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The National Priority List of Exotic Environmental Pests, Weeds and Diseases

Information Paper

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Australian Bureau of Agricultural and Resource Economics and Sciences report to the Office of the Chief Environmental Biosecurity Officer, Department of Agriculture, Water and the Environment.

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Australia is renowned for its unique biodiversity and highly diverse environment, which include many endemic species and world heritage sites that are valued for their aesthetic, cultural and recreational benefits. Invasive species are the number one threat to Australia's fauna and flora. Australia's strong biosecurity system aims to mitigate the risk of new introductions of pests, weeds and diseases that could impact on our unique environments, industries and our way of life. The Australian Government Department of Agriculture, Water and the Environment (DAWE) is the primary agency responsible for biosecurity measures pre-border and undertakes a number of activities that aim to prevent and prepare for new incursions of exotic species should they occur.

In 2017, an independent review of the capacity of the national biosecurity system and its underpinning intergovernmental agreement identified the need to adopt a systematic approach to determining and planning for national priority animal, plant and environmental pests and diseases. It was recommended that a national priority list of exotic environmental pests and diseases be developed, in partnership with system participants, by 2020.

This report provides an overview of the development of the National Priority List of Exotic Environmental Pests, Weeds and Diseases (the Exotic Environmental Pest List, or EEPL), and an earlier version of this report was provided to support the public consultation process. The project began in 2017 and was led by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) and other key areas of DAWE in collaboration with over 100 subject matter experts. The overall process and methodology, as well as the shortlisting and assessment of species for the EEPL was developed through collaboration and partnership with experts from:

- Commonwealth and state and territory governments
- New Zealand government
- Centre of Excellence for Biosecurity Risk Analysis (CEBRA)
- Centre for Invasive Species Solutions (CISS)
- Commonwealth Scientific Industrial Research Organisation (CSIRO)
- Animal Health Australia (AHA)
- Plant Health Australia (PHA)
- Wildlife Health Australia (WHA)
- Universities, museums, consultancies and other environmental biosecurity agencies.

The EEPL contains 168 entries from eight biological groups (thematic groups) that were selected from a much larger pool of over 9000 candidates using an assessment process and subject matter experts. Entries on the EEPL can be either a single species, a small set of very closely related species or can refer to a genus but are all referred to as 'species' in this document for ease of communication.

The assessment process ranked the EEPL species according to overall risk per biological group. The top five or six higher-risk species from each of the eight biological groups was compiled into an EEPL subset of 42 species referred to as higher-risk. The eight biological groups are:

- aquatic animal diseases
- freshwater invertebrates
- marine pests
- native animal diseases
- plant diseases
- terrestrial invertebrates
- vertebrates; and
- weeds and freshwater algae.

The listed pests, weeds and diseases are not the only species of environmental biosecurity concern to Australia but serve to highlight and prioritise the sort of environmental biosecurity risks that Australia faces. After this important first step, further work would be required including the development of preparedness plans, as well as raising public awareness of these higher-risk species and environmental biosecurity issues more generally.

The EEPL is not a static list—mechanisms have been developed to ensure it can be kept up to date. Species can be added to the list using a formal process that takes into account changing circumstances in the field or the availability of new knowledge. Listed species can also be removed if they are considered to no longer be a risk species, or when an incursion has occurred, and eradication is deemed to be impracticable. The Chief Environmental Biosecurity Officer (CEBO) is the custodian of the EEPL. The CEBO will coordinate amendments and reviews of the list with the oversight of the Environment and Invasives Committee (EIC).

Introduction

Australia is known for its unique and biologically diverse environment, being identified as one of the 17 megadiverse countries (Cresswell and Murphy 2017). The megadiverse countries combined account for 70% of the world's biological diversity across less than 10% of the world's surface. Contributing to this uniqueness is Australia's high number of endemic species, which includes 94% of Australia's amphibians, 93% of flowering plants, 93% of reptiles, 69% of mammals and 46% of birds (Cresswell and Murphy 2017). Australia is also home to 19 world heritage sites (Cresswell and Murphy 2017). Given the uniqueness of Australia's environment and its rich biodiversity, it is imperative to safeguard against potential threats. Established invasive species are currently the biggest threat to species listed as threatened under Australia's *Environment Protection and Biodiversity Conservation Act 1999* (Kearney et al. 2018). There are 1257 listed species known to be imperiled by invasive species, which accounts for 82% of all threatened species in Australia (Kearney et al. 2018). Invasive species that are not yet in Australia have the potential to significantly impact our biodiversity—it is vital and a key priority that Australia's environment is protected from future threats of invasive species.

Australia's biosecurity system aims to protect our unique environment and biodiversity from the risk of harmful exotic invasive species entering, establishing and spreading. National biosecurity efforts protect $65 billion in farm, fisheries and forestry products and $54 billion in agriculture, fisheries and forestry exports annually (2017-18 financial year, ABARES 2019). It also contributes to the protection of our $42.5 billion inbound and $89 billion domestic tourism industry (2017-18 financial year, Tourism Research Australia 2019), and helps to protect human health and social amenity. The Department of Agriculture, Water and the Environment is the primary agency responsible for biosecurity measures pre-border, aiming to prevent and be prepared for incursions of exotic species. The foundation of the national biosecurity system is an operating model for managing biosecurity risks to a level agreed by all Australian governments, known as the Appropriate Level of Protection (ALOP). ALOP provides for a high biosecurity standard that aims to manage and reduce risks to a very low level, recognising that a zero-risk stance is not feasible. Biosecurity policies internationally reflect that there can never be zero risk associated with trade and the movement of people and goods. Proposed interventions must therefore be prioritised according to their costs and expected benefits to ensure the best return on public expenditure (Dodd et al. 2017). Prioritising species that are a major threat to Australia's industry, environment and human health is an important step in mitigating the risk of incursions of exotic invasive species.

Recent reviews of the national biosecurity system and the arrangements for the management of environmental biosecurity have recommended the development of a priority list of exotic environmental pests and diseases. In 2015, the Senate Environment and Communications References Committee report into environmental biosecurity (2015 senate inquiry) provided a number of recommendations to strengthen the arrangements to prevent the entry and establishment of invasive species likely to harm Australia's environment. One of these recommendations was that the former Department of the Environment work with the former Department of Agriculture (now combined as the Department of Agriculture, Water and the Environment) to develop and publish a national priority list of pests and diseases not yet established in Australia that are of environmental biosecurity concern (Commonwealth of Australia 2015).

In 2016/17, an independent review of the capacity of the national biosecurity system and its underpinning intergovernmental agreement (the independent review) identified the need to adopt a systematic approach to determining and planning for national priority animal, plant and environmental pests and diseases (Craik et al. 2017). The independent review noted that some work to prioritise national biosecurity risks has already occurred or is underway, but that further work is needed.

An area considered by the review as a priority for reform was the adequacy of the national biosecurity system in addressing biosecurity risks impacting the environment and social amenity. Environmental biosecurity is defined as the protection of the environment and social amenity from the risks and negative effects of pests, weeds and diseases entering, emerging, establishing or spreading in Australia, where:

- The environment includes Australia's natural terrestrial, inland water and marine ecosystems and their constituent parts, and their natural and physical resources.
- Social amenity includes the social, economic and cultural aspects of the environment, including tourism, human infrastructure, cultural assets and national image.

Incursions of exotic organisms harmful to Australia's environment and social amenity have been the focus of recent emergency responses (for example, red imported fire ant (*Solenopsis invicta*)). The National Environmental Biosecurity Response Agreement (NEBRA), established under the Intergovernmental Agreement on Biosecurity (IGAB), sets out emergency response arrangements for incursions and biosecurity incidents that primarily impact on the environment and social amenity. The NEBRA aims to strengthen Australia's biosecurity preparedness and enables early response assistance to pest and disease incursions that threaten the environment. However, at the time of the independent review, pest, weed and disease risks that predominantly impact on the environment or social amenity had not yet been systematically identified, prioritised, or planned for at the national level. Craik et al. (2017) suggested that the prioritisation of biosecurity considerations for the environment and social amenity should be comparable to those for human health and primary production, and that national arrangements be explicitly developed to address environmental risks.

In particular, Recommendation 11 of the review stated that:

> The National Biosecurity Committee (NBC) should adopt a systematic approach to determine and plan for national priority pests and diseases:
>
> 1. Three national priority lists—one each for animal, plant and environmental pests and diseases—should be developed in partnership with system participants.
>
> 2. The three national lists should be completed by 2020.
>
> 3. Thereafter, the NBC should lead reviews of the national priority lists at least every five years, reporting to [Agriculture Senior Officials Committee] AGSOC and [Agriculture Ministers' Forum] AGMIN. (Craik et al. 2017)

Australia is one of many countries developing priority pest lists for invasive species beyond their borders. This international activity is aligned with the Aichi Biodiversity Targets adopted in 2010 for the 2011–2020 period under the Convention on Biological Diversity (CBD), to which Australia is a signatory. Aichi Target 9 requires that:

> By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment (CBD 2010).

The development of a national priority list for environmental pests, weeds and diseases will help Australia to achieve its Aichi Target 9 commitments.

A range of activities have been initiated to strengthen Australia's national biosecurity system and to deliver on international commitments. The development of the EEPL (and its subset of higher risk species) is just one of these activities.

The EEPL aims to support and strengthen the capability of the biosecurity system through focus and awareness, to safeguard our diverse and unique environment, ecosystems and social amenity. A national priority environmental list will help strengthen Australia’s environmental biosecurity capability by providing a focus on key environmental biosecurity threats—enhancing the awareness and engagement of stakeholders in environmental biosecurity—and enabling more efficient and effective targeting and coordination of prevention activities. These include areas such as awareness-raising, guiding surveillance and detection activities, strengthening preparedness and response, and informing research and development.

This report provides a description of the prioritisation methodology used to develop the EEPL (and its subset of higher risk species), including background information that supported the public consultation process. The report also includes the EEPL of assessed species (168 exotic pests, weeds and diseases); the subset of 42 higher risk species that pose the greatest risk to Australia’s environmental biosecurity; species-specific information on the higher risk species; and a list of participants involved in the development of the EEPL.

The National Priority List of Exotic Environmental Pests, Weeds and Diseases

Purpose of the EEPL

The primary purpose of the EEPL (and its subset of higher risk species) is to facilitate activities that help prevent the entry, establishment and spread of exotic pests, weeds and diseases that have the potential for nationally important negative impacts on Australia's environment and social amenity. Thus, it is intended that the list will:

- identify pests, weeds and diseases that are likely to cause nationally important negative impacts on Australia's environment, Aboriginal and Torres Strait Islander heritage, and social amenity dependent upon the natural environment,
- inform more efficient and effective targeting of activities and resources with the aim of preventing the entry, establishment and spread of nationally important environmental pests, weeds and diseases, which may include:
  - i) developing preparedness and response plans,
  - ii) guiding surveillance and detection activities, and
- raise government, industry and community awareness of, and engagement with, nationally important environmental pests, weeds and diseases.

The list does not directly inform response or management actions as it does not consider what actions could mitigate the threats, nor does it assess the feasibility of management actions. Importantly, it is not intended that the EEPL will be used as a substitute for existing processes and requirements under the national emergency response agreements, notably the National Environmental Biosecurity Response Agreement (NEBRA).

Scope of the EEPL

The focus of the EEPL is on those species that are of the greatest threat to the environment and social amenity at the national level. That is, species on the EEPL are those that have been assessed to have nationally important negative impacts on one or more of the following:

- the natural environment and ecosystems,
- infrastructure causing disruption to more than one state or territory,
- substantial damage to, or deterioration of infrastructure used by a significant proportion of people over an extensive area,
- amenity of resources, such as public lands and waters, and has the potential to affect more than one state or territory, and
- Australian culture, cultural assets, Aboriginal and Torres Strait Islander heritage practice or custom, or national image.

It is recognised that jurisdictions and other organisations may have specific pests and diseases of concern to them, which may not be on the EEPL. The scope includes all pests, weeds and diseases that could be of concern to the environment and social amenity at the national level. Species that have significant impacts at the state, regional or local level, but are not determined to have nationally important impacts, are out of scope for the EEPL. Species that may be of concern to external territories, such as Norfolk Island, have not been considered for this process. External territories are likely to have their own priorities and those threats may include species exotic to Australia, as well as those native to the Australian mainland.

The EEPL focuses on exotic species, that is, species is absent from Australia. The species must not have been introduced to Australia (unless it has been eradicated or is under an official eradication program) or not have established self-sustaining populations in Australia. Non-native species that are permitted to be legally kept by the general public in any jurisdiction in Australia, such as ornamentals (for example, garden plants) or pets, do not meet the definition of exotic in this context. Species that are permitted to be kept in Australia in a highly contained environment (such as in zoos or in botanic gardens) are included in the definition of exotic. Species that are already in Australia, such as weed species on the National Environmental Alert List, are out of scope of this project.

Species on the EEPL may also be on other national lists. In other words, there may be an overlap between the EEPL and the National List of Notifiable Animal Diseases, the National List of Reportable Diseases of Aquatic Animals, the National Priority Plant Pest List and the Australian Priority Marine Pests List. This is due to the intent of the EEPL to deliver an understanding of pests and diseases posing a high risk to the Australian environment and social amenity across a broad spectrum of species and ecosystems (terrestrial, freshwater and marine). The other national lists that have been developed will remain, as they have been developed for a specific purpose.

It is also important to note that the EEPL is not exhaustive but is a prioritised list of species that have been assessed to be of significant risk to Australia for the focus of further action. By no means are these pests and diseases the only species of environmental biosecurity concern; rather, the list serves to highlight and prepare for the sort of environmental biosecurity risks that Australia faces. It should be noted that species that are not on the EEPL will still be managed at the border to protect Australia from potential pests and diseases. The EEPL does not limit the ability of states, territories or industry to take actions to manage pests or diseases that are not included on the list.

The EEPL consists of eight biological/thematic groups:

- Aquatic animal diseases (Table B1),
- Freshwater invertebrates (Table B2),
- Marine pests (Table B3),
- Native animal diseases (Table B4),
- Plant diseases (Table B5),
- Terrestrial invertebrates (Table B6),
- Vertebrate pests (Table B7), and
- Weeds and freshwater algae (Table B8).

The EEPL and its underpinning purpose, listing criteria and methodology will be subject to regular review. The first review of the list is intended to be undertaken within three years of the list's completion, to ensure its effectiveness. However, subsequent reviews are expected to be undertaken less frequently (every five years after the initial review). Importantly, the process has been developed to ensure that it can be built upon as new information arises, and mechanisms have been put in place to ensure that ad hoc amendments can be made to the list, including assessment of new recognised higher-risk species.

Other nationally endorsed lists

The EEPL has been developed specifically to identify pests and diseases that are of high risk to Australia's environment and social amenity. There are other national priority lists that may capture some of these species. It is important to note that the EEPL will not replace these other lists as they have been developed for their own intended purposes. As of July 2019, there are four nationally endorsed lists where the predominant focus is on exotic species. These are:

- National List of Notifiable Animal Diseases (endorsed by Animal Health Committee),
- National List of Reportable Diseases of Aquatic Animals (endorsed by Animal Health Committee),
- National Priority Plant Pest List (endorsed by the Plant Health Committee), and
- Australian Priority Marine Pest List (endorsed by the Marine Pest Sectoral Committee).

A short summary of each national list and their purpose have been included in Appendix A. It should also be noted that each jurisdiction has their own priority lists, some of which are regulated lists. These lists have been compiled primarily on impacts affecting the agricultural economy, whereas the EEPL has been compiled based on the species impacts affecting the environment.

Collaboration and partnerships to develop the EEPL

The EEPL (and its subset of higher risk species) has been developed as part of a collaborative partnership with key stakeholders. The Australian Bureau of Agricultural and Resource Economics and Science (ABARES) and other key areas of the Department of Agriculture, Water and the Environment led the process in collaboration with over 100 subject matter experts. Stakeholders and experts involved have included those from state, territory and Australian governments and organisations responsible for pest, weed and disease research and management. This includes the Centre of Excellence for Biosecurity Risk Analysis (CEBRA), the Centre for Invasive Species Solutions (CISS), the Commonwealth Scientific Industrial Research Organisation (CSIRO), Animal Health Australia (AHA), Plant Health Australia (PHA), Wildlife Health Australia (WHA), and other researchers and environmental biosecurity stakeholders from universities and museums.

Collaboration is a key component to the success of this process. All stakeholders involved in this process have played an important role in decision making. Joint decisions have been made on the purpose, use and audience for the EEPL, as well as the structure and functionality of the methodology. Key decisions were also made by the group on the number of species that should be placed on the EEPL subset of higher risk species. Experts have played a vital role in the expert elicitation process to shortlist and assess species for the EEPL. A full list of experts involved in the development of the methodology, the shortlisting and assessment of species can be found in Appendix E.

The EIC has policy oversight of the national priority environmental list. The Plant Health Committee (PHC), Animal Health Committee (AHC) and the Marine Pest Sectoral Committee (MPSC) were consulted in the development of the list and will play an ongoing role in reviews of and amendments to the EEPL.

The process to determine the EEPL

Developing the process

The EEPL comprising 168 species was compiled through a process involving the appraisal by subject matter experts of a much larger pool of over 9000 candidate species. The prioritisation assessment process to determine risk ranking of the EEPL species was developed in collaboration with technical stakeholders at all stages. This included two workshops that facilitated joint decisions on the purpose and the methodology for determining the species posing significant environmental biosecurity risk. A review of priority list methods in Australia and worldwide was conducted prior to the workshops to inform a suitable process for the purposes of this list. This included review of processes from Australia (for example, MPSC 2018; Department of Agriculture, Water and the Environment 2018), New Zealand (McDonald et al. 2015), United States (CAPS 2017) and Europe (Roy et al. 2014; Roy et al. 2019; Kelly et al. 2013). Some of these list makers were also consulted to obtain further learnings from their experience. The methodology that was developed after workshop one was reviewed by CEBRA and refined based on their feedback. The method was further refined after workshop two, based on expert advice. The methodology and results of the entire process will be published in a peer-reviewed scientific journal.

The method for assessing and prioritising pest, weed and disease threats to Australia's environment and social amenity is a systematic process. Figure 1 provides an overview of the three phases in the process:

- identification of global species for shortlisting,
- expert screening to identify candidate species, and,
- assessment of candidate species by experts using a semi-quantitative method.

The questions in the semi-quantitative method were developed based on the listing criteria agreed at the expert workshop one in March 2018. The criteria are consistent with those of the National Priority Plant Pest List 2016, the Australian Priority Marine Pests List (APMPL) and recommendations of the Craik et al. (2017) review. For a species to be on the EEPL (and its subset of higher risk species)), the species must:

1. be a pest, weed or disease (including, where relevant, genus, subspecies, strain or biotype of plant, animal or pathogenic agent) that has demonstrated negative impacts on the environment and/or social amenity and,
2. be exotic to Australia. That is, the pest, weed or disease is not currently known to be present in Australia, or, if present, is subject to nationally agreed eradication and,
3. have at least one known or potential pathway of entry to Australia and,
4. have the potential to establish and spread in Australia and,
5. have the potential for nationally important negative impacts on the environment or social amenity.

Phase 1: Identification of global species for expert screening

Phase 1 of the process involved compiling a pool of potential species for each biological group using the method described in Evans et al. (2017). The resulting "long list" contained over 800 species for most biological groups, with some groups containing up to 3300 potential species. In total, the long list contained over 9000 species in total across all groups. Invasive species were sourced from global databases, lists of species considered as invasive and/or of concern by countries or regions, government reports and peer-reviewed scientific literature.

Global species were then shortlisted for expert screening (the "short list") using the following criteria.

- Recorded as an invasive by two or more national, regional or global lists.
- Exotic to Australia (determined using publicly available information).
- Have reported impacts on environment or social amenity. Species with only agricultural impacts or with no documented environment or social amenity impacts are considered out of scope and therefore were not included in the short list (but were available for viewing and further consideration by experts in the long list).

The short list contained approximately 700 species across the eight biological groups.

Phase 2: Expert screening to identify candidate species for assessment

The number of species in the candidate list for phase 3 was limited to 20-25 species per biological group due to limited expert time, as well as project time and resource constraints. In phase 2 (expert screening), experts were asked to select 20-25 candidate species per biological group for assessment during phase 3. Experts in each group were provided with the long list and the short list from phase 1, and a proposed list of species recommended by experts at workshop two. Experts were also sent a fourth list of 20-30 species (determined using only the criterion of species presence on national, regional or global priority lists). The fourth list was used as a tool to stimulate conversation (by email and teleconference) and focus attention to come to a final 20-25 candidate species per biological group. Experts were asked to consider whether the species in the fourth list should be assessed, or whether there were other species from the long list, short list and expert-recommended list from workshop two that should make it to the final candidate species list for assessment. Experts were asked to make these decisions as a group, via email conversations and teleconferences. Reasons for adding or removing species from the short list included habitat/climate suitability, impact on environment/social amenity, pathway for entry into Australia, and consideration of suitable hosts or vectors. The final 20-25 species proposed by each group (totalling 169 species across all groups) were then assessed during the expert elicitation process using a semi quantitative methodology (phase 3). The outcome from phase 2 is the candidate list of 169 species for assessment in phase 3, and this candidate list formed the EEPL.

Phase 3: Assessment of candidate species using structured expert elicitation and semi-quantitative methodology

Phase 2 resulted in 169 species from the eight biological groups, for assessment by experts in phase 3 to determine the 'higher risk' EEPL species. All species that were assessed under the full methodology can be found in Appendix B.

For each group, species were assessed using a semi-quantitative method. This method consists of five categories:

- likelihood of entry,
- likelihood of establishment,
- likelihood of spread,
- environmental impact and,
- social impact.

The likelihood of entry, establishment and spread are modelled on a geometric scale over six categories. This is consistent with the Australian Biosecurity Import Risk Analysis and the New Zealand Organism Ranking System (ORS) (McCarthy 2007; McDonald et al. 2015). The assessment of environmental and social impacts is based on adapted versions of the Environmental Impact Classification of Alien Taxa (EICAT) (Blackburn et al. 2014; Hawkins et al. 2015) and the Socio-Economic Impact Classification of Alien Taxa (SEICAT) (Bacher et al. 2017) methods, respectively. EICAT has been adopted by the IUCN (International Union of Nature Conservation) as a consistent means by which to assess the environmental impacts of species globally. SEICAT (Bacher et al. 2017) was developed to complement EICAT for assessing the socio-economic impacts of alien taxa. These processes were also adapted to support an Australian context. The NEBRA national significance criteria were also used as a guide to determine the value and importance of species and places when assessing environmental impacts.

The expert elicitation phase followed a structured modified Delphi approach, which involved:

- an initial teleconference to explain the methodology and answer questions,
- round one of assessments by experts, where scoring was based on evidence,
- teleconference for experts to discuss round 1 result's and share relevant evidence (scores kept anonymous),
- round two of assessments where experts could change their initial scores based on evidence shared at the discussion teleconference, and
- final teleconference to share final results.

Each expert within a group assessed around 10 species. This meant that each species was assessed by four to five different experts. In total, 169 species across all biological groups were fully assessed for the EEPL. For each species an expert assessed, they provided a score for each parameter (entry, establishment, spread, environmental and social impact), and a confidence level (high, medium, low). Experts also provided evidence sourced from scientific literature and/or their opinion representative of their knowledge and experience to justify these scores. An overall score was calculated for each species, with the mean of each parameter (likelihood of entry, establishment and spread, and impacts (environment + social)) from round two multiplied to give the final score. Sensitivity analysis was also conducted on the final results to determine whether those that ranked at the top, always ranked at the top, regardless of the expert scoring it.

The outcome from the assessment process (phase 3) was 42 species referred to as the 'higher risk' EEPL.

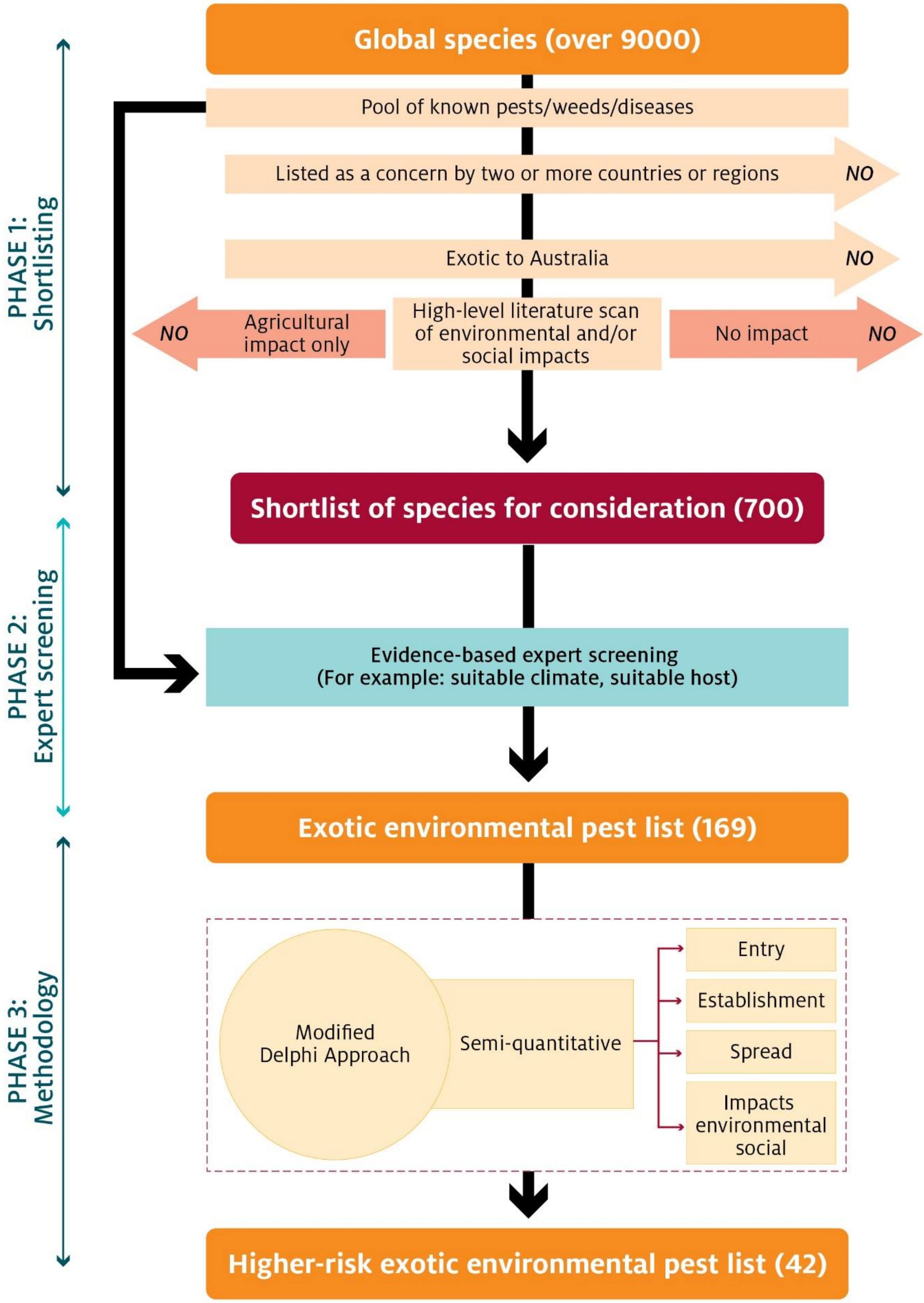

Figure 1. Process to select species for the National Priority List of Exotic Environmental Pests, Weeds and Diseases.

Public consultation of an interim priority list

An interim priority list consisting of both the 169 shortlisted species and the 42 higher risk species was circulated to all stakeholders for public consultation at a national level in late 2019 to elicit comments and suggestions. The consultation process presented all 169 species, with emphasis on the 42 higher risk species. The approach of having around five species represented from each biological group (a total of around 40) for the 'higher risk' list was considered suitable for engaging with the public, and for increasing awareness of the key environmental biosecurity threats facing Australia. Ranking within specific thematic areas, rather than across all thematic areas was also important to ensure that certain environments or biological/ecological groups were not under-represented on the list and to allow a broader understanding of the environmental biosecurity threats Australia faces.

Over 50 responses were received which dealt with a range of topics including the composition of the proposed work programs. After the assessment and public consultation process, one species (Wobbly possum disease virus) out of the 169 assessed in phase 3 was removed from the final list as the species was later considered to be established in Australia and therefore no longer met the list's eligibility criteria.

The Environment and Invasives Committee (EIC) considered the stakeholder submissions and, after a small number of changes, approved the list for submission to the National Biosecurity Committee for finalisation.

Endorsement of the EEPL

Following the public consultation process, the EEPL containing 168 species of pests, weeds and diseases from the eight biological groups, including the 42 'higher risk' EEPL species, was endorsed by the National Biosecurity Committee. The EEPL was publicly released in November 2020 and is available on the department website.

The top ranked higher risk species from each biological group are presented in Appendix C. Note that species in each thematic group are listed alphabetically, rather than in ranked order.

A short description of each of the top ranked pests, weeds and diseases (higher risk species) are provided in Appendix D.

Appendix A: Summary and purpose of endorsed national lists

National list of notifiable animal diseases

The purpose of the National animal disease list is focussed on production, trade, international reporting obligations, and human health. It also supports domestic jurisdictional surveillance and control programs. The Animal Health Committee has oversight of the development, maintenance and review of the national list of notifiable diseases of terrestrial animals (98 diseases), as well as the national list of notifiable diseases of bees (five diseases).

National list of reportable diseases of aquatic animals

The Sub-Committee on Aquatic Animal Health (SCAAH) manages the National List of reportable diseases of aquatic animals, which includes diseases of marine and freshwater finfish, molluscs, crustaceans and amphibians. There are a total of 50 diseases on this national list, including exotic and endemic diseases to Australia. Similar to the terrestrial animal disease list, the aquatic animal disease list's primary purpose is around international reporting, supporting trade and domestic control programs, and as a general tool to collate and disseminate information on aquatic diseases of national importance (SCAAH 2017).

National priority plant pest list 2016

The National priority plant pest list, often referred to as the 'Top 40' list, does not contain the only plant pests of biosecurity concern, but highlights the types of threats Australia faces (Department of Agriculture, Water and the Environment 2017). The list includes more than 40 species, as some 'species' on the list comprise a number of species, for example, 'fruit flies'. The list is to be used as a guide for national decision-making, including the selection of pests for the National Plant Health Surveillance Program and preparedness activities.

Australian priority marine pest list

The Marine Pest Sectoral Committee endorsed the national list of priority marine pests, the APMPL, which includes both established and exotic species. The intention of the APMPL is to facilitate national improvements in marine pest communication, surveillance, preparedness, response and management for pests deemed a national priority. The list is not exhaustive and is primarily a list of examples to aid in these activities.

Appendix B: 169 species shortlisted (Phase 2) for the EEPL

Table B1 Aquatic Animal diseases

Common name	Scientific name
Bonamiosis	*Bonamia ostreae*
Crayfish plague	*Aphanomyces astaci*
Grouper iridoviral disease	Singapore grouper iridovirus (SGIV) and Grouper iridovirus (GIV) (Genus *Ranavirus*)
Infectious hematopoietic necrosis	Infectious hematopoietic necrosis virus (IHNV) (Genus *Rhabdovirus*)
Infectious myonecrosis	Infectious myonecrosis virus (IMNV) (Genus *Totivirus*)
Infectious pancreatic necrosis	Infectious pancreatic necrosis virus (IPNV) (Genus *Aquabirnavirus*)
Marteiliosis (Aber disease)	*Marteilia refringens*
Megalocytivirus	Infectious spleen and kidney necrosis virus (ISKNV) and Red sea bream iridovirus (RSIV) (Genus *Megalocytivirus*)
Mikrocytosis (Denman Island disease)	*Mikrocytos mackini*
Necrotising hepatopancreatitis	'*Candidatus* Hepatobacter penaei'
Perkinsosis/ Dermo disease	*Perkinsus marinus*
Protozoic whirling disease	*Myxobolus cerebralis* / *Microsporidium takedai*
Taura syndrome	Taura syndrome virus (TSV) (Genus *Aparavirus*)
Viral haemorrhagic septicaemia	Viral haemorrhagic septicaemia virus (VHSV) (Genus *Novirhabdovirus*)
White spot syndrome	White spot syndrome virus (WSSV) (Genus *Whispovirus*)
Withering syndrome (of abalones)	'*Candidatus* Xenohaliotis californiensis'
Yellow head disease	Yellow head virus genotype-1 (YHV1) (Genus *Okavirus*)

Total number of pathogens considered for short-listing: 165

Table B2 Freshwater invertebrates

Common name	Scientific name
Asian clam	*Corbicula fluminea*
Assassin snail	*Clea / Anentome* spp.
Bloody-red mysid shrimp	*Hemimysis anomala*
*Chinese mitten crab	*Eriocheir sinensis*
Chinese mystery snail and Japanese mystery snail	*Cipangopaludina chinensis* and *C. japonica*
Danube crayfish / Turkish crayfish	*Astacus leptodactylus*
Freshwater mussel	*Cristaria plicata*
Golden apple snail and Island apple snail	*Pomacea canaliculata* and *P. maculata*
Golden mussel	*Limnoperna fortunei*
Horn snail	*Indoplanorbis exustus*
Louisiana red crayfish / Red swamp crayfish	*Procambarus clarkii*
Mud snail	*Galba truncatula*
Northern crayfish / Virile crayfish	*Orconectes virilis*
Quagga mussel and Zebra Mussel	*Dreissena bugensis* and *D. polymorpha*
Quilted melania	*Tarebia granifera*
Rusty crayfish	*Orconectes rusticus*
Serrate crownsnail	*Pyrgophorus platyrachis*
Signal crayfish	*Pacifastacus leniusculus*
Spinycheek crayfish	*Orconectes limosus*
Land snails *Radix* genus	Exotic *Radix* spp.
Freshwater snails *Bioophalaria* genus	*Biomphalaria* spp.
Freshwater snails *Bulinus* genus	*Bulinus* spp.
Freshwater snails *Oncomelania* genus	*Oncomelania* spp.

Total number of species considered for short-listing: 90

* Note that Chinese mitten crab has both freshwater and marine phases in its lifecycle

Table B3 Marine pests

Common name	Scientific name
Asian brackish-water clam/ Overbite clam	*Potamocorbula amurensis*
Asian green mussel	*Perna viridis*
Atlantic oyster drill	*Urosalpinx cinerea*
Black-striped false mussel	*Mytilopsis sallei*
Brown mussel	*Perna perna*
Brush-clawed shore crab	*Hemigrapsus takanoi*
Carpet sea squirt	*Didemnum vexillum*
Centric diatom	*Chaetoceros concavicornis*
*Chinese mitten crab	*Eriocheir sinensis*
Comb jelly	*Mnemiopsis leidyi*
Harris' mud crab	*Rhithropanopeus harrisi*
Japanese shore crab	*Hemigrapsus sanguineus*
Japanese skeleton shrimp	*Caprella mutica*
Japanese wireweed	*Sargassum muticum*
Lady crab / Asian paddle crab	*Charybdis japonica*
New Zealand green-lipped mussel	*Perna canaliculus*
Rapa whelk	*Rapana venosa*
Red-gilled mudworm	*Marenzelleria neglecta*
Soft shelled clam	*Mya arenaria*
Toxic dinoflagellate	*Dinophysis norvegica*

Total number of species considered for short-listing: 988

* Note that Chinese mitten crab has both freshwater and marine phases in its lifecycle

Table B4 Native Animal Diseases

Common name	Scientific name
Avian paramyxovirus-3 (PMV3) and Avian paramyxovirus-5 (PMV5)	Avian paramyxovirus-3 (PMV3) and Avian paramyxovirus-5 (PMV5)
Bubonic plague	*Yersinia pestis*
Exotic novel nidovirus strains in reptiles	Exotic novel coronavirus, including python nidovirus (Order *Nidovirales,* Family *Coronaviridae*)
Deformed wing virus in bees	Deformed wing virus (DWV) (Family *Iflaviridae*)
Duck viral enteritis / duck plague	Anatid herpesvirus-1
Exotic Flaviviruses (Bagaza and Usutu)	Exotic Flaviviruses – Bagaza virus and Usutu virus
Exotic novel herpesviruses of reptiles	Family *Herpesviridae*, Subfamily *Alphaherpesvirinae*
Exotic highly pathogenic avian influenza	Exotic highly pathogenic avian influenza viruses (HPAI)
New Zealand wobbly possum disease*	Wobbly possum disease virus (WPDV) (Novel nidovirus, Family Arteriviridae)
Ophidian paramyxovirus (OPMV) / Fer-de-lance virus - infection of snakes	Subfamily *Paramyxovirinae*, genus *Ferlavirus*
Pacheco's disease and internal papillomatosis disease	Psittacid herpesvirus-1 (PsHV-1)
Phocine distemper	Phocine distemper virus (PDV) (Genus *Morbillivirus)*
Proventricular dilatation disease	Parrot bornavirus (PaBV)
Psittacine pox virus	Psittacine pox virus (PsPoV) (Genus *Avipoxvirus*)
Rabies virus	Rabies virus / Rabies lyssavirus (Genus *Lyssavirus*)
Screwworm fly	*Chrysomya bezziana* and *Cochliomyia hominivorax*
Severe Perkinsea infection in frogs	Pathogenic Perkinsea Clade of frogs
Snake fungal disease	*Ophidiomyces ophiodiicola*
Surra	*Trypanosoma evansi*
West Nile virus infection	West Nile virus lineages - other than 1b (WNV Kunjin)
White nose syndrome of bats	*Pseudogymnoascus destructans*

Total number of pathogens considered for short-listing: 664

*It should be noted that, after the assessment and public consultation process, this disease was removed from the final list as it was later considered to be established in Australia and therefore no longer met the list's inclusion criteria.

Table B5 Plant Diseases

Common name	Scientific name
Annosus root and butt rot	*Heterobasidion annosum*
Armillaria root rot	*Armillaria mellea*
Blood disease of banana and clove wilt	*Ralstonia syzygii*
Ceratocystis wilt	*Ceratocystis manginecans*
Ceratocystis wilt	*Ceratocystis albifundus*
Chestnut blight	*Cryphonectria parasitica*
Chrysoporthe canker / Eucalyptus canker	*Chrysoporthe austroafricana*
Coconut lethal yellowing	'*Candidatus* phytoplasma palmae'
Dutch elm disease	*Ophiostoma ulmi* sensu lato
Elm yellows / Elm phloem necrosis	'*Candidatus* phytoplasma ulmi'
Fusarium wilt	*Fusarium euwallaceae*
Huanglongbing / Citrus greening	'*Candidatus* Liberibacter asiaticus', '*Candidatus* Liberibacter africanus' and '*Candidatus* Liberibacter americanus'
Myrtle rust (exotic strains)	*Austropuccinia psidii* -exotic strains
Oak wilt	*Ceratocystis fagacearum*
Phytophthora blight	*Phytophthora kernoviae*
Sudden oak death/Ramorum blight	*Phytophthora ramorum*
Teratosphaeria canker	*Teratosphaeria gauchensis*
Teratosphaeria leaf blight / Teratosphaeria stem canker	*Teratosphaeria destructans / T. zuluensis*
Texas root rot	*Phymatotrichopsis omnivora*
Xylella	*Xylella fastidiosa*

Total number of pathogens considered for short-listing: 822

Table B6 Terrestrial invertebrates

Common name	Scientific name
Africanised honeybee	*Apis mellifera scutellata* and its hybrids
Annona mealybug / Pineapple mealybug	*Dysmicoccus neobrevipes*
Asian / Yellow-legged hornet	*Vespa velutina*
Asian bee mite	*Tropilaelaps clareae*
Asian bee mite	*Tropilaelaps mercedesae*
Asian gypsy moth	*Lymantria dispar* (*Lymantria dispar asiatica, Lymantria dispar japonica* and *Lymantria dispar dispar*)
Brown marmorated stink bug	*Halyomorpha halys*
Cape honeybee	*Apis mellifera capensis*
Common eastern bumblebee	*Bombus impatiens*
Cycad aulacaspis scale	*Aulacaspis yasumatsui*
Delta wasp	*Delta pyriforme*
Dichroplus grasshopper	*Dichroplus elongatus* and *D. maculipennis*
Electric ant	*Wasmannia auropunctata*
Formosan subterranean termite	*Coptotermes formosanus*
Giant African snail	*Achatina fulica*
Gold dust weevil	*Hypomeces squamosus*
Harlequin lady beetle/ Multicolored Asian lady beetle	*Harmonia axyridis*
Honey bee tracheal mite	*Acarapis woodi*
Oriental powderpost beetle	*Lyctoxylon dentatum*
Picnic beetle	*Glischrochilus fasciatus* and *G. quadrisignatus*
Red imported fire ant	*Solenopsis invicta*
Rosy predator snail	*Euglandina rosea*
Shot hole borer	*Euwallacea fornicatus* complex
Western drywood termite	*Incisitermes minor*

Total number of species considered for short-listing: 2267

Table B7 Vertebrates

Common name	**Scientific name**
African pygmy hedgehog	*Atelerix albiventris*
Asian black-spined toad	*Duttaphrynus melanostictus*
Asian painted frog	*Kaloula pulchra*
Boa constrictor	*Boa constrictor*
Burmese python	*Python bivittatus*
Chinese carp	*Ctenopharyngodon idella*
Climbing perch	*Anabas testudineus*
Common snapping turtle	*Chelydra serpentina*
Corn snake	*Pantherophis guttatus*
Fire bellied newt	*Cynops orientalis*
Flat-tailed house gecko	*Hemidactylus platyurus*
Green iguana	*Iguana iguana*
Grey squirrel	*Sciurus carolinensis*
House crow	*Corvus splendens*
Nile tilapia	*Oreochromis niloticus*
Oriental garden lizard	*Calotes versicolor*
Pacific rat	*Rattus exulans*
Red-eared slider turtle	*Trachemys scripta elegans*
Silver carp	*Hypophthalmichthys molitrix*
Snakeheads	*Channa* spp. (including *Channa striata*)
Stoat	*Mustela erminea*
Veiled chameleon	*Chamaeleo calyptratus*
Walking catfish	*Clarias batrachus*

Total number of species considered for short-listing: 1032

Table B8 Weeds and freshwater algae

Common name	Scientific name
Asiatic sand sedge	*Carex kobomugi*
Black sage	*Cordia curassavica*
Black swallow-wort	*Vincetoxicum nigrum*
Brittle naiad	*Najas minor*
Cane tibouchina	*Tibouchina herbacea*
Didymo	*Didymosphenia geminata*
Halogeton	*Halogeton glomeratus*
Karoo thorn	*Vachellia karoo*
Lagariosiphon	*Lagarosiphon major*
Leafy spurge	*Euphorbia esula*
Manchurian wildrice	*Zizania latifolia*
Mikania	*Mikania micrantha*
Mouse-ear hawkweed	*Hieracium pilosella*
Nepalese browntop	*Microstegium vimineum*
Portuguese broom	*Cytisus striatus*
Slangbos	*Seriphium plumosum*
South African ragwort	*Senecio inaequidens*
Spiked pepper	*Piper aduncum*
Water primrose	*Ludwigia grandiflora*
Wiregrass	*Ventenata dubia*

Total number of species considered for short-listing: 3347

Appendix C: The higher risk EEPL species (Phase 3)

Common name(s)	Scientific name
Aquatic Animal Diseases	
Bonamiosis	*Bonamia ostreae*
Crayfish plague	*Aphanomyces astaci*
Megalocytiviruses	Infectious spleen and kidney necrosis virus (ISKNV) and Red sea bream iridovirus (RSIV)
White spot syndrome	White spot syndrome virus (WSSV)
Yellow head disease	Yellow head virus-1 (YHV1)
Freshwater Invertebrates	
Asian clam	*Corbicula fluminea*
Chinese mystery snail and Japanese mystery snail	*Cipangopaludina chinensis* and *C. japonica*
Golden apple snail and island apple snail	*Pomacea canaliculata* and *P. maculata*
Quagga mussel and zebra mussel	*Dreissena bugensis* and *D. polymorpha*
Quilted melania	*Tarebia granifera*
Marine Pests	
Asian green mussel	*Perna viridis*
Black-striped false mussel	*Mytilopsis sallei*
Carpet sea squirt	*Didemnum vexillum*
Chinese mitten crab	*Eriocheir sinensis*
Lady crab / Asian paddle crab	*Charybdis japonica*
Native Animal Diseases	
Duck viral enteritis / Duck plague	Anatid herpesvirus-1
Exotic West Nile virus disease	West Nile virus (WNV) (other than WNV lineage 1b (Kunjin virus))
Pacheco's disease and Internal papillomatosis disease	Psittacid alphaherpesvirus-1 (PsHV-1)
Proventricular dilatation disease	Parrot bornavirus (PaBV)
White nose syndrome	Pseudogymnoascus destructans
Plant Diseases	
Ceratocystis wilt	*Ceratocystis manginecans* (and other exotic *Ceratocystis* spp.)
Myrtle rust (exotic strains)	*Austropuccinia psidii* - exotic strains
Fusarium wilt	*Fusarium euwallaceae*
Sudden oak death/Ramorum blight	*Phytophthora ramorum*
Teratosphaeria leaf blight / Teratosphaeria stem canker	*Teratosphaeria destructans* and *T. zuluensis*

Xylella	*Xylella fastidiosa*

Terrestrial Invertebrates

Asian gypsy moth	*Lymantria dispar*
Formosan subterranean termite	*Coptotermes formosanus*
Giant African snail	*Achatina fulica*
Harlequin lady beetle / multicolored Asian lady beetle	*Harmonia axyridis*
Invasive ants – (red imported fire ant and electric ant)	*Solenopsis invicta* and *Wasmannia auropunctata*

Vertebrates

Asian black-spined toad	*Duttaphrynus melanostictus*
Boa constrictor	*Boa constrictor*
Climbing perch	*Anabas testudineus*
Corn snake	*Pantherophis guttatus*
Red-eared slider turtle	*Trachemys scripta elegans*
Silver carp	*Hypophthalmichthys molitrix*

Weeds and Freshwater Algae

Didymo	*Didymosphenia geminata*
Manchurian wild rice	*Zizania latifolia*
Mikania	*Mikania micrantha*
Mouse-ear hawkweed	*Pilosella officinarum*
Spiked pepper	*Piper aduncum*

Appendix D: Summary of higher risk species and their impacts

Aquatic animal diseases

Bonamiosis (*Bonamia ostreae*) is a lethal disease caused by a Haplosporidia protozoan parasite which infects flat oysters (*Ostrea* spp.) and some cupped oysters (*Crassostrea* spp.) (CABI 2017a; World Organisation for Animal Health 2018d). The infection has been found in Europe, North America (CABI 2017a) and New Zealand (Biosecurity New Zealand MPI 2019).

The environmental impacts of this pathogen are poorly known; however, it can be highly pathogenic to new oyster hosts, which provide key habitat structures of ecosystems around Australia (Baud et al. 1997). Australia has a number of susceptible native oysters that could be affected by this parasite, so this disease could have negative environmental impacts on associated species and ecosystems (Biosecurity New Zealand MPI 2019). The disease could also result in negative social amenity impacts on recreational and Indigenous fishers that harvest or use shellfish as bait (Airoldi et al. 2009).

The parasite could enter Australian waters from biofouling of susceptible species on ships, and from imported infected molluscs for human consumption, although its pathway of entry to Australia is not described (Arzul et al. 2011). Movement restrictions and disease management practices may be able to control the spread of the disease if it were to enter Australia (CABI 2017a).

Crayfish plague (*Aphanomyces astaci*) is caused by a water mould agent that results in rapid mortality to potentially all freshwater crayfish and crabs, with Australian freshwater crustaceans found to be highly susceptible to the disease (GISD 2019a; World Health Organisation for Animal Health 2018a). The disease originates from North America, and has been introduced to Europe, Turkey, and Russia (GISD 2019a).

Infection of Australian native freshwater crayfish with crayfish plague could cause localised extinctions around Australia (GISD 2019a; Freeman et al. 2010; Coughran & Furse, 2012). Crayfish are keystone species (being predators, herbivores and detritus degraders), so their loss would lead to major changes in the food web, altered ecology of the freshwater environment, and lower biodiversity of overall native species (GISD 2019a). Ostracods and copepods are likely the most important carriers of the disease. However, it is currently not known if other freshwater crustaceans could become carriers of this disease or develop the disease in the wild in Australia (Department of Agriculture, Water and the Environment 2005). In Australia, crayfish have a significant social and cultural value for recreational fishers and Indigenous communities, who would be negatively impacted by outbreaks of crayfish plague (Geddes & Jones 1997).

It is unlikely for the pathogen to enter Australia legally, as imported freshwater crayfish are cooked to remove potential diseases. However, it is possible that this disease could enter and spread in the natural environment through escape from aquariums or other confinement, through movement of contaminated baitfish and fishing equipment, and through illegal importation of ornamental freshwater crayfish and crabs. Flooding and rainfall events could further spread this disease if it establishes in Australia (Mrugla et al. 2015; World Health Organisation for Animal Health 2018a). This disease has a wide temperature tolerance, remains viable for a long period, and only a low infective dose is needed to cause an outbreak (Alderman et al. 1987). Movement of fish, birds and other wildlife may assist the disease's spread, as well as movement of contaminated equipment by people (e.g. fishing gear, boots and nets) (World Health Organisation for Animal Health 2018a; DAWR 2016). Once a population of crayfish has been infected by the disease, its spread cannot be controlled (World Health Organisation for Animal Health 2018), although natural barriers and current containment measures may partially limit its spread (Department of Agriculture, Water and the Environment 2005).

Megalocytivirus (Infectious spleen and kidney necrosis virus (ISKNV) and Red sea bream iridovirus (RSIV)) ISKNV and RSIV are two viruses in the genus *Megalocytivirus*. Viruses within this genus infect a broad range of marine and freshwater fish, which can result in mass mortalities (CABI 2017b; Kurita & Nakajima 2012). Both diseases are exotic to Australia. Infection with ISKNV-like viruses, to be linked with the ornamental fish trade, was previously reported in a Murray cod farm and an ornamental fish farm in Australia (Lancaster, Williamson & Schroen 2003; Mohr et al. 2015). ISKNV-like viruses were periodically detected in imported ornamental fish before the new import condition was put in place in Australia (Rimmer et al. 2015; Hood et al. 2019).

Over 40 species of fish are known to be susceptible to RSIV and over 30 species to ISKNV-like virus (DAFF 2012a,b). Native fish species, including Murray cod and barramundi, are susceptible to these viruses (Yanong & Waltzek 2016), which could result in significant loss of iconic species, as well as trophic and structural changes in the ecology of freshwater environments. However, the environmental impact of these viruses on wild populations is not fully known, as impacts from these and related viruses have been reported mainly from cultured marine and freshwater fish, and tropical ornamental fish (Kurita & Nakajima 2012). The loss of Murray cod, barramundi, and other native fish species would impede recreational fishing and Indigenous fishing practices (Diggles 2017).

Infected fish that is illegally or unintentionally released from containment is the main pathway for introducing ISKNV and RSIV to wild populations in Australia (Go et al. 2006). If established in the wild, the spread of these infections may be able to be contained through management as many native fish have fragmented ranges (Go & Whittington 2006; Jin et al. 2014).

White spot syndrome (White spot syndrome virus (WSSV)) is a severe, contagious pathogen in the genus *Whispovirus*, which rapidly infects a broad range of aquatic crustaceans, including prawns, crabs, crayfish and lobsters (especially decapods) in marine, brackish and freshwater environments (CABI 2018a; World Organisation for Animal Health 2018b). The virus was first identified in Taiwan. It is distributed throughout Bangladesh, Hong Kong, Indonesia, Japan, Korea, Malaysia, and Costa Rica (CABI 2018a). There has been a recent outbreak in Australia in both farmed and wild prawns, which is currently subject to eradication measures (Queensland Government 2019).

WSSV causes mass mortalities in farmed shrimps and associated negative industry impacts, although impacts on wild populations are less well understood (McIlwain et al. 1997; Pantoja et al. 1999; Department of Agriculture, Water and the Environment 2013; Lafferty et al. 2015). Many native species of decapods could be affected by WSSV, which could result in reduced biodiversity and altered structure of freshwater, brackish and marine communities (Harvell et al. 2002; Harvell et al. 2004). The disease could also have negative impacts on recreational and Indigenous fishers (both individuals and communities) who conduct shrimping and crabbing, or use crustaceans as bait.

Live crustaceans are not allowed to be imported into Australia. However, adult brood stock are sourced from Australian waters and the Torres Strait Protected Zone, which could contain species that carry sub-clinical infections and act as a reservoir for this disease (Department of Agriculture, Water and the Environment 2013). Susceptible crustacean hosts are highly mobile, have pelagic larvae and have overlapping ranges, which are factors that allow WSSV to rapidly spread over large areas (Kanchanaphum et al. 1998; Sahul Hameed et al. 2002). Unregulated use of frozen, imported crustaceans as fishing bait, as well as the movement of contaminated fishing equipment, are known to introduce the disease to the natural environment. This is because dead and moribund animals can be a source of disease transmission (Lo & Kou 1998), and the virus is still viable when frozen. The virus is also viable for 30 days at 30°C in seawater under laboratory conditions, which is within commercial shipping times from south-east Asia (Momoyama et al. 1998; Biosecurity Australia 2009). WSSV can also be transmitted horizontally when infected tissue is consumed (e.g. cannibalism or predation by animals such as birds, which could spread the disease further), and by water-borne routes (e.g. aquaculture effluent).

Yellow head disease (Yellow head virus -1 (YHV1)) is an infection by yellow head virus genotype 1, which is in the genus *Okavirus* (World Organisation for Animal Health 2018c) (other genotypes of this virus are rarely or not associated with disease). Yellow head disease has caused severe to total mortalities of farmed penaeid shrimps in three to five days (Chantanachookin et al. 1993). This disease was originally detected in Thailand, and introduced to the USA and Mexico, although there is little information available for other regions (Sánchez-Barajas et al. 2008).

The environmental impacts of this disease in the wild are not fully known (Lightner 1996; Lightner et al. 2011). All commercially farmed marine shrimp species appear to be susceptible to the disease (World Health Organisation for Animal Health 2018c). In tested wild populations, evidence of infection has been found without signs of the disease (Castro-Longoria et al. 2008). If diseased cultured shrimps were accidentally introduced to the wild, yellow head disease could lead to mass mortalities of native tropical and sub-tropical penaeid shrimps, such as giant tiger prawns (*Penaeus monodon*), white leg shrimps (*P. vannamei*), blue shrimps (*P. stylirostris*), daggerblade grass shrimps (*Palaemonetes pugio*), and jinga shrimps (*Metapenaeus affinis*), especially when combined with other factors such as environmental stress (World Health Organisation for Animal Health 2018c). High mortalities have not yet been associated with the virus on freshwater shrimps, but they could act as reservoir hosts of the virus (Sánchez-Barajas et al. 2008). Outbreaks of the disease have spread rapidly in aquaculture settings and would be difficult to contain in wild populations (Chantanachookin et al. 1993). The loss of shrimps from the disease could result in ecosystem changes, and negative social amenity impacts for recreational fishers (Walker and Mohan 2009).

The virus is known to enter new environments from human-mediated movement of live animals, particularly brood and post-larvae stock (Briggs et al. 2004). Susceptible live shrimps are not allowed to be imported into Australia; however, adult brood stock that are sourced from Australian waters and the Torres Strait Protected Zone could be within disease emergence zones, which enable the disease to enter and establish within cultured shrimps. Non-viable susceptible shrimps (e.g. dead/moribund) that are imported into Australia for food could introduce the disease to the wild if used as fishing bait (Flegel et al. 1995). Only a small viral load is needed to cause shrimp mortalities (Oanh et al. 2011; World Organisation for Animal Health 2018c). Movement of infected shrimps by humans, birds and other species are known vectors in spreading the disease (Sánchez-Barajas et al. 2008).

Freshwater invertebrates

Asian clam (*Corbicula fluminea*) is a highly adaptable, burrowing mollusc that filters its food (plankton, which are small animals and plants that live in water bodies) from the surrounding water. It is native to south and east Asia (including eastern Russia), but has invaded North America, Central America and South America, and Europe (CABI 2018b).

Asian clams can reduce the diversity of native mussel and other bivalve communities by out-competing them for space, and by consuming their larvae as food (CABI 2018b). This species' rapid consumption diminishes native planktonic communities (Karatayev et al. 2005, 2007), which reduces the amount of food available for native freshwater animals, and leads to decreases in native biodiversity, particularly mussels (Sousa et al. 2008; CABI 2018b). This feeding strategy also increases light penetration, which leads to increases in the cover of aquatic plants and changes in the entire freshwater environment. Their burrowing activity can disturb and release toxic heavy metals, which can negatively impact native fish species further up the food chain (Sousa et al. 2008; CABI 2018b). These clams could invade freshwater habitats in warm temperate regions of Australia, which would include several World Heritage Sites and internationally important Ramsar wetlands. The clams and their empty shells clog intake pipes of water and power industries overseas (CABI 2018b), and in Australia similar clogging might occur in irrigation pipes and pumps (CABI 2018b). Asian clams are also known to host many parasites, which could cause problems to people if consumed (CABI 2018b).

This species can enter Australia as a stowaway attached to boats or freight, carried in water or gravel, used as live bait or human food, or sold in the aquarium trade. The clam can be spread by water currents to new locations as juveniles or adults (Sousa et al. 2008; CABI 2018b). Larvae and juveniles may also attach to aquatic birds and fishing equipment, and be transported by them to other inland waterbodies (Britton & Murphy 1977; CABI 2018b). Asian clams reproduce and spread rapidly in many different water environments as they are highly adaptable and can self-fertilise (Sousa et al. 2008; Pereira et al. 2017). This species is difficult to distinguish from native *Corbicula* species, so new incursions may be difficult to detect early (Ponder et al. 2016a).

Chinese mitten crab (*Eriocheir sinensis)*: see Marine Pest list. This species is migratory between estuarine and freshwater environments, and can be found in marine, estuarine and freshwater environments.

Chinese mystery snail (*Cipangopaludina chinesis*) and Japanese mystery snail (*Cipangopaludina japonica*) are relatively long-lived (3-5 years) freshwater snails from temperate climates in south-east Asia and eastern Russia (Ponder et al. 2016b). They are suspension feeders, extracting plankton (small animals and plants) from the surrounding water. The Chinese mystery snail has been introduced to the USA (TISS 2018a) and parts of Europe (Van den Neucker et al. 2017). The Japanese mystery snail was also introduced to the USA (GISD 2015; Kipp et al. 2019a,b). In Australia, the latter was found in an outdoor pond in Sydney, but it is not thought to be established in the wild (Ponder et al. 2016c).

Both species can be detrimental to native freshwater snail populations by competing for food and habitat (TISS 2018a; Solomon et al. 2010). They also reduce algal abundance and alter nutrient availability, which reduces food availability and makes the environment unfavourable for native freshwater plants and animals (Johnson et al. 2009; Solomon 2010; Olden et al. 2013). These snails could reduce the biodiversity of freshwater environments in a broad temperate region of southern coastal Australia, which encompasses World Heritage sites, national parks, and Ramsar Wetlands. Both snail species are hosts to parasites that could impact native water birds, freshwater mussels, clams (USFWS 2018a,b; Harried et al. 2015) and humans (Kipp et al. 2019a,b). Where there are dense populations, they can clog screens and water intake pipes, and their empty shells litter lake shorelines, which would be a negative impact on social amenity (TISS 2018a; Aquatic Invasive Species Profile 2005).

Potential pathways into Australia include escape into waterbodies from the aquarium trade, attachment on imported ornamental freshwater plants, or through intentional introductions (e.g. via food markets or smuggled in luggage) (Kipp et al. 2019a,b; GISD 2015; USFWS 2018a,b; Van den Neucker et al. 2017). Mystery snails can survive out of water for extended periods, which makes it possible to spread them between lakes by overland transport (e.g. trailered boats) (GISD 2015). Both species reproduce multiple times throughout their life, have broad environmental tolerances, and have a ‘trap door’ feature which allows them to close up the opening in their shell when water conditions are unfavourable. These characteristics enhances their ability to establish and spread in the environment (Van den Neucker et al. 2017; Mackie 2000; GISD 2015).

Golden apple snail (*Pomacea canaliculata*) and island apple snail (*Pomacea maculata*) are two of many species of apple snail native to South America that have been sold around the world as aquarium pets in many regions, including eastern and south-eastern Asia, Africa, North and Central America, southern South America, Spain, Guam and Papua New Guinea (CABI 2018c,d; Ponder et al. 2016d).

Where they have been introduced, apple snails can completely consume all types of water plants, including plants on the water edge. This makes the water more turbid, and impairs the ecological functioning of the waterbody environment (CABI 2018c,d). They also compete with native freshwater snails and other native invertebrates that water birds, native fish and other larger animals depend on for food. These snails could be invasive across all of Australia’s freshwater environments (lakes, billabongs, marshes, forested wetlands) which could affect many World Heritage sites, and internationally important Ramsar Wetlands. These large snails can also damage infrastructure and be a public nuisance as they clog pipes, and carry parasites that affect humans, which may reduce people’s enjoyment of freshwater environments (CABI 2018c,d).

In Australia, another species of apple snail (*Pomacea diffusa*) has been introduced through the aquarium trade, being sold as the ‘mystery snail’ or ‘golden apple snail’. It is already found in the wild in some places in Queensland, with reports of environmental impacts (Ponder et al. 2016d).

Golden and island apple snails have been introduced, either deliberately or accidentally, for food production, through the aquarium trade, and for biological control of nuisance plants. They are spread into new environments by floods, deliberate release into the wild, or by hitchhiking on clothing, birds, boats, plants and soil material (CABI 2018c,d). Golden apple snails breed quickly when ample food is available, and can avoid predators by moving at night (Holswade & Kondapalli 2013). They prefer temperatures around 25°C, but can tolerate the cold (Cowie, 2005). Less is known about island apple snails, but they likely have similar environmental tolerances and behaviour to golden apple snails. The many different species of apple snails can be difficult to distinguish, even by experts, which can hamper detection of new incursions to an area (CABI 2018c,d).

Quagga mussel *(Dreissena bugensis)* and zebra mussel *(Dreissena polymorpha)* are freshwater bivalves from the temperate zone with a broad habitat range. They often occur in enormous numbers, and rapidly filter plankton from the water body that they live in (CABI 2018e,f). The quagga mussel has been introduced from the Ukraine to North America, Russia and several countries in Europe. The zebra mussel is native to the Ukraine, Russia and Turkey, and has been introduced to Europe, Greenland, and North America (Domm et al. 1993; Mills et al 1996; Molloy et al. 2007).

These mussels impact native freshwater molluscs, crayfish and turtles by attaching to their shells, which impede mobility, feeding and respiration, and often lead to their death (Karateyev et al. 2002; CABI 2018e,f). They compete with native mussels and other lake- and river-bed invertebrate species, reducing freshwater biodiversity and significantly altering the relationships between animals (Johnson & Carlton, 1996; Nalepa & Schlosser 2013). They consume large amounts of plankton, which reduces the amount of food for native species, such as fish, and especially those animals living on the riverbed or lake bottom (Birnbaum 2011; Karayayev et al. 2002; Ricciardi et al 1998; Ward & Ricciardi 2007). Their filtering and excretion activities can alter physical and chemical conditions, which can affect native species. These mussels concentrate heavy metals and toxins in their bodies, which may harm animals at higher trophic levels (Benson et al. 2019). These mussels could impact the biodiversity of native temperate freshwater environments in southern Australia, including those in national parks, World Heritage sites, and Ramsar Wetlands. Recreational activities on lakes and rivers can be affected due to large numbers of the mussels accumulating on docks, buoys, boat hulls and anchors; as well as the sharp edges of their empty shells, which can deter swimmers and other recreational users from accessing the lakeshore or riverbank (Minchin et al. 2002; Pimental et al 2005; Nalepa & Schlosser 2013).

Quagga and zebra mussels could be introduced to Australia via the pet trade (and introduced to the wild from aquarium dumping), or by the transport of contaminated fishing equipment, river gravel or timber (as they can survive for several days out of water). Overseas, quagga and zebra mussels have probably been unintentionally introduced into new waterways through transfer of freshwater animals (e.g. crayfish) between stocking farms, as well as transfer in ballast water and attaching to boat hulls from freshwater ports. However, freshwater ports are not a pathway for entry for these mussels to Australia as there are no freshwater ports here (Olenin et al. 1999; Mills et al. 1994; Roy et al. 2014; Strayer 1991; Johnson & Carlton 1996; Ng et al 2016).

Quilted melania (*Tarebia granifera*) is a freshwater and estuarine snail which tolerates a wide range of habitats and has a broad diet (USFWS 2018c). It is native to south-east Asia and parts of Oceania, including Papua New Guinea (Fofonoff et al. 2018), but has been introduced and spread rapidly in South Africa, Hawaii, Idaho, Texas, California, and Florida in the USA, Puerto Rico and the US Virgin Islands (Fofonoff et al. 2018; Appleton et al. 2009; Miranda et al. 2011).

Where introduced, quilted melania can outcompete native snail species (Moslemi et al. 2012) and consume eggs of native fish (Fofonoff et al. 2018). High densities of the snail can cause changes to the ecosystem, including increased nitrogen levels leading to eutrophication (excessive nutrients leading to algae blooms and low oxygen levels) (Fofonoff et al. 2018). This species could impact temperate and tropical streams, lakes, rivers and estuaries across Australia, impacting many World Heritage Sites, Ramsar Wetlands, and protected and unprotected coastal wetlands. It also carries trematode parasites that can infect native bird species as well as humans (Appleton et al. 2009; TISS 2018b). This species also has a tendency to form dense beds, leading to blocked pipes and damaged water pumps (Fofonoff et al. 2018).

Overseas, it has been introduced through the aquarium trade, and as a biological control for nuisance plants (Karatayev 2009; Ponder et al. 2016e; Appleton & Nadasan 2002). Quilted melania reproduces through parthenogenesis, where only a single female is needed for reproduction, so the snail can spread rapidly if is introduced (Miranda et al. 2011; TISS 2018b). This species can also withstand long periods out of the water (Jones et al. 2017; USFWS 2018c).

Marine pests

Asian green mussel (*Perna viridis)* is a large (adult 8-16cm long) estuarine, shallow water mussel that generally lives on hard substrate in warm temperate to tropical waters. It is native to the Arabian Sea, India, Thailand, Malaysia and Philippines, and has been introduced intentionally for aquaculture to south-west China, New Caledonia, Fiji, Polynesia, Tahiti, parts of Japan and the Cape Verde Islands, and unintentionally and most likely as vessel biofouling or possibly ballast water, to the south-east coast of the USA, the Caribbean, Venezuela, Hong Kong, Japan, and South Africa (Baker et al. 2007). It is known as both an important aquaculture species, and a serous pest in cooling water conduits of marine industries (Rajagopal et al. 2006).

In Tampa Bay, Florida, the Asian green mussel established predominantly on artificial structures but also colonised native oyster reefs and displaced about half of the oysters (Baker et al 2006, 2007). The mussel grew in a range of habitats, with pilings, piers and floating objects favoured, mangroves, flats and seawalls not, and shell and rock intermediate (Baker, Fajans & Baker 2012), and an aggregation was also found in a seagrass meadow (Johansson & Avery 2004 as cited in Baker, Fajans & Baker 2012). High densities and almost complete dominance occurred in some habitats, suggesting the potential to adversely impact native species such as oysters through space competition, but studies found that these impacts were unlikely to be consistent across, or within habitat types (Baker, Fajans & Baker 2012). Under favourable environmental conditions, rapid growth and clearance rates suggest the potential for Asian green mussel to become the dominant grazer and to outcompete smaller, slower growing native bivalves. However, this impact is considered likely to be limited by salinity variation (McFarland, Donaghy & Volety 2013). From observations in Florida, the establishment of Asian green mussel in favourable environments in tropical and subtropical Australia could lead to localised impacts on native benthic communities.

Asian green mussels commonly colonise artificial structures, and population densities of up to 35,000 individuals per square metre, weighing ~72kg, are known. The mussel impacts on marine infrastructure by fouling vessels, wharves, buoys and mariculture equipment (Baker & Benson 2002) which are important for tourism and recreation activities as well as the economy. They also foul industrial cooling systems in which they can cause pipe blockages, corrosion, mechanical damage to pumps, and reduced cooling efficiency (Rajagopal et al. 1998). Like other filter-feeding species, this mussel concentrates heavy metals and toxins, and can be an agent for shellfish poisoning caused by harmful algal blooms, all of which can be harmful to humans when eaten (Fung et al. 2004).

This species has been detected on numerous vessels entering Australian waters but is yet to establish (Heersink et al. 2014). It has been found on vessel hulls, in sea chests, around rudders, and in internal seawater piping systems. Other possible routes of entry to Australia include ballast water, illegal importation for food, and marine debris such as driftwood (Hayes & Sliwa 2003). This mussel is considered as a potential successful invader due to its long mobile larval stage (2-3 weeks), fast growth rate, high levels of reproduction in warm waters, early maturity (within 2-3 months), and an ability to survive fluctuations in seawater conditions (Rajagopal et al. 2006; Department of Agriculture, Water and the Environment 2015).

Black-striped false mussel (*Mytilopsis sallei*) is a small (up to 2.5cm long) invasive marine bivalve, often found in subtropical to tropical estuarine and shallow marine environments. Black-striped false mussel is native to both the central and western Atlantic Ocean (Caribbean Sea), Guatemala and the West Indies, but has invaded Fiji, Indonesia, Singapore, Malaysia, Mexico, Taiwan, India, China and West Africa. It was eradicated from Darwin marinas in 1999.

This fast-growing, highly reproductive species has wide environmental tolerances (see Morton 1981 for review), which may have enabled the species to rapidly colonise new environments. It is a fouling species which can form dense communities (Tan & Morton 2006). High densities of black-striped false mussel have been found to reduce the density and biomass of macrofaunal fouling communities, and aquatic environmental quality (Cai et al. 2014). Black-striped false mussel fouls marine infrastructure (wharves, marinas), which was seen during its 1999 incursion in a Darwin marina (Willan et al. 2000). It has been found to form high density monospecific belts and has excluded all other species in areas in a Hong Kong dockyard (Morton 1989). Its ability to foul marine infrastructure could interfere with the use of harbour facilities for marine recreational activities.

The most likely pathway of entry to Australia is by hull or internal seawater system fouling of vessels (Bax et al. 2002; Chu et al. 1997), and other pathways of entry could include ballast water and marine debris. Black-striped false mussels have broad temperature, salinity and oxygen tolerances, so they could potentially establish in all marine waters of Australia (Richmond, Darbyshire & Summerson 2010).

Carpet sea squirt (*Didemnum vexillum*) is a temperate climate colonial sea squirt that can grow on most hard substrates, including other seabed animals and man-made structures. The carpet sea squirt is believed to be native to Japan, and has been introduced to Europe, North America and New Zealand.

Where it has invaded, it is known to form large colonies quickly, which can smother other seabed animals and change the seafloor community. This sea squirt is known to have few predators that can limit its growth (Lambert 2009). It reduces the area of habitats for other native seabed animals to live, which could lead to changes in the structure of the ecosystem (Morris et al. 2009; Fletcher, Forrest & Bell 2009). Its presence has led to known reductions in sea urchins and brittle stars, and reductions in the number of sites available for scallops and mussels to live. This species is also a nuisance fouler on vessel hulls, which could have negative impacts on recreational activities in areas that are popular with recreational fishers.

The main vector for introducing the carpet sea squirt to new areas is fouling on the hulls of vessels (NSW DPI 2010). The movement and transfer of mariculture equipment (including seed/immature mussels from carpet sea squirt infested areas) could also be an entry vector (Coutts 2005). This sea squirt has broad temperature and salinity tolerance, and would likely be able to establish in temperate areas of southern Australia.

Chinese mitten crab (*Eriocheir sinensis*) is a medium-sized burrowing crab (shell up to 8 cm long), which spends most of its life in freshwater environments, but returns to the marine environment and brackish waters to breed. The Chinese mitten crab is native to China and Korea, and has invaded the USA (North East Pacific) and temperate regions of central and northern Europe (Naser et al. 2012).

This crab could have significant impacts in freshwater and brackish environments in Australia. It is an efficient predator and competitor for a wide selection of food, which is detrimental to freshwater and brackish communities, particularly native crabs and crayfish. The Chinese mitten crab damages the environment by burrowing, which causes erosion of tidal marshes, earth dams, and riverbanks. Additionally, this crab is a carrier of crayfish plague (a disease that is not present in Australia), which would devastate native crayfish species. This species carries lung fluke and concentrates heavy metals in its tissues, both of which may harm local native seabed animals and social fishing activities. The reduction of species, especially crabs and crayfish, may have negative effects on recreational fishers. These crabs have also been reported to have negative impacts on marine infrastructure, for example, by obstructing cooling systems of power plants (Dittel & Epifanio 2009 as cited in Murphy & Paini 2010).

Potential pathways for the introduction of this species into Australia are shipping, possibly both ballast water (larvae can survive 2 months) and hull fouling, or intentional introduction by people. The Chinese mitten crab is edible and is transported live around Asia for food, so there is a risk of intentional/illegal importation by humans (Naderloo 2014; Benson & Fuller, 2019). The crab has broad temperature and salinity tolerances, so once it is introduced, it could potentially establish and spread extensively within Australia.

Lady crab / Asian paddle crab (*Charybdis japonica)* is a swimming crab, with shell up to 12 cm wide, found in warm marine environments. The native range of this species includes central and eastern Asia (China, Korea, Malaysia, Taiwan and Thailand) and it has been introduced to New Zealand (Wong et al. 2016). The lady crab has previously been detected in South Australia and Western Australia (Hoursten et al. 2015; Poore 2004).

Where it has been introduced, this crab has negatively impacted native estuarine communities by competing for space and resources with native crabs. This crab is generalist predator, consuming mussels, crustaceans, fish and octopus over large distances. In New Zealand, this crab's establishment has caused changes in the numbers of large seabed animals that it competes with or eats, such as urchins, mussels and crabs (Fowler, Muirhead & Taylor 2013; Townsend et al. 2015). This species also transmits diseases that affect native shellfish, particularly white spot syndrome virus (Maeda et al. 1998). The presence of this invasive crab could also have negative impacts on recreational shellfish fishing.

The likely pathway of introduction for this crab is by the transport of ballast water (larvae) or on the hulls of ships (juveniles and adults) (Wong et al. 2016; Hayes & Sliwa 2003), or entrainment into sea chests (Lewis, pers. Obs). The lady crab can be difficult to distinguish from a number of native or other exotic *Charybdis* species in the field, which may result in its invasion not being detected early. It has the potential to establish in all Australian marine waters given its wide temperature tolerances. These features, along with high levels of reproduction and rapid growth, were important factors in its establishment in New Zealand, which was thought to be founded by only three individual crabs (NIMPIS 2017; Fowler & McLay 2013; Wong et al. 2016)

Native animal diseases

Duck viral enteritis / duck plague (Anatid herpesvirus-1) is a contagious and often deadly infection of ducks, geese, swans and other waterfowl (*Anatidae* family) caused by a herpesvirus **(Anatid herpesvirus-1)**. Its range is potentially global; however, it is believed to be not present in Australia (WHA 2012).

Duck viral enteritis (DVE) can cause mass mortalities in susceptible anatid (*Anatidae*) species. If introduced to Australia, it could result in extinctions of endangered and vulnerable duck and geese species, or lead to significant population impacts in highly susceptible species. Impacts on waterfowl populations may result in ecosystem changes and reduced social amenity.

Illegal imports of infected live birds and infected bird products (e.g. eggs) is a potential pathway of the virus' entry to Australia (Dhama 2017), while legal importation of birds and products would carry a much lower risk due to quarantine and testing procedures (Docherty 1999). Globally, this disease has been introduced via migratory waterfowl between continents (Dhama 2017). There is no regular migration of ducks or geese to Australia or from Australia; however, natural movement of birds can occur (McCallum 2008). Migratory non-anatid waterbirds can also carry this virus (Dhama 2017). Outbreaks can occur and spread between domestic birds and wild birds sharing the same environment. If established, the virus can spread easily as nomadic waterfowl species in Australia move large distances across continental Australia in response to flooding or drought (Roshier et al. 2002, Tracey et al. 2004).

Exotic West Nile virus disease (West Nile virus (WNV) other than WNV lineage 1b (Kunjin virus)) is mainly hosted by birds, but mammals and reptiles can also become infected. It is transmitted by bites of a mosquito vector to other animals and can result in severe neurological disease and death in susceptible species. This virus is widely distributed through Africa, Asia, the Middle East and Europe and is the leading cause of mosquito-borne disease in the continental United States (CDC 2018).

Kunjin is an endemic strain of WNV present in Australia. It is transferred by mosquito vectors and has many reservoir hosts, which suggests that exotic West Nile virus strains could establish in Australia. The presence of Kunjin in Australia might make it difficult to ascertain the full impact of exotic West Nile virus on native birds.

However, recent introductions of exotic WNV strains overseas (e.g. North America) have resulted in cyclical mortalities of native birds, with risk of extinctions of small bird populations (Gamino et al. 2013; Prow et al. 2016; WHA 2016). There could be social amenity impacts from exotic strains if domestic mammals (horses, small domestic pets) were affected or if national parks and other public amenities were closed to avoid human exposure to infected birds or mosquitoes.

Exotic strains of the virus could enter Australia and spread through the movement of mosquitoes or infected animal hosts (Iowa State University 2013; Hayes et al 2005). Mosquitoes can be stowaways on boats and aeroplanes, or be windblown from nearby land masses. The virus can also be introduced via natural migration or illegal imports of infected birds (AHA 2018; Bakonyi et al. 2006; McMullen et al. 2013). The climate in parts of Australia is suitable for this virus to establish (ECDC 2018).

Pacheco's disease and internal papillomatosis disease is caused by a herpesvirus **(Psittacid alphaherpesvirus-1)** and is associated with two main disease syndromes in parrots (Pacheco's disease and internal papillomatosis disease). Both diseases can cause rapid acute fatalities in captive and wild parrots. This virus likely co-evolved with South American parrots and has been found in North America, Europe, the Middle East, Japan, New Zealand and Australia (but only found on imported captive birds in Australia).

Native Australian parrots are likely to be susceptible to this virus and could potentially demonstrate a more severe form of the disease as they are not the natural hosts for the virus (Biosecurity New Zealand MPI 2010). The impact of this virus could push several endangered or vulnerable species towards extinction (WHA 2012). This disease has been reported in captive populations of Australian birds species overseas, including sulphur-crested cockatoo, gang-gang cockatoo, galah, green rosella, Eastern rosella, pale-headed rosella, crimson rosella, Port Lincoln parrot, yellow rosella, regent parrot, cockatiel, princess parrot, fig parrot, eclectus parrot, and red-rumped parakeet (WHA 2012). As parrots are ubiquitous and iconic to the parks and urban land spaces in Australia, people's enjoyment of these spaces (including tourists) would be affected if parrots were severely impacted by this pathogen (WHA 2012).

As this virus has a long incubation period, the disease could enter Australia via live imported parrots that are infected but do not shown signs of the disease (Biosecurity New Zealand MPI 2010; WHA 2012; Department of Agriculture, Water and the Environment 2018a). The virus has not been reported in wild Australian parrots, although the virus has previously been found to be present in some captive bird collections (when birds have been imported into Australia before testing for this disease) (WHA 2012).

Proventricular dilatation disease in parrots has increasingly been shown to be caused by **Parrot bornaviruses (PaBV)**. Proventricular dilatation disease (PDD) results from damage to the nervous system which can result in neurological (loss of balance) and/or gastrointestinal (starvation) disease, and is often fatal. The disease has been documented in over 50 species of parrot in North and South America, Europe, Africa, the Middle East, Japan and Australia, predominantly affecting captive birds.

Australian species known to develop this disease in overseas captive populations include sulphur-crested cockatoo, palm cockatoo, red-tailed black cockatoo, galah, gang-gang cockatoo, cockatiel, red-capped parrot and eclectus parrot (WHA 2013). Many more native parrot species are likely to be susceptible to this infection. Introduction of the virus into wild populations could push many endangered and vulnerable parrot species closer to extinction, or severely reduce their populations, making them vulnerable to other threats (WHA 2013; Biosecurity New Zealand MPI 2010; Department of Agriculture, Water and the Environment 2018a). As parrots are ubiquitous and iconic to parks and urban land spaces in Australia, people's enjoyment of these spaces, including tourists, would be affected if parrots were harmed by the disease.

The virus could be intentionally or unintentionally introduced and spread within Australia via the trade in live caged birds and eggs, particularly wild caught and domestically raised parrots. Tests have been developed to detect this virus; however, it is difficult to confirm the infection in birds (WHA 2013). While there are no reports of the virus in the wild, there are indications that captive birds in Australia have strains of the virus which can cause PDD. It is highly possible that the virus could be introduced and spread to wild parrot populations with significant negative consequences (WHA 2013).

White nose syndrome of bats is caused by a cold-tolerant fungal pathogen **(*Pseudogymnoascus destructans*).** It has caused mass mortality of hibernating, insectivorous bats in North America following its recent introduction, with mortality estimates of over 6 million bats (NPS 2017). The fungus is present in Europe and Asia, and is thought to have been introduced from Europe to North America.

White nose syndrome could cause severe declines in cave-dwelling insectivorous bat species (microbats) in Australia, with bats that form large colonies being more at risk (WHA 2017). Seven species of bats from southern Australia, including the southern bent-wing bat (*Miniopterus orianae bassanii*), have been identified as being most at risk from white nose syndrome (Holz et al. 2016; WHA 2017). The southern bent-wing bat is critically endangered, and could be at risk of widespread population decline or even extinction from the addition of this disease to the list of existing threatening processes. The reduction of bat species would result in ecosystem changes, including changes to rare and endemic invertebrate communities in cave ecosystems that rely on bat guano. Invertebrate numbers could also be affected, for example, an increase in mosquito numbers from a decline in bats could have affect public health (WHA 2017). If the fungus was present in Australia, the closure of caves to cavers and the public (to prevent disease spread) would negatively impact on social amenity.

Human-mediated pathway is the most likely way that this fungus could enter Australia, particularly through contaminated clothes, shoes and equipment used in affected caves overseas (e.g. by tourists, cavers, researchers) from the USA and Europe (Holz et al. 2016; WHA 2017). The cooler southern Australian climate is suitable for establishment of this fungal pathogen in caves. While there is still uncertainty regarding the effect of the disease on the ecology of Australian bats, any level of mortality could be significant, especially to threatened species. Once established in Australia, bats could easily spread the disease as all Australian bats move between multiple caves (Holz et al. 2016). Human transmission of the disease between caves on contaminated clothing and equipment is also possible.

Plant diseases

Ceratocystis wilt (*Ceratocystis manginecans* and other exotic *Ceratocystis* spp.) are fungal pathogens of woody plants, including native acacia and eucalypts, as well as non-native ornamental trees. The pathogen is transmitted by wood-boring insects (native and non-native nitidulid beetles), which naturally carry fungus. Species boundaries for the genus *Ceratocystis* are currently unclear; however, many currently described species are exotic to Australia, and these are known to occur in tropical, sub-tropical and temperate climates globally (Nasution et al. 2019).

C. manginecans affect acacias and mango trees, while other exotic *Ceratocystis* species have been found to impact native eucalypts (De Beer et al. 2014; Wingfield, Roux & Wingfield 2011). Native species that could be affected by exotic Ceratocystis wilt include wild acacia and eucalypt species found on the Australian east coast (tropical and subtropical), such as the IUCN threatened *Acacia crassicarpa* (Tarigan et al. 2011; van Wyk et al. 2007), and the common flooded gum (*Eucalyptus grandis*) (De Beer et al 2014). *C. manginecans* and other exotic *Ceratocystis* spp. pathogens could affect coastal forest structure and diversity, resulting in associated biodiversity loss of dependent animals and plants in Australia. The loss of urban trees, native and non-native, would impact on social amenity throughout Australia.

The major pathway for exotic Ceratocystis wilt to enter Australia is via imported plant material, including cuttings, packing material, fruit infested with infected insects, soil, and hitchhiking of an infected insect (e.g. nitidulid beetles and other related species) (Tarigan et al. 2011; Al Adawi et al. 2013a,b; Galdino et al. 2016). Acacias are susceptible to *C. manginecans*, so this pathogen can establish in these hosts in both natural and urban environments (Lee et al. 2014; Heath et al. 2009). The climate of Australia, particularly tropical and subtropical, also appears suitable for the pathogen to establish and spread. A number of insects that can transmit Ceratocystis wilt already exist in Australia, so risk of spread in the environment is high.

Exotic strains of myrtle rust (*Austropuccinia psidii*) are several strains of the myrtle rust fungus that are not currently in Australia. Myrtle rust attacks species in the Myrtaceae plant family, which includes *Eucalyptus* (eucalypts), *Melaleuca* (paperbarks), *Leptospermum* (tea tree) and *Syzygium* (lilly pilly). This plant disease is native to South and Central America, but has spread to North America, Asia, South Africa, New Caledonia and, more recently, New Zealand.

Myrtle rust attacks the young tissues of plants, which causes deformation of leaves, defoliation, stunted growth, dieback and in severe cases, death. It also infects flowers and fruits, and especially young seedlings, thus inhibiting reproduction of Myrtaceae species. Myrtle rust has caused serious damage to eucalypt plantations in South America and paperbark trees in Florida (Coutinho et al. 1998; Glen et al. 2007). There are over 2250 species of Myrtaceae in Australia (Makinson 2018) and they dominate many plant communities and forests in Australia, with 79% of forested area in Australia being occupied by Eucalypts or Melaleuca forest types (MIG & NFISC 2018). Myrtle rust has a known host range globally of over 525 species across almost 70 genera, with over 350 species known to be infected in Australia (Berthon et al. 2018; Makinson 2018; Soewarto, Giblin & Carnegie 2019).

In Australia, the established strain, known as the pandemic strain, has already caused localised extinctions of Australian native species (Carnegie et al. 2016; Pegg et al. 2017; Makinson 2018). Myrtle rust is predicted to cause significant changes to the structure and function of native forest ecosystems at the landscape level, as well as localised extinctions (including threatened species) (Carnegie et al. 2016; Pegg et al. 2017; Makinson 2018; Carnegie & Pegg 2018). The biodiversity of native animals and plants that depend on Myrtaceae for food and habitat would also be negatively affected (Makinson 2018; Loope & La Rosa, 2008). If another strain of myrtle rust is introduced to Australia, the host range of the disease is likely to broaden substantially, and it could increase the genetic diversity of this rust, which could impact plants that are resistant to the current strain (Makinson 2018; Carnegie & Pegg 2018). There would also be major impacts on national parks, World Heritage sites and Indigenous Protected Areas, as well as on social amenity trees in urban environments (Berthon et al. 2018).

Australia already has an established exotic (pandemic) strain of myrtle rust, so the risk of introduction, establishment and spread of other exotic strains in Australia is potentially high (Stewart et al. 2018). Myrtle rust can enter legally or illegally on imported seedlings, plant material, contaminated equipment, and luggage of travellers returning from infected areas (CABI 2019a). Beside human assistance, its spores can be further spread through wind dispersal, and the movement of animals such as birds, bats, possums and insects, making it impossible to eradicate when established. Long distance dispersal, a wide and expanding host range of native and non-native plants, as well as ideal climate conditions, would make it very easy for a new strain of myrtle rust to establish and spread in Australia, causing further significant damage to native ecosystems (CABI 2019a; Makinson 2018).

Teratosphaeria leaf blight and canker (*Teratosphaeria destructans* and *Teratosphaeria zuluensis*) are fungal pathogens that affect a wide range of eucalypts. *T. destructans* occurs in Indonesia, Thailand, Vietnam, China, East Timor and South Africa. *T. zuluensis* occurs in South Africa, Zambia, Malawi, Mozambique, Ethiopia, Uganda, as well as China, Vietnam, Thailand and Mexico. Several species of *Teratosphaeria*, including many natives, have been described in Australia. *T. destructans* was initially thought to be present in Australia, but it is now recognised to be absent from the country (Andjic et al. 2019).

T. destructans and *T. zuluensis* are serious pathogens of eucalypt plantations, causing leaf damage, dieback, and occasional death (Andjic et al. 2016; Wingfield et al. 1996). Eucalypts are a significant, widespread tree species in Australia, and their loss could alter forest communities and the biodiversity of animals and plants dependent on these communities. These pathogens are likely to have more severe impacts on tropical and subtropical areas of Australia (Chen et al. 2011). There could also be impacts on social amenity due to loss and disfigurement of amenity eucalypts trees. Natural resistance to native *Teratosphaeria* may reduce the impacts of this pathogen; however, these pathogens could result in eucalypts being more susceptible to other stresses and diseases.

These pathogens could enter Australia via legal and illegal transportation of infected plants, timber, wood packing, bark, and seeds; however, legal pathways are well-controlled in Australia (EPPO 2019; PHA 2015; Jimu et al. 2014; Kliejunas et al. 2001). As the pathogens can survive on eucalypt logs and bark chippings, they may not be detected within the mandatory 12 month growth period in quarantine (Jimu 2016). Establishment can easily occur as eucalypts are a major host for the pathogens, and the climate in southern Australia is similar to the climate in southern Africa where the pathogens occur. Spread can be assisted by the movement by wind, plant material (including logs and bark), people and contaminated equipment (PHA 2015; Andjic et al. 2016). Knowledge gaps of the systematics and taxonomy are a barrier in understanding the entry, establishment and spread potential of these pathogens in Australia (Hunter et al. 2011).

Fusarium wilt *(Fusarium euwallaceae)* is a fungus associated with an ambrosia beetle, the exotic polyphagous shot hole borer beetle (PHSB) (*Euwallacea fornicatus*). The beetle introduces the fungus *F. euwallaceae* into the tree to feed its larvae. This fungus then invades the host plant's vascular system, which results in disease and death of susceptible tree species. The beetle and fungus are native to Asia (China, Taiwan, Vietnam), but have invaded Israel, South Africa, and California.

PSHB and fusarium wilt is a significant emerging disease that affects hundreds of species of trees in over 40 genera, including *Eucalyptus* (eucalypts), *Acacia* (wattles), *Ulmus* (elms), *Quercus* (oaks), *Jacaranda*, *Populus* (poplars), *Platanus* (plane trees), and *Ficus* (fig trees) (University of California 2019). Species in these genera dominate native forests and amenity plantings in Australia. The pathogen causes tree deaths in infected areas, which could have significant impacts on Australian national parks, World Heritage Areas, and Indigenous Protected Areas, as well as impact on native animal and plant communities dependent on these habitats (Paap et al. 2018). Recent incursions in South Africa have found that this pathogen rapidly kills street trees, which would be a major negative impact to social amenity in urban and public spaces in Australia (University of California 2019).

This pathogen could enter Australia through illegally and legally imported wooden items, plants, and wooden packing material (dunnage) (Paap et al. 2018; Tuffen et al. 2015). If the host beetle enters with this associated fungus, then establishment will be successful, due to the beetle's wide host range (e.g. native, amenity and agricultural tree species). Another known insect vector with a different *Fusarium* strain has previously entered, established and spread in Australia (Freeman et al. 2013, Eskalen et al. 2013). Combined with suitability of climate particularly in the southern states, this contributes to a high risk for entry, establishment and spread of this pathogen. Host beetles can be spread via the movement of infested timber or plants, and localised flights by beetles could increase the success of this pathogen's spread (Paap et al. 2018; Tuffen et al. 2015). There are native ambrosia beetles in Australia that spread other novel *Fusarium* strains, so these native beetles could spread this exotic fungal species (Paap et al. 2018; Freeman et al. 2013).

Sudden oak death/Ramorum blight (*Phytophthora ramorum*) is also known as "sudden oak death" overseas because it has killed many oak forests. It is a fungus-like pathogen that infects native and non-native hardwood trees (including the native Myrtaceae family), conifers, shrubs, herbaceous plants, and ferns. It is a water- and air-borne pathogen which affects stems, trunks and leaves of plants (NGIA 2018). This pathogen is found in many countries within Europe and the USA.

P. ramorum infects over 130 tree and shrub species across 37 families, causing dieback in garden and cultivated plant species, including pittosporum and macadamia (CABI Plantwise Knowledge Bank 2019). Native trees and shrubs can also be impacted, such as mountain ash (*Eucalyptus regnans*), rose coneflower (*Isopogon formosus*), Errinundra shining gum (*E. dendiculata*), maidenhair fern (*Adiantum*), as well as purple coral pea (*Hardenbergia*) (Ireland et al. 2011). Infection of trees in southern Australian coastal national parks and protected areas can negatively affect plant diversity and structure, which could have flow on impacts on dependent plants and animals. Social amenity impacts from this pathogen include the loss of street and park trees in urban areas, and the restriction of people's movement in national parks to prevent the pathogen from spreading (Ireland et al. 2011; Parke & Rizzo 2011; Forest Research n.d.).

P. ramorum could enter Australia through legally and illegally imported plants, plant and soil material, and soil-contaminated goods (CABI 2018g; Parke & Rizzo 2011; Forest Research n.d.). Current legal import pathways of entry have treatment and control measures to limit the entry of this pathogen (CABI 2018g; Grünwald et al. 2008). Establishment of this pathogen is possible as Australia contains a broad range of host plants and suitable temperate environment; particularly along more humid and cooler southern and coastal areas (CABI 2018g; Forest Research n.d; Parke & Rizzo 2011). The pathogen can quickly spread through the environment through wind-blown rain, as well as soil and water movement (floods, rivers) (Sansford et al. 2009a,b). The pathogen is also often transported over long distances via infected nursery plants, clothing and equipment (CABI 2018g; Forest Research n.d.; Parke & Rizzo 2011; USDA 2019). It can impact roots of host species without indicating symptoms in the leaves, which could hamper early detection and containment efforts (Kliejunas 2003).

Xylella (*Xylella fastidiosa*) is a xylem-limited bacterial pathogen, with several strains of this species complex known to cause different diseases on many plant species. This pathogen is thought to originate from the American continent, and it is distributed in South and Central America, Canada, USA, India, Taiwan, Iran, and parts of Europe including Italy and France (CABI 2019b).

Strains of this pathogen are known to infect over 400 plant species from 95 families including horticultural, ornamental, as well as native tree species such as acacias and eucalypts (Department of Agriculture, Water and the Environment 2018b,c). Therefore, if established, Xylella could structurally alter communities with these tree species. Xylella would result in damage and deaths of susceptible plant species in national parks and public spaces throughout Australia. To manage this pathogen, people's movement in public spaces (e.g. national parks) would likely be restricted, which would impact access to social amenity (EFSA 2018).

Xylella could enter Australia through legally and illegally imported infected soil and plant material, such as cuttings, grafts and wood packaging. This pathogen could also enter Australia with xylem sap-feeding insect vectors such as sharp shooters, spittlebugs and related leafhoppers infected by Xylella, which could enter Australia as stowaways (e.g. on aircraft and containers) (Department of Agriculture, Water and the Environment 2018b,c; EFSA 2018). The availability of native insect vectors and plant hosts that are potential carriers of Xylella (e.g. various wild grasses, sedges, shrubs and trees) can further spread the pathogen in the environment. Once established, it may be impossible to successfully eradicate Xylella (Department of Agriculture, Water and the Environment 2018b,c).

Terrestrial invertebrates

Asian gypsy moth (*Lymantria dispar*) is a highly invasive forest-dwelling moth, which include three sub-species: Asian gypsy moth (*Lymantria dispar asiatica*), Japanese gypsy moth (*L. dispar japonica*) and European gypsy moth (*L. dispar dispar*). All three subspecies can hybridise. The Asian gypsy moth is native to China and Far East Russia, and has spread to Korea, Japan and Europe while the Japanese gypsy moth is native to Japan. The European gypsy moth originated from southern Europe and North Africa, and has spread to North America.

Asian gypsy moths are of major concern to Australia's biodiversity and social amenity as the moths can defoliate and damage a large number of plant species (over 600 species), including many native tree species, as well as shade, fruit and ornamental/amenity species planted in urban environments (CABI 2018h; Matsuki et al. 2001; Davidson et al. 1999). Their broad host range allows them to outcompete many native leaf feeders, and affected trees can be more vulnerable to other pests and diseases. Their caterpillars and egg masses have tiny stinging hairs that can cause rashes and allergic reactions to people, which would be further negative impact on social amenity in parks and urban/semi-urban areas during large infestations (CABI 2018h).

The main entry pathways for Asian gypsy moths are eggs or larvae found on plant material, nursery stock, freight (e.g. cargo ships), pallets, and containers (Department of Agriculture, Water and the Environment 2018d; CABI 2018h). Their egg masses can contain over 1000 eggs (Diss et al. 1996). The moths can fly over long distances, with adult female Asian gypsy moths able to fly up to 40 km. Their spread can be further assisted by vehicle movement, as well as by wind, as caterpillars can spin silk threads that help them fly large distances in the air (Tobin & Blackburn 2008). However, female European gypsy moths cannot fly, which limits their ability to spread as adults. The moths use many plants as hosts, including native eucalypts, so they can potentially establish in many different environments in Australia (Matsuki et al. 2001).

Formosan subterranean termite (*Coptotermes formosanus*) is an invasive termite species that lives in large colonies, often containing several million individuals. It forages up to around 100 metres from the primary nest, and can form above-ground nests. It originates from south-east Asia (including Hong Kong, Macau, and three provinces on mainland China), but has been introduced to mainland China, Japan, Taiwan, South Africa, North America, and the Virgin Islands and Marshall Islands in the Pacific Ocean. (CABI 2018i; Lax & Osbrink 2003).

Heavy infestations of formosan subterranean termites could reduce the diversity of many species of native termites and plants, including native eucalypts and amenity tree species (Henderson, 2001; CABI 2018i). This species not only attack and hollow out dead plants but can also attack—and in some cases, kill—living plants. They outcompete native subterranean termites by depleting their wood resources (food and habitat) (CABI 2018i; Mullins et al. 2011). Historic buildings of cultural significance are particularly vulnerable to damage, as the species is difficult to control. This species can also attack inorganic materials such as plastic, plaster, asphalt and soft metal sheets, so other buildings and public infrastructure could be affected (CABI 2018i; Hussender et al. 2012).

The termite could be introduced to Australia through contaminated ships, containers, plants and soil material at ports. The species can survive being transported on timber, paper, cardboard and similar plant-based material, as long as there is enough moisture (CABI 2018i). Although they prefer dead wood, live eucalypts are a known host, which could assist the termites' rapid establishment and spread through the Australian environment. Once established, they could spread inland via road, air and rail infrastructure (CABI 2018i; Scheffrahn & Crowe 2011). Established populations of this species have never been eradicated (Hussender et al. 2012).

Giant African snail (*Achatina fulica*) is a large land snail that feeds on a wide variety of plants. It originated from eastern Africa and has now spread invasively throughout Asia, Africa, North America, Central America, Caribbean, South America and parts of Oceania (Department of Agriculture, Water and the Environment 2018e, CABI 2018j).

This species will eat many plant species (over 500 species), so it can affect natural Australian habitats by damaging the growth of native plants, particularly seedlings, as well as ornamental plant species that provide important social amenity in urban environments (CABI 2018j; Barker 2002). Besides voraciously consuming plants, it also outcompetes native snails and can modify habitats and nutrient cycling during heavy outbreaks (Thiengo et al. 2006; Meyer et al. 2008). They can also spread plant diseases such as *Phytophora palmivora*, and host parasites that affect wildlife, domestic animals and humans (Raut & Barker 2002). Large infestations of these snails could cause a nuisance in public spaces as they are viewed as unsightly and smelly (CABI 2018j; QDAF 2015).

The main entry pathways to Australia are stowaways in transported machinery, containers, soil, plants, nursery material and personal belongings, as well as being illegally imported as pets (Civeyrel & Simberloff 1996). This snail can be transported as a stowaway at any life stage, including during hibernation and as eggs; however, it is easy to detect as older adults thanks to its large size. This snail has a wide environmental tolerance and can establish in many habitats (forest to urban) (Queensland Government 2018). Their ability to lay over 1200 eggs per year, the low mortality of juveniles, and human-assisted movement (e.g. by attaching to machinery and soil/plant material) allows this species to rapidly spread in the environment (Vázquez et al. 2018; Roda et al. 2016).

Harlequin lady beetle / multicolored Asian lady beetle (*Harmonia axyridis*) is a large variable coloured beetle that feeds on aphids and other small insects, including lady beetles (coccinellids). It is native to central and eastern Asia, and has been introduced to the US, Europe, Canada, Argentina, Brazil, the Middle East, South Africa, New Zealand and Chile (including through intentional release as a biological control agent).

The harlequin lady beetle competes with the food resources of, and predates on, native species that feed on aphids, which include lady beetles, and other soft bodied insects such as silver-fish/bristletails, mites, and eggs of butterflies and moths, and other insects (CABI 2018k, GISD 2019b). When food resources are scarce, they can dominate the community, which leads to significant declines in the population and diversity of native lady beetles (Brown et al. 2008; Lanzoni et al. 2004; Martin 2018). In the colder months, harlequin lady beetles can become a public nuisance as they aggregate indoors in high numbers (hundreds to thousands of individuals), and in extreme infestations, they can cause allergic reactions to humans (CABI 2018k; Martin 2018; Goetz 2008).

This species can be unintentionally introduced to Australia by being transported as stowaways on shipping containers, aircraft and wood packaging, and as contaminants on cut flowers and plant material (CABI 2018k; GISD 2019b). This species can be difficult to detect on commodities (CABI 2018k), although, there are effective treatments of non-plant cargo which rapidly reduce the chances of it getting past the border (Kenis et al. 2008).

The variable appearance of the harlequin lady beetle often make it difficult to distinguish from other lady beetles, which may hinder early detection in the field (Martin 2018). The beetle's broad environmental tolerance has led to its successful establishment and spread in many countries it has been introduced to. It is a successful invader because it has a high reproductive rate, short generation time, ability to fly large distances (over 50 km a year), and its high adaptability (CABI 2018k). It also has the ability to defend itself from attack by secreting a toxic chemical that deter potential predators, including native lady beetles (CABI 2018k; Yong 2013).

Invasive ants: Red imported fire ant (*Solenopsis invicta*) and electric ant (*Wasmannia auropunctata*) are two highly invasive, aggressive ant species that can rapidly establish and spread if introduced. Red imported fire ant (RIFA) is native to South America, but has been introduced to China, Malaysia, Singapore, Taiwan, Mexico, southern USA, Central America and the Caribbean, as well as Queensland (Australia) where it is currently being eradicated. The electric ant is native to Central and South America, and has been introduced to western Africa, the Middle East, UK, North America and South America, several Caribbean and Pacific Ocean islands, and is also being eradicated in Queensland (CABI 2018l,m).

Where introduced, these ants have severe negative impacts on native invertebrate populations (ants, tree-dwelling and flying insects, snails and arachnids) via competition. They also impact on small vertebrate populations (birds, reptiles, amphibians, fish and mammals) via predation, competition and harm (stinging) (CABI 2018l,m; Maloney & Vanerwoude 2002; Allen et al. 2017). Their invasion could disrupt the dispersal of plants by native ants, as well as pollination by other native insects. RIFA also cause damage to native flora, crops, turf, as well as infrastructure from their mound-building activity (CABI 2018l,m ; Wylie & Janssen-May 2017), while electric ants attack native reptiles and ground-nesting birds. These two ant species may also cause changes in ecosystem functioning and community structure, and can invade protected areas in Australia (Wylie & Janssen-May 2016; Wetterer 2013; Le Breton et al. 2005). Both ant species inflict painful, persistent stings (with RIFA stinging en masse), which can prevent people from using outdoor spaces. Stings can cause allergic reactions to people and domestic animals, including causing blindness to pets (CABI 2018l,m; Wylie et al. 2016; Wetterer 2013).

Introduction risks are high via infested nursery potting material, hay bales, soil, vegetative waste, and objects contaminated with soil, including used outdoor equipment or machinery (CABI 2018l,m; Wylie et al. 2016; Wetterer 2013). These ants are highly invasive and can establish rapidly due to their fast growth, high reproductive potential, and their adaptability to different environments. Habitat modelling indicates that much of Australia is suitable for establishment (CABI 2018l,m ; Wylie & Janssen-May 2017). The ants' spread is assisted by human activity, such as movement of vehicles and machinery, and they can spread on floating debris during floods (CABI 2018l,m ; Lach & Barker 2013).

Vertebrates

Asian black-spined toad (*Duttaphrynus melanostictus*): is a stocky, poisonous large toad that is highly adapted to many climates and environments, including brackish water. The Asian black-spined toad (ABST) is widespread throughout south-east Asia, being native to north Pakistan, Singapore and parts of Indonesia. It has now established in the rest of Indonesia, Papua New Guinea, Andaman and Nicobar Islands, East Timor, and Madagascar.

The impacts of ABST are thought to be comparable to the cane toad (*Rhinella marina*) (Christy & Kirkpatrick 2017a). However, ABST can tolerate a wider range of climates, so it could impact over much of Australia, including high conservation habitats in temperate areas. ABST could significantly reduce Australian biodiversity by outcompeting and displacing native species and transmitting diseases. It outcompetes native amphibians by feeding on a wide range of native insects, and also feeds on the eggs and juveniles of other amphibians. It has glands that secrete toxins that can poison native species that predate on it, such as quolls. The parasites and diseases that this toad carries, could further reduce populations of native species (Rahman et al. 2008). Chytrid is present in Australia; however, it is thought that ABST could increase the risk of chytrid infections in frogs (Christy & Kirkpatrick 2017a). In terms of social impacts, this poisonous toad would be a nuisance to and cause harm to people and pets (USFWS 2018d), and their presence would be damaging to important iconic, cultural and heritage regions, for example Kakadu National Park.

ABST has entered Australia on a number of occasions but has been eradicated each time. This species has been an accidental stowaway in luggage, ships, machinery, and shipping containers from south-east Asia (Tingley et al. 2017; NSW DPI 2018a; DPIRD 2017). This species looks like other toad species when juvenile and have varied colourations as an adult, so it could be difficult to detect in the wild.

Boa constrictor (*Boa constrictor*) is a large non-venomous, nocturnal, heavy-bodied predatory snake that occupies a wide range of warm environments such as forests, grasslands, farmland and suburban areas. It can live both on land and in trees. It is native to most of temperate and tropical South America, but has been introduced to south-east Asia, USA, Puerto Rico, Mexico and Aruba.

If established in Australia, the boa constrictor could negatively impact on biodiversity by preying on our native fauna, especially as it does not have any known predators in Australia. The boa predates heavily on a broad range of native species, such as birds, bats, amphibians, small mammals, lizards and other snakes, as well as eggs (Ernst & Ernst 2003; Greene 1983; Quick et al. 2005; Reed & Rodda 2009; GISD 2019c). Boas will compete with larger snakes, such as native pythons. Boas may impact on the health of our native fauna, as they are known to host parasites and diseases such as paramyxovirus and inclusion body disease (IBD) of pythons (Reed & Rodda 2009; Henderson 2011; DPIPWE 2011). It can also be a threat to people, particularly children, as well as pets.

The boa has been introduced to many countries via the pet trade and has been intentionally or unintentionally released into the wild. Illegal trade is one of the most likely pathways of entry into Australia. It could also enter as a stowaway (Christy & Kirkpatrick 2017b; DPIPWE 2011; Reed & Rodda 2009). Given that this species is nocturnal, secretive, and similar looking to native pythons, it may be difficult to detect if introduced. It has proven to be difficult to eradicate from areas where it has established (Henderson, Bomford & Cassey 2004; Christy & Kirkpatrick 2017b; DPIPWE 2011; Reed & Rodda 2009).

Climbing perch (*Anabas testudineus*) is a small hardy freshwater fish that lives in canals, lakes, ponds and swamps. It is highly adaptable to different environments and can tolerate freshwater and brackish water. It is native to India and China, and has established in Indonesia, Papua New Guinea and the Torres Strait islands.

Where it has been introduced, it has had negative impacts on the environment by outnumbering and outcompeting native fish species, often becoming the dominant species. It reduces overall biodiversity by competition, predation, and modifying the habitat through increased water turbidity (East & Micke 2008; Miller et al. 1995; Storey et al. 2002). It consumes aquatic plants, shrimps, snails, worms, insects and small fishes, which can reduce overall species diversity in waterbodies (Hitchcock 2006). Native species that could potentially predate on the climbing perch could be impacted, as it can inflate its body to block the airways of predators thus killing them. In terms of social impacts, this species could reduce the diversity of native fish for recreational fisheries and could harm pets if ingested (East & Micke 2008; Hitchcock 2008).

This species could be introduced to Australia as a stowaway aboard local fishing vessels, through discarded bycatch, or illegal trade for food or aquariums (East & Micke 2008). Climbing perch are highly resilient and mobile, as the species is able to survive for up to 6 days out of water and can use its fins to walk from one water source to another. The combination of broad tolerances, adaptability and competitive behaviours would enable this species to establish and spread widely within Australia (Hitchcock 2008). This fish has proved difficult to eradicate where it has invaded.

Corn snake (*Pantherophis guttatus*) is a small species of rat snake that inhabits a range of environments including grasslands, forest, farmland and semi-urban areas. It is native to southern North America and has invaded the Cayman Islands, Virgin Islands and the Bahamas.

The corn snake is an emerging invasive species worldwide. Its impacts on the environment include competition with and predation on native snakes and prey. This snake is a generalist predator that could have significant impacts on native rodents, nesting birds, amphibians and lizards if it establishes in Australia (Lever 2003; Kraus 2009; Meshaka Jr 2011; Xiao et al. 2004). Other impacts include being a host for exotic pests and diseases that could further threaten native hosts (e.g. *Ehrlichia ruminantium* tick; cryptosporidiosis disease).

The most likely pathways of entry of corn snakes into Australia are through illegal trade or as a stowaway. The corn snake has been intercepted at the Australian border on several occasions, and this appears to be on the rise. The corn snake is popular in the illegal pet trade industry, with high numbers predicted to be in captivity in Australia. It has also been intentionally or unintentionally released into the wild (Henderson, Bomford & Cassey 2011; Csurhes & Fisher 2016). This species can climb trees and shelter under rocks, which makes it difficult to detect. This snake has a broad diet, breeds rapidly and is long-lived, which contribute to its high risk of establishment and spread (Csurhes & Fisher 2016; de Magalhaes & Costa 2009; Ernst & Ernst 2003).

Red-eared slider turtle (*Trachemys scripta elegans*) is a medium-sized freshwater turtle that is highly adaptable and lives in a broad range of habitats including swamps, lakes, ponds and rivers, as well as brackish water. It is native to the Midwestern states of the USA and north-eastern Mexico and is now feral on every continent except Antarctica.

The red-eared slider turtle is an opportunistic omnivore, which consumes a broad range of plants and animals, including algae, pond grasses, fish eggs, snails, fly larvae, insects, crustaceans, small fish and small aquatic snakes. If it were to establish in Australia, this species could compete with native turtles for food, nesting and basking sites. Vulnerable or endangered species of native turtles would be most at risk, which include Western Swamp tortoise, Mary River turtle, Bell's Saw-Shelled Turtle, Gulf Snapping Turtle; Brisbane River Turtle and Krefft's Turtle (Cann 1998; Kirkpatrick, Page & Massam 2007). The red-eared slider turtle could impact nesting birds using the same bank environment. It is also known to transmit diseases to other native species as well as humans or domestic pets (e.g. being a reservoir for salmonella bacteria).

The red-eared slider turtle has been very popular in the pet trade since the 1970s, and has been intentionally and unintentionally released into the wild on numerous occasions (Kirkpatrick, Page & Massam 2007). Illegal trade is the major pathway of its entry into Australia. It has been reported to be localised in some states in Australia. The species is long-lived, breeds rapidly, and has a broad environmental range, so it has a high risk of establishment and spread throughout Australia.

Silver carp (*Hypophthalmichthys molitrix*) is a freshwater carp that resides in lakes and ponds but requires moving water to spawn. Its native range includes China and eastern Siberia. It has been introduced and/or spread by interconnected waterways to 88 countries around the world (in Africa, the Americas and Europe; also Fiji, New Zealand, and Papua New Guinea).

Silver carp poses a large threat to Australia's environment as it can consume large quantities of phytoplankton, thus competing with and depleting native diversity, particularly that of similar types of fish and other phytoplankton feeders. This species could lead to shifts in food webs if stable populations were to establish in the wild. If phytoplankton is scarce, this species would consume zooplankton, substantially reducing their biomass (Spataru & Gophen 1985). There would also be considerable losses in macro-invertebrates and benthic aquatic plants in Australian waterbodies. This species can also transport diseases to new areas, such as *Salmonella typhimurium* (GISD 2019d). When startled, this heavy-bodied fish can jump 2 m into the air, which could cause injuries to recreational fishers and other boat- or water-users (Chapman 2004, CABI 2018n; Fulton & Hall 2014).

This species has been introduced to many countries in the world for aquaculture purposes as well as for controlling excessive growth of phytoplankton in natural waters (Elvira 2001). Pathways to Australia would include accidental stowaway, illegal smuggling as food, or escape from confinement, especially during a flooding event. This species is also often released into the wild for cultural/religious practices. It has a wide temperature and salinity tolerance, so it would be able to establish across much of Australia (Nico, Fuller & Li 2018; GISD

2019d). It is an efficient breeder, and can spread rapidly through connected waterways, which would be a major threat if it enters the Murray Darling Basin.

Weeds and freshwater algae

Didymo (*Didymosphenia geminata*) is a microscopic freshwater diatom (type of algae) that forms dense mats in clear freshwater streams and rivers with low nutrient levels, and occasionally lakes. Didymo is widespread throughout North America, Asia, Russia and Europe, and has established in temperate New Zealand, South America and Sierra Leone (CABI 2018o).

Didymo would be of major concern to Australia's biodiversity and social amenity if it were to establish in the country. It produces thick mats that can rapidly spread and smother several kilometres of a river or lakebed, and has been shown to negatively impact native fish, insects, crustaceans, snails as well as other animal and plant communities (Blanco & Ector 2009). Infestations of didymo can result in reduced water quality and food availability, and detrimental changes in relationships between freshwater plants and animals (Ladrera et al. 2018; CABI 2018o). Didymo blooms are unsightly and known to impede recreational activities (i.e. fishing) and tourism (Blanco & Ector 2009; CABI 2018o).

The major pathway of didymo into Australia is through contaminated recreational equipment (e.g. fishing gear, waders, and boating equipment) from infected regions. These entry pathways are currently managed in Australia; however, unintentional entry is still possible and poses a high risk. This is especially true because didymo can still survive outside of water in damp, dark conditions for a long period (over 40 days) (Kilroy et al. 2006; CABI 2018o), and a single diatom is all that is needed for its successful establishment in a freshwater environment. Didymo has successfully invaded temperate regions globally, which indicate that there is a high risk of it establishing in waterbodies across the southern and highland areas of Australia (Randall 2017; Ladrera et al. 2018; Sturtevant & Hopper 2018).

Manchurian wildrice (*Zizania latifolia*) is a highly adaptable aquatic plant that lives in lagoons, rivers, lakes, tidal flats, ditches and waterlogged grasslands in temperate, and subtropical environments (Champion & Hofstra 2010; Randall 2017). This plant is rare in its native range, which includes China and the surrounding countries of India, Japan, Korea, Myanmar, Russia, Taiwan and Vietnam. It has been introduced to New Zealand, the United Kingdom, and several other European countries, and Hawaii.

Where Manchurian wildrice has been introduced, its dense growth has excluded many native species of plants and animals. As it can grow in salt and freshwater, it could cause serious impacts to both freshwater and estuarine native plant and animal communities (Champion & Hofstra 2010). This includes internationally important Ramsar freshwater wetlands and protected and unprotected coastal wetlands and lagoons across most of Australia. Coastal and freshwater wetlands support many thousands of rare and threatened native plants and animals, which could be harmed if this aquatic plant established in Australia. This plant can alter water flow by blocking drainage systems and the built up sediments could result in reduced flood protection in natural and urban environments. This plant is likely to be a nuisance to recreational users of riverine regions across Australia and it could also cause a decrease in the enjoyment and aesthetic value of lakes, wetlands and rivers by visitors.

This plant is used as a culinary delicacy and for herbal medicine, so it could be illegally or unintentionally transported into Australia as seeds or cuttings. In New Zealand, it was thought to be introduced in the 1900s to the Northern Wairoa River via ballast water (Champion & Clayton 2000). However, the risk of introduction to Australia would be minimal, due current ballast water management regulation. This species is difficult to eradicate as root and rhizome fragments can easily regrow; however, current management practices may be able to reduce the risk of spread (Yamaguchi 1990; Champion & Hofstra 2010).

Mikania (*Mikania micrantha*) is a fast growing competitive creeper that tolerates a range of tropical, subtropical, and warm temperate environments. This species is native to South and Central America, and has been introduced to many regions, including the south-east Asia and Pacific region, and the United States. It is under eradication in Queensland, Australia.

Mikania is a threat to Australia's natural environment due to its highly competitive nature. Once established, it smothers native vegetation, including trees, killing them and reducing diversity of species that depend on impacted native trees and plants. It also outcompetes all native gasses and herbaceous species (Day et al. 2016; Shen et al. 2013). This species has been found to reduce species richness by 30% and discourage growth of seedlings (Kaur et al. 2012). It can also alter the soil chemistry and nutrient recycling, which leads to changes in soil microbial communities, and overall community structure (Shen et al. 2015). Several of the mikania infestations in Queensland that are under eradication border onto rainforests of the Wet Tropics World Heritage Area (Waterhouse 2003). There would be severe social amenity impacts if iconic and culturally important rainforests were degraded by infestations of this weed.

Mikania is believed to have previously entered Australia as a contaminant of imported palm seeds. Seeds entering Australia are regulated and this species is prohibited entry. However, it could enter Australia unintentionally through contamination of nursery stock and seeds, luggage, cargo, mail, animal and plant products, machinery and equipment, as well as via intentional smuggling (Day et al. 2016; Waterhouse 2003). This species was once intentionally planted in Asian and Pacific regions (including Papua New Guinea, West Papua, East Timor), so the risk of entry from these nearby regions is regarded as high (Biosecurity Queensland 2016; Randall 2017; NSW DPI 2018b).

Mouse-ear hawkweed (*Hieracium pilosella*) is a perennial flowering plant species in the daisy family. This species is native throughout Europe, and northern and western Asia, and has spread rapidly to several other countries in Asia, North and South America, and New Zealand (CABI 2018p), where it causes severe impacts. This species is under eradication in the alpine regions of Australia (New South Wales and Victoria).

Mouse-ear hawkweed can have a major impact on native plant communities and associated biodiversity in Australia by altering soil properties, nutrient cycling and overall community structure. It can outcompete native plants by secreting chemicals in the soil that prevent the germination and growth of other plants (McIntosh, Loeseke & Bechler 1995). This species can establish in a broad range of habitats, with south-eastern Australian tussock grasslands and tablelands in alpine regions the most vulnerable to invasion. This species is also known to rapidly displace native vegetation, including inter-tussock vegetation in alpine environments, which would lead to the loss of potentially rare and threatened plant and animals that are dependent on these alpine communities, and is also a serious risk to production lands (or productivity, as it is unpalatable, etc.). Where it invades, mouse-ear hawkweed could reduce the aesthetics of alpine regions for visitors and tourists.

Seeds of mouse-ear hawkweed are very small, and could be unintentionally introduced into Australia from people's clothing, outdoor equipment, shoes and luggage; as well as through the movement of contaminated plants and soil. This species can grow vigorously and reproduce asexually, and its seeds are easily spread by wind. It has the potential to spread across large areas of south eastern Australia, including New South Wales, Victoria, Tasmania and South Australia. This species could persist across large areas of Australia in a number of different environments, if it establishes and spreads further.

Spiked pepper (*Piper aduncum*) is a tropical and subtropical flowering small tree with a broad altitudinal range. This plant is native to the West Indies and tropical central and southern America, and is considered invasive in its native range. This plant has been introduced to several regions, such as Florida, Hawaii, Puerto Rico, Tanzania, south-east Asia (Papua New Guinea, Indonesia and Malaysia) and nearby Pacific islands (including Christmas Island, Solomon Islands, Vanuatu, Kiribati and Fiji).

Spiked pepper is of major concern to Australia's biodiversity and social amenity. This plant can rapidly occupy fragmented forests (e.g. due to tree fall, landslides, bush fires, and cyclone damage) and exclude other native pioneer plant species. Its ability to outcompete native plant species, particularly pioneer trees and shrubs in the tropics, but also native trees, could significantly alter tropical and subtropical Australian habitats in northern

Australia and coastal New South Wales, leading to a reduction in the biodiversity of associated native plants and animals. This species could impact recreational and tourism uses in national parks and state forests from a reduction in the aesthetic value or the restriction of people's access to these places due to weed management (Siges et al. 2005).

Spiked pepper could be introduced accidentally via contaminated freight, outdoor clothing and equipment; as well as through the movement of land vehicles and machinery from affected areas (Randall 2017; CABI 2018q). This species is ornamental and has medicinal properties, so seeds could be illegally brought into Australia through international post. Seeds could also be transported naturally by nomadic bats and birds from Papua New Guinea and Indonesia. Spiked pepper can easily establish and spread in the environment as it is a pioneer species that grows and reproduces quickly, able to regrow vegetatively from stem fragments after damage, produces seeds all year round, and dominates the seed bank compared to native seeds.

Appendix E: Participants and experts involved

Table E1 Participants and experts at workshop one – methodology development

Name	Organisation
Sandra Parsons	ABARES – Project team
Jessica Evans	ABARES – Project team
Bo Raphael	ABARES – Project team
Marwan El Hassan	ABARES – Project team
Katherina Ng	ABARES – Project team
Bertie Hennecke	ABARES
Sindy Ramanadhan	Department of Agriculture, Water and the Environment – Project team
Kristie Logus	Department of Agriculture, Water and the Environment – Project team
Belinda Wright	Animal Health Australia
Aaron Dodd	Centre of Excellence for Biosecurity Risk Analysis / University of Melbourne
Daryl Venables	Commonwealth Department of the Environment and Energy
Ben Gooden	CSIRO
Cheryl Grgurinovic	Department of Agriculture, Water and the Environment
Paul Pheloung	Department of Agriculture, Water and the Environment
Carina Moeller	Department of Agriculture, Water and the Environment
Brett Herbert	Department of Agriculture, Water and the Environment
Karina Keast	Department of Agriculture, Water and the Environment
Kate Fitzpatrick	Department of Agriculture, Water and the Environment
Corrie Croton	Department of Agriculture, Water and the Environment
Thomas Krijnen	Department of Agriculture, Water and the Environment
Nick Housego	Department of Agriculture, Water and the Environment – facilitator
Steve Csurhes	Department of Agriculture and Fisheries (QLD)
Richard Stafford-Bell	Department of Economic Development, Jobs, Transport and Resources (Vic)
Glenn Edwards	Department of Environment and Natural Resources (NT)
Stephen Johnson	Department of Primary Industries (NSW)
Nathan Cutter	Department of Primary Industries (NSW)
Rod Randall	Department of Primary Industries and Regional Development (WA)
Michelle Christy	Centre for Invasive Species Solutions
Ross Meffin	Department of Primary Industries and Regions South Australia
Michelle Besley	Department of Primary Industries and Regions South Australia
Michael Noble	Department of Primary Industries, Parks, Water and Environment (Tas)
Alison McInnes	Environment and Sustainable Development Directorate (ACT)
Stephan Halloy	New Zealand Government Ministry for Primary Industries
Hillary Cherry	Office of Environment and Heritage (NSW)
Tiggy Grillo	Wildlife Health Australia
Lee Skerratt	Wildlife Health Australia

Table E2 Participants and experts at workshop two – methodology development

Name	Organisation	Working group
Jessica Evans	ABARES	Project team
Bo Raphael	ABARES	Project team
Katherina Ng	ABARES	Project team
Marwan El Hassan	ABARES	Project team
Rachel Downey	ABARES	Project team
Sindy Ramanadhan	Department of Agriculture, Water and the Environment	Project team
Kristie Logus	Department of Agriculture, Water and the Environment	Project team
Bertie Hennecke	ABARES	-
Robert Kancans	ABARES	-
Libby Rumpff (Facilitator)	Centre for Environmental and Economic Research, University of Melbourne	-
Terry Walshe (Facilitator)	Centre for Environmental and Economic Research, University of Melbourne	-
Andrew Robinson (Facilitator)	Centre of Excellence for Biosecurity Risk Analysis (CEBRA), University of Melbourne	-
Ross Meffin	Department of Primary Industries and Regions, South Australia (PIRSA)	Weeds
Stephen Johnson	NSW Department of Primary Industries	Weeds
Aaron Dodd	Centre of Excellence for Biosecurity Risk Analysis, University of Melbourne	Weeds
Ben Gooden	CSIRO	Weeds
Zoe Knapp	Department of Environment and Energy, ABRS	Weeds
Michael Noble	Department of Primary Industries, Parks, Water and Environment, Tasmanian Government	Weeds
Glenn Edwards	NT Department of Primary Industry and Resources	Vertebrate pests
Michelle Christy	Centre for Invasive Species Solutions (CISS)	Vertebrate pests
Daryl Venables	Department of Environment and Energy	Vertebrate pests
Rob Hunt	NSW Office of Environment and Heritage	Vertebrate pests
Matt Beitzel	Environment, Planning and Sustainable Development Directorate, ACT Government	Vertebrate pests
Sridevi Embar-Gopinath	Department of Agriculture, Water and the Environment	Vertebrate pests
Richard Stafford-Bell	Department of Economic Development, Jobs, Transport and Resources (DEDJTR) VIC	Marine pests
Michelle Besley	Department of Primary Industries and Regions, South Australia (PIRSA)	Marine pests
John Lewis	ES Link Services	Marine pests
Marnie Campbell	Murdoch University	Marine pests
Brett Herbert	Department of Agriculture, Water and the Environment	Marine pests
Nick Moody	CSIRO Australian Animal Health Laboratories (AAHL)	Aquatic animal diseases
Paul Hick	University of Sydney	Aquatic animal diseases
Tracey Bradley	Department of Economic Development, Jobs, Transport and Resources (DEDJTR) VIC	Aquatic animal diseases
James Forwood	Department of Agriculture, Water and the Environment	Aquatic animal diseases
Tiggy Grillo	Wildlife Health Australia	Native animal diseases
Lee Skerratt	Wildlife Health Australia	Native animal diseases
Belinda Wright	Animal Health Australia	Native animal diseases

Corrie Croton	Department of Agriculture, Water and the Environment	Native animal diseases
Andrea Reiss	Wildlife Health Australia	Native animal diseases
Haylee Weaver	Department of Environment and Energy, ABRS	Native animal diseases
Scott Carver	University of Tasmania/Wildlife Disease Association	Native animal diseases
Louise Shuey	QLD Department of Agriculture and Fisheries	Plant pathogens
Caroline Mohammed	University of Tasmania	Plant pathogens
Carina Moeller	Department of Agriculture, Water and the Environment	Plant pathogens
Francisco (Paco) Tovar	Plant Health Australia	Plant pathogens
Rohan Burgess	Plant Health Australia	Plant pathogens
Chris Palmer	Department of Agriculture, Water and the Environment	Terrestrial invertebrates
Rachel Slatyer	Department of Agriculture, Water and the Environment	Terrestrial invertebrates
Mike Hodda	CSIRO	Terrestrial invertebrates
Simon Lawson	University of Sunshine Coast	Terrestrial invertebrates
Stephan Halloy	NZ Ministry for Primary Industries	Terrestrial invertebrates
Richard Marchant	Museums Victoria	Freshwater invertebrates
Paul Cooper	Australian National University	Freshwater invertebrates

Table E3 Experts involved in the expert elicitation process (shortlisting species and assessment*)

Name	Organisation	Group*
Jessica Evans	ABARES	ABARES project team
Katherina Ng	ABARES	ABARES project team
Bo Raphael	ABARES	ABARES project team
Rachel Downey	ABARES	ABARES project team
Joy Becker	University of Sydney	Aquatic animal diseases
Tracey Bradley	Department of Economic Development, Jobs, Transport and Resources (DEDJTR) VIC	Aquatic animal diseases
Marty Deveney	SARDI Aquatic Services, Department of Primary Industries and Regions, South Australia (PIRSA)	Aquatic animal diseases (assessment)
James Forwood	Department of Agriculture, Water and the Environment	Aquatic animal diseases
Jane Frances	NSW Department of Primary Industries	Aquatic animal diseases (assessment)
Paul Hick	University of Sydney	Aquatic animal diseases
Lone Høj	Australian Institute of Marine Sciences	Aquatic animal diseases (assessment)
Susan Kueh	WA Department of Primary Industries and Regional Development	Aquatic animal diseases (assessment)
Tim Lucas	Biosecurity Queensland	Aquatic animal diseases (assessment)
Nick Moody	CSIRO Australian Animal Health Laboratories (AAHL)	Aquatic animal diseases (shortlisting and advice)
Jayne Brimbox	NT Department of Environment and Natural Resources	Freshwater invertebrates (assessment)
Bruce Chessman	University of New South Wales	Freshwater invertebrates (assessment)
Paul Cooper	Australian National University	Freshwater invertebrates
Adrian Dusting	University of Canberra	Freshwater invertebrates (assessment)
Anders Hallan	Australian Museum	Freshwater invertebrates
Hugh Jones	NSW Office of Environment and Heritage	Freshwater invertebrates (assessment)
Richard Marchant	Museums Victoria	Freshwater invertebrates
Fran Sheldon	Griffith University	Freshwater invertebrates (assessment)
Michelle Besley	Department of Primary Industries and Regions, South Australia (PIRSA)	Marine pests
Brett Herbert	Department of Agriculture, Water and the Environment	Marine pests
John Lewis	ES Link Services	Marine pests
Craig Sherman	Deakin University	Marine pests (assessment)
Richard Stafford-Bell	Department of Economic Development, Jobs, Transport and Resources (DEDJTR) VIC	Marine pests
Melissa Walker	Department of Primary Industries NSW	Marine pests (assessment)
Marnie Campbell	Murdoch University	Marine pests (shortlisting)
Rohan Burgess	Plant Health Australia	Plant pathogens
Fiona Constable	Department of Economic Development, Jobs, Transport and Resources (DEDJTR) VIC	Plant pathogens (assessment)
James Cunnington	Department of Agriculture, Water and the Environment	Plant pathogens (assessment)
Jacky Edwards	Agriculture Victoria & La Trobe University	Plant pathogens (assessment)
Cheryl Grgurinovic	Department of Agriculture, Water and the Environment	Plant pathogens
Andrew Manners	QLD Department of Agriculture and Fisheries	Plant pathogens (assessment)
Alistair McTaggart	University of Queensland (QAAFI)	Plant pathogens (assessment)

Lucy Tran-Nguyen	NT Department of Primary Industry and Resources	Plant pathogens (assessment)
Louise Shuey	QLD Department of Agriculture and Fisheries	Plant pathogens
Francisco (Paco) Tovar	Plant Health Australia	Plant pathogens
Angus Carnegie	NSW Department of Primary Industries	Plant pathogens (shortlisting and advice)
Geoff Pegg	QLD Department of Agriculture and Fisheries	Plant pathogens (shortlisting advice)
Rachel Mann	Department of Economic Development, Jobs, Transport and Resources (DEDJTR) VIC	Plant pathogens (shortlisting advice)
Stephan Halloy	NZ Ministry of Primary Industries	Terrestrial invertebrates
Matt Hill	CSIRO	Terrestrial invertebrates
Mike Hodda	CSIRO	Terrestrial invertebrates
Ary Hoffmann	University of Melbourne	Terrestrial invertebrates (assessment)
Lori Lach	James Cook University	Terrestrial invertebrates (assessment)
Simon Lawson	University of Sunshine Coast	Terrestrial invertebrates
Helen Nahrung	University of Sunshine Coast	Terrestrial invertebrates (assessment)
Michael Nash	School of Agriculture, Food and Wine, University of Adelaide & School of Life Science, La Trobe University	Terrestrial invertebrates (assessment)
Chris Palmer	Department of Agriculture, Water and the Environment	Terrestrial invertebrates
Linda Semeraro	Department of Economic Development, Jobs, Transport and Resources (DEDJTR) VIC	Terrestrial invertebrates (assessment)
Rachel Slatyer	Department of Agriculture, Water and the Environment	Terrestrial invertebrates (assessment)
Ross Wylie	QLD Department of Agriculture and Fisheries	Terrestrial invertebrates
Jenny Shanks	Plant Health Australia	Terrestrial invertebrates (shortlisting advice)
Lindell Andrews	Department of Primary Industries and Regions, South Australia (PIRSA)	Vertebrate pests (assessment)
Alex Chalupa	Department of Primary Industries and Regions, South Australia (PIRSA)	Vertebrate pests (assessment)
Michelle Christy	Centre for Invasive Species Solutions (CISS)	Vertebrate pests
Gina Crabbe	Department of Economic Development, Jobs, Transport and Resources (DEDJTR) VIC	Vertebrate pests (assessment)
Glenn Edwards	NT Department of Primary Industry and Resources	Vertebrate pests
Pablo Garcia-Diaz	Wildlife Ecology and Management Team, Manaaki Whenua, Landcare Research, Lincoln NZ; School of Biological Sciences, University of Aberdeen (current)	Vertebrate pests (assessment)
Martin Hannan-Jones	QLD Department of Agriculture and Fisheries	Vertebrate pests (assessment)
Win Kirkpatrick	WA Department of Primary Industries and Regional Development	Vertebrate pests
Rebecca Morello	QLD Department of Agriculture and Fisheries	Vertebrate pests (assessment)
Matthew Pauza	Department of Primary Industries, Parks, Water and Environment TAS	Vertebrate pests (assessment)
Daryl Venables	Department of Environment and Energy	Vertebrate pests
Matthew Beitzel	Environment, Planning and Sustainable Development Directorate, ACT Government	Vertebrate pests (shortlisting)
Nathan Cutter	NSW Department of Primary Industries	Vertebrate pests (shortlisting)
Adam Kay	Department of Economic Development, Jobs, Transport and Resources Victoria	Vertebrate pests (shortlisting)
Belinda Mitterdorfer	Department of Agriculture, Water and the Environment	Weeds and freshwater algae (assessment)
Ben Gooden	CSIRO	Weeds and freshwater algae

Hillary Cherry	NSW Office of Environment and Heritage	Weeds and freshwater algae
Michael Noble	Department of Primary Industries, Parks, Water and Environment, Tasmanian Government	Weeds and freshwater algae
Stephen Johnson	NSW Department of Primary Industries	Weeds and freshwater algae
Zoe Knapp	Department of Environment and Energy, ABRS	Weeds and freshwater algae
Samantha Setterfield	Charles Darwin University	Weeds and freshwater algae (assessment)
Ross Meffin	Department of Primary Industries and Regions, South Australia (PIRSA)	Weeds and freshwater algae (shortlisting)
Rod Randall	Department of Primary Industries and Regional Development (WA)	Weeds and freshwater algae (shortlisting)
Aaron Dodd	CEBRA	Weeds and freshwater algae (shortlisting)
Barbara Waterhouse	Department of Agriculture, Water and the Environment, NAQS	Weeds and freshwater algae (shortlisting and advice)
John Westaway	Department of Agriculture, Water and the Environment, NAQS	Weeds and freshwater algae (shortlisting and advice)
Stephen McKenna	Department of Agriculture, Water and the Environment, NAQS	Weeds and freshwater algae (shortlisting and advice)
Craig Marston	Department of Agriculture, Water and the Environment, NAQS	Weeds and freshwater algae (shortlisting and advice)
Michael Banyard	Australian Veterinary Association / Australian Veterinary Conservation Biology	Native animal diseases (assessment)
Andrew Breed	Department of Agriculture, Water and the Environment	Native animal diseases (assessment)
Scott Carver	University of Tasmania / Wildlife Disease Association	Native animal diseases
Corrie Croton	Department of Agriculture, Water and the Environment	Native animal diseases
Tiggy Grillo	Wildlife Health Australia	Native animal diseases
Rachel Iglesias	Department of Agriculture, Water and the Environment	Native animal diseases (assessment)
Andrea Reiss	Wildlife Health Australia	Native animal diseases
Sally Salmon	Department of Economic Development, Jobs, Transport and Resources Victoria	Native animal diseases (assessment)
Cathy Shilton	NT Department of Primary Industry and Resources	Native animal diseases (assessment)

(*) Where not specified, experts were involved in both shortlisting and assessment

Glossary

Term	Definition
biosecurity	Managing risks to Australia's economy, environment and community of pests and diseases entering, emerging, establishing or spreading in Australia.
exotic	A species that is not known to be present in Australia. The species must not have been introduced to Australia (unless it has been eradicated or is under an official eradication program) or have established self-sustaining populations in Australia. Non-native species that are permitted to be legally kept in any jurisdiction in Australia by the general public such as ornamentals (for example, garden plants) or as pets do not meet the definition of exotic in this context. Species that are permitted to be kept in Australia in a highly contained environment (such as in zoos or in botanic gardens) are included in the definition of exotic.
infrastructure	Facilities, services and installations that support society, such as water, power, transport and communication systems.
nationally important impacts	For a pest, weed or disease to be considered nationally important, it must have nationally important negative impacts on one or more of the following: the natural environment and ecosystems; infrastructure causing disruption to more than one state/territory; substantial damage to, or deterioration of infrastructure used by a significant proportion of people over an extensive area; amenity of resources, such as public lands and waters, and has the potential to affect more than one state/territory; Australian culture, cultural assets, practice or custom, or national image.
pest, weed, disease	A pest, weed or animal/plant disease is defined as those species that cause or are likely to cause negative impacts on the environment (terrestrial, freshwater or marine), economy and/or social amenity. This includes any species (including, where relevant, subspecies, strains and biotypes), of plants, animals, bacteria, fungi, protists (for example, algae), viruses and parasites, or other pathogenic agent.

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