National Weed Biocontrol Pipeline Strategy: Initial Stage

NATIONAL WEED BIOCONTROL PRIORITISATION FRAMEWORK

A FRAMEWORK FOR THE PRIORITISATION OF WEEDS FOR BIOCONTROL WITHIN THE AUSTRALIAN CONTEXT

December 2024

Prickly acacia gall thrips damage;
Weed - Vachellia nilotica *subsp.* Indica;
Photo – QDAF.

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ACKNOWLEDGEMENTS
This Framework was developed by the CSIRO, Wild Matters and CISS. Cross-jurisdictional input on the Framework was sought from members of the Weed Biocontrol Expert Panel and State and Federal department representatives who attended workshops in the initial stages of development. Constructive feedback from the Australian Government, the Environment and Invasives Committee's Weeds Working Group and the Weed Biocontrol Alliance are also gratefully acknowledged.

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CITATION
CSIRO, Wild Matters and Centre for Invasive Species Solutions (2024) National Weed Biocontrol Prioritisation Framework: A framework for the prioritisation of weeds for biocontrol within the Australian context, Centre for Invasive Species Solutions, Canberra.

ENDORSEMENT
This Framework was endorsed by the Environment and Invasives Committee out-of-session paper 19 November 2024.

ISBN
e-Book 978-1-922971-84-5
Print 978-1-922971-85-2

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PREAMBLE

Classical weed biological control, hereafter biocontrol, is an effective tool to manage weeds at the landscape scale. Biocontrol is the practice of managing weeds by introducing 'natural enemies', such as insects and pathogens (known as biocontrol agents) from the weed's native range. Success stories include biocontrol programs for prickly pear *(Opuntia spp.),* skeleton weed *(Chondrilla juncea)* and Paterson's curse *(Echium plantagineum)*, in which the density of these weeds in heavily invaded areas has been significantly reduced, resulting in the restoration of environmental and production values to these landscapes.

The *National Weed Biocontrol Pipeline Strategy* (CSIRO and Centre for Invasive Species Solutions 2023) was established to guide the coordination of weed biocontrol research, development and extension (RD&E) investment in accordance with national weed priorities, and to align RD&E across government, industry, community, research and on-ground weed management. As part of implementing the strategy, a National Weed Biocontrol Prioritisation framework (the framework) was developed to enable transparent and robust selection and assessment of candidate weeds for biocontrol.

This document, the National Weed Biocontrol Prioritisation framework, is structured in two parts: Part A, which has three sections, and Part B, which has three stages (see Figure 1).

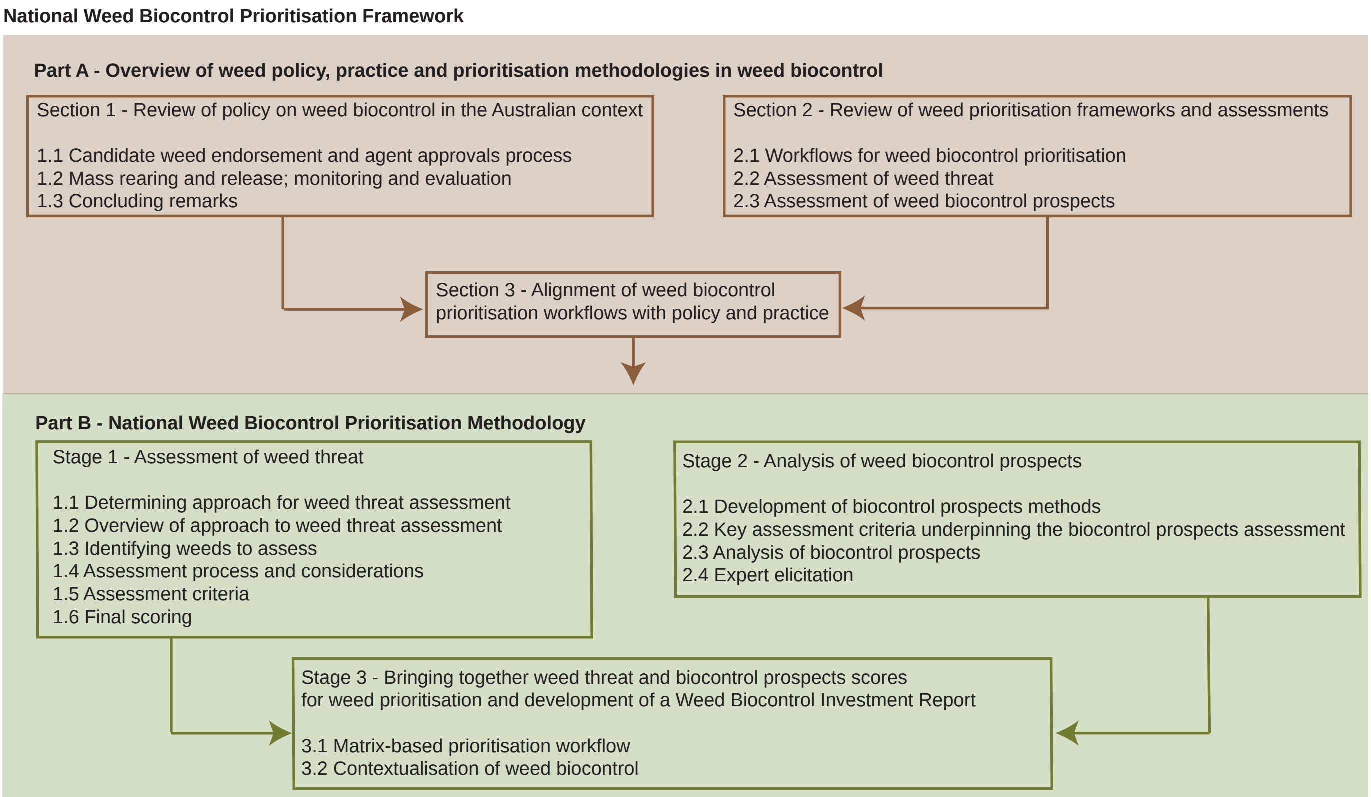


Figure 1 Schematic of the components of the National Weed Biocontrol Prioritisation framework

ABBREVIATIONS

ACT	Australian Capital Territory
ALOP	Appropriate Level of Protection
BC	Biological control
BCTS	Biological control target system
Cth	Commonwealth
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFF	Department of Agriculture, Fisheries and Forestry
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DPI	Department of Primary Industries
DPIRD	Department of Primary Industries and Regional Development
EEPL	Exotic Environmental Pests and Diseases List
EIC	Environment and Invasives Committee
EICAT	Environmental Impact Classification for Alien Taxa
EPDNS	Established Pest and Diseases of National Significance
GRDC	Grains Research and Development Corporation
IPA	Indigenous Protected Area
MLA	Meat and Livestock Australia
NSW DPIRD	New South Wales Department of Primary Industries and Regional Development
NT	Northern Territory
Qld	Queensland
RD&E	Research, development and extension
SEICAT	Socioeconomic Impact Classification of Alien Taxa
Tas	Tasmania
Vic	Victoria
WA	Western Australia
WAOL	Western Australian Organism List
WoNS	Weeds of National Significance
WRA	Weed risk assessment
WRM	Weed risk management
WRMS	Weed risk management system

KEY TERMS AND DEFINITIONS

Biocontrol feasibility	Broadly defined as logistical and ecological factors related to the target weed and candidate agent/s that influence the ability to obtain, host-range test and release those agent/s into the Australian environment.
Biocontrol prospects	The interaction of biocontrol feasibility (ability to obtain and host-range test biocontrol agents) and the impact (likelihood of success according to factors affecting the impacts of biocontrol agents on the performance of their host weed) of biocontrol.
Classical weed biological control	The practice of managing weeds by introducing 'natural enemies', such as insects and pathogens (known as biocontrol agents) from the weed's native range.
Likelihood of success	Considers abiotic and biotic factors that predict the impacts of biocontrol agent/s on the target weed.
National Weed Biocontrol Prioritisation Framework	A method for identifying priority weed candidates for biocontrol RD&E investment in accordance with a combination of weed threat and prospects.
Weed Biocontrol Investment Report	Informed by the outputs from the weed biocontrol prioritisation and will recommend specific research activities that could be undertaken for prioritised weeds to deliver novel biocontrol solutions.
Weed threat	Evaluation of a weed's impacts and invasiveness using defined assessment criteria.

PART A

OVERVIEW OF WEED POLICY, PRACTICE ANDPRIORITISATION METHODOLOGIES IN WEED BIOCONTROL

Quarantine host specificity testing; Weed - Lycium ferocissimum*; Photo – CSIRO; People in photo – Kylie Ireland and Gavin Hunter (Research Scientists).*

Flying drone over Hudson pear;
Weed - Cylindropuntia pallida; Photo – NSW DPI;
Person in photo - Andrew McConnachie

SECTION 1. REVIEW OF POLICY ON WEED BIOCONTROL IN THE AUSTRALIAN CONTEXT

Developed by Wild Matters

Weed biocontrol RD&E in Australia is embedded in a well-defined policy and regulatory setting. The purpose of this review is to ensure that development of the framework and the prioritisation methodology that it recommends are consistent with and complementary to the existing setting.

This review identifies three steps to the release of biocontrol agents. These are:

1. weed identification and prioritisation for biocontrol
2. candidate weed endorsement and biocontrol agent approvals
3. the mass rearing, release, monitoring and evaluation of biocontrol agents.

The National Weed Biocontrol Prioritisation framework seeks to formalise a process for the identification and prioritisation of weeds for biocontrol (Step 1). There is currently no policy or regulatory process governing this process; hence, Step 1 is not included in this policy review and is considered in the review of scientific weed-prioritisation frameworks and assessments (see Part A Section 2).
Section 1 therefore focuses on the policy and regulatory setting of Steps 2 and 3 by reviewing the literature and documents listed in Figure A1.

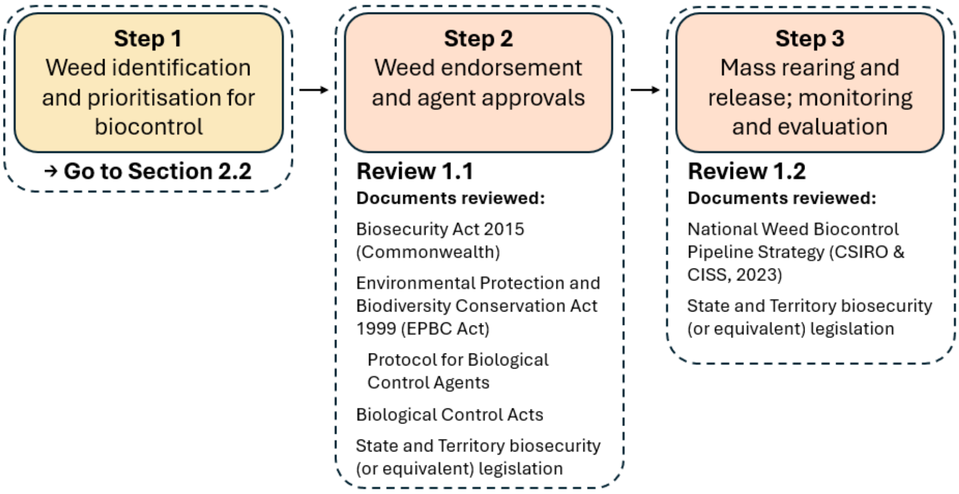


Figure A1 The three broad steps to biocontrol agent release in Australia

This document does not review methodologies and standards in weed biocontrol research (e.g. centrifugal phylogenetic distance method underpinning host test list development or host-specificity experimentation workflows) but instead aims to place research practice in a broader policy and practice framework in the Australian context.

1.1 CANDIDATE WEED ENDORSEMENT AND AGENT APPROVALS PROCESSES

1.1.1 Principal legislation

The endorsement of candidate weeds and approval of potential biocontrol agents is governed by the *Biosecurity Act 2015* (Cth) and the *Environment Protection and Biodiversity Conservation Act 1999 (Cth)* (the EPBC Act). The overarching process is described in the *Protocol for Biological Control Agents* (Department of Agriculture, Fisheries and Forestry 2022).

The process for the endorsement of candidate weeds for biocontrol under the Biosecurity Act and the EPBC Act is described in Section 1.1.3.

The Biosecurity Act requires potential biocontrol agents to undergo risk assessment overseen by the Department of Agriculture, Fisheries and Forestry (DAFF). There is also an approval process for agents that are animals in the EPBC Act. This is overseen by the Department of Climate Change, Energy, the Environment and Water (DCCEEW). The biocontrol agent importing, testing and releasing approvals process is described in Section 1.1.4.

1.1.2 Other legislation

'Biological Control Acts' refers to the biological control 'mirror' legislation scheme, consisting of the *Biological Control Act 1984 (Cth)* (which applies in the ACT, including Jervis Bay Territory) and the parallel *biological control legislation* (BC Act) in all states and the NT. Each BC Act is identical in its intent, which is to provide legal indemnity and prevent legal proceedings from being initiated. Use of the Act is not mandatory for release of an agent to occur and is typically only used for commercially or socially important species in which the impacts from an agent release may have economic or social impacts.

The Protocol for Biological Control Agents is used to assess and approve biocontrol agents under the Biosecurity Act and the EPBC Act. A BC Act decision is subordinate to decisions made under the Biosecurity Act or the EPBC Act. However, when significant conflicts of interest are identified (as detailed in Table 1) in consideration of a weed under the Biosecurity Act and the EPBC Act, it may be pertinent for state and territory jurisdictions to consider jointly invoking the protections afforded under a BC Act to manage conflicts. The BC Acts also include a mechanism to prevent legal proceedings to be instituted in respect of release of agent organisms in the jurisdiction covered by the BC Acts.

1.1.3 Process for target-weed endorsement

The target weed must be endorsed by the Environment and Invasives Committee (EIC) through the current procedure before permission is sought to release a biocontrol agent. The applicant prepares an application that includes information on taxonomy, habitat (including current and potential distribution), importance of the weed (including detrimental and beneficial aspects) and information on key stakeholders that may benefit from or be disadvantaged by the release of effective biocontrol agents on the weed, including evidence of consultation with stakeholders.

The EIC determination is based on the likelihood and severity of conflicts of interest around the weed's negative impacts and its beneficial uses. When there are concerns or contentions about the use of a plant, the EIC may also refer to other groups, including the Weeds Working Group, the Plant Health Committee or broader stakeholder consultation, for advice. For instance, gamba grass *(Andropogon gayanus)* is considered by some groups as a highly valued pasture species and required extensive external consultation before being endorsed as a candidate weed for biocontrol. When there are unresolved conflicts, the BC Act process may be used to formally consider the weed as a biocontrol candidate. Table A1 lists the categories of conflicts considered by the EIC and the recommended course of action.

Table A1 Environment and Invasives Committee weed biocontrol candidate categorisation and outcomes

Category	Subcategory	Descriptor	Outcome
No foreseen significant conflict	N/A	The weed is already declared for control under jurisdictional biosecurity legislation and no permits have been issued to allow commercial use of the species, or the weed is not known to have significant useful attributes.	Endorse
Possible significant conflict or adverse comment	Minor or major conflict resolved	Any identified conflict has been resolved (e.g. by restricting the endorsed target to a particular taxon within a species complex).	Endorse
	Minor conflict not resolved	Potential benefits versus adverse impacts are considered to be highly favourable, according to available analyses.	May recommend that the proposal proceed to an application and formal consideration under a BC Act. Agriculture Ministers Meeting may be required to consider and make a determination.
	Major conflict not resolved	The EIC will advise that proceeding is not supported in accordance with existing conflicts.	The EIC may advise that a formal analysis and formal consideration under a BC Act would be needed. Agriculture Ministers Meeting may be required to consider and make a determination.

Table modified from the Procedure for Endorsing Candidate Weeds for Biological Control by the EIC (2019).

1.1.4 Protocol for biocontrol agent importation, testing and release approval

The *Protocol for Biological Control Agents* (*Department of Agriculture, Fisheries and Forestry 2022*) provides a national standard for introducing exotic biocontrol agents into Australia and is outlined in the biological control agent import application and risk-analysis process (see Figure A2). The protocol identifies steps to progress potential biocontrol agents towards release, including applicants' actions (submission, research and assessments) and regulators' approvals.

The steps in the protocol help to establish the level of risk of off-target damage by the potential biocontrol agent. In line with Australia's *Appropriate Level of Protection* (*ALOP*), only agents that have very low or negligible levels of risks will satisfy the Biosecurity Act. In addition, the agent must be permitted for release into the Australian environment under the EPBC Act. A DCCEEW decision to amend the live import list (for animal or insect biological control agents) is independent of the Biosecurity Act. The risk assessment prepared by DAFF is reviewed by DCCEEW.

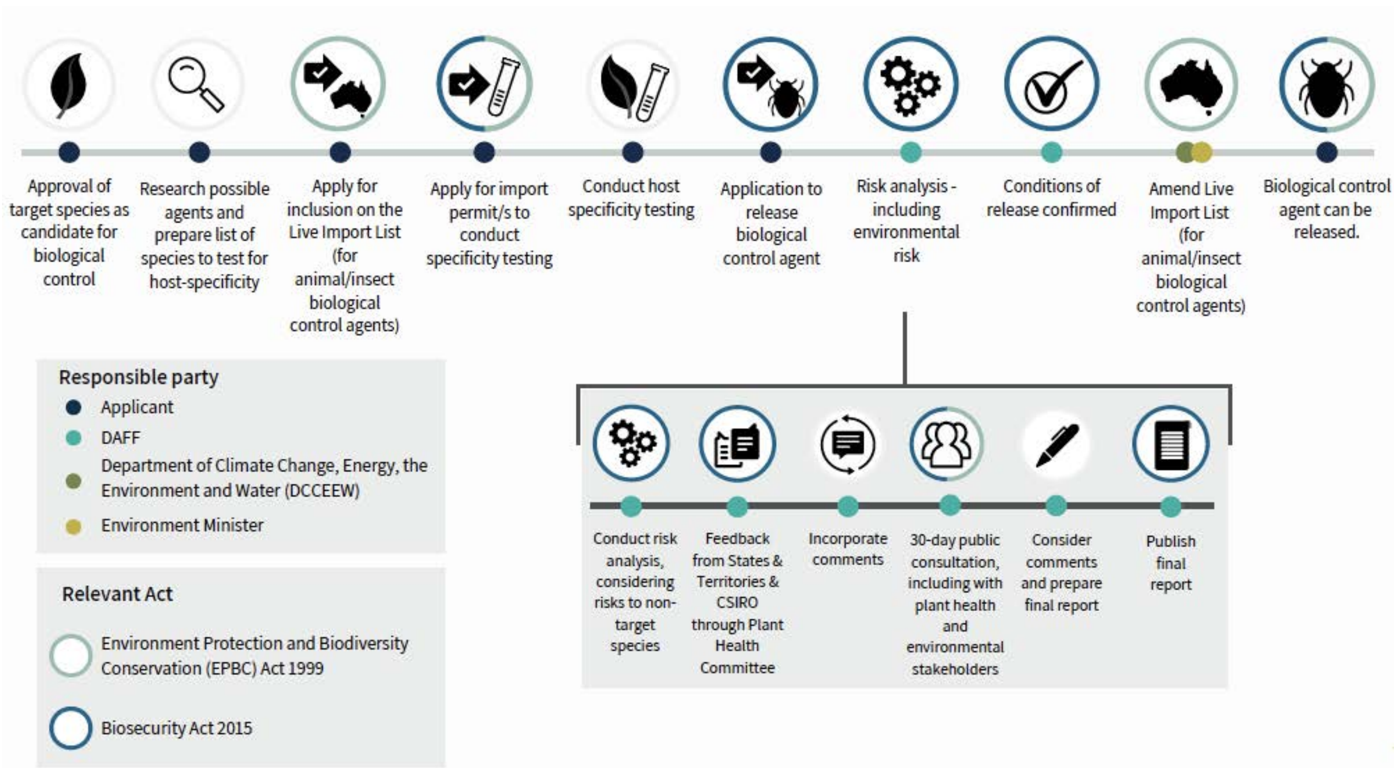


Figure A2 Schematic of impact application and risk-analysis process for biological control agents

A summary of steps in the protocol as described in Figure A2 is provided as follows.

1. Approval of the weed as a candidate for biological control

Step 1: This is discussed in Section 1.1.3.

2–5. Planning and host-specificity investigations for potential biocontrol agents

[Forms Phases 1 and 2 of the National Weed Biocontrol Pipeline Strategy]

Step 2: This may include employing molecular, bioclimatic and phylogenetic methods to native and introduced weed populations to optimise where and how native range surveys for prospective biocontrol agents are undertaken. Preliminary offshore host-specificity testing of potential agents may also be undertaken. Step 2 also involves developing a host-specificity test list of non-target plants. This list should be developed by the applicant in consultation with experts and using the phylogenetic methods described by Wapshere (1974), Briese (2003, 2005), Sheppard *et al*. (2005) and Barratt *et al*. (2007) biocontrol agents. These lists should prioritise native plants, plants of cultural significance and commercially important plants that are phylogenetically related to the target weed. The list, which may be published on the DAFF website for public comment, does not require endorsement by DAFF.

Step 3: When a potential biocontrol agent is an animal and is not on the live import list, a 'testing permit' must be obtained from DCCEEW to allow the species to be imported into quarantine. This involves applying to amend the live import list. If it is decided to progress the biocontrol agent to the release stage, the application must be finalised and a decision made by the minister responsible for the EPBC Act.

Step 4: The approvals stage involves obtaining a valid import permit issued by DAFF under the Biosecurity Act to import the potential biocontrol agent to approved arrangement sites (previously Quarantine Approved Premises and Compliance Agreements) for host-specificity testing. The permit stipulates any conditions attached to the importation and containment of the potential biocontrol agent.

Step 5: After importing the potential biological control agents, the applicant can undertake host-specificity testing under approved biosecurity containment conditions.

6–10. Release assessment for prospective biocontrol agent

[Forms part of Phase 2 of the National Weed Biocontrol Pipeline Strategy]

Step 6: The application stage requires the proponent to apply to the Plant Import Operations Branch in DAFF to release a potential biocontrol agent into the Australian environment ('Release Package'). The Release Package must include information such as the current status and endorsement of the weed biocontrol target in Australia, the agent's potential for control of the target, a report on the host-specificity testing, including an evaluation of risks to non-target species, and information on how the initial releases would be made. Information required in the release package is outlined further on Pages 4 and 6 of the protocol.

Step 7: Assessment involves DAFF assessing the Release Package by conducting a risk analysis under the Biosecurity Act. This focuses on the likelihood and magnitude of potential off-target impacts and risks to the environment, not the probability of entry, establishment and spread and whether this meets Australia's ALOP. Consultation by DAFF consists of a preliminary draft risk-analysis report for state and territory primary industry departments and the CSIRO through the Plant Health Committee. In addition, a draft risk-analysis report is made available for a 30-day public comment period, including with plant health and environmental stakeholders. If the potential biocontrol agent is found to have either very low or negligible levels of risk of off-target impacts, it meets Australia's ALOP and may be recommended for release.

Step 8: In the Approvals stage, if release is recommended by DAFF, it will stipulate any release conditions and requirements.

Step 9: For additional approvals for potential biocontrol agents that are animals, the risk-analysis reports produced by DAFF in Step 7 may be used by the minister for the environment and water in deciding, under the EPBC Act, to include the species in the *list of specimens taken to be suitable for live import* (amendment of the Live Import List).

Step 10: If DAFF approves release and the biological control agent is added to the Live Import List (if applicable), then the agent can be released, subject to the conditions of release.

1.1.5 Roles and responsibilities

Roles and responsibilities are indicated in the agent impact application and risk-analysis process schematic, as per the responsible party legend (see Figure A2). Table A2 lists the roles and responsibilities of additional parties involved in weed biocontrol not listed in Figure A2.

Table A2 Additional roles in the weed biocontrol and agent approval process

Name	Responsibilities
Environment and Invasives Committee (EIC)	Consider applications for weed biocontrol candidates and either endorse the weed as a candidate for biocontrol or refer the weed to the Agriculture Ministers Meeting or the BC Acts process
Weeds Working Group	Provide guidance to the EIC on conflict weeds

1.1.6 Additional jurisdictional processes

All states and territories align with DAFF's protocol for biological control agents (Department of Agriculture, Fisheries and Forestry 2022). Except WA and Tasmania, the protocol and the biological control 'mirror' legislation scheme provide the only current policy and regulation on biocontrol. The Office of the Gene Technology Regulator is developing policy on gene drives, which may have some applicability to weed biocontrol in the future. Additional jurisdictional processes are outlined below.

Western Australia

The Biosecurity and Agriculture Management Act 2007 (WA) (BAM Act) specifies which organisms are permitted entry into WA. The mechanism for this is the WA organism list (WAOL). If a biocontrol agent is not listed on the WAOL, it will need to be added to the list before the agent can be released in WA. The plant biosecurity branch of the WA Department of Primary Industries and Regional Development (DPIRD) is responsible for recommending to the minister the declaration of an insect or pathogen as a permitted organism for WA. Recommendations may be submitted quarterly; thus, depending on the cycle for submissions, the total process may take up to six months.

DPIRD has advised that the appropriate time for the department's quarantine entomologist and pathologist to commence assessing an organism for inclusion on the WAOL is when DAFF's release package is provided for stakeholder consultation (Step 7). This analysis contains the information required for DPIRD's internal considerations.

The risk-assessment consultation and candidate-approval processes do not currently incorporate the organism-declaration process in WA; however, this is the stage that DPIRD would start the assessment.

Tasmania

Biocontrol agents are considered biosecurity matter under the *Biosecurity Act 2019 (Tasmania)*. These are restricted matter if not otherwise classified as prohibited or permitted matter or a declared pest.

For importation into Tasmania, an individual permit is required. The permit, once issued, details any conditions on importation and use in the state. A notice of intention to import must be submitted to Biosecurity Tasmania (along with permit) at least 24 hours before consignment arrival. This process is likely to be initiated after DAFF recommends releasing the agent.

1.2 MASS REARING AND RELEASE; MONITORING AND EVALUATION

Following Steps 9 and 10 of the protocol (Department of Agriculture, Fisheries and Forestry 2022), when an agent is approved for release, the National Weed Biocontrol Pipeline Strategy recognises two implementation phases:

Phase 3: Mass rearing and release is typically facilitated by networks of community members and stakeholders (including councils, research and development corporations, and community-led not-for-profit organisations) and requires extension and engagement with these groups led by the research agency.

Phase 4: Monitoring and evaluation involves on-ground monitoring of agent establishment, changes in the density of weed populations and asset recovery (e.g. desirable pasture vegetation).

Once an agent is approved for release, policy and regulation of the agent falls to jurisdictions. It may require permits or licences under state or territory legislation to enable the movement or release of the declared weed species or agents (see Box A1). When a weed is declared, it may also be necessary to include biocontrol in current management advice or requirements. This may include:

- revising existing information on best practice for weed management to include biocontrol
- educating and training on biocontrol and agent release
- developing or supporting release programs
- developing or supporting monitoring programs.

In addition, the likelihood of a biocontrol agent establishing once released may depend on the management objective assigned to the weed in each jurisdiction (e.g. Van Klinken *et al*. 2016). For instance, widespread weeds with an asset protection management objective may be suitable for biocontrol because they typically have large populations and limited control activities, whereas weeds targeted for eradication typically have small populations that are frequently treated and therefore may not support the establishment of the biocontrol agent.

Box A1 Examples of requirements to move or release weed species or agents

New South Wales

A licence is required under the *Biodiversity Conservation Act 2016 (NSW)* to liberate animals. Biosecurity permits are needed to deal with declared weeds (e.g. Hudson pear cladodes carrying *Dactylopius tomentosus)* under the *Biosecurity Act 2015 (NSW)*. Dealings include

- keeping biosecurity matter
- moving biosecurity matter
- releasing biosecurity matter or a carrier from captivity
- breeding, propagating, growing, raising, feeding or culturing biosecurity matter or a carrier, experimenting with biosecurity matter or a carrier.

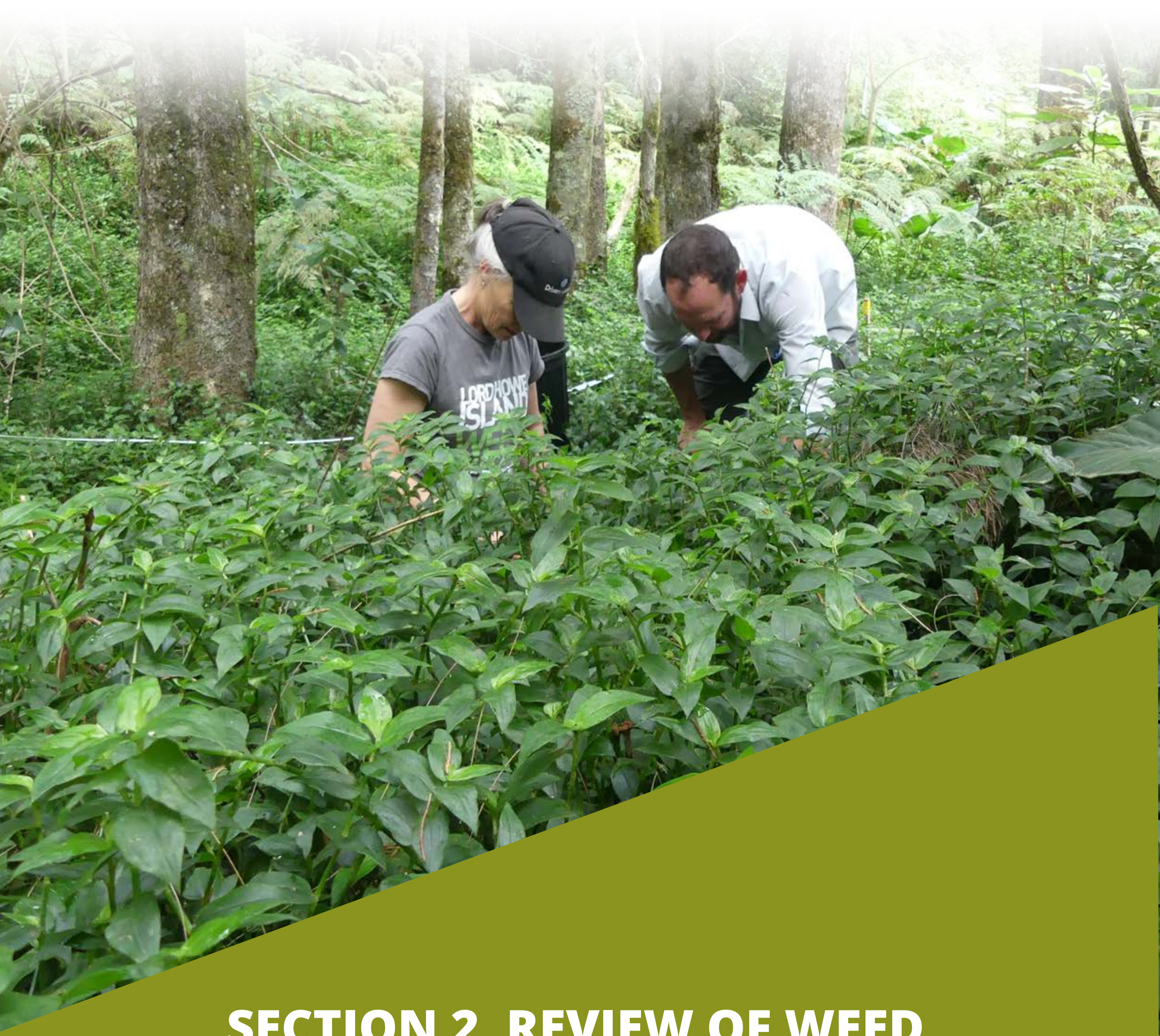
Victoria

If a weed is declared under the *Catchment and Land Protection Act 1994 (Vic*), a permit may be required to disperse agents if dispersal involves the movement of the weed. Releasing the agent will not be actively promoted in regions in which the target weed is regionally prohibited because landholders are required to take all reasonable steps to eradicate these weeds from their land.

1.3 CONCLUDING REMARKS

This policy review outlined the existing policy and regulatory context for endorsing weed biocontrol candidates and progressing the importing, testing and releasing approvals for potential biocontrol agents in Australia. It also outlined in broad terms the policy setting to implement biocontrol as a management tool.

The National Weed Biocontrol Prioritisation Framework is concerned only with developing a process to identify and prioritise weeds for biocontrol, which precedes the policy and regulatory processes discussed in this review. Part B of the framework does not conflict with the policy or regulatory process but complements and supports them while formalising a process to prioritise weed candidates and provide a list of target weeds for biocontrol.



SECTION 2. REVIEW OF WEED PRIORITISATION FRAMEWORKS AND ASSESSMENTS

Developed by Wild Matters (Section 2.2) and the CSIRO (Sections 2.1 and 2.3).

This review of weed-prioritisation frameworks and assessments is divided into three subsections:

- **Section 2.1** provides a review of overarching workflows to prioritise weed biocontrol and, in a general sense, of how assessment components (weed threat, biocontrol feasibility and biocontrol likelihood of success) have been combined by previous and current prioritisation frameworks to select weeds for biocontrol investment.
- **Section 2.2** reviews methodologies used to prioritise weeds according to threat, within existing biocontrol prioritisation frameworks and through broader processes to prioritise weed management.
- **Section 2.3** reviews methodologies for assessing biocontrol prospects (a combination of biocontrol feasibility and biocontrol likelihood of success) in the Australian context.

2.1 WORKFLOWS FOR WEED BIOCONTROL PRIORITISATION

This review primarily considers prioritisation frameworks developed in the Australian context. The South African biocontrol prioritisation system and its adaptation for use in the United States are also considered (i.e. Canavan *et al*. 2021, Winston *et al.* 2024). This review does not, however, seek to provide a comprehensive appraisal of similar prioritisation frameworks developed internationally.

Two prioritisation frameworks for biocontrol have been developed in Australia: Improving Targeting of Weed Biological Control Projects in Australia (Paynter *et al*. 2009) and Prioritising Targets for Biological Control of Weeds, a Decision Support Tool for Policy Makers (Hennecke *et al.* 2013). The latter was adopted as the national standard by Australian governments and biocontrol practitioners.

These national frameworks were preceded by other jurisdictional (e.g. Morin *et al.* 2016, 2019, Gooden *et al*. 2023 for environmental weeds in NSW) and sectoral prioritisations (e.g. Van Klinken *et al.* 2016 for weeds impacting grazing, Morin and Raghu 2020 for weeds impacting grain production). Several other prioritisation frameworks, some of which were informed to some degree by the Paynter *et al.* (2009) and Hennecke *et al*. (2013) frameworks, have also been applied recently at an international scale (i.e. Canavan *et al.* 2021, Lesieur *et al*. 2023, Winston *et al*. 2024; see Figure A3).

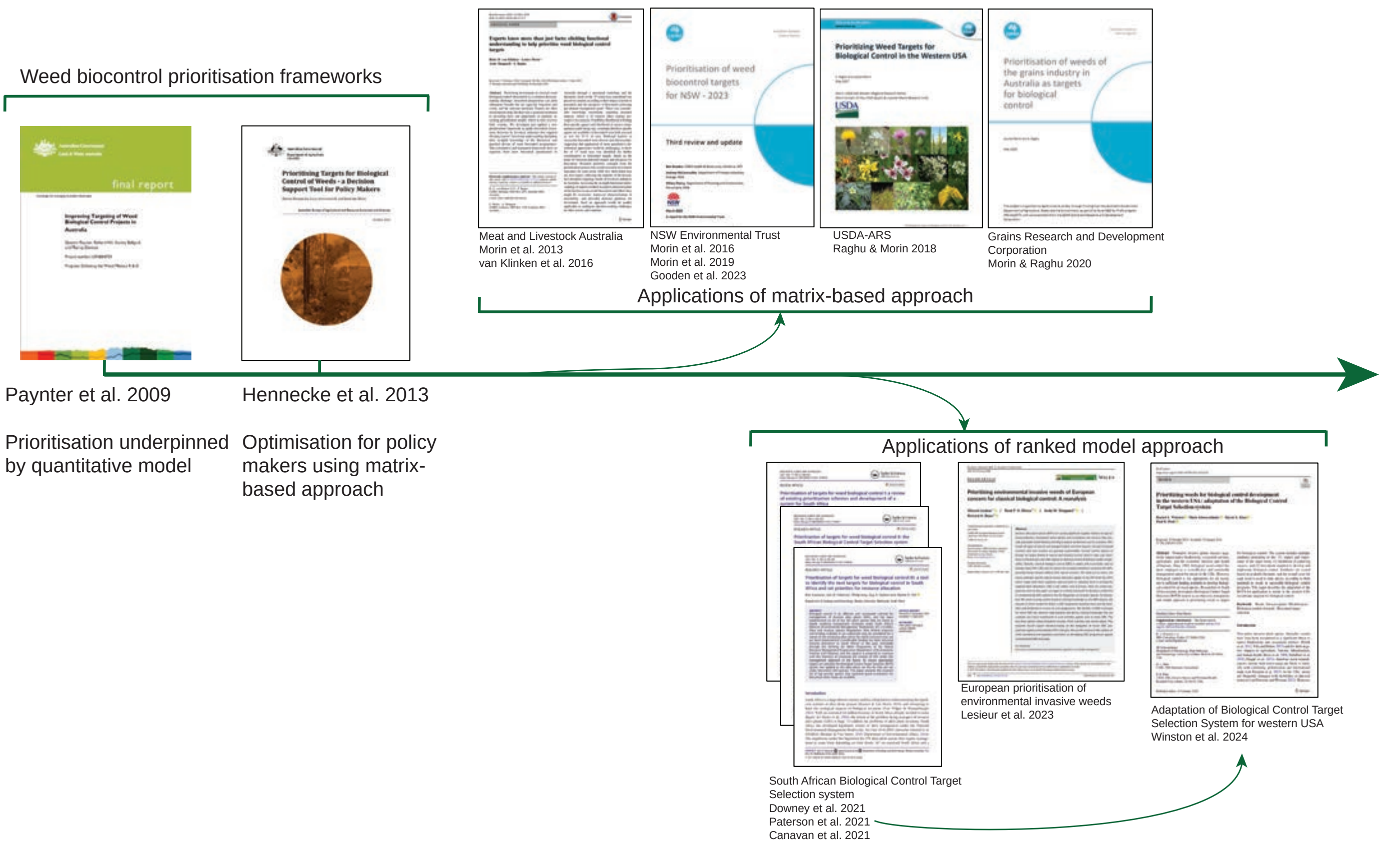


Figure A3 Schematic of development of frameworks for weed biocontrol prioritisation over time

The foundational Paynter *et al.* (2009) framework sought to prioritise weeds for biocontrol using a quantitative approach and weighted scores applied to three stages (termed 'modules' by the authors):

- **Module 1:** weed importance and desirability of biocontrol (described in Section 2.2)
- **Module 2:** effort required to obtain and host-range test biocontrol agents (described in Section 2.3.1)
- **Module 3:** potential impact of biocontrol on target weed (described in Section 2.3.2).

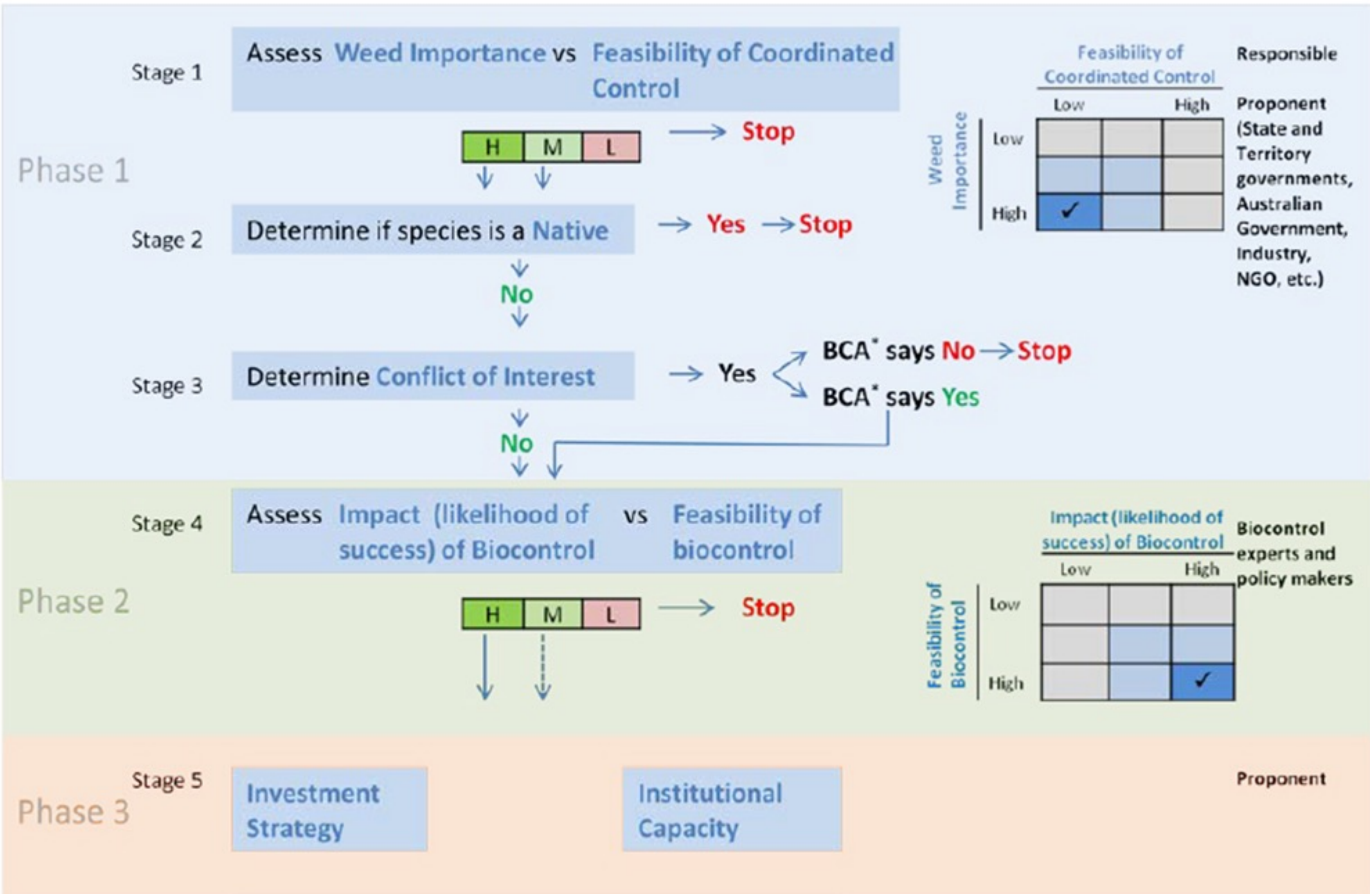
Paynter *et al.* (2009) proposed a quantitative approach for ranking weeds by their 'priority for biocontrol', calculated as the product of the scores for each of the three modules:

$$\textit{Priority for biocontrol} = \textit{Weed importance score} \times \textit{Biocontrol impact score} \times (\textit{Biocontrol effort score})^{-1}$$

Subsequently, upon advice sought by participating experts at a workshop on Australian biocontrol prioritisation that aimed to develop a decision tool for policymakers, Hennecke *et al.* (2013) suggested a decoupling of the Paynter *et al.* (2009) framework's 'weed importance', 'biocontrol feasibility' and 'likelihood of success' modules because 'weed importance' was deemed to be context specific, that is, dependent on jurisdiction, sector or values impacted. A separate initial assessment was recommended to identify the priority weeds on which biocontrol prospects would be subsequently evaluated.

In contrast to Paynter *et al.* (2009), Hennecke *et al.* (2013) recommended the use of a matrix approach for prioritising weeds for biocontrol research using two rather than three assessment phases (see Figure A4):

- **Phase 1:** assessment of weed importance (risk/threat/impact) and feasibility of coordinated control, undertaken by relevant jurisdictions and sectors managing weed threats. In this phase, weeds are prioritised in a matrix by having medium-high importance and low-medium feasibility of control (see Section 2.2). Prioritised weeds then flow through to Phase 2 for biocontrol prospects analysis
- **Phase 2:** assessment of biocontrol prospects according to interaction of biocontrol feasibility (ability to obtain and host-range test biocontrol agents) and biocontrol impact (likelihood of success according to factors affecting the impacts of biocontrol agents on the performance of their host weed) (see Section 2.3). Feasibility and likelihood of success are equivalent to Paynter's Modules 2 and 3, respectively. Weeds that have medium to high prospects are then delivered to the project proponent for investment consideration and strategic planning. The Hennecke framework does not, however, determine a final priority list of species according to the interaction of weed importance and biocontrol prospects.



*The Biological Control Act 1984 (BCA) manages cases where there is a conflict of interest.

Figure A4 Process framework in prioritising targets for biocontrol of weeds

Subsequently, Morin *et al.* (2016) developed and applied a modified version of the Hennecke *et al.* (2013) matrix-based prioritisation framework for environmental weeds in the NSW context. The Morin *et al.* (2016) framework prioritised weeds by combining weed importance (low, moderate, high, very high; according to weed-risk scores) with biocontrol prospects (low, moderate, high; see Figure A5).

Two weed prioritisations in Australia (Van Klinken *et al*. 2016, Morin and Raghu 2020) and one in the United States (Raghu and Morin 2018), which also adopted the modified matrix-based method, included a further element of 'defining the primary management goal(s) of the biocontrol program' within the step of determining the level of weed importance. This aimed to inform biocontrol investments that would best meet on-ground management needs (e.g. agents that target seed set if the primary management goal is to reduce invasion risk by seed spread).

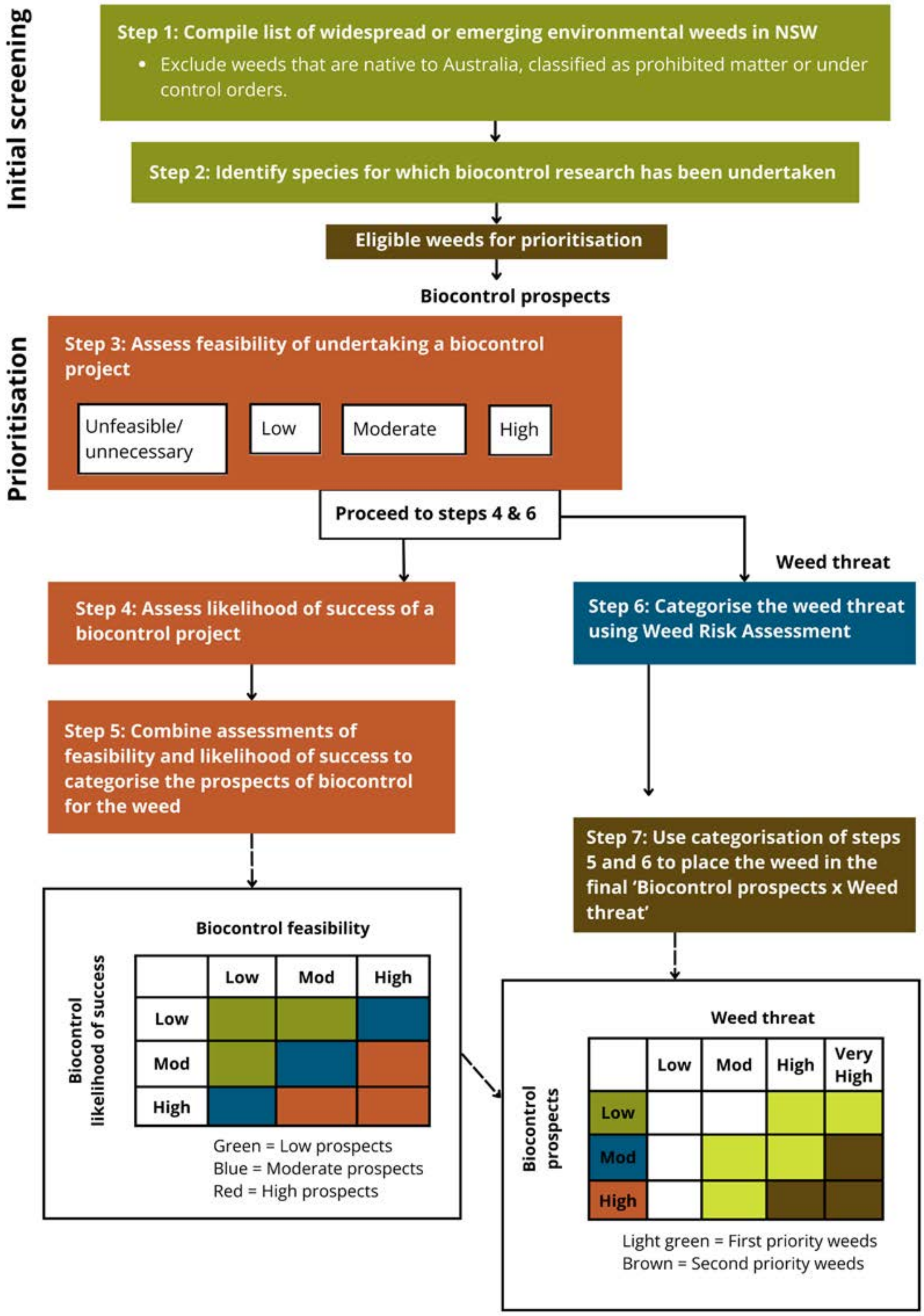


Figure A5 Schematic of prioritisation framework deployed in New South Wales

Furthermore, the Paynter *et al.* (2009) quantitative approach was recently applied in the European context by Lesieur *et al.* (2023) without modification, and a Biological Control Target System (BCTS) was developed and applied in a series of three recently published papers in South Africa (Downey *et al*. 2021, Paterson *et al.* 2021, Canavan *et al.* 2021). The BCTS system retains the three-module quantitative approach developed by Paynter *et al.* (2009) and uses a modified scoring system as follows:

$$\textit{BCTS index} = \textit{Impact of target plant} \times \textit{Likelihood of achieving success} + \textit{Investment required}$$

The investment-required component of the BCTS system consists of attributes that are considered under feasibility of biocontrol (Morin *et al.* 2016). The BCTS system has furthermore been adapted for use in the western United States with some attribute and scoring modifications (Winston *et al.* 2024).

2.2 ASSESSMENT OF WEED THREAT

The fundamental requirement to identify a weed's 'importance' is introduced in Paynter *et al.* (2009), which notes the need to ensure appropriate allocation of public investment into biocontrol RD&E by ensuring robust identification of priority weeds. Paynter also noted the lack of significant research to determine the most suitable assessment criteria to determine priority weeds.

The review in Section 2.2 largely explores the accepted approach described by Hennecke *et al.* (2013) of separately assessing a weed's importance. Weed importance has been defined differently in the various biocontrol prioritisation processes, and these are summarised in Table A3. Typically, all processes assess weed impacts, and some processes also assess other factors. For simplicity and consistency, weed 'importance' is referred and equated to hereafter as 'weed threat'.

Table A3 Summary of characteristics of frameworks for weed biocontrol prioritisation and their Australian and international weed-prioritisation derivatives

Reference	Type of Document and Description	Assessment of Weed Threat ('Weed Importance')
Paynter *et al.* (2009)	Weed biocontrol prioritisation framework The first framework developed in Australia and applied for a compiled list of Australian weeds, which includes the 71 nominated Weeds of National Significance (WoNS), 50 approved biocontrol weed targets and biocontrol target weeds in operation prior to 1983.	Weed threat is assessed against a single question: Is the weed sufficiently widespread/intractable/important to justify investment in biocontrol? The weed-threat score = WoNS ranking × 43.29 for the 71 weeds proposed for WoNS listing and 0.35 × 43.29 = 15.15 for all non-WoNS weeds.
Hennecke *et al.* (2013)	Weed biocontrol prioritisation framework A decision support tool that uses a matrix approach which is conducted by the proponent (e.g. state or territory governments, Australian Government, industries, non-government organisations). It is based on a modified Paynter *et al*. (2009) and is endorsed as a national standard for prioritising weed biocontrol candidates.	This is a decision support tool that recommends the use of existing systems to assess weed risk to prioritise weeds to be considered for biocontrol prospects analysis. It recommends that this is achieved by assessing weed importance and the feasibility of coordinated control. Weed importance is not defined or described. These two factors are scored between low, medium and high. Only weeds scoring medium or high for each factor are progressed, where they are then combined in a matrix (impact × feasibility of coordinated control).
Van Klinken *et al.* (2016)	Australian weed prioritisation A qualitative-assessment method developed for the pastoral industry, using a matrix approach. It is funded by Meat and Livestock Australia and is aimed at synthesising knowledge (including expert elicitation) into a form readily accessible by decision-makers.	A weed candidate list was predetermined by Grice *et al*. (2014) and provided for assessment. Weed impact (current and potential) information is collated from published literature, internet resources and consultation with on-ground weed officers. Impacts are scored in a single question and categorised as negligible, low, moderate or high, using predefined criteria according to scale of production loss or disruption to enterprise ('impact of weed to grazing industry'). 'Negligible' scores are not considered further in the process. It also includes identification of the primary goal/s of management programs.
Morin *et al.* (2016, 2019) Gooden et al. (2023)	Australian weed prioritisation, various This was developed for environmental weeds in NSW and includes a comprehensive list of 266 key weeds that threaten biodiversity.	Weed importance is derived by assessing weed risk (NSW weed risk management system; Johnson 2009a) in accordance with multiple questions related to weed invasiveness, weed impacts and potential distribution. Weed-risk scores are then categorised into negligible, low, moderate, high and very high categories for analysis alongside biocontrol prospects within the assessment matrix.
Raghu and Morin (2018)	International weed prioritisation This was developed for the western United States.	US state coordinators requested a list of key weeds of importance in their jurisdiction. An online survey was circulated by state coordinators to relevant stakeholders to seek their input on economic and environmental impacts. Survey results were summarised and circulated to state coordinators, followed by a face-to-face workshop in which weed economic and environmental impacts were classified as negligible, low, moderate or high, according to descriptive categories.

Reference	Type of Document and Description	Assessment of Weed Threat ('Weed Importance')
Paterson *et al.* (2021) Canavan *et al.* (2021)	International weed prioritisation This was developed for South Africa as a section of the Biological Control Target System.	A total of 367 weeds are regulated under the *National Environmental Management: Biodiversity Act 2004* (South Africa). Further, 68 species listed have had biocontrol agents released on them; thus, 299 species were considered potential targets in the Biological Control Target System. This is in accordance with four attributes that can be scored from 1 to 10: (a) threat or impact posed by the target plant, (b) geographic distribution, (c) alternative control options and (d) conflicts of interest.
Lesieur *et al.* (2023)	International weed prioritisation This was developed for Europe.	An initial weed candidate list consisted of the 'Union List' (Regulation (EU) No 1143/2014 2022; European Parliament 2022). This was adapted from Paynter *et al.* (2009) and includes 12 questions, covering aspects such as the distribution of the weed in EU, current range expansion, invasive status elsewhere and ecological, economic, human or animal health impacts (in EU and worldwide). Total score is calculated to a maximum of 100. Scoring is conducted by a group of experts and stakeholders. Native species and potential conflicts of interest are excluded.
Winston *et al.* (2024)	International weed prioritisation This was adapted from the South African Biological Control Target System for use in the western United States.	Noxious weed lists from 12 western states were compiled. Weeds previously or currently targeted for biocontrol in the United States were removed from the list, yielding a starting list of approximately 300 species. The impact and importance of the target weed are based on the four attributes proposed in the South African Biological Control Target System, but the scoring is modified for western US context.

Hennecke *et al.* (2013) recommended the use of existing systems to assess weeds in order to prioritise those to be considered for biocontrol prospects analysis but did not describe or prescribe a methodology. In Hennecke *et al.* (2013), weed importance is also undefined but taken to be akin to weed risk. Morin *et al*. (2016) and Gooden *et al.* (2023) used the outcomes of the NSW system for weed risk management (WRM; Johnson 2009a), adopted from the SA system described by Virtue (2010). These two state systems strongly align with the National Post-Border Weed Risk Management Protocol (WRM protocol; Standards Australia International 2006), which is considered best practice. This protocol and other systems that are included in this review are summarised in Table A4. These are considered along with biocontrol prioritisation processes in the following discussion.

This review acknowledges that other states and territories in Australia use a post-border weed risk management system (WRMS). Other WRMS include:

- a literature review-style risk assessment, which describes a weed's biology and considers distribution, preferred habitat, impacts and pest potential. It is used in Qld (Queensland Government 2021)
- a two-factor, multi-question assessment of impacts and invasiveness, and a ratio of present to potential distribution. It is used in Vic (Standards Australia International 2006)
- an assessment of weed risk (invasiveness, impact and potential distribution) and no consideration of management feasibility. It is used in WA (Moore *et al.* 2022)
- a multi-question assessment, including historical, biogeographical and biological/ecological details of the species to determine whether the weed should be rejected, evaluated or accepted into the state (in which evaluation may include reassessment using more information or a cost-benefit analysis). In addition, species may also have detailed assessment reports. It is used in Tasmania (Tasmanian Government 2024).

While these other systems are considered robust and fit-for-purpose processes, they do not strictly adhere to the WRM protocol (Standards Australia International 2006) and are therefore not thoroughly considered in this review.

Table A4 Key national processes for weed-management prioritisation considered in this review, and a summary of their applications

System	Description and Application
National Framework for the Management of Established Pests and Diseases of National Significance (EPDNS)	The EPDNS is a key deliverable of the Intergovernmental Agreement on Biosecurity, providing a strategic, consistent, scientific and risk-based approach to managing the impacts of nationally significant pests and diseases. The framework allows for prioritising actions and focusing on pests and diseases according to risk. It does not prescribe a prioritisation process but rather provides criteria that need to be satisfied for a species to be included under the EPDNS. Programs such as Weeds of National Significance (WoNS)* that are developed under the EPDNS satisfy the criteria and develop their own prioritisation process. Biocontrol fits broadly within the EPDNS; however, the pipeline strategy also states that biocontrol priorities should extend to new and emerging species. *Note that previous iterations of WoNS predated the EPDNS and hence EPDNS only applies to determining any future WoNS.
National Post-Border Weed Risk Management Protocol	This protocol represents current best practice for weed-management science and underpins two Australian and New Zealand Standards (AS/NZS 4360:2004 Risk management, and HB 203:2006 Environmental risk management: principles and process). It is used by NSW (Johnson 2009a) and SA (Virtue 2010) and is adapted for the NT (Setterfield *et al.* 2022). Further, it has been used or recommended for use in some of the frameworks for biocontrol-specific prioritisations (Hennecke *et al*. 2013, Morin *et al*. 2016, Gooden *et al*. 2023). The protocol employs a multi-step iterative process to determine risk and includes extensive analyses of a weed's invasiveness, impacts, current and potential distribution and spread pathways. A total risk score is combined in a matrix with a score for feasibility of control to determine a management objective. The system requires the land use to be identified so the impacts questions are answered in relation to the specified land use. If a weed has production and environmental impacts, a separate assessment is required for each land use. Impacts on human and animal health and some aspects of social values are considered but cultural values are not..
Weeds of National Significance (WoNS)*	This is an assessment process to determine high-impact widespread weeds that could benefit from national coordinated action. The original methodology was developed for the first 20 WoNS (Thorp and Lynch 2000) and reviewed by the Bureau of Rural Sciences in 2009 for an additional 12 WoNS (Lizzio *et al*. 2010). The Bureau of Rural Sciences methodology was further refined through an expert elicitation workshop and informed the final 2010 prioritisation methodology (Mewett *et al*. 2011), upon which species are ranked. Assessment of the second round of WoNS considered • weed risk, which includes invasiveness, impacts and values (environmental, economic, social) criteria, all weighted equally • feasibility of control, in accordance with nationally agreed feasibility-of-control criteria. Species are ranked according to final scores, which are determined using the following formula: Score= (Invasiveness + Spread) × (Impacts + Value) Feasibility of coordinated control is considered in that species have to demonstrate that they meet technical feasibility criteria from the National Environmental Biosecurity Response Agreement, but this criterion is not scored or considered further in the final ranking. Ranked species are then subject to policy considerations that influence the final 12 WoNS. *The WoNS assessment methodology is currently being updated.
National Priority List of Exotic Environmental Pests, Weeds and Diseases	This is a priority list based on risk assessment to identify high-risk pests, weeds and diseases. The list contains 168 exotic species of significant environmental and social amenity risk to Australia across eight biological groups (ABARES 2021). Species are assessed and ranked against five parameters using a semi-quantitative method in an expert elicitation process. The parameters are entry, establishment, spread, impact on the environment and impact on social amenity. It adapts the Environmental Impact Classification for Alien Taxa (EICAT) and Socioeconomic Impact Classification of Alien Taxa (SEICAT) categories for assessing environmental and social impacts, respectively (ABARES 2021).

The key elements of systems to assess weed risk (those specific to biocontrol and more general systems) are described and compared in the sections that follow.

2.2.1 Determining weeds for prioritisation

Before assessing a weed's threat, it is necessary to have a list of suitable weeds to assess for prioritisation. Some methodologies include a process for selecting relevant weeds for assessment when they have not been able to rely on pre-determined lists. ABARES (2021) developed a multistep process that begins with an informed 'long list' of possible species for assessment and applies various filters to create a 'short list' of species.

Many biocontrol prioritisation methodologies are able to use pre-existing species lists, that is, a set of weeds that have been identified for their relevance through other research or prioritisation processes. For example, Paynter *et al*. (2009) relied on the 1999 Weeds of National Significance (WoNS) assessments, supplemented with additional weeds, to identify weeds' 'importance'. Gooden *et al*. (2023) used a list of environmental weeds that had been prioritised using the NSW WRMS (Johnson 2009a). Some industry prioritisation approaches draw on known 'weeds of importance' in that industry (e.g. Van Klinken *et al*. 2016, Morin and Raghu 2020). In processes in which a weed list has already undergone a form of threat or risk assessment, the list of weeds typically moves straight to assessing biocontrol prospects.

In fewer cases, for example, the exotic environmental pests and diseases list (EEPL) and the western US biocontrol prioritisation process, the list of weeds of importance had to first be compiled for subsequent weed-threat assessment (ABARES 2021) or biocontrol prospects analysis (Raghu and Morin 2018).

Predetermined lists can be useful in certain contexts, such as agricultural and pastoral industries, in which the importance of a weed may be linked more strongly to production costs. Consideration should be given to how pre-existing lists are determined to avoid potential bias in selecting weed candidates for prioritisation. While it is appropriate to include weeds in accordance with restricted impacts in the above example, for this project, consideration should be given to weeds impacting a range of values, including social, cultural, agricultural and environmental. Although some pre-existing national lists are relevant to this project (e.g. WoNS, weeds listed in national Threat Abatement Plans), they should serve as a starting point and be supplemented through other means.

2.2.2 Eligibility criteria

Screening questions or eligibility criteria are a feature of some prioritisation processes and provide a stop-go point that excludes weeds that do not meet an essential requirement. They also increase the efficiencies of the formal assessment process by limiting the number of weeds for further assessment. This is often necessary to meet capacity limitations in assessing large numbers of species (ABARES 2021).

Prioritisations undertaken for industry groups in Australia (Van Klinken *et al*. 2016, Morin and Raghu 2020) and those developed for overseas (Raghu and Morin 2018, Paterson *et al*. 2021, Lesieur *et al*. 2023) do not disclose whether screening questions are a feature of prioritisation processes. It appears, in some cases, that prioritisations are conducted on predetermined weed lists, such as jurisdictional or national noxious weed lists.

Species inclusions

Most systems reviewed exclude native species from further assessment (Paynter *et al*. 2009, Hennecke *et al*. 2013, ABARES 2021). Some systems prioritise established weeds over new and emerging weeds (Morin and Raghu 2020) while others include both (Van Klinken *et al*. 2016). Conversely, systems used to prioritise prevention targets screen for weeds that are not present in Australia or weeds subject to a national eradication program (ABARES 2021).

Conflict species

Conflict species are those for which there is a divergence of opinion on the detrimental impacts of a plant as a weed and any economic, amenity or environmental use (EIC 2019). These species are approached differently across biocontrol frameworks and processes. While Paynter *et al*. (2009) excluded weeds that have significant or insurmountable conflicts of interest from further weed-impact assessment, Hennecke *et al*. (2013) did not exclude them but required these species to be identified and considered in the EIC endorsement process (determined by the Biological Control Act; see Section 1).

Morin *et al*. (2016) and Gooden *et al*. (2023) did not consider conflict species upfront but incorporated this factor into the 'feasibility' dimension of the biocontrol prospects analysis. When significant and insurmountable conflicts are identified (e.g. *Arundo donax*), biocontrol is deemed unfeasible or unnecessary and is not analysed further for 'likelihood of success'; thus, the species are excluded from the final priority list.

While investigation of issues associated with conflict species is important, an existing intergovernmental process is in place and provides an agreed-upon procedure to review potential conflicts (EIC 2019). This procedure takes precedence over any other assessment of a weed's potential conflict and is viewed as the principal means by which conflict should be considered.

Species' extent

Of the methodologies reviewed, only two overtly consider the extent of weed distribution in Australia as an eligibility criterion. Selection of the 12 additional WoNS in 2012 required the weed to be naturalised and invasive in at least one state or territory and for its potential range to involve more than one state or territory (Australian Weeds Committee 2011).

The national EEPL (ABARES 2021) screens for exotic invasive species, that is, those that are not present in Australia or subject to national eradication. This variation occurs because the EEPL focuses on preventing invasive species that are not present in Australia, a different context to determining the threat of established weeds. In other methodologies, weed distribution is considered in the assessment of threat (Paynter *et al*. 2009, Morin *et al*. 2016, 2019, Gooden *et al*. 2023).

Given that the scope of the National Weed Biocontrol Pipeline Strategy (CSIRO and Centre for Invasive Species Solutions 2023) is to consider weeds that are either emerging or widespread in Australia, it is reasonable to require a species to be present in at least one state or territory to meet eligibility requirements. This encompasses nationally significant weeds (e.g. WoNS) and those considered priorities by a limited number of stakeholders. Weed distribution is further considered in Section 2.2.3 on assessment criteria.

Eradication targets

Morin *et al*. (2016) and Gooden *et al*. (2023) included a screening question on the management objective of a species. Prohibited matter (NSW eradication targets or weeds under control) are excluded from further assessment for NSW environmental weeds prioritisation because retaining populations of these weed targets upon which to release biocontrol agents was not deemed desirable.

Selection of the 12 WoNS in 2012 also required that eradication of the weed was not considered feasible (Australian Weeds Committee 2011). This requirement was recommended as a screening question to determine future WoNS (Wild Matters 2023). Detail on the scale of eradication (e.g. national, jurisdictional or other) was not clear.

A national program needs to consider the scale of the eradication. It would be reasonable to exclude a weed that is a national eradication target because there is a national consensus on the management approach. However, there are instances (e.g. parthenium) in which a weed is an eradication target in one state but widespread in another. In this instance, consideration of a biocontrol agent to assist management where it is widespread could be reasonable.

Prior level of biocontrol investment

Morin *et al*. (2016) and Gooden *et al*. (2023) excluded weeds that either had no previous biocontrol research worldwide or were only at the exploratory stage of research, acknowledging the desire for investment of project funds into Phase 2 host-specificity testing that has a lower risk and higher potential impact, and Phase 3 mass rearing and release of identified and most promising candidate biocontrol agents. This was decided at the project level to identify areas of investment that would result in on-ground activity within three to five years.

Given that the scope of this project focuses on categorising weeds along the entire RD&E biocontrol pipeline, it is considered inappropriate to exclude weeds according to no or low prior levels of biocontrol research.

2.2.3 Assessment criteria

Assessment criteria, that is, individual factors that describe a weed's threat, vary across methodologies. Some approaches consider a single criterion, such as impacts (Van Klinken *et al*. 2016, Morin and Raghu 2020) while others (Paynter *et al*. 2009, Morin *et al*. 2016, 2019, Paterson *et al*. 2021, Gooden *et al*. 2023) assess multiple criteria, including:

- impacts (current or potential)
- invasiveness
- feasibility of control options (biocontrol and other)
- weed distribution (current or potential).

How these criteria are structured also varies but broadly falls into one of two approaches:

1. a standard weed risk assessment approach (aligned with the WRM protocol), which includes several questions per criteria (e.g. Johnson 2009a, Lizzio *et al*. 2010, Virtue 2010). Each question is scored, and scores are combined to form a final score for each criterion
2. an alternative approach that includes one question per criterion (e.g. Van Klinken *et al*. 2016, Raghu and Morin 2018, Evans *et al*. 2019). A single score is applied for each criterion.

Application of the criteria may focus on assessing criteria from the perspective of multiple values (e.g. impacts to agriculture, the environment and society) or a single value, such as weeds impacting the grains or livestock industry or environmental values.

Commonly applied criteria are explored in more detail in the subsections that follow.

Impacts

This criterion considers the potential and realised environmental, social and economic impacts of a weed. Weeds can cause a loss in the supply, quality or use of desired products and services, for example, agricultural production, nature conservation, recreation, water supply and urban infrastructure. Weeds can also affect human health directly.

Impacts are assessed in all the systems for biocontrol and weed prioritisation reviewed, and their assessment is considered a critical element. How impacts are described varies between methodologies but can include:

- reduced establishment and yield of desired plants
- reduced quality of products or services
- ability to restrict movement and access to people, water and machinery
- impacts on the health of people, animals and the environment
- changes to the way enterprises are managed because of weed invasion
- changes to size and fitness of native plant or animal populations
- changes to the structure and composition of ecosystems, including species' extinction.

One of two general approaches are typically taken when assessing impacts:

1. Score-based assessment to quantify the impact factors listed above

This approach is used in the WRM protocol (Standards Australia International 2006). Box A2 highlights impact questions from the NSW Weed Risk Management System (NSW WRM; Johnson 2009a). This approach does not separate environmental, agricultural or social impacts or values. Rather, it requires the assessor to specify the affected land use, and the impacts are based on that land use. For example, if the land use is 'conservation and natural environments', the assessment only considers environmental impacts and some associated social impacts, such as human and animal health and access restrictions. Conversely, if the land use is 'cropping', the same questions are answered through an agricultural lens. If the weed affects multiple land uses, separate assessments are required.

Box A2 Impact questions from the NSW Weed Risk Management System (Johnson 2009b)

Q1. Does the weed reduce the establishment of desired plants?
Q2. Does the weed reduce the yield or amount of desired vegetation?
Q3. Does the weed reduce the quality of products, diversity or services available from the land use?
Q4. What is the weed's potential to restrict the physical movement of people, animals, vehicles, machinery or water?
Q5. What is the weed's potential to negatively affect the health of animals or people?
Q6 Does the weed have major positive or negative impacts on environmental health?

2. Category-based assessment

Category-based assessment systems typically ask a single question for each impact area or value (e.g. environment, agriculture and social), and all outputs are aggregated to give a final impact ranking.

The Environmental Impact Classification for Alien Taxa (EICAT; International Union for Conservation of Nature 2020) and the Socioeconomic Impact Classification of Alien Taxa (SEICAT; Bacher *et al*. 2018) are considered international standards for measuring the severity of impacts caused by animals, fungi and plants living outside their natural range. These systems assign a category (e.g. high, medium, low) by asking a single impact question per impact type and choosing a statement that best describes the current or potential impact. This approach was adapted for the EEPL by modifying categories and adding scores (Evans *et al*. 2019).

Biocontrol prioritisation systems for the grains and livestock industries also apply this approach (Van Klinken *et al*. 2016, Morin and Raghu 2020).

Invasiveness

Invasiveness refers to a weed's ability to establish, reproduce and spread. Faster spreading weeds are considered a higher priority for control. Direct measurement of spread is difficult without data collected over time; hence, invasiveness is typically assessed by proxy characteristics known to be linked to invasiveness, including:

- the ability of the weed to establish among existing plants
- the weed's tolerance to average weed-management practices
- the reproductive ability of the weed
- the dispersal ability of the weed
- the likelihood of its long-distance dispersal by human-assisted and natural means.

Invasiveness is considered in most existing systems for biocontrol threat prioritisation using approaches to the WRM protocol (Standards Australia International 2006). Prioritisation processes such as EEPL (Evans *et al*. 2019) assess entry, establishment and spread, which incorporate many of the above considerations of invasiveness.

Potential distribution

Under the WRM protocol approach, potential distribution means the potential area the weed may occupy, for example, 'the weed has a potential to spread to between 40% and 60% of the land use in the [defined area; e.g. Region, Jurisdiction]' (Johnson 2009b). Other post-border systems:

- estimate the area (in hectares) of suitable soils and climates (Moore *et al*. 2022)
- use a ratio of current to potential distribution (Lizzio *et al*. 2010, Agriculture Victoria 2024)
- calculate climate and habitat suitability scores and the extent of the habitat the weed could occur in (Setterfield *et al*. 2022).

While distribution data (current and potential) is an important factor in determining weed risk, it is important to recognise data limitations, in which data are often incomplete or there is low confidence in the data. In addition, the methodology used to collect it may vary temporally or geographically, making the aggregation of data sets or the direct comparison between weeds more difficult (Mewett *et al*. 2011). This uncertainty and data incompleteness is likely to be greater in a national system of weed risk assessment than regional or state ones.

In the case of the SA, NSW and NT WRM systems, potential distribution is a single-question factor that is multiplied with both invasiveness and impacts (both of which have multiple questions). As a result, a weed's potential distribution may heavily weight the final risk score (specifically if the weed has a moderate to high potential distribution). When there is a level of uncertainty associated with the potential distribution, this may result in an artificially high weed-risk score. Assessment of weed distribution is acknowledged as introducing significant uncertainty in the various Australian-based methods for assessing weed risk and is not approached consistently across these methods (Stone and Byrne 2011).

Assessment of potential distribution at a national scale has been undertaken for WoNS (Lizzio *et al*. 2010), which considered four questions on current and potential distribution (see Box A3). These questions required national current distribution data (provided by states and territories) and modelling outputs from Climatch. Given that distribution data were provided in many 'different non-compatible spatial formats and projections', work was required to convert data into a useable format for analysis (Hennecke 2012).

Box A3 Current and potential distribution questions to assess Weeds of National Significance

- What is the weed's current distribution (measured as a percentage of Australian grid cells in which the weed is present)?
- In how many jurisdictions are populations of the weed currently present?
- What is the weed's current potential ratio (i.e. what percentage of the potential distribution is currently occupied by the weed and, therefore, what is its maximum potential for spread)?
- What is the future potential (based on 2020 climate projection) distribution (compared with potential and rate as contracting, steady and expanding)?

Factors relating to potential distribution, such as climate and habitat suitability, were also considered for the EEPL (Evans *et al*. 2019) when assessing entry, establishment and spread.

Feasibility of control

Feasibility of control, sometimes referred to as 'feasibility of coordinated control', is considered in the WRM protocol (Standards Australia International 2006) and other WRMSs that align with the WRM protocol, including Virtue (2010) and Johnson (2009b). Feasibility of control is an assessment of the practicalities of targeted control and how successful it is likely to be. In the WRM protocol, feasibility is assessed through three criteria:

- current distribution
- control costs
- duration (or persistence).

Hennecke *et al*. (2013) recommended that 'feasibility of coordinated control' be considered in Stage 1 and suggested that feasibility criteria in existing systems to assess weed risk be used. The most relevant of these is the aforementioned WRM protocol (Standards Australia International 2006).

Under the WRM protocol, a weed that has a high feasibility of control typically has restricted current distribution, low control costs, high efficacy of available treatments, a short-lived seed bank and a low chance of reinvasion occurring from outside of controlled areas. The WRM protocol (Standards Australia International 2006) selects for these, and they are assigned a higher score.

The application of this approach is confused by the fact that Hennecke *et al*. (2013) proposed the selection of weeds for subsequent biocontrol prospects analysis as those that have low feasibility of control (presumably weeds that are costly to control or have control methods that have low efficacy, are widespread and have long-lived seed banks). This is where biocontrol options are considered to provide the most benefit. This is the inverse of how feasibility is applied through the WRM protocol (Standards Australia International 2006).

A similar approach to Hennecke *et al*. (2013) was adopted by Paterson *et al*. (2021), scoring plants that can be controlled by other methods low and plants that can only be controlled through biocontrol as high. However, using the approach of Patterson *et al*. (2021), most plants received an intermediate score (i.e. they were only partially controlled by other methods), which reduced the ability of the criteria to prioritise one species over another.

2.2.4 Assessment process

Two main assessment processes have been employed for weed-threat prioritisation and are discussed in the subsections that follow.

Expert elicitation

The use of expert elicitation and judgement has become a routine part of decision-making process in biosecurity and other areas of natural-resource management (Van Klinken *et al*. 2016, Hemming *et al*. 2018).

The optimal group size for experts making accurate decisions is between five and 12 participants, resulting in reduced or limited bias (Robertson *et al*. 2003 in Paynter *et al*. 2009, Van Klinken *et al*. 2016).

Expert elicitation processes typically follow structured protocols to ensure the quality and reliability of expert judgements (Hemming *et al*. 2018). Protocols, such as IDEA (Hemming *et al*. 2018) and the modified Delphi approach used in Evans *et al*. (2019), consider psychological and mathematical research and decision theory to minimise cognitive and emotional biases. These protocols recommend the number of participants, how the information is elicited and how questions should be asked. Figure A6 summarises the elicitation process conducted for the EEPL (Evans *et al*. 2019, ABARES 2021).

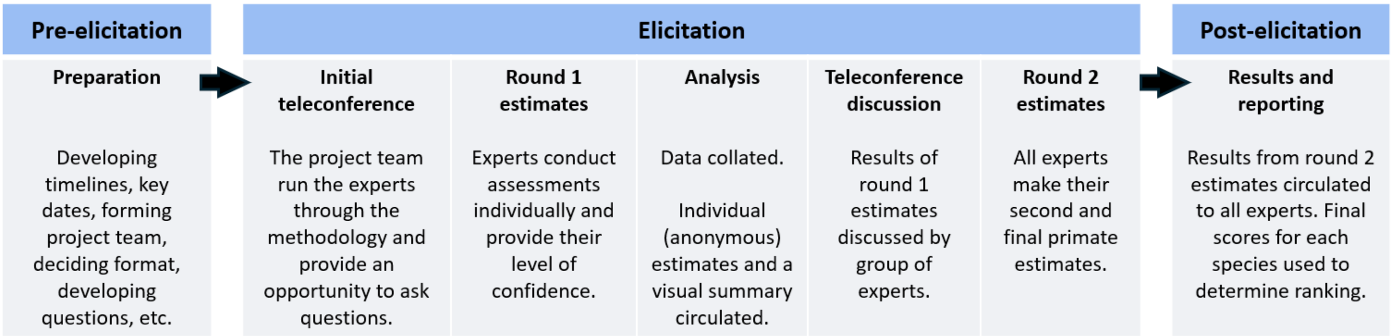


Figure A6 Expert elicitation used in the Exotic Environmental Pests and Diseases list

Other processes

Pooled independent group judgements through expert elicitation have been found to outperform potentially biased individual expert assessments, specifically, in data-limited, high-uncertainty contexts (Hemming *et al*. 2018). However, a range of other assessment processes are also used, specifically, when resources are limited, data are deficient, or time limits are short.

The WRM protocol (Standards Australia International 2006) emphasises the importance of a consultative team approach that captures various views, experiences and expertise, giving the example of running a series of workshops and building on existing systems and networks that may be in place at local or regional levels. User guides for the SA (Virtue 2008) and NSW (Johnson 2009b) systems do not prescribe or recommend an assessment process; however, both independent and group assessment are undertaken in NSW, depending on the situation (Johnson, personal communication, 19 June 2024).

Observations of the approaches used in the NSW WRM suggest that assessment processes undertaken at the jurisdictional and regional levels can vary. Assessments are generally conducted in a facilitated group setting with representatives from across weed-management organisations. While this is a form of expert elicitation, it typically does not follow a specific protocol and is instead conducted in an open group setting, relying heavily on pooling knowledge and facilitation to reach consensus. In other cases, specifically, for weeds for which there are good references and high-confidence data sources (Johnson, personal communication, 19 June 2024), assessments are completed by independent experts on weed risk assessment, who gather information from available literature (e.g. on seed longevity, impacts) and seek input from weed managers on current distribution and management feasibility. Hybrids of these two approaches are also in use in NSW, in which multiple experts conduct independent assessments, compare and adjust results before presenting to a land-management representative group for peer review.

The assessment process used in the NT WRMS is described in Setterfield *et al*. (2022) and prescribes that assessments are to be completed by a technical committee, consisting of broad stakeholder representation. Evidence is prepared and presented to the committee, which then debates and determines the outcome through consensus.

Biocontrol prioritisation conducted by Morin *et al*. (2016, 2019) and Gooden *et al*. (2023) used existing assessments prepared by individual experts on weed risk assessment, which were successfully used to provide weed risk assessment scores, contributing to the prioritisation outcome.

Expert elicitation is considered the best approach to assessments; however, there are also many instances or processes in which assessments are conducted by individuals, with or without additional peer review. Thus, the two approaches are considered to provide an acceptable level of rigour, providing the process is adequately described and, ideally, contains a level of peer review.

Data deficiencies and confidence

Data deficiencies and confidence are critical considerations when prioritising weeds and are typically considered in weed risk assessments. Uncertainty can stem from a lack of information about a weed's potential distribution, impacts and invasiveness. In addition, not all information sources are equal, requiring consideration of the level of confidence the assessor can place on the information gathered.

A derivative of the WRM protocol (Standards Australia International 2006) in NSW (Johnson 2009b) uses an uncertainty score. Uncertainty is calculated by the scores of the 'do not know' compared with the total score (a percentage). Predefined levels of this percentage indicate varying confidence in the assessment. In contrast, Auld *et al*. (2012) correctly pointed out that this measure only considers gaps in knowledge (which may become future research priorities) instead of uncertainty because of biological variability, differences in perception and uncertainty because of various language-specificity issues.

The prioritisation methodology for EEPL requires experts, when assessing species, to provide evidence of the information source, along with their scores for each criterion. They are also required to self-assign a confidence level for each answer to rate the quality of information used in the assessment. The guidance provided to experts to assign a confidence rating between low and high followed the confidence level and corresponding evidence for use in the elicitation process used in EEPL (Evans *et al*. 2019). While the confidence rating does not influence the assessment score, it does allow for greater utility and understanding of the scores, as well as identifying areas requiring more research and development.

2.2.5 Scoring methods

Paynter *et al*. (2009) did not prescribe scoring methods for weed threat and instead used the original WoNS scores to identify it. Hennecke *et al*. (2013) did not prescribe a detailed scoring method, other than the identification of a weed threat into low, medium or high categories.

For other methods that were reviewed, the scoring of assessment criteria varied but was generally approached in one of two ways:

1. scoring of a single criterion that represents weed threat, for example, weed impacts (Morin *et al*. 2013, Van Klinken *et al*. 2016, Raghu and Morin 2018). In these instances, weed threat is scored or categorised as low, medium or high (or equivalent categories)
2. scoring of multiple criteria, which are combined to assign a total score, for example, questions on weed impact, invasiveness, distribution and feasibility of control are all scored, and then a formula is applied to determine a weed-threat score, allowing for ranking of species if desired (Lizzio *et al*. 2010, Morin *et al*. 2016, 2019, Gooden *et al*. 2023). In some processes criteria are weighted. Ranking of species for the EEPL also occurs, in which likelihood of entry, establishment, spread and impacts scores are calculated using a formula (Evans *et al*. 2019).

Prioritisation processes ideally aim to prioritise one species over another, and consideration must be given to the ability to separate species according to their threat category or score. A lack of separation between species limits prioritisation and instead may 'clump' species together. Some approaches avoid this by multiplying factors together to give a greater range of possible scores or by allowing scoring on a continuous scale to reduce the coarseness of the categories (e.g. high, medium, low), ensuring species are adequately separated once their final rank score is calculated (Evans *et al*. 2019). Further detail on scoring approaches is summarised in Table A3.

2.3 ASSESSMENT OF WEED BIOCONTROL PROSPECTS

The analysis of weed biocontrol prospects originally developed by Paynter *et al*. (2009) and refined by Hennecke *et al*. (2013) for application by policymakers across Australian jurisdictions combines two key dimensions: biocontrol 'feasibility' and 'likelihood of success'.

2.3.1 Biocontrol feasibility

This first dimension was considered by Paynter *et al*. (2009) as *'factors that influence the difficulty of obtaining and host-range testing biocontrol agents'*. Feasibility in Paynter *et al*. (2009) brought together four key criteria:

1. previous or current biocontrol research on the target weed conducted elsewhere. Paynter's rationale was that novel research in Australia would be more feasible (cost-effective, time-efficient) if promising candidate agents had already been identified as a result of adequately resourced and robust host-specificity testing conducted overseas
2. accessibility and ease of working in the native range of the weed
3. quality and accessibility of literature (and other evidence) regarding natural enemies of the target weed. Paynter identified that knowledge gaps on identification (taxonomy and source location) of the candidate agent/s and the target weed would delay the preparation of import permits, commencement of host-specificity testing, confidence in the resultant data and subsequent release applications
4. phylogenetic associations (relatedness) between the target weed and native or other valuable non-target plant species. Paynter identified that target weeds that had relatively close phylogenetic affinities with native or other important plants in Australia (e.g. member of the same genus) would require more effort in host-specificity testing, specifically: more extensive testing would be required on a larger pool of closely related plant species, and a higher risk of a candidate agent being rejected for release because of a broad host range.

In the workshop underpinning the Hennecke *et al*. (2013) prioritisation framework, participating experts on weed biocontrol were generally 'comfortable with Paynter's principle of assessing feasibility of biocontrol' (Hennecke *et al*. 2013). Subsequently, the CSIRO led the development and implementation of biocontrol prioritisation frameworks for environmental weeds in NSW in 2016 (this exercise was repeated in 2019 and 2023), weeds of importance to the grazing sector for Meat and Livestock Australia (MLA; Van Klinken *et al*. 2016) and grains weeds for the Grains Research and Development Corporation (GRDC; Morin and Raghu 2020).

In each of these derived frameworks, the suite of feasibility criteria was customised for each specific land use and management context. For example, Morin *et al*. (2016) incorporated additional criteria related to 'constraints and opportunities considering a range of social/political/financial, logistical and ecological attributes of the weed and candidate agent', expanding from four to nine key criteria. Morin *et al*.'s (2016) framework was refined for application in the NSW context, targeting environmental weeds only and having no scope for investment in exploratory surveys to identify novel candidate agents in the weed's native range. Thus, the Morin feasibility analysis placed greater emphasis on agent availability, knowledge of the agent and weed, and desirability of the weed as a target for biocontrol research (i.e. consideration of socioeconomic conflict, nomination status) and included the following criteria:

1. availability of a promising candidate agent
2. socioeconomic barriers/conflicts (this criterion was considered by Paynter under his 'weed importance' dimension)
3. whether the weed has already been nominated as a candidate for biocontrol research
4. investment opportunities, namely, a perception that enough investment has been made on the weed already
5. accessibility of a candidate agent
6. availability of research infrastructure and collaborative links
7. knowledge of the target weed
8. relatedness of the weed to non-target plant species in Australia
9. knowledge of the candidate agent.

2.3.2 Biocontrol likelihood of success

Paynter *et al*. (2009) developed a quantitative-assessment method to evaluate biocontrol likelihood of success according to factors affecting the impacts of biocontrol agents on the performance of their host weeds (Paynter referred to likelihood of success as 'potential impact of biocontrol'). Paynter *et al*. (2009) identified these factors using generalised linear-modelling approaches and empirical data on host-weed responses to biocontrol agents released in Australia (data for 27 weeds), South Africa (data for 23 weeds) and continental United States (data for 31 weeds). Factors tested within the models included:

1. whether the target weed is considered 'weedy' in its native range, on the premise that such weedy species are likely to be more abundant than less weedy species, less likely to be constrained by natural enemies and thus more difficult to control by introducing host-specific agents to the plant's invaded range
2. taxonomic isolation, specifically, whether the weed has any congeneric native or other valuable non-target plant species within its invaded range, on the premise that risk of non-target damage increases for non-target species that are more closely related to the target weed

3. weed life cycle (annual herb v. biennial or perennial), in accordance with prior evidence that annual plants are more difficult to control than biennial or perennial species, for example, a candidate agent would have to control an annual plant seed set within a single season at a faster rate than the host plant can set ripe fruit and then persist across seasons until the host-weed populations reemerge within the standing vegetation in the following season
4. mode of reproduction of the target weed (sexual v. asexual/vegetative), in accordance with the hypothesis that plants reproducing asexually are more heavily affected by attack from biocontrol agents than sexually reproducing species
5. weed ecosystem (terrestrial v. aquatic), in accordance with the hypothesis that aquatic weeds are more heavily affected by attack from biocontrol agents
6. geographic area and climate range, and biocontrol success is predicted to be lower for weeds that have broad geographic or climate ranges because of variation in performance of the candidate agents across habitat and climate contexts
7. number of plant species within the target-weed's genus, testing the hypothesis that there will be an increased chance of finding a suitable candidate agent for weeds belonging to more species-rich genera.

Overall, the Paynter *et al*. (2009) model combining data from Australia, South Africa and continental United States identified a subset of four key factors significantly predicting target-weed responses to attack by the released biocontrol agents; that is, the impacts of biocontrol on host-weed performance were significantly higher for species growing in aquatic or wetland ecosystems, biennial or perennial species with vegetative reproduction, and species that had restricted distributions that were not considered weedy in the native range.

In line with the outcomes of these quantitative models, along with other considerations related to knowledge of existing promising candidate agents and biocontrol research programs, Paynter *et al*. (2009) included the following criteria within the 'likelihood of success' assessment:

1. whether a well-resourced biocontrol program had been previously undertaken for the target weed overseas
2. weed ecosystem: aquatic or wetland versus terrestrial
3. weed life cycle: temperate annual, tropical or subtropical annual, or biennial or perennial
4. weed reproduction: vegetative versus seed or spores
5. weediness in native range
6. variation in plant form and function (quoted from Paynter *et al*. 2009: 'Difficulty targeting multiple forms of the weed or probability of replacement of the weed by forms or congeners of the target following successful biological control thereby negating benefits of the successful program on the subset population of the target weed')
7. growing in competitive environment: agricultural versus environmental weed
8. phylogenetic context: presence of native or valued non-native congeners in the weed's introduced range.

In the NSW prioritisation framework for environmental weeds, Morin *et al*. (2016) expanded the assessment criteria to seven for biocontrol likelihood of success:

1. weed life cycle
2. type, severity and duration of damage by candidate agent
3. synchronisation of damage by the agent with the weed life cycle
4. sensitivity of the weed to damage by the agent
5. weed habitat (but not considering agricultural v. environmental context)
6. climate matching between native and introduced range
7. parasitism or predation of candidate agent.

Some elements of Paynter *et al*. (2009) were not explicitly included in the framework for NSW weed biocontrol prioritisation, such as whether the plant is a weed of agricultural or environmental contexts (because the NSW program focused on environmental weeds only), whether the weed is aquatic or terrestrial, mode of plant reproduction, or whether the plant is considered weedy across its native range. The NSW prioritisation (Morin *et al*. 2016) also explicitly excluded from the outset weeds for which no promising biocontrol agent had been previously identified. This means that the final set of prioritised weeds in NSW were only eligible for Phase 2 (host-specificity testing) or Phase 3 (mass rearing and release) research, and no investment was available to support exploratory research int he native range to identify novel candidate biocontrol agents.

The set of likelihood of success criteria was further refined for the MLA and GRDC prioritisation frameworks, to reflect the particular land use context of the target weeds. For example, the likelihood of success criteria for grain weeds (the

GRDC framework) emphasises synchronisation of the target-weed's life cycle with the activity and damage caused by the candidate agent/s and the risks of agent populations not persisting or being sustained over growing seasons for ephemeral weed species. The GRDC framework also emphasises the importance of habitat, climate and land use variation in mediating the damage caused by the candidate agent/s to target-weed populations. These examples highlight the need and value of critically reviewing and then customising assessment criteria as required for each specific jurisdiction, land use sector or stakeholder group.

2.3.3 Scoring methods

The Paynter *et al*. (2009) scoring method weighted criteria according to which factors *'explained the most variance'* of weed biocontrol impacts, resulting from the statistical models developed using data derived from examples in Australia, South Africa and the United States (i.e. *'weighting of important factors was increased and less important factors were reduced, keeping the maximum score at 100 points'*).

However, experts participating in the Hennecke *et al*. (2013) prioritisation workshop noted that *'there is a lack of transparency in the Paynter approach inherent in its scoring system. It was agreed that the scoring system in Paynter appeared somewhat arbitrary and it was difficult to understand why certain weights and scores had been chosen'*. Hennecke *et al*. (2013) thus recommended a matrix-based approach to analysing biocontrol prospects (see Section 2.1), and no weighting amongst the assessment criteria. Subsequent refinements of the Hennecke *et al*. (2013) matrix-based approach found that giving a single score to questions inadequately draws on expert knowledge and thus lacks transparency (Van Klinken *et al*. 2016, Raghu and Morin 2018).

The NSW prioritisation approach (Morin *et al*. 2016, 2019, Gooden *et al*. 2023) assigns each of the 16 criteria a non-weighted nominal (ordinal) score of 'negative influence' (e.g. not supporting the criterion, for example, no suitable candidate agents identified), 'neutral influence' (e.g. natural enemies identified but no knowledge of their impacts on the host weed) or 'positive influence' (e.g. promising agent/s identified with known adverse impacts on the target weed). Feasibility and likelihood of success are then categorised overall into low, medium and high, according to the combination of their criteria scores. These approaches further improved the quantitative system by including commentary and rationale behind decisions to increase its transparency (Morin *et al*. 2016, Raghu and Morin 2018, Morin *et al*. 2019, Gooden *et al*. 2023).

2.3.4 Calculation of biocontrol prospects

The Paynter model does not include an explicit stand-alone calculation of biocontrol prospects but instead combines weed importance/threat with biocontrol feasibility and likelihood of success into the same equation, resulting in a single 'priority for biocontrol' score for each target weed (see Section 2.1). In contrast, Hennecke *et al*. (2013) and subsequent applications in NSW and elsewhere categorised 'biocontrol prospects' into low, medium and high for each weed by bringing together the feasibility and likelihood of success values into a two-dimensional matrix (see Figures 5 and 6). This decision-matrix approach is more transparent and flexible and provides more room for experts to reach a consensus (Hennecke *et al*. 2013).

3.1 ALIGNMENT OF WEED BIOCONTROL PRIORITISATION WORKFLOWS WITH POLICY AND PRACTICE

In line with the reviews of policy (see Part A Section 1) and existing prioritisation methodologies (see Part A Section 2), the key considerations of the authors of the framework to develop the present national weed biocontrol prioritisation methodology (see Part B) were:

- retainment of the overarching weed biocontrol–prioritisation workflows presented by Hennecke *et al*. (2013) and refined by subsequent applications of the matrix-based approach (Morin *et al*. 2016, Van Klinken *et al*. 2016, Raghu and Morin 2018, Morin *et al*. 2019, Gooden *et al*. 2023).
    - The workflows have demonstrated robust and transparent prioritisation of weed candidates for biocontrol for Australian jurisdictions and stakeholders.
    - The BCTS has explicitly removed weeds that have been or are in the RD&E biocontrol pipeline from consideration at the outset (see Table 3). We intend to present a research pipeline prioritisation approach (as outlined in the endorsed strategy) and a matrix workflow that is able to accommodate weeds that may already be in the RD&E biocontrol pipeline.
- weed eligibility criteria:
    - include weeds established in at least one state or territory.
    - exclude national eradication targets but include weeds that are an eradication target in one state or territory when they are also widespread in another state or territory
    - do not preclude weeds in accordance with any perceived conflicts.
    - do not preclude weeds in accordance with whether prior biocontrol RD&E has occurred (or the outcome of that RD&E; see Section 2.2.2).

Additional points to note were:

- acknowledgement of the lack of readily transferrable model for assessing weed threat at the national scale prior to this framework. This review identified processes that use expert elicitation or assessment by individuals in similar systems.
- the need to modify the existing process for assessing weed risk to make its application at the national scale suitable and practical.
- the inclusion of data deficiencies and data confidence as critical components in the assessment methodology.
- that biocontrol prospects considered relevant criteria developed by Paynter *et al*. (2009) and used by the BCTS (Paterson *et al*. 2021, Winston *et al*. 2024), and included criteria relevant to the Australian context in the matrix-based approach.
- a non-weighted criteria approach to scoring outlined in the NSW prioritisation (Morin *et al*. 2016, 2019, Gooden *et al*. 2023) be maintained.

PART B

METHODOLOGY FOR NATIONAL WEED BIOCONTROL PRIORITISATION

Jatropha gall midge on bellyache bush;
Weed - **Jatropha gossypiifolia***; Photo – QDAF.*

The assessment methodology was developed using the overview of weed policy, practice and existing weed biocontrol–prioritisation methodologies (see Part A). This document comprises three main activities:

- Stage 1: Identifying weeds for assessment and assessing the weed threat using two criteria (impacts and invasiveness).
- Stage 2: Assessing weed biocontrol prospects.
- Stage 3: Combining Stages 1 and 2, resulting in a prioritised list of weeds and their prospects against the pipeline of research.

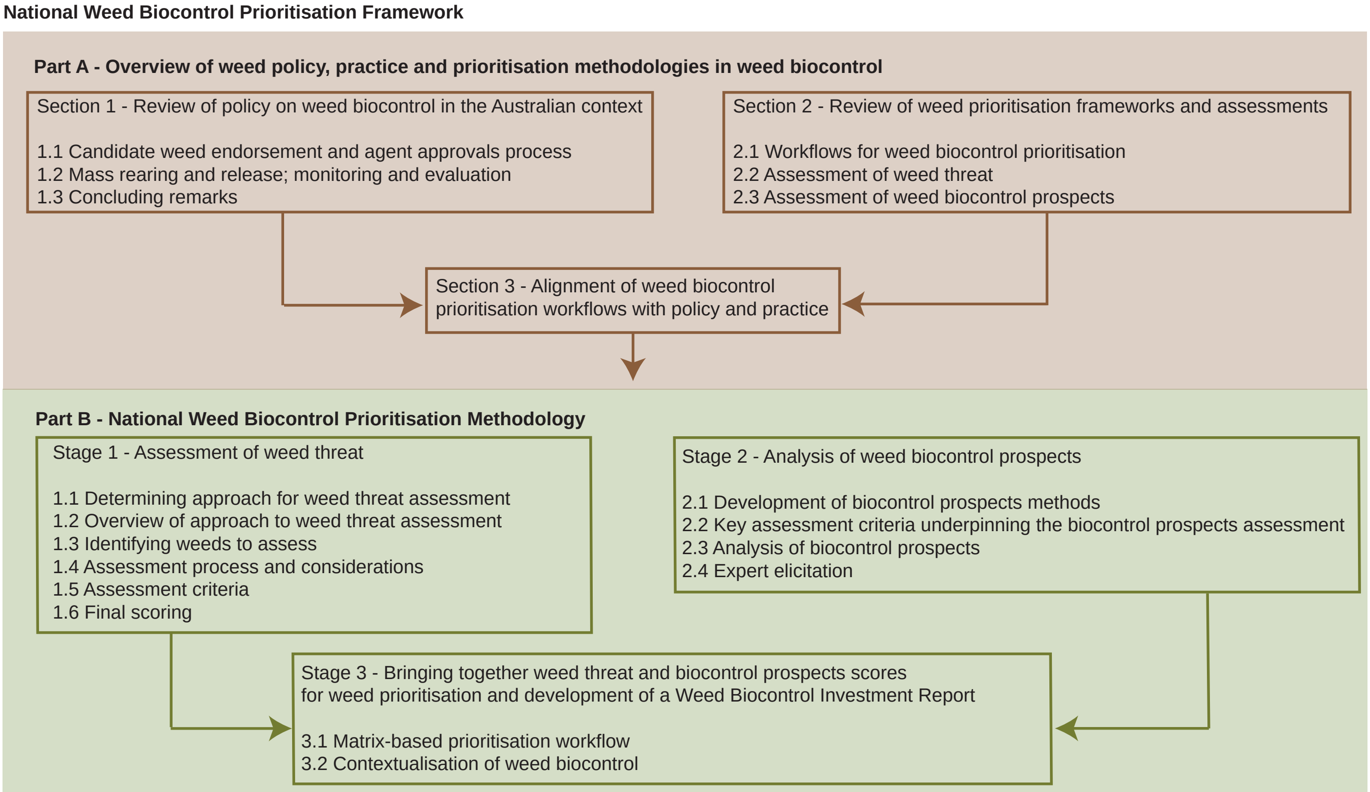


Figure 1 Schematic of components of the Framework for National Weed Biocontrol Prioritisation

Native range surveys of Parkinsonia in Argentina with FuEDEI. Photo – CSIRO.

STAGE 1: ASSESSMENT OF WEED THREAT

Developed by Wild Matters

Development of this methodology was preceded by a literature review of approaches used to prioritise weeds according to threat, within existing biocontrol prioritisation frameworks and through broader weed management–prioritisation processes. Principally focused on the Australian context, the review also considered examples from South Africa and the United States. Key reference sources included:

- Improving targeting of weed biological control projects in Australia (Paynter *et al*. 2009)
- Prioritising Targets for Biological Control of Weeds: a Decision Support Tool for Policy Makers (Hennecke *et al*. 2013)
- Australian approaches to biocontrol prioritisation (Van Klinken *et al*. 2016, Morin *et al*. 2016, 2019, Morin and Raghu 2020, Gooden *et al*. 2023)
- International approaches to biocontrol prioritisation (Raghu and Morin 2018, Paterson *et al*. 2021, Canavan *et al*. 2021, Winston *et al*. 2024)
- Other Australian weed-prioritisation approaches, including the WRM protocol (Standards Australia International 2006) and its derivatives (Johnson 2009b, Virtue 2010); the assessment methodology for WoNS (Lizzio *et al*. 2010); and the EEPL (Evans *et al*. 2019, ABARES 2021).

Following the review, two workshops were held to consider and advise on potential threat-assessment approaches, including key assessment criteria. Workshops were attended by policymakers, technical experts on weed risk assessment, weed management professionals, and environment and industry representatives (see Appendix 1).

Facilitated by Wild Matters, the workshops considered:

- the determination of weeds to be assessed
- eligibility criteria
- existing assessment methods (as covered by the review and listed above)
- pros and cons of two key assessment approaches: (i) those aligned with the WRM protocol and (ii) other approaches, such as the EEPL method
- key assessment criteria, including the merits and feasibility of their inclusion in this methodology
- the assessment process, including the assessment team and managing data confidence and deficiencies.

As a result of the review and engagement with technical experts, the methodology presented is an adaptation of the NSW WRMS, which is currently used by the NSW Department of Primary Industries (DPI) and Local Land Service regions to identify priority weeds and their associated management objectives. The WRMS methodology is not applied in its entirety to determine weed threat. Part B Sections 1.1 and 1.2 provide further detail on the assessment approach and key criteria.

1.1 DETERMINING APPROACH FOR WEED THREAT ASSESSMENT

The decision support tool for the prioritisation of weeds for biocontrol (Hennecke *et al*. 2013) recommends using existing systems to assess 'weed importance' and feasibility of coordinated control. This was interpreted as using systems described by Virtue (2010) and Johnson (2009b) that align with the WRM protocol. These systems comprise an assessment of two key components:

- weed risk (impacts × invasiveness × potential distribution)
- feasibility of coordinated control (control costs × persistence × current distribution).

Adopting this approach in its entirety was explored through two technical workshops and system analysis. As a result, a decision was made to use the NSW WRMS process, with some modifications. Key modifications are excluding potential distribution and feasibility of coordinated control from the methodology.

As a result, this methodology comprises an assessment of:

- weed impacts
- weed invasiveness.

The questions and assumptions used to assess impacts and invasiveness, as well as the individual scores associated with each question, remain unchanged from the NSW WRMS methodology.

The exclusion of potential distribution and feasibility of coordinated control is presented in more detail in Part B Sections 1.1.1 and 1.1.2. These exclusions required changes to determining final score categories. These changes are described in Part B Section 1.6 and Appendix 4.

1.1.1 Potential distribution

Several issues of potential distribution were noted during the methodology-development workshops, including:

- the ability of this criterion to significantly increase risk scores, specifically, if a weed has a moderate to high potential distribution (see Appendix 4)
- concern that this criterion may skew a weed-risk score, specifically, if there is a high degree of uncertainty associated with the potential distribution score, for example, a reliance on modelling data or knowledge that is lacking or out of date
- that the potential distribution score is derived from a single question, which may compound any uncertainty or misrepresentation associated with a potential distribution score (as opposed to other multifactor criteria, such as impacts and invasiveness)
- that, if included, a greater importance is placed on weeds occurring over large areas, as opposed to those occurring in high-value systems at smaller scales. Some weeds (such as coastal or alpine species) may have very low potential distribution nationally but may be able to occupy 100% of that habitat. These weeds, even if having a very high level of impact on that habitat, receive a lower weed-risk score in accordance with potential distribution
- the likelihood that readily available data are lacking for some species, resulting in an inability to accurately predict potential distribution
- scoring categories in the NSW WRMS are tailored to the state or regional level and cannot be applied at the national scale without modification, which would be a significant undertaking.

Assessment of weed distribution is acknowledged as introducing significant uncertainty in the various Australian-based methods to assess weed risk and is not approached consistently across these methods (Stone and Byrne 2011). Prior national assessment of weed distribution (e.g. for WoNS) required significant work to convert data into a useable format (Hennecke 2012).

Other ways of assessing weed distribution were considered, including the use of current to potential distribution ratios, binary scoring that identifies whether a weed is likely to spread throughout much of Australia versus only occurring in a restricted range, the potential of a weed's impacts to increase over time, or whether weed-range expansion occurs. Disregarding the merit of these measures, these approaches do not fit neatly into the NSW WRMS and incorporating them or changing the score banding of the existing potential distribution question is beyond the project's capacity and resources.

For these reasons, most workshop attendees agreed with excluding potential distribution from the methodology. It was considered a factor that could be used to inform investment decisions (see Part B Stage 3) in a qualitative or consultative way rather than form part of the formal assessment of weed threat.

1.1.2 Feasibility of coordinated control

The NSW WRMS also assesses feasibility of coordinated control through three components: control costs, persistence and current distribution. Highest priority is given to weeds that have high control feasibility (low control cost, highly effective control methods, low weed persistence and low current distribution), including biocontrol.

By contrast, the decision support tool (Hennecke *et al*. 2013) prioritises low feasibility of control, articulating the desire to invest in biocontrol solutions when existing control options have low effectiveness or feasibility. This might occur when there are no other viable control methods or low efficacy of existing methods, when current distribution is high or when control cost for other methods is prohibitively high. The NSW WRMS scoring of control feasibility would need to be altered to accurately reflect the intent of Hennecke *et al*. (2013).

In addition, concerns were raised about the relevance of assessing the feasibility of existing biocontrol options as part of weed-threat assessment when this is considered in the biocontrol prospects analysis (Part B Stage 2 of the project).

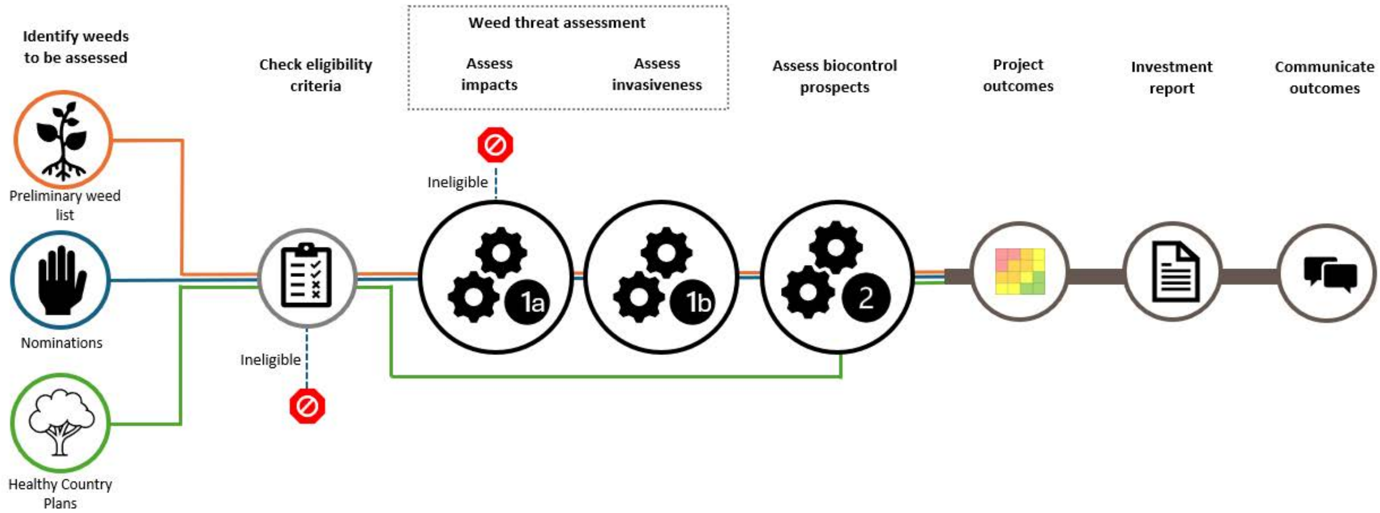
Finally, some questions on feasibility were considered difficult to answer at the national scale, at which homogenisation of results across land uses at a large scale may provide inaccurate responses to certain questions. Given these complexities, feasibility of coordinated control was considered another factor that should not be included and would be better used to inform investment decisions (see Part B Stage 3) in a qualitative or consultative way rather than form part of the formal assessment of weed threat.

1.2 OVERVIEW OF APPROACH TO WEED THREAT ASSESSMENT

The assessment approach comprises the following key components:

- identification of weeds for assessment: this considers which weeds to assess and the application of eligibility criteria
- assessment process: including how and by whom weeds will be assessed and key considerations
- assessment criteria: evaluation of a weed's impacts and invasiveness
- final scoring: assignment of a threat category according to scoring of assessment criteria.

These components (partially captured in Figure B1) are further described in the remaining sections of this methodology (see Part B Sections 1.3 to 1.6).



Preliminary weed list: State and territory priority weeds identified by weed management agencies. Weeds that meet eligibility criteria are assessed for threat.

Nomination process: Individuals, community groups NGOs, LGAs, NRM, Industry etc. nominate weeds via the online portal. Weeds that meet eligibility criteria are assessed for threat.

Healthy Country Plans: Weeds identified as having an impact on First Nations people (and their culture), identified through Healthy Country Plans and targeted engagement with First Nations organisations. Weeds that meet eligibility criteria are assessed for biocontrol prospects only, not for weed threat.

Eligibility Criteria: Each weed needs to satisfy five eligibility criterion to progress to assessment. The plant must:

1. not be native to Australia
2. be established in at least one state or territory
3. be identified to the species level
4. not be a national eradication target
5. have at least 3 reputable information sources relevant to the Australian context, that provide sufficient detail on the weed's distribution, impact and invasiveness.

Ineligible weeds that will not be progressed for assessment.

1a **Weed threat assessment: Impacts**, where weeds from the preliminary list and the nomination process that meet the eligibility criteria will be assessed for impacts. Low impact weeds will not be assessed further. Weeds with an impact category of medium or above will undergo full assessment.

1b **Weed threat assessment: invasiveness,** where invasiveness will be assessed and combined with impacts (previous step) to provide a threat score. Assessment of invasiveness considers the weed's ability to establish and persist, reproduce and disperse.

2 **Biocontrol prospects analysis**, where biocontrol feasibility and likelihood of success are analysed.

Outcomes
A National Weed Biocontrol Priority List will be developed resulting from combining the outcomes of the weed threat and biocontrol prospects assessments in a matrix.

Weed Biocontrol Investment Report
A report will be developed for approximately 20 candidate weeds with five-year implementation plans. The report will inform future investment decisions in nationally coordinated weed biocontrol projects.

Communicate outcomes
Links to project outcomes will be communicated to nominees via email at the end of the project (end of 2024).

Weeds that were deemed ineligible will also be communicated to nominees at the end of the process.

Figure B1 Summary of process for weed threat assessment to determine high-threat weeds and national weed biocontrol priorities

1.3 IDENTIFYING WEEDS TO ASSESS

The first step in assessing weed threat identifies which weeds to assess. The National Weed Biocontrol Pipeline Strategy (CSIRO and Centre for Invasive Species Solutions 2023) outlines the desire to reduce the threat of weeds to natural environments, agricultural production and livelihoods, cultural values and social values and assets. Thus, developing a list of weeds for assessment considers weeds that impact this breadth of values.

Weeds of interest were identified through the following sources:

1. A preliminary weed list: This comprised state and territory priority weeds identified by weed-management agencies. Determination of the preliminary list occurred through the following steps:

    a. The Weeds Working Group identified information sources, from which a long list of weeds could be compiled. Sources typically comprised weeds declared under jurisdictional legislation, and some weeds had undergone a prioritisation or risk-assessment process. In some instances, jurisdictions filtered sources in line with consultation with regional weed organisations or information on weed risk assessment.

    b. Long lists were compiled by Wild Matters and provided back to members, including an indication, where possible, whether weeds had also been identified as agricultural or environmental priorities (according to information sources included in Appendix 2).

    c. Each state and territory then further narrowed down long lists to the 20 highest priority weeds that met the eligibility criteria.

    d. Jurisdictional short lists were compiled and duplications removed to create a preliminary weed list of 111 species (including one hybrid species and one species aggregate).

2. **Open nominations**: Any additional weeds not already on the preliminary list were suggested for inclusion through an open online nomination form (see Appendix 3). The preliminary weed list was made publicly available, so potential nominees could identify whether their weed of interest was listed (in which case a nomination was not necessary).
3. Weeds identified as having an **impact on First Nations people (and their culture) were identified through healthy country plans and targeted engagement** with First Nations organisations. These weeds will not be assessed for weed threat (see Figure B1).

1.3.1 Nomination process

Individuals, community groups (Non-Government Organisations, Local Government Areas, Natural Resource Management, industry bodies, etc.) could nominate weeds for assessment of their threats and biocontrol prospects via the Weeds Australia platform. The nomination portal was open for one month and provided:

- background information on the project
- details on how to nominate
- an online form
- the preliminary weed list
- contact details for more information.

The online form sought information on the weed, for example, whether at least three reputable information sources existed (relevant to the Australian context) that provided sufficient detail on the weed's distribution, impact and invasiveness. This information was used to determine the weed's eligibility. Nominations were collated and their eligibility assessed (see Part B Section 1.3.2). Nominees of eligible weeds received automated confirmation that the nomination was received. Eligible weeds then proceeded to an impact assessment (see Part B Section 1.4.1). Weeds that did not satisfy the eligibility criteria or were found to have low impacts were not considered further, and the outcome was communicated to the nominee at the end of the process via email.

1.3.2 Eligibility criteria

The following criteria must be met for an assessment of threat to occur. This applies to weeds from any of the sources identified above.

1. **The species is native**

   Yes = Stop
   No = Proceed

The species proposed for assessment must not be an Australian native species. While some native species have weedy tendencies when growing outside of their range, these weeds are not eligible for assessment.

2. **The weed is established* in at least one state or territory, such that it is beyond the point of national eradication**

   Yes = Proceed
   No = Stop

* In this context, 'established' describes a weed that has self-sustaining populations and a national distribution that may be either new and emerging or widespread in nature. In either instance, these weeds are not considered feasible to eradicate at the national level.

Examples of **eligible** weeds, for which jurisdiction refers to states and territories, are:

- Weeds that occur in multiple jurisdictions and eradication is considered unfeasible in all jurisdictions.
- Weeds that occur in multiple jurisdictions, in which the weed may be targeted for eradication in one jurisdiction, but eradication is considered unfeasible in another jurisdiction. For example, parthenium (*Parthenium hysterophorus*) is an eradication target in NSW but widespread in parts of Qld. In this example, parthenium weed would be eligible for assessment because it would be reasonable to seek biocontrol solutions for a weed that is beyond national eradication.

Examples of ineligible weeds are:

- weeds subject to a formal national eradication program. These are *Limnocharis flava*, *Miconia calvescens, M. nervosa, M. racemosa, Mikania micrantha* and *Striga asiatica*
- weeds that only occur in one jurisdiction and are eradication targets in that jurisdiction are viewed as national eradication targets
- weeds that occur in multiple jurisdictions and are eradication targets in all jurisdictions. For example, mouse-ear hawkweed (*Pilosella officinarum*) is an eradication target in all jurisdictions in which it occurs—Vic and NSW.

3. **The weed is a single species**

   Yes = Proceed
   No = Stop

Weeds proposed for assessment must be a single species and identified to the species level. For example, genus level proposals are not eligible for assessment.

4. **There is sufficient* data to support assessment of the species**

* Sufficient data includes multiple (three or more) reputable sources relevant to Australia that provide detail on the weed's distribution, impact and invasiveness to enable assessment questions to be confidently answered.

   Yes = Proceed
   No = Stop

Assessing a weed's threat relies on sufficient evidence to support a robust assessment. High-quality data are the most desirable form of evidence to support a weed's nomination. Examples of data that have high levels of confidence can be found in Part B Section 1.4.4 (data deficiency and confidence).

For this reason, hybrid species, while not ineligible, may fare less favourably than other species if there is insufficient evidence to support a thorough assessment.

An assessor checked this eligibility criterion by:

- reviewing the information sources provided by nominees in the nomination process
- conducting a 30-minute combined general web search (e.g. Google) and publication database search (e.g. Web of Science, CABI: CAB Abstracts) using botanical and common name/s and other appropriate keywords.

From these searches, the assessor determined whether there was likely to be sufficient information to address the impacts and invasiveness questions and hence determined whether these eligibility criteria were satisfied.

1.4 ASSESSMENT PROCESS AND CONSIDERATIONS

Weeds identified through the preliminary list and open-nomination process that met the eligibility criteria progressed to weed-threat assessment (see Figure B1). This consisted of:

- an assessment of impacts
- an assessment of invasiveness.

Outcomes of each assessment were combined to produce a weed-threat score **(Impacts × Invasiveness).**

1.4.1 Impact assessment

An assessment of impact was used to screen out less impactful weeds from further assessment. Weeds that met the impact threshold (see Part B Section 1.5.1) progressed to a further assessment of invasiveness (see Figure B1). Weeds that scored below the threshold were considered ineligible and were not assessed further for invasiveness or biocontrol prospects (see Figure B1).

Assessing impact as an initial screen is an efficient way of:

- checking the validity of nominated weeds, given their unknown level of threat
- processing high numbers of weeds.

Box B1 Weeds that threaten cultural values

The impact of weeds on First Nations cultural values is not specifically assessed for weed threat; however, weeds that were identified as impacting the cultural values of First Nations peoples were noted, allowing inclusion of these species in Stage 2 (analysis of weed biocontrol prospects).

1.4.2 Assessment workflow

A panel of three assessors was assigned to the project. Each assessment was largely conducted by one assessor, who followed the following steps:

1. Check eligibility against criteria (see Part B Section 1.3.2). If weed is eligible, proceed to Step 2 (except weeds that impact First Nations cultures, which will not be assessed for threat).
2. Gather relevant information on the weed from Australian and international sources (where available).
3. Populate the assessment template with baseline information, including weed name, land use, assessor name and date.
4. Conduct assessment of weed impact, populating with relevant information, including data sources and confidence.
   a. If impacts are above the threshold (see Part B Section 1.5.1), proceed to Step 5.
   b. If impacts are below the threshold, stop assessment.
5. Undertake assessment of weed invasiveness, populating with relevant information, including data sources and confidence.

6. Review the assessment, noting any criteria for which data are ambiguous or introduce a level of uncertainty. In this instance, the assessor may determine a second assessment of the criteria is necessary. In this case proceed to Step 7. Alternatively, proceed to Step 8.
7. Assign a second assessor to blind assess the criteria without knowledge of the first assessor's scores. Compare the two scores and, if necessary, facilitate a conversation to resolve any differences in scoring.
8. Calculate final threat score (impacts × invasiveness).

1.4.3 Seeking technical advice

When information is lacking, an assessor may also seek advice or information about the impact and invasiveness of the weed in the relevant land use. This may be included as personal communication (see Table B1 for descriptions).

1.4.4 Assessment considerations

Land use

Assessments are made in accordance with the land use that the weed is most likely to occur in and affect. An appropriate land use category must be selected from a standard list of land uses at the start of the assessment. Each subsequent question must be answered by considering that land use.

Some weeds occur in and affect more than one land use. In these instances, an assessment must be completed for each land use. While all assessments are recorded and accessible, only the highest scoring assessment is combined with the biocontrol prospects analysis.

An assessment may also be warranted for a land use that has the potential to be affected by the weed, despite the weed being currently absent from that land use. This may occur when an assessor finds evidence or information that suggests an unoccupied land use may be affected in future. This may trigger a new assessment.

Land use categories are described below and are based on the Australian Land Use Mapping Classification System V8 (ABARES 2016).

1. Conservation and natural environments

1.1. Nature conservation (national parks, nature reserves and other legally protected areas)
1.2. Managed resource protection (land other than nature conservation areas managed for biodiversity or landscape values, such as water catchments and traditional indigenous use)
1.3. Other minimal use (defence land, stock routes, remnant native vegetation and rehabilitation)

2. Production from relatively natural environments

2.1. Grazing natural vegetation (intact native vegetation used for grazing)
2.2. Production forestry (native forest and vegetation managed for timber and other production)

3. Production from dryland agriculture and plantations

3.1. Plantation forestry (soft and hard wood and other products)
3.2. Grazing modified pastures (native or exotic species of woody fodder or pasture legumes or sown grasses)
3.3. Cropping (cereal, oil seeds, sugar, cotton, legumes, hay and silage, tobacco, beverage and spice crops)
3.4. Perennial horticulture (plants living more than two years, such as tree fruits, olives, vine fruits, tree nuts, shrub nuts, flowers, bulbs, vegetables and herbs)
3.5. Seasonal horticulture (plants living less than two years, such as fruits, nuts, flowers, bulbs, vegetables and herbs)
3.6. Land in transition (degraded, abandoned, rehabilitation or other)

4. Production from irrigated agriculture and plantations

4.1. Irrigated plantation forestry (irrigated, but otherwise as for 3.1)
4.2. Irrigated modified pastures (woody fodder or pasture legumes or sown grasses)
4.3. Irrigated cropping (irrigated, but otherwise as for 3.3)

4.4. Irrigated perennial horticulture (irrigated, but otherwise as for 3.4)
4.5. Irrigated seasonal horticulture (irrigated, but otherwise as for 3.5)
4.6. Irrigated land in transition (irrigated, but otherwise as for 3.6)

5. Intensive uses

5.1. Intensive horticulture (shade and glasshouses)
5.2. Intensive animal production (dairy, cattle, sheep, poultry, pigs and aquaculture)
5.3. Manufacturing and industrial
5.4. Residential (urban and rural residential, and rural living)
5.5. Services (areas for commercial, public, recreation, defence and research use)
5.6. Utilities (electricity transmission and generation; gas treatment, storage and transmission)
5.7. Transport and communication (roads, railways, airports and aerodromes, ports, water transport, navigation and communication)
5.8. Mining (mines, quarries and tailings)
5.9. Waste treatment and disposal (stormwater, landfill, solid garbage, sewage and incinerators)

6. Water
6.1. Lakes (for conservation, production or intensive uses)
6.2. Reservoirs and dams (reservoirs, water storage for intensive uses, farm dams, evaporation basins and effluent ponds)
6.3. Rivers (for conservation, production or intensive uses)
6.4. Channels and aqueducts (supply and drainage channels and aqueducts)
6.5. Marshes and wetlands (for conservation, production or intensive uses)
6.6. Estuary and coastal waters (for conservation, production or intensive uses)

Current weed-management practices

Weeds that are not controlled by current management practices are more likely to reach high numbers and have greater impacts than those that are controlled. Assumptions about the current routine practices of weed management for each land use examined need to be clearly stated and recorded, for example, standard herbicide use, cultivation or physical control. In practical terms, this may mean the herbicides used and the number and type of cultivation events performed by farmers in a land use, such as dryland cropping.

Practices may vary considerably between (and even within) land uses, and no routine weed management may be undertaken for some land uses, for example, in natural environments. Stating and recording these assumptions help all assessors to accurately and consistently answer the questions and reduce any possible conflict.

Each question assesses weed potential under current practices of routine weed management. As outlined earlier, this may or may not affect the weed.

Density

To answer impact questions, it is necessary to first estimate and note weed density in land use (e.g. low, medium or high). In most cases the weed's impact relates to its density or abundance. Stating and recording this assumption is important to help all assessors accurately and consistently answer the questions.

Data deficiency and confidence

Data deficiency and data confidence are critical considerations when prioritising weeds. Uncertainty can stem from a lack of information about any factor being assessed. In addition, not all information sources are equal, requiring consideration of the level of confidence that can be assigned to the information gathered.

Definitions of confidence to be used are provided in Table B1. Assessors identify and record the confidence level of each question between low and high. While the confidence rating does not influence the assessment score, it does allow for greater utility and understanding of the scores, as well as identifying areas requiring more research and development.

During the nomination process (see Section 1.3.1) weeds may be determined 'data deficient' and screened out (see Section 1.3.2) if an assessor concludes that any available information sources do not contain the information required to answer the majority of questions. For example, a Google and database search may only result in information on a weed's taxonomy and how to control it but no information on its invasiveness or impacts. In this instance, an assessment should not be continued.

Weeds that are considered eligible may still have data deficiencies or information sources that have low confidence for some questions. In these situations, the assessor can select 'don't know' to individual questions. This may occur when there:

- is an absence of any information, preventing assessment of a question from occurring
- are multiple, conflicting data sources, preventing an assessment being made with any level of confidence.

It is preferable for assessors to answer the question, even with low confidence, rather than select 'don't know'.

The primary assessor may recommend a second assessment if data sources are ambiguous or contradictory (see Table B1) or they believe a second assessment may assist in instances when 'don't know' responses are provided. In these instances, the question is independently assessed by a second assessor, endeavouring to improve (or confirm) confidence where possible.

Table B1 Confidence level and corresponding evidence for use in the elicitation process used in the EEPL to be adopted in the assessment of weed threat. Adapted from Evans et al. (2019)

Confidence Level	Evidence/Information Source	Example of Data Source
High	There is good-quality directly relevant evidence (this can be evidence of impacts of species from other countries; however, the relevance to Australia needs to be considered). There are reliable sources/good-quality data or non-contradictory/non-controversial information.	• Peer-reviewed scientific papers • High-quality science or taxa-specific books • Unpublished reports from highly reliable sources • Non-peer-reviewed scientific papers (e.g. conference proceedings) • Personal communications from experts (e.g. PhD or higher degree on species being assessed) • Internet information that cites any of these 'high' category sources
Medium	There is some evidence to support the assessment. Some information is indirect (e.g. assumptions based on analogies from phylogenetically or functionally similar species). The interpretation of data may, to some extent, be ambiguous or contradictory.	• Unpublished reports from uncertain sources • Internet information from government or university websites • Information from general books (e.g. Encyclopaedia Botanica) • Personal communications from people who have some experience with the species being assessed • Internet information that cites any of these 'medium' category sources
Low	There is little or no direct evidence to support the assessment (e.g. only data from other species have been used as supporting evidence). Unreliable sources of information that are poor quality or difficult to interpret.	• Anecdotal data from non-experts • Internet information that cites anecdotal, non-expert sources • Internet information from uncertain/uncited sources • General webpages

1.5 ASSESSMENT CRITERIA

Weed-threat assessment focuses on two criteria: impact and invasiveness. The two criteria are assessed against multiple questions and scored individually, enabling a total score to be determined for each.

Impacts are the economic, environmental and social impacts the weed may cause when established. An assessment is made of the weed's ability to reduce the establishment and yield of desired vegetation, which may also have implications for animals relying on such vegetation (e.g. for fodder). Additional questions consider any reduction in the quality of services, products or diversity within the identified land use; whether the weed restricts movement of people, animals or vehicles; and the impacts of the weed on environmental health.

Invasiveness considers the weed's ability to establish, reproduce and spread in the land use. A weed's ability to establish among existing vegetation is considered a measure of the weed's competitiveness. Reproductive ability considers seed production and the ability to reproduce vegetatively. The weed's spread considers mechanisms and distances of propagule dispersal.

For the two criteria, higher scores indicate a higher level of risk.

Impact and invasiveness questions, explanatory notes and assumptions were taken from Johnson (2009b) and modified where necessary.

1.5.1 Impacts

Weeds can cause a loss in the supply, quality or use of desired products and services, for example, agricultural production, nature conservation, recreation, water supply and urban infrastructure.

Impact assessment allows for the relative assessment of a weed's potential environmental, social and economic impacts by focusing on the types and size of the impacts, as related to weed density and abundance.

Each question is answered with a land use in mind and assessors should:

- assume that the weed has spread across a whole field, orchard, plantation, nature reserve or water body and that the commonly used weed-management practices have not changed to specifically target the weed
- estimate weed density in the land use and record it (e.g. low, medium or high). In most cases the weed's impact relates to its density or abundance. Stating and recording this assumption is important for transparency and is useful should the assessment be reviewed by someone other than the primary assessor
- consider that if the weed is well controlled by commonly used weed-management practices then it occurs at a low density and has minimal impacts. Alternatively, if the weed is poorly controlled by these common practices, then it may reach a high density and have substantial impacts. If the weed has an effective biocontrol agent established, which substantially reduces its growth, then the weed's impacts will be reduced
- consider only negative impacts in Questions 1 to 5 of this section.

To readily identify weeds that have potential versus actual impacts, assessors note whether the impact is known to be currently occurring or is a potential impact in accordance with impacts occurring elsewhere (e.g. overseas) or in another land use. This information is then available to inform Stage 3 (investment planning and assignment of weeds along the RD&E pipeline) if necessary.

Impacts Question 1

Does the weed reduce the establishment of desired plants?

Importance of the question: Weeds that greatly reduce the establishment of desirable plants are more likely to have greater impacts.

Explanation and assumptions: This question considers whether the weed prevents the establishment of desired plants so that the density of these is reduced. Desirable plants can be crops, pastures, planted trees or native vegetation. A reduction in desirable plants may cause a reduction in the abundance of animals that depend on these plants.

The weed may prevent the germination of desired plants by dense shading or by forming a physical barrier to water movement or light to the soil. The weed may kill or stunt seedlings by competing for moisture, light and nutrients. Weeds can also reduce the establishment of desirable plants through allelopathy (when one plant produces chemicals that reduce the establishment or growth of another plant).

Desired plants may mainly establish after a major disturbance, for example, after cultivation or a fire. Weeds may also establish at these times and affect desirable plant establishment.

1. Does the weed reduce the establishment of desired plants?		Score
> 50% reduction	The weed stops the establishment of more than 50% of desired plants, for example, regenerating pasture, sown crops, planted trees or regenerating native vegetation, by preventing germination or killing seedlings.	3
10–50% reduction	The weed stops the establishment of between 10 and 50% of desired plants.	2
<10% reduction	The weed stops the establishment of less than 10% of desired plants.	1
No reduction	The weed does not affect the germination and seedling survival of desired plants.	0
Do not know		1.5
Source and comments		

Impacts Question 2

Does the weed reduce the yield or amount of desired vegetation?

Importance of the question: Significance is given to weeds that greatly reduce the yield or amount of desired vegetation. Following on from Question 1, this question considers the growth achieved by desirable plants that did establish despite the weed. It also considers the reduction in yield or growth of plants that were already established before the weed invaded.

Explanation and assumptions: Weeds can reduce the growth of other plants by competing for moisture, light and nutrients or via allelopathy. Weed competition is greater when a weed is larger (e.g. a tall weed that has a dense leaf canopy and an extensive root system) and grows at the same time as desirable plants. Some weeds also compete by forming physical barriers that stop plants growing to reach light, water and nutrients, for example, the tuber mat of Bridal creeper (*Asparagus asparagoides*).

Production context: This question considers the degree of yield loss in crops, pastures or other produce, for example, fruit or forestry. Weeds reduce the growth of other plants by competing for moisture, light and nutrients or via allelopathy. This may have flow-on impacts, such as reduced fodder for grazing animals.

Environmental context: This question considers the degree of suppression of mature native vegetation caused by the weed.

The question is answered on a **per hectare basis** in comparison with similar vegetation that is free of the weed. For native vegetation, it may be useful to consider percentage cover or biomass instead of the amount of mature native vegetation.

2. Does the weed reduce the yield or amount of desired vegetation?		Score
> 50% reduction	The weed reduces crop, pasture or other produce, for example, fruit or forestry yield, or the amount of mature native vegetation by more than 50%.	4
25–50% reduction	The weed reduces yield or amount of desired vegetation by between 25 and 50%.	3
10–50% reduction	The weed reduces yield or amount of desired vegetation by between 10 and 25%.	2
<10% reduction	The weed reduces yield or amount of desired vegetation by up to 10%.	1
No reduction	The weed has no effect on yield or the growth of the desired vegetation.	0
Do not know		2
Source and comments		

Impacts Question 3

Does the weed reduce the quality of products, diversity or services available from the land use?

Importance of the question: Weeds may cause reductions in the quality of products, diversity or services available.

Explanation and assumptions: This question considers whether a weed causes a loss in the supply, quality or use of desired products or the diversity of services available from the land use. The question's focus is on the negative impacts that are caused by weeds and the size of these impacts. In most cases, the magnitude of impacts relates to the weed's density or abundance. This question is answered using the weed density that is assumed throughout the impacts section.

Production context: Examples of a weed impacting the quality of products in a production context include tainting of meat or milk, discolouration, tainting or otherwise reducing the quality of water, or weed-seed contamination of grain, seed, hay, wool, fruit or timber. Consideration should be given to industry priority weeds and seed quality standards of other states and countries.

The quality of products of sustainable harvesting should be considered here, if applicable. Impacts on fishing and hunting by all members of the community are also considered here.

Environmental context: In native vegetation, the decline of native plant species diversity and abundance are the main concerns (and the flow-on impacts to animal diversity). This affects ecosystem structure and function and eventually conservation significance, as well as recreational and tourism values. Weeds may threaten biodiversity by negatively impacting threatened plant and animal species or communities.

Built environments/public amenity context: In residential areas, the weed may cause damage to physical infrastructure, such as buildings, roads and footpaths. Damage to human infrastructure, such as fences, should also be considered here. Reductions in visibility and aesthetics are considered low impacts.

In answering this question, assessors **should not** consider:

- reductions in livestock condition or weight because these are due to a reduction in available feed (Question 2)
- restrictions of physical movement because this is considered in Question 4
- animal health impacts caused by eating the weed because this is considered in Question 5 (e.g. the red flowering form of *Lantana camara*).

3. Does the weed reduce the quality of products, diversity or services available from the land use?		Score
High	The weed severely reduces product quality such that it cannot be sold. This may be due to severe contamination, slight contamination when zero tolerance exists, toxicity, tainting or abnormalities (chemical or physical). For natural vegetation, the weed severely reduces biodiversity (plants and animals) such that it is not suitable for nature conservation or nature-based tourism. For residential areas, the weed causes severe structural damage to physical infrastructure, such as buildings, roads and footpaths.	3
Medium	The weed substantially reduces product quality such that it is sold at a much lower price or for a lower grade use. For natural vegetation, the weed substantially reduces biodiversity such that the area is given lower priority of nature conservation or nature-based tourism. For residential areas, the weed causes some structural damage to physical infrastructure, such as buildings, roads and footpaths.	2
Low	The weed slightly reduces a product's quality, lowering its price, but it still passes as a first-grade product. For natural vegetation, the weed has only marginal impacts on biodiversity, but is visually obvious and degrades the natural appearance of the landscape. For residential areas, the weed causes negligible structural damage but reduces the aesthetics of an area through untidy visual appearance or unpleasant odour.	1
No reduction	The weed does not affect the quality of products, services or diversity.	0
Do not know		1.5
Source and comments		

Impacts Question 4

What is the weed's potential to restrict the physical movement of people, animals, vehicles, machinery or water?

Importance of the question: Weeds that restrict the physical movement of people, animals, vehicles, machinery or water are likely to have greater impacts.

Explanation and assumptions: This question considers the degree to which a dense infestation of the weed physically restricts movement. Weeds that are tall, thorny, tangled or dense may restrict movement. Examples of how weeds limit movement include:

- blocking or slowing access of cars, bikes, quad bikes or other machinery by a physical barrier, by tangling or by tyre puncture
- blocking or slowing farm machinery at sowing or harvesting
- interference with boat access or manoeuvrability
- blocking or slowing of water flow
- reduced access to pasture
- interference with thinning operations in forestry
- prevention of livestock access to pasture or water by physical barrier or discomfort
- prevention of animal access to nesting sites by physical barrier or discomfort
- impediment to movement of people on foot by physical barrier or discomfort.

In answering this question, assessors **should not** consider human health impacts that result from flooding of areas where humans live. These are considered in Question 5.

4. What is the weed's potential to restrict the physical movement of people, animals, vehicles, machinery or water?		Score
High	Weed infestations are a major impediment to access throughout the year. They are almost always impenetrable and cause a major obstruction, completely preventing the physical movement of people, animals, vehicles, machinery or water.	3
Medium	Weed infestations are a moderate impediment and access is difficult. Infestations may be sometimes impenetrable. Significant slowing of the physical movement of people, animals, vehicles, machinery or water occurs throughout the year.	2
Low	Weed infestations are never impenetrable but do significantly slow or obstruct the physical movement of people, animals, vehicles, machinery or water at certain times of the year. Alternatively, a minor obstruction occurs throughout the year.	1
No reduction	The weed has no effect on physical movement.	0
Do not know		1.5
Source and comments		

Impacts Question 5

What is the weed's potential to negatively affect the health of animals or people?

Importance of the question: Weeds can adversely affect the health of people, livestock or native animals.

Explanation and assumptions: This question considers how the weed affects the health of animals (domestic livestock and native) and people.

Many plants have a negative effect on human and animal health, and these impacts may vary considerably from person to person or from species to species. For example, an individual may have an allergic reaction to a certain plant but many others will not. In addition, while a weed may be highly toxic to animals, if the weed is not palatable or is actively avoided, the impacts posed by the weed may not be realised.

Some examples of weeds that have known impacts on human health are Poison ivy (*Toxicodendron radicans*) and parthenium weed (*Parthenium hysterophorus*), which have high and medium impacts, respectively. Examples of weeds that affect animal health are St John's wort (*Hypericum perforatum*) and all red flowering varieties of lantana (*Lantana camara*) in NSW.

Some aquatic weeds have the potential to slow water flows. This may lead to mosquito breeding and an increase in mosquito-borne human diseases. Alternatively, aquatic weeds may block drainage, resulting in flooding of areas in which humans live, again resulting in human disease concerns. Infestations of such weeds may result in medium impacts on human health.

In answering this question, assessors **should not** consider:

- any starvation impacts from reduced growth of pasture or reduced access to pasture because these are covered in Questions 2 and 4
- any impacts caused by aquatic weeds via flooding to built infrastructure and areas in which humans live (e.g. damage to infrastructure) because these are considered in Question 3.

5. What is the weed's potential to negatively affect the health of animals or people?		Score
High	The weed is highly toxic and frequently causes death or severe illness in people, livestock or native animals.	3
Medium	The weed occasionally causes significant physical injuries (because of spines or barbs) or significant illness (chronic poisoning, strong allergies) in people, livestock or native animals, occasionally resulting in death.	2
Low	The weed can cause slight physical injuries or mild illness in people, livestock or native animals but there are no lasting impacts. For example, hay fever or minor rashes.	1
None	The weed does not affect the health of animals or people.	0
Do not know		1.5
Source and comments		

Impacts Question 6

Does the weed have major positive or negative impacts on environmental health?

Importance of the question: Greatest significance is given to weeds that are 'ecosystem transformers', that is, those that change the character, condition and nature of ecosystems over substantial areas. Often these plants form monocultures. Plants that have a major negative impact on a range of environmental health measures are likely to have the greatest impacts.

Explanation and assumptions: This question considers whether the weed has major long-term impacts on a land use's environment. These impacts may be beneficial or harmful. Assessors should consider the following assumptions:

- Impacts are more likely where the weed substantially changes the vegetation structure, such as woody weed invasion of grassland.
- A major effect is one that is well known, that is, supported by scientific studies or expert opinion, and has significant impacts across the landscape.
- A minor effect should also be well known but is either limited in the area of its impact or if its impact is widespread it is not significant.
- A long-term effect becomes apparent over several years and may even be opposite to the initial effect the species gave. For example, lippia (*Phyla canescens)* was once planted to stabilise soils but is now recognised as causing significant slumping of soil banks in riparian areas.
- A species is considered not to have an effect if it has been well studied but there is nothing in the literature that refers to an effect on environmental health.

In answering this question, assessors **should not** consider:

- pasture for livestock because this is considered in Question 2
- the death of native animals because this is considered in Question 5
- competition for nutrients (decreased nutrient levels) because this is covered indirectly in Question 2
- competition for water because this is indirectly covered in Question 2.

The following are additional explanations for specific questions in Question 6:

Food/shelter: Examples of those that have negative impacts on food and shelter are blackberry (*Rubus fruticosus* spp. *agg*.), which can harbour rabbits, and grass weeds, such as Johnson grass (*Sorghum halepense*), which host cereal crop pests and pathogens. Examples of those that have positive impacts include lantana (*Lantana camara*), African boxthorn (*Lycium ferocissimum*) and African olive (*Olea europaea* subsp. *cuspidata*), which can provide food and shelter for native animals when none exists (although this is likely to be a minor positive effect in most cases).

Fire regime: Consider changes in normal frequency, intensity or timing of fires. Examples of weeds that have major impacts include some introduced grasses, such as gamba grass (*Andropogon gayanus*), invading open woodland savanna and increasing fire heights and fire intensities.

Nutrient levels: Some plants increase nutrient levels, for example, legumes can increase soil nitrogen. This may make native vegetation more prone to invasion by other weeds but would be beneficial to agriculture. Other plants alter nutrient cycling and this can result in changes to the diversity of native vegetation. For example, lantana (*lantana camara*) alters nitrogen distribution in the soil.

Soil salinity: Soil salinity may be altered by plant growth. For example, the leaves of athel pine (*Tamarix aphylla*) have high levels of salt, and leaf decomposition may increase salinity at the soil surface.

Soil stability: Soil stability may be affected because plants may increase the risk of soil erosion or silting of water ways. Examples include Lippia *(Phyla canescens*), willows (*Salix* species) and Athel pine (*Tamarix aphylla*).

Soil water table: Some plants may substantially raise or lower the soil water table compared with other plants. This may have positive or negative impacts.

In the 'Source and comments' response for this question, assessors should mention any other negative impacts, such as:

- decaying infestations of water weeds, such as Salvinia (*Salvinia molesta*), or other weeds swept into waterways and reducing oxygen levels and pH in water

- soil acidification caused by decaying Pine (*Pinus* species) wilding leaf material
- any increase in the flooding regime caused by stream-bed blockage caused by, for example, willow (*Salix* species)
- if the specific negative effect is unknown.

6. Does the weed have major positive or negative impacts on environmental health?				
	Major Positive Effect	**Major Negative Effect**	**Minor or No Effect**	**Do Not Know**
(a) Food/shelter				
(b) Fire regime				
(c) Altered nutrient levels				
(d) Soil salinity				
(e) Soil stability				
(f) Soil water table				
Total (a+b+c+d+e+f)	>3	2–3	0.5–1.5	0 or less
Score	3	2	1	0
Source and comments				

Impact scoring

The scores of each impact question are added together to give a raw score using the following calculation. The result is rounded to the nearest decimal place:

$$Impact\ raw\ score = Q1+Q2+Q3+Q4+Q5+Q6$$

The higher the score, the greater the negative impacts caused by the weed.

Impact bands

Impact bands are used to assign an impact category. To calculate bands, a distribution of all possible impact scores was derived from a uniform distribution of Question 1 (0 to 3), Question 2 (0 to 4), Question 3 (0 to 3), Question 4 (0 to 3), Question 5 (0 to 3) and Questions 6a through 6f (each −1 to 1). Question 6 was then converted to a score between 0 and 3 in accordance with the cut-offs provided (≤ 0 → 0; 1 →1; 2 or 3 → 2; 4 to 6→ 3). The scores for each question are added to produce a total impacts score between 0 and 19. Each question is assumed to be independent from (uncorrelated with) all other questions.

To provide five bands of approximately equal probability, the quintiles (evenly spaced 20% quantiles) of this distribution were calculated. The resulting bands are shown below.

Frequency Bands and Impact Categories		
Frequency Band	Impact Score	Impact Category
80–100% (top 20% of possible scores)	12–19	Very high
60–80%	10–11	High
40–60%	9	Medium
20–40%	7–8	Low
0–20% (bottom 20% of possible scores)	0–6	Negligible

Impact threshold

The impact threshold score was set at 9, which excludes weeds that have a negligible or low impact. If impacts are < 9, then stop, because this is a low-impact weed and is not considered further. If impacts are ≥ 9, then proceed to the invasiveness assessment.

If there is a limit to the number of weeds that can be assessed, weeds can be ranked by their impact score and the cut-off set at the number of weeds that can be fully assessed. For example, if there are 30 weeds but there is only capacity to fully assess 15, the top-scoring 15 weeds (for impacts) continue to the assessment of invasiveness and biocontrol prospects.

Adjusting impact scores

For weeds that continue to be assessed for invasiveness, the raw impact score is adjusted to within a range of 10 using the following calculation, and the result is rounded to the nearest decimal place. The higher the score, the greater the negative impacts caused by the weed.

$$Impact = \left(\frac{Raw\ impact\ score}{19}\right) \times 10$$

1.5.2 Invasiveness

Invasiveness is a measure of a weed's ability to establish, reproduce and spread. Faster spreading weeds are a higher priority for control. Invasiveness often varies between land uses because of differences in management practices, disturbance regimes and resources available for weed growth. Direct measurement of spread is difficult without information collected sequentially over time.

This section uses five questions to analyse how quickly a weed can spread within a particular land use. All questions are answered in relation to the land use, except for Question 5(a), because people often deliberately spread plants irrespective of land use.

Invasiveness Question 1

What is the ability of the weed to establish amongst existing plants?

Importance of the question: Weeds that are able to become established among existing plants are likely to be more of a problem. Greater significance is given to weed species that can readily become established among existing vegetation, having the capacity as seedlings or juveniles (young plants) to tolerate competition for light, moisture or nutrients.

Establishment may occur from seeds or from vegetative units, for example, bulbs, root fragments, tubers or rhizomes. Larger propagules (seeds or vegetative units) usually have greater reserves for establishment.

Seedlings that have shade tolerance, nitrogen fixation, rapid root growth or drought tolerance are also likely to have a greater ability to become established among competing vegetation. Weed species that have a poor ability to become established among existing vegetation mainly become established after significant vegetation disturbance events, such as fire, cultivation, drought or overgrazing.

Explanation and assumptions:

- Assume that there are no weed control practices.
- Assume that the weed has just arrived.
- Weeds that invade well-managed land uses (in which a dense soil cover is maintained) have a higher weed potential.
- For agricultural contexts and land uses, 'vegetation' may be crops, pastures or lawns.
- For environmental contexts and land uses, 'vegetation' refers to native vegetation.
- The density of existing plants depends on the land use, for example, dense vegetation in grazing modified pasture land use may be quite sparse when compared with dense vegetation in a natural environment land use, such as a forest.
- 'Seedlings' includes growth from dispersed vegetative propagules, for example, broken fragments of Alligator weed (*Alternanthera philoxeroides*) stems or silver-leaf nightshade (*Solanum elaeagnifolium*) roots and spores, in addition to seeds.
- 'Seedlings' do not include new vegetative growth attached to the parent plant, for example, by stolons, rhizomes or lateral roots. This feature is covered in Question 3(c).

1. What is the ability of the weed to establish amongst existing plants?		Score
Very High	Seedlings' can establish within dense vegetation or among thick infestations of other weeds.	3
High	'Seedlings' become readily established within more open vegetation or among average infestations of other weeds.	2
Medium	'Seedlings' mainly become established when there has been moderate disturbance to existing vegetation that significantly reduces competition from other plant species. This could include intensive grazing, mowing, raking, clearing of trees, temporary floods, seasonal droughts or, in some cases, fire.	1
Low	"Seedlings" mainly need bare ground to establish including removal of stubble/leaf litter. This occurs after major disturbances such as cultivation, overgrazing, hot fires, grading, long-term floods or long droughts.	0
Do not know		1.5
Source and comments		

Invasiveness Question 2

What is the weed's tolerance to average weed-management practices in the land use?

Importance of the question: Weeds that are more able to tolerate management will have greater survival and spread.

This question examines whether the new weed is killed by the weed-management practices that are commonly used across the land use. For example, a new grass weed may be killed by a grass herbicide along with existing grass weeds in a broad-leaf dryland crop. If few individuals of the new weed are killed, then changes to weed-management practices will eventually be needed.

Assessors should refer to the assumptions recorded about the average or common weed-management practices in Part B Section 1.4.4 (current weed-management practices).

Explanation and assumptions:

- Assume that the weed is new to the area.
- Current weed-management practices may include herbicides, cultivation, cutting or slashing, grazing and fire, and maintaining the competitiveness of desirable vegetation, for example, by fertiliser or pest and disease control. The types and timing of these practices may vary within a land use. For example, weed management may vary between cereal cropping and broad-leaf cropping within dryland cropping land use or between vineyards and citrus production in dryland perennial horticulture land use. Average the weed's survival if this is the case.
- If a weed grows and sets seeds when there is normally no weed management (e.g. during a winter fallow in a summer crop), then it is highly tolerant of common weed-management practices.
- In native vegetation, there may be no commonly used weed-management practices. If this is the case, this should be recorded in the assumptions about the land use.

Examples of weeds that have a high tolerance to routine weed management include silver-leaf nightshade (*Solanum elaeagnifolium*) and Alligator weed (*Alternanthera philoxeroides*), which are difficult to kill, and fireweed (*Senecio madagascariensis*), which is quick to set seed and may therefore escape routine controls.

2. What is the weed's tolerance to average weed-management practices in the land use?		Score
Very High	Over 95% of weeds survive commonly used weed-management practices.	3
High	Between 50 and 95% of weeds survive.	2
Medium	Between 5 and 50% of weeds survive.	1
Low	Less than 5% of weeds survive.	0
Do not know		1.5
Source and comments		

Invasiveness Question 3

What is the reproductive ability of the weed in the land use?

Importance of the question: Weeds that can reproduce quickly produce more seed, and those that have vegetative reproduction are more likely to be a problem.

Explanation and assumptions: This question considers how well the weed can reproduce to rapidly build up its numbers at a site under current weed-management practices for the land use. Highly invasive weeds often reproduce both by seed and vegetatively. Three factors are important. All parts of the question should be answered.

1. **Time to seeding.** How long does it take from establishment (from seed or vegetative propagules) to the production of viable (live) seed? Annual plants, for example, Fireweed (*Senecio madagascariensis*), have a faster rate of population growth (that initially build up numbers faster) than slow-growing trees such as camphor laurel (*Cinnamomum camphora*).
2. **Seed production.** How much seed is produced? This is best considered the average number of viable seeds produced per square metre of ground area underneath the canopy per year. A high seed production is > 1,000 viable seeds/m2.
3. **Vegetative reproduction**. Does the weed have frequent vegetative reproduction? 'New plants' are defined as shoots that have their own root system. There may still be some connection to the parent plant.
   - Frequent vegetative reproduction is > 10 new plants per year from a mature parent plant.
   - Vegetative reproduction is the average number of new plants produced each year by such means as

bulbs, bulbils, corms, tubers, rhizomes, stolons, root suckers, root fragments, shoot fragments or new shoots (e.g. in the case of plantlets produced on leaves by species such as mother-of-millions *[Bryophyllum species]*).
- Vegetative reproduction is not shoot regrowth following shoot removal.
- Management in certain land uses may increase vegetative reproduction. For example, cultivation of areas containing weeds such as perennial ragweed (*Ambrosia psilostachya*) or black knapweed (*Centaurea nigra*) increase the number of new plants arising from vegetative reproduction.
- If a weed is never able to reproduce in a land use (e.g. because it is intensively managed), then it scores 0.

3. What is the reproductive ability of the weed in the land use?						**Total (a+b+c)**	**Score**
(a) Time to Seeding		(b) Annual Seed Production Per m2 or Per Plant		(c) Vegetative Reproduction			
1 year or less	2	High	2	Frequent	2	5 or 6	3
>1 to 3 years	1	Low	1	Infrequent	1	3 or 4	2
>3 years/Never	0	None	0	None	0	1 or 2	1
Do not know	1	Do not know	1	Do not know	1	0	0
Source and comments							

Invasiveness Question 4

How likely is long-distance dispersal (>100 m) by natural means?

Importance of the question: More significant weeds are likely to be those that have more means of dispersal or have propagules that are regularly moved long distances from parent plants. These weeds tend to spread faster.

Explanation and assumptions: This question considers how well the weed can spread its propagules (seed, vegetative or spores) by natural means to start new weed outbreaks at a long distance (>100 m) from the original outbreak. Dispersal ability depends on the number of dispersal modes for a plant species, the number of times this occurs and the dispersal distance achieved.

Assessors should:

- consider whether a plant is adapted for long-distance dispersal by any of the natural means mentioned in this question, that is, by flying animals, other wild animals, water or wind
- ignore domestic and farm animals because these are covered in Question 5(d).

Features favouring long-distance dispersal by flying animals and other wild animals include:

- whole fruits that are eaten with viable seed defecated or regurgitated
- seeds that have an aril or coating that is attractive to birds or animals, and the viable seed is discarded. Examples include bitou bush and boneseed (*Chrysanthemoides monilifera* subsp. *rotundata* and *monolifera*, respectively), broad-leaf pepper tree (*Schinus terebinthifolius*), camphor laurel (*Cinnamomum camphora*), olives *(Olea europaea*, both subspecies), privet species (*Ligustrum lucidum* and *L. sinense*) and sweet briar (*Rosa rubiginosa*)
- propagules that have hooks, barbs or sticky substances that attach to feathers, hairs or skin, for example, horehound (*Marrubium vulgare*) and Noogoora and Hunter burr (*Xanthium occidentale* and *X. italicum*, respectively)
- very small seeds that can lodge within feathers, hairs or feet, for example, nutgrass (*Cyperus* species)
- vegetative components that may be picked up and carried by birds or animals, for example, grass stems carried by grazing animals that may take root.

Examples of wild animals include emus, foxes, kangaroos, rabbits, reptiles, feral horses, goats and cattle. Wild animals disperse seeds through the gut or by external transport on their fur or feet.

Seeds of most species can be dispersed short distances by water run-off after heavy rainfall events. However, aquatic, coastal and riparian species may be pre-adapted for long-distance water dispersal. Long-distance water dispersal is more likely for:

- propagules that float (consider wind-assisted water movement as water dispersal)
- weeds located in or near moving water
- areas that receive frequent floods.

Examples of weed species commonly dispersed long distance by water include many floating aquatic species, such as water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*), and emergent aquatic species, such as sagittaria (*Sagittaria platyphylla*), rubber vine (*Cryptostegia grandiflora*) and mimosa (*Mimosa pigra*). Seed-producing willows (*Salix* species) are also dispersed by water.

Research has shown that the majority of wind-dispersed propagules land close to the parent plants. Dispersal beyond 100 m is generally uncommon. Despite this, long-distance wind dispersal is more likely to be occasional or common for:

- tall trees that have light seeds
- weeds that have light seeds with wings, plumes or hairs, for example, Siam weed (*Chromolaena odorata*), and seed-producing willows (*Salix* species)
- weeds that have propagules which can snap off after fruiting and roll across sparsely vegetated ground, for example, African turnip weed (Sisymbrium thellungii), kochia (*Bassia scoparia*) and serrated tussock (*Nassella trichotoma*).

4. How likely is long-distance dispersal (>100 m) by natural means?				**Total (a+b+c)**	**Score**
(a) Flying Animals (Birds, Bats)		**(b) Other Wild Animals**			
Common	2	High	2	6, 7 or 8	3
Occasional	1	Low	1	3, 4 or 5	2
Unlikely	0	None	0	1 or 2	1
Do not know	1	Do not know	1	0	0
(c) Water		**(d) Wind**			
Common	2	Common	2		
Occasional	1	Occasional	1		
Unlikely	0	Unlikely	0		
Do not know	1	Do not know	1		
Source and comments					

Invasiveness Question 5

How likely is long-distance dispersal (>100 m) by human means?

Importance of the question: Weeds that have more means of dispersal tend to spread faster and are potentially more significant.

Explanation and assumptions: This question considers how well the plant can spread its propagules (seed, vegetative or spores) by human-influenced means (deliberate and accidental) to start new weed outbreaks at a long distance (>100 m) away from the original source.

- Consider whether the plant is adapted for long-distance dispersal by any of the means below and how regularly these means of dispersal occur.
- Answer each part of the question.
- **Ignore the land use for Question 5a only** because people often deliberately spread plants irrespective of land use.

Deliberate human spread includes plants that are currently or have been historically planted for use in agriculture, forestry and horticulture (including the nursery trade) and for medicinal, aquatic, turf, amenity, shelter or soil-protection purposes. It also includes those planted in research sites for these purposes but have then escaped.

Plants that are or have been widely planted have greater potential for dispersal because of many introduction points. Examples include African lovegrass (*Eragrostis curvula*), pines (*Pinus* species), olives (*Olea europaea*, both subspecies), blackberry (*Rubus* species), willows (*Salix* species), gorse (*Ulex europaeus*), Athel pine (*Tamarix aphylla*) and bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata*), among many other species.

Deliberate human spread also includes plants that have been deliberately planted or kept but later dumped as garden waste or in streams. This may include parts of or whole plants. For example, plants that have attractive flowers, such as the Cape tulip (*Moraea* species), are picked and then discarded or aquarium plants are discarded. It also includes plants that are deliberately moved by people in the mistaken belief they are something else, for example, when identifying grasses or other species is difficult and this confusion results in seed or plants of a weed species being collected, moved and planted.

Although a weed may be legally restricted from sale, it may still be propagated and planted illegally.
Features favouring accidental human and vehicle dispersal are:

- weeds that grow in heavily trafficked areas, so transport by footwear, clothing or vehicles (including farm machinery, slashers, earthmoving equipment and boats) may occur, for example, parthenium weed (*Parthenium hysterophorus)* and salvinia (*Salvinia molesta*)
- weeds that are dragged by farm machinery, for example, paddy melon (*Citrullus lanatus*)
- plant propagules that have hooks, barbs or sticky substances to attach to objects such as clothing or equipment, for example, horehound (*Marrubium vulgare*)
- weeds that have very small propagules that can lodge in cracks in footwear, clothing or vehicles, for example, serrated tussock (*Nassella trichotoma*).

Propagules of potential weeds can be dispersed via contaminated produce, including farm, mining and landscaping products, such as crop seed, pasture seed, hay, grain, soil, sand, gravel, fertilisers, manures or mulch. Contaminated produce also includes the by-products or waste of industries, such as stockfeed manufacturers and tanneries, and may include weeds on or in rolled turf. Examples of weed species commonly dispersed long distance as produce contaminants include Paterson's curse (*Echium plantagineum*), soursob (*Oxalis pes-caprae*) and wild radish (*Raphanus raphanistrum*). Do not consider contaminants in wool when this relates to animals that are sold between properties because this is covered in Question 5(d) (of this question).

Features favouring dispersal by domestic or farm animals, for example, sheep, cattle, horses, goats and dogs include:

- when whole fruits are eaten and viable seeds are defecated or regurgitated, for example, ryegrass (*Lolium* species)
- propagules that have hooks, barbs or sticky substances that attach to feathers, hairs, wool or skin, for example, horehound (*Marrubium vulgare*) and Noogoora burr (*Xanthium occidentale*)
- very small seeds that can lodge within feathers, hairs or feet, for example, nutgrass, (*Cyperus* species)
- weeds that grow in or near pasture, paddocks, stables, cattle yards, watering holes, homesteads, tracks or roads, for example, serrated tussock and Chilean needle grass (*Nassella trichotoma* and *N. neesiana*, respectively).

5. How likely is long-distance dispersal (>100 m) by human means?				**Total (a+b+c)**	**Score**
(a) Deliberate Spread by People		(b) Accidental Spread by People and Vehicles			
Common	2	Common	2	6, 7 or 8	3
Occasional	1	Occasional	1	3, 4 or 5	2
Unlikely	0	Unlikely	1	1 or 2	1
Do not know	1	Do not know	1	0	0
(c) Contaminated Produce		(d) Domestic and Farm Animals			
Occasional	2	Occasional	2		
Unlikely	1	Unlikely	1		
Do not know	0	Do not know	0		
Source and comments					

Invasiveness scoring

The scores of each invasiveness question are added together to give a raw score using the following calculation, and the result is rounded to the nearest decimal place:

$$\textit{Raw invasiveness score} = Q1+Q2+Q3+Q4+Q5$$

The raw score is then adjusted to within a range of 10 so it is in the same range as impacts and rounded to the nearest decimal place. The higher the score, the greater the invasiveness of the weed.

$$\textit{Invasiveness} = \left(\frac{\textit{Raw invasiveness score}}{15}\right) \times 10$$

Unlike the impacts score, it is not necessary to assign an invasiveness category at this point.

1.6 FINAL SCORING

1.6.1 Comparative weed-threat score

The score for weed threat is calculated by multiplying the adjusted impact and invasiveness scores. Weed threat has a maximum of 100 and a minimum of 0. The higher the score, the greater the threat posed by the weed.

Comparative weed threat=Impacts x Invasiveness

1.6.2 Comparative weed-threat bands

To compare relative weed threats and prioritise weeds accordingly, all possible scores from lowest to highest were divided into 20% bands to give categories of negligible, low, medium, high and very high. This provided a distribution of all possible scores for impacts and invasiveness, and assumed a uniform distribution. See Appendix 4 for a detailed explanation of how the bands were determined.

The resultant bands for weed threat are shown below.

Frequency Bands and Weed-threat Categories		
Frequency Band	Weed-threat Score	Impact Category
80–100% (top 20% of possible scores)	> 44.6	Very high
60–80%	25–44.6	High
40–60%	12.3–24.9	Medium
20–40%	4.0–12.2	Low
0–20% (bottom 20% of possible scores)	< 4.0	Negligible

Reviewing banding

The frequency bands are based on the methodology used in the SA and NSW WRM systems (see Appendix 4). While the use of these theoretical bands is considered appropriate, there is the potential for a perverse outcome in which weeds may 'clump' into the same frequency band (e.g. most weeds score > 44.6, very high), making it difficult to apply cut-offs or prioritise weeds.

To address this, following all assessments, all high-threat weed scores may be plotted and visually assessed. If there is poor alignment with the frequency bands or if clumping occurs, further statistical analysis may be used to fit alternative banding according to actual outcomes. The appropriate alternative analysis will be determined in consultation with the Statistical Consulting Centre, School of Mathematics and Statistics, The University of Melbourne, and described in a revised methodology.

1.6.3 Weeds occurring in multiple land uses

Sometimes a weed may occur in more than one land use, and more than one assessment may be required (see Part B Section 1.4.4). In these instances, the assessment that has the highest threat rating is taken as the final threat rating for that weed (e.g. a weed has two assessments; one produces a medium threat rating and the other produces a high rating). In this instance the assessment that produces the high threat rating is used in Stage 2 (biocontrol prospects analysis).

STAGE 2: ANALYSIS OF WEED BIOCONTROL PROSPECTS

Developed by the CSIRO

This stage outlines the methodology used to assess weed biocontrol prospects for high-threat species nominated by Australian states and territories and other key land-management sectors (e.g. grains, grazing, etc) under Stage 1 of the prioritisation framework. This report builds on the review of methodologies for weed biocontrol prioritisation relevant to the Australian context, as presented in Part A (see Sections 2.1–2.3) of the framework.

This section of the framework presents:

- the key assessment criteria underpinning biocontrol prospects assessment and how these criteria are scored
- the proposed method for expert elicitation on biocontrol prospects assessment criteria

2.1 DEVELOPMENT OF BIOCONTROL PROSPECTS METHODS

The proposed biocontrol prospects analysis was first informed by a review of the existing literature on factors underpinning weed biocontrol feasibility, likelihood of success and prioritisation frameworks in the Australian context (see Section 2 within Part A of the framework). Principally, this included:

- Foundational research delivered for the Australian context: Paynter Q, Hill R, Bellgard S and Dawson M (2009) Improving targeting of weed biological control projects in Australia. A report for Land and Water Australia, Canberra.
- Refinement of the Paynter *et al*. (2009) methodology for application by policymakers across Australian jurisdictions: Hennecke, B., Arrowsmith, L. and ten Have, J. (2013). *Prioritising targets for biological control of weeds—a decision support tool for policy makers*. Australian Bureau of Agricultural and Resource Economics and Sciences, Canberra.
- Application of the matrix-based approach recommended by the Hennecke *et al*. (2013) model in the NSW context by Morin *et al*. (2016), Morin *et al*. (2019) and Gooden *et al*. (2023).

Further, we considered and refined the proposed biocontrol prospects analysis and its constituent assessment criteria by reviewing more recent prioritisation frameworks that were informed by Paynter *et al*. (2009), Paterson *et al*. (2021) for South Africa and Winston *et al*. (2024) in the western United States.

The outcomes of the review were shared at two online workshops with weed biocontrol experts who currently work in the Australian context, representing the CSIRO, Agriculture Victoria, the Queensland Department of Agriculture and Fisheries, and NSW DPIRD. The two workshops were held in January and March 2024 and were led by the CSIRO. During each workshop, experts were invited to review the biocontrol prospects assessment criteria derived from the foundational Paynter *et al*. (2009) framework and the other key frameworks listed above. The workshop leader facilitated experts to share knowledge and discuss the utility and merits of:

- the two dimensions of the biocontrol prospects assessment (feasibility and likelihood of success)
- assessment criteria underpinning the biocontrol feasibility and likelihood of success dimensions
- scoring methods for the assessment criteria
- calculation of the biocontrol prospects value
- expert elicitation methodology
- prioritisation workflow (not presented in this document).

During the second workshop, consensus was reached on key criteria to include in the proposed prospects analysis, presented in Table B2.

2.2 KEY ASSESSMENT CRITERIA UNDERPINNING THE BIOCONTROL PROSPECTS ASSESSMENT

Biocontrol prospects for each target weed are determined as the product of two key dimensions, specifically, ‘biocontrol feasibility’ and ‘likelihood of success’, each consisting of multiple assessment criteria. The framework adopts the broad definitions of biocontrol feasibility and likelihood of success that were developed by Paynter *et al*. (2009) and subsequently adopted by Hennecke *et al*. (2013) for policymakers in the Australian context (outlined in Sections 2.2.1 and 2.2.2 below).

Definitions for constituent assessment criteria generally followed Paynter *et al*. (2009) but were further refined through reviewing real-world applications of weed biocontrol prioritisation by Morin *et al*. (2016, 2019) and Gooden *et al*. (2023) for environmental weeds in NSW and, more recently, by Paterson *et al*. (2021) in South Africa and Winston *et al*. (2024) in the western United States.

A final list of proposed feasibility and likelihood of success criteria, along with their definitions and assessment guidelines for this proposed national framework, is provided in Table B2. Appendix 6 summarises the full list of criteria considered by weed biocontrol experts at the online workshop (1 March 2024), including those recommended for removal.

2.2.1 Biocontrol feasibility

Biocontrol feasibility is broadly defined as logistical and ecological factors related to the target weed and candidate agent/s that influence the ability to obtain, host-range test and release those agent/s into the Australian environment. Such factors include whether the target weed has been nominated and endorsed as a candidate for biocontrol in Australia; knowledge of any existing candidate agent/s and successful research programs in other jurisdictions (within Australia and overseas); accessibility of agent/s in the native range; knowledge about weed population origins in their native range, to optimise exploratory survey locations and sourcing of known agent/s; and relatedness of the weed to important non-target plant species in Australia (see Table B2).

A key difference between this proposed national framework and the Paynter *et al*. (2009) and Morin *et al*. (2016) models is the recommendation to exclude historical and current investment opportunities from the feasibility assessment. (The Morin *et al*. [2016] framework penalised weeds for which current investments were deemed sufficient to meet research objectives, '*thus no further investment needed/justified', or where there was a 'perception that enough investment has been made on the weed already*'.) There was consensus among the experts who attended the biocontrol prospects design workshops in January and March 2024 that it would not be appropriate for biocontrol practitioners to share their perceptions of 'adequate resourcing' of legacy projects that may influence future investment decisions by other stakeholder groups. This is because such perceptions are context dependent and change over time, especially as new information arises or advanced technologies are developed that enhance the efficacy or feasibility of historical biocontrol programs.

It was also recommended that perceived sociopolitical and economic values and conflicts are not considered within the feasibility assessment for this proposed national framework. This deviates from the Paynter *et al*. (2009) and Morin *et al*. (2016) models. Australia has a rigorous process for weed biocontrol nomination and assessment that formally determines candidacy of weeds for biocontrol research. Authority to determine such eligibility rests with jurisdictional members of the National Biosecurity Committee's EIC, not the weed biocontrol researchers per se (but such experts routinely prepare draft nominations for sponsorship by a particular jurisdiction to the EIC). Although weed biocontrol researchers have expertise in weed invasion and impacts, they are typically not responsible for evaluating weed risks, threats or impacts; weed listings or declarations; or sociopolitical or economic conflicts across various stakeholder groups for their host organisations.

During the methods development workshops in January and March 2024, biocontrol experts provided examples of weeds for which perceived sociopolitical and economic conflicts did not impede endorsement by the EIC, as a result of extensive consultation with key stakeholders while developing the nomination documents (e.g. gamba grass, African lovegrass). Further, such conflicts may be resolved as values change over time within key sectors or by aligning biocontrol research with key weed management objectives that balance multiple, often conflicting, values (e.g. a stem-boring agent that damages and reduces culm height and reproductive output in an invasive grass, resulting in reduced invasion potential and fire risk across the landscape, while maintaining forage condition/quality to support livestock grazing).

Experts will be invited to describe the most feasible phase of biocontrol research for each target weed (see Criterion 4 in Table B2), including reflections and comments about how each phase could be developed and implemented. Expert descriptions and opinions elicited in this criterion will be drawn upon when developing the post-prioritisation investment plan, which aims to map prospective research targets across a biocontrol RD&E pipeline. This ensures that the highest priority weed targets for Phase 1 exploratory research can be considered within the investment plan, thus supporting a sustainable research pipeline going forward.

2.2.2 Likelihood of success

Likelihood of success considers abiotic and biotic factors that predict the impacts of biocontrol agent/s on the target weed in Australia, defined by Paynter *et al*. (2009) as 'the proportional reduction in weed density due to biological control'. This definition of impact also considers the type and degree of damage required to achieve the desired reduction in target-weed performance (abundance, reproduction, spread, etc.). Such factors include type of recipient ecosystem (terrestrial, aquatic or wetland) and habitat (environmental, disturbed agricultural); target-weed life cycle (annual, biennial, perennial) and mode of reproduction (sexual, asexual); and type and level of damage by candidate agent/s to the target weed (see Table B2).

In line with the consensus among weed biocontrol experts at the biocontrol prospects design workshops (see Appendix 5), the following likelihood of success criteria from the Paynter *et al*. (2009) and Morin *et al*. (2016) frameworks were recommended not to be included within this national framework's biocontrol prospects assessment at this stage, given significant data deficiencies and limited analytical capabilities, that is, whether the target plant is considered 'weedy' in its native range (i.e. comparison of the relative abundance of the weed between its native and introduced range; Paynter *et al*. 2009), and the diversity of habitats and climates occupied by the weed in its introduced range (from Morin *et al*. 2016).See further details and explanation in Appendix 6.

2.3 ANALYSIS OF BIOCONTROL PROSPECT

First, experts assign one of three numerical scores (either 0, 1 or 2) to each of the seven feasibility and seven likelihood of success criteria. In general, a zero score is assigned to a criterion that has factors which significantly reduce the feasibility (e.g. no promising biocontrol agent/s identified) or likelihood of success (e.g. no precedent to believe that the required damage by the candidate biocontrol agent/s will be achieved following release). A score of 1 is assigned to a criterion for which factors have neither strong negative nor positive influences on biocontrol feasibility and likelihood of success. A score of 2 is assigned for a criterion that has factors which positively influence feasibility or likelihood of success. Operational definitions to guide experts in applying these scores to each criterion are provided in Table B2.

When assessing each criterion, experts are required to provide a written explanation of their choice of score, including a list of references, where available, or other pieces of evidence (e.g. consultation with experts on the target weed or candidate agent/s, including with international collaborators where necessary).

A score of 'unfeasible' is assigned as a stop-go score to two feasibility criteria: 'promising candidate agent/s identified' and 'accessibility of candidate agent/s'. The unfeasible score is only applied if an expert believes that all realistic options for biocontrol have already been explored or exhausted and there are no prospects for identifying additional novel biocontrol agents. This may include weeds that have already been adequately controlled across Australia by one or more biocontrol agent/s. A weed is also deemed unfeasible for ongoing biocontrol research when insurmountable barriers to accessing the agent/s are identified at this stage (this status may change over time); for example, if exporting live cultures is banned from the country of origin, or sociopolitical unrest or other environmental factors render exploratory surveys or collections of known agent/s in the field unacceptably unsafe.

For each expert, overall values for feasibility and likelihood of success are calculated as the sum of their constituent criterion scores (maximum: 2 x 6 feasibility criteria = 12, and 2 x 7 likelihood criteria = 14). Following recommendations from Hennecke *et al*. (2013), each criterion (and their constituent scores) is equally weighted within the biocontrol prospects analysis. These values are then converted to values out of 10. Such standardisation allows for an increase (or decrease) in the number of assessment criteria within the biocontrol feasibility and likelihood of success dimensions in future iterations of this national prioritisation framework, without changing the numerical range of the resultant biocontrol prospects value.

A single biocontrol prospects value for each expert is then calculated as the product of the feasibility and likelihood of success values (maximum: 10 feasibility × 10 likelihood of success = 100). Average and median biocontrol prospect for each target weed is calculated across the participating experts.

2.4 EXPERT ELICITATION

2.4.1 Elicitation workflow

Analysis of the weed biocontrol prospects uses data elicited from experts in weed biocontrol research in the Australian context. It is proposed that the elicitation framework follows a modified Delphi approach, similarly to that deployed by the Australian Bureau of Agricultural and Resource Economics and Sciences for the EEPL (Evans *et al*. 2019), based on an elicitation workflow adapted from Hemming *et al*. (2018).

Expert elicitation involves the following steps:

1. **Training:** Participating experts are trained at an online workshop. Experts are provided with written instructions and taken through a worked example using the online digital tool.
2. **Round 1 assessments:** Experts are provided with a unique identification code, along with a list of predetermined target weeds, in an email. Each expert is invited to assess multiple target weeds for assessment, and weeds are assigned to experts at random. Up to 30 experts will participate in the assessment, ensuring that a broad spectrum of expert judgements is canvassed and reducing bias arising from strong and often divergent opinions shared among a small number of experts. Assessments are undertaken independently and there is no consultation, discussion or collaboration among experts. Elicited data remains de-identified at all stages of assessment, meaning experts cannot see who has conducted each assessment, including at the follow-up review workshop (see Step 4). Data are elicited using an online digital tool, and relevant data fields are populated with the feasibility and likelihood of success criterion scores and text boxes for explaining the rationale for each score based on available evidence (published data, expert opinion, etc).
3. **Analysis:** Data elicited from the first round of estimates are synthesised across participating experts. This involves calculating median biocontrol feasibility and likelihood of success and mean and median biocontrol prospects values for each weed (see Figure B2). Median values are accompanied by first and third quartiles (bounding approximately 50% of the data) and any potential outliers for further consideration. Raw data are presented alongside each median (see Figure B2).
4. **Review of Round 1 biocontrol prospects results:** Experts are invited to a follow-up online workshop to review and discuss the first round of biocontrol prospect assessment. Experts are presented with the synthesis of de-identified data (in the format presented in Figure B2).
5. **Round 2 assessments:** A second round of assessment is undertaken for all weeds to allow experts the opportunity to update their initial scores (if they wish to) in accordance with evidence discussed at the workshop.
6. **Review of final biocontrol prospect and prioritisation analyses:** A third online workshop is held, during which the final set of biocontrol prospect results is shared among the participating experts. Outcomes of the prioritisation analysis (i.e. arrangement of the target weeds in the weed threat × prospects matrix) are also presented to biocontrol experts at this workshop, although there is not scope for biocontrol experts to recommend changes to the relative position of weeds within the prioritisation matrix at this stage of elicitation. During this third workshop, experts are invited to discuss how prioritised weeds could be allocated across Phases 1 to 4 of the research pipeline, to inform the subsequent investment report.

2.4.2 Evaluating confidence in expert-elicited data

Variation and uncertainty in estimated scores among experts is evaluated in three primary ways:

1. **Confidence:** This is evaluated using categories (high, medium and low) that have been modified from Evans *et al*. (2019; see Table B4). Confidence estimates are collected during the elicitation phase, alongside scores for each criterion. These are used to identify weeds that have high levels of uncertainty about biocontrol prospects and stimulate further discussion among experts to resolve strongly conflicting views in accordance with variable evidence. Experts are required to provide a written explanation or justification of their assessments by listing or citing evidence, ranging from published documents and data sets to undocumented observations and conversations with experts in weed biocontrol who have first-hand experience with the target weed and any identified candidate biocontrol agent/s. Confidence scores guide conversations and identify areas requiring more research and development but do not influence the feasibility, likelihood of success or prospect values per se.
2. **Data deficiency:** Following methodology described by Froese *et al*. (2021) for weed impact assessments in NSW, experts are able to select 'data deficient' for each criterion if they consider there is not enough evidence to make an assessment (see further instructions in Table B4). However, if experts can make a judgement, albeit with a

high level of uncertainty, it is preferable to assign a low confidence score (Froese *et al*. 2021).
3. **Variation:** Variation in feasibility, likelihood of success and biocontrol prospects among experts is evaluated by inspecting and comparing the spread of data around each median value. Consideration is given especially to individual expert scores that are statistical outliers, specifically, falling 1.5 times above or below the interquartile range. Such variability is shared and discussed with experts (ensuring all individual data points remain de-identified) at the second workshop (when the Round 1 assessment results are reviewed), using the format exemplified in Figure B2.

Table B2 Proposed list of criteria, definitions and guidelines to support biocontrol practitioners to analyse biocontrol prospects as part of the framework for national weed biocontrol prioritisation

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2]			
		Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutral Definition (Score = 1)	Positive Definition (Score = 2)
Biocontrol feasibility					
1. Weed nominated as candidate for biocontrol	Weed nominated as candidate for biocontrol research through the cross-jurisdictional National Biosecurity Committee's Environment and Invasives Committee, as per endorsed lists hosted on the Weeds Australia website: https://weeds.org.au/overview/lists-strategies/ (correct as of October 2023). Experts should consider the eligibility for weeds in historical biocontrol research programs that proceeded the approval processes that have occurred since 1983 (list also provided on the Weeds Australia website).	No score given	Weed is not currently nominated as candidate for biocontrol and has not been the focus of a historical research program (i.e. preceding the approval processes that have occurred since 1983) has not been undertaken for the weed.	No score given	Weed already successfully nominated as candidate for biocontrol. OR Historical research program (i.e. preceding the approval processes that have occurred since 1983) has been undertaken for the weed.

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2] Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutral Definition (Score = 1)	Positive Definition (Score = 2)
Biocontrol feasibility					
2. Promising candidate agent/s identified	Promising candidate agent/s identified in the weed's native range, and weed successfully targeted for biocontrol overseas or elsewhere in Australia, underpinned by comprehensive and well-resourced exploratory surveys and host-specificity testing. Definition derived from Paterson et al. (2021) in the South African context: 'This attribute examines whether or not any biocontrol programmes have been initiated for the target plant elsewhere in the world. One of the best predictors of whether a biocontrol agent might be successful in the country of interest is assessing the outcome of any biocontrol programmes that may exist elsewhere and when biocontrol has been initiated elsewhere this will help reduce the cost of a potential programme as the prior work conducted will help with a number of aspects of a project such as reducing the number of host plants needed for testing'. Also considered in scope are biocontrol agents that have already been released in Australia but only in a small part of the weed's introduced range, and there is potential for further rollout at a national scale. Such cases will be considered when the approved agents are unlikely to disperse throughout the full range of the weed in Australia without further human assistance. This criterion does not evaluate the degree of the damage caused to the host weed by one or more approved biocontrol agents. Experts should note the names where known and other details of agent/s being assessed.	Consensus among experts that all realistic options for biocontrol have already been explored or exhausted, and there are no realistic prospects of finding additional (novel) biocontrol agents in the weed's native range. 'Not necessary' may also be selected when there is consensus among experts that the weed is already adequately controlled by one or more biocontrol agents across its introduced range in Australia.	No suitable agents are currently known but may be identified through initiation of exploratory surveys in the weed's native range. OR To date, known candidate agents are not sufficiently host specific, according to research conducted in Australia or overseas, but there remains enough scope that it is premature to consider that no realistic options remain (i.e. completely unfeasible).	One or more promising agents may have been identified through exploratory surveys, although the risk of non-target attack may not have been evaluated through comprehensive host-specificity testing, or ongoing tests are not yet completed.	Promising agent/s identified through exploratory surveys and at least one proved to be host specific to the target weed, either in Australia or overseas. OR Agent/s already approved but not yet released into the Australian environment, or only released in a small part of the Australian range and scope for further rollout at a national scale.

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2]			
		Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutral Definition (Score = 1)	Positive Definition (Score = 2)
Biocontrol feasibility					
3. Knowledge of candidate agent/s	Knowledge of candidate agent/s' biology (including life cycle, feeding, reproductive dynamics, etc), taxonomy, rearing or culturing methods and other aspects of ecology relevant to biocontrol feasibility.	No score given	Candidate agent/s' biology, taxonomy, rearing or culturing methods and ecology unknown or unresolved at this stage, hampering progress with collecting the agent/s from the field or host-specificity testing.	Knowledge of a candidate agent/s' biology, taxonomy, rearing or culturing methods and ecology incomplete but can likely be resolved with additional research. Not deemed a significant barrier to progress on host-specificity testing or other phases of biocontrol research at this stage.	Candidate agent/s' biology, taxonomy, rearing or culturing methods and ecology are well known, enabling progress on host-specificity testing or other phases of biocontrol research.

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2]			
		Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutral Definition (Score = 1)	Positive Definition (Score = 2)
Biocontrol feasibility					
4. Most promising phase/s of prospective biocontrol research	Experts are prompted to select one (or more) of the following biocontrol phases for future research activity from a dropdown list. Multiple phases can be selected, for example, in instances when more than one promising candidate agent is identified and are currently at different phases along the research pipeline. 1: exploratory research 2: host-specificity testing 3: mass rearing and release (including to new parts of the weed's introduced range in Australia where an existing approved agent has not been released and where there would be limited opportunity for agent spread and establishment without human-assisted dispersal) 4: monitoring and evaluation of existing weed targets of released biocontrol agent/s Unknown: selected when research phase is unclear and can be discussed among experts at follow-up elicitation workshops. Experts then requested to provide a written description of each identified research phase, including reflections and comments about how each phase could be developed and implemented. Experts should note any historical host-specificity testing that may have resulted in false positive results in terms of damage to non-target plants and thus may warrant re-evaluation using contemporary risk analytical methodologies. Expert descriptions and opinions elicited in this criterion are drawn upon when developing the post-prioritisation investment plan, which aims to map prospective research targets across the biocontrol pipeline. This ensures that the highest priority weed targets for Phase 1 exploratory research can be considered within the investment plan, thus supporting a sustainable research pipeline going forward.	No score given	No score given	No score given	No score given

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2] Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutral Definition (Score = 1)	Positive Definition (Score = 2)
Biocontrol feasibility					
5. Accessibility of native range	Accessibility of native range to undertake Phase 1 exploratory surveys for novel biocontrol agent/s. Accessibility of identified candidate agent/s: consideration of existing laboratory cultures or stored viable material, potential to export candidate agent/s and the need to recollect in the field and gain access to the native range, including the ability to acquire collection permits or conduct exploratory surveys with or without local collaborators. Further consideration should be given to the availability of suitable research infrastructure and collaborative links, given that local organisations that have a robust research capacity enhance the potential to find new effective agents and conduct in-country research upon them. As considered by Paterson *et al*. (2021) and references therein: 'Exploration within native ranges is a critical initial component of classical biocontrol of weeds and difficulties encountered here can often limit the ability to conduct a programme. This stage of a biocontrol programme is often limiting because it can be restrictively expensive, logistically difficult and is sometimes constrained by administrative problems, such as acquiring permits. The levels of safety, infrastructure and the presence of biocontrol research organisations in the region of origin are used in this attribute to determine the level of effort to source potential biocontrol agent populations'.	Deemed unfeasible because of insurmountable barriers to accessing the agent (e.g. exportation of live cultures banned from country of origin; sociopolitical unrest or environmental risks rendering exploratory surveys or recollections of known agent/s in the field unacceptably unsafe).	Native range is deemed generally safe but there is either no biocontrol research facility or group in that country or to date there has been no effort to identify and collect the candidate agent/s from the field to establish a clean lab-reared colony.	Accessibility of native range is not considered to influence research feasibility strongly either in a positive or negative direction.	Native range readily accessible and a strong potential for an agent colony to be established through collection from the field or a clean lab-reared colony already established, supported by strong collaborative links with international weed biocontrol research facilities or groups.

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2]			
		Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutral Definition (Score = 1)	Positive Definition (Score = 2)
Biocontrol feasibility					
6. Knowledge of weed origin/s and taxonomy	Origins: Limited knowledge of weed-population genetic diversity and origins can reduce confidence in location of exploratory surveys and risk genotypic mismatches in host plant-enemy associations, resulting in reduced biocontrol feasibility and efficacy. Taxonomic resolution or delimitation of the weed. As noted by Winston et al. (2024) and references therein: 'Ambiguity in taxonomic delineation can lead to exploration of an incorrect plant species in the native range or the collection of biocontrol candidates that readily attack the ambiguous species in the native range but not the biotypes present in the invaded range'. Hybridisation: Considered by Winston et al. (2024) where the weed has arisen as a 'result of artificial selection that has created hybrid cultivars' that have naturalised in the invaded range but do not occur in wild populations, including hybridisation with native flora. Winston et al. (2024) rationalised the inclusion of this criterion as follows: 'Sourcing suitable biocontrol candidate populations for hybrid cultivars could be problematic because herbivore populations adapted to these cultivars may not exist'.	No score given	Origins: No knowledge of the target weed's population genetics and origins, hampering progress with exploratory surveys (e.g. source location of candidate agent/s best matched to weed populations in Australia). This may include instances where candidate agent/s have already been identified but there is a mismatch between their source location and the genetic diversity and origin of the weed populations in Australia. OR Taxonomy: This score may also be given in instances where the weed's taxonomy remains poorly resolved. OR Hybridisation: This score may be given in instances where the weed has arisen because of hybridisation through cultivar development or hybridisation with native plant species.	Knowledge of the target weed's population genetics origins and taxonomy may be incomplete but not deemed a significant barrier to progress on biocontrol research at this stage.	Target weed's population genetics and origins are well known, enabling targeted exploratory surveys and progress on other biocontrol research phases. AND Weed not considered to have arisen through hybridisation.

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2] Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutral Definition (Score = 1)	Positive Definition (Score = 2)
7. Relatedness of the weed to non-target species	Phylogenetic relatedness of the target weed to potential non-target plant species in the introduced range, inferred by membership of the same plant family and presence of congeneric species. Rationale from Paynter *et al*. (2009): 'Weeds with closely related non-target plants should be harder to control due to the potential for non-target attack'. Further rationale from Paterson *et al*. (2021) and refences therein: 'Native plants in the same genus as target weeds are much more likely to be suitable hosts for natural enemies than more distantly related plant species. The most common reason that potential biocontrol agents are rejected is that the agent is not suitably host specific and in most cases can feed on congeneric species. Identifying if there are closely related plant species to the target alien plant in South Africa is therefore seen as a good predictor of the chances of finding a suitably specific biocontrol agent'.	No score given	At least one or more congeneric plant species present in the introduced range (e.g. Senecio, Solanum). OR Phylogenetic associations between the weed and native species unknown because of unresolved species taxonomy. .	No congeneric species present but shared membership of the same plant family in the introduced range (e.g. Cabombaceae).	No shared membership of the same plant family (e.g. Cactaceae).
Likelihood of success (i.e. potential impact) of biocontrol					
8. Ecosystem	Predominant ecosystem supporting target-weed populations. Broad comparison of terrestrial versus aquatic or wetland ecosystems.	No score given	No score given	Terrestrial	Aquatic or wetland
9. Habitat stability	Weed adapted predominantly to disturbed contexts. Noted in Paterson *et al*. (2021): 'Habitat stability, i.e. target plants that occupy areas that are frequently disturbed, such as cultivated land and improved pastures, are less likely to sustain adequate biocontrol agent populations'.	No score given	No score given	Predominantly a disturbance-adapted weed of cultivated lands, crops, improved pastures and disturbed aquatic ecosystems.	Predominantly a weed of relatively undisturbed environmental contexts (which may include grazed rangelands).
10. Weed life cycle	Predominant life cycle duration. Noted in Paterson *et al*. (2021): 'Plants that are annual have been found to be more difficult to control compared with biennial and perennial plants ... and biocontrol on annuals can only be successful if biocontrol agents are able to impact seed production within a single growing season'.	No score given	No score given	Annual or ephemeral	Biennial or perennial

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2]			
		Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutral Definition (Score = 1)	Positive Definition (Score = 2)
Likelihood of success (i.e. potential impact) of biocontrol					
11. Weed reproduction	Predominant mode of reproduction in its introduced range. Noted in Paterson et al. (2021): 'Plants that can only reproduce asexually and are, therefore, clonal have been found to have a greater chance of being controlled using biocontrol agents'.	No score given	No score given	Predominantly sexually reproducing (but can include species that can also reproduce vegetatively).	Asexual: only reproducing by vegetative means or apomixis.
12. Damage by candidate agent/s to the target weed	Type, severity and duration of damage inflicted by candidate agent/s to host-weed populations. Experts invited to describe the known or predicted nature of the damage (e.g. seed feeding, stem boring, leaf infection) and predicted outcomes of such damage for weed populations. This criterion also considers biotic factors that may reduce the efficacy of biocontrol, for example, sustained attack of the agent/s by predators or parasitoids and variable plant growth form or habits. In situations where there are no existing agents, because of a lack of exploratory surveys, assess the target weed in accordance with any existing knowledge of closely related or functionally similar species. Where this may still fail to provide clarity, select the 'Negative' score.	No score given	In accordance with prior research in or outside Australia on the target weed or closely related or functionally similar species, there is no precedent to believe that candidate agent/s will become successfully established or significantly damage the host weed following their release (i.e. no to low impacts on the weed population). This score may be given when high levels of sustained attack of candidate agent/s by their predators or parasitoids in the native and introduced ranges have been demonstrated to reduce agent efficacy. This score may also be given when there is expected to be difficulties targeting multiple forms of the weed or a high probability of replacement by other forms or congeners following successful biocontrol, thus negating benefits, for example, terrestrial and aquatic forms of alligator weed (Alternanthera philoxeroides).	In accordance with prior research in or outside Australia on the target weed or closely related or functionally similar species, there is evidence that candidate agent/s can become established following release but with only moderate damage to the host weed, resulting in no significant reduction in weed populations. Predators or parasitoids or variation in plant growth form or function not expected to negatively or positively influence damage caused by the candidate agent/s.	n accordance with prior research in or outside Australia on the target weed or closely related or functionally similar species, there is evidence that the required damage by candidate biocontrol agent/s will be achieved, resulting in significant reductions in weed populations. No identified impediments to effective biocontrol by predators or parasitoids or variation in plant growth form or function.

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2]			
		Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutra l Definition (Score = 1)	Positive Definition (Score = 2)
13. Synchronisation of agent with weed life cycle	Consideration of synchrony or any potential mismatch between weed life cycle and damage by the candidate agent/s. In situations when there are no existing agents, because of a lack of exploratory surveys, assess the target weed in accordance with any existing knowledge of closely related or functionally similar species. When this may still fail to provide clarity, select the 'Negative' score.	No score given	In accordance with prior research in or outside Australia on the target weed or closely related or functionally similar species, it is expected that there are significant mismatches between weed life cycle and damage by identified candidate agent/s, resulting in no overall impact on weed populations, for example, a short-lived annual plant that can set viable seed faster than the rate of production and spread of the spores of a fungal pathogen released as a biocontrol agent, thus resulting in no meaningful reduction in weed-invasion risk over broad spatial and temporal scales.	Synchronisation with weed life cycle not considered to influence the likelihood of success strongly either in a positive or negative direction.	Strong synchrony between weed life cycle and damage by the candidate agent/s.

Criterion Name	Criterion Description and Guideline[1]	Criterion Scores[2] Unfeasible/Not Necessary (Stop)	Negative Definition (Score = 0)	Neutral Definition (Score = 1)	Positive Definition (Score = 2)
14. Weed resilience to damage by candidate agent/s	Level of resilience (response or recoverability) of weed populations to attack by candidate agent/s.	No score given	Weed is expected to have high capacity for resilience to attack by candidate agent/s, for example, through resprouting from an extensive root system that may enable recovery from damage (for example, African boxthorn's capacity for mature plants to reshoot despite defoliation by the fungal pathogen Puccinia rapipes). This score may also be chosen when it is identified that a very large reduction in weed growth rates or reproduction sustained over many years would be required to reduce host-weed populations	Weed resilience not considered to influence the likelihood of success strongly either in a positive or negative direction.	Weed displays limited resilience to attack by candidate agent/s, resulting in sustained population declines over time.

[1] Guidelines supported where necessary by quotations from key prioritisation frameworks:

Paynter Q, Hill R, Bellgard S and Dawson M (2009) Improving targeting of weed biological control projects in Australia. A report for Land and Water Australia, Canberra.

Paterson ID, Hill MP, Canavan K and Downey PO (2021) Prioritisation of targets for weed biological control II: the South African biological control target selection system. Biocontrol Science and Technology 31(6), 566–583.

Winston RL, Schwarzländer M, Hinz HL and Pratt PD (2024) Prioritising weeds for biological control development in the western United States: adaptation of the Biological Control Target Selection System. BioControl, 69, 335-351.

Morin L, McConnachie A and Turner P (2016) Prioritisation of weed biocontrol targets for NSW. A report for the NSW Environmental Trust, CSIRO, Sydney.

[2] Note that the numerical values correspond to the negative (0), neutral (1) and positive (2) scores deployed by Morin *et al*. (2016) for environmental weeds in NSW. Experts agreed to assign 0 rather than negative scores for criteria that have significantly reduced biocontrol feasibility or likelihood of success, given that the multiplication of two negative scores results in a large positive biocontrol prospect value and the inappropriate intermixing of weeds that have both very high and very low biocontrol prospects at the top of the list of prioritised species.

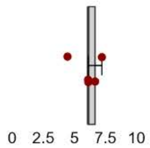
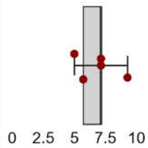
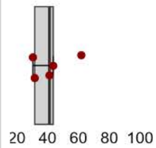
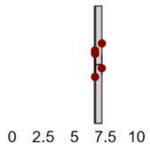
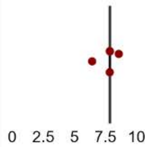
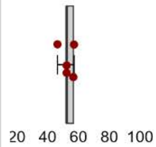
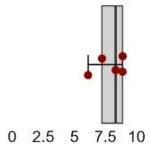
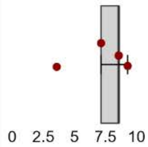
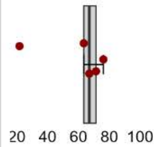
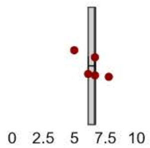
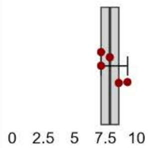
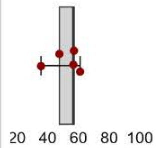
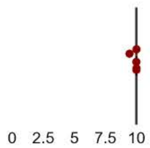
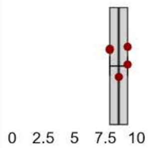
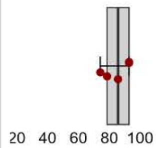
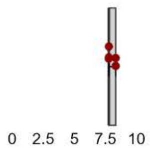
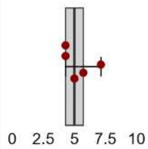
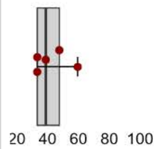
		Feasibility					Likelihood						
			Confidence (%)					Confidence (%)				Biocontrol Prospects (%)	
Weed Species	**n**	**Value**	**H**	**M**	**L**	**Data Def (%)**	**Value**	**H**	**M**	**L**	**Data Def (%)**	**Value**	**Average**
Species A	5		0	40	40	n/a		0	40	40	n/a		42
Species B	5		0	20	40	n/a		0	20	40	n/a		53
Species C	5		0	60	0	n/a		0	60	0	n/a		60
Species D	5		20	20	60	n/a		20	20	60	n/a		52
Species E	5		80	20	0	n/a		80	20	0	n/a		85
Species F	5		0	40	20	n/a		0	40	20	n/a		43

Figure B2 Visual summary of expert-elicited biocontrol feasibility, likelihood of success and prospects data

Table B4 Confidence level and corresponding evidence for use in the process for biocontrol prospects elicitation, adapted from Evans et al. (2019) for use in the weed biocontrol context

Confidence Level	Evidence/Information Source	Example of Data Source
High	There is good-quality directly relevant evidence to support each criterion, derived from reputable and verifiable sources in Australia or overseas. There are reliable sources/good-quality data or non-contradictory/non-controversial information in support of each criterion.	Direct observations (e.g. biocontrol agent populations and host-weed responses in the field) Peer-reviewed scientific papers High-quality technical reports (e.g. weed-candidate nomination documents, biocontrol agent release applications) Unpublished reports from highly reliable sources Non-peer-reviewed scientific papers (e.g. conference proceedings) Personal communications from experts
Medium	There is some evidence to support the assessment for each criterion, although some evidence may be indirect and drawn from phylogenetically or functionally similar weed species or candidate agent/s. The interpretation of data may, to some extent, be ambiguous or contradictory.	Unpublished reports from uncertain sources Personal communications from people who have some experience but limited expertise with the species being assessed Good-quality evidence drawn from phylogenetically or functionally similar weed species or candidate agent/s
Low	There is little or no direct evidence to support the assessment for each criterion, specifically, only unreliable sources of information that are poor quality or difficult to interpret.	Anecdotal data from non-experts Information from uncertain/uncited sources
Data deficient	Following the methodology described by Froese *et al*. (2021) for weed-impact assessments in NSW, experts should only select 'data deficient' for each criterion if they consider that there is not enough information (including their own expert opinion and observations) available for them to make an assessment with any level of confidence. However, if experts can make a judgement, albeit with a high level of uncertainty, it is preferable for them to assign a low confidence score (Froese *et al*. 2021).	

STAGE 3: BRINGING TOGETHER WEED THREAT AND BIOCONTROL PROSPECTS SCORES FOR WEED PRIORITISATION AND DEVELOPMENT OF A WEED BIOCONTROL INVESTMENT REPORT

Developed by the CSIRO

3.1 MATRIX-BASED PRIORITISATION WORKFLOW

Stage 3 of the Weed Biocontrol Prioritisation Framework outlines the workflow used to prioritise weed biocontrol investments by combining the outputs of the weed threat assessment (Stage 1) and the biocontrol prospects analysis (Stage 2) for up to 150 weeds (see Figure B3). It is anticipated that the five highest ranking weeds in each of the four research phases (up to 20 weeds in total) will be prioritised for inclusion in the Weed Biocontrol Investment Report.

Weed species prioritised for inclusion in the Weed Biocontrol Investment Report are contextualised across six dimensions (see Section 3.2) to support relevant stakeholders when considering weed biocontrol investment decisions.

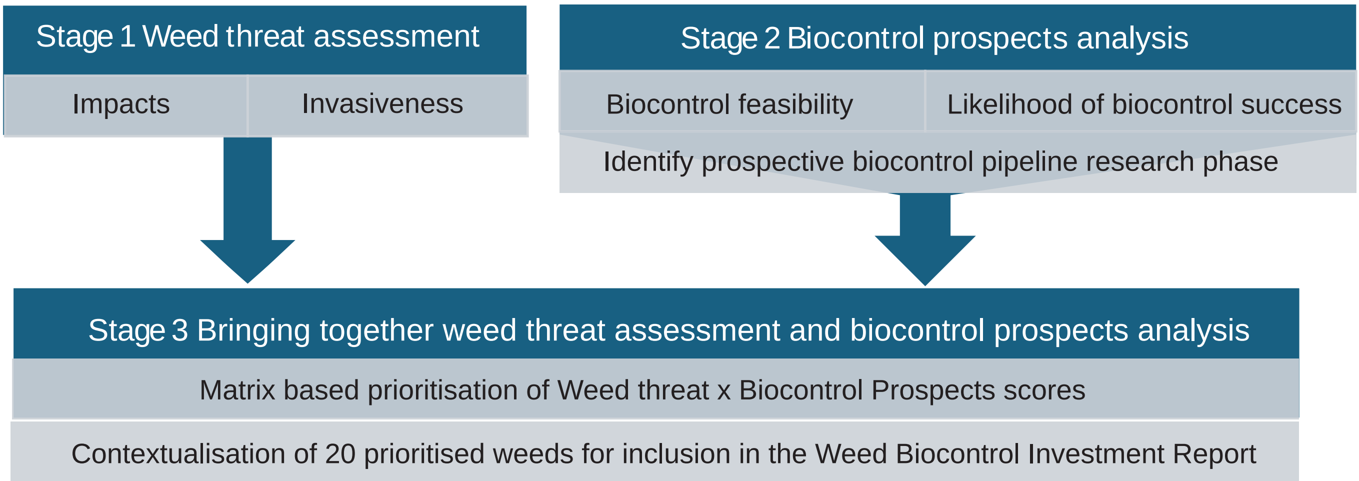


Figure B3 Flow diagram of Stage 1, 2 and 3 of the Framework

A series of schematic diagrams are presented (see Figures B4 to B7) to demonstrate the proposed matrix-based workflow to prioritise the target weeds for biocontrol research investment, using mock data for 25 fictitious weed species. In this scenario, prioritisation aims to select 12 research targets, equally distributed across the four key biocontrol research phases.

The first step in bringing Stages 1 and 2 together is to combine the results of the weed threat assessments and biocontrol prospects analysis into an unmodified two-dimensional plot. Figure B4 plots the weed-threat values (unmodified from the threat assessment) against the biocontrol prospect values for the 25 fictitious weed species. Weed species are coded by their most promising biocontrol research phase/s (exploratory research, host-specificity testing, mass rearing and release, monitoring and evaluation), identified by the panel of experts during the biocontrol feasibility assessment stage (see Figure B4, denoted in brackets).

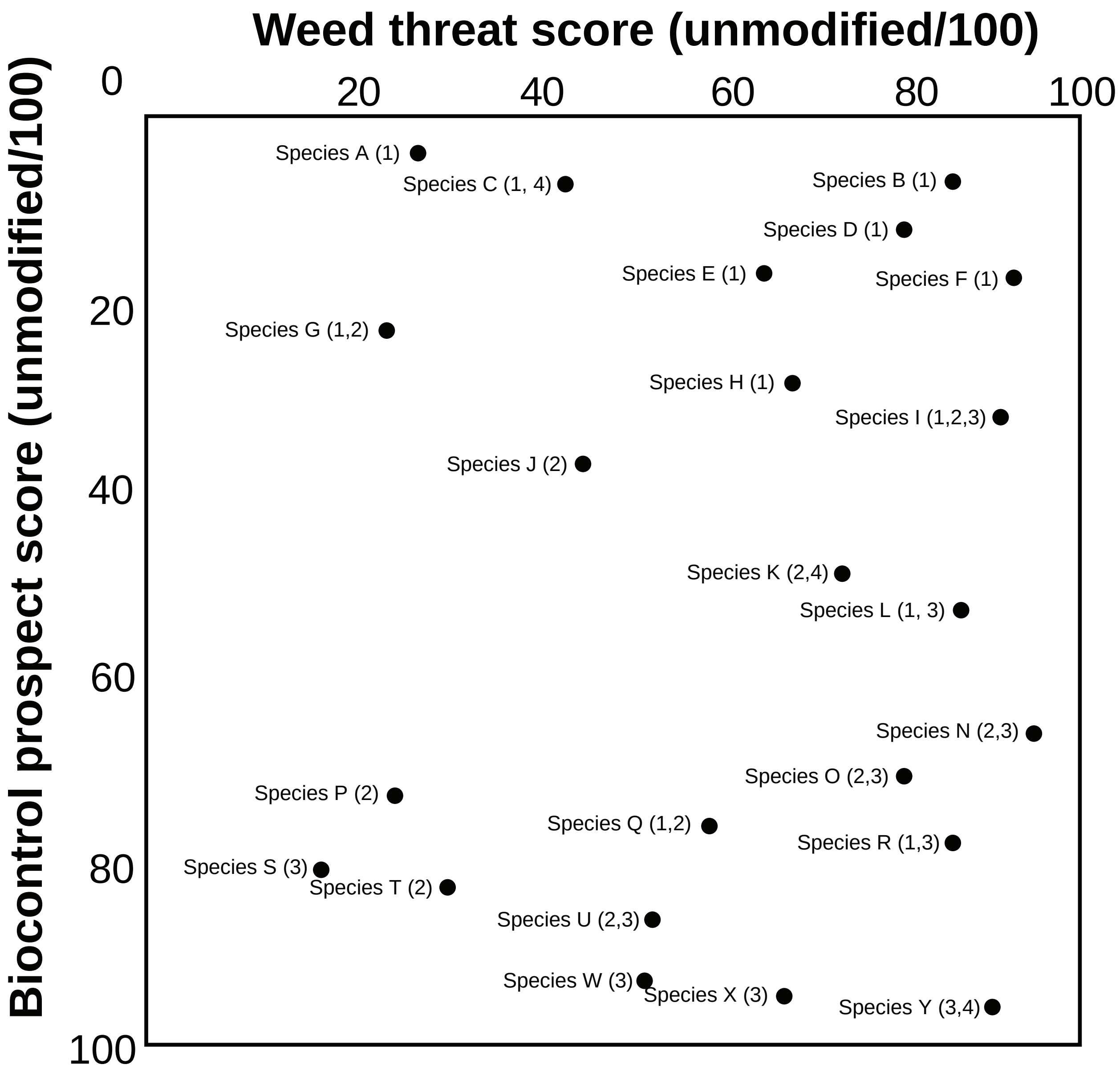


Figure B4 Unmodified weed threat × biocontrol prospect values (black dots) for 25 fictitious species, A to Y

The second step is to convert the scatter plot into a scaled matrix by overlaying the prioritisation categories (very low, low, medium, high and very high) used in the threat assessment (see Section 1.6) and biocontrol prospects analysis (see Section 2.3 Figure B5). Such scaling (see Section 1.6 and Appendix 4) is included in the prioritisation framework to account for the possibility of data not being evenly distributed along the weed-threat dimension. Intrinsic biases in the assessment of weed biocontrol prospects are probable because high-threat weeds at the exploratory research phase tend to have lower feasibility scores than equally high-threat weeds that have approved agents available for mass rearing and release into the Australian environment (see description and assigned scores for feasibility Criterion 2, identification of promising candidate agent/s, and Criterion 3, knowledge of candidate agent/s, in Section 2.2).

Mock weed species	Weed Threat	Biocontrol Prospect	Threat x Prospect score	Prioritisation category
V	95	89	8455	Very High
Y	89	95	8455	Very High
R	83	78	6474	High
X	68	94	6392	High
N	94	66	6204	High
M	97	60	5820	High
O	79	70	5530	High
W	51	93	4743	High
U	55	86	4730	High
L	85	52	4420	High
I	91	27	2457	High
F	92	18	1656	High
Q	59	75	4425	Medium
K	73	49	3577	Medium
T	30	82	2460	Low
J	45	38	1710	Low
H	67	25	1675	Low
P	23	72	1656	Low
S	18	80	1440	Low
E	62	15	930	Low
D	79	11	869	Low
B	83	5	415	Low
G	22	22	484	Very Low
C	42	6	252	Very Low
A	24	3	72	Very Low

Frequency band	Weed Threat score range	Biocontrol prospect score range
0 - 20	<4	<17.4
20- 40	4.0 - 12.2	17.5 - 44.6
40- 60	12.3 - 24.9	44.5 - 70.8
80 - 60	25 - 44.6	70.9 - 82.8
80 - 100	>44.6	>82.8

Prioritisation category	No. species	% species
Very Low	3	12
Low	8	32
Medium	2	8
High	10	40
Very High	2	8

Figure B5 Table of unmodified data for 25 fictitious species demonstrating how species are allocated to each of frequency bands and prioritisation categories

Within the matrix, species are grouped into five biocontrol prioritisation categories (very low to very high, blue shading in Figure B6). This matrix-based approach, as detailed in Figure B6, provides transparency in the prioritisation workflow by presenting values for the two assessment dimensions separately rather than masking the underpinning data by presenting a single ranked prioritisation value.

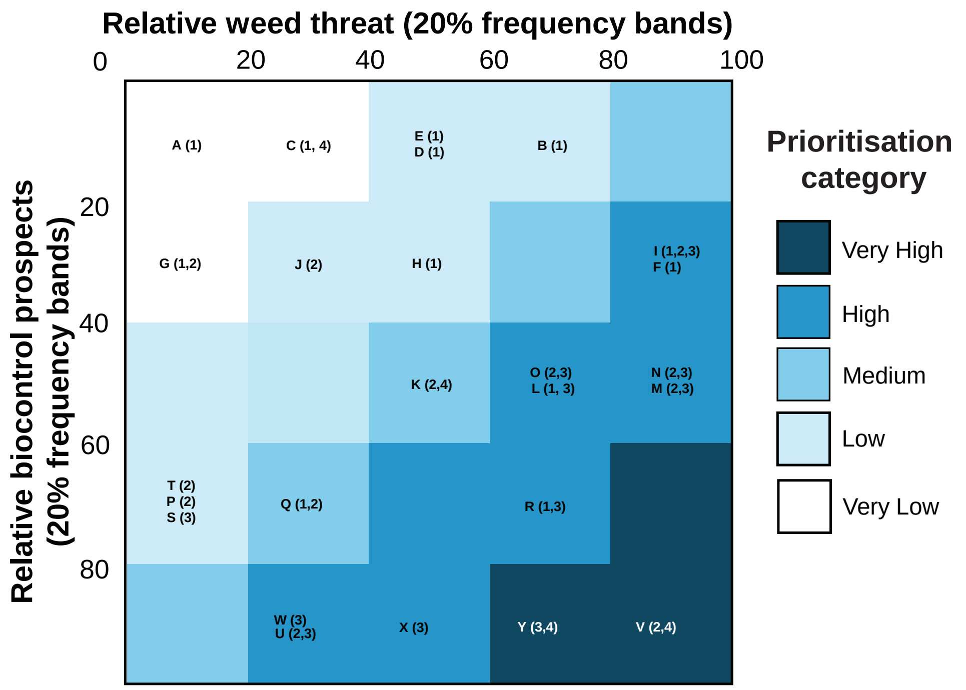


Figure B6 Scaled matrix depicting standardised relative distributions of species across the weed threat and prospects dimensions

Finally, a selection of 20 targets (five species from each research phase) will be selected for contextualisation in the investment report. This selection method is illustrated using the same fictitious example of 25 species (A to Y) depicted in Figure B4 in Figure B7. In this scenario, the aim of investment is to deliver research on three targets for each of the four research phases (up to 12 targets). Priority is given to the three highest ranked weeds in each research phase, independent of species identity, to ensure that each phase is equally represented within the investment portfolio. This may result in the same high priority weed species being targeted for multiple investments if it has more than one feasible research phase (e.g. 'Species Y' in Figure B7). Species are first selected from the highest to lowest prioritisation categories until three targets per research phase are selected. In this scenario, nine species are selected, ranging from the highest priority, 'Species V', to the fourteenth priority,
'Species K'.

Mock weed species	Exploratory research	Host-specificity testing	Mass-rearing & release	Monitoring & evaluation	Weed Threat	Biocontrol Prospect	Threat x Prospect score	Prioritisation category	Investment opportunity
V		2		4	95	89	8455	Very High	✓
Y			3	4	89	95	8455	Very High	✓
R	1		3		83	78	6474	High	✓
X			3		68	94	6392	High	✓
N		2	3		94	66	6204	High	✓
M		2	3		97	60	5820	High	✓
O		2	3		79	70	5530	High	
W			3		51	93	4743	High	
U		2	3		55	86	4730	High	
L	1		3		85	52	4420	High	✓
I	1	2	3		91	27	2457	High	✓
F	1				92	18	1656	High	
Q	1	2			59	75	4425	Medium	
K		2		4	73	49	3577	Medium	✓
T		2			30	82	2460	Low	
J		2			45	38	1710	Low	
H	1				67	25	1675	Low	
P		2			23	72	1656	Low	
S			3		18	80	1440	Low	
E	1				62	15	930	Low	
D	1				79	11	869	Low	
B	1				83	5	415	Low	
G	1	2			22	22	484	Very Low	
C	1			4	42	6	252	Very Low	
A	1				24	3	72	Very Low	

Frequency band	Weed Threat score range	Biocontrol prospect score range
0 - 20	<4	<17.4
20- 40	4.0 - 12.2	17.5 - 44.6
40- 60	12.3 - 24.9	44.5 - 70.8
80 - 60	25 - 44.6	70.9 - 82.8
80 - 100	>44.6	>82.8

Prioritisation category	No. species	% species
Very Low	3	12
Low	8	32
Medium	2	8
High	10	40
Very High	2	8

Figure B7 Table of raw data demonstrating how species are allocated to each of five 20% frequency bands (grey shading), and prioritisation categories (blue shading) from scaled matrix

This approach to targeting the highest priority research phases is a foundational principle underpinning the National Weed Biocontrol Pipeline Strategy (i.e. 'categorising prioritised weeds along the biocontrol research pipeline'). It ensures a sustainable pipeline of biocontrol research across the five-year implementation cycles and balances risk and reward for prospective investors by targeting high-threat weeds at the exploratory research phase, as well as opportunities for release of approved biocontrol agents.

The prioritisation workflow has been designed to be adaptive (not prescriptive), and all stages will be made available for independent review by relevant jurisdictions and stakeholder groups before implementation. Adjustments can be made if, for example, some prioritised species represent undesirable investment targets. For instance, in the scenario depicted in Figure B7 potential investors may perceive that Phase 4 monitoring and evaluation for 'Species K' (medium priority) offers relatively poor value, and thus instead invest in Phase 3 mass rearing and release of the approved agent for 'Species N' (high priority). Such recommendations to vary the prioritisation workflow must be clearly justified and agreed to by the Alliance and the EIC Weeds Working Group before inclusion in the Weed Biocontrol Investment Report.

3.2 CONTEXTUALISATION OF WEED BIOCONTROL

In this framework, we contextualise the potential benefits of biocontrol to weed management and asset protection against conflicts of interests and investment risks across stakeholder groups and land use sectors by gathering publicly available information for each component (literature review) and complementing it, where necessary, with targeted conversations with relevant jurisdictional and sectoral representatives.

Contextualisation of weed biocontrol is conducted for the 20 highest priority targets for investment and not the full suite of species that were assessed for weed threat and biocontrol prospects. The outcomes of the biocontrol contextualisation do not influence the prioritisation results but provide further background on potential risks and benefits underpinning investment decisions and research opportunities. A written summary of the outcomes is presented using a traffic light system, alongside the prioritisation results for each weed species within the investment report.

It is proposed that biocontrol contextualisation considers conflicts of interest, desired weed management goals, current control feasibility, knowledge gaps and research opportunities, investment complementarity with existing or historical research investments, and weed distributions. These considerations are defined below, detailed further in Table B5 and reported on in the Weed Biocontrol Investment Report.

Conflicts of interest

This component identifies and describes any potential socioeconomic values that may be disrupted by the release of approved biocontrol agent/s and thus reduce the acceptability of biocontrol for the target weed (e.g. the weed is a significant threat to environmental assets but is also valued as a productive pasture species supporting the livestock industry).

When such conflicts are likely to be high, it is recommended that comprehensive stakeholder engagement is conducted as a standalone dedicated research project that accompanies an application for approval of the target weed as a candidate for biological control by the EIC.

Management goals

This component outlines key management objectives for each target weed and describes the potential contribution of biocontrol to meeting those objectives (e.g. mitigating invasion risk by reducing seed set or reducing competitive performance to enhance pasture production and livestock health outcomes).

Biocontrol complementarity

The component considers feasibility of existing weed control methods and the potential benefits of biocontrol for enhancing existing weed management outcomes. The assessment highlights any instances in which the target weed is known to have low feasibility for existing control tools or limited opportunities for coordinated control across jurisdictions. These weeds are likely to benefit more strongly from sustained landscape-scale impacts of biocontrol activity and thus represent more attractive investment targets (Hennecke *et al*. 2013).

Consideration is also given to how weed biocontrol could be integrated with existing management technologies and strategies (e.g. WoNS best practice management plans) and opportunities or benefits of coordination across stakeholder groups and land use sectors.

Knowledge gaps and research opportunities

This summarises key knowledge gaps related to weed biocontrol feasibility and likelihood of success that were identified by experts during the elicitation stage of the biocontrol prospects assessment. Identifying such knowledge gaps supports research-implementation planning, for example, analysis of weed population genetics and modelling of climate niches to optimise the location of native range exploratory surveys for novel candidate biocontrol agents.

Identification of many knowledge gaps across key biocontrol feasibility and likelihood of success criteria may highlight any significant risks for investment (i.e. low confidence in returns on investment and achieving desired outcomes for weed threat mitigation). This then triggers preliminary investment in addressing such knowledge gaps before formal commencement of the prioritised research phase.

Investment complementarity

This component brings together information across jurisdictions on historical and current investments that support research into one or more activities for each prioritised weed. The aim of this exercise is to identify complementarities and align research interests to enhance the overall value and likelihood of achieving desired outcomes.

Weed distribution

The National Weed Biocontrol Pipeline Strategy seeks to prioritise both established and emerging weeds that have a high threat potential. Given the long-term pipeline from biocontrol research inception to agent release, investing in new and emerging weed research may be considered a strategic and pre-emptive approach that could reduce the severity of future impacts being realised. Weeds that have a limited current distribution are considered equally important as those that have a greater current distribution, thus weed distribution is not included in Table B5 as part of the traffic light process.

Considering weed distribution in the Weed Biocontrol Investment Report is useful:

- when understanding the specific impacts and management objectives associated with the weed (i.e. the land uses, sectors and communities at risk, and what required of weed management),
- when identifying key stakeholders to engage in biocontrol research implementation.

Given the long-term pipeline from biocontrol research inception to agent release, investing in new and emerging weed research may be considered a strategic and pre-emptive approach that could reduce the severity of impacts being realised.

Table B5 Qualitative contextualisation framework for biocontrol consideration, using a traffic light system

Contextual Considerations	Conflicts of Interest	Management Goals	Biocontrol Complementarity	Knowledge Gaps and Research Opportunities	Investment Complementarity
Key questions to consider (but not limited to)	What are the various social, cultural, economic, political and environmental values of the weed? What is the potential for biocontrol to significantly disrupt these values and generate conflict?	What is the primary management goal for biocontrol of the weed, that is, what desired outcomes are to be achieved? Answers to this question might help to target specific aspects of the weed's life cycle for biocontrol intervention (e.g. seed production).	Is the weed known to have low feasibility of control that may especially benefit from biocontrol? How might biocontrol complement or integrate with existing control techniques or management programs?	What are some of the key knowledge gaps that may hamper progress on biocontrol research for the weed? What research activities may be undertaken to fill these gaps and improve overall confidence in biocontrol for the weed?	What are some of the key knowledge gaps that may hamper progress on biocontrol research for the weed? What research activities may be undertaken to fill these gaps and improve overall confidence in biocontrol for the weed? Have existing investments been made available for biocontrol research on the weed? If so, are those investments sufficient to achieve the desired biocontrol outcomes for the weed? If not, what gaps in research may benefit from new investment to enhance the overall value of biocontrol for the weed?
Green: No mitigating actions required. Proceed with research-implementation planning	No significant conflicts of interest identified. Commence implementation planning for new research program. At any time, nominate the weed as a candidate for biocontrol research (if the weed is not already an approved candidate for biocontrol).	Strong alignment of biocontrol prospects with overall management goals for the target weed. Commence implementation planning for new research program.	There are limited existing control options, resulting in poor management outcomes. This may include existing biocontrol options. Investment in biocontrol RD&E is considered a key need to achieve weed management outcomes.	No significant knowledge gaps identified. Commence implementation planning for new research program.	No existing research investments identified. Commence implementation planning for new research program.

Contextual Considerations	Conflicts of Interest	Management Goals	Biocontrol Complementarity	Knowledge Gaps and Research Opportunities	Investment Complementarity
Amber: Some mitigating actions required at the research-implementation planning stage	Moderate conflict/s of interest. Commence implementation planning for new research program that includes a stakeholder-engagement phase and nomination of the weed as a candidate for biocontrol research.	Moderate disconnect between biocontrol prospects and management goals. Commence implementation planning for new research program that includes a stakeholder-engagement phase to strengthen alignment between biocontrol research and weed-management practice.	There are existing control options, but they may not always be effective, affordable and available, depending on land use, location, land manager experience and capacity. This may include existing biocontrol options. Even where existing control options are effective, the addition of novel biocontrol agents will likely enhance overall management outcomes.	Some key knowledge gaps identified that can be readily resolved through targeted research during the implementation-planning phase. Key examples: weed-population genetics and climate-niche modelling to pinpoint source locations of exploratory surveys in the weed's native range.	One or more existing investments identified. Ensure new investments support complementary research activities. Where appropriate, foster collaborations across complementary investment streams.
Red: Considered stepwise approach, and significant mitigating actions are needed	Significant conflict/s of interest identified that pose risks to biocontrol research implementation. Do not commence full research-implementation planning until conflicts have been addressed. Consider a standalone project focused on extensive stakeholder engagement to determine whether a weed can be successfully nominated as a candidate for biocontrol.	Significant disconnect between biocontrol prospects and management goals for the target weed. If stakeholder consultation fails to align biocontrol research with management goals, consider redirecting investment to a more desirable weed target.	Existing control options are available, effective and affordable and allow land managers to achieve weed-management goals. This may include existing biocontrol options. Consider redirecting investment to a more desirable weed target.	Significant gaps in knowledge identified and low confidence in biocontrol prospect analyses undertaken by experts, which pose risks to biocontrol research implementation. Do not commence implementation planning until identified knowledge gaps have been addressed with some preliminary standalone research activities.	There is a widespread perception that existing (including historical) investments are sufficient to achieve desired biocontrol research outcomes without any further contribution. If complementary research activities across investments cannot be identified, consider redirecting new investments to a more desirable weed target

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APPENDIX 1: ATTENDEES OF THREAT ASSESSMENT WORKSHOPS

Workshop 1: 13 March 2024	
Stephen Johnson	NSW DPIRD
Nigel Ainsworth	Agriculture Victoria
Alexi Rowles	Agriculture Victoria
Sandra Parsons	ABARES
Jens Froese	CSIRO
Jackie Steele	Agriculture Victoria
Karen Stewart	Biosecurity Tasmania
Craig Hunter	Biosecurity Queensland
Giverny Rogers	PIRSA
Michelle Franklin	NT Weeds Branch
Margie Heath	DAFF
John Moore	DPIRD
Mariana Hopper	CSIRO
Allan Peake	MLA
Cameron Allen	MLA
Kathryn Bachelor	DPIRD
Kellie Passeretto	DBCA
Tony Dugdale	Agriculture Victoria
Megan Wylie	ACT Parks and Conservation Service
Isabel Zeil-Rolfe	CSIRO
Matt Sheehan	Wild Matters
Laura Fernandez	Wild Matters
Shauna Potter	Wild Matters
Workshop 2: 29 April 2024	
Claire Lock	NSW National Parks & Wildlife Service
Stephen Johnson	NSW DPIRD
Nigel Ainsworth	Agriculture Victoria
Alexi Rowles	Agriculture Victoria
Jess Clarke	ABARES
Jens Froese	CSIRO
Jackie Steele	Agriculture Victoria
Karen Stewart	Biosecurity Tasmania
Craig Hunter	Biosecurity Queensland
Susan Ivory	Landscapes SA
Marty Bower	PIRSA
Michelle Franklin	NT Weeds Branch
Margie Heath	DAFF
John Moore	DPIRD
Matt Sheehan	Wild Matters
Laura Fernandez	Wild Matters
Shauna Potter	Wild Matters

APPENDIX 2: INFORMATION SOURCES FOR WEEDS OF INTEREST

First Nations information sources	
Various documents, including Healthy Country plans, Indigenous Protected Area management plans, Land and Sea Country plans, national park management plans and regional Natural Resource Management plans.	
National Weeds of Interest sources	
Thorp JR and Lynch R (2000) The determination of Weeds of National Significance. A report for the Commonwealth of Australia and National Weeds Strategy Executive Committee.	
Mewett O, Richmond L, Southwell D, McCowen S, Sands A and Hennecke B (2011) Assessing new Weeds of National Significance candidates. A report for the Australian Weeds Committee, Canberra.	
Grice T, Morin L, Scott J, Liu S (2014) A review of recent weed research and management relevant to Australian livestock industries and proposals for future investments. A report for Meat and Livestock Australia and CSIRO.	
Department of Agriculture, Water and the Environment. Threat abatement plan to reduce the impacts on northern Australia's biodiversity by the five listed grasses (Review 2012–2021). A report for the Australian Government.	
Department of the Environment (2015) Threat abatement advice for ecosystem degradation, habitat loss and species decline in arid and semi-arid Australia due to the invasion of buffel grass (Cenchrus ciliaris and C. pennisetiformis).	
Preliminary Weed List	
NSW	Central Tablelands Regional Strategic Weed Management Plan 2023–2027
	Central West Regional Strategic Weed Management Plan 2023–2027
	Greater Sydney Regional Strategic Weed Management Plan 2023–2027
	Hunter Regional Strategic Weed Management Plan 2023–2027
	Murray Regional Strategic Weed Management Plan 2023–2027
	North West Regional Strategic Weed Management Plan 2023–2027
	Northern Tablelands Regional Strategic Weed Management Plan 2023–2027
	Western Regional Strategic Weed Management Plan 2023–2027
	South East Regional Strategic Weed Management Plan 2023–2027
ACT	Priority established weeds, ACT NatureMap, ArcGIS online data, provided by Steve Taylor on 7 March 2024.
NT	Alice Springs Regional Weeds Strategy 2021–2026
	Tennant Creek Regional Weeds Strategy 2021–2026
	Darwin Regional Weeds Strategy 2021–2026
Qld	Biosecurity Act 2014, Queensland Government, reprint current from 1 February 2024
SA	Weed list provided by Giverny Rodgers, PIRSA, 27 March 2024
Tas	Weed list provided by Karen Stewart, Biosecurity Tasmania, 4 April 2024
Vic	Victorian Noxious Weeds List, 20 July 2017, Schedule 2
WA	Western Australia Department of Biodiversity, Conservation and Attractions. Priority established weeds for biocontrol consideration, provided by Kellie Passeretto, 19 March 2024
	WA DPIRD. Declared species from the Western Australian organism list; data exported on 27 March 2024 and provided by John Moore

APPENDIX 3: NOMINATION FORM FOR HIGH-THREAT WEEDS

ELIGIBILITY CHECK

1. Enter the botanical name of the weed you would like to nominate.

   'Please note: You must nominate a weed to the species level (e.g. Salix cinerea). Nominations to genus level (e.g. Salix spp.) will not be eligible'.

   → If weed on list, weed is already being considered. STOP POINT.
   Automatic message: 'This species is already being assessed. You do not need to proceed with the nomination process'.

   → If it is subject to a national eradication program, weed is ineligible. STOP POINT.

   Automatic message: 'This weed is not eligible for assessment as it is a national eradication target'.

   → If not on list, PROCEED to next page/question

2. Is this species native to Australia?

   Yes ☐ STOP POINT, Automatic message:
   'This species is not eligible for assessment'

   No ☐ PROCEED to next page/ question

'Please note that the response to this question will be verified by the assessment team'

3. Is the weed established* in at least one state/territory in Australia, such that it is beyond the point of national eradication?

   Yes ☐ PROCEED to next page/ question

   No ☐ STOP POINT, Automatic message:
   'This species is not eligible for assessment'

'Please note that the response to this question will be verified by the assessment team'

4. Are there at least three reputable information sources relevant to the Australian context that provide sufficient detail on the weed's distribution, impact and invasiveness? Examples of reputable information sources include scientific papers, information from government or university websites and personal communication from experts.

   Yes ☐ PROCEED to next page/ question

   No ☐ STOP POINT, Automatic message:
   'This species is not eligible for assessment'

   → Please provide link to or name of information source where possible [Free text]
   → Upload any documents

'Please note that the response to this question will be verified by the assessment team'

'Your selected weed is eligible for assessment, subject to verification by the assessment team. Please continue'

Contact information (MANDATORY FIELDS)

- Name [TEXT FIELD]
- Organisation/affiliation [TEXT FIELD]
- Email [TEXT FIELD]
- Phone [TEXT FIELD]
- State/territory [DROP DOWN]

5. List any regions where the weed is established, if known [DROP DOWN]

   → Other comments [free text]

* ‘Established’ describes a weed with self-sustaining populations and a national distribution that may be either new and emerging or widespread in nature. In either instance, these weeds are not considered feasible to eradicate at the national level.

Examples of eligible weeds (note: jurisdiction refers to states and territories):

- Weeds that occur in multiple jurisdictions and eradication is considered unfeasible in all jurisdictions are eligible for assessment.
- Weeds that occur in multiple jurisdictions, where the weed may be targeted for eradication in one jurisdiction but eradication is considered unfeasible in another jurisdiction. For example, parthenium (Parthenium hysterophorus) is an eradication target in NSW but widespread in parts of Queensland. In this example, parthenium weed would be eligible for assessment as it would be reasonable to seek biocontrol solutions for a weed that is beyond national eradication.

Examples of ineligible weeds:

- Weeds subject to a formal national eradication program are not eligible for assessment. These are *Limnocharis flava, Mikania micrantha, Miconia calvescens, M. nervosa, M. racemosa* and *Striga asiatica*.
- Weeds that only occur in one jurisdiction and are eradication targets in that jurisdiction are viewed as national eradication targets and are not eligible for assessment.
- Weeds that occur in multiple jurisdictions and are eradication targets in all jurisdictions are not eligible for assessment. For example, mouse-ear hawkweed (*Pilosella officinarum*) is an eradication target in all two jurisdictions it occurs in—Vic and NSW.

APPENDIX 4: CALCULATION OF IMPACT, INVASIVENESS AND WEED-THREAT SCORE DISTRIBUTIONS

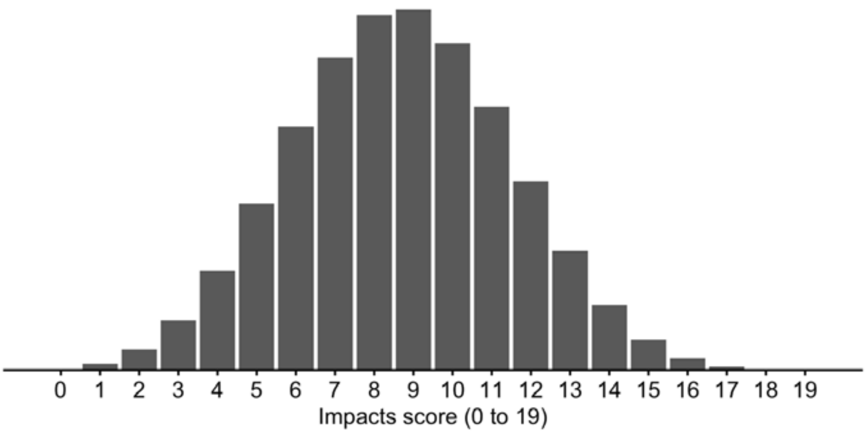
The Statistical Consulting Centre at Melbourne University was engaged by Wild Matters to assist in adapting the calculation of weed-risk scores from the three factors (invasiveness, impacts, potential geographic distribution) used by Virtue (2010) and Johnson (2009b) to two factors (invasiveness and impacts only).

The question of statistical interest is finding the distribution of these scores under the assumption of a uniform distribution of each individual item contributing to the total score.

Distribution of impacts scores

A distribution of impacts scores was derived from a uniform distribution of Question 1 (0 to 3), Question 2 (0 to 4), Question 3 (0 to 3), Question 4 (0 to 3), Question 5 (0 to 3) and Questions 6a through 6f (each –1 to 1). Question 6 was then converted to a score between 0 and 3 in accordance with the cut-offs provided (≤ 0 → 0; 1 → 1; 2 or 3 → 2; 4 to 6 → 3), and the scores for each question were added to produce a total impacts score between 0 and 19. Each question was assumed to be independent from, that is, uncorrelated with, all other questions.

The resulting distribution of the impacts score is shown below:



The sum of many independent uniform distributions produces a bell-shaped curve. This is an expected result of central limit theorem. Intuitively, a lot more combinations result in middle scores than extreme scores such as 0 or 19.

To provide five bands of approximately equal probability, the quintiles (evenly spaced 20% quantiles) of this distribution were calculated. The resulting bands are:

	I (0–20%)	II (20–40%)	III (40–60%)	IV (60–80%)	V (80–100%)
Score range	0 to 6	7 to 8	9	10 to 11	12 to 19
Probability	22%	25%	14%	23%	16%

Given the discrete nature of this distribution, it is not possible to have bands of exactly 20% probability each. The ranges shown are the closest achievable.

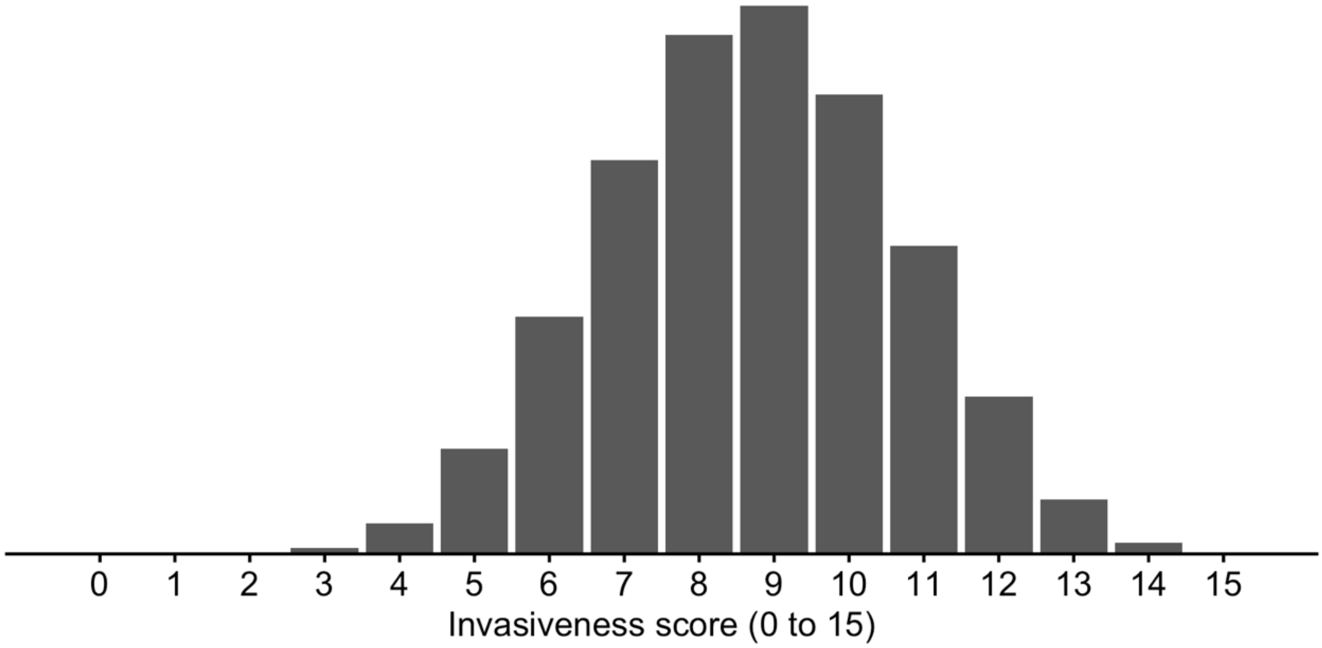
These bands can be rescaled to take a range of 0 to 10 in the same way as the scores themselves, that is, by dividing by 19 and multiplying by 10.

Distribution of invasiveness scores

A distribution of invasiveness scores was derived from a uniform distribution of Question 1 (0 to 3), Question 2 (0 to

3), Question 3a through 3c (each 0 to 2), Questions 4a through 4d (each 0 to 2) and Questions 5a through 5d (each 0 to 2). Questions 3 through 5 were then converted to scores between 0 and 3 in accordance with the cut-offs provided. For Question 3, the cut-offs were 0 → 0; 1 or 2 → 1; 3 or 4 → 2; 4 to 6 → 3. For Questions 4 and 5, the cut-offs were 0 → 0; 1 or 2 → 1; 3 to 5 → 2; 6 to 8 → 3. The scores for each question were added to produce a total invasiveness score between 0 and 15. Each question was assumed to be independent from, that is, uncorrelated with, all other questions.

The resulting distribution of the invasiveness score is shown below:



To provide five bands of approximately equal probability, the quintiles (evenly spaced 20% quantiles) of this distribution were calculated. The resulting bands are:

	I (0–20%)	**II** (20–40%)	**III** (40–60%)	**IV** (60–80%)	**V** (80–100%)
Score range	0 to 7	8	9	10	11 to 15
Probability	27%	18%	19%	16%	19%

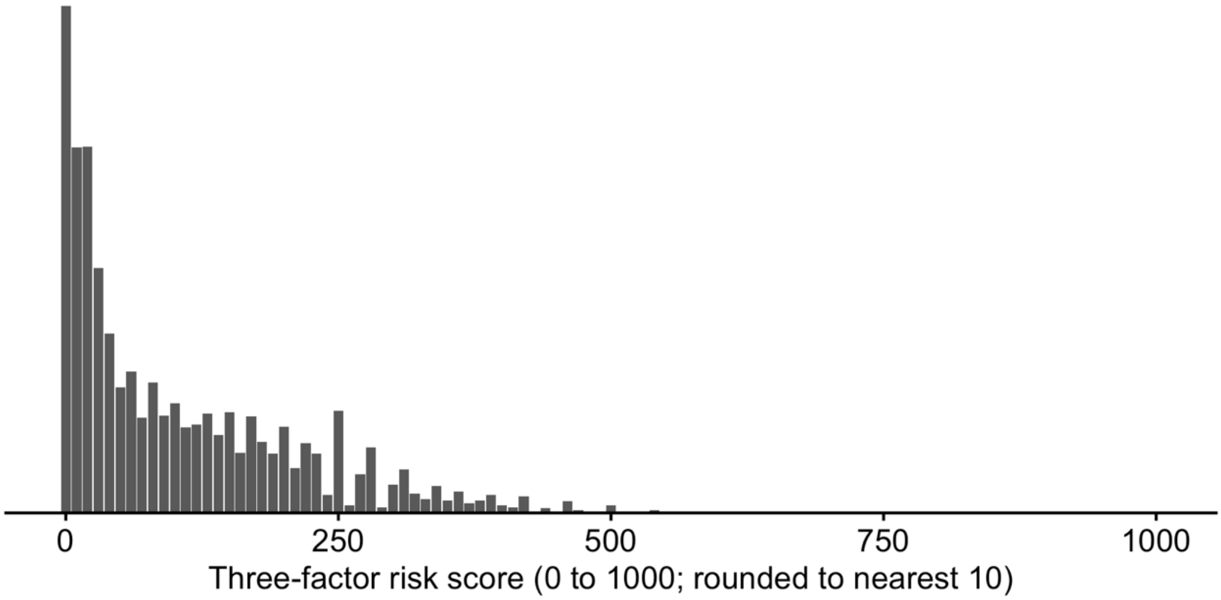
Given the discrete nature of this distribution, it is not possible to have bands of exactly 20% probability each. The ranges shown are the closest achievable.

These bands can be rescaled to take a range of 0 to 10 in the same way as the scores themselves, that is, by dividing by 15 and multiplying by 10.

Replication of original three-factor weed-risk score bands

Before deriving a distribution for the new two-factor weed-risk score, it was considered prudent to confirm that the methods described here are the same as those implemented by Virtue (2010) to derive the published bands for the three-factor weed-risk score. The distributions of impacts scores and invasiveness scores described so far were combined with a uniform distribution on the potential geographic distribution, which has possible scores of 0, 0.5, 1, 2, 4, 6, 8 and 10. Impacts, invasiveness and potential geographic distribution were assumed to be independent (uncorrelated) in this method. The impacts scores and invasiveness scores were rescaled to take possible values from 0 to 10 and rounded to one decimal place. An overall risk score was calculated by multiplying the impacts, invasiveness and potential geographic distribution scores and then rounding the result to one decimal place. This risk score takes possible values from 0 to 1,000.

The resulting distribution is shown below:



Multiplying different variables is not generally expected to result in a bell-shaped distribution, and because the potential geographic distribution has a substantial probability mass at zero, this results in a peak around 0 and low risk scores more broadly.

To provide five bands of equal probability, the quintiles (evenly spaced 20% quantiles) of this distribution were calculated. The resulting bands are:

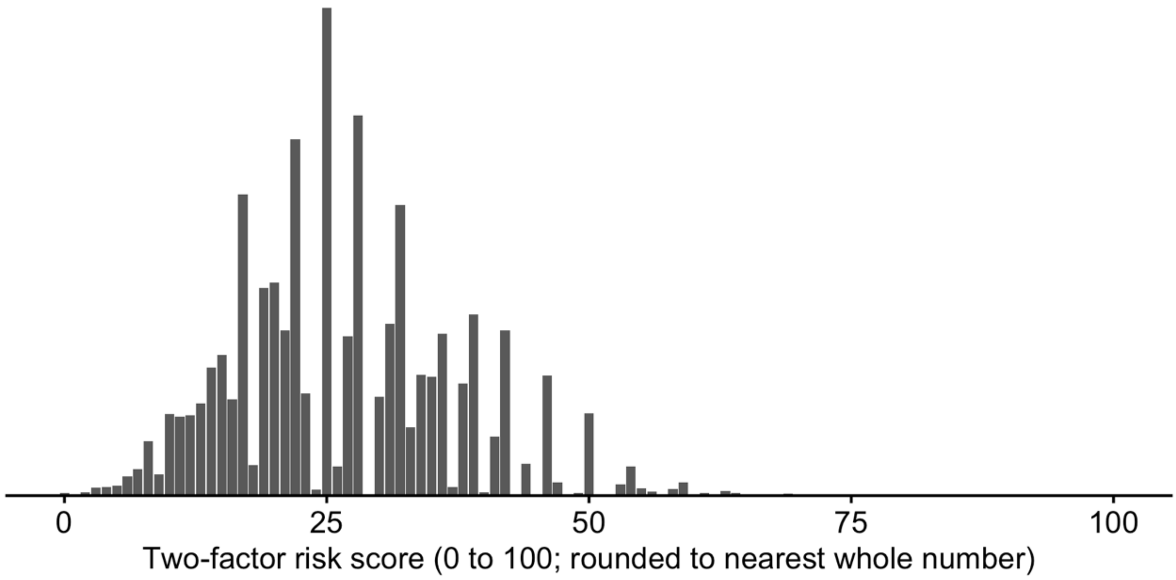
	I (0–20%)	II (20–40%)	III (40–60%)	IV (60–80%)	V (80–100%)
Score range Probability	0.0 to 12.6	12.6 to 38.9	38.9 to 100.8	100.8 to 192.0	192.0 to 1,000.0

Rounded to the nearest whole number, these bands are the same as published in the South Australia weed risk management guide.

Determination of score bands for two-factor weed-risk score

The method described previously to calculate a distribution for a three-factor weed-risk score was adapted to a two-factor score, considering impacts and invasiveness only, by removing the potential geographic distribution from consideration. As for the method for the three-factor score, impacts and invasiveness were assumed to be independent (uncorrelated). Each of the impacts and invasiveness scores were scaled to a range of 0 to 10, rounded to one decimal place and then multiplied to obtain a weed-risk score from 0 to 100. The final score was also rounded to one decimal place.

The resulting distribution is shown below:



Given that both the impacts and invasiveness scores had distributions favouring the middle values (approximately 5 out of 10), the resulting two-factor risk score has a distribution that peaks at 25 (5 × 5).

To provide five bands of equal probability, the quintiles (evenly spaced 20% quantiles) of this distribution were calculated. The resulting bands are:

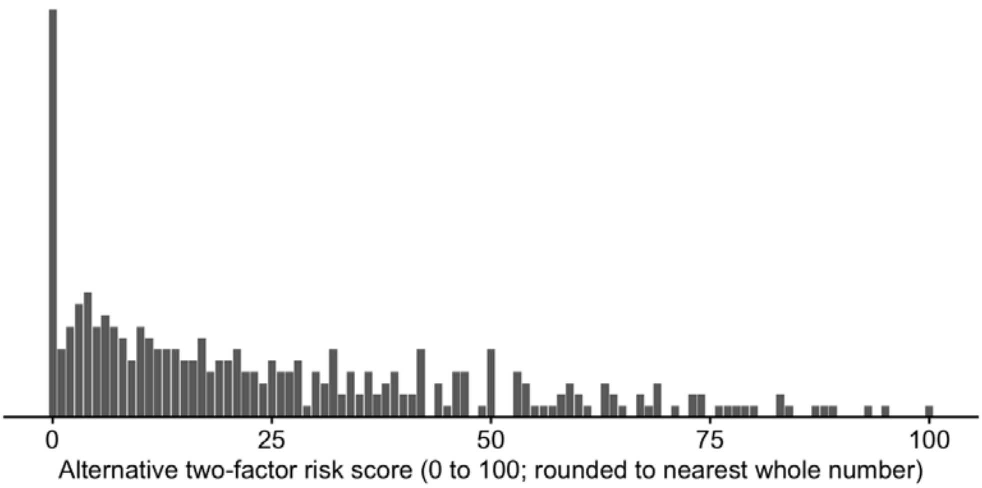
	I **(0–20%)**	**II** **(20–40%)**	**III** **(40–60%)**	**IV** **(60–80%)**	**V** **(80–100%)**
Score range Probability	0.0 to 17.4	17.4 to 22.3	22.3 to 28.1	28.1 to 34.8	34.8 to 100.0

The middle bands here are quite closely spaced, and the first and last band contain a large proportion of the possible values. This is because the assumed distribution of impacts and invasiveness makes extreme values very unlikely.

Alternative method for two-factor weed-risk score bands

The closely spaced bands were considered undesirable, given that it would be more difficult to prioritise high-threat weeds. An alternative calculation that assumes a uniform distribution of the impacts and invasiveness scores, that is, each total score from 0 to 19 or 0 to 15 is considered equally likely, was adopted. This approach still assumes independence of impacts and invasiveness, which may not be plausible, but by using a broader distribution of each independent factor, the distribution of the overall risk score is more spread out, which is also the case if impacts and invasiveness are correlated.

The distribution resulting from this method is shown below:



In this model, similarly to the original three-factor score, the most likely risk score is 0 because that occurs if either of the impacts or invasiveness scores are 0.

To provide five bands of equal probability, the quintiles (evenly spaced 20% quantiles) of this distribution were calculated. The resulting bands are:

	I (0–20%)	**II (20–40%)**	**III (40–60%)**	**IV (60–80%)**	**V (80–100%)**
Score range Probability	0.0 to 4.0	4.0 to 12.2	12.2 to 24.9	24.9 to 44.6	44.6 to 100.0

This alternative approach was adapted to determine banding for the comparative risk score.

APPENDIX 5: ATTENDEES OF WEED BIOCONTROL PROSPECT WORKSHOP

Workshop 1: 23 January 2012	
Andrew McConnachie	NSW DPIRD
Kunjithapatham Dhileepan	Biosecurity Queensland
Jason Callander	Biosecurity Queensland
Jeff Makinson	CSIRO
Tamara Taylor	Biosecurity Queensland
Isabel Zeil-Rolfe	CSIRO
Greg K Lefoe	Agriculture Victoria
Rae M Kwong	Agriculture Victora
Tony Pople	Biosecurity Queensland
Mariana Hopper	CSIRO
Ben Gooden	CSIRO
Michelle Rafter	CSIRO
Workshop 2: 1 March 24	
Andrew McConnachie	NSW DPIRD
Kunjithapatham Dhileepan	Biosecurity Queensland
Jason Callander	Biosecurity Queensland
Jeff Makinson	CSIRO
Isabel Zeil-Rolfe	CSIRO
Greg K Lefoe	Agriculture Victoria
Rae M Kwong	Agriculture Victora
Tony Pople	Biosecurity Queensland
Mariana Hopper	CSIRO
Ben Gooden	CSIRO
Michelle Rafter	CSIRO
Matt Sheehan	Wild Matters
Shauna Potter	Wild Matters
Matt Sheehan	Wild Matters

APPENDIX 6: COMPLETE LIST OF CRITERIA CONSIDERED BY WEED BIOCONTROL EXPERTS AT THE 1 MARCH 2024 ONLINE WORKSHOP, INCLUDING THOSE RECOMMENDED FOR REMOVAL AND REFINEMENT FOR INCLUSION IN THE PROPOSED NATIONAL WEED BIOCONTROL PRIORITISATION FRAMEWORK (PRESENTED IN TABLE B2)

<table>
<tr><td colspan="2">Criterion</td><td>Promising candidate agent/s</td></tr>
<tr><td colspan="2">Notes From Paynter et al. (2009)</td><td>Implicitly considered by Paynter et al. in Questions 4 (page 30) and 8 (page 31): ‘Has the weed been a subject of an adequately resourced biocontrol program elsewhere’?</td></tr>
<tr><td colspan="2">Notes From Morin et al. (2016)</td><td>Considered an obstacle by Morin et al. 2016 (Appendix 2, page 22): ‘A biocontrol project for the weed is already funded and focused on all potential candidate agents; all realistic options for biocontrol have already been</td></tr>
<tr><td colspan="2">Recommendation</td><td>Adopt criterion (with modification)</td></tr>
<tr><td colspan="2">Notes</td><td>This criterion also considers some biocontrol programs run within one or a few jurisdictions in Australia and has potential for further rollout at a national scale but where no current investment is available (e.g. between July 2023 and June 2026, investment is available from the NSW Environmental Trust for mass-release of the African boxthorn rust fungus in NSW only, and no capacity for coordinated releases at a national scale).
As per Paterson et al. (2021): ‘This attribute examines whether or not any biocontrol programmes have been initiated for the target plant elsewhere in the world. One of the best predictors of whether a biocontrol agent might be successful in the country of interest is assessing the outcome of any biocontrol programmes that may exist elsewhere and when biocontrol has been initiated elsewhere this will help reduce the cost of a potential programme as the prior work conducted will help with a number of aspects of a project such as reducing the number of host plants needed for testing’.
This criterion does not evaluate the degree of the damage caused to the host weed by one or more approved biocontrol agents.
Experts are required to note the names, where known, and other details of agent/s being assessed.</td></tr>
<tr><td rowspan="5">Criterion Score</td><td>Definition</td><td>Promising candidate agent/s identified in the weed’s native range and weed successfully targeted for biocontrol overseas or elsewhere in Australia, underpinned by comprehensive and well-resourced exploratory surveys and host-specificity testing.</td></tr>
<tr><td>Unfeasible (Stop)</td><td>Consensus among experts that all realistic options for biocontrol have already been explored or exhausted, and no additional novel biocontrol agents identified in the weed’s native range.
This may include that the weed is already adequately controlled across its invaded range by biocontrol.
Do not proceed to answering 1(b) if unfeasible has been selected.</td></tr>
<tr><td>Negative Definition (Score = 0)</td><td>No promising agent/s available (e.g. because of lack of exploratory research or candidate agent/s deemed not to be sufficiently host specific according to previous risk analysis, within Australia or overseas)</td></tr>
<tr><td>Neutral Definition (Score = 1)</td><td>One or more promising agents identified through exploratory surveys.
Risk of non-target attack not evaluated through comprehensive host-specificity testing or ongoing tests not yet completed.</td></tr>
<tr><td>Positive Definition (Score = 2)</td><td>Promising agent/s identified through exploratory surveys and at least one proved to be sufficiently host-specific to the target weed, either in Australia or overseas</td></tr>
</table>

Criterion		Most promising phase/s of biocontrol research
Notes From Paynter *et al*. (2009)		Not explicitly considered.
Notes From Morin *et al*. (2016)		Recommendations made on feasible research pathways for host-specificity testing and release of biocontrol agents in the NSW context in accordance with knowledge of research outcomes in other jurisdictions (either in Australia or overseas).
Recommendation		New criterion
Notes		This criterion prompts experts to provide a description of which phase/s of biocontrol research are most promising for investment in accordance with current capabilities, for example, exploratory research, host-specificity testing, mass rearing and release (including to new parts of the weed's introduced range in Australia to which the agent has not been released and there would be limited opportunity for agent spread and establishment without human-assisted dispersal).
Criterion Score	**Definition**	n/a
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	n/a
	Neutral Definition (Score = 1)	n/a
	Positive Definition (Score = 2)	n/a

Criterion		Knowledge of candidate agent/s
Notes From Paynter *et al*. (2009)		Question 6 (page 30): 'Literature regarding natural enemies well known/accessible'.
Notes From Morin *et al*. (2016)		Considered an obstacle (Appendix 2, page 22): 'Limited or no knowledge of agent biology; taxonomy of agent not resolved to species level; rearing/culturing methods not developed or suboptimal; limited knowledge of agent host specificity'.
Recommendation		Adopt criterion
Notes		This criterion should only be answered when promising candidate agent/s have been identified. A score of 0 is automatically assigned to this criterion if no promising agent/s have been identified
Criterion Score	**Definition**	Knowledge of the biology (including life cycle, feeding, reproductive dynamics, etc), taxonomy, rearing or culturing methods and other aspects of ecology relevant to biocontrol feasibility.
	Unfeasible (Stop)	No score given
	Negative Definition (Score = 0)	Candidate agent/s' biology, taxonomy, rearing or culturing methods and ecology unknown or unresolved at this stage, hampering progress with collecting the agent/s from the field or host-specificity testing.
	Neutral Definition (Score = 1)	Knowledge of a candidate agent/s' biology, taxonomy, rearing or culturing methods and ecology is incomplete but can likely be resolved with additional research. Not deemed a significant barrier to progress on host-specificity testing or other phases of biocontrol research at this stage.
	Positive Definition (Score = 2)	Candidate agent/s' biology, taxonomy, rearing or culturing methods and ecology are well known, enabling progress on host-specificity testing or other phases of biocontrol research.

Criterion		Weed nominated as candidate for biocontrol
Notes From Paynter *et al*. (2009)		Not explicitly considered.
Notes From Morin *et al*. (2016)		Considered an obstacle (Appendix 2, page 22): 'Insufficient data available on impact to support nomination to national Invasive Plant and Animal Committee'.
Recommendation		Adopt criterion
Notes		Information on weed nomination status could be prepopulated within the data-elicitation tool before expert engagement.
Criterion Score	**Definition**	Weed nominated as candidate for biocontrol
	Unfeasible (Stop)	No score given (weeds not supported by the Environment and Invasives Committee as candidates for biocontrol research; already filtered out of analysis under Stage 1 weed-threat assessment).
	Negative Definition (Score = 0)	Weed not already nominated as candidate for biocontrol.
	Neutral Definition (Score = 1)	No score given
	Positive Definition (Score = 2)	Weed already successfully nominated as candidate for biocontrol.

Criterion		Weed nominated as candidate for biocontrol
Notes From Paynter *et al*. (2009)		Not explicitly considered.
Notes From Morin *et al*. (2016)		Considered an obstacle (Appendix 2, page 22): 'Insufficient data available on impact to support nomination to national Invasive Plant and Animal Committee'.
Recommendation		Adopt criterion
Notes		Information on weed nomination status could be prepopulated within the data-elicitation tool before expert engagement.
Criterion Score	**Definition**	Weed nominated as candidate for biocontrol.
	Unfeasible (Stop)	No score given (weeds not supported by the Environment and Invasives Committee as candidates for biocontrol research; already filtered out of analysis under Stage 1 weed-threat assessment).
	Negative Definition (Score = 0)	Weed not already nominated as candidate for biocontrol.
	Neutral Definition (Score = 1)	No score given
	Positive Definition (Score = 2)	Weed already successfully nominated as candidate for biocontrol.

Criterion	Investment opportunities
Notes From Paynter *et al*. (2009)	Question 4 (page 3): 'Has the weed been/is a subject of adequately resourced biocontrol program elsewhere?'
Notes From Morin *et al*. (2016)	Considered an obstacle (Appendix 2, page 22): 'Perception that enough investment has been made on the weed already'.
Recommendation	Remove from prospects analysis and consider when compiling the investment report

Notes		The overall aim of the framework analysis is to prioritise species for potential investment by independent third parties. It was recommended The overall aim of the framework analysis is to prioritise species for potential investment by independent third parties. It was recommended to remove this criterion from the biocontrol prospects analysis because there was consensus among biocontrol experts that it would not be appropriate for biocontrol practitioners to deliberate on perceptions of 'adequate resourcing' of legacy projects that may justify (or otherwise) future potential investments. Previous investments may have little bearing on future biocontrol prospects in accordance with new available knowledge or advanced technological capabilities (e.g. molecular methods in selecting candidate agents for testing). We recommend including a statement about prior and current investments in the final investment report.
Criterion Score	**Definition**	n/a
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	n/a
	Neutral Definition (Score = 1)	n/a
	Positive Definition (Score = 2)	n/a

Criterion		Accessibility of candidate agent/s, research infrastructure and collaborative links
Notes From Paynter *et al*. (2009)		Question 5 (page 30): 'Accessibility and ease of working in the native range'.
Notes From Morin *et al*. (2016)		Considered an obstacle for this criterion (Appendix 2, page 22): 'No clean laboratory culture or stored viable material exist; difficulties to export the candidate agent because of biodiversity convention; candidate agent needs to be recollected from the field in the native range; access to the native range difficult'.
Recommendation		Adopt criterion
Notes		Adopt definitions (with modification) from Paterson *et al*. (2021).
Criterion Score	**Definition**	Accessibility of candidate agent/s, including consideration of status of existing laboratory cultures or stored viable material, potential to export candidate agent, need to recollect in the field and access the native range; research infrastructure and collaborative links.
	Unfeasible (Stop)	Deemed unfeasible because of insurmountable barriers to accessing the agent (e.g. no agent/s identified; exportation of live cultures banned from country of origin; sociopolitical unrest rendering exploratory surveys or recollections of known agent/s in the field unacceptably unsafe).
	Negative Definition (Score = 0)	Native range is deemed generally safe but there is either no biocontrol research facility or group in that country, or, to date, there has been no effort to collect the candidate agent/s from the field to establish a clean lab-reared colony.
	Neutral Definition (Score = 1)	Native range is deemed generally safe and there is an active biocontrol research facility or group in that country; a clean lab-reared culture of the candidate agent/s may be available or, if not, there is at least potential for such a colony to be readily established through collection of the agent/s from the field.
	Positive Definition (Score = 2)	Candidate agent/s readily available as a clean lab-reared culture, supported by strong collaborative links with international weed biocontrol research facilities or groups.

<table>
<tr><td colspan="2">Criterion</td><td>Research infrastructure and collaborative links</td></tr>
<tr><td colspan="2">Notes From Paynter et al. (2009)</td><td>Not explicitly considered but may relate to Question 5 (accessibility of agent).</td></tr>
<tr><td colspan="2">Notes From Morin et al. (2016)</td><td>Considered an obstacle for this criterion (Appendix 2, page 22): ‘Australia does not have a history of collaboration with overseas group that has been working on the candidate agent’.</td></tr>
<tr><td colspan="2">Recommendation</td><td>Reject as a standalone criterion and combine with ‘Accessibility of candidate agent/s’.</td></tr>
<tr><td colspan="2">Notes</td><td>The value of this criterion was deemed unclear, because novel collaborative links could be established as required through engagement within the broader network of weed biocontrol researchers at the international scale, even when such links are currently unformed.
Research infrastructure and strong collaborative links also underpin the feasibility of accessing a clean culture of the candidate biocontrol agent in Australia. Thus, it was recommended to combine this criterion with ‘Accessibility of candidate agent’.</td></tr>
<tr><td rowspan="5">Criterion Score</td><td>Definition</td><td>n/a</td></tr>
<tr><td>Unfeasible (Stop)</td><td>n/a</td></tr>
<tr><td>Negative Definition (Score = 0)</td><td>n/a</td></tr>
<tr><td>Neutral Definition (Score = 1)</td><td>n/a</td></tr>
<tr><td>Positive Definition (Score = 2)</td><td>n/a</td></tr>
</table>

<table>
<tr><td colspan="2">Criterion</td><td>Knowledge of weed origin/s</td></tr>
<tr><td colspan="2">Notes From Paynter et al. (2009)</td><td>Not explicitly considered.</td></tr>
<tr><td colspan="2">Notes From Morin et al. (2016)</td><td>Not explicitly considered.
Adapted from source: ‘Taxonomy of weed unresolved; genetic diversity of weed in Australia unknown; most vulnerable stage in life cycle to regulate weed populations unknown’.</td></tr>
<tr><td colspan="2">Recommendation</td><td>Create criterion</td></tr>
<tr><td colspan="2">Notes</td><td>This criterion is adapted from Morin et al. 2016 and seeks to summarise the general state of knowledge about the candidate weed. During the workshop on 1 March 2024, some experts questioned the value of this standalone criteria because such knowledge (e.g. weed taxonomy, stage of life cycle most vulnerable to agent attack) is evaluated in other criteria.
However, it was agreed that information on weed-population genetics and origin or source locations in the native range should be considered part of biocontrol feasibility because this helps optimise exploratory survey and agent/s’ collection locations. Poor knowledge of weed-population genetic diversity and origin can reduce confidence in exploratory surveys (from where to source candidate agent/s?) and introduce genotypic mismatches in host plant-enemy associations that result in reduced biocontrol efficacy.</td></tr>
<tr><td rowspan="4">Criterion Score</td><td>Definition</td><td>Knowledge of target weed’s population genetics and origins.</td></tr>
<tr><td>Unfeasible (Stop)</td><td>No score given</td></tr>
<tr><td>Negative Definition (Score = 0)</td><td>No knowledge of the target weed’s population genetics and origins, hampering progress with exploratory surveys (e.g. source location of candidate agent/s best matched to weed populations in Australia).
This may also include instances in which candidate agent/s have already been identified but there is a mismatch between their source location and the genetic diversity and origin of the weed populations in Australia.</td></tr>
<tr><td>Neutral Definition (Score = 1)</td><td>Knowledge of the target weed’s population genetics and origins may be incomplete but not deemed a significant barrier to progress on biocontrol research at this stage.</td></tr>
</table>

	Positive Definition (Score = 2)	The target weed's population genetics and origins are well known, enabling targeted exploratory surveys and progress on other biocontrol research phases.

Criterion		Relatedness of the weed to non-target species in Australia
Notes From Paynter *et al*. (2009)		Question 7 (page 31) and 15 (page 34).
Notes From Morin *et al*. (2016)		Was placed within 'feasibility' dimension. Considered an obstacle for this criterion: 'Weed is closely related to crop or native species; limited information on the phylogenetic placement of weed'.
Recommendation		Adopt criterion
Notes		Suggest retaining this criterion in 'feasibility' because it relates to finding a promising host-specific candidate biocontrol agent, not necessarily the impacts of the agent on the host weed. Disagree with Paynter *et al*. 2009 advice to include phylogenetic relatedness twice, once in feasibility and once in impact dimension. Adopt Paynter's rationale and references therein: 'Weeds with closely related non-target plants should be harder to control because of the potential for non-target attack'. While Paynter *et al*. 2009 focused on 'potential non-target congeneric plant present, yes or not?', we recommend three tiers: (2) highest feasibility (chance of finding a promising candidate agent) for species with no non-target plant species within the same family (e.g. no native Australian plant species within the family Cactaceae), (1) plants that have no congenerics but genera within the same family are present (e.g. no native Australian plant species within the genus Cabomba, although there is at least one known native plant within a different genus, Brasenia schreberi, that is also a member of Cabombaceae) and (0) congeneric non-target plant species present, often speciose genera (e.g. Senecio, Solanum, etc).
Criterion Score	**Definition**	Phylogenetic relatedness of the target weed to potential non-target plant species in the introduced range, inferred by membership of the same plant family and presence of congeneric species. This also considers taxonomic resolution of the weed and its relatedness to important non-target plant species
	Unfeasible (Stop)	No score given
	Negative Definition (Score = 0)	At least one or more congeneric plant species present in the introduced range (e.g. Senecio, Solanum). This score may also be given in instances when the weed's taxonomy or its associations with non-target plants species remain poorly resolved.
	Neutral Definition (Score = 1)	No congeneric species present but shared membership of the same plant family in the native range (e.g. Cabombaceae).
	Positive Definition (Score = 2)	No shared membership of the same plant family (e.g. Cactaceae).

Criterion		Ecosystem
Notes From Paynter *et al*. (2009)		Question 9 (page 32): aquatic or wetland weeds that have a higher probability of success, and terrestrial weeds that have a lower probability of success.
Notes From Morin *et al*. (2016)		Not considered.
Recommendation		Adopt criterion
Notes		Consistent with rationale of Paterson *et al*. (2021), that is, 'aquatic plants were found to have a statistically significant higher probability of successful biocontrol'.
Criterion Score	**Definition**	Predominant ecosystem supporting target-weed population.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	No score given

	Neutral Definition (Score = 1)	Terrestrial
	Positive Definition (Score = 2)	Aquatic or wetland

Criterion		Habitat stability
Notes From Paynter *et al*. (2009)		Question 14: predominantly agricultural versus environmental.
Notes From Morin *et al*. (2016)		Not considered.
Recommendation		Adopt criterion
Notes		Use description from Paterson *et al*. (2021): 'Habitat stability, i.e. target plants that occupy areas that are frequently disturbed, such as cultivated land and improved pastures, are less likely to sustain adequate biocontrol agent populations'.
Criterion Score	**Definition**	Weed adaptation to land use disturbances.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	No score given
	Neutral Definition (Score = 1)	Predominantly a disturbance-adapted weed of cultivated lands, crops and improved pastures.
	Positive Definition (Score = 2)	Predominantly a weed of relatively undisturbed environmental contexts (which may include grazed rangelands).

Criterion		Weed life cycle
Notes From Paynter *et al*. (2009)		Question 10 (page 32).
Notes From Morin *et al*. (2016)		Considered an obstacle: 'Population of the candidate agent may not be sustained over time because the weed is annual and ephemeral'.
Recommendation		Adopt criterion
Notes		Consistent with rationale of Paterson *et al*. (2021), that is, 'Plants that are annual have been found to be more difficult to control compared with biennial and perennial plants … and biocontrol on annuals can only be successful if biocontrol agents are able to affect seed production within a single growing season'.
Criterion Score	**Definition**	Predominant life cycle duration.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	No score given
	Neutral Definition (Score = 1)	Annual or ephemeral
	Positive Definition (Score = 2)	Biennial or perennial

Criterion		Weed reproduction
Notes From Paynter *et al*. (2009)		Question 11: capable of vegetative versus seed or spore production only.
Notes From Morin *et al*. (2016)		Not considered.
Recommendation		Adopt criterion
Notes		Consistent with rationale of Paterson *et al*. (2021): 'Plants that can only reproduce asexually and are, therefore, clonal have been found to have a greater chance of being controlled using biocontrol agents'.
Criterion Score	**Definition**	Predominant mode of reproduction in Australia (introduced range only).
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	No score given
	Neutral Definition (Score = 1)	Capable of sexual reproduction, including those that can also reproduce vegetatively, in the introduced range.
	Positive Definition (Score = 2)	Asexual: reproducing by vegetative means or apomixis in the introduced range.

Criterion		Damage by candidate agent/s to the target weed
Notes From Paynter *et al*. (2009)		Not explicitly considered. Source inferred impact through various other strong predictors (surrogates, indicators), such as weed habitat, mode of reproduction, life cycle, etc.
Notes From Morin *et al*. (2016)		Considered an obstacles: 'A very large reduction in weed growth rates or reproduction sustained over many years will be required; most seeds (> 99%) will have to abort or be destroyed to affect weed population; based on previous research in or outside of Australia on the target weed or functionally similar species, there is no precedent to believe that the required damage will be achieved'.
Recommendation		Adopt criterion
Notes		n/a
Criterion Score	**Definition**	Type, severity and duration of damage by candidate agent. This criterion also considers biotic factors that may reduce the efficacy of biocontrol, for example, sustained attack of the agent/s by predators or parasitoids and variable plant growth form or habit. Experts are asked to describe the nature of the damage (e.g. seed feeding, stem boring, leaf infection) and predicted outcomes for weed populations.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	A very large reduction in weed growth rates or reproduction sustained over many years is required to reduce host-weed populations. For example, most seeds (> 99%) will have to abort or be destroyed to significantly reduce invasion risk (Morin *et al*. 2016). Alternatively, in accordance with prior research in or outside Australia on the target weed or functionally similar species, there is no precedent to believe that the required damage by the candidate biocontrol agent/s will be achieved following their release. This score may be given when high levels of sustained attack of the agent/s by predators or parasitoids in the native and introduced ranges are demonstrated. This score may also be given when there are difficulties targeting multiple forms of the weed or a high probability of replacement by other forms or congeners following successful biocontrol, thus negating benefits, for example, terrestrial and aquatic forms of alligator weed (Alternanthera philoxeroides).
	Neutral Definition (Score = 1)	Target-weed populations could effectively be controlled through reduced growth and reproductive output, but there is no evidence in or outside Australia on the target weed or functionally similar species that such desired levels of damage could be achieved by the candidate biocontrol agent/s.
	Positive Definition (Score = 2)	In accordance with prior research in or outside Australia on the target weed or functionally similar species, there is evidence that the required damage by the candidate biocontrol agent/s will be achieved, resulting in desired reductions in weed populations. No identified impediments to effective biocontrol by predators or parasitoids or variation in plant growth form or function.

Criterion		Synchronisation of damage with weed life cycle
Notes From Paynter *et al*. (2009)		Not explicitly considered.
Notes From Morin *et al*. (2016)		Considered an obstacle: 'Weed inflorescence is produced early in the growing season and it is unlikely that the candidate agent will be capable of eliminating seed production'.
Recommendation		Adopt criterion
Notes		n/a
Criterion Score	**Definition**	Synchronisation of damage with weed life cycle.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	Significant mismatch between weed life cycle and damage by the candidate agent/s, resulting in no overall impact on weed populations, for example, a short-lived annual plant that can set viable seed faster than the rate of production and spread of the spores of a fungal pathogen released as a biocontrol agent, thus resulting in no meaningful reduction in weed-invasion risk over broad spatial and temporal scales. This score may also be given when there is a high level of uncertainty about which stage of the weed life cycle is most vulnerable to attack by the candidate agent/s.
	Neutral Definition (Score = 1	Synchronisation with weed life cycle not considered to influence the likelihood of success strongly either in a positive or negative direction.
	Positive Definition (Score = 2)	Strong synchrony between weed life cycle and damage by the candidate agent/s, resulting in desired impacts on host-weed populations.

Criterion		Weed resilience to damage by candidate agent/s
Notes From Paynter *et al*. (2009)		Not explicitly considered.
Notes From Morin *et al*. (2016)		Considered an obstacle: 'The weed has an extensive root system and is expected to be able to readily recover from damage unless it is very severe and sustained over many years'.
Recommendation		Adopt criterion
Notes		In accordance with definition by Morin *et al*. 2016, we recommend changing the term 'sensitivity' to 'resilience'.
Criterion score	**Definition**	Resilience of weed to damage by candidate agent/s.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	Weed has a high level of capacity for resilience to attack by candidate agent/s, for example, through resprouting from an extensive root system that may enable recovery from damage unless it is very severe and sustained over many years (e.g. African boxthorn and capacity for reshooting of large mature plants, despite defoliation by the fungal pathogen Puccinia rapipes).
	Neutral Definition (Score = 1	Weed resilience not considered to influence the likelihood of success strongly either in a positive or negative direction.
	Positive Definition (Score = 2)	Weed displays limited resilience to attack by candidate agent/s, resulting in sustained population declines over time.

Criterion		Habitat diversity
Notes From Paynter *et al*. (2009)		Not explicitly considered.
Notes From Morin *et al*. (2016)		Considered a barrier: 'The weed occurs over a wide range of habitats, which means that candidate agent densities and thus efficacy will be more variable; the weed grows in low fertility soil and will have poor nutritional value for herbivorous insects'.
Recommendation		Reject criterion. Agreed by all biocontrol experts (1 March 2024).

Notes		Scope of criterion unclear without further analysis of habitat range of the weed in Australia. At best, at a national level, the current and predicted range of the weed is known, but no analysis pipeline is available to infer the diversity of habitats occupied by each weed (e.g. creek lines v. roadsides v. gullies v. forests v. heathland and so on). Options: Accept predictions from experts in accordance with observations and anecdotes. Disregard and remove criterion from analysis. At the workshop on Friday 1 March 2024, all attendees agreed that it was not possible at this stage to operationally define and then analyse the habitat diversity of the target plant in its native and introduced ranges.
Criterion Score	**Definition**	Variety of habitats occupied by the weed within its introduced range.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	Weed occurs in a wide variety of habitats, which may (or may not) differ from the set of habitats occupied in its native range; thus, candidate agent/s' populations and impacts on the target weed are likely to be more variable across the introduced range. For example, African boxthorn can occur in coastal headlands, creek lines under tree canopy, riverine floodplains and grazed pastures.
	Neutral Definition (Score = 1)	Habitat diversity not considered to influence the likelihood of success strongly either in a positive or negative direction.
	Positive Definition (Score = 2)	Weed occurs in a limited number of habitats, often similar to those from the native range (e.g. sea spurge Euphorbia paralias populations limited to coastal dunes).

Criterion		Climate
Notes From Paynter *et al*. (2009)		Not explicitly considered.
Notes From Morin *et al*. (2016)		Considered an obstacle: 'The climate of the introduced range is very different to that of the native range where the candidate agent was/would be sourced; the weed occurs over a wide range of climatic zones, which means that the candidate agent densities and thus efficacy will be more variable'.
Recommendation		Reject criterion. Agreed by all biocontrol experts (1 March 2024).
Notes		Scope of criterion unclear without further analysis of climate range of the weed in Australia. Options: Accept predictions from experts in accordance with observations and anecdotes in most cases and data or analyses where available from published studies (e.g. Gallagher *et al*. 2010). Commission climate niche overlap analysis for weeds undergoing biocontrol prospects analysis. Disregard and remove criterion from analysis. At the workshop on Friday 1 March 2024, all attendees agreed that it was not possible at this stage to operationally define and then analyse the climate matching for the target plant between its native and introduced ranges.
Criterion Score	**Definition**	Weed climate niche overlap and diversity between its native and introduced ranges.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	The climate of the weed's introduced range is strongly divergent to its native range in which the candidate biocontrol agent/s have been or would be sourced (e.g. Onopordum acanthium; Figure 2b, page 796, Gallagher *et al*. 2010). Or, the weed occurs over a wide range of climatic zones in its introduced range, such that the candidate agent/s populations and impacts on the host weed are likely to be highly variable and limited to a small subset of locations.
	Neutral Definition (Score = 1)	Partial overlap of native and introduced climate niches (e.g. Fumaria muralis; Figure 2c, page 796, Gallagher *et al*. 2010). Or, the weed occurs in multiple climatic zones, but the candidate agent/s populations and impacts on the host weed are not expected to be influenced by such climatic variation.
	Positive Definition (Score = 2)	Strong climate overlap between the weed's introduced and native ranges, including cases in which the introduced climate niche is a subset of the native climate niche (e.g. Hypericum perforatum, Figure 2a, and Macfadyena unguis-cati, Figure 2d; page 796, Gallagher *et al*. 2010). Or, the weed occurs in a limited climatic zone in the introduced range.

Criterion		Parasitism or predation of candidate agent
Notes From Paynter *et al*. (2009)		Not explicitly considered.
Notes From Morin *et al*. (2016)		Considered an obstacle: 'The candidate agents that could achieve the required damage are known to be highly vulnerable to predation'.
Recommendation		Reject as a standalone criterion but consider within the 'Damage by candidate agent/s to the target weed' criterion.
Notes		Experts considered that this would be difficult to qualify in most cases but could be considered a dimension within the damage criterion.
Criterion Score	**Definition**	Candidate biocontrol agent/s' vulnerability to predation.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	Candidate biocontrol agent/s known to be highly vulnerable to predation (especially by parasitoids), within and outside their native ranges, and there is potential to reduce their capacity to achieve the required damage to the host weed upon release.
	Neutral Definition (Score = 1)	Predation not known to limit performance of the candidate biocontrol agent/s but have been shown to limit performance of related taxa with similar life cycles. Or, where predators are known to attack the promising candidate biocontrol agent/s, there is no evidence that this results in reduced impacts on the host weed.
	Positive Definition (Score = 2)	Promising candidate biocontrol agent/s not known to be vulnerable to predation (especially by parasitoids), resulting in reduced impacts on the host weed.

Criterion		Plant considered a weed in its native range
Notes From Paynter *et al*. (2009)		Question 12.
Notes From Morin *et al*. (2016)		Not considered.
Recommendation		Reject criterion. Agreed by all biocontrol experts (1 March 2024).
Notes		Unclear application in Paynter *et al*. 2009, and no operational definition of weediness and difference in recommendation between Q12 (weedy = lower probability and non-weedy = higher probability of biocontrol impact) versus Figure 12. The rational outlined by Paynter *et al*. 2009 was that plants 'that are more abundant in the introduced range versus the native range should be easier to control because these species are more likely to be limited by natural enemies in the native range'. Paynter *et al*. 2009 did not compare spatial ranges for each weed between the native and introduced range but instead inferred range differences based on 'weediness', that is, 'determined whether or not each plant species is considered a weed in the native range' on the assumption that 'to be a weed in the native range, a plant must be abundant there'. Paynter *et al*. 2009 ascertained 'weed status in native range' by searching 'CAB abstracts' and other references to 'see if there were published records of a weed biocontrol target as being weedy in its native range'. We do not believe that this method is satisfactory to either determine differences in a plant species' range size between its native and introduced ranges, nor to infer weediness, which is often habitat and context specific and not always directly related to current or potential distribution (e.g. sea spurge in Australia has a very high level of local impact on coastal dunes but has potential to occupy only a very small proportion of Australia's land surface area). At the workshop on Friday 1 March 2024, all attendees agreed that it was not possible at this stage to operationally define and then analyse the 'weediness' of the target plant in its native range.
Criterion Score	**Definition**	n/a
	Unfeasible (Stop)	n/a

	Negative Definition (Score = 0)	n/a
	Neutral Definition (Score = 1)	n/a
	Positive Definition (Score = 2)	n/a

Criterion		Plant growth form and function
Notes From Paynter *et al*. (2009)		Question 13 (page 33): 'Difficulty targeting multiple forms of the weed or probability of replacement by forms or congeners following successful biocontrol, thus negating benefits'.
Notes From Morin *et al*. (2016)		Not considered.
Recommendation		Reject as standalone criterion and include within the 'Damage by candidate agent/s to the target weed' criterion.
Notes		Several examples have been provided, terrestrial and aquatic forms of Alligator weed (Alternanthera philoxeroides) and genotypes of skeleton weed (Chondrilla juncea), which show differential leaf morphologies and susceptibility to biocontrol agent/s.
Criterion Score	**Definition**	Variation in susceptibility of the weed to identified agent/s across plant growth forms or habit, or genotypes.
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	n/a
	Neutral Definition (Score = 1)	n/a
	Positive Definition (Score = 2)	n/a
Contextual information sought after prioritisation analysis to inform investment and implementation planning		
Criterion		Previous and current investment opportunities to guide prospective investment decisions
Notes From Paynter *et al*. (2009)		n/a
Notes From Morin *et al*. (2016)		n/a
Recommendation		Adopted, but decision is still required on where, when and by whom the information will be considered.
Notes		Note that Morin *et al*. (2016) included a criterion that penalised weeds for which current investments were deemed sufficient to meet research objectives ('thus no further investment needed/justified') or when there was a 'perception that enough investment has been made on the weed already'. We believe that caution must be applied in such cases, because perceptions are context dependent and change over time, especially as new information on historical biocontrol programs may enhance biocontrol prospects and stimulate renewed interest by investors. For example, it was recently discovery that introduced fireweed (Senecio madagascariensis) populations in Australia likely originated from Eastern Cape (South Africa), not KwaZulu-Natal as originally assumed, thus opening future opportunities to recollect promising candidate agent/s that may have stronger genetic affinity with Australian fireweed populations. Similarly, sufficient investment was made to support releases of the sagittaria weevil by Agriculture Victoria and NSW DPIRD to June 2023, but only at a small set of nursery sites, and there is limited capacity for natural dispersal of the weevil to nearby sites until initial populations become well established. Thus, there may be merit in future investments to support broader mass rearing and release of the weevil across the full range of sagittaria in Vic and NSW to accelerate impacts on the target weed. We also consider it to be inappropriate for biocontrol practitioners to evaluate biocontrol prosects in accordance with perceptions of historical investments—hence our recommendation for this criterion to be removed from the prioritisation analysis.

Criterion Score	**Definition**	n/a
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	n/a
	Neutral Definition (Score = 1)	n/a
	Positive Definition (Score = 2)	n/a

Criterion		Management objectives for biocontrol, including consideration of management feasibility or desirability of biocontrol
Notes From Paynter *et al*. (2009)		n/a
Notes From Morin *et al*. (2016)		n/a
Recommendation		Further advice sought on if and where this criterion should be considered (in Stage 1 before biocontrol prospects analysis?) and by whom (weed-threat experts, investors, biocontrol experts?).
Notes		Advice from Ireland *et al*. (2019): 'Insufficient engagement with stakeholders and regulators has been identified as a limiting factor for effective adoption of biocontrol globally'. 'Management objectives gleaned from stakeholder consultation can guide selection and evaluation of candidate biocontrol agents', for example, seed-feeding insects, when the objective is to reduce weed-invasion risk by the production and dispersal of viable seeds. Consideration of management objectives may inform investment preferences and agent desirability and feed into the development of nomination documents that require extensive stakeholder consultation.
Criterion Score	**Definition**	n/a
	Unfeasible (Stop)	n/a
	Negative Definition (Score = 0)	n/a
	Neutral Definition (Score = 1)	n/a
	Positive Definition (Score = 2)	n/a

Criterion	Socioeconomic barriers or conflicts of interest
Notes From Paynter *et al*. (2009)	Considered in Question 2 (page 29) under the 'weed importance' dimension.
Notes From Morin *et al*. (2016)	Considered an obstacle (Appendix 2, page 22): 'The weed is valued by a sector of society and conflict between interests of different stakeholders is most likely'.
Recommendation	Consider when compiling the investment report.
Notes	Was previously considered a criterion in biocontrol prospects analysis by Morin *et al*. 2016, but we now recommend that it is considered when preparing the investment report. Biocontrol experts deemed it unsuitable for themselves to consider perceived conflicts for such weeds and that perceived conflicts that have not been comprehensively considered through the Environment and Invasives Committee nomination process are not necessarily barriers to research (e.g. gamba grass, African lovegrass). Considered for weeds that have not already been successfully nominated as candidates for biocontrol research.

Criterion Score		
	Definition	Potential (perceived and demonstrated) socioeconomic barriers or conflicts of interest for weeds that have not already been endorsed as candidates for biocontrol research.
	Unfeasible (Stop)	Deemed unfeasible at this stage because of intractable barriers to undertaking weed biocontrol research in Australia, and consensus among practitioners that the weed should not be nominated as a candidate for biocontrol research to the Environment and Invasives Committee at this stage.
	Negative Definition (Score = 0)	Significant socioeconomic barriers or conflicts of interest identified that require extensive stakeholder engagement to better understand and address such conflicts, including identifying opportunities for biocontrol actions that do not significantly reduce the perceived values of the weed to some sectors (e.g. invasive grasses posing a high level of threat to environmental assets and ecosystem function that are widely perceived as providing valuable pasture for livestock).
	Neutral Definition (Score = 1)	Some socioeconomic barriers or conflicts of interest may exist but, in accordance with lessons learned from nomination of similar weeds in Australia, are not expected to impede the preparation and submission of a nomination application following stakeholder engagement (e.g. African lovegrass).
	Positive Definition (Score = 2)	No socioeconomic barriers or conflicts of interest identified.

Notes

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