be achieved via cross-tenure and multi-organisation collaboration. However, agricultural and horticultural activities have a long history of contributing weed threats that impact on natural ecosystems, a threat source that continues today. These conflict species broaden the group of stakeholders of relevance to managing weed impacts on biodiversity. Moreover, Indigenous-led land management accounts for a significant and increasing proportion of the State, adding cultural complexity to prioritising weed management based on biodiversity values. While improved collaboration between land managers will be able to improve outcomes based on existing knowledge, addressing research knowledge gaps is an area that is likely to add considerable value to the conservation of biodiversity.

In many ways Western Australia is unique when it comes to the management of weeds. The State has specific biosecurity advantages, relative to other states, which presents both opportunities and challenges from a weed management perspective. Western Australia has diverse climates, ranging from arid desert to Mediterranean to tropical monsoon, with distinct weed threats even compared to similar ecosystem types in other states and territories. However, our low population means we cannot attract national research resources for WA weeds as effectively as in more populated states such as New South Wales and Victoria. Even so, weed research undertaken in Western Australia would remain incredibly useful for other states and even international weed management programs.

The current low level of investment in weed research and management in Western Australia is strikingly at odds with the high threat weeds pose to our unique biodiversity, cultural heritage and agricultural production. Western Australia has world class border protection programs to minimise the risk of new arrivals, but inadequate resources to support sustainable management programs for existing and emerging threats from weeds that are already present, let alone those new species that will inevitably arrive. It may even be that the worst weeds of the future are already within our State, with highly invasive plants promoted in the nursery trade and still utilised for pastures.

Lastly, a significant proportion of the personnel with considerable expertise on weeds in Western Australia have recently retired or are likely to retire in the next five years. There is, therefore, a need to ensure proactive succession planning so that the State does not lose the knowledge held by these individuals and by the various research institutions across Western Australia. A focused and prioritised applied research program for addressing weed threats is an ideal vehicle to reinstate the considerable weed research and practical outcomes from decades past.

LEFT: Measuring sea spurge (*Euphorbia paralias*) growth rates, Photo: Paul Yeoh, CSIRO

4 Program outline

There is growing awareness on the need to improve outcomes from weed management programs in Australia, and a recognition that research to address knowledge gaps, with associated funding provision are critical parts of that need.

A step change in the quantity and duration of funding and resourcing for weed control is of fundamental importance, in order to address knowledge gaps and to deploy new knowledge generated. Returns on such investment could be rapid, with considerable scope for improvement of current control options, as well as integration with indirect control methods, such as the management of fire and grazing.

Despite these changes being critical for achieving near term impacts, significant knowledge gaps remain relating to the ecology, impacts and management of weeds, particularly which relate to local context in the wide range of environments across Western Australia. Such knowledge is equally relevant to improving existing control methods as it is to developing novel control solutions. These new methods, such as new biological control solutions, require greater long-term investment so they can be deployed against a wider range of threatening weed targets.

To address these needs, WABSI has acted on end user led momentum to initiate the development of a prioritised research program on weeds in Western Australia. WABSI research programs bring together a diversity of stakeholders to achieve consensus on the most important factors limiting progress against challenges of great importance for biodiversity conservation in the State. The program document is written for a broad audience of stakeholders, including research providers, funding bodies, regulatory authorities, the full range of land managers in the state, as well as members of the general public with an interest in biodiversity threats and weed management. As such, the program needs to cover the interests of a very diverse stakeholder group, despite being end user led. This research program, when implemented via a steering committee (or equivalent), will provide a framework for identifying and implementing the highest priority research on weeds, and a pathway to maximise the adoption of that research to improve on-ground outcomes.

MAIN IMAGE: Using fire to manage weed impacts, Photo: Judy Dunlop

INSETS (from left): Cypress vine (*Ipomoea quamoclit*), Photo: Lee Fontanini; Parkinsonia (*Parkinsonia aculeata*), Photo: Bruce Webber; Queensland silver wattle (*Acacia podalyriifolia*) a garden escapee invading around Manjimup, Photo: Lee Fontanini

In developing this program on mitigating weed threats to biodiversity, it is clear that:

- Weeds represent a significant threat to the conservation of biodiversity in Western Australia;
- There is a need to address knowledge gaps as a critical component of improved weed management outcomes; and
- It is essential to improve the value proposition for resourcing the mitigation of weed threats, including understanding the consequences of delaying action or doing nothing.

It is recognised that there is significant complementarity to the program, particularly in regard to the management and control of agricultural weeds and the mitigation of weed impacts on social and cultural values. A program of prioritised research to address knowledge gaps for weeds that are threatening biodiversity values is highly likely to also have shared benefits for a range of ecosystems and contexts in the State, as well as for weed management across all ecosystems nationally and internationally.

Objectives

The objective of this research program is to provide a prioritised framework for identifying knowledge gaps for mitigating weed threats to biodiversity in Western Australia. By identifying a clear pathway from knowledge generation to on-ground uptake, this program will encourage complementarity and collaboration, will identify potential targets for resourcing and funding the work, and will provide clarity on how best to translate research findings into improved outcomes for end users.

Vision

Address priority knowledge gaps with new research while facilitating the translation of these insights into effective on-ground outcomes, thereby addressing the threat of weeds on native biodiversity, and enhancing conservation outcomes in Western Australia.

Outcomes

A step change in our understanding of weeds, their impacts, and their control options, which delivers improved management programs in Western Australia resulting in tangible on-ground improvements in the mitigation of weed threats on native biological diversity. Worthy goals include:

- Double the number of successful weed eradication programs;
- Reduce the overall number of weeds by making eradications more numerous than new introductions;
- Double the number of successful biocontrol programs to reduce the requirement for costly ongoing interventions;
- Stronger weed control policy and regulation; and
- Cross-tenure collaborations as the default approach to weed management.

BELOW: Controlling non-native species as part of coastal dune restoration efforts, Photo: Bruce Webber, CSIRO

ABOVE: Managing stinking passionflower (*Passiflora foetida*) invasions on Murujuga (Burrup Peninsula), Photo: Bruce Webber, CSIRO

RIGHT: Bridal creeper (*Asparagus asparigoides*), Photo: Louise Morin, CSIRO

5 Program stakeholders

Stakeholders of this research program include:

- The research community, in Western Australia, nationally and internationally, whose members are working towards more effective, efficient and sustainable tools for managing weeds;
- Government organisations (local, state and federal), some of whom invest resources into the protection of natural environments through quarantine, biosecurity, ecological research, on-ground weed control, and education;
- Natural Resource Management (NRM) organisations, Recognised Biosecurity Groups (RBGs), Land Conservation District Committees (LCDCs) and other organisations who frequently lead community conservation or biosecurity initiatives by bringing together rural landholders and stakeholder groups (for example, GreenSkills Inc);
- Indigenous land owners and managers, including Aboriginal Corporations and ranger groups with an interest in managing their country for biodiversity values (including areas where weeds are impacting on culturally significant assets);
- Indigenous Protected Area managers – making up a large proportion of area in the State that is part of the National Reserve System;
- Non-government conservation organisations (NGOs) who dedicate considerable time and resources towards weed control and community education;
- The nursery and garden industry who adhere to current regulations regarding the importation of correctly labelled and permitted species into Western Australia;
- The Western Australian Weeds Society, who is part of the biennial weeds conference that represent a critical forum for sharing knowledge on weeds between researchers and end users of research findings;

MAIN IMAGE: Understanding herbicide effectiveness against stinking passionflower (*Passiflora foetida*) on Murujuga (Burrup Pensinsula), Photo: Dan Pedersen

INSETS (from left): Mexican poppy (*Argemone ochroleuca*), Photo: Lee Fontanini; Butterfly pea (*Clitoria ternatea*). Photo: Lee Fontanini

- The compliance and regulatory sectors, including government at the local, state and federal levels, that are working to ensure weed species are managed in accordance with current legislation or environmental impact statements;
- The agricultural and forestry sectors, whose ability to productively manage their land may be impacted by weeds and new weed incursions;
- The environmental consulting and contractor sector, including pest management technicians, that are implementing weed management programs and who would benefit from improvements to control options;
- The mining sector, through offset and policy driven requirements, as well as best practice environmental management and restoration efforts, which undertakes weed management programs on land under their tenure;
- The tourism sector, which relies on Western Australia's natural environment, often including reserves and parks that are directly threatened by weeds, for a significant component of their appeal to visitors;
- The Australian Defence Force, which undertakes weed management on their extensive military training areas in the State;
- Community groups, including Landcare, Coastcare, wildflower societies, Friends of and Naturalist groups that have a focus on appreciating natural biodiversity and advocating for issues relating to the conservation and protection of remnant bushland and parks;
- The general public, which has an interest in the health of the environment and the conservation of native biodiversity.

6

Value proposition

There are few places globally that can rival Australia for both the devastating impacts from non-native species on ecosystem values, as well as the opportunities for a step change in improved outcomes for native biodiversity from evidence-based and appropriately resourced weed management.

Although there is recognition that Australia's best-practice border biosecurity has reduced new incursion problems compared with the rest of the world (Seebens et al. 2017), the sheer scale of the non-native plant problem in Australia is vast – and growing – each year due to spill-over from horticultural and agricultural escapees into natural environments. Only a small fraction of these non-native species become threatening invasives, but their associated damage and management costs are incredibly high.

While the staggering economic costs of problem weeds have been estimated conservatively (Sinden et al. 2004, McLeod 2018, Diagne et al. 2021), social (including public health and safety), cultural and environmental costs have been less well considered. Remarkably, no valuation of the full costs of problem weeds – environmental, economic, social and cultural – is available for the whole state of Western Australia, combining both resource and environmental sectors, and this severely limits policy and management responses.

Moreover, a sole focus on direct economic costs could risk de-valuing the importance of cultural identity, a 'sense of place' for Western Australians, intangible benefits from preserving native biodiversity within iconic Australian landscapes, and the tangible tourism, cultural integrity and human welfare benefits that flow from this. What is needed most is a complete integration of the direct and indirect damage costs from problem weeds, across social, cultural, environmental and economic values combined.

MAIN IMAGE: Love grass (*Eragrostis curvula*) dominating road verges in the wheatbelt, Photo: Bronwen & Greg Keighery

INSETS (from left): Bellyache bush (*Jatropha gossypifolia*), Photo: Lee Fontanini; Silverleaf nightshade (*Solanum elaeagnifolium*), Photo: DPIRD Agpix; Painted Lady (*Gladiolus angustatus*), Photo: Bronwen & Greg Keighery

Tackling problem weeds effectively across large spatial scales with sustainable long-term investment will require new research to lift barriers to successful management. The barriers themselves have explicit social, cultural, economic and environmental dimensions that will need to be addressed head-on, such as differing value-judgements on what constitutes a priority weed in the first place, and differing trade-offs in costs and benefits of management.

Lifting barriers to effective long-term management of problem weeds

Four key pathways to success can be identified in which research is needed to lift barriers to effective long-term management of problem weeds in Western Australia: **Authentic** communication of values and risks, **Clear** reporting of the relative costs and benefits and outcomes of management intervention; **Timely** and informed decision-making, and **Efficient** optimisation of management resources ('ACTE').

Authentic communication of values and risks

Effective long-term management of problem weeds requires a common set of goals and priorities across land tenures and stakeholder groups.

Setting goals and priorities is hampered by real and perceived differences in stakeholder values, and conflict over how best to quantify the benefits and risks of non-native species and the benefits and risks of management actions.

Two examples of polarised views that represent a barrier to progress, are:

(i) Extreme environmental sector viewpoints that all non-native species are implicitly 'bad', despite obvious empirical evidence that the vast majority of positive socio-economic benefits stemming from agriculture in Australia are founded on non-native plant species; and

(ii) Extreme industry sector viewpoints that short-term economic values should take primacy in decision-making, despite obvious quantifiable risks of spill-over of non-native plants from horticulture or agriculture to adjacent natural environments where they may constitute problem weeds with significant environmental and social costs that are not currently accounted.

Genuine progress will require both awareness and acknowledgement of context-dependence in the values placed on non-native plants. At a fundamental level, overcoming a widespread disinterest and lack of understanding on the existence of weeds as a concept, as well as the threats that they represent, presents an earlier barrier to recognition of weed issues. Even with awareness, not all people value species or their impacts in the same way, and these values can vary from place to place (Bartz and Kowarik 2019).

Acknowledging these differing values will require authentic communication of the positive and negative effects that different stakeholders perceive each non-native species to have, across dimensions of social, cultural, environmental and economic impacts (Figure 3).

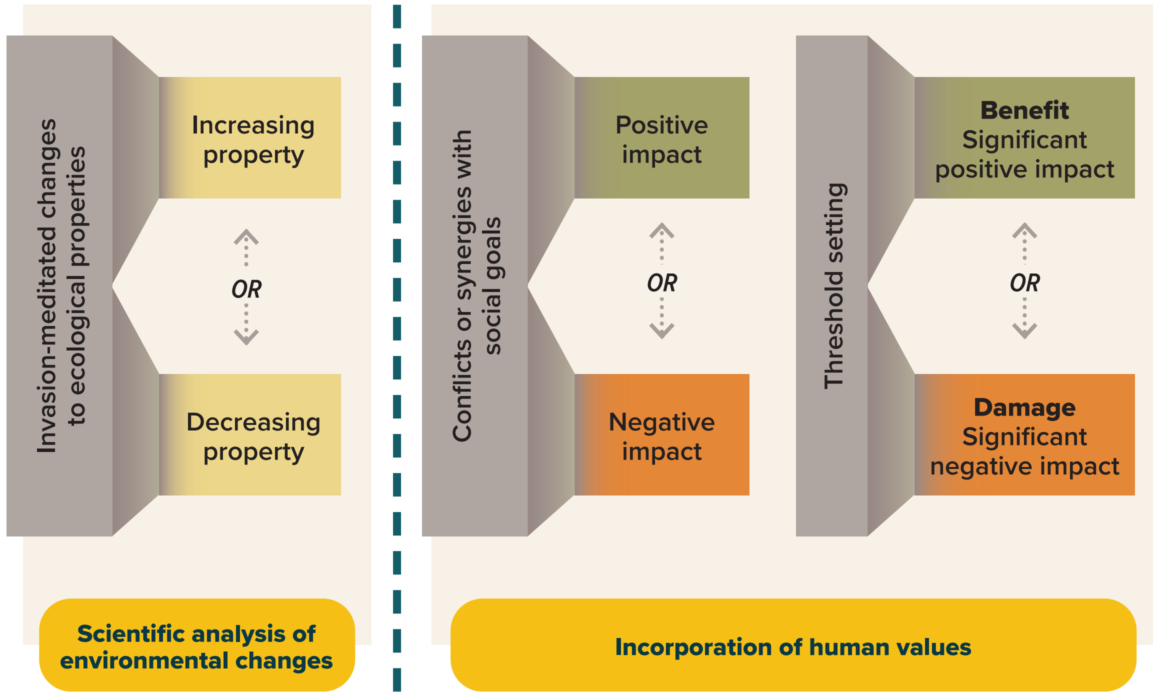


FIGURE 3. Not all non-native plants are 'problem weeds' that cause damage (significant negative impact). Perceived environmental, social and economic values of non-native species may vary between species and between stakeholders. Identifying perceived conflicts in values, and perceived risks of management action (or inaction) is a crucial first step in the social licence to manage non-native plants.

Adapted from Bartz and Kowarik 2019.

ABOVE: Wheel cactus (*Opuntia robusta*), Photo: DPIRD Agpix

Moreover, social acceptance of different types of management approaches to problem weeds is changing rapidly, particularly in attitudes to chemical control options, potentially narrowing available management strategies, or suggesting the need for better stakeholder education on the relative risks and benefits of different tools and techniques.

It is expected that authentic, transparent, and inclusive communication that would be core to the research program will deliver greater engagement across stakeholder groups as they perceive that their values are better acknowledged and incorporated into decision-making. The end result is likely to be a decrease in conflicts among stakeholders that would otherwise slow the path to timely decisions and effective long-term management.

Clear reporting of the relative costs and benefits and outcomes of management intervention

In most cases, once a decision has been taken to manage a problem weed, management actions are not followed up with clear accounting or reporting of the relative costs and benefits of action (Iacona et al. 2018, Hanley and Roberts 2019). Not surprisingly, then, there is almost never a clear understanding of what 'success' looks like in terms of efficient optimisation of management resources, and a net benefit of management action.

Clear reporting of the relative costs, benefits and outcomes of management is urgently needed. Recent valuation of the global costs of invasive species (Diagne et al. 2021), makes it clear that the major economic costs to society are actually borne through indirect damage to environmental and social values. Traditionally, it was considered difficult (or impossible) to economically value intangible non-market goods, such as human welfare and protection of biodiversity and cultural heritage. However, recent work provides a comprehensive approach to the general principles of economic valuation of environmental change (Hanley and Barbier 2009). There are also good economic models for the optimal level of management effort, the timing of control actions (Sims and Finnoff 2013) and the relative

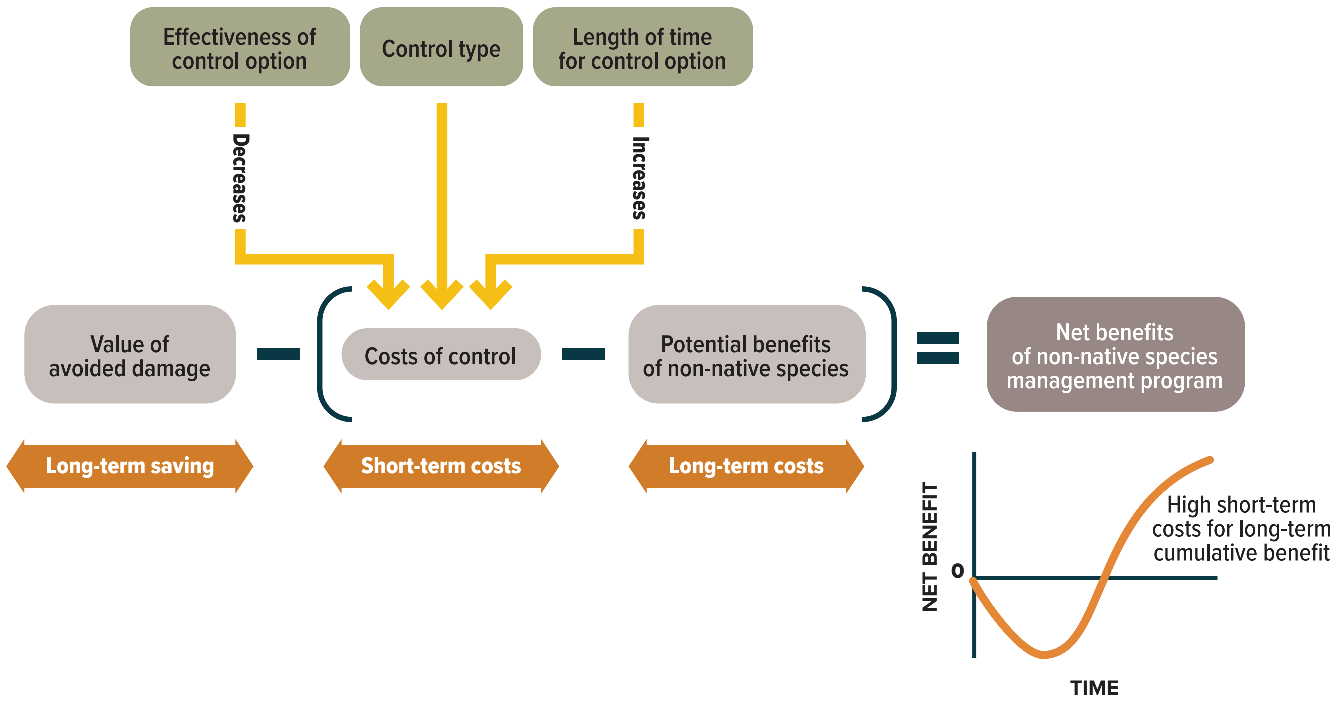


FIGURE 4. Calculation of the net benefit of non-native invasive species management.
Adapted from Hanley and Roberts 2019

investment in biosecurity measures to prevent incursion versus managing spread (Rout et al. 2011), in the context of social, environmental and economic considerations. This focus will be enhanced by the development of a broader national environmental economic accounting process to appropriately value and hence prioritise protection and restoration activities.

Hanley and Roberts (2019) take the economic benefits of invasive species management to be equal to the avoided costs of damages from invasive species, if the management action had not taken place (Figure 4). This approach explicitly contrasts the stream of values that might stem from a business-as-usual scenario, with the stream of values stemming from management action.

The net benefits of management, therefore, are equal to the value of avoided damage minus the costs of control, including any negative off-target effects of management and any benefits forgone that were provided by the invasive species.

Effective accounting of avoided damages and the net benefit of weed management hinges on clear reporting of the costs and benefits and outcomes of management interventions (Iacona et al. 2018).

Improved reporting on the economic, social and environmental costs of management interventions could enhance outcomes in three ways (Iacona et al. 2018): first, it could improve understanding of the costs and benefits of management within and across agencies and practitioners, leading to improved efficiency and accountability as well as data integration that can inform priorities and review approaches; second, it could deliver better quantitative decision-support tools and enable improved prioritisation of management actions; and third, it could provide the baseline data to better predict the costs of future management interventions, ensuring appropriate resourcing.

Timely and informed decision-making

Decisions on whether to act, when to act and how to act on a weed problem all require informed knowledge.

Currently, Western Australia lacks the foundational data repository to know which weeds occur where in the State, with records in existing databases often extremely limited and geographically biased. The data also fail to record what control efforts have been deployed against those weeds and what the status and trends in population abundances are, even for current problem weeds let alone 'sleeper weeds' that could represent future problems.

Timely and informed decision-making is further hampered by the long lag-phase that many non-native species go through, followed by a rapid transition in distributional spread, exponential population growth, and dramatically escalating impacts. This is problematic, as delays in management action during the crucial exponential growth phase of impacts are well recognised to limit effective long-term control. For instance, Sims and Finnoff (2013) show that a 'wait and see' management approach might be a viable option in order to collect more data and make a more informed decision, but only when an invasion is proceeding slowly. Unfortunately, temporal spread data shows that most invasions spread too rapidly and unpredictably to do anything other than respond immediately (Sims and Finnoff 2013). The cost of not acting immediately can frequently be 10 to 100 times greater than rapid responses (Harris and Timmins 2009, Ahmed et al. 2021).

A new program of research would allow more effective integration of underlying data repositories within the State, risk analysis and incursion action plans for more species, investment in the creation and adoption of rapid response program employing novel early-detection tools, real-time remote sensing of status and trends in weed populations, predictive tools to determine when and how to act in order to minimise negative impacts, and the revision of the regulatory framework needed to support and deliver more timely decision-making.

Efficient optimisation of management resources

Effective long-term management of problem weeds must balance maximum (net) benefits of management within the limits of available management resources. Optimising the most cost-effective management strategies requires an understanding of both the benefits and the costs of potential actions, weighed against the benefits and costs of inaction.

Australia is a global leader in tools and technology for managing problem weeds, from mechanical to chemical to biological control measures. However, the choice of preferred tools to use in a specific circumstance is not always well considered, with a reliance on broad-spectrum chemical control. There are also inherent limitations posed by the large spatial scale and remote nature of the landscape over which control measures must be implemented in the Western Australian context, and the rapidly changing social acceptance of different control options. New technologies will undoubtedly be needed in the management toolkit, including those that improve the effectiveness of detection and identification of impact as well as control.

However, the 'toolkit' is only one component ('implementation') of five key management cost considerations in tackling invasive species in general. Holmes et al. (2015, 2016) proposed a breakdown of management costs into five sub-categories of planning, implementation, off-target impacts, remoteness and human population considerations.

Potential non-target effects of management are relatively rarely considered, beyond direct localised impacts on nearby native plants. Mounting evidence suggests that the type of management approach used can have important ecological consequences, and even constrain the ability of systems to recover. For example, Flory & Clay (2009) found that the method used to remove problem weeds could influence the likely degree of recovery of native plants following control.

INSETS (from left): Onion weed (*Asphodelus fistulosus*), Photo: John Huisman; Calotropis (*Calotropis procera*), Photo: Louise Beames; Snake vine (*Distimake dissectus* syn *Merremia dissecta*), Photo: Louise Beames

Inadequate consideration of the ecological role of weeds in ecosystems, could also mean that the removal of one problem weed leads to the increase of another. These types of effects are largely unpredictable and increase in magnitude the longer a problem weed has been in the environment, its effect on the soil stored seed bank of native plants, and the more abundant it is. Some problem weeds have important feedback effects on ecosystem-level disturbance processes, such as fire and flood regimes. The unpredictable nature of these effects, and their detrimental consequences, call for a whole ecosystem approach to weed management and augmented and natural native ecosystem restoration.

As the IUCN (2018) suggest, understanding the timing, dynamics and limits of spread can help guide and optimise management. Simple risk management considerations suggest that the optimal approach in many cases would be to eradicate or manage new incursions in the early lag phase of establishment, before unpredictable environmental and social constraints develop (Rejmánek and Pitcairn 2002, Booy et al. 2017). Purely in economic terms, Harris and Timmins (2009) estimate that early eradication costs for weeds are on average 40 times lower than later attempts to extirpate widely established populations.

Beyond economic and environmental considerations, it should be remembered that whether, and how, problem weeds are controlled is also becoming an increasingly important societal issue. Willingness to pay for high management costs may be limited, and there may be opposition to specific types of management, such as widespread broad-spectrum chemical control. Some non-native species also have important cultural values (Roberts et al. 2018), leading to potential conflicts over the positive and negative values of management. In these cases, when conflict resolution has high political costs, management outcomes are uncertain, or damage costs are estimated to be low relative to management costs, then it may be socially desirable to abandon control measures and instead manage the resulting damage (Hanley and Roberts 2019).

A new program of research would allow more efficient optimisation of management resources across all components of management cost considerations from planning and implementation of actions, particularly in remote areas, to off-target environmental and social impacts as an indirect result of management.

The cost of inaction

Australia now has more species of non-native plants than native plants. Most of these are currently at low levels in the environment, but every year new problem weeds ‘jump the garden fence’ and invade native ecosystems. Current management options and levels of investment are failing to tackle today’s weed problems, let alone the projected exponential increase in new weed problems in the future.

Globally, damage costs from invasive species are increasing 10-fold every decade, while management expenditure only increases 2-fold per decade (Diagne et al. 2021). Accurate cost estimates for problem environmental weeds in Australia are not known but are likely to be increasing at equivalent rates. The majority of these costs will be indirect social, environment and economic damages, which are currently poorly quantified.

In most cases, the costs of preventing or controlling these invasions would be 10 to 100 times lower (Bradshaw et al. 2021b). Therefore, the ‘cost of inaction’ increases exponentially the longer a problem weed invasion is allowed to progress (Ahmed et al. 2021). Ahmed et al. (2021) identify a ‘runaway point’ at which it is too late to avoid the worst of the cumulative damages of problem weeds (Figure 5), but there is also an earlier and more important ‘tipping point’ (Figure 5) beyond which it is not possible to ‘flatten the curve’ on damages without inaction costs spiralling out of control.

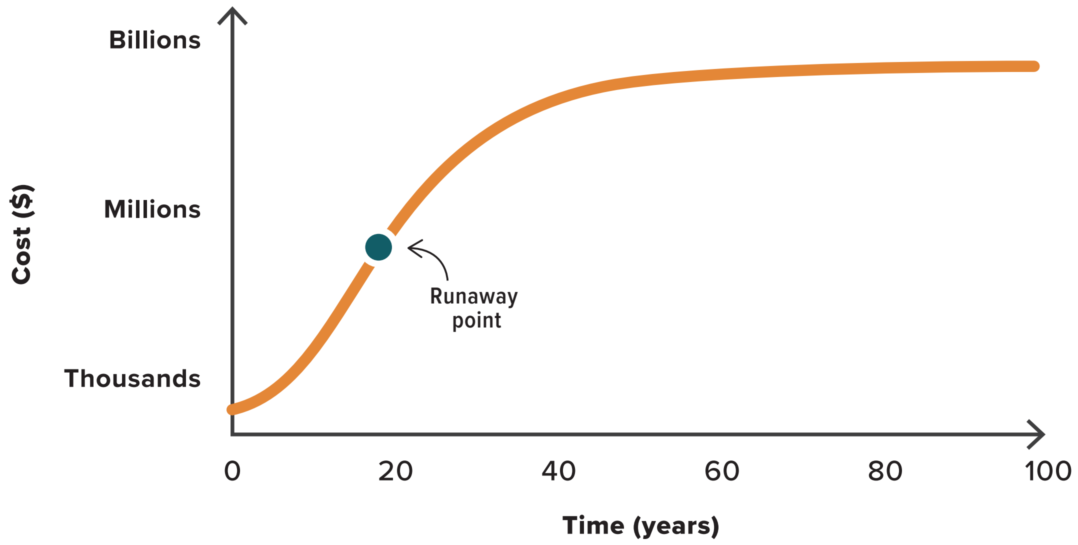


FIGURE 5. Cumulative damage costs for inaction against weed species.
Adapted from Ahmed et al. 2021

Failing to lift the barriers to effective long-term management of problem weeds will impact Western Australia in at least four ways:

- Failure to ensure **Authentic communication** of values and risks will reduce the social licence to operate within biosecurity and weed management, reduce engagement and cooperative efforts by stakeholders, increase the degree of conflict among stakeholders, and escalate the political costs of action or inaction.
- Failure to ensure **Clear reporting** of the relative costs, benefits and outcomes of management intervention will mean there is no accountability for management actions, the State will have no quantifiable measure of return on investment, and there will be no added value from predicting future management outcomes from past evidence of successes and failures.
- Failure to ensure **Timely decision-making** will lead to increasing rates of spread and greater dominance of problem weeds in the landscape, resulting in faster rates of native species decline, more fire-prone landscapes through altered ecosystem dynamics, and ultimately greater risks to biodiversity and human livelihoods. Economic costs of delayed action will be 10 to 100 times higher than effective timely management.
- Failure to ensure **Efficient optimisation** of management resources will mean that there is a perceived expectation that producers and community groups must bear the cost of early intervention, reducing engagement capacity, and that the State then needs to invest in later stage ongoing management actions. Delayed investment risks not achieving satisfactory societal outcomes and a failure to also provide net benefits for the environment and mitigate economic damage.

7

Weed research in Western Australia

Research on weeds in Western Australia has a long history, with a broad remit of research focusing on ecological understanding, impacts and control. An overview of this past and current research, as it applies to Western Australia includes, but is not limited to, research from the following organisations.

Department of Biodiversity, Conservation and Attractions (DBCA)

DBCA and its predecessors have a long history of undertaking research on weeds recognised as a threat to the biodiversity of Western Australia. Within the Department, research has been directed to operational methods of controlling weeds and has also involved funding and collaborating with external institutions in aspects of impact and control (e.g. Hopley et al. 2021). Liaison with the many and varied NGO groups, government bodies and landowners in providing research results, identification aids, application support and advice both physically and digitally (Brown and Bettink 2009) has been a cornerstone of this applied research.

The Department maintains, via the collections at the WA Herbarium, the list of recognised naturalised plants of Western Australia. The Herbarium also provides a weeds identification service. These identifications are backed by voucher material and are available publicly via Florabase. Documenting, reviewing and publishing on this continually changing list of species is an on-going endeavour (Keighery and Mitchell 2021). Taxa have been allocated into agricultural and environmental weeds (Keighery and

MAIN IMAGE: Understanding herbicide effectiveness against stinking passionflower (*Passiflora foetida*) on Murujuga (Burrup Pensinsula), Photo: Dan Pedersen

INSETS (from left): Lantana (*Lantana camara* cv), Photo: Bronwen & Greg Keighery; Cape gooseberry (*Physalis peruviana*), Photo: Vicki Long; Butterfly pea (*Clitorea ternatea*), Photo: Louise Beames

Longman 2004), the latter category largely of concern to DBCA, although declared plants are also a priority.

The Department's key aims centre on biodiversity maintenance, so research has worked at multiple levels, from aspects of weed control of individual species (Brown and Brooks 2003), to management after disturbance events (Gosper et al. 2011), and weed management in threatened species habitat and threatened ecological communities (detailed in management plans; Yates and Broadhurst 2002). An increasing number of weed-focused projects have been delivered in collaboration with CSIRO over the last 10 years, making the most of cross-institution capabilities and collaborations with other land managers including Indigenous groups and mining companies. A broader approach to research on weeds as part of a range of ecosystem threats and processes is being pursued by DBCA scientists in collaboration with other WA research institutions (Gosper et al. 2011, Brown et al. 2016, Taylor et al. 2018).

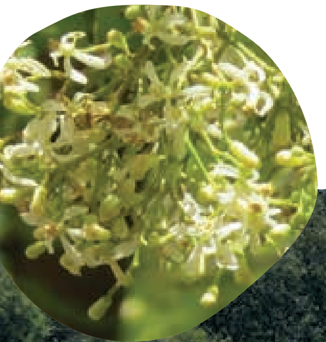
The Department is required to manage weeds on the conservation estate and Unallocated Crown Lands. Resource limitations mean that the effectiveness of this management is variable, particularly in more remote regions. With these lands covering broad swathes of the State, considerable effort has been placed on prioritising the most problematic weed species and most valued biodiversity assets so that limited management resources are allocated most effectively at both the regional and local level (Passeretto and Powell 2012, Gosper et al. 2015).

Department of Primary Industry and Regional Development (DPIRD)

DPIRD has been involved in weed research and invasive species regulation for many decades (including earlier research by the Agricultural Protection Board), resulting in contributions to a number of published compilations on weed ecology and control options (Meadley 1965, Hussey et al. 2007, Moore and Wheeler 2020). In recent years DPIRD staff numbers in weed research have declined considerably, with most weed research now being delivered via collaborations with other organisations, such as CSIRO.

The Western Australian Organisms List was developed by DPIRD after the successful eradication of *Bassia scoparia* (kochia) to help reduce the risk of plants with unknown invasiveness entering WA. This research-informed management is supported by front line staff at the Pest and Disease Information Service (PADIS) who handle over 10,000 enquiries each year and 51 biosecurity officers who help detect new threats. Eradication programs have targeted many species, with skeleton weed being the longest running. *Galium tricornutum* (bedstraw) is all but eradicated (Moore and Dodd 2008), while the kochia eradication was the largest successful weed eradication in the world (Dodd and Moore 1993, Dodd and Randall 2002, Moore 2003).

Current work involves research integrated with management of 60 declared species of plants including a significant research project on skeleton weed and innovative non-chemical controls such as electrocution and microwaves on skeleton weed, gorse and wattles. DPIRD maintains a large database of weed research trials and traditional control in addition to support of commerce and industry (e.g. Moore 1999). Web based tools such as MyPestGuide™ and an informative website are currently maintained by DPIRD and are used to aggregate and inform weed research projects. Biocontrol projects in the State have usually been run in collaboration with CSIRO or other government departments and have made use of DPIRD's extensive rural network.



MAIN IMAGE BELOW: Hydrocotyl (*Hydrocotyle ranunculoides*), Photo: DPIRD Agpix

INSETS (from left): Neem (*Azadirachta indica*), Photo: DPIRD Agpix; Water hyacinth (*Eichhornia crassipes*), Photo: DPIRD Agpix

Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Up to the 1950s CSIRO was engaged in weed related research in Western Australia via providing biological control agents based on research and cultures maintained in Canberra. Locally, release and assessment of establishment of agents was carried out by the then WA Department of Agriculture. CSIRO increased its effort on biological control of weeds from the 1980s with the establishment of a weed research presence in Western Australia (Scott 1984). During the same period CSIRO was also engaging in weed related research as part of a broader focus on landscape restoration (Hobbs 1989, Hobbs and Humphries 1995).

In the last 15 years CSIRO's work in WA has continued to span the development of improved control solutions for weeds (McCarren and Scott 2008, Scott et al. 2010, Jucker et al. 2020), characterising weed ecology to inform management (Aghighi et al. 2014, Scott et al. 2019), and establishing the threat that weeds represent as one of a number of global environmental change drivers impacting on biodiversity values (Gosper et al. 2011, Gosper et al. 2015). Climate change impacts on weeds has been a particular focus (Webber and Scott 2012, Webber et al. 2014) as well as the modelling of weed distributions (Webber et al. 2011, Scott et al. 2014). CSIRO has been and continues to be a leader in the development of biological control solutions for the State, including for bridal creeper, blackberry, Parkinsonia and skeleton weed (Scott et al. 2002, Van Klinken 2006, Turner et al. 2008, Cullen 2012, Aghighi et al. 2014). Many of these programs were delivered in collaboration with DPIRD.

CSIRO's current focus on weeds in Western Australia is on developing science-based solutions for improved invasive species management in the areas of biosecurity, plant ecology and plant-herbivore interactions. A significant part of this has been prioritising weeds based on their impact and using new technology to generate process-based insight at scale to improve weed management. The development of biocontrol solutions for weeds remains a strong focus. Much of the current research undertaken by CSIRO in WA involves partnerships with DBCA, DPIRD and the universities, with applied outcomes enhanced by collaborations with Indigenous ranger groups and community organisations.

BELOW: Quantifying stinking passionflower (*Passiflora foetida*) impacts, Photo: Bruce Webber, CSIRO

Other Western Australian organisations

While no university research group in recent times has made weed research a central focus, Western Australian universities have, from time to time, undertaken research relevant to weed impacts on biodiversity, often as part of broader restoration and community ecology work. This includes a considerable body of work from The University of Western Australia (UWA) on novel ecosystems and their management, including weeds, as a part of restoration efforts (e.g. Hobbs et al. 2009, Hobbs and Richardson 2011), as well as occasional weed ecology work at other universities (Funk et al. 2016, Calviño-Cancela and van Etten 2018). Research at UWA on herbicide resistance in agricultural weeds has relevant insight to species that also impact on natural ecosystems (e.g. Powles and Yu 2010, Norsworthy et al. 2012). Current weed research at UWA involves ongoing work on invasive grasses primarily in the Northern Territory (Rossiter-Rachor et al. 2017, Setterfield et al. 2018a, Setterfield et al. 2018b), representing what could be expanding weed research capability for the State. Murdoch University, through the Harry Butler Institute, is developing broader biosecurity interests but does not have weed focused expertise at the present time.

Community groups are active in pursuing applied research in the form of trials, monitoring and analysis. While these rarely result in academic papers, these groups work to ensure their experiential knowledge reaches the broader community through regular engagement with research organisations, reports in the grey literature, departmental papers and workshops (Beames et al. 2017). Community groups have also been active in applying research knowledge to the development of interim management plans for regions, knowledge resources for practitioners, facilitation of new technology to land managers and campaigns to remove the promotion of problematic weeds by the nursery industry and others (Harding et al. 2009, Miller and Beames 2018).

Environmental consulting companies do undertake limited weed management research, particularly in relation to herbicide trials. However, confidentiality clauses and data intellectual property issues prevent much of this knowledge from being shared in the public domain, and therefore contributing to broader progress against mitigating weed impacts across jurisdictions.

RIGHT: Blackberry (*Rubus anglocandicans*) monitoring, Photo: Paul Yeoh

Cooperative Research Centres

Federally funded Cooperative Research Centres (CRCs) have provided the resources for considerable weed research in Western Australia of relevance to this program. The CRC for Weed Management Systems ran from 1994 to 2001, followed by the CRC for Australian Weed Management (2001–2008). Some significant biocontrol research involving CSIRO and DPIRD was funded by these CRCs (Scott and Wykes 1997, Yeoh et al. 2012), as well as notable weed publications. The most successful project during this period was against bridal creeper (*Asparagus asparagoides*), which is now under control (Turner et al. 2008). More recently the CRC for Plant-Based Management of Dryland Salinity followed by the Future Farms CRC were both based in Perth (UWA) and led Australia in developing post-border weed risk assessment system for assessing the risk of agricultural plants becoming environmental weeds (Stone et al. 2008, Munday et al. 2012).

Interstate research and expertise relevant to Western Australia

Research undertaken both interstate and overseas is likely to be informative for delivering this prioritised research program, even if the work does not take place within Western Australia. For example, due to climatic similarities and many shared weed problems, opportunities exist across northern Australia for improved collaboration between states to research and implement sound weed management and knowledge sharing. Many interstate weed research groups maintain collaborative links with WA researchers. In the university sector, strong weed ecology and broader weed biosecurity groups are currently found at Macquarie University, the University of Melbourne and the University of Wollongong. Charles Darwin University and the University of Adelaide also run weed research programs, particularly focused on fire-promoting invasive grasses (both tropical and arid) and arid zone grasses, respectively. CSIRO maintains considerable expertise in invasive weed management across multiple states, including classical biological control skills, who work closely with the CSIRO biosecurity staff in Perth. The Centre for Invasive Species Solutions is also providing national reach with their efforts to build up the plant side of their work.

ABOVE: Monitoring for impacts of bridal creeper (*Asparagus asparagoides*) biocontrol agents, Photo: Paul Yeoh, CSIRO

ABOVE: Controlling rubber vine (*Cryptostegia grandiflora*), Photo: John Szymanski

Program development and framework

The program development process

The WABSI program development pathway is an iterative process, engaging both end users and researchers. Stakeholders help scope, define and set research priorities.

A process to scope, define and prioritise research needs was undertaken broadly following the WABSI program development pathway. This approach follows an iterative model with stakeholder engagement led by end users, but with ongoing engagement between end users and research expertise throughout a series of workshops to define and refine the program scope and priorities (Figure 6).

MAIN IMAGE: Gamba grass (*Andropogon gayanus*) control, Photo: Tracey Vinnicombe, DPIRD

INSETS (from left): Yellow bells (*Tecoma stans*), Photo: Lee Fontanini; Lead tree (*Leucaena leucocephala*) was introduced as a fodder crop for cattle but is now a threatening weed in the Pilbara and Kimberley, Photo: Lee Fontanini

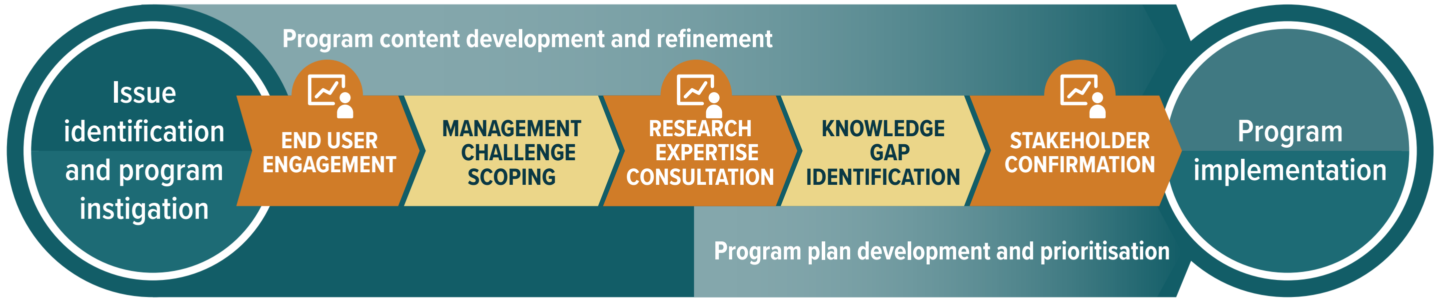


FIGURE 6. The program development pathway to establish a research program for improving management of weed impacts on native biodiversity. Orange boxes highlight the three sets of workshops held to develop the program.

As in previously developed WABSI programs, it was accepted that a range of underlying factors can be responsible for effecting positive change in regard to addressing weed threats, either alone or in concert. These factors including further research, improved management, policy change, improved communication, and increased or more appropriate targeting of funding can all improve outcomes for biodiversity conservation. To delimit the scope of this research program it was deemed that research needed to be an element (but not necessarily the sole element) of delivering a given outcome (Figure 7).

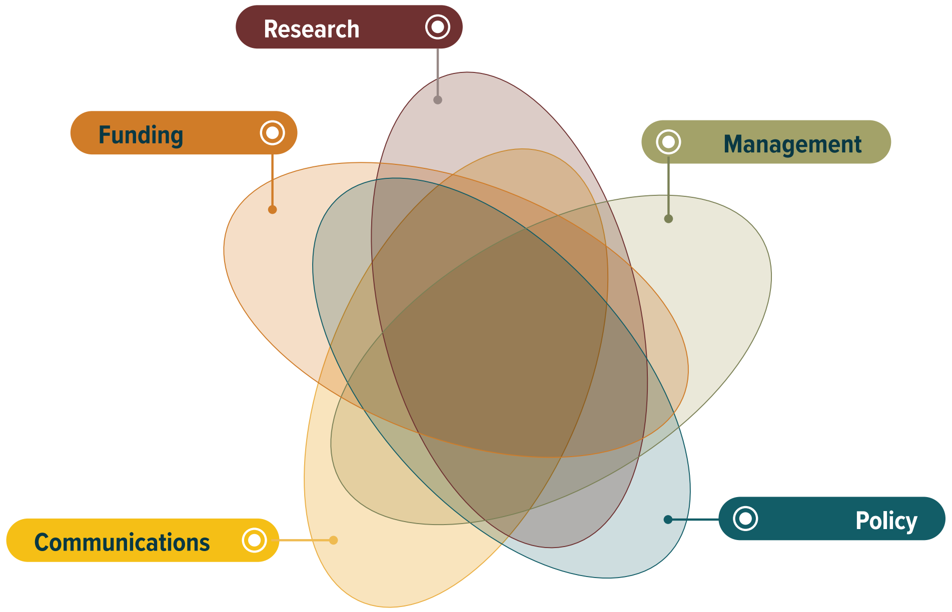


FIGURE 7. Factors that are likely to improve outcomes of weed management can fall into one or more solution components: (1) research addressing a knowledge gap; (2) altered management; (3) policy change; (4) increased or better targeted funding; and (5) improved communications, including education, teaching, lobbying and advocacy. The remit for activity against this program is restricted to the region encompassed by the red research circle.

Stakeholder mapping identified over 400 people across more than 50 organisations with relevant interests in a weeds research program for Western Australia. The vast majority of these people were land managers and other end users of research findings, rather than research providers. Given that stakeholders for this program were located across the State, the program was delivered via virtual and electronic engagement only. Workshops were held virtually using online video conferencing, and content sharing and feedback was facilitated by phone and email between workshops. This structure also responded to restrictions imposed during 2020 and 2021 as a result of the COVID-19 pandemic.

One benefit of an online delivery model was that it allowed us to engage with more stakeholders who otherwise may have been unable to attend a face-to-face meeting. It also enabled us to efficiently structure engagements based on regions to ensure local context and state-wide variation was captured (see Program Workshops section). A clear limitation of this approach was that it impacted on the ability of remote Indigenous communities, rangers and land managers to engage with the program development. This limitation was in part due to reduced access to technology, but also recognises that different engagement styles are more effective and appropriate for different stakeholders. In this situation, while on-Country and face to face consultations would have been desirable, this was simply not possible with travel restrictions.

BELOW: Kapok bush (*Aerva javanica*) and buffel grass (*Cenchrus ciliaris*) invading Thevenard Island, Photo: Vicki Long

Program workshops

The first phase of end user workshops was structured geographically based on Regional Development Commission regions (Figure 8), with one additional meeting catering to those end users who are involved with weed management across the entire State. These six workshops were held between the 14th and 21st October 2020, engaging with a total of 68 people based on targeted invites to ensure maximum diversity of participants across professional sectors and organisations (Appendix 1). Many attendees spoke on behalf of a wider network of colleagues at their respective organisations. The end user workshops had two primary objectives:

1. Develop a refined understanding of current and future issues relevant to addressing the threat of weeds on native biodiversity; and
2. Identify the key actions that are most likely to achieve more effective weed management in Western Australia.

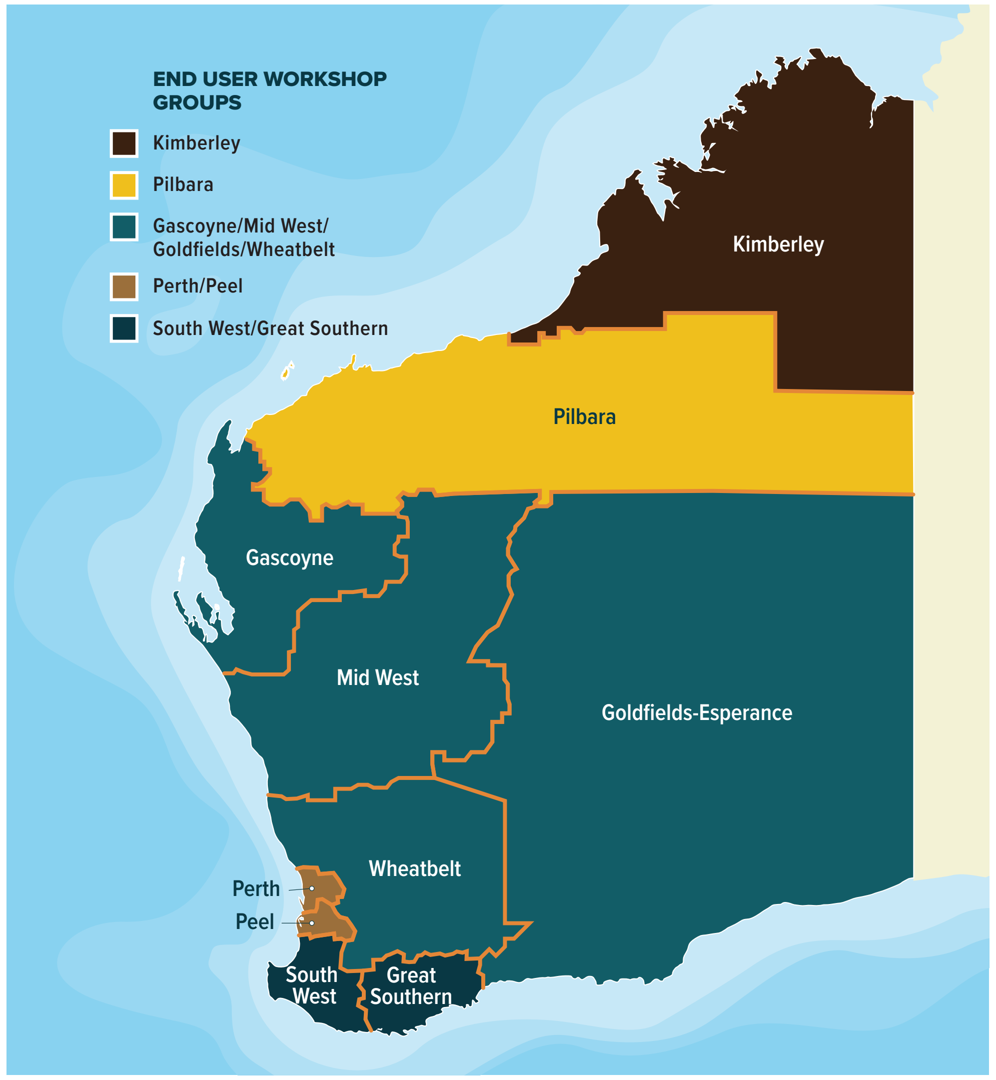


FIGURE 8. End user workshops were defined by Regional Development Commission regions, with one additional meeting for end users who work state-wide.

Participants were encouraged to focus on issues that applied at a higher level to maximise state-wide relevance and were specifically discouraged from simply listing the most challenging weed species currently threatening biodiversity in their given region. Stakeholders were asked to consider:

- What common issues sit behind your priority weed management lists?
- Do you have the management tools you need?
- What weed management issues are being ignored (for example, too hard, too expensive, not considered significant)?
- What issues are holding you back from better weed management outcomes?

Attendees were also asked to reflect on what weed management was being done well, in order to celebrate successes and to help define where there is adequate knowledge already.

Emerging from these end user workshops was a set of 120 issues, representing either knowledge gaps or challenges, in the management of weeds in Western Australia (Appendix 1). These topics were not prioritised by the attendees of these end user workshops.

The second phase of workshops with researchers was again held by video conference and was attended by 22 people at a single event held on the 4th November 2020. These stakeholders represented all organisations undertaking weed research in Western Australia, as well as selected weed researchers with relevant national expertise and experience (Appendix 2). This group was provided with the issues identified in the first phase of end user workshops and were then asked to add to or refine these items (including merging them as appropriate). Importantly, it was clarified that no issue could be discarded. While considerable refinement and additional context and examples were added to the initial list, no new high-level issues were identified during the researcher workshop.

To provide a logical synthesis for prioritisation at the final combined workshop, issues were further refined and then aggregated into research topics. The 120 issues initially identified were merged where there was significant overlap in scope, resulting in a reduction to 118 issues. Although superficially some of the remaining issues appeared similar, often local context and emphasis precluded further merging. Of the 118 issues, 38 did not relate to management issues that would (even in part) involve research (see Appendix 1), and therefore these issues were not considered further (i.e. were out of scope for this research program; Appendix 1, Figure 7). These issues represent barriers to weed management that are perhaps better addressed with changes to funding, policy or communication. The remaining 78 issues identified were grouped into 28 research topics, which were in turn aggregated into eight focal areas (Appendix 1).

In preparation for the final workshop, an online survey was developed to obtain anonymous feedback on (1) prioritisation and categorisation of the issues, and (2) the utility and value of a proposed program framework for guiding delivery. This survey was sent to 192 stakeholders who had been invited to the program workshops. Of the 63 respondents, de-identified representation metrics revealed that the feedback spanned a range of regions and stakeholder types (Figure 9a-c).

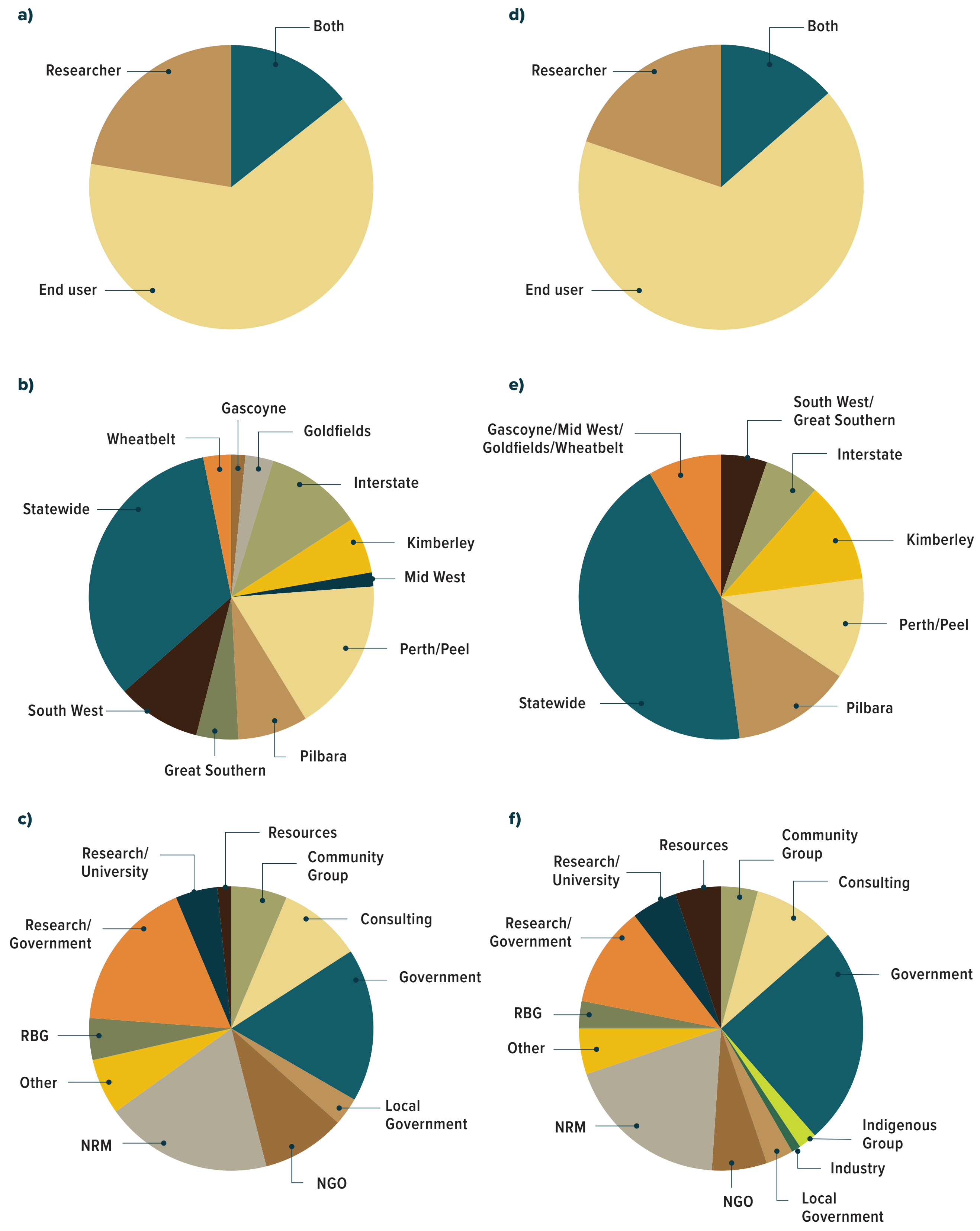


FIGURE 9. Stakeholder engagement diversity across stakeholder groups (researcher, end user or both), Regional Development Commission regions (Figure 8) and engagement sector for the online stakeholder survey (a-c) and the set of three virtual workshops (d-f).

The third and final workshop phase involved all stakeholders – both researchers and end users – from across Western Australia and interstate. The goal of this final workshop was to refine and prioritise the outputs from the first two workshop phases. Forty-nine people attended, with some deliberate overlap with the first two workshops to ensure continuity, but with a more diverse group of end users to maximise the range of contributing viewpoints (Appendix 2). Across the three phases of workshops, attendee diversity across stakeholder group, region and engagement sector mirrored that of the online survey (Figure 9d-f). Attendees at the final workshop were tasked with:

- Critically assessing the research issues identified at earlier workshops;
- Aligning and merging issues under outcome-focused research topics;
- Prioritising these issues based on their ability to address critical knowledge gaps; and
- Refining a high-level research framework for developing future research projects.

Two rating metrics were generated for stakeholder feedback. The first captured regional variation by identifying how many regions raised the issue as an important priority during consultation (higher values indicate more regions rate the issue as important, with state-wide prioritisation carrying greater weight; Appendix 1). The second metric represented a normalised rating derived from the survey tool average ranking score for the issues clustered under each research topic (0-1, higher values indicate higher importance; Figure 10).

To provide a combined overall representation of order of importance of topic, importance rankings were assigned: A (survey rating > 0.6 or workshop score = 10), B (survey rating 0.4 ≤ x ≤ 0.6 or workshop score = 9) or C (survey rating < 0.4 or workshop score < 9; Table 2). We recognise that these ratings are somewhat arbitrary and should be interpreted with that knowledge in mind. It is important to note that all 28 research topics are considered important and a priority to pursue; these rankings simply provide a convenient scale to that importance.

Finally, an earlier draft of this research program was subsequently sent around for stakeholder feedback. Over two circulated iterations, feedback on the draft was provided by a total of 30 individuals as well as de-identified aggregated feedback from 5 organisations (Appendix 3).

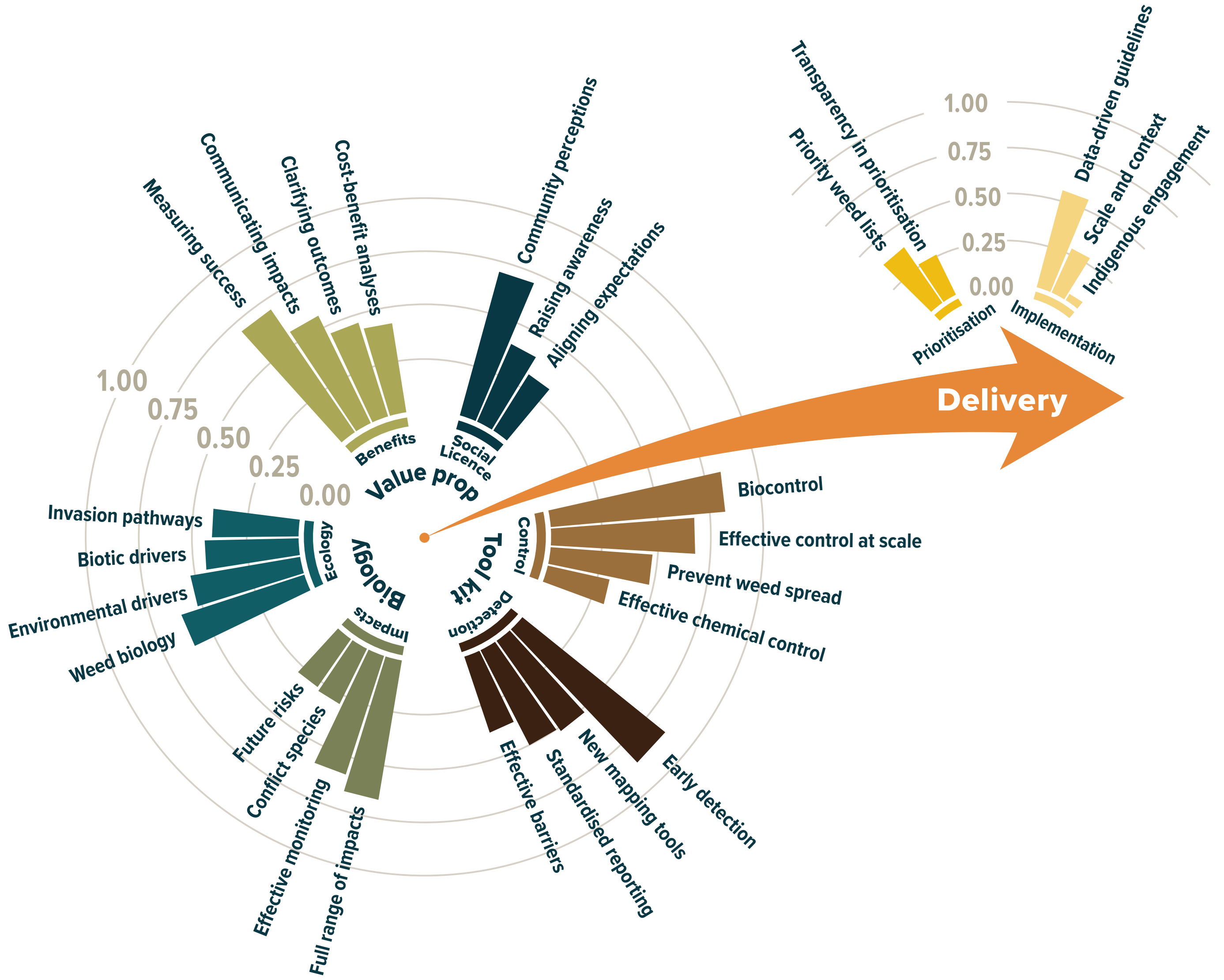


FIGURE 10. Normalised ratings for end user defined research topics. Values were derived from the survey tool ranking score based on anonymous feedback from 63 respondents across a range of stakeholder groups (Figure 9).

BELOW: Sea spurge (*Euphorbia paralias*) fringes the fore dune of Bunker Bay, Photo: Bruce Webber

INSETS (from left): Coral vine (*Antigomon leptopus*), Photo: Louise Beames; Snake vine (*Distimake dissectus* syn *Merremia dissecta*), Photo: Louise Beames

9. Research program details

Research program structure

The three workshop phases delivered consensus on a framework to structure the research program.

This process aligned 78 prioritised issues against 28 research topics that were grouped into eight focal areas within four strategic themes (Figure 11). Three enabling themes – the tool kit, value proposition and biology of weeds – were identified as underpinning priority knowledge gaps, while the delivery of weed research was also identified as a theme requiring new knowledge. The four pathways to success (Clear reporting, Authentic communication, Timely decision-making and Efficient optimisation; see Section 6) impact across all of these focal areas, with improved outcomes in one focal area likely to have flow on implications for other areas. This inter-relationship across themes and between focal areas illustrates the importance of making progress against knowledge gaps across all prioritised topics in parallel, rather than focusing on one theme to the detriment of others.

While there was some variation between regions in how each of the 28 research topics were ranked, the broad trends supported the ranking data generated by the stakeholder survey (Appendix 1). Importantly, there were no research topics that ranked poorly, supporting the strong engagement on all of these issues across the three phases of stakeholder workshops.

MAIN IMAGE: Stakeholder engagement on the Roebourne grass plains, Photo: Bruce Webber, CSIRO

INSETS (from left): Peacock moraea (*Moraea aristata*), Photo: Lee Fontanini; Coffee bush (*Leucaena leucocephala*), Photo: Louise Beames

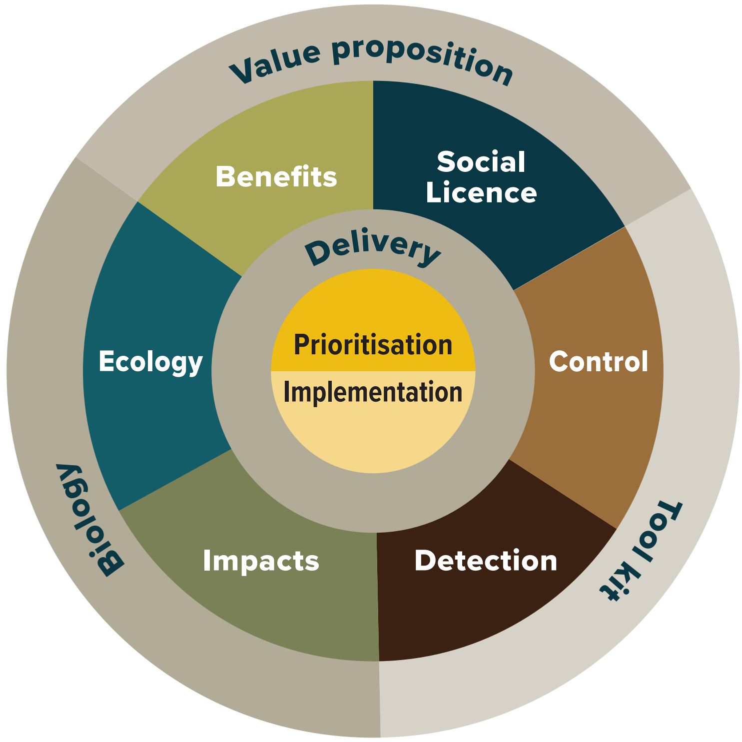


FIGURE 11. A framework for a new program of research to address weed impacts. Research topics have been grouped into four strategic themes (Tool kit, Biology, Value Proposition, Delivery) and eight focal areas (Control, Detection, Ecology, Impacts, Social Licence, Benefits, Implementation, Prioritisation).

TABLE 2. Prioritised research topics to address weed threats to biodiversity in Western Australia grouped by focal area and theme. The 28 research priorities were derived from a total of 78 issues identified as important in stakeholder workshops. Rankings are based on relative importance from feedback gathered through the workshops as well as the online survey (Section 8; Appendix 1).

THEME: Value Proposition	RANKING
FOCAL AREA 1 — Benefits	
Research Topic 1: Defining and measuring success for weed control programs	A
Research Topic 2: Communicating the impact of weeds on biodiversity	A
Research Topic 3: Clarifying the outcomes of past weed control	B
Research Topic 4: Cost benefit analysis of existing control tools	B
FOCAL AREA 2 — Social licence	
Research Topic 5: Understanding community perceptions of weed impacts and control	A
Research Topic 6: Raising community awareness of weed impacts	A
Research Topic 7: Aligning weed control expectations for outcomes and resourcing	C

THEME: Biology	RANKING
FOCAL AREA 3 — Ecology	
Research Topic 8: Weed biology, phenology and seed bank dynamics	A
Research Topic 9: Environmental drivers of weed impacts	A
Research Topic 10: Biotic facilitation and hindrance of weed invasions	B
Research Topic 11: Greater clarity on weed invasion pathways	B
FOCAL AREA 4 — Impacts	
Research Topic 12: Quantifying the full range of weed impacts	A
Research Topic 13: Effective, standardised monitoring of weed control outcomes	B
Research Topic 14: Understanding future weed risks and impacts	B
Research Topic 15: An evidence-based approach to conflict species	C

THEME: Tool kit	RANKING
FOCAL AREA 5 — Control	
Research Topic 16: More effective control strategies for large scale problems	A
Research Topic 17: New biological control solutions	A
Research Topic 18: Greater ability to prevent weed spread by humans	A
Research Topic 19: More effective and efficient chemical control strategies	C
FOCAL AREA 6 — Detection	
Research Topic 20: Earlier detection of new weed incursions	A
Research Topic 21: New tools for mapping weeds (presence, absence, delimitation)	B
Research Topic 22: More effective barriers to novel introduction routes	C
Research Topic 23: Standardising the approach to weed detection and reporting	C

THEME: Delivery	RANKING
FOCAL AREA 7 — Prioritisation	
Research Topic 24: Making weed lists more relevant	B
Research Topic 25: Improving the transparency of weed control prioritisation	B
FOCAL AREA 8 — Implementation	
Research Topic 26: Data driven management guidelines	B
Research Topic 27: Scale and context for effective weed control	B
Research Topic 28: Enhancing outcomes with Indigenous engagement	C

FOCAL AREA 1 Benefits

Rationale

Clearly capturing the benefits of investment in weed control programs is central to an ongoing justification for investing resources in these activities. Benefits of prevention through well-resourced biosecurity programs are evident in Western Australia by the number of species intercepted at ports and inter-state border control points. Measuring the success or otherwise of weed management programs for species already within the State is much harder for two reasons. First, many weed programs are initiated without a clear understanding of what 'success' looks like for the chosen investment, including a lack of delimitation of resource needs and the duration of investment required. Second, monitoring the progress of control efforts is rarely undertaken, particularly for metrics that capture mitigated weed threats rather than just area treated or a reduction in weed population range or abundance. If we are to improve the value proposition of investing in weed management, greater effort needs to be invested in establishing tools for all sector stakeholders to track that investment, or lack thereof. Such insight includes documenting the direct improvement of biodiversity values, rather than just a reduction in weed presence, as well as clarifying the lost opportunity costs following inaction after weed introductions. It also requires a better understanding of the costs and benefits of different control methods, particularly in regard to the wide range of contexts in which they could be considered for deployment across the State.

Objectives:

- Devise evidence-based assessments for realistic 'start' and 'end' points to weed control programs, so that impact mitigation becomes the driving priority.
- Produce refined metrics for the costs, benefits and outcomes of weed management, including lost opportunity costs following inaction and return on investment valuations resulting from early eradications.
- Undertake an assessment of past expenditure on weed control versus the success of those programs to inform the design and location of future weed control prioritisation and investments.
- Achieve a clearer value proposition via a cost-benefit analysis of different control methods, including the value of ecological knowledge for improving the effectiveness of control techniques.

Outcomes:

- Weed control programs are clearly defined and adequately resourced for the chosen 'end-point'.
- The success or otherwise of previous weed control programs is clarified and the reasons for these outcomes are used to improve future programs.
- More effective weed management programs are delivered due to improved clarity around the costs and benefits of different weed management tools.

MAIN IMAGE: Stinking passionflower (*Passiflora foetida*) invading Millstream Chichester National Park, Photo: Bruce Webber

INSETS (from left): Verano stylo (*Stylosanthes hamata*), Photo: Vicki Long; Pine (*Pinus patula*) invading near Manjimup, Photo: Bronwen & Greg Keighery; Blackberry (*Rubus ulmifolius*), Photo: Bronwen & Greg Keighery

FOCAL AREA 2 Social licence

Rationale

A resounding message that came through strongly in all stakeholder engagement sessions to develop this program was that weed management, and the research needed to deliver more effective control, is significantly under-resourced in Western Australia. This lack of adequate resourcing relative to the threat weeds represent to biodiversity values in the State is long standing, and reflects similar investment priorities that have been implemented at the national level. If we are to begin to build a case for a step change in investment for weed control, then the value proposition needs to be absolutely clear. Yet awareness of the value of controlling weeds is not just important for land managers, it is also important for the general community to have buy in. For example, the majority of weeds in the State can be traced back to horticultural introductions and humans are a common dispersal agent via unintended means. Public perception in relation to high value landscapes for tourism is often cited as a reason for undertaking weed control, but such rationale is often not paired with strong reasons for control from a biodiversity conservation perspective. The wider community is also becoming increasingly vocal against the use of chemicals in the environment, and there are threats to the long-term availability of certain herbicides that are central to some weed control programs. To retain and enhance social licence for weed control, and to improve the case for increased investment in such activities, we must better demonstrate the value proposition of weed prevention and management amongst the general public. Central to this need is a clearer communication framework to articulate the impact of weeds on biodiversity to a lay audience, and to ensure that the considerable resources required to mitigate these threats are understood. This clarity is of particular importance to weed management programs that set eradication as the end goal. Part of the case for investment must focus on (1) a clear understanding of any off-target impacts of control tools on biodiversity and ecosystem condition and function and (2) the alternative scenario of what happens if investment is either delayed or denied, in terms of increased costs into the future, or sometimes impacts that are near impossible to reverse.

Objectives:

- Establish communication frameworks to deliver a clearer understanding and improved awareness of the need for weed control amongst stakeholders and the general public, driven by a focus on weed impacts on biodiversity.
- Generate a more effective process for helping land managers to understand the true resource commitments required for different weed management goals, and to establish frameworks to ensure resources are sufficiently and efficiently allocated to achieve these outcomes.
- Proactively address changing community attitudes to weed control options to avoid limiting future management programs, particularly in regard to chemical control solutions.

Outcomes:

- Improved awareness of the benefits of weed control for biodiversity conservation, particularly by the general public and 'non-invested' parties.
- Better incorporation of cultural variation in how the value proposition for weed control is perceived and prioritised.
- Greater clarity on the resourcing and duration requirements for delivering successful weed control programs.
- The extent of land benefitting from more effective weed management is significantly increased, along with a step change in the improved resourcing of weed control programs.
- An evidence-based rationale underpins public acceptance of a responsible approach to ongoing deployment of weed control options, particularly with regard to controversial techniques.

FOCAL AREA 3 Ecology

Rationale

Weed control programs can operate with significantly improved effectiveness and efficiency if they can utilise ecological knowledge of the target species and any interactions with its recipient ecosystem. Without this knowledge, control solutions necessarily revert to generic approaches, such as manual control. Yet knowledge on phenological cycles, genetics, population dynamics and seedbank ecology can transform how a weed population is managed. Seedbank longevity, for example, can quickly determine whether or not eradication is feasible for a recent introduction. Plants with long lived seed banks combined with rapid dispersal or invasion are almost impossible to completely eradicate. Applying knowledge on the ecology of a weed target is informative for most control techniques but is considered essential for pursuing a biological control program, where detailed knowledge on the host plant improves the chances of identifying an effective control agent. Ecological knowledge, particularly in the context of a rapidly changing climate, is also important to help understand weed impacts on their recipient ecosystems. For example, many weeds (particularly non-native invasive grasses) can increase landscape fuel loads, leading to changes in the fire regime of invaded ecosystems by increasing the frequency, intensity and spatial extent of fires. These environmental drivers of weed presence and abundance can also be targeted to improve outcomes from weed control programs, particularly in areas where logistics are challenging or methods are resource intensive. A whole of system 'healthy country' approach to weed management, where weed control programs are integrated within ecosystem restoration, disturbance and fire management programs, is a promising step in achieving weed control impacts at scale. This approach requires explicitly factoring in social and cultural values, particularly when working with Indigenous stakeholders and working across landscapes with mixed values other than biodiversity conservation. Lastly, the ecological aspects of weed dispersal to or from new regions can significantly alter management planning, making an understanding of dispersal ability critical to devising an effective weed control program. Taken together, greater knowledge of a weed's ecology and ecosystem interactions can make a significant difference to improving control options and understanding threat risk.

Objectives:

- Generate an improved ecological understanding of weed phenology, population dynamics, genetics and seedbank ecology, and weed response to climate change to underpin more effective control solutions and programs.
- Characterise how environmental drivers, such as altered water regimes and contemporary fire regimes, influence weed presence and abundance and in particular how these relationships can be targeted to implement more effective weed control.
- Quantify how weed impacts are influenced by biotic factors, including both native and non-native animals.
- Establish a greater understanding of weed invasion pathways, both natural and human-mediated, and how to mitigate such risks.

Outcomes:

- The ecology of more of our most threatening weeds is characterised and leveraged to improve the effectiveness and efficiency of prevention and control programs.
- More effective use of environmental drivers for improving weed control outcomes via improving ecosystem resilience.
- A reduction in the facilitation of weed invasions and threats by biotic factors.
- New weed incursions at a variety of scales (state, regional, local) are reduced due to a better understanding and management of dispersal risk and invasion pathways.

FOCAL AREA 4 Impacts

Rationale

Management frameworks are increasingly moving toward impact related measures to prioritise which weeds to control, and away from past measures of 'weed abundance' or decisions entirely unrelated to weed impacts on biodiversity (such as employment opportunities). Unfortunately, however, the impact of weeds on their recipient communities is rarely understood and even less frequently quantified. Moreover, some of the biggest impacts of weeds on biodiversity in these ecosystems are through indirect interactions with other species and ecological processes, rather than the direct interactions that remain easier to characterise and measure. While impacts on biodiversity remain a central focus for the development of this research program, it is recognised that there are related market (social outcomes) and non-market (biodiversity, cultural heritage, amenity, aesthetics) values that also contribute to the bigger picture of weed impacts. All of these values should be taken into account when seeking to quantify the full range of weed impacts. Equally, mitigating weed impacts is often attempted, but the success of these programs is often not quantified, removing the opportunity for learning from past efforts and to collaborate across arbitrary land tenure boundaries. Weed risks do not only relate to existing weed problems, but they also include managing the risks of species that are yet to arrive, or yet to have negative impacts. Global environmental change drivers, such as climate change and land clearing, can be major factors in changing the future risk profile of weeds that are otherwise relatively harmless to biodiversity at present. Climate change in particular must be an active consideration in the design of any research programs on weeds, as well as factored into the implementation of new findings. Adequately resourcing proactive management is the key to more effectively reducing the risk of future weed threats. One of the most challenging aspects of managing weed impacts effectively is the issue of 'conflict' species – those weeds for which different stakeholders view its impacts in a very different light. Bringing more of an evidence-based approach to resolving conflict species challenges, particularly where ecosystem impacts can be quantified, will likely lead to far better outcomes for biodiversity.

Objectives:

- Improved quantification of the full range of weed impacts, including market and non-market values and the relationship between weed abundance and impact.
- Reform the monitoring of weed management programs to generate a standardised reporting system for understanding actual outcomes and investment returns.
- Strengthen our understanding of future weed risks, particularly in regard to climate change, to underpin proactive management or policy decisions to mitigate risk.
- Establish an evidence-based approach to conflict weed species that applies compatible and accountable standards across stakeholder sectors and working together where there is consensus on issues.

Outcomes:

- Weed impacts on market and non-market values provided by native biodiversity are identified and quantified.
- Standardised monitoring and reporting frameworks transform the value of data flowing from weed management programs, particularly in regard to informing cross-tenure assessments.
- Proactive management programs are implemented to prevent risky new weed incursions and to target existing weeds earlier in the invasion curve.
- Conflict weed species are managed in an evidence-based way where impacts on biodiversity are prioritised based on a broader understanding of value.

MAIN IMAGE: African daisy (*Arctotis stoechadifolia* cv) invading coastal dunes, Photo: Bronwen & Greg Keighery

INSETS (from left): Ursina (*Ursinia anthemoides*), Photo: John Huisman; Gorse (*Ulex europaeus*), Photo: Bronwen & Greg Keighery

FOCAL AREA 5 Control

Rationale

Effective weed control programs can be delivered by a variety of methods deployed alone or in combination, including with other landscape management tools. A consistent message across all stakeholder interactions for this program was the need to prioritise improved weed control solutions that can deliver impact at very large spatial scales. Some of the biggest weed challenges faced in the State occur over vast areas where access and management logistics are often challenging. New approaches to the deployment of existing tools and methods as well as the development of novel technology focused solutions will both address this need. In regard to the latter point, exploring the feasibility of new biological control options for controlling the more widespread and threatening weeds in the State was a clear priority. These weed infestations are often well beyond being feasibly controlled across their full range by other methods and a fall-back position of indefinite abundance reduction or containment is a frequent program goal. While biological control requires a high initial investment cost, long term studies show a return of 23:1 on that upfront cost with time. Moreover, the ecological insight gained on the target species during biocontrol programs can also be used to improve the effectiveness of other control methods. In this regard, there remains considerable scope to improve the efficacy of chemical control strategies for weeds. More targeted research on herbicide application to new weed species, and more specific guidelines in regard to application regimes, particularly in challenging landscapes (for example, riparian and wetland environments), would improve management outcomes. There remains considerable scope for improving the effectiveness of delayed action tools, such as granular and residual herbicides, both in their mechanism of delivery and application to new target weeds. While control of established weed populations will always remain a high priority, preventing the arrival of new introductions in the first place remains the most effective way to avoid weed impacts on biodiversity. Dispersal of weed propagules into new areas is therefore, an area in which improvements in practice and awareness can make a big difference. Human-mediated propagule movement can be via direct or indirect means, and frequently is accidental due to poor weed hygiene and lack of awareness of the risks involved.

Objectives:

- Optimise and enhance the effectiveness of existing control methods, particularly for those that can be applied to address large scale problems often across multiple tenures.
- Develop new biological control solutions for weeds, particularly for priority weeds with challenging logistical constraints particularly biological control solutions.
- Enhance our ability to reduce the spread of weeds by human agency, both via direct and indirect dispersal pathways.
- Establish more effective chemical control solutions for weeds, including herbicides with broader application compatibility, greater selectivity and novel delayed modes of action.

Outcomes:

- The efficacy of weed control programs is improved due to more effective tools applied more appropriately.
- A greater number of weeds are effectively controlled in an ongoing way due to new biological control programs, improved deployment of resources and technology and more appropriate application of chemical control solutions.
- The incidence of new weed incursions is reduced and many are extirpated.

LEFT: Burning buffel grass (*Cenchrus ciliaris*), Photo: Louise Beames

FOCAL AREA 6 Detection

Rationale

Eradication is an appealing strategy for serious weeds because other alternatives (such as containment or control to a level below an impact threshold) require permanent, ongoing investment of resources unless a target weed can be brought under effective biological control. Unfortunately, the likelihood of eradication of widespread weeds in natural ecosystems is extremely low, as the lag time between first detection and resourcing a control program is often lengthy. Excessive reliance on 'scorched earth' chemical control in agricultural landscapes and for managing mining tenements can also lead to complacency in the monitoring for new incursions. The sooner a control campaign can commence against threatening weeds, the greater the likelihood these impacts can be mitigated, and the fewer resources that will be required to achieve this goal. Therefore, improving our ability to detect new weed incursions and act fast is a matter of priority. Detecting new incursions in vast and inaccessible landscapes requires a very high level of efficiency and a high level of expertise to be able to determine what plants are non-native to the region. New technology such as remote sensing and automated image analysis, and molecular detection methods are fast becoming the tools of choice for surveillance over large areas. However, fine tuning this technology to address the questions relevant to weed detection requires further work. A complementary approach is harnessing the power of citizen science to improve surveillance by adapting existing tools and developing new methods. Physical detection is one thing, but electronic surveillance of novel dispersal pathways is another tool to reduce the risk of weeds becoming established. Global connectivity via trade opens up new mechanisms for accidental dispersal, as well as new routes to deliberately disperse potential weed problems. Effective ways to prevent weed propagule movements via online trading platforms, international seed stock providers not subject to the same biosecurity restrictions as Australia and other novel dispersal pathways will go a long way towards reducing weed impacts on biodiversity. Once weeds or their propagules are detected, a standardised, efficient and open-data driven platform for consistent and timely weed reporting will help inform management, particularly for improving cross-tenure control efforts.

Objectives:

- Refine and expand the suite of tools available for detection, delimitation and mapping of weeds, including automated and semi-automated analyses, with a focus on new weed incursions.
- Identification of new invasion routes and the establishment of effective biosecurity barriers to mitigate the risk of new introductions.
- A gap analysis of tools and techniques fit for purpose for weed detection and reporting in Western Australian landscapes.

Outcomes:

- New weed incursions and invasion fronts are efficiently tracked, permitting faster and more targeted control responses.
- Improved detection and prevention of novel introduction pathways for weeds.
- Greater consistency in weed detection and reporting tools enables more efficient cross-tenure weed management.

FOCAL AREA 7 Prioritisation

Rationale

Despite an increasing focus on the importance of managing ecosystems at the community level, weed control programs remain dominated by single-species focused management. This approach is understandable and often still appropriate, given the community wide impacts that a single weed species can cause. Exactly which species are targeted for control are often dictated by weed priority lists, derived from a given set of values and specific to a defined area (often tenement- or IBRA region-focused in Western Australia). Robust work on developing a more accountable and evidence-based approach to weed lists has been done by DBCA. Yet the exact set of values defining these lists are not deployed consistently across the State, many regions do not have lists where relevant context is taken into account making such lists ineffective, and for many lists the values used to determine priorities are opaque and not well justified, relying heavily on the opinions of just a few weed experts. While these opinions are likely to be well informed, optimising weed lists would benefit from a more evidence-based approach to defining priorities. Lists would also benefit from frameworks that allow for regular interrogation and updating to avoid perverse outcomes when new information comes to light. The transparency and accountability of weed control prioritisation is likely to also improve with further research. A shift to prioritising weeds based on their impacts rather than their ease of control or aesthetic values was a view pushed strongly by the majority of stakeholders, while also recognising that there may be specific occasions where control may be undertaken for other reasons (which participants considered valid, as long as the rationale is clearly articulated). It will be important to assess impacts not only from the threat posed by weeds, but also by considering the vulnerability and resilience of impacted communities, including the threat of weed impacts interacting with other threats. Such efforts would remove subjectivity from the process and possibly unlock weed control resources tied up by compliance related control activities relating to lists that have little relevance for applied biodiversity outcomes.

Objectives:

- Develop frameworks and delivery mechanisms that ensure weed control lists are context specific, regularly updated and cover all regions as well as dealing with area-, community- and species-specific prioritisation.
- Ensure that weed lists underpin best practice weed management, which necessarily involves improving the transparency of prioritisation decisions, removing subjectivity and finding ways to unlock ineffective control programs that are driven by compliance regulations rather than impact mitigation.
- Ensure compliance regulations are relevant.

Outcomes:

- Weed prioritisation lists enable effective, adaptable and relevant weed control at a range of scales across Western Australia.
- Weed control programs factor in direct impacts of weeds, as well as the vulnerability and resilience of recipient communities being impacted.
- Transparency, accountability and objectivity are improved in weed program delivery focused on mitigating impacts on biodiversity as a significant driver of investment.
- Compliance regulations are best practice, fit for purpose and widely implemented as well as followed.

FOCAL AREA 8 Implementation

Rationale

A significant factor in determining the ultimate impact of weed management is the set of guidelines that shape the delivery of control programs. When appropriately designed, such guidelines provide clarity on when programs are likely to achieve their stated aims and when to transition to different management strategies. Yet these guidelines often only exist for weeds that garner the most attention, for example Weeds of National Significance, and sometimes the generic advice presented lacks the 'downscaled' context required to make control relevant to certain regions. A frequently raised issue through stakeholder engagement was that of management of weeds on 'low value' land, where high management costs limit control feasibility, particularly when optimal control windows align with poor site access (for example, during the wet season). It is also frequently unclear as to when weed control programs should be stopped to transition to post-control monitoring of native vegetation recovery as well as any rebound in weed range or abundance. Too soon or too limited an area controlled without factoring in delimitation and containment could see weed 'spill over' effects where regions initially benefit from control but quickly see rapid reinvasion. Lastly, stakeholders recognised the significant role that land managers have in shaping the design and deployment of control programs, particularly for Indigenous land managers. There is a real opportunity to use a transdisciplinary approach to improving weed control via two-way learnings and co-design of weed management and monitoring programs, particularly across the large areas of the State under management by Indigenous groups.

Objectives:

- Devise and synthesise management guidelines for a greater range of threatening weeds to improve evidence-based management programs and to identify knowledge gaps for further research.
- Determine how to address and manage the issue of scale and context in delivering weed control programs, particularly for remote regions with high costs and low relative returns, and for highly impacted but restricted areas in vast landscapes.
- Assess the impacts and threat of weeds to Indigenous values, and refine and resource more effective approaches to two-way design with Indigenous land managers for programs on country.

Outcomes:

- Land managers in Western Australia are able to deploy evidence-based control programs against a far broader suite of priority weeds.
- Weed control programs explicitly factor in scale and context to deliver more effective outcomes.
- Weed control programs involving Indigenous land managers are underpinned by two-way design and are implemented widely across the State.

MAIN IMAGE: Arum lily (*Zantedeschia aethiopica*), Photo: Bruce Webber

INSET IMAGES (from left): Victorian tea tree (*Leptospermum laevigatum*), Photo: Lee Fontanini; Mesquite (*Prosopis* sp.), Photo: Bruce Webber

Program implementation

Funding Strategy

As the scope of the research program is large and the nature of individual components varies, a number of funding models are likely to be targeted. The research program is likely to involve a combination of short (1 year), mid (5 year) and long (>10 year) term projects, depending on the priority being addressed.

ARC Linkage Projects

The Australian Research Council (ARC) Linkage Projects scheme promotes collaboration and research partnerships between key end users in research and innovation including higher education institutions, government, business, industry and end users. Research and development are undertaken to apply advanced knowledge to problems, acquire new knowledge and as a basis for securing commercial and other benefits of research. The Linkage Projects scheme provides funding to eligible organisations (higher education institutions) to support research and development projects which are collaborative, are undertaken to acquire new knowledge and involve innovation. Proposals for funding under the Linkage Projects scheme must include at least one partner organisation. The partner organisation must make a contribution in cash and/or in-kind to the project. The combined (cash and in-kind) partner organisation contributions must at least match the total funding requested from the ARC. The Linkage Projects scheme provides project funding of A$50,000 to A$300,000 per year for two to five years.



MAIN IMAGE: Eradication survey for bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata*), Photo: Bruce Webber, CSIRO

INSETS (from left): Rubber vine (*Cryptostegia grandiflora*), Photo: Lee Fontanini; Calotropis (*Calotropis procera*), Photo, Bruce Webber

Lotterywest

Lotterywest funds environmentally focused projects of a range of size and duration that help understand and/or conserve the Western Australian environment. Projects must be community focused, not-for-profit, end user led and involve a strong element of delivering on-ground outcomes. This funding structure is well suited to encourage stronger collaborations between community groups and researchers to undertake applied research and management programs.

Industry associations

Supported by levies applied to primary industry production, industry associations facilitate mid to long-term research to address problems that directly affect productivity. Industry levies are provided for under the Commonwealth Primary Industries (Excise) Levies Act (1999), and Primary Industries Levies and Charges Collection Act (1991). Industry association grants do not require in-kind or cash contributions and are open to higher education institutions, government, business, industry and end users.

Examples of industry levies that could facilitate weed research:

- Cattle, sheep and goat farmers may pay a levy on the sale of livestock. A proportion of that levy goes to Meat and Livestock Australia (MLA), who invest in research in several biological control projects that impact on pastoral lands. These programs, in turn, could have direct benefits for biodiversity, particularly for conflict weed species.
- The Nursery and Garden Industry pay a levy on all plants sold in Australia. This levy is collected at the wholesale level on plastic plant pots at the rate of 5% of the pot cost. Of that levy, 0.25% goes toward Plant Health Australia to deliver biosecurity programs, one of which is weed management. In 2019/2020, the nursery industry levy receipts were $2.13 million (Horticulture Innovation Australia Ltd 2020), with A$114,000 delivered to Plant Health Australia (Horticulture Innovation Australia Ltd 2017). There remains considerable potential to improve funding for weed management via applying either a greater levy or a higher rate of transfer to Plant Health Australia to assist in research into weed management from garden escapes.

ABOVE: Stinking passionflower (*Passiflora foetida*) at Danggu (Geikie Gorge), Photo: Ruchira Somaweera, CSIRO

- The Grain Seeds and Hay Industry Funding Scheme (GSHIFS) and the Commonwealth Department of Agriculture and Water Resources Levy and Export charge are both industry levies that have a primary interest in funding research on weeds that will lead to economic benefits in agricultural production. GSHIFS is a state-based levy applied to each tonne of grain/seed or hay sold in the southern agricultural areas of Western Australia. In 2019, the GSHIFS received $4.4 million in contributions from growers (Department of Primary Industries and Regional Development 2019), spending over A$3.5 million on skeleton weed and three-horned bedstraw management. The Levy and Export charge levies against the net farm-gate value from 25 crop species, including wheat, coarse grains, oilseeds and pulses. Contributions are managed by the Grains Research and Development Corporation (GRDC) and Plant Health Australia (PHA). In 2019/2020, GRDC received over A$95 million in industry contributions (Grains Research and Development Coorporation 2020).

NRM grants

State NRM grants as well as NRM group small grants can be used to fund components of research, usually embedded in a bigger management program primarily focused on delivering on-ground management outcomes.

National Landcare Program Grants

National Landcare Program 2017-2023 invested A$1.1 billion to support community managed projects of one to five years duration that deliver on-ground improvements in biodiversity and sustainable agriculture. Included was the Environment Small Grants scheme for projects between A$5,000 and A$50,000 for on-ground weed management. Similar to NRM grants, National Landcare Grants can be used to fund components of research as part of a larger management program.

Mining companies

As part of their environmental impact assessments mining companies are required to survey for weeds, and as part of their offset conditions, they can be required to control weeds. For projects that are clearly focused on near term on-ground outcomes, there may be relationships to establish with mining companies to provide resources, data or funding. Furthermore, environmental offset funds paid by mining companies are an obvious source of funding for research that would improve weed management. A logical fit to this research program could include initiatives, such as the Pilbara Environmental Offset Fund, with the ability to deliver strategic, lasting conservation benefits through transparent and accountable research projects.

National Environmental Science Program (NESP)

The National Environmental Science Program Phase 2 (NESP2) will allocate A$149 million between 2021 to 2027 of which A$47 million has been allocated to the Resilient Landscapes Hub. This hub, led by Professor Michael Douglas of The University of Western Australia, will provide research to inform management of Australia's terrestrial and freshwater habitats to promote resilience, sustainability and productive practices. A specific focus on "invasive species impacts, and accessible science to assist land managers develop and maintain resilient, sustainable and productive landscapes" seems ideally aligned to supporting priority weed management research identified in this research program.

Philanthropy and strategic alliances

Collaborative alliances with land managers linked to NGOs or philanthropic partnerships are an option for co-investing in complementary research. Not-for-profit groups such as the Australian Wildlife Conservancy and Bush Heritage Australia, Indigenous ranger groups, and the Centre for Invasive Species Solutions (CISS) all present well-aligned collaborative options in this regard.

Payment for ecosystem services

As an innovative funding model worthy of further consideration, payment for ecosystem services could be sought from end users. For example, if weed management provides benefits to water volumes or water quality, end users of that water resource could pay for weed management through a tariff on their water account. This charge could be optional (at first) or enforced. Even small amounts per person could add up to considerable ongoing resources for reinvesting to achieve further gains in mitigation of weed impacts.

Governance

The successful delivery of this research program is contingent on an appropriate governance structure. The WABSI research program framework specifies that a steering committee be established to administer the program. Steering committees should comprise key stakeholders, researchers and at least one representative from the regulatory sector to ensure that outcomes are consistent with policy objectives. Following the WABSI approach will ensure that this prioritised program is translated into research outputs and, in turn, on-ground outcomes. While WABSI will play an active role in the implementation of the research program via the Steering Committee, the appointed group will ensure that delivery of the research program endures should WABSI involvement be either reduced or withdrawn.

The primary role of a steering committee that will guide the implementation of the research program is to ensure that:

- Projects developed under the research program are well integrated and engaged and will deliver on a shared vision;
- The scope of projects and intended outcomes meet the requirements of end users;
- The science being delivered is of a high standard without duplication of research effort;
- Outcomes are able to be translated effectively to all end users of the knowledge to encourage adoption of research findings;
- The research program plan is up to date and best reflects the current end user needs and research capability;
- Activities are aligned to relevant state and Commonwealth objectives; and
- Proposed outcomes are achieved.

Risk management

This section outlines key risks identified in relation to the research program.

Governance

Description	Likelihood	Impact	Mitigation action
Steering committee not able to represent the interests of all stakeholders	Possible	Moderate	• Membership comprises key stakeholders who have a long-term interest in the intended outcomes of the program • Where possible, prioritise remuneration for those who cannot engage as part of their current professional workload
Sub-standard collaboration and communication between research providers	Possible	Moderate	• Steering committee liaises with project leaders throughout the projects to facilitate effective collaboration • Project agreements clearly indicate the collaborative nature of projects and communication requirements
Projects do not deliver against identified research priorities	Possible	Major	• Project planning to be established at project commencement and evaluated by the steering committee • External independent peer review of project proposals and reporting as appropriate
Indigenous engagement is not conducted appropriately	Unlikely	Major	• Research projects are aligned with WABSI Indigenous engagement principles • Indigenous engagement is enabled via steering committee membership and/or other suitable engagement mechanisms • Research projects meet the requirements of their own organisation's Indigenous engagement policy
Misuse of funds	Unlikely	Major	• Project proposals are clear as to how the funds will be expended against each milestone • Organisations managing project funds must provide evidence of appropriate financial management systems and protocols
Insufficient funds are realised to implement key components of the program	Possible	Major	• Program components are carefully and strategically prioritised • Options for funding are fully explored • Significant effort put into community outreach to justify the program and its implementation, and to chart its successes

Research delivery

Description	Likelihood	Impact	Mitigation action
Lack of capability and expertise	Possible	Major	• Sufficient research capability in partner organisations is able to cover the expanded requirements needed to deliver the program • Succession planning and knowledge transfer is supported across organisations • Research partners collaborate effectively to ensure capability is available to deliver against research projects
Loss of key personnel	Possible	Moderate	• Sufficient research depth in partner organisations allows for substitution of expertise • Project resources are prioritised for multi-year projects accompanied by multi-year contracts for key personnel • WABSI research provider network knowledge is leveraged by the steering committee
Research outputs are of sub-standard quality	Possible	Moderate	• Steering committee maintains close oversight throughout research projects • External peer review of project proposals and reporting as appropriate
Research outputs do not directly address a prioritised information gap	Unlikely	Major	• Steering committee maintains close oversight on research project scoping • Scope of work and path to impact are clearly articulated • End to end consultation with key stakeholders on the development of priorities, scoping of research, implementation and outputs
Research outputs do not clearly articulate what 'success' looks like or implement measures to meet these goals	Unlikely	Major	• Steering committee maintains close oversight on research project scoping • End point of research is clearly defined, as well as pathway to impact for applied on-ground outcomes
Research outputs are not delivered on time or on budget	Possible	Major	• Adoption of a proactive project management process with steering committee involvement • Early interception of timeline deviations before milestones are missed • Clear contractual obligations relating payments to milestones

Description	Likelihood	Impact	Mitigation action
Research outputs are not shared appropriately with end users	Possible	Moderate	• Research proposals clearly articulate a path to impact approach, including how the research will be translated into a user-friendly format for all end users • Intellectual property and information sharing agreements are clearly articulated in project agreements • There will be an assumption that all results will be made public with open access publication unless there is sufficient justification for privacy
Research not able to deliver on objectives	Possible	Major	• Scope of work and risks are clearly articulated • The steering committee helps to find an optimal balance between aspiration and reality in regard to project scope • Mitigation strategies are included in project risk assessments
Research is being duplicated	Possible	Moderate	• Project scopes and outputs are communicated clearly and promptly to the research community • Relevant state and Commonwealth entities are kept informed of all new initiatives • The WABSI website (and others as appropriate) are kept up to date with information on all projects
Insufficient funds are realised to implement key components of the program54	Possible	Major	• Program components are carefully and strategically prioritised • Options for funding are fully explored • Significant effort put into community outreach to justify the program and its implementation, and to chart its successes

Impact and adoption

Description	Likelihood	Impact	Mitigation action
Communication plans do not address adoption of research outcomes	Possible	Major	• All projects to have a communication plan that includes an adoption strategy • Relevant stakeholders are consulted when forming research adoption plans • End to end project communications with stakeholder groups
Social licence is not secured, maintained and enhanced for all planned activities	Possible	Major	• All projects consider social licence issues in their scoping and risk assessment • All projects take a proactive approach to engagement with stakeholders and interested parties during project scoping and delivery
Active interference with research program goals by special interest groups	Possible	Moderate	• All projects take a proactive approach to engagement with stakeholders and interested parties during project scoping and delivery • Research projects take a proactive, neutral and respectful approach to communicating results and engaging with the public, including paying careful attention to language and framing
Research outcomes are not adopted by end users	Possible	Major	• All projects take a proactive approach to identifying end users during project scoping • Project leaders to work with the steering committee to ensure optimal adoption by end users • Research is conducted in tandem with applied projects and ongoing engagement with stakeholder groups to facilitate transfer of knowledge and ownership of outcomes • Adoption milestones are included in all projects, and developed in consultation with the steering committee
Insufficient funds are realised to implement key components of the program	Possible	Major	• Program components are carefully and strategically prioritised • Options for funding are fully explored • Significant effort put into community outreach to justify the program and its implementation, and to chart its successes

Policy

Description	Likelihood	Impact	Mitigation action
Policy changes work against the research outcomes of the program	Possible	Moderate	• Ensure that the regulatory sector is represented on the steering committee • Ensure effective communication between the steering committee and policy makers/ regulators • Ensure that policy makers and regulators have access to the latest evidence-based knowledge
Policy changes alter the likely impact of the research outcomes	Unlikely	Major	• Ensure that the regulatory sector is represented on the steering committee • Ensure effective communication between the steering committee and policy makers/ regulators

MAIN IMAGE: Weed survey, Millstream Chichester National Park, Photo: Bruce Webber, CSIRO

INSETS (from left): Maltese cockspur (*Centaurea melitensis*), Photo: Lee Fontanini; Coffee bush (*Leucaena leucocephala*), Photo: Lee Fontanini

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Appendix 1. Issues raised during stakeholder engagement

The 118 issues identified by stakeholders that are a priority need to address weed threats to biodiversity. For the 78 issues that related to research, these were grouped into 28 research topics, which were in turn aggregated into eight focal areas across four themes. An additional 38 issues that related to non-research needs were aggregated into four non-research related delivery areas. An 'X' was recorded when stakeholders considered that issue significantly important across regionally focused workshops defined by Regional Development Commission boundaries for the South West and Great Southern (1), Perth and Peel (2), Gascoyne, Goldfields, Mid West and Wheatbelt (3), Pilbara (4) and Kimberley (5) as well as a meeting for those with state-wide interests (6). Two rating metrics were generated for stakeholder feedback. The first metric (in bold for each research topic) represented a normalised rating derived from the survey tool average ranking score for the issues clustered under each research topic (0-1, higher values indicate higher importance). The second metric captured regional variation by identifying how many regions raised the issue as an important priority during consultation (higher values indicate more regions rate the issue highly, with state-wide prioritisation carrying greater weight (1 for each region, 5 for the state-wide meeting).

Theme	Focal area	Research topic | Issue	Region						Metrics
			1	2	3	4	5	6	
Value Proposition	Benefits	**Defining and measuring success for weed control programs**							**0.71**
Value Proposition	Benefits	Refined metrics for costs/benefits of management (including 'lost opportunity costs' and 'return on investment' from early eradication)	X	X		X		X	8
Value Proposition	Benefits	Better understanding of what success looks like — definition and quantification (e.g. area treated vs area restored)	X	X	X	X	X	X	10
Value Proposition	Benefits	Transforming understanding of the value proposition of controlling weeds (many don't understand, don't care, or care more about profit)	X		X	X	X	X	9
Value Proposition	Benefits	Establishing ways to set realistic control targets (eradication is the target too often, extirpation far more realistic)		X				X	6
Value Proposition	Benefits	**Communicating the impact of weeds on biodiversity**							**0.57**
Value Proposition	Benefits	Better awareness of weeds and their impacts in the landscape (recognising native vs non-native)	X	X	X			X	8
Value Proposition	Benefits	Clearer more accessible demonstration of the impacts and costs of inaction against weeds					X		1
Value Proposition	Benefits	Raising awareness of the sheer scale of weed problems in the north (contrasting scales of land management units in different regions)	X			X	X		3
Value Proposition	Benefits	**Clarifying the outcomes of past weed control**							**0.47**
Value Proposition	Benefits	Better awareness of past expenditure on control versus success (where are our wins and how/why)		X				X	6
Value Proposition	Benefits	Breaking the fallacy that ecological knowledge doesn't improve weed control effectiveness (too much ineffective 'just spray everything')			X	X	X		3
Value Proposition	Benefits	**Cost benefit analysis of existing control tools**							**0.44**
Value Proposition	Benefits	Cost benefit analysis of all control tools (e.g. steam uses 600x more water than herbicide)		X					1
Value Proposition	Social Licence	**Understanding community perceptions of weed impacts and control**							**0.71**
Value Proposition	Social Licence	Improved community understanding of what it takes to effectively control weeds (i.e. just how hard it is to get effective outcomes)	X	X		X		X	8
Value Proposition	Social Licence	Low community understanding of the impact of weeds or the need to control weeds (apathy, cultural variation in value proposition)						X	5
Value Proposition	Social Licence	Addressing changing attitudes to chemical control options to avoid limiting future management options	X	X					2
Value Proposition	Social Licence	**Raising community awareness of weed impacts**							**0.40**
Value Proposition	Social Licence	Improving awareness of the need for weed control, increase interest/scientific literacy of public	X	X	X		X	X	9
Value Proposition	Social Licence	Landholders may not appreciate the impact of weeds if it's not impacting on core business				X			1

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Theme	Focal area	Research topic I Issue	Region 1	2	3	4	5	6	Metrics
Value Proposition	Social Licence	**Aligning weed control expectations for outcomes and resourcing**							**0.32**
Value Proposition	Social Licence	Greater clarity on the flow on benefits of control – understanding true resource commitments and setting realistic goals	X		X	X			3
Value Proposition	Social Licence	Improving transparency around the chosen rationale for weed control (i.e. control is often not to improve biodiversity outcomes)	X					X	6
Biology	Ecology	**Weed biology, phenology and seed bank dynamics**							**0.61**
Biology	Ecology	Understanding the lifecycle stages/phenology to maximise control effectiveness			X	X		X	7
Biology	Ecology	Understanding seedbank dynamics, including enhanced seedbank depletion	X	X	X	X			4
Biology	Ecology	The role of genetic variation in invasions and impacts of weedier cultivars (e.g. buffel)						X	5
Biology	Ecology	**Environmental drivers of weed impacts**							**0.52**
Biology	Ecology	Whole-system ('healthy country') approach where system restoration, disturbance and fire management are part of weed control programs		X					1
Biology	Ecology	Understanding whether weeds are the driver of passenger of ecosystem breakdown	X	X	X	X	X		5
Biology	Ecology	Improved ability to tackle associated environmental drivers of increasing weed impacts	X	X			X		3
Biology	Ecology	Better management of environmental drivers influencing weed impacts (e.g. fire)		X					1
Biology	Ecology	More effective utilisation of weather cycles for planning weed control (drought, rainfall events etc)		X	X		X	X	8
Biology	Ecology	Unplanned burns vs controlled burns in managing weeds, including post-burn control		X					1
Biology	Ecology	Fire outcome feedback loops for weed management (particularly grasses)				X		X	6
Biology	Ecology	Controlling native weeds invading due to landscape change/degradation based on impacts/threats			X	X			2

Theme	Focal area	Research topic I Issue	Region 1	2	3	4	5	6	Metrics
Biology	Ecology	**Biotic facilitation and hindrance of weed invasions**							**0.44**
Biology	Ecology	Improved understanding of weed management biotic context (pollinators, soil carbon/microbes)			X		X		2
Biology	Ecology	Impact of invasive pest animals on weed spread and abundance (directly or via general habitat degradation)	X			X		X	7
Biology	Ecology	Can soil health be improved to favour non-weed species?					X		1
Biology	Ecology	**Greater clarity on weed invasion pathways**							**0.41**
Biology	Ecology	Greater understanding of pathways to invasion (wind dispersal, vectors, human activity, grey nomads)					X		1
Biology	Impacts	**Quantifying the full range of weed impacts**							**0.67**
Biology	Impacts	Better valuation of weed impacts — market values (social outcomes) and non-market values (biodiversity, amenity, aesthetics)	X	X	X	X	X	X	10
Biology	Impacts	Impact of weeds and their control on other organisms (positive and negative)	X		X	X			3
Biology	Impacts	Impact of weeds on cultural values in addition to biodiversity and industry (i.e. rarely is triple bottom line well considered)			X	X	X		3
Biology	Impacts	A better understanding of impact vs abundance relationships for weeds, including tipping points			X	X			2
Biology	Impacts	**Effective, standardised monitoring of weed control outcomes**							**0.60**
Biology	Impacts	Improve monitoring of weed control outcomes (most weed control is never monitored and becomes a 'tick box' activity)				X		X	6
Biology	Impacts	Improving post-removal restoration of areas impacted by transformer species (i.e. avoiding erosion, reinvasion)					X		1
Biology	Impacts	Clearer monitoring methods/standards to measure success or progress toward weed control outcomes				X			1
Biology	Impacts	**An evidence based approach to conflict species**							**0.29**
Biology	Impacts	More accountable resolution of conflict species challenges (e.g. buffel grass control vs desire for pasture)				X			1
Biology	Impacts	More compatible and accountable standards for weed risk assessment across environmental and ag/hort sectors						X	5

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Theme	Focal area	Research topic I Issue	Region						Metrics
			1	2	3	4	5	6	
Biology	Impacts	**Understanding future weed risks and impacts**							**0.28**
Biology	Impacts	Identifying future weeds (e.g. those favoured by climate change) to either ban them or control them earlier in the invasion curve	X	X				X	7
Biology	Impacts	Strengthening the case to ban further weed imports (e.g. future conflict species, likely garden escapees)	X	X	X	X		X	9
Biology	Impacts	Understanding future impacts of range-extenders and weedy natives (particularly relating to climate change)				X		X	6
Tool Kit	Control	**More effective control strategies for large scale (space/time) problems**							**0.69**
Tool Kit	Control	Effective large-scale strategies (space/time) for large scale problems			X	X	X		3
Tool Kit	Control	More effective/efficient tools to enable landholders to manage weeds over large areas	X		X	X	X	X	9
Tool Kit	Control	Enhancing the use of existing control tools			X				1
Tool Kit	Control	New techniques for managing vast areas of weedy grasses		X					1
Tool Kit	Control	**New biological control solutions**							**0.83**
Tool Kit	Control	More biocontrol options needed for threatening weeds (particularly those with challenging control logistics)			X	X	X	X	8
Tool Kit	Control	**Greater ability to prevent weed spread by humans**							**0.49**
Tool Kit	Control	More effective weed hygiene techniques, including critical assessment of existing methods.	X		X				2
Tool Kit	Control	Wider awareness of how human activity moves weeds across the landscape	X	X	X	X	X	X	10
Tool Kit	Control	Impact of recreation (e.g. horses/bikes) on weed spread		X					1
Tool Kit	Control	**More effective and efficient chemical control strategies**							**0.30**
Tool Kit	Control	More effective integrated weed management options to counter an over-reliance on herbicides		X	X		X		3
Tool Kit	Control	Improved chemical and chemical adjuvants with broader application compatibility					X	X	6
Tool Kit	Control	More effective delayed action tools (i.e. granular herbicides, residual herbicides)					X		1

Theme	Focal area	Research topic I Issue	Region						Metrics
			1	2	3	4	5	6	
Tool Kit	Detection	**Earlier detection of new weed incursions**							**0.86**
Tool Kit	Detection	Increased efficiency for early detection of new weed incursions to allow for widespread deployment				X	X		2
Tool Kit	Detection	New (semi-)automated technologies to aid early detection	X		X		X		3
Tool Kit	Detection	**New tools for mapping weeds (presence, absence, delimitation)**							**0.52**
Tool Kit	Detection	New tools for detection, delimitation, mapping, including automated image processing		X	X	X	X	X	9
Tool Kit	Detection	Delimitation and detection of weeds over large and/or inaccessible areas					X		1
Tool Kit	Detection	Increased reliance on 'scorched earth' chemical control over IPM leading to ineffective surveillance			X				1
Tool Kit	Detection	**More effective barriers to novel introduction routes**							**0.37**
Tool Kit	Detection	Improved detection and prevention of online sales imports of threatening weeds						X	5
Tool Kit	Detection	**Standardising the approach to weed detection and reporting**							**0.50**
Tool Kit	Detection	Standardised approach to weed control monitoring for improving cross-tenure management				X			1
Tool Kit	Detection	Gap analysis of current tools for weed detection relevant to WA landscapes							
Delivery	Prioritisation	**Making weed lists more relevant**							**0.40**
Delivery	Prioritisation	More effectively prioritising areas as well as species for weed management	X		X	X	X	X	9
Delivery	Prioritisation	Ensuring weed lists are species and location specific to ensure effective context				X			1
Delivery	Prioritisation	More efficient and regular updating of weed priority lists to avoid perverse outcomes				X		X	6
Delivery	Prioritisation	Addressing a lack of regional priority lists to focus on for funding applications					X		1

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Theme	Focal area	Research topic | Issue	Region 1	2	3	4	5	6	Metrics
Delivery	Prioritisation	**Improving the transparency of weed control prioritisation**							**0.26**
Delivery	Prioritisation	Improved prioritisation for impacts over ease of control (e.g. woody weeds vs herbs)			X			X	6
Delivery	Prioritisation	Removing subjectivity from priority weed lists (i.e. mining compliance lists vs DBCA lists, aesthetic weeds vs threatening spp)	X			X		X	7
Delivery	Prioritisation	Unlocking ineffective weed control resources tied into compliance weed lists driven by mining compliance regulations				X			1
Delivery	Implementation	**Data driven management guidelines**							**0.55**
Delivery	Implementation	Best practice management guides for more than just WONS, including existing tools & invasion pathways	X	X	X	X		X	9
Delivery	Implementation	Better tools to determine when to stop managing weeds (i.e. switch to monitoring only)	X			X			2
Delivery	Implementation	**Scale and context for effective weed control**							**0.25**
Delivery	Implementation	Context-dependence of management effectiveness; 'downscaling' of generic control tools to consider specific local context/problems	X			X	X		3
Delivery	Implementation	Avoiding weed 'spill over' effects where limited areas are controlled but see rapid reinvasion (involves cost-benefit analysis)	X	X	X	X		X	9
Delivery	Implementation	High cost weed management often occurs on low value land, limiting control feasibility (i.e. financial drivers dominate priorities)					X		1
Delivery	Implementation	Improving control in inaccessible regions, specifically wet-season access				X	X		2
Delivery	Implementation	Context specific prioritisation for restricted yet highly impacted areas in vast landscapes (e.g. riparian zone weeds, wetlands)		X	X		X		3
Delivery	Implementation	**Enhancing outcomes with Indigenous engagement**							**0.03**
Delivery	Implementation	More effective two-way design and deployment of control programs involving Indigenous land managers				X			1

Theme	Focal area	Delivery area	Region 1	2	3	4	5	6	Metrics
Non-research	Communications	Cross-tenure information sharing platform for presence and control				X		X	6
Non-research	Communications	A strategic framework to assist citizen science to improve weed management outcomes (forum moderators, MyPestguide™ Reporter, HerbiGuide)						X	5
Non-research	Communications	No central repository/hub for environmental weed advice		X					1
Non-research	Communications	Dichotomy between 'biosecurity vs pest management' (are these just differing points on invasion curve)	X						1
Non-research	Communications	Harness citizen science for surveillance, seasonal work programs					X		1
Non-research	Funding	Funding inconsistencies (short term funding cycle, short timeframes, time-consuming application process)			X	X	X	X	8
Non-research	Funding	Declining availability of experienced weed personnel in all agencies, all regions	X	X		X		X	8
Non-research	Funding	Limited competitive funding calls (funds, duration) negatively impacts on collaboration	X					X	6
Non-research	Funding	Inability to access emergency funds for new incursions				X		X	6
Non-research	Funding	State govt weed research now almost non-existent with largely management now supported						X	5
Non-research	Funding	Personnel to deliver accurate identification and weed risk assessments of species for sale in nurseries						X	5
Non-research	Funding	Inefficient application of weed control — inexperienced staff, bad timing, limited knowledge of weed biology	X	X	X	X			4
Non-research	Funding	High staff turnover and loss of knowledge because of and between short funding cycles	X		X		X		3
Non-research	Funding	High staff turnover effects ability to detect new incursions, lost skills in surveillance	X		X		X		3
Non-research	Funding	RBGs funding locked to WONS or alert lists			X	X			2

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Theme	Focal area	Delivery area	Region						Metrics
			1	2	3	4	5	6	
Non-research	Funding	Insufficient resources to tackle existing lists		X		X			2
Non-research	Funding	Managing the staff resourcing surge — peak seasons then a long period of no requirement/ability to engage				X	X		2
Non-research	Funding	Way too much reliance on good will and (aging) volunteers for controlling weeds across the State	X						1
Non-research	Funding	Insufficient resources to perform robust weed risk assessments (more a box ticking exercise)		X					1
Non-research	Funding	Financial contribution to weed control unfairly levied to agricultural landholders, need a levy for tourists, nursery and forest industry etc					X		1
Non-research	Management	Detection tools/resources are not evenly distributed across tenures that have shared weed problems, making landscape level detection patchy				X		X	6
Non-research	Management	Bunnings are the biggest horticultural buyer of plants yet don't care where they get their stock from (huge biosecurity risk/ opportunity)						X	5
Non-research	Management	RBGs are not a good collaborative model for deploying weed control						X	5
Non-research	Management	Limited or no data/research sharing between departments/organisations despite overlap in interests	X	X		X	X		4
Non-research	Management	Need better coordination of land managers cross-tenure and regionally	X	X		X			3
Non-research	Management	Knowledge on best technique for weeds is generally well known, but individual motivation/ethos/ability is not always aligned	X						1
Non-research	Management	Accountability for weed control needs to be policed — it only takes one land manager to bring down many others.				X			1

Theme	Focal area	Delivery area	Region						Metrics
			1	2	3	4	5	6	
Non-research	Policy	Inconsistency in legislation, policy/ management actions in different jurisdictions; cross tenure control, state borders	X	X	X	X	X	X	10
Non-research	Policy	Unallocated crown land is a significant challenge for weed management, falling between the gaps (and a source of many reinvasions)	X		X	X	X	X	9
Non-research	Policy	Lack of agency to support declared species for environmental weeds, or at least remove invasive species from nursery trade		X	X	X		X	8
Non-research	Policy	RBGs resourced to control listed agricultural weeds and WONS of their own choosing. Not rehabilitation.	X	X				X	7
Non-research	Policy	State weed prioritisation not relevant to remote regions (and dominated by SWWA over northern WA)				X	X	X	7
Non-research	Policy	Unallocated crown land is a significant problem (weed reservoir) and falls between the gaps in many control programs	X		X			X	7
Non-research	Policy	No government push (State or Commonwealth) to accredit nurseries to reduce weed risks						X	5
Non-research	Policy	Funding often locked to WONS or listed long present species, therefore limited ability to respond to emerging threats	X	X	X		X		4
Non-research	Policy	WA biosecurity priorities are dominated by agriculture/pastoralists over those managing natural ecosystems		X		X	X		3
Non-research	Policy	Need better legislation to enforce eradication of weeds via lists and/or offset requirements			X	X	X		3
Non-research	Policy	Declared species mostly agricultural, lack of agency to support declared species for environmental weeds	X			X			2
Non-research	Policy	Difficulty in getting threatening species removed from trade (gap in government remit)		X					1
Non-research	Policy	Internally within WA there are no mandatory biosecurity checks between regions, creating a big gap in surveillance				X			1

Appendices

Appendix 2. Workshop attendees

End user workshops

Workshop 1: Goldfields-Esperance, Wheatbelt, Mid West, Gascoyne, 14th October 2020

First	Surname	Institution
Kathryn	Batchelor	CSIRO
Krystie	Bremer	Carnarvon Rangelands Biosecurity Association Inc
Jimmy	Cocking	10 Deserts / Arid Lands Environment Centre (ALEC)
Chris	Curnow	Rangelands NRM
Anika	Dent	Wheatbelt NRM Inc
Raphael	Didham	The University of Western Australia / CSIRO
Kane	Watson	Northern Agricultural Catchments Council
Bruce	Webber	WABSI

Workshop 2: South West, Great Southern, 14th October 2020

First	Surname	Institution
Sally	Atkinson	South Coast NRM
Kathryn	Batchelor	CSIRO
Justin	Bellanger	South Coast NRM
Jenny	Carley	Blackwood Biosecurity Inc
Julie	Chapman	Leschenault Biosecurity Group Inc
Raphael	Didham	The University of Western Australia / CSIRO
Cheryl	Hamence	Blackwood Biosecurity Inc
Genevieve	Hanrahan-Smith	Nature Conservation Margaret River
Josephine	Mead	Department of Water and Environmental Regulation / Warren Catchment Council
Dennis	Rafferty	Department of Primary Industries and Regional Development
Bruce	Webber	WABSI

Workshop 3: Kimberley, 16th October 2020

First	Surname	Institution
Kathryn	Batchelor	CSIRO
Louise	Beames	Environs Kimberley
Raphael	Didham	The University of Western Australia / CSIRO
Nerylie (Blu)	Gaff	Kimberley Rangelands Biosecurity Association
Jeff	Gooding*	Kimberley Development Commission
Jason	Laverty	Ex Kimberley LCDC / Australian Wildlife Conservancy (Kangaroo Island, South Australia)
Jardine	McDonald	Rangelands NRM
Jean-Paul	Slaven	Department of Primary Industries and Regional Development
Ellie	Summers	Rangelands NRM
John	Szymanski	West Kimberley Rubber Vine Eradication and Aquila Project
Tom	Vigilante*	Bush Heritage Australia
Tracey	Vinnicombe	Department of Primary Industries and Regional Development
Bruce	Webber	WABSI
Noel	Wilson	Department of Primary Industries and Regional Development

**Contribution by correspondence*

Workshop 4: Perth, Peel, 19th October 2020

First	Surname	Institution
Kathryn	Batchelor	CSIRO
Melanie	Davies	Western Australian Local Governments Association
Raphael	Didham	The University of Western Australia / CSIRO
Dan	Friesen	Perth NRM (Ex-South East Regional Centre for Urban Landcare)
Steve	Gates	Nature Reserves Preservation Group of Kalamunda
Mary	Gray	Urban Bushland Council
Mike	Griffiths	Peel-Harvey Catchment Council
Ian	Hunter	City of Stirling
John	Moore	Department of Primary Industries and Regional Development
Anna	Napier	Cambridge Coastcare
Jason	Pitman	Perth Region NRM
Paula	Pownall	Peel-Harvey Catchment Council
Don	Poynton	Joondalup Community Coast Care Forum Inc
Bruce	Webber	WABSI
Cat	Williams	South East Regional Centre for Urban Landcare (SERCUL)

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Workshop 5: Pilbara, 21st October 2020

First	Surname	Institution
Kathryn	Batchelor	CSIRO
Kirsty	Beckett	Fortescue Metals Group
Paul	Buckland	Rangelands NRM
Tracy	Carboon	Kanyirninpa Jukurrpa Aboriginal Corporation
Chris	Curnow	Rangelands NRM
Bill	Currans	Pilbara Regional Biosecurity Group
Raphael	Didham	The University of Western Australia / CSIRO
Todd	Edwards	Fortescue Metals Group / Pilbara Rehabilitation Group
Vicki	Long*	Vicki Long & Associates
Lara	Martin	Department of Primary Industries and Regional Development
Graham	McKay	Land Alliance
Sean	McNair	Yamatji Marlpa Aboriginal Corporation (YMAC)
Jeremy	Naaykens*	Rio Tinto
George	Watson	BHP
Bruce	Webber	WABSI
Alicia	Whittington	Department of Biodiversity, Conservation and Attractions
Jo	Williams	Pilbara Mesquite Management Committee (PMMC)

Contribution by correspondence

Workshop 6: State-wide, 21st October 2020

First	Surname	Institution
Peter	Adams	Department of Primary Industries and Regional Development
Kathryn	Batchelor	CSIRO
Phil	Boglio	Department of Mines, Industry Regulation and Safety
Raphael	Didham	The University of Western Australia / CSIRO
Michelle	Hall	Bush Heritage Australia
Sandy	Lloyd	Department of Primary Industries and Regional Development
Aaron	Maxwell	Department of Agriculture, Water and the Environment
David	Mitchell	Department of Biodiversity, Conservation and Attractions
Sharyn	Moore	Astron Environmental Services
John	Moore	Department of Primary Industries and Regional Development
Kellie	Passeretto	Department of Biodiversity, Conservation and Attractions
Danielle	Risby	Department of Mines, Industry Regulation and Safety
Bruce	Webber	WABSI
Tory	Weir	Department of Primary Industries and Regional Development
Cliff	Winfield	Biosecurity Council of WA

Researcher workshop

Workshop 7: State-wide, 4th November 2020

First	Surname	Institution
Kathryn	Batchelor	CSIRO
Margaret	Byrne	Department of Biodiversity, Conservation and Attractions
Mariana	Campos	Murdoch University
Hillary	Cherry	Office of Environment & Heritage (NSW) - National Parks and Wildlife Service
Roger	Cousens	University of Melbourne
Raphael	Didham	The University of Western Australia / CSIRO
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Greg	Keighery	Ex-Department of Biodiversity, Conservation and Attractions
Wolfgang	Lewandrowski	Department of Biodiversity, Conservation and Attractions
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John	Scott	CSIRO
Samantha	Setterfield	The University of Western Australia
Tim	Storer	Department of Water and Environmental Regulation
Andrew	Storrie	Agronomo
Stephen	Van Leeuwen	Curtin University
John	Virtue	SA Department of Primary Industries and Regions (PIRSA)
Bruce	Webber	WABSI

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Combined workshop

Workshop 8: State-wide, 1st December 2020

First	Surname	Institution
Victoria	Aitken	Department of Primary Industries and Regional Development
Megan	Barnes	Department of Biodiversity, Conservation and Attractions
Glenice	Batchelor	Shire of Tammin
Kathryn	Batchelor	CSIRO
Louise	Beames	Environs Kimberley
Hanouska	Bishop	Rio Tinto
Steve	Blyth	Nursery and Gardens Industry Association WA
Amanda	Bourne	Northern Agricultural Catchments Council
David	Broadhurst	South Coast NRM
Mariana	Campos	Murdoch University
Hillary	Cherry	Office of Environment & Heritage (NSW) – National Parks and Wildlife Service
Mike	Christensen	South West Catchments Council
Jimmy	Cocking	10 Deserts / Arid Lands Environment Centre (ALEC)
Chris	Curnow	Rangelands NRM
Melanie	Davies	Western Australian Local Governments Association
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Mary	Gray	Urban Bushland Council
Mike	Griffiths	Peel-Harvey Catchment Council
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Nigel	Rowe	Main Roads
Raghu	Sathyamurthy	CSIRO
John	Scott	CSIRO
Andrew	Storrie	Agronomo
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Stephen	Van Leeuwen	Curtin University
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Tory	Weir	Department of Primary Industries and Regional Development
Jo	Williams	Pilbara Mesquite Management Committee (PMMC)
Colin	Yates	Department of Biodiversity, Conservation and Attractions

Appendices

Appendix 3. Contributors to program drafting

In addition to Cambridge Coastcare, the Department of Biodiversity, Conservation and Attractions, Environs Kimberley, Northern Agricultural Catchments Council and Peel Harvey Biosecurity Group, who provided aggregated feedback for their respective organisations, the following people provided feedback on program drafts.

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Mariana	Campos	CSIRO
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Melanie	Davies	Western Australian Local Governments Association
Judy	Dunlop	WA Feral Cat Working Group
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Gwyn	Jones	Integrated Agri-Culture
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Rae	Kolb	Stirling Natural Environment Coastcare
Vicki	Long	Vicki Long and Associates
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Simon	Mereweather	Department of Primary Industries and Regional Development
Andrew	Mitchell	Ex-Department of Primary Industries and Regional Development
Geoff	Moore	Department of Primary Industries and Regional Development
Sharyn	Moore	Astron Environmental Services
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Samantha	Setterfield	The University of Western Australia
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