DEPARTMENT OF PLANNING, INDUSTRY & ENVIRONMENT

Assessing invasive alien species pressures on biodiversity in New South Wales

Implementation for the invasive species (pests, weeds, disease) indicator

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Authorship and citation

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Context

The goals of the New South Wales (NSW) Government's *Biodiversity Conservation Act 2016* (BC Act) include the conservation of biodiversity at bioregion and state levels, a reduction in the rate of species loss, and effective management to maintain or enhance the integrity of natural habitats. To contribute to assessing the performance of the legislation, the former NSW Office of Environment and Heritage established the Biodiversity Indicator Program to report on the status of biodiversity and ecological integrity at regular intervals. Responsibility for implementing this program now rests with the Environment, Energy and Science Group within the Department of Planning, Industry and Environment (DPIE).

Monitoring of biodiversity across New South Wales is a large, complex task requiring novel approaches to data collection and use, including the application of models to help track change. The overarching monitoring framework, or method, which outlines how indicators are related and derived, is presented in *Measuring Biodiversity and Ecological Integrity in New South Wales: Method for the Biodiversity Indicator Program* (OEH & CSIRO 2019).

The method for the Biodiversity Indicator Program established a nested design within which all **indicators**, as they are developed, have a place. Each indicator is nested with others of its type in an **indicator family**, and each family is nested within one of five **themes** which are associated with either the biodiversity or ecological integrity **class** of indicators (Figure 1). Some indicators may have multiple **dimensions** to fully characterise how they are measured and reported.

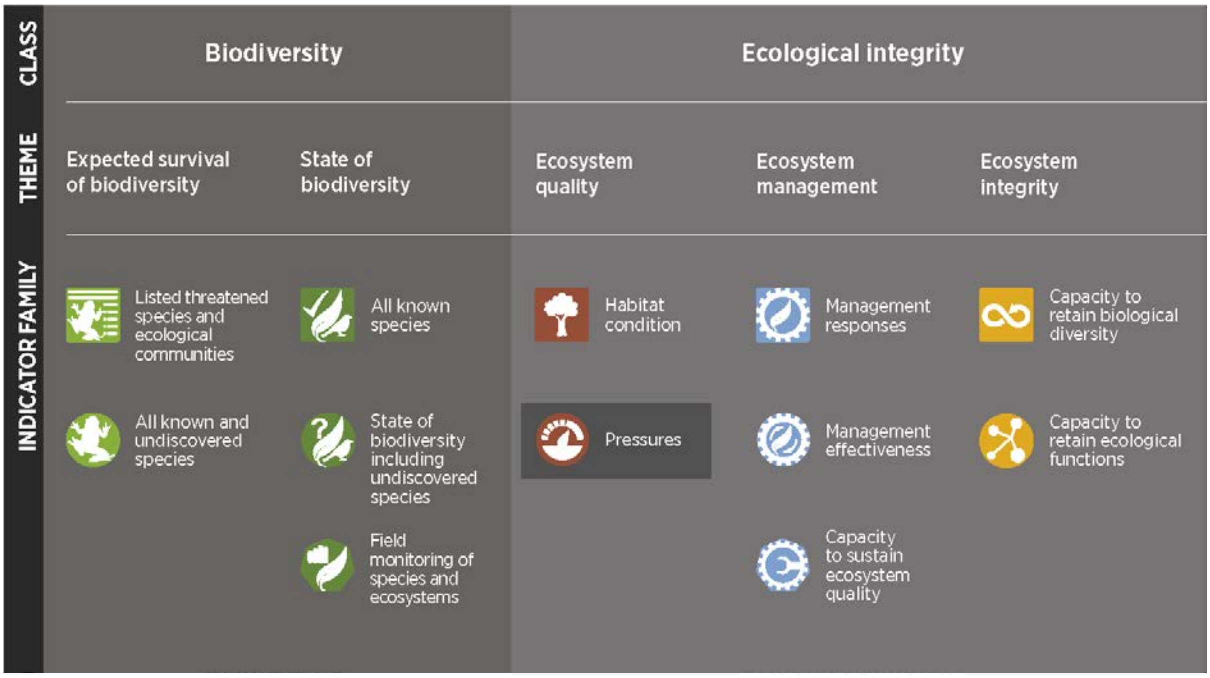


Figure 1 **Nested structure used to arrange indicators for measuring biodiversity and ecological integrity in New South Wales.**

This implementation report covers the indicator: Invasive species (pests, weeds, disease) in the pressures indicator family (shown by the darker grey box).

The indicators in the **ecosystem quality** theme assess the condition of ecosystems and the habitats that plants and animals depend on and the pressures that threaten habitat condition or biodiversity. The **pressures** indicator family identifies general pressures that cause biodiversity loss or threaten the quality of ecosystems and, therefore, impact on the survival of species or ecological communities; and provides supporting information on disturbance.

The invasive species (pests, weeds, disease) indicator measures the extent and impact of invasive species on sensitive ecosystems and sits within the nested framework as follows (OEH & CSIRO 2019):

Class:	**Ecological integrity**
Theme:	3. Ecosystem quality
Indicator family:	3.2 Pressures
Indicator:	3.2e Invasive species (pests, weeds, disease) *The extent and impact of invasive species on sensitive ecosystems*
Readiness category:	3

The method for the Biodiversity Indicator Program (OEH & CSIRO 2019) identified three categories of indicators based on their level of ‘readiness’ to implement. Some indicators were ready to implement in the first assessment (readiness category 1), but others required further development (categories 2 and 3).

Summary

The Biodiversity Indicator Program reports on the status of biodiversity and ecological integrity in New South Wales (NSW) under the *Biodiversity Conservation Act 2016* (the BC Act). The method and results detailed in this technical implementation report describe the development and ‘first assessment’ (i.e. prior to or at the commencement of the BC Act) for the **invasive species (pests, weeds, disease)** indicator in the pressures family of indicators. The key results and highlights of this first assessment are presented in a supplement report card to the first *NSW Biodiversity Outlook Report* (DPIE 2020). In this report, we refer to ‘invasive species’ as ‘invasive alien species (IAS)’, and the three biological dimensions (biological groups) of IAS as follows: ‘pests’ as ‘pest animals’, ‘weeds’ as ‘weeds’, and ‘disease’ as ‘diseases’.

IAS were defined as species whose introduction or spread outside their natural distribution threatens biodiversity and ecosystem quality. For the purpose of the Biodiversity Indicator Program, IAS must be alien to New South Wales, that is, cannot be native (naturally occurring in any location in the State). But not all alien species are IAS, because not all alien species threaten biodiversity and ecosystem quality. In this first assessment, we compiled an ‘IAS status list’ comprised of 413 species (360 weeds, 49 pest animals and four diseases) that had been identified as threats to native biodiversity and ecosystem quality in New South Wales in at least one of several authoritative data sources. These included both widespread IAS that are currently threatening native biodiversity and ecosystem quality in New South Wales as well as emerging or new IAS that have already been identified as posing a potential future threat.

The indicator method focused on establishing a comprehensive conceptual framework and implementing quantifiable indicator metrics that are robust, representative and repeatable, and that can be used to detect changes in future assessments over a five-year timescale at state, bioregional and local reporting scales for the three IAS biological dimensions (pest animals, weeds and diseases).

The indicator reports on two linked but separately measured indicator dimensions by which IAS pressures on native biodiversity and ecosystem quality in New South Wales can be quantified:

- **exposure**, which refers to the presence, size and extent of IAS pressures on native biodiversity and ecosystem quality
- **impact**, which refers to the detrimental consequences of IAS pressures to native species and ecological communities.

In this first assessment, we implemented several metrics to quantify exposure and impact from data and knowledge sources that were readily available and accessible at the time of implementation.

Invasive alien species exposure dimension

The degree of exposure to IAS pressures depends on both the 'invasiveness' of invading species (i.e. their ability to invade areas, habitats and ecosystems) and the 'invasion level' of invaded areas (i.e. the severity of the observed invasion). We developed repeatable workflows for collating data on IAS status and occurrence in New South Wales, generating area of occupancy (AOO) maps, and quantifying both the invasiveness of species (using the metric 'IAS spatial extent') and the invasion level of invaded areas (using the metric 'IAS richness').

IAS spatial extent was calculated as the proportion of NSW grid cells with a resolution of approximately 5 kilometres (the equivalent of around 25 km^2 cell size) where an IAS was recorded as naturalised (i.e. having established in the wild, unaided by active human husbandry) in at least one location. This metric was based on occurrence records during the period 1 January 1980 to 25 August 2017 (the commencement date of the BC Act) collated from multiple data sources.

IAS richness was calculated as the number of IAS that were recorded as naturalised in at least one location in an invaded area. It was measured at three spatial scales that define what constitutes an 'invaded area' (i.e. statewide, bioregion and 5-kilometre resolution grid cell scales) for the three IAS biological dimensions: pest animals, weeds, diseases. We reported IAS richness as both an absolute species count and a proportional metric. At the statewide scale, the proportional metric was the proportion of all identified current or potential future IAS that were recorded in New South Wales; and at the bioregion and grid scales it was the proportion of all IAS recorded in New South Wales that were recorded in the bioregion, or grid cell, respectively.

In this first assessment, we focused on metrics that can be derived from information about IAS status and species occurrence records. We adopted an integrative approach to collating fragmented and often incomplete datasets across agencies and data repositories. However, we relied on major data sources with statewide coverage to ensure that repeatable data collation and harmonisation workflows with limited manual processing could be developed. We had limited capacity to address incompleteness or potential bias in data sources. Hence, **assessment results should be viewed as representing publicly accessible records for the most commonly identified IAS in the most well-documented biological groups – weeds and (mostly vertebrate) pest animals.** The indicator design allows for updated and improved measurements if new information or better spatial data become available, for example, if a new IAS is identified in one of data sources used to compile the IAS status list, or more systematic IAS surveys are conducted.

Invasive alien species impact dimension

Understanding the consequences of native species and ecological community exposure to IAS is critical for targeting investments and evaluating the effectiveness of threat mitigation. However, IAS impacts are highly context-dependent and direct empirical measurements of species at local scales cannot be readily generalised across localities or compared to other species.

In this first assessment we developed a systematic, repeatable and comparable method for assessing the current magnitude of IAS impacts on native species and ecological communities in New South Wales, drawing on standards in IUCN's Environmental Impact Classification for Alien Taxa (EICAT) and customising it to address the requirements of the Biodiversity Indicator Program. Our intent was to conduct a pilot study that demonstrates how the proposed method may be consistently implemented using a structured expert elicitation protocol. The impact assessment was implemented between August and November 2019.

Experts assessed particular pairwise 'interactions' between an IAS and a co-occurring 'sensitive' native species or ecological community. A sensitive species or community was one that was known to be detrimentally affected by the IAS. We elicited categorical information on the mechanisms by which impacts occur, the magnitude of impacts currently observed, the degree of confidence in an assessment, and any supporting evidence. We used this information to derive two probabilistic metrics: 'likelihood of IAS impact', and 'most harmful IAS' (defined as IAS that were assessed by experts as having a greater than 50% chance of causing local population extirpations among threatened species and ecological communities). We also determined the most likely magnitude of impact category for each interaction between an IAS and a native species or ecological community.

We focused on developing comprehensive elicitation materials and guidance as well as repeatable analyses to facilitate consistent application of the method. However, implementation of this first assessment was limited to a set of 'assessable interactions' between widespread IAS that are currently of significant concern (pest animals and weeds only, not diseases) and native species or ecological communities that are listed as threatened under the BC Act. Hence, **the results of this pilot study should be reported and interpreted with appropriate caution. They refer only to those widespread IAS and listed threatened species and ecological communities that were assessed and reflect the knowledge of a small number of experts (n = 36)**. Findings are not representative of all available evidence about all IAS impacts on all native species and ecological communities sensitive to these impacts. While the method can be consistently applied in future assessments, we caution against directly comparing any future findings to the results reported here and make suggestions to enable better comparability in future.

Recommendations

The Biodiversity Indicator Program method assigned the invasive species (pests, weeds, disease) indicator to readiness category 3, meaning that 'the need has been identified, but the methods, science and data need to be assessed, requiring research, development and testing' (OEH & CSIRO 2019:22). The method presented in this report updates the indicator to readiness category 2, meaning that a longer period of development is required for full implementation (OEH & CSIRO 2019:22). Not all design principles related to the robustness, representativeness, repeatability and reporting of indicator metrics could be implemented within the data, capacity and time constraints of the first assessment. Assessment results reflect data and knowledge that were readily available and accessible at the time of implementation. We recommend that future assessments consider a range of improvements to metrics and workflows, as well as development of alternative metrics. Where improved data or workflows are incorporated into the indicator method, the metrics reported in this first assessment must be retrospectively recalculated to allow comparisons across time.

Invasive alien species exposure dimension

- Review and extend the IAS status list of identified current or potential future threats to native biodiversity and ecosystem quality in New South Wales in consultation with domain experts to better integrate biological groups other than weeds and vertebrate pest animals (especially diseases) as well as alien species that have not yet been introduced, or are only recently emerged, in New South Wales and that may pose a potential future threat.
- Integrate additional spatial data on IAS occurrence, ideally including systematically collected field monitoring data that reliably labels IAS presence and absence. This would enable more accurate AOO mapping at a finer spatial resolution (e.g. 2 kilometres as used for IUCN Red List of Threatened Species™) and improve comparability between IAS and IAS biological groups as well as change detection across time. This would require additional investment into statewide data collection and integration.
- Develop alternative metrics for reporting on IAS exposure that address shortcomings and give complementary insights into the invasiveness of species (e.g. IAS abundance) or the invasion level of invaded areas (e.g. relative IAS richness). Collecting spatial data on the abundance of a large number of IAS at the statewide scale may be cost-prohibitive, however, deriving a measure of native species richness from existing data sources and integrating it into a relative IAS richness metric may be feasibly achieved. Model-based approaches could also be investigated further.

Invasive alien species impact dimension

- Implement a systematic approach to selecting a set of ‘assessable interactions’ that is comprehensive, comparable between different IAS, and ideally representative of all IAS impacts (including from other IAS biological groups such as diseases) on all NSW native species and ecological communities that are sensitive to these impacts (including non-threatened species and ecological communities).
- Invest more time and resources into recruiting a larger pool of expert assessors. Implement a staged approach including expert calibration, training and elicitation activities to reduce potential bias and increase the robustness of findings. Amend the proposed assessment method to address issues encountered during elicitation and ensure a consistent interpretation of impact by all expert assessors.
- Explore options for better verifying expert-elicited assessment results, for example:
  - using expert-provided evidence to verify or reject expert judgements
  - analysing assessment uncertainty using information about expert participation, expert confidence and expert agreement
  - validating expert-elicited assessments against a systematic review of the published literature or, most importantly, field monitoring data collected in New South Wales.
- Develop alternative metrics for reporting on IAS impact, for example, measuring the breadth, rather than magnitude, of impact (i.e. the number and diversity of species, communities and ecosystems impacted); or assessing impact for invaded areas, rather than invading species, using spatially explicit methods. These could include data-intensive bottom-up methods synthesising and expanding on the methods for measuring IAS exposure and IAS impact developed in this first assessment, or macro-ecological top-down methods that measure the collective impact of all IAS in an invaded area without considering which species the IAS assemblage is made up of.

Key findings

Invasive alien species richness (a metric of the exposure dimension)

- An IAS status list was compiled which listed alien species that had been identified as current or potential future threats to native biodiversity and ecosystem quality in New South Wales in at least one of several authoritative data sources. The IAS status list included 413 species (360 weeds, 49 pest animals and four diseases).
- Only IAS that were naturalised in at least one location in New South Wales during the period 1980 to 2017 were assessed. Based on the publicly accessible data sources used in this first assessment, 344 IAS were recorded as naturalised. This represents 83% of the 413 species on the IAS status list.
- Among those 344 IAS there were 305 weeds (85% of the 360 identified weeds on the IAS status list), 36 pest animals (73% of the 49 identified pest animals on the IAS status list) and three diseases (75% of the four identified diseases on the IAS status list). The data on diseases collated in this first assessment was considered insufficient to enable further analysis, and therefore is not included in the report card for this indicator.
- Weed richness varied considerably along a coastal–inland gradient. Of the 305 weeds recorded, 264 species (87%) and 210 species (69%) were recorded in the Sydney Basin and North Coast bioregions, respectively. In contrast, the arid Simpson Strzelecki Dunefields and Channel Country bioregions contained only 6 and 4 weed species, respectively. Weed richness also varied considerably within each bioregion. Areas of very high local weed richness were concentrated around human population centres. Up to 109 species were recorded in individual ~5-kilometre resolution grid cells.
- Pest animal richness was much more evenly distributed throughout the State. Pest animal richness ranged between 10 species (28% of all 36 pest animals recorded) in the Simpson Strzelecki Dunefields bioregion and 34 species (94% of all 36 pest animals) in the Sydney Basin bioregion. There was no 5-kilometre resolution grid cell in New South Wales that was entirely free of pest animals, and up to 24 species (66% of all 36) were recorded in some individual grid cells.

Invasive alien species spatial extent (a metric of the exposure dimension)

- The area occupied by each of the 344 IAS that were recorded in at least one location in New South Wales during the period 1980 to 2017 was mapped using an approximately 5-kilometre resolution raster grid. Based on the publicly accessible data sources used in the first assessment, their spatial extent varied significantly from close to 100% of grid cells occupied (red fox and feral cat) to only one occurrence recorded (0.003% of grid cells) for several emerging weed species.
- The 36 mapped pest animals occupied on average a much larger area (14.8% of grid cells; median = 2.7%) than the 305 mapped weeds (0.6% of grid cells; median = 0.1%) and three diseases (0.2% of grid cells; median = 0.2%). Most weeds (84% or 257 species), many pest animals (36% or 13 species) and all three diseases had a very limited spatial extent, being recorded in <1% of grid cells. Three weeds (1% of the 305 mapped species) and 12 pest animals (33% of the 36 mapped species) were recorded in more than 5% of grid cells, and six of these pest animals were widely recorded over more than a quarter of the State.

Likelihood of invasive alien species impact (a metric of the impact dimension)

- In total, 179 interactions between 22 widespread IAS (seven pest animals and 15 weeds) and 97 listed threatened species and ecological communities (16 threatened animals, 46 threatened plants and 35 threatened ecological communities) were assessed by 36 experts for the current magnitude of impacts caused by these IAS.
- The likelihood of IAS impact metric integrated information on both the magnitude of impact assigned by expert assessors and the uncertainty in assessments (relating to both the confidence of each expert in making a judgement, and to diverging assessments between different experts).
- Based on the average of all expert assessments, there was an 85% chance that assessed threatened species are experiencing a decline in population size, and assessed threatened ecological communities are experiencing compositional changes (due to a population decline in at least one characteristic species), as a result of weed impacts. The likelihood of causing population declines was assessed similarly (78% chance) for pest animals.
- Weeds overall (n=15) were assessed by experts as much more likely (57% chance) to cause extirpation (i.e. local extinction) of at least one local population of a threatened species, or at least one characteristic species in at least one remnant patch of a threatened ecological community than the seven assessed pest animals (36% chance).
- The magnitude of impact varied between the 16 threatened animals, 46 threatened plants and 35 threatened ecological communities that were assessed. While the likelihood of experiencing population declines due to IAS impacts was assessed similarly (between 77% and 84% chance), experts assessed threatened ecological communities as more likely affected by extirpations of characteristic species in at least one remnant patch (54% chance) than threatened animals or plants by extirpations of at least one local population (45% and 41% chance respectively).
- The magnitude of IAS impact for 11 out of the 179 interactions was assessed by experts as most likely leading to irreversible local population extirpations (i.e. if the IAS were no longer present, the native species would not naturally return to the area where it has been extirpated without additional human assistance).

Most harmful invasive alien species (a metric of the impact dimension)

- Nine out of 22 (41%) IAS were assessed by experts as having, on average, a greater than 50% chance of causing local population extirpations (reversible or irreversible) among assessed threatened species and ecological communities.
- These ‘most harmful IAS’ included one pest animal (red fox) and eight weeds. Of the eight weeds, all assessed grasses (African lovegrass, coolatai grass and serrated tussock), all vines (cat’s claw creeper and Madeira vine), as well as two woody shrubs (bitou bush and lantana) and one invasive tree (African olive) were among the most harmful IAS.

1. Introduction

1.1 Biodiversity Indicator Program invasive alien species indicator

The former NSW Office of Environment and Heritage collaborated with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Macquarie University and the Australian Museum to develop a method for the collection, monitoring and assessment of biodiversity information in New South Wales (NSW) at regional and statewide scales (OEH & CSIRO 2019). This technical implementation report establishes the development and ‘first assessment’ (i.e. at the commencement of the *Biodiversity Conservation Act 2017*, the BC Act) for the **invasive species (pests, weeds, disease)** indicator in the pressures family of indicators.

In the Biodiversity Indicator Program method, pressures refer to threats in the landscape that cause biodiversity loss or threaten the quality of ecosystems (OEH & CSIRO 2019). Six indicators have been identified, representing the most pervasive pressures in New South Wales:

- land-use and management practices (indicator 3.2a)
- native vegetation extent (indicator 3.2b)
- inappropriate fire regimes (indicator 3.2c)
- inappropriate hydrological regimes (indicator 3.2d)
- invasive species (pests, weeds, disease) (indicator 3.2e)
- altered climatic regimes, variability and extremes (indicator 3.2f).

In future, these terrestrial indicators may be expanded to incorporate other pressures and be complemented by indicators of pressures that threaten freshwater and marine habitats (OEH & CSIRO 2019).

In order to understand ecosystem quality, including why and where ecosystems and the habitats that native plants and animals depend on are becoming degraded, supporting information about these pressures is needed. In the Biodiversity Indicator Program nested framework (Figure 1), measuring pressures (indicator family 3.2) provides a basis for attributing cause to observed change in the state of biodiversity (indicator family 2.2) or in ecological condition (indicator family 3.1) as well as for evaluating management responses (indicator family 4.1) and management effectiveness (indicator family 4.2) (OEH & CSIRO 2019).

The Biodiversity Indicator Program method described pressure indicator 3.2e: invasive species (pests, weeds, disease) as measuring *the extent and impact of invasive species on sensitive ecosystems* (OEH & CSIRO 2019:42). In this report, we refer to ‘invasive species’ as ‘invasive alien species (IAS)’ and the three biological dimensions (biological groups) of IAS as follows: ‘pests’ as ‘pest animals’, ‘weeds’ as ‘weeds’, and ‘disease’ as ‘diseases’. We reconceptualised the purpose of the two indicator dimensions of IAS pressure (i.e. **extent** and **impact**) more generally as measuring both the exposure of native biodiversity and ecosystems to IAS pressures as well as the consequences of these pressures (see section 2).

In line with the Convention on Biological Diversity (CBD), we defined IAS as species whose introduction or spread outside their natural distribution threatens biodiversity (CBD Secretariat 2019b). This includes:

> [any] species, subspecies or variety or cultivar moved intentionally or unintentionally by human activities beyond the limits of its native geographic range, or resulting from breeding or hybridisation and being released into an area in which it does not naturally occur, [… and] whose introduction and/or spread threatens biological diversity (IUCN 2019a:9).

For the purpose of the Biodiversity Indicator Program:

- An IAS must be alien to New South Wales (i.e. not naturally occurring in any location in the State).
- Native species (i.e. naturally occurring in at least one location in New South Wales) cannot be IAS, even where they display invasive tendencies in parts of their range (e.g. due to environmental or land-use change).
- Not all alien species are invasive alien species (IAS), because not all alien species threaten biodiversity and ecosystem quality. For many alien species, IAS status is not known or unclear.

IAS may have already been introduced and widely spread in New South Wales and be currently threatening native biodiversity and ecosystem quality; or they may not have been introduced yet or only recently emerged in the State and are likely to pose a potential future threat.

IAS threaten biodiversity and ecosystem quality in many ways. Introduced alien animals can become invasive ‘pests’ that displace native species through competition and predation and affect the integrity of vegetation through grazing and trampling. Introduced alien plants can become invasive ‘weeds’ and smother or out-compete native vegetation. Introduced alien pathogens may cause widespread disease and population decline in native plants or animals.

Globally, native biodiversity and ecosystems are exposed to a multitude of IAS pressures, with well over 10,000 alien species having established naturalised populations, and a continued increase in the number of new introductions (Seebens et al. 2017). The consequences of IAS pressures are also immense. IAS are considered one of the world’s most important direct drivers of biodiversity loss (Díaz et al. 2019) and detrimental impacts are often reported as increasing (Rabitsch et al. 2016).

In Australia, over 650 land-based alien animals have been introduced since European colonisation and some 3000 alien plants have established naturalised populations (Dodd et al. 2015; EPA 2018). A recent analysis has shown that biodiversity exposure to IAS pressures is particularly ubiquitous in Australia compared to other parts of the world, with IAS affecting more vulnerable species than any other threat (Kearney et al. 2019).

Many of Australia’s alien species have also been recorded in New South Wales and several hundred are recognised as invasive (EPA 2018). In New South Wales, IAS are thought to impact an estimated 70% of all listed threatened species (EPA 2018). Under the BC Act, the most pervasive or locally intense pressures have been listed as key threatening processes (KTPs) because of direct causal links to species extinction risk or ecosystem degradation leading to collapse. Of the 39 KTPs listed in Schedule 4 of the BC Act, 27 are attributed to invasive species, including 16 pest animals, seven weeds, and four diseases. However, not all of these KTPs fall within our definition of IAS. For example, because the noisy miner is native to New South Wales, it is not an IAS even though “aggressive exclusion of birds from woodland and forest habitat by abundant noisy miners” is listed as a KTP.

1.2 Related invasive alien species indicators

In response to the increasing global significance of IAS, Aichi Target 9 of the CBD's *Strategic Plan for Biodiversity 2011–2020* (CBD Secretariat 2019a) states:

> 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.

Similarly, the United Nation's Sustainable Development Goal 15.8 (UN 2015) states:

> By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species.

This prioritisation in international policy fora has sparked the development of a suite of monitoring and evaluation frameworks to inform progress towards targets and objectives.

McGeoch et al. (2010) proposed a suite of four complementary indicators measuring (i) the number of documented IAS, (ii) the Red List Index for the impacts of IAS, and the development and adoption of (iii) international policy, and (iv) national legislation relevant to reducing IAS threats. The authors place these indicators in a pressure–state–response framework, together allowing the monitoring and evaluation of the size/extent of IAS pressures (pressure), the impact of IAS pressures on biodiversity (state) and progress towards reducing IAS pressures and their impacts on biodiversity (response). This core set of indicators has been applied at the global scale by the international Biodiversity Indicators Partnership (BIP 2019). For the European Union, Rabitsch et al. (2016) expanded the set of indicators to six, adding indicators related to the pathways (drivers) of invasion, the impacts of IAS on ecosystem services and disease incidence, and the costs of IAS management and research.

Effective monitoring and evaluation of IAS indicators continues to be impeded by data deficiencies relating to both the quality and consistency of available IAS data. Latombe et al. (2017) therefore proposed three essential variables (i.e. minimum information requirements) for monitoring biological invasions: alien species occurrence (presence and where possible absence records), alien species status (classification as either alien or native), and alien species impact (classification by the magnitude of detrimental impacts on biodiversity). Latombe et al. (2017) further outlined how this information could be integrated to inform a range of IAS indicators, including those originally proposed by McGeoch et al. (2010).

Wilson et al. (2018) pointed out that the underlying rationale for these global IAS indicators and essential variables was to establish protocols that can be adopted by all countries. This demanded focussing on readily available data, and on selected aspects of biological invasions. To complement this approach, Wilson et al. (2018) developed a framework underpinning the development of indicators for monitoring biological invasions at a national scale, using South Africa as a case study. The authors proposed a system of 20 indicators reporting on (i) pathways (of introduction and spread), (ii) species (alien species or IAS), (iii) sites (invaded geographic areas), and (iv) policy or management interventions (in terms of inputs, outputs and outcomes).

In New South Wales, IAS indicators have previously been developed as part of the *NSW State of the Environment 2018* (EPA 2018) and *NSW State of Biosecurity* (DPI 2018) reports.

The *NSW State of the Environment 2018* (EPA 2018) reported on three indicators: two indicators described the exposure to IAS pressures (number of new IAS detected and spread of emerging IAS), and one indicator described the consequences of IAS pressures (impact of widespread IAS). All three indicators were reported at the species level and state scale (i.e. without reference to particular invaded areas in New South Wales) with regard to three categories of IAS: new, emerging and widespread (EPA 2018). These categories are related to the four major invasion stages (i.e. introduction, incursion, expansion and dominance), each of which aligns with a particular management goal (i.e. prevention, eradication, containment and mitigation) (Wilson, Panetta & Lindgren 2017). All indicators in the *State of the Environment 2018* report were informed by selected findings reported in the literature. For example, impact of widespread IAS was measured as the proportion of threatened species thought to be impacted and the estimated costs of IAS to the NSW economy. Invasion pathways as well as policy and management interventions were also reported. However, it is unclear how literature-based insights were aggregated to the three high-level indicators, raising questions as to their repeatability.

The *NSW State of the Environment 2018* report referred to the inaugural *NSW State of Biosecurity 2017* report as containing a suite of:

> new indicators to more effectively identify the impacts of invasive species and the effectiveness of management [interventions … as well as] changes in distribution and population size of invasive species in NSW (EPA 2018).

However, the *NSW State of Biosecurity 2017* report's stated aim was to:

> highlight progress in achieving the objectives of the NSW Biosecurity Strategy 2013-2021 [, … providing] a narrative of the work being conducted in NSW (drawing data from the period 2008 to 2017) (DPI 2018:7).

Policy, institutional and management responses were comprehensively covered in the State of Biosecurity 2017 report, which focused mostly on the inputs and outputs, and to a lesser extent also on the outcomes of management interventions. A range of IAS indicators were also presented, but these focused solely on IAS counts at the state scale (i.e. number of IAS in New South Wales that are naturalised, detected, eradicated, managed, assessed, etc.). A spatially explicit perspective on biodiversity exposure to IAS pressures across invaded areas in the State, or an assessment of the consequences of IAS pressures, were not provided.

IAS indicators have also been developed in other states. South Australia's *Environmental Trend and Condition Report Card 2018 – Land: Invasive species* (DEW 2018) reported on the abundance and distribution of established invasive species. The indicator was based on a small set of 23 priority weeds and pest animals and reported for IAS (spatial extent) as well as invaded areas (abundance trend per natural resource management region). A statewide indicator of IAS impacts (median condition score of regions when considering the effects of IAS pressures) was also reported, but reliability was assessed as low. The need for methodologies to systematically assess IAS impacts as well as trends in distribution and abundance was explicitly recognised (DEW 2018).

2. Indicator design

The invasive species (pests, weeds, disease) indicator method was developed based on the following design principles:

- Embed the method in a comprehensive conceptual framework that aligns with the two indicator dimensions, extent and impact, put forward in the Biodiversity Indicator Program method (see section 1.1) as well as related frameworks for monitoring invasive alien species at the global, national and state scales (see section 1.2).
- Develop quantifiable indicator metrics that:
    - add value to previous indicator and monitoring efforts in New South Wales
    - are conceptually and methodologically robust
    - are representative of IAS pressures on all of NSW biodiversity
    - are based on repeatable workflows
    - can be used to detect changes in future assessments over a five-year timescale
    - can be reported at the state, bioregional and local (i.e. 5-kilometre resolution grid cell) scales
    - can be reported across the three biological dimensions (biological groups) of IAS: pest animals, weeds and diseases.
- Where these design principles cannot be implemented within the data, capacity and time constraints of the first assessment, provide clear recommendations on how metrics and workflows could be improved, and alternative metrics developed, to enhance representativeness, robustness, repeatability, change detection and reporting.

In our conceptual framework, there are two distinct dimensions by which IAS pressures on native biodiversity and ecosystem quality is measured: exposure and impact.

> **Exposure** refers to the presence, size and extent of IAS pressures on native biodiversity and ecosystem quality (McGeoch et al. 2010; Early et al. 2016; OEH & CSIRO 2019).
>
> **Impact** refers to the consequences of IAS pressures, that is, the changes to the properties of ecosystems caused by IAS to the detriment of native species and ecological communities (IUCN 2019a; OEH & CSIRO 2019).

These dimensions of IAS pressure are linked in practice: where there is no exposure to IAS pressures there is no impact, and where there is no impact there is no IAS pressure (defined as a threat to native biodiversity and ecosystem quality) in the first place. Yet, it is widely acknowledged that exposure does not equal impact and separate measurements are essential (O'Loughlin et al. 2019; see also section 2.2). Such measurements may be conducted at the species level (e.g. what is the exposure to, or impact from, an IAS?) or for invaded geographic areas (e.g. what is the exposure to, or impact from, all IAS in an area?) (Wilson et al. 2018).

A synthesis of exposure and impact measures is possible and is in fact routinely done at the species level as part of comprehensive IAS risk assessments aimed at identifying, ranking and prioritising IAS (HB294:2006; Roy et al. 2018; Vilà et al. 2019). However, such a synthesis has rarely been attempted for invaded areas due to its complexity and data requirements (see section 5.2). Here, we focused on measuring exposure to IAS pressures and the biodiversity consequences (impacts) of these pressures separately.

Two further well-recognised dimensions of IAS pressure, pathways and responses (McGeoch et al. 2010; Wilson et al. 2017), were not included in the indicator method implemented in this first assessment. Policy and management interventions to prevent, reverse, contain or mitigate exposure to IAS pressures and their detrimental consequences were already captured in the *NSW State of Biosecurity 2017* report (DPI 2018) and through the management responses and management effectiveness indicator families within the Biodiversity Indicator Program nested design (OEH & CSIRO 2019). Pathways of introduction and spread were not directly assessed because our focus was on measuring observed exposure to, and impacts from, IAS pressures rather than predicting future exposure and impacts. However, where such invasion pathways result in the introduction or further spread of new, emerging or established IAS, quantifiable changes in IAS exposure and impact using the metrics developed here may be expected in future assessments.

The indicator method implemented in this first assessment is schematically illustrated in Figure 2. For each dimension of the IAS indicator (IAS exposure and IAS impact), a range of data inputs were sourced from which essential variables were derived and quantifiable metrics calculated using repeatable workflows. Most of these metrics (IAS spatial extent, likelihood of IAS impact and most harmful IAS) were measured at the species level, subsequently aggregated to the three biological dimensions of IAS and reported at the state scale. In addition, we measured IAS richness at three spatial scales (statewide, bioregions and 5-kilometre resolution grid cell) to give a spatially explicit perspective on IAS exposure for invaded areas across New South Wales (McGeoch et al. 2016; Wilson et al. 2018).

The Biodiversity Indicator Program method assigned the invasive species (pests, weeds, disease) indicator to readiness category 3, meaning that the need has been identified, but the methods, science and data need to be assessed, requiring research, development and testing (OEH & CSIRO 2019:22). The indicator method presented in this report (design and implementation) updates the indicator to readiness category 2, meaning that a longer period of development is required for full implementation (OEH & CSIRO 2019:22). Assessment results reflect data and knowledge that were readily available and accessible at the time of implementation, focusing mainly on vertebrate pest animals and weeds. In section 5.2 we discuss how metrics and workflows could be improved, and alternative metrics developed, to enhance representativeness, robustness, repeatability, change detection and reporting at different spatial scales. Where improved data or workflows are incorporated into the indicator method, the metrics reported in this first assessment must be retrospectively recalculated to allow comparisons across time. Specific recommendations are provided in the Summary.

The following sections provide an overview of the concepts, data, methods and metrics used to measure both pressure dimensions of the indicator: IAS exposure (see section 2.1) and IAS impact (see section 2.2). Details of the implementation and results of the first assessment are presented in section 3 (IAS pressure) and section 4 (IAS impact). A detailed workflow diagram and technical description of data inputs, analytical processes and derived outputs for each pressure dimension is provided in Appendix A.

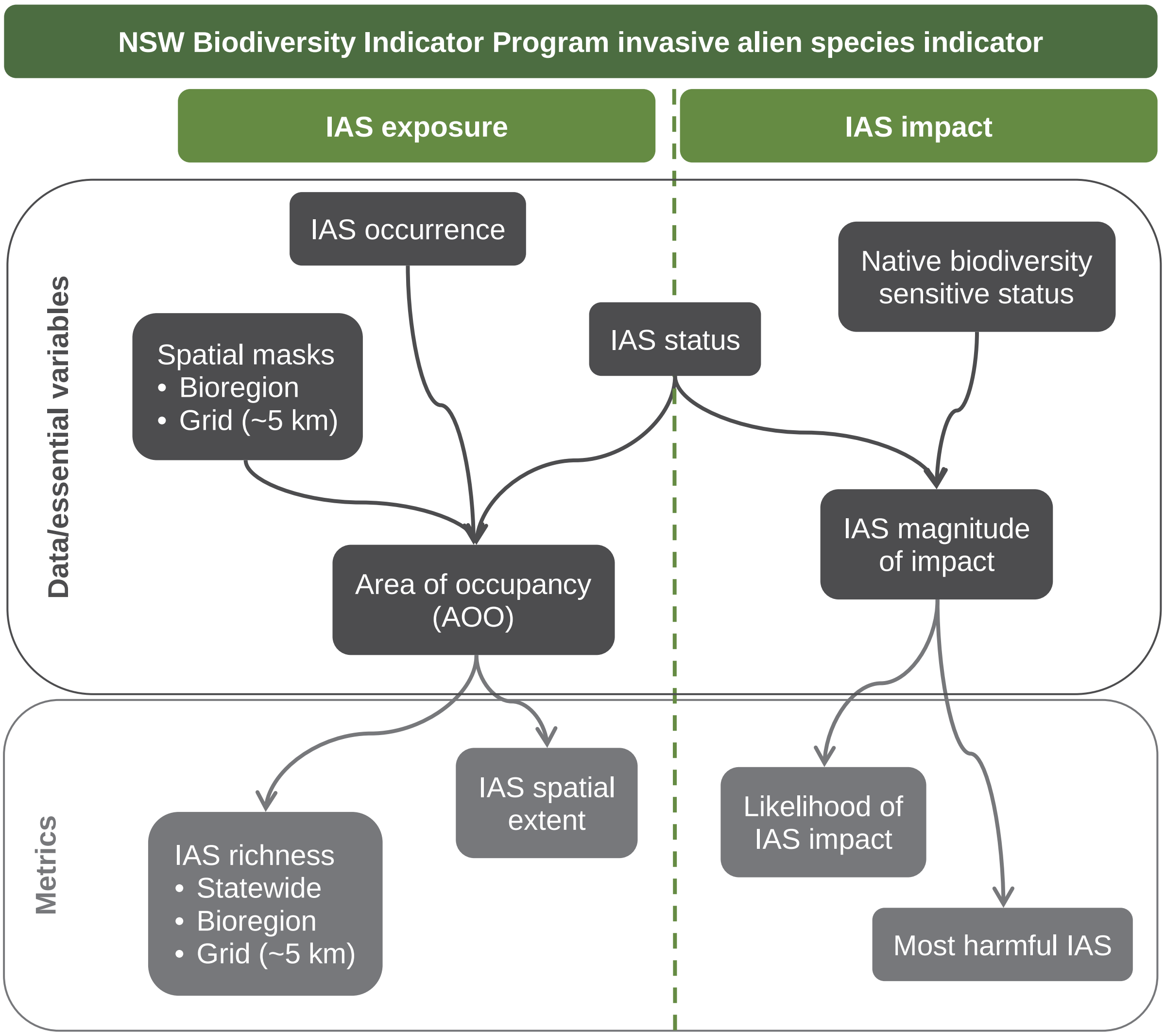


Figure 2 **Schematic design of the invasive species (pests, weeds, disease) indicator method.**

The figure shows data inputs, derived essential variables and metrics implemented in this first assessment to measure each of the two implemented dimensions of IAS pressure: IAS exposure and IAS impact. A comprehensive description of indicator workflows is provided in Appendix A.

2.1 Invasive alien species exposure

By definition, IAS are occurring in areas outside their natural distribution where they are threatening native biodiversity and ecosystem quality (CBD Secretariat 2019b; IUCN 2019a). Measuring the exposure to these IAS pressures has been a major aim in invasion research and monitoring programs (McGeoch et al. 2010; Catford et al. 2012; Early et al. 2016; Wilson et al. 2018). The presence, size and extent of IAS pressures depends on both the ‘invasiveness’ of invading species and the ‘invasion level’ of invaded areas (McGeoch et al. 2010; Catford et al. 2012). A range of metrics to quantify these properties of species or invaded areas have been proposed.

Invasiveness refers to a species’ ability to invade geographically defined areas, habitats and ecosystems over both local and broad scales (Pearson et a. 2016). Drawing on original work by Parker et al. (1999), Pearson et al. (2016:163) suggest that the invasiveness of a species ‘can be quantified by its demographic success, i.e., its local population densities [… i.e.

Parker's *A* = *Abundance*] and/or how widely that species establishes [… i.e. Parker's *R* = *Range*]'. Sandvik et al. (2019) quantify what they term the invasion potential of a species as a function of population longevity, spread rate and invaded range.

The invasion level of a geographically defined area, habitat or ecosystem refers to the severity of the observed invasion (Catford et al. 2012). According to Catford et al. (2012), invasion level may be quantified using metrics such as:

- IAS richness, being the number of different IAS that are occurring in an invaded area.
- IAS abundance, being the number of individuals, biomass, per cent cover or density of all IAS that are occurring in an invaded area; the most appropriate unit of measurement depending on the biological group under consideration (Wilson et al. 2018).
- Relative IAS richness or relative IAS abundance, being the proportion of all species (including native and alien), or the proportion of all individuals (or the total biomass) occurring in an invaded area, that are IAS.

In line with the indicator design principles we aimed to develop metrics that are representative of a wide range of IAS and can be measured using repeatable workflows to detect changes in IAS exposure from local to statewide spatial scales. Information about IAS status and occurrence are by far the most readily available and accessible types of data for a large number of IAS at the statewide scale (Catford et al. 2012; Latombe et al. 2017; O'Loughlin et al. 2019). Hence, in this first assessment, we implemented the invasiveness metrics 'IAS spatial extent' and the invasion level metric 'IAS richness', which can both be derived from data about IAS status and occurrence alone. We acknowledge that these metrics give a relatively simplistic view on biodiversity exposure to IAS pressures. They imply that widely distributed IAS are more invasive, and that the presence of greater number of IAS indicates a higher invasion level. IAS abundance has often been found to be a more useful surrogate for invasiveness, invasion level, or even for impact (Pearson et al. 2016; Fleming et al. 2017; Wilson et al. 2018; O'Loughlin et al. 2019).

Relative IAS richness or relative IAS abundance, by accounting for variation in native species richness or native species abundance, may most accurately capture the degree of biodiversity exposure to IAS pressures (Catford et al. 2012; Wilson et al. 2018). We strongly recommend that future assessments consider developing either or both of these complementary spatially explicit indicator metrics. This would require additional investments into collecting new, and integrating existing, spatial data on IAS abundance and/or native species richness and abundance (see section 5.2).

Here, we adopted an integrative approach to collating and harmonising fragmented and often incomplete datasets across agencies and data repositories. In the section below we outline methods for identifying alien species with IAS status in New South Wales and the spatial occurrence of all identified IAS, mapping the area of occupancy (AOO) of identified IAS, and quantifying both invasiveness (using the IAS spatial extent metric) and invasion level (using the IAS richness metric) from the derived data products.

2.1.1 Invasive alien species status

Identifying IAS in New South Wales, that is, alien species that are known to be threatening native biodiversity and ecosystem quality, is a significant task because:

- There are many alien species from a range of biological groups already established or recently emerging in the State, but for most there is limited knowledge about their current or potential future impacts on native biodiversity and ecosystem quality (DPI 2018; EPA 2018). Downey et al. (2010) previously identified a comprehensive list of 340 invasive weeds based on their threat and ability to impact on biodiversity, but this snapshot list is potentially outdated today. Other more recent IAS priority lists are typically tied to specific management objectives or legislation and therefore not representative of all IAS across the State.

- There are an even larger number of alien species that are not yet present in New South Wales but may be introduced in future. Establishing which of these species may pose a potential future threat to native biodiversity and ecosystem quality in the State is difficult (Carboneras et al. 2018; Evans & Parsons 2018; ABARES 2019; Roy et al. 2019).

An IAS status list that may be used to detect changes in IAS exposure through time must be comprehensive (ideally including all current or potential future threats) and updateable (based on repeatable workflows).

In this first assessment, we compiled an 'IAS status list' of alien species that had been identified as current or potential future threats to native biodiversity and ecosystem quality in New South Wales in at least one of several authoritative data sources (see section 3.1). Some of these data sources included both widespread IAS that are currently threatening native biodiversity and ecosystem quality in the State, as well as emerging or new IAS that have already been identified as posing a potential future threat, without clearly distinguishing between the two. We included any identified IAS, regardless of whether they have already been recorded in New South Wales or not (see below). In this first assessment, we had limited capacity to address incompleteness or potential bias in data sources and focused on adequately capturing (mostly vertebrate) pest animals and weeds. Further review is recommended in future assessments to better integrate other IAS biological groups such as invertebrate pest animals, freshwater aquatic pests and diseases, as well as new or recently emerged IAS that may pose a potential future threat to native biodiversity and ecosystem quality in NSW (discussed in section 5.2).

2.1.2 Spatial data sources

For all IAS on the final IAS status list, spatial information about their NSW occurrence needed to be collated. Comprehensive surveys establishing IAS presence or absence are rarely available at the statewide scale. The geographic range of species is thus commonly inferred from species occurrence records (also referred to as presence-only records, detection records, locality records, distribution data or observations; e.g. Gaston & Fuller 2009; Elith et al. 2010). The availability and accessibility of occurrence records has proliferated over recent decades with the establishment of virtual herbaria and large-scale data aggregation and dissemination ('atlas') infrastructure such as the Global Biodiversity Information Facility (GBIF) and the Atlas of Living Australia (ALA) (Hardisty et al. 2019). While these repositories invest considerable resources into data acquisition, harmonisation and verification, there are several limitations that apply especially to IAS occurrence records:

- Data fragmentation and accessibility: Particularly for widespread IAS, even large data repositories cannot aggregate all available data. Data is often located in a variety of databases hosted by local to national-level stakeholders and not publicly accessible.
- Data deficiency and reporting bias: For many IAS, data is available only for parts of their invaded range, and data is often influenced by differences in reporting (e.g. due to accessibility, privacy concerns, perceived impacts on land value or IAS legal status) rather than differences in true field occurrence.
- Data quality and verification: Occurrence records are often aggregated and accumulated in a non-systematic manner with inconsistent data quality or verification (Haque et al. 2017). Making comparisons between different IAS or time periods difficult.

To minimise the effects of these issues, we integrated occurrence records for all identified IAS from multiple sources. We relied on two major data repositories with statewide coverage at the expense of completeness to ensure that repeatable data collation and harmonisation workflows with limited manual processing could be developed. The two data repositories are the ALA and NSW BioNet Atlas. As IAS occurrence records are inconsistently accumulated across space and time (Haque et al. 2017), in this first assessment we chose to include any records from an extended period from 1 January 1980 to 25 August 2017 (i.e. the commencement date of the BC Act). Hence, not all records may represent current occurrences at the time of this assessment (but noting that local eradication of recorded infestations is rarely achieved; DPI 2018).

For 16 vertebrate pest animals, we complemented occurrence records with a statewide gridded dataset containing information on species presence, relative abundance or absence. This NSW Pest Animal Survey (Trotter pers. comm.) was collated by the NSW Department of Primary Industries in 2009 and 2016 by eliciting field knowledge from regional pest animal management practitioners on a statewide map grid with an approximate 5-kilometre resolution (see section 3.2). We were unable to source and access similar up-to-date presence/absence data for other biological groups of IAS on our status list.

The two integrated spatial data types are difficult to compare. On the one hand, the atlas data are incomplete but mostly verified occurrence records collected between 1980 and 2017 for all identified IAS. On the other hand, the pest animal survey data are complete but unverified expert information collected in 2009 and 2016 for a limited number of pest animals. Further spatial data could be integrated in future assessments to enhance data completeness and comparability across all identified IAS (discussed in section 5.2).

2.1.3 Area of occupancy maps

There are many approaches to inferring a species' geographic range (i.e. the area in which it occurs, also referred to as spatial extent or distribution) from occurrence records (Gaston & Fuller 2009). The issue of data deficiency and reporting bias can be effectively addressed with the help of statistical, niche-based species distribution models (Elith et al. 2010). However, these typically indicate suitable habitat which a species may potentially occupy based on its environmental tolerances rather than where it actually occurs (Gaston & Fuller 2009). For range-expanding IAS this approach can be particularly problematic (Elith et al. 2010).

The *IUCN Red List Categories and Criteria* (IUCN 2017) use two approaches for mapping species ranges:

- the extent of occurrence (EOO) refers to the total range area as delimited by the outermost occurrence records
- the area of occupancy (AOO) is the area within the EOO which is currently occupied, excluding unsuitable and unoccupied areas (Gaston & Fuller 2009).

By discriminating between unoccupied and occupied areas, the AOO measure is conceptually useful for monitoring changes over time in range-expanding IAS (Hardisty et al. 2019). AOO is measured by mapping occurrences onto a regular raster grid, typically with a 2-kilometre resolution suitable for Red Listing purposes.

Converting occurrence records into AOO maps that can inform consistent reporting on IAS indicators requires complex workflows including both automated and manual processing steps (Hardisty et al. 2019). Here, we developed repeatable workflows for generating AOO maps for all IAS that were (i) identified on our IAS status list as threats to native biodiversity and ecosystem quality in New South Wales, and (ii) recorded as naturalised (i.e. having become established in the wild, unaided by active human husbandry) in at least one location in New South Wales in any of our spatial data sources. We considered a larger cell size to be more appropriate to limit the effects of data gaps and reporting bias (i.e. IAS not being accurately recorded throughout their 'true' invaded range), at the expense of potentially overestimating AOO. We settled on the same ~5-kilometre grid cell resolution (which equates to approximately 25 km^2) at which the gridded NSW Pest Animal Survey had previously been mapped (Trotter pers. comm. 2019).

2.1.4 Indicator metrics

The generated IAS status list and AOO maps can be regarded as essential variables from which a range of metrics may be derived to report on biodiversity exposure to IAS pressures (Latombe et al. 2017; Wilson et al. 2018; Hardisty et al. 2019). We used the IAS spatial extent metric to quantify the invasiveness of invading species and the IAS richness metric to quantify the invasion level of invaded areas in New South Wales.

- The **IAS spatial extent** metric was calculated as the proportion of NSW grid cells with a resolution of approximately 5 kilometres where an IAS was recorded as naturalised (i.e. having established in the wild) in at least one location. Due to the relatively coarse AOO mapping resolution, reporting spatial extent in square kilometre units (Wilson et al. 2018; Hardisty et al. 2019) may give a misleading sense of accuracy (e.g. for an IAS with only one occurrence record, the reported spatial extent of the occupied grid cell would have been ~25 km^2 when it may actually be several orders of magnitude smaller). While our proportional measure is equally affected by the AOO mapping grid (Gaston & Fuller 2009), we felt that its more abstract reporting (e.g. in the above case, spatial extent would be ~0.003 %, see Appendix B) is less susceptible to misinterpretation. This metric may be used to demonstrate future range expansions of IAS and highlight management needs (Hardisty et al. 2019).
- The **IAS richness** metric was calculated as the number of IAS that were recorded as naturalised in at least one location in an invaded area. It was measured at three spatial scales that define what constitutes an ‘invaded area’, both as an absolute species count and a proportional metric. We reported IAS richness separately for the three biological dimensions (biological groups) of IAS: pest animals, weeds and diseases.
  - At the statewide scale, we reported both the number (count) of IAS that were recorded in New South Wales and the proportion (%) of all identified current or potential future IAS threats on the IAS status list that were recorded in the State. This indicates the overall size of the IAS management challenge in New South Wales (Catford et al. 2012) and may be used to track new introductions (of alien species identified on the IAS status list but not yet recorded in the State) in future assessments.
  - At the bioregion scale, we reported the number (count) of IAS that were recorded in a bioregion, and the proportion (%) of all IAS recorded in New South Wales that were recorded in a bioregion. Bioregional patterns and trends in IAS richness may be considered in future management planning (e.g. indicating the need for mitigation activities in regions with high IAS richness and preventative measures in adjacent regions with low IAS richness).
  - At the grid scale, we reported the number (count) of IAS that were recorded in a ~5-kilometre resolution grid cell, and the proportion (%) of all IAS recorded in New South Wales that were recorded in a grid cell. These gridded IAS richness maps may be usefully integrated with other data products in a range of spatial analyses, including to inform future iterations of the Biodiversity Indicator Program indicator 3.1a: ecological condition (OEH & CSIRO 2019) or spatially explicit metrics of IAS impact (see section 5.2).

The metrics developed and implemented in this first assessment report on aspects of IAS exposure that can be derived from information about IAS status and occurrence. However, in the interest of repeatability we focused on major data sources, and we had limited capacity to address incompleteness or potential bias in data sources. Assessment results should thus be viewed as representing publicly accessible records for the most commonly identified IAS in the most well-documented biological groups: weeds and (mostly vertebrate) pest animals. Improvements to these metrics and workflows, and suggestions for alternative metrics of invasiveness and invasion level that may address shortcomings and give complementary insights on IAS exposure, are discussed in section 5.2. A synthesis of recommendations for future assessments is reiterated in the Summary.

2.2 Invasive alien species impact

In the context of global, national or statewide biodiversity targets and assessment frameworks (UN 2015; BIP 2019; CBD Secretariat 2019a; OEH & CSIRO 2019), understanding the impacts of biological invasions is critical (Latombe et al. 2017). Impacts are here defined as the consequences of IAS pressures, that is, the changes to the properties of ecosystems caused by IAS to the detriment of native species and ecological communities (IUCN 2019a; OEH & CSIRO 2019). However, IAS impact is a complex and highly context-dependent issue (O'Loughlin et al. 2019), and a contested and evolving area of research.

Parker et al. (1999) originally proposed that the total magnitude of IAS impact is a function of a species' invasiveness (O'Loughlin et al. 2019) or invasion potential (Sandvik et al. 2019) and its per capita effect. Many additional variables of IAS impact have since been identified, including the persistence and potential reversibility of impacts; cumulative effects from interacting mechanisms of impact or from different IAS; the breadth of impact, that is, the number and diversity of species, communities and ecosystems impacted; or the status and sensitivity of affected species, communities and ecosystems (Blackburn et al. 2014; Roy et al. 2018; Vilà et al. 2019). Bartz & Kowarik (2019) further placed IAS impact in the context of competing values and a suite of variables affecting the management of impacts.

Due to this complexity, it becomes clear that quantifying the magnitude of IAS impacts empirically is exceedingly difficult and rarely done. Where empirical data on IAS impacts has been collected, it can be difficult to generalise or compare local-scale results to other species and areas (Bartz & Kowarik 2019; O'Loughlin et al. 2019). Instead, monitoring and reporting has often focused on surrogate measures of invasiveness such as species presence or abundance, or assumptions about impact from evidence elsewhere (O'Loughlin et al. 2019). We take the view that measures of invasiveness can only describe the exposure to IAS pressures, but not the consequences of these pressures, and assumptions about potential impacts do not indicate current detrimental impacts in New South Wales.

Various impact assessment protocols have recently been developed that aim to synthesise evidence from a range of sources in a systematic, repeatable and comparable form (Vilà et al. 2019; Bartz & Kowarik 2019). Protocols vary in scope and comprehensiveness, but often employ semi-quantitative scoring methods to derive an integrated measure of impact (Downey et al. 2010; Kumschick et al. 2012; Blackburn et al. 2014; Sandvik et al. 2019).

The recently proposed (Blackburn et al. 2014; Hawkins et al. 2015) and currently revised (IUCN 2019a, 2019b) IUCN Environmental Impact Classification for Alien Taxa (EICAT) framework is increasingly suggested as the standard method for assessing IAS impact from global to regional scales (Latombe et al. 2017; Wilson et al. 2018; Roy et al. 2019). Australia is currently still lagging behind in the implementation of standardised impact assessment methods such as EICAT. A modified EICAT method has recently been used within a broader risk assessment framework to develop a national *Priority List of Exotic Environmental Pests and Diseases* (Evans & Parsons 2018; ABARES 2019). We are not aware of a published application at the state scale.

In this first assessment, we aimed to conduct a pilot study that demonstrates how the EICAT method could be adapted to collect data on the current magnitude of IAS impacts on native species and ecological communities in New South Wales. This pilot study did not seek to undertake a comprehensive assessment representative of all IAS impacts on all native species and ecological communities sensitive to these impacts, which would require a greater effort. Our focus was on developing a consistent assessment framework, customised to the needs of the Biodiversity Indicator Program, as well as repeatable methods for its implementation. We took a pragmatic approach to data collection, drawing on agency knowledge on significant IAS status (i.e. known to pose a major and widespread threat in New South Wales) and native biodiversity sensitive status (i.e. known to be impacted by a particular IAS).

2.2.1 IUCN Environmental Impact Classification for Alien Taxa

In the EICAT method, the impact caused by an IAS is assessed as falling into one of five impact categories. Each of these impact categories reflects a different magnitude of impact, depending on the level of biological organisation of a native species that is negatively impacted and the lasting consequences of this impact. Thus (IUCN 2019a, 2019b):

- minimal concern (MC) refers to negligible impacts on individuals of a native species
- minor (MN) refers to impacts that affect the performance of individuals (i.e. their ability to survive and reproduce successfully) of a native species
- moderate (MO) refers to impacts that affect local population size (i.e. the abundance of mature individuals) of a native species
- major (MR) refers to impacts that cause local population extinction (i.e. extirpation) of a native species, which is reversible (due to recolonisation without additional human assistance)
- massive (MV) refers to impacts that cause local population extinction (i.e. extirpation) of a native species, which is irreversible (due to isolation or fundamental changes in ecosystem properties).

A data deficient (DD) category is assigned where there is insufficient evidence to place an IAS into one of these five impact categories.

Furthermore, the magnitude of impact is assessed with regard to each of 12 specific mechanisms by which these impacts may occur, ranging from competition, predation and disease transmission impacts on native species; to chemical, structural or physical impacts on native ecosystems (see section 4 for a detailed description of the 12 mechanisms).

EICAT is an evidence-based scheme, where assessments are based on data about impacts for which there is evidence. Relevant evidence may come from a variety of published or unpublished sources and may be either directly observed (which relates to the variables of interest when assigning impact categories; i.e. performance of individuals, local population size, local population extirpation status), or inferred (which does not directly relate to the variables of interest, but to other observed variables that are assumed to be related to these). Potential impacts of IAS that could be expected in future invasion scenarios based on experiences elsewhere, or hypothetical impacts given assumptions about management regimes and their effectiveness, are not considered in EICAT.

Finally, an estimate of the degree of uncertainty is assigned to all assessments in the form of a confidence score (high, medium or low). Confidence refers to the likelihood that the ‘’true impact category is equal to the assigned one. When assigning confidence scores, factors related to the type, quality, coherence, sources and spatial scale of evidence as well as the likelihood of confounding effects may be considered (IUCN 2019a, 2019b).

A major drawback of the EICAT standard (IUCN 2019a, 2019b) for the purposes of the Biodiversity Indicator Program is its de facto unresponsiveness to measuring *changes* in the magnitude of impact. EICAT was designed to facilitate comparisons across biological groups and invaded regions (e.g. countries) and prioritisation of high impact invaders (IUCN 2019a). Thus, only the maximum observed impact category in a region (across all impacted native species and impact mechanisms), and at the global scale across all assessed invaded regions, is reported (IUCN 2019a). This masks variability at the interaction level, with not all sensitive native species being equally affected by a particular IAS (Dueñas et al. 2018). Furthermore, while the maximum observed impact category may be revised upward or downward, this is difficult to justify in practice: IAS impacts typically increase (e.g. due to invasive spread or contextual factors) or decrease (e.g. due to successful management) at local scales or with regard to specific native species (e.g. listed threatened species) rather than across all affected species in the invaded region (e.g. New South Wales) (O’Loughlin et al. 2019).

2.2.2 Magnitude of impact assessment

The EICAT method is sufficiently flexible to be adapted to particular policy and management contexts (e.g. Evans & Parsons 2018; Roy et al. 2019). Here, we attempted to maintain EICAT principles and standards, while making the following modifications to enhance our ability to detect variability in IAS impacts as well as changes in future assessments for the Biodiversity Indicator Program (see section 4 for details of our implementation):

- We assessed the magnitude of impact with regard to particular pairwise interactions between an IAS and a co-occurring ‘sensitive’ (i.e. known to be detrimentally affected by that IAS) native species or ecological community. This required extending the EICAT method and terminology to also apply to ecological communities rather than just species, while also maintaining comparability between the two entities.
- In this first assessment we took a pragmatic approach to data collection, limiting the assessment to a set of known interactions between widespread IAS that are currently of significant concern (vertebrate pest animals and weeds only) and native species or ecological communities that are listed as threatened under the BC Act. Assessment results are thus not representative of the magnitude of IAS impacts on all NSW native species and ecological communities and should be reported with appropriate caution. Future assessments should consider a more systematic approach to selecting a representative set of interactions.
- We implemented the impact assessment via a structured expert elicitation protocol (McBride et al. 2012; Hemming et al. 2018). In making their assessments, experts were asked to draw on all available evidence, including published and unpublished documents, documented field monitoring data as well as undocumented anecdotal observations and field knowledge. We focused on developing comprehensive elicitation materials and guidance as well as repeatable analyses to facilitate consistent application of the assessment method. Future assessments should invest more time and resources into expert recruitment, calibration and training as well as verification of expert-elicited assessment results (most importantly, against field monitoring data).
- We assessed the currently observed rather than maximum observed magnitude of impact. All assessment materials specifically referred to evidence of impacts caused by IAS ‘under current contexts’ at the time of the assessment. Hence, experts were asked to implicitly consider contextual variables such as the spatial distribution, abundance and demographics of both invasive alien and native populations, the structure and composition of ecological communities, and current management regimes and practices in their assessments. Future changes in these contextual variables may lead to a different assessment of the magnitude of impact. The impact of an IAS on a native species or ecological community may vary between regions and spatial scales due to differences in context. In line with the standard EICAT method (IUCN 2019a, 2019b), experts were asked to base their assessments on evidence of the highest impact observed in at least one local population of a native species, or at least one remnant patch of an ecological community.

2.2.3 Indicator metrics

In order to allow quantitative analyses and aggregation of assessment results across experts, interactions and IAS, we followed EICAT guidelines to translate each combination between an impact category and a confidence score assigned by an expert into a likelihood distribution that the 'true' impact is of a certain magnitude (IUCN 2019b). This probabilistic metric can be regarded as a composite, higher-level essential variable of impact (Latombe et al. 2019). From this essential variable we derived two metrics that are proposed for reporting on the IAS impact indicator dimension: 'likelihood of IAS impact' and 'most harmful IAS'. These metrics integrated information on both the magnitude of impact and the uncertainty in its assessment (relating to both the confidence of each expert assessor in making a judgement, and to diverging assessments between different experts).

- The **likelihood of IAS impact** metric was calculated as the average expert-elicited likelihood that impacts caused by assessed IAS on assessed native species and ecological communities are of a certain magnitude. It was reported at the levels of individual IAS and two IAS biological dimensions: pest animals and weeds.
- The **most harmful IAS** metric was defined as the expert-elicited number, proportion and name of assessed IAS which are more likely than not (>50% average likelihood) of causing local population extirpation among assessed native species or ecological communities. This may be useful to communicate the magnitude of impacts caused by New South Wales' most significant IAS in an easy-to-understand measure.

We also determined the most likely magnitude of impact category for each assessed pairwise interaction between an IAS and a native species or ecological community by calculating the 'expected value' from the averaged likelihood distributions across all contributing experts. This deterministic impact metric was compiled in a colour-coded table that visualises, at a glance, the expert-elicited magnitude of impact for each assessed interaction.

It must be stressed that all impact metrics developed and reported here refer only to those IAS and listed threatened species and ecological communities that were assessed. Our intent was to demonstrate how a systematic, repeatable and comparable method for assessing IAS impact could be implemented in the Biodiversity Indicator Program, drawing on the international EICAT standard. While the method can be consistently applied in future assessments, allowing us in principle to detect change over time, we caution against directly comparing any future findings to the results of this pilot study. Improvements to these metrics and workflows, and suggestions for alternative metrics that may address shortcomings and give complementary insights on IAS impact, are discussed in section 5.2. A synthesis of recommendations for future assessments is reiterated in the Summary.

3. Implementation and results for invasive alien species exposure

3.1 Invasive alien species status list

In order to compile an IAS status list of previously identified alien species that pose a threat to native biodiversity and ecosystem quality in New South Wales, we drew on a range of available data sources which we considered to be authoritative, sufficiently up-to-date and relevant to our definition of IAS. These are listed in Table 1.

Table 1 Data sources for compiling an IAS status list for New South Wales.

Data source	Data access and workflows
NSW Department of Primary Industry (DPI) WeedWise	• Accessed database using NSW WeedWise advanced search • Conducted an advanced search (no filter, ordered by scientific name) and added all 'weed species' to IAS status list
NSW key threatening processes (KTP) scientific determinations	• Accessed KTP list • Added all 'pest animal' and 'disease' KTPs to IAS status list • For weed KTPs, listed as types of species, searched scientific determination and added all species mentioned to IAS status list
NSW *Biosecurity Act 2015*, Schedule 2 – Prohibited matter (Biosecurity Act)	• Accessed Schedule 2 • Added all 'terrestrial and freshwater weeds' and 'pest terrestrial invertebrates' to IAS status list
NSW Biosecurity Regulation 2017, Schedule 3 – Weeds (Biosecurity Reg)	• Accessed Schedule 3 Weeds and added all to IAS status list
Weeds of National Significance (WoNS)	• Accessed WoNS list and added all to IAS status list
National Environmental Alert List (NEAL)	• Accessed NEAL list and added all to IAS status list
National Parks and Wildlife Service 'List of key weeds that may impact biodiversity in NSW, May 2016' (NPWS weeds)	• Unpublished list compiled by the NSW National Parks and Wildlife Service (NPWS) for the purpose of regional weed management planning • Contacted NPWS data custodian for access and added all to IAS status list
NSW Local Land Services regional strategic pest animal management plans (LLS plan)	• Accessed 11 regional plans • Added all priority pest animal species to IAS status list, including those species mentioned under higher-level headings (e.g. deer, pest birds, pest fish)
NPWS regional pest management strategies (NPWS plan)	• Accessed 14 regional plans • Added all pest animal species mentioned in Section 6 'Pest species overviews' to IAS status list

Note: All data sources were accessed and queried in November 2019.

Following data collation, we initially merged the IAS extracted from data sources by scientific name into a table containing 492 unique alien taxon names. We maintained all names, but in some instances resolved taxonomic discrepancies at this stage (e.g. naming errors, synonymous taxon names in different lists). We also added a range of contextual fields for subsequent analyses and added labels to each identified alien taxon as follows:

- 'IAS biological group': labelled as [pest animal, weed, disease]
- 'IAS type': assigned labels from ancillary information in the data sources (e.g. 'plant type' label in the WeedWise database, listing within KTP functional types) or elsewhere as follows:
    - weeds were labelled as [Grass-like, Tree-like, Shrub-like, Herb-like, Vine or scrambler, Succulent, Aquatic plant]
    - pest animals were labelled as [Amphibian, Bird, Fish, Insect, Mammal, Reptile]
    - diseases were labelled as [Virus, Fungus]
- 'Taxonomic level': labelled as [Variety, Subspecies, Species, Genus, Order]
- Each data source had one field ('WeedWise', 'KTP', 'WoNS', 'NEAL', 'Biosecurity Act/Reg', 'NPWS weeds', 'LLS plan', 'NPWS plan'; see Table 1); and were labelled as [1] if listed in the data source.

Some alien taxa were listed in different data sources at different taxonomic levels resulting in duplicate records in the merged list (e.g. six species of invasive deer listed by species name were also included in the family level KTP listing Cervidae). For consistency, we maintained records at the species level and removed higher-level taxonomic classes for these taxa (i.e. deer are counted as six species rather than one family). Where no species-level listing was available, the next higher-level taxonomic class was maintained (e.g. genus).

Some of the data sources in Table 1 were not limited to alien taxa that conform to our definition of IAS (see section 1.1). Hence:

- We removed taxa that are not known to threaten native biodiversity and ecosystem quality (i.e. are listed for socio-economic impacts). For any alien taxon that was not also identified in the WoNS, NEAL, KTP or NPWS data sources (which explicitly contain only threats to biodiversity), we searched the WeedWise database and other information sources, and removed any taxon where no suggestion of biodiversity impacts could be found
- We removed taxa that are native to New South Wales. For weeds, we searched the WeedWise database (advanced search filtered by 'weed category > Native plant'); for pest animals, we assigned native status based on information sourced from NSW and federal government websites.

A total of 79 taxa were thus excluded from the original 492 that were extracted from data sources listed in Table 1. To prepare the IAS status list for automated downloads and queries of spatial data (see section 3.2), we performed taxonomic naming checks. For pest animals and diseases, these were done manually. For weeds, we updated taxon names to conform to the Australian Plant Name Index (accessed in November 2019). In this process, one further synonymous taxon was excluded (*Cenchrus spinifex* syn. *C. incertus*). The final IAS status list implemented in this first assessment (see Appendix B) contained 413 unique verified IAS, including 360 weeds and 49 pest animals, but only four diseases (those listed as NSW KTPs at the time of this first assessment).

3.2 Spatial data sources

All spatial processing of data sources was conducted in the Esri ArcGIS Desktop v.10.5.1 software. Data sources and automated Esri ArcGIS ModelBuilder processing workflows are provided as part of the indicator data package (see section 6).

3.2.1 Spatial masks

First, we created two spatial analysis masks for the purposes of (i) consistently processing IAS occurrence records, and (ii) reporting IAS richness at three spatial scales (statewide, bioregion and ~5-kilometre resolution grid).

NSW bioregion mask

Bioregion-scale analyses were based on the *Interim Biogeographic Regionalisation for Australia, Version 7 (Subregions) – States and Territories* dataset (DoE 2012). We extracted polygons for all 19 bioregions that are fully or partly contained in areas administered by the State of New South Wales. This included coastal islands as well as the Lord Howe Island group in the Pacific Subtropical Islands bioregion. The contiguous territories (Australian Capital Territory, ACT, and Jervis Bay Territory) were excluded. Bioregions extending across multiple disconnected parts (e.g. broken up by state boundaries) were dissolved to generate a single polygon for each of NSW's 19 bioregions (see Table 2).

This NSW bioregion mask was also used to define the clipping geometry for both the coarser-scale statewide and finer-scale ~5-kilometre resolution grid data extraction and analyses.

Table 2 List of 19 NSW bioregions.

Code	Bioregion name
AUA	Australian Alps
BBS	Brigalow Belt South
BHC	Broken Hill Complex
CHC	Channel Country
COP	Cobar Peneplain
DRP	Darling Riverine Plains
MDD	Murray Darling Depression
MUL	Mulga Lands
NAN	Nandewar
NET	New England Tablelands
NNC	NSW North Coast
NSS	NSW South Western Slopes
PSI	Pacific Subtropical islands (Lord Howe Island group only)
RIV	Riverina
SEC	South East Corner
SEH	South Eastern Highlands
SEQ	South Eastern Queensland
SSD	Simpson Strzelecki Dunefields
SYB	Sydney Basin

NSW raster grid

A NSW raster grid was generated to map AOO for each IAS and to perform grid-scale analyses. We based our implementation on the same NSW and ACT Regional Climate Modelling project (NARCliM) grid (i.e. projection: EPSG:9802 – Lambert Conic Conformal (2SP), resolution: ~91.716 metres) that had been used in previous grid-scale analyses for the Biodiversity Indicator Program (Nipperess et al. 2020). First, we expanded the spatial extent of the NARCliM grid (maintaining origin, projection and resolution) to cover the Lord Howe Island group and converted into polygon fishnet. Using a similar upscaling method to the one described in Nipperess et al. (2020), we multiplied the fishnet by a factor of 54 (resolution: ~4952.658 metre). Polygons from this upscaled fishnet intersecting with the NSW bioregion mask were converted to a raster grid, containing 32,794 cells with a cell resolution of ~5 kilometres (4,952.658 metres) and a cell size of ~25 km^2. This method ensured complete coverage of all areas administered by the State of New South Wales (including Lord Howe Island).

3.2.2 Occurrence records

We integrated occurrence records from three major data sources with statewide coverage. Data collation, pre-processing and integration steps for each data source are outlined below.

Atlas of Living Australia

An initial ALA batch taxon search for point occurrence records was conducted in October 2019 using the scientific name field in the IAS status list (see section 3.1) to determine the existence of valid records, using the following search filters (permanent download link):

- occurrence decade: 1980 OR 1990 OR 2000 OR 2010
- state: NSW OR Australian Capital Territory.

Using Microsoft power query for Excel*,* records were filtered to include only records from the time period 1 January 1980 to 25 August 2017 (i.e. commencement date of the BC Act). Unused fields were discarded and erroneous records removed (e.g. records with an invalid event date or location, data that had been entered incorrectly). Some taxa returned no records, while others returned multiple taxonomic naming variations (e.g. *Vulpes vulpes* and *Vulpes vulpes vulpes*). Naming variations were matched back to the original species on the IAS status list.

Our search filters were deliberately broad, and no other filters (e.g. basis of information or observation type) were applied. This maximised the number of occurrence records returned for all biological groups and minimised the likelihood of missing mislabelled or unlabelled valid records (i.e. naturalised populations). However, it also increased the likelihood of returning invalid records (i.e. not naturalised populations). To address this issue, we undertook a manual verification step on the final integrated dataset (see below).

A second batch taxon search was conducted in January 2020 using the scientific name field of only species on the IAS status list that returned valid and manually verified records on the initial download, with the same filters as above (permanent download link). Microsoft power query for Excel was again used to filter records by date (1 January 1980 to 25 August 2017) and to remove unused fields and erroneous records. Naming variations were matched back to the IAS status list, and two new fields added to the attribute table:

- 'Data_source': labelled as [ALA]; used for data integration
- 'Occurrence': labelled as [1]; used for AOO map generation (see section 3.3).

BioNet Atlas

Point occurrence records from the NSW BioNet Atlas were accessed using the BioNet web services API using Microsoft power query for Excel software.

First, the fields ‘scientificName’ and ‘currentScientificName’ from the BioNet Species Names entity set were queried using the scientific name field in the IAS status list. Returned species names records contained multiple taxonomic naming variations (e.g. *Vulpes vulpes* and *Vulpes vulpes vulpes*). Naming variations were matched back to the original species on the IAS status list and used as query terms in the next step.

Second, the BioNet Species Sightings entity set was queried with all naming variations to maximise the number of occurrence records returned for each species on the IAS status list. Query filters were again deliberately broad and filtered only by date (1 January 1980 to 25 August 2017) and location (New South Wales or ACT). Unneeded fields and erroneous records were removed, and two new fields were added to the attribute table:

- ‘Data_source’: labelled as [BioNet]; used for data integration
- ‘Occurrence’: labelled as [1]; used for AOO map generation (see section 3.3).

NSW Pest Animal Survey 2009 and 2016

For 16 vertebrate pest animals, point occurrence records were complemented by the statewide ~5-kilometre resolution grid data in the NSW Pest Animal Survey (Trotter pers. comm.). This unpublished dataset was provided by the data custodians at the NSW Department of Primary Industries (DPI) via email in vector polygon format. For 14 species, we used data on species presence and relative abundance collected in a 2016 survey. Polygons assigned with any of the categories ‘present’, ‘low’, ‘medium’ or ‘high’ were extracted for further analysis. Polygons assigned with the categories ‘absent’ or ‘unknown’ were discarded. For two species, feral cat (*Felis catus*) and red fox (*Vulpes vulpes*), no data was supplied but mapping of a previous 2009 survey indicated that they were thought to occur throughout mainland New South Wales. We dissolved the NSW bioregion mask into a single polygon to represent these two species’ statewide mapped occurrence and assigned the abundance category ‘present’.

Each of the 16 vector polygon feature classes were then converted to raster format using the NSW raster grid. Although this grid had the same ~5-kilometre spatial resolution as the NSW Pest Animal Survey vector polygons, the two mapping grids were not aligned due to differences in origin and projection. Only those grid cells whose centroid intersected with a species’ presence polygon were assigned the ‘Occurrence’ value [1]. Thus, some raster grid cells that partly intersected with a polygon (but not in their centroid) where nevertheless assigned the [NoData] value. Any information loss due to the vector to raster conversion was minimal and could be further reduced with a finer-grained raster grid resolution (e.g. as recommended in section 5.2). Finally, the 16 raster grids were converted to an ArcGIS point feature class, whereby point occurrence records were placed in the centroid of each grid cell labelled as [1] (i.e. presence in any abundance category).

In order to integrate this dataset with point occurrence records sourced from ALA and BioNet Atlas, we added two new fields to the attribute table as above:

- ‘Data_source’: labelled as [DPI]; used for data integration
- ‘Occurrence’: labelled as [1]; used for AOO map generation (see section 3.3).

Integrated invasive alien species occurrence dataset

The IAS occurrence records from the three data sources were merged and clipped with the NSW bioregion mask to remove records external to New South Wales. The final integrated IAS occurrence dataset contained 961,795 records. Note that not all of these were unique records. In particular, there was considerable overlap between the ALA and BioNet Atlas datasets resulting in many duplicates, whose removal from the merged dataset would require several additional processing steps (Hardisty et al. 2019). As duplicate records do not affect the calculation of any of the metrics reported here, we did not remove them in this intermediate data product. Contextual fields from the IAS status list ('IAS group', 'IAS type', 'Taxonomic level', 'Data source') and from the NSW bioregion mask ('bioregion code', 'bioregion name') were joined to the attribute table of the integrated IAS occurrence dataset, and a common naming field ('IAS_Name') was added.

Finally, we verified occurrence records in the integrated dataset for all IAS with fewer than five records across all data sources to ensure that only IAS that have indeed naturalised in at least one location in New South Wales are included. An assessment of all records as well as a cross-check with the NSW WeedWise database and ancillary literature was undertaken to determine if an IAS was naturalised in New South Wales. IAS records for species not considered to be naturalised (e.g. garden specimens) were removed. We did not verify any records for IAS with five or more records, although these may also contain invalid records. However, we considered these IAS unlikely to contain only invalid records, and that the effects on AOO mapping and indicator reporting would be small enough to warrant omitting this labour-intensive additional verification step.

3.3 Data analysis

Spatial analyses were conducted in Esri ArcGIS Desktop v.10.5.1, Microsoft Excel and *R* (v 3.4.3; R Core Team 2018) software. Automated Esri ArcGIS ModelBuilder analysis workflows and data products are provided as part of the indicator data package (see section 6).

3.3.1 Area of occupancy maps

We generated AOO maps for all IAS in the integrated IAS occurrence dataset, that is, the IAS that were recorded as naturalised in at least one location in New South Wales during the period 1980 to 2017. First, the integrated IAS occurrence dataset was split by taxonomic name and separate point feature classes for each IAS written into an output directory. Second, the point feature classes were mapped onto the NSW raster grid using the 'points to raster' conversion tool and separate AOO raster layers for each IAS written into an output directory. The resulting 5-kilometre resolution grid cells took the value [1] if they contained at least one occurrence record, and the value [NoData] if they did not intersect with any occurrence records.

3.3.2 Invasive alien species spatial extent

The attribute table of each IAS AOO raster layer contained a count of grid cells with the value [1] (i.e. that contained at least one occurrence record for that IAS). To calculate spatial extent (i.e. the proportion of NSW grid cells occupied by an IAS), this cell count was divided by the total number of cells in the NSW raster grid (32,794) and the result added as a new field to each raster attribute table. After appending a second field containing the IAS scientific name, all attribute tables were merged and added as a single lookup table to the IAS status list for further analysis. We then appended the biological group to each IAS and generated histogram plots (suggested in Wilson et al. 2018 and implemented in DEW 2018) showing the distribution of spatial extent among all IAS for which AOO was mapped (i.e. that were recorded as naturalised in at least one location in New South Wales) as well as summary statistics, separately for each IAS biological dimension: pest animals, weeds, diseases.

3.3.3 Invasive alien species richness

Statewide analysis

To calculate IAS richness at the statewide scale, we manipulated the attribute table of the integrated IAS occurrence dataset using Microsoft power query for Excel. Occurrence records were summarised by the scientific name attribute field and the result added as a lookup table to the IAS status list. The IAS richness metric was then calculated as the number of IAS for which at least one occurrence record was returned in the integrated IAS occurrence dataset. To derive a proportional metric, we divided the number of recorded IAS by the number of identified species on the IAS status list (413). Both metrics were calculated separately for each IAS biological dimension (pest animals, weeds, diseases) and for all biological dimensions combined.

Bioregion-scale analysis

As each occurrence record in the integrated IAS occurrence dataset had been appended with contextual information from the IAS status list and NSW bioregion mask, we could also summarise the dataset by bioregion name and biological dimension (pest animals, weeds, diseases). An IAS was counted towards a bioregion if at least one occurrence record intersected with that bioregion. Separately for each biological dimension of IAS, we then divided bioregional species counts by the number of IAS recorded anywhere in the State (see statewide analysis above). Finally, the summarised table was joined to the NSW bioregion mask and exported as a vector polygon feature class for mapping. The summarised table was also used to perform a range of bioregion-scale analyses (mean, standard deviation, plotting).

Grid-scale analysis

Finally, we calculated cell statistics on a list of all IAS AOO raster layers. For each grid cell, we counted all AOO rasters that contained a value of [1] and ignored any AOO rasters that contained a [NoData] value. This grid-scale analysis was again applied separately to each IAS biological dimension. A proportional metric of IAS richness was generated using the ‘raster calculator’ tool, dividing each grid cell’s species count by the number of IAS recorded anywhere in New South Wales (see statewide analysis above).

3.4 Results: invasive alien species richness

3.4.1 Statewide results

Based on the publicly accessible data sources used in this first assessment, 344 IAS were recorded as naturalised in at least one location in New South Wales during the period 1980 to 2017 (see list in Appendix B). This represents 83% of the 413 species on the IAS status list of previously identified current or potential threats to native biodiversity and ecosystem quality in New South Wales.

Among those 344 IAS, there were 305 weeds (85% of the 360 identified weeds on the IAS status list), 36 (mostly vertebrate) pest animals (73% of the 49 identified pest animals on the IAS status list) and three diseases (75% of the four identified diseases on the IAS status list, all of which were listed as KTPs at the time of this assessment). The data on disease IAS status and occurrence collated in this first assessment were insufficient to enable a detailed analysis at the bioregion and grid scales.

3.4.2 Bioregion-scale results

IAS richness (species count) in each NSW bioregion is shown in Figure 3, and IAS richness in each bioregion as a proportion of all IAS recorded in the State is shown in Figure 4.

At the bioregion scale, weed richness varied considerably along a coastal–inland gradient (Figure 4a). It was highest in the Sydney Basin, where most of the 305 weeds recorded anywhere in New South Wales were recorded (264 species, or 87%). Other coastal bioregions also had high weed richness, with the NSW North Coast harbouring 69%, South Eastern Queensland 59%, and South East Corner 53% of all 305 weeds recorded in the State. In contrast, the arid Simpson Strzelecki Dunefields and Channel Country bioregions contained only 6 and 4 weed species respectively. A total of 50 species (16% of all 305 weeds) were recorded on the ~15 km^2 Lord Howe Island in the Pacific Subtropical Islands bioregion (Figure 3, Appendix C).

The proportion of all 36 NSW pest animals recorded in a bioregion was, on average, much higher and more evenly distributed throughout the State (mean = 64%; SD = 22%) than for weeds (mean = 31%; SD = 24%) (Figure 4b, Appendix C). For example, the semi-arid inland Mulga Lands bioregion contained 56% of all NSW pest animals (20 species), but only 6% of all weeds (18 species). Across mainland bioregions, pest animal richness ranged between 10 species (28%, n = 36) in the Simpson Strzelecki Dunefields and 34 species (92%, n = 36) in the Sydney Basin. Five pest animal species were recorded on Lord Howe Island in the Pacific Subtropical Islands bioregion (Figure 3, Appendix C).

3.4.3 Grid-scale results

Weed richness also varied considerably within each bioregion (Figure 4a inset, Figure 5a). Up to 109 species (36% of all 305 weeds recorded anywhere in NSW) were recorded in an individual ~5-kilometre resolution grid cell, that is, within an area covering ~25 km^2 (Figure 5a). These areas of very high local weed richness were concentrated around human population centres (Figure 4a inset highlights high weed numbers around the Hunter Valley, Tamworth and Armidale).

Local variability in pest animal richness was much less pronounced. There was no grid cell in New South Wales that was entirely free of pest animal occurrence records, and some individual grid cells contained up to 24 species (67% of all 36 pest animals recorded anywhere in NSW) (Figure 4b inset, Figure 5b).

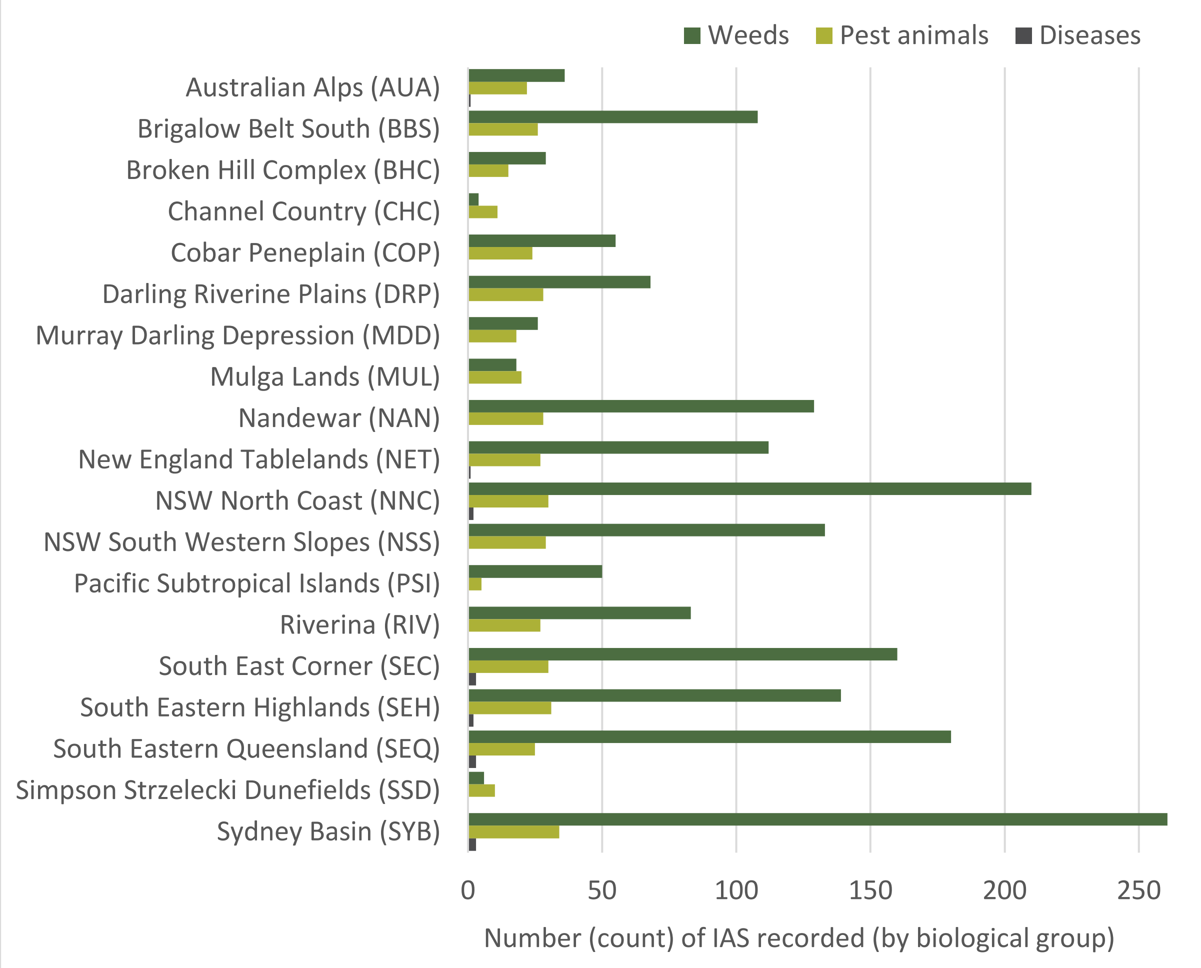
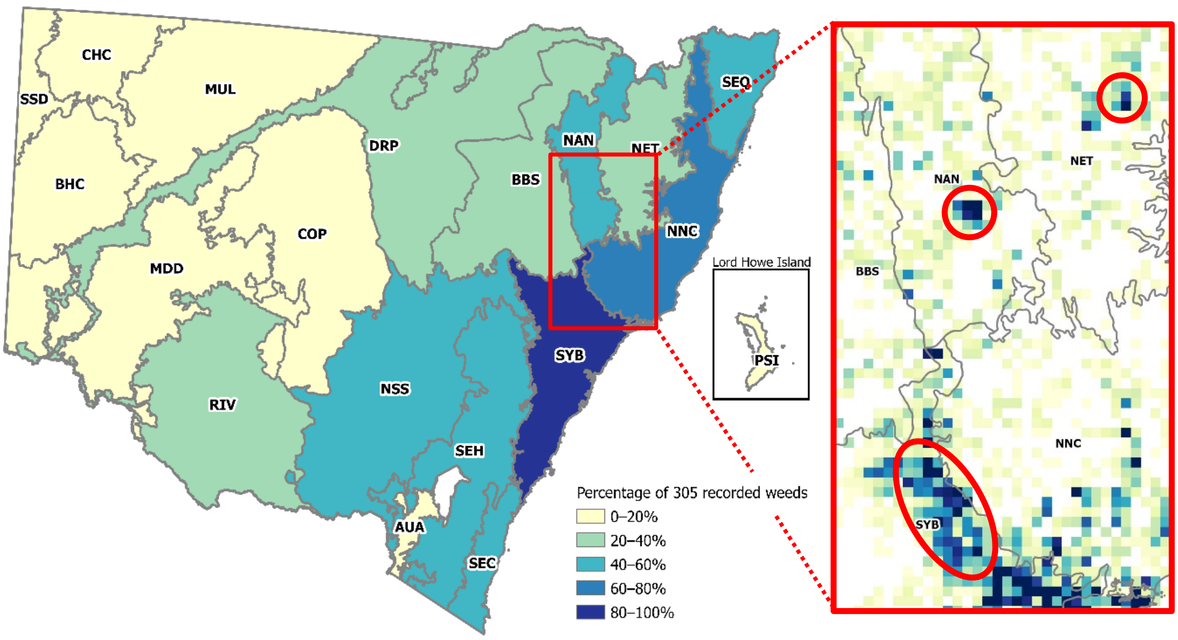


Figure 3 **IAS richness (species count) in the 19 NSW bioregions (y-axis).**

Bars show the number (count) of IAS that were recorded in each bioregion, separated into the three IAS biological dimensions (biological groups): weeds, pest animals and diseases (the latter is shown here for completeness but was not further analysed or mapped due to insufficient data). Results for the Pacific Subtropical Islands (PSI) bioregion include occurrence records for Lord Howe Island only. The data underlying this figure are provided in Appendix C.

(a) Weeds



(b) Pest animals

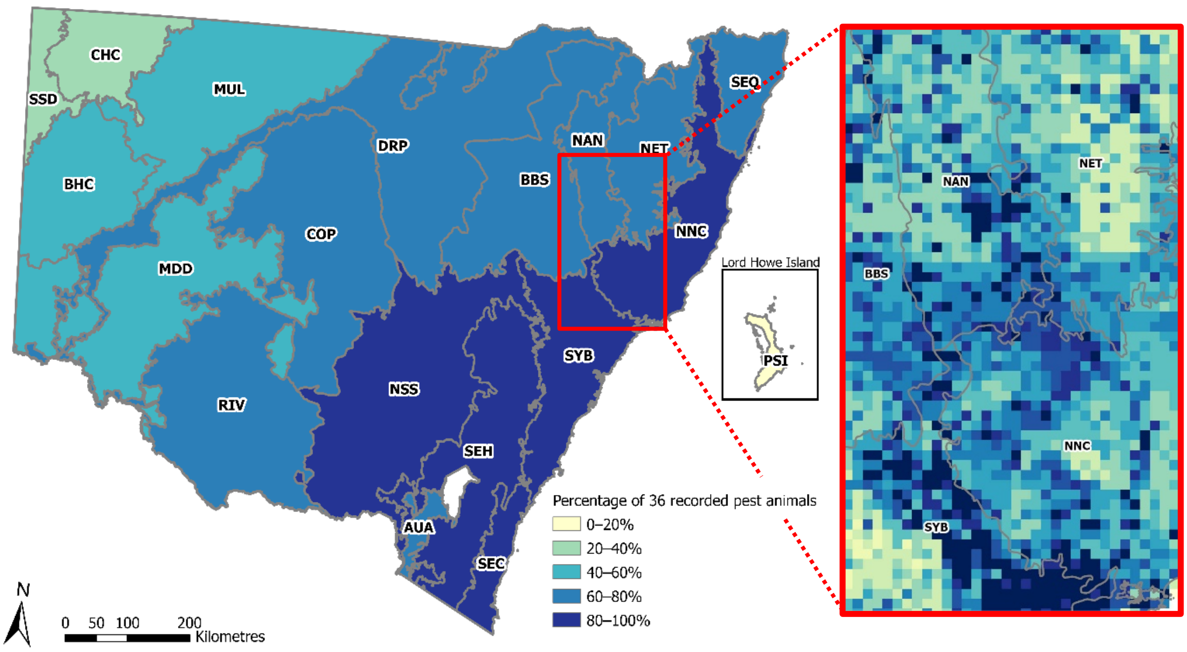


Figure 4 Bioregion-scale IAS richness (percentage of all IAS recorded in the State) for (a) weeds and (b) pest animals.

Maps show the percentage of all IAS in each biological dimension (305 weeds and 36 pest animals) recorded in New South Wales that were recorded in a bioregion. The insets show an example of IAS richness at the grid scale to highlight local variability within bioregions. Human population centres with very high local weed richness are shown in red circles in the inset of panel (a). Bioregion names corresponding to the codes displayed on this map are in Table 2.

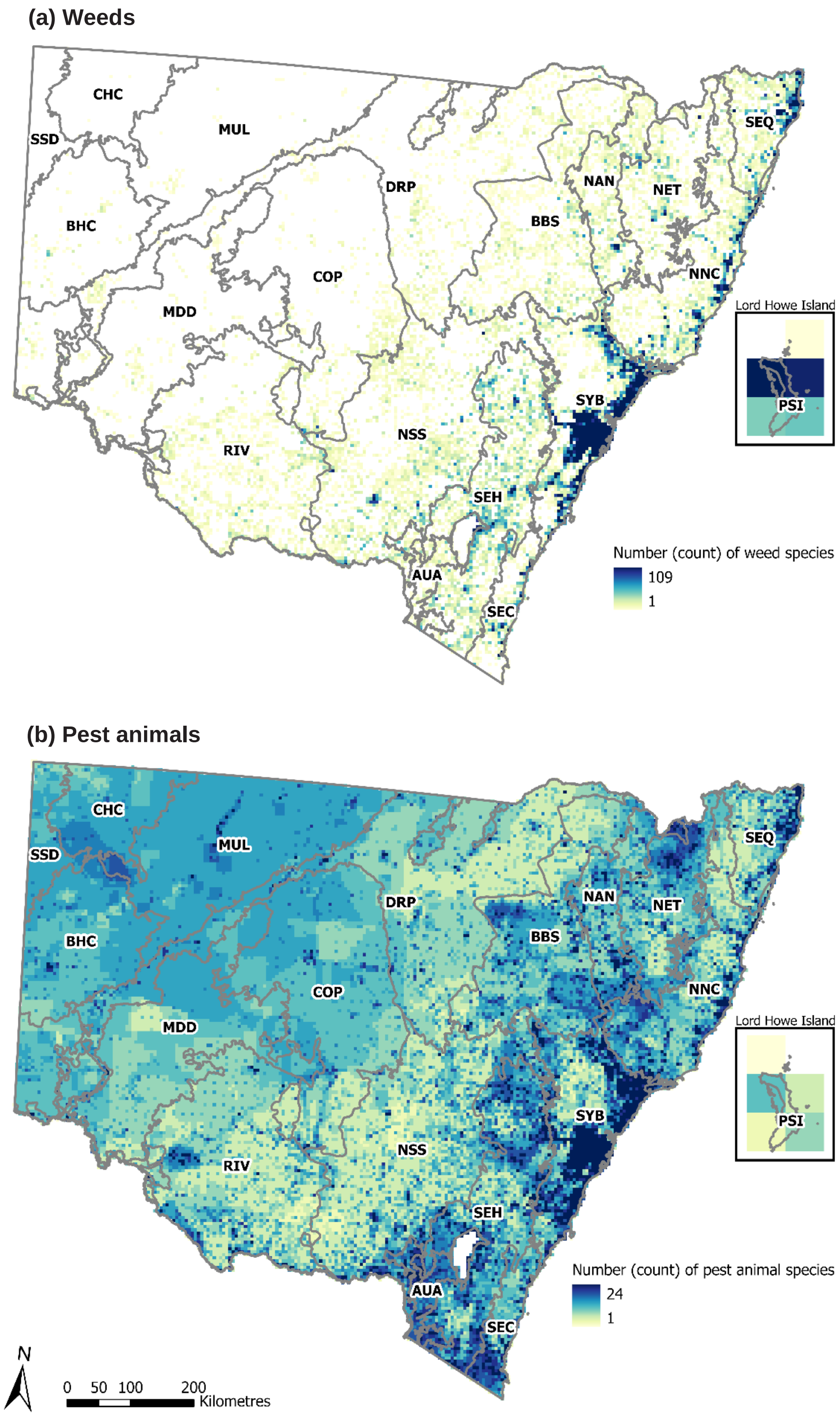


Figure 5 **Grid-scale IAS richness (species count) for (a) weeds and (b) pest animals.**

Maps show the number (count) of IAS in each biological dimension that were recorded in each NSW grid cell with a resolution of ~5 kilometres (out of 305 weeds and 36 pest animals).

3.5 Results: invasive alien species spatial extent

The spatial extent of the 344 IAS for which occurrence records were returned and AOO was mapped varied significantly (Figure 6 and Appendix B). It ranged from close to 100% of NSW grid cells occupied (red fox and feral cat) to only one occurrence recorded (i.e. 0.003% of grid cells) for several emerging weed species (Appendix B). The 36 mapped pest animals occupied on average a much larger area (14.8% of grid cells; median = 2.7%; SD = 28.4%) than the 305 weeds (0.6% of grid cells; median = 0.1%; SD = 1.1%) and three diseases (0.2% of grid cells; median = 0.2%; SD = 0.1%).

Most weeds (84% or 257 species), many pest animals (36% or 13 species) and all three diseases had a very limited spatial extent, being recorded in less than 1% of grid cells (Figure 6). Three weeds (1% of the 305 mapped species) and 12 pest animals (33% of the 36 mapped species) were recorded in more than 5% of grid cells, and six of these pest animals were widely recorded over more than a quarter of the NSW raster grid (Figure 6). These widespread vertebrate pest animals were the red fox (*Vulpes Vulpes*), feral cat (*Felis catus*), European rabbit (*Oryctolagus cuniculus*), feral pig (*Sus scrofa*), feral goat (*Capra hircus*) and wild dog (*Canis lupus*). The most widespread weeds were Paterson's curse (*Echium plantagineum*), sweet briar (*Rosa rubiginosa*) and saffron thistle (*Carthamus lanatus*), occupying between 5% and 8.5% of NSW grid cells (Table 3).

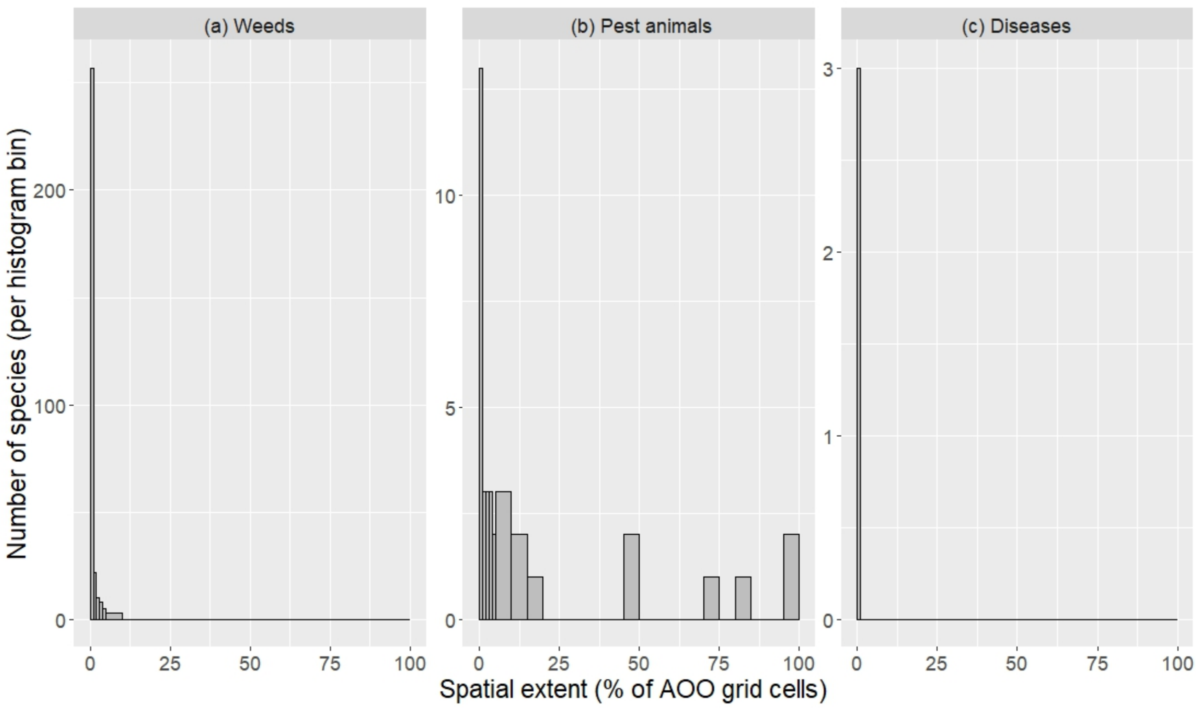


Figure 6 **Histogram plot of IAS spatial extent for (a) weeds, (b) pest animals and (c) diseases.**

Note that the y-axis is scaled differently due to the vastly different numbers of weeds (n=305), pest animals (n=36) and diseases (n=3) for which AOO was mapped. The data underlying this figure are provided in Appendix B.

Table 3 IAS spatial extent as the proportion of NSW grid cells where an IAS was recorded as naturalised in at least one location.

We show only (a) weeds and (b) pest animals that were recorded in more than 1% of NSW grid cells. Data are sorted from highest to lowest spatial extent. The spatial extents of all 344 IAS (305 weeds, 36 pest animals, three diseases) recorded in NSW are provided in Appendix B.

(a) Weeds			Spatial extent
Type	Scientific name	Common name	(%)
Herb-like	*Echium plantagineum*	Paterson's curse	8.523
Shrub-like	*Rosa rubiginosa*	Sweet briar	5.025
Herb-like	*Carthamus lanatus*	Saffron thistle	5.004
Shrub-like	*Lantana camara*	Lantana	4.934
Herb-like	*Marrubium vulgare*	Horehound	4.726
Succulent	*Opuntia stricta*	Common pear	4.690
Herb-like	*Senecio madagascariensis*	Fireweed	4.409
Shrub-like	*Rubus fruticosus*	Blackberry	4.178
Grass-like	*Holcus lanatus*	Yorkshire fog	3.809
Shrub-like	*Lycium ferocissimum*	African boxthorn	3.775
Herb-like	*Hypericum perforatum*	St. John's wort	3.641
Grass-like	*Phalaris aquatica*	Phalaris	3.461
Grass-like	*Cyperus eragrostis*	Umbrella sedge	3.126
Grass-like	*Cenchrus clandestinus*	Kikuyu	3.095
Herb-like	*Xanthium spinosum*	Bathurst burr	3.058
Grass-like	*Dactylis glomerata*	Cocksfoot	3.010
Grass-like	*Eragrostis curvula*	African lovegrass	2.946
Herb-like	*Romulea rosea*	Onion grass	2.839
Shrub-like	*Solanum mauritianum*	Tobacco bush	2.622
Shrub-like	*Ligustrum sinense*	Privet, narrow-leaf	2.357
Grass-like	*Andropogon virginicus*	Whisky grass	2.336
Shrub-like	*Ageratina adenophora*	Crofton weed	2.260
Grass-like	*Anthoxanthum odoratum*	Sweet vernal grass	2.241
Herb-like	*Verbena rigida*	Veined verbena	2.241
Grass-like	*Chloris gayana*	Rhodes grass	2.183
Tree-like	*Cinnamomum camphora*	Camphor laurel	2.071
Herb-like	*Tradescantia fluminensis*	Trad	1.958
Grass-like	*Ehrharta erecta*	Panic veldgrass	1.860
Tree-like	*Pinus radiata*	Monterey pine	1.756
Tree-like	*Ligustrum lucidum*	Privet, broad-leaf	1.714
Grass-like	*Nassella trichotoma*	Serrated tussock	1.680
Grass-like	*Hyparrhenia hirta*	Coolatai grass	1.668
Shrub-like	*Senna pendula* var. *glabrata*	Cassia	1.644
Vine or scrambler	*Araujia sericifera*	Moth vine	1.641

(a) Weeds			Spatial extent
Type	**Scientific name**	**Common name**	**(%)**
Grass-like	*Paspalum urvillei*	Vasey grass	1.619
Shrub-like	*Crataegus monogyna*	Hawthorn	1.564
Vine or scrambler	*Asparagus aethiopicus*	Ground asparagus	1.494
Tree-like	*Schinus areira*	Pepper tree	1.415
Shrub-like	*Ochna serrulata*	Ochna	1.363
Vine or scrambler	*Asparagus asparagoides*	Bridal creeper	1.259
Herb-like	*Heliotropium europaeum*	Common heliotrope	1.229
Grass-like	*Stenotaphrum secundatum*	Buffalo grass	1.229
Vine or scrambler	*Lonicera japonica*	Japanese honeysuckle	1.220
Herb-like	*Urtica urens*	Stinging nettle	1.208
Vine or scrambler	*Passiflora subpeltata*	Passion flower	1.159
Tree-like	*Olea europaea* subsp. *cuspidata*	African olive	1.147
Herb-like	*Ageratina riparia*	Mistflower	1.107
Herb-like	*Alternanthera pungens*	Khaki weed	1.086

(b) Pest animals			Spatial extent
Type	**Scientific name**	**Common name**	**(%)**
Mammal	*Vulpes vulpes*	Red fox	98.536
Mammal	*Felis catus*	Feral cat	98.295
Mammal	*Oryctolagus cuniculus*	European rabbit	82.442
Mammal	*Sus scrofa*	Feral pig	70.135
Mammal	*Capra hircus*	Feral goat	47.344
Mammal	*Canis lupus*	Wild dog	45.877
Bird	*Sturnus vulgaris*	Starling	17.933
Mammal	*Dama dama*	Fallow deer	10.551
Bird	*Passer domesticus*	Sparrow	10.435
Bird	*Turdus merula*	European blackbird	5.815
Mammal	*Mus musculus*	House mouse	5.303
Mammal	*Cervus elaphus*	Red deer	5.038
Bird	*Streptopelia chinensis*	Spotted dove	4.540
Bird	*Sturnus tristis*	Common (Indian) myna	4.046
Mammal	*Equus caballus*	Feral horse	3.796
Mammal	*Cervus unicolor*	Sambar deer	3.421
Mammal	*Rattus rattus*	Black rat	3.007
Mammal	*Lepus capensis*	Cape hare	2.958
Fish	*Gambusia holbrooki*	Plague minnow	2.388
Mammal	*Bos taurus*	Feral cattle	2.278
Fish	*Cyprinus carpio*	Common carp	1.747
Fish	*Carassius auratus*	Goldfish	1.122
Amphibian	*Rhinella marina*	Cane toad	1.022

4. Implementation and results for invasive alien species impact

In this first assessment we developed a systematic, repeatable and comparable method for assessing the current magnitude of IAS impacts on native species and ecological communities in New South Wales, drawing on EICAT principles and standards and customising it to address the requirements of the Biodiversity Indicator Program. Our intent was to conduct a pilot study that demonstrates how the proposed method may be consistently implemented using a structured expert elicitation protocol.

4.1 Selection of assessable interactions

During an initial scoping workshop involving participants from the Biodiversity Indicator Program as well as selected IAS experts, seven widespread vertebrate pest animal species that are currently of significant concern (all currently listed as KTPs in the BC Act) were selected for assessment (Table 4). The large number of significant weed species necessitated a staged approach. During the workshop, eight weed functional groups were identified, each consisting of species with broadly similar impacts. These functional groups closely aligned with the weed species or groups that are listed as KTPs in the BC Act. Workshop participants also identified preliminary lists of species representative of each functional group, largely based on their previous listing as WoNS and known potential to significantly impact biodiversity and ecosystem quality. Following the workshop, a smaller group of experts decided on one to three species from each functional group to be included in this first assessment, amounting to 15 weeds (Table 4).

In a second step, pairwise interactions between these IAS and a limited set of sensitive native species and ecological communities were selected by the same smaller group of experts based on agreed criteria. These criteria were:

- The native species or ecological community is known to be detrimentally affected by the impacts caused by the assessed IAS in New South Wales.
- Interactions are indicative of the variety of impacts caused by that IAS, including different types of native species, ecological communities, impact mechanisms, habitat types and bioregions.
- The assessment is feasible within the time constraints of the first assessment, i.e. evidence and expert knowledge are likely available and accessible.
- A change in the magnitude of impact may be detected in future assessments, due to a change in the status of either the IAS or the impacted native species or ecological community.

Based on these criteria, it was considered most appropriate to first assess IAS impacts on species and ecological communities currently listed as threatened in the BC Act. Particular threatened species and ecological communities known to be impacted by the seven pest animals were selected based on information in their respective KTP scientific determination or information about threats in the NSW *Saving our Species* database. To select threatened species and ecological communities known to be impacted by the 15 weeds for assessment, we additionally drew on information in the *Biodiversity Priorities for Widespread Weeds Statewide Framework* (DPI & OEH 2011). Preference was given to species and ecological communities that occurred in many priority management sites and were identified as sensitive to a weed's impacts (Hamilton pers. comm.).

This process resulted in 212 pairwise interactions with threatened species or ecological communities being selected for assessment across the seven pest animals and 15 weeds. The number of 'assessable interactions' varied between IAS ranging between two interactions selected for sagittaria (*Sagittaria platyphylla*) and 13 for cat's claw creeper (*Dolichandra unguis-cati*), lantana (*Lantana camara*) and others. Likewise, some threatened species or ecological communities were selected for assessment against only one IAS, while others were selected for assessment against up to eight IAS (the River-Flat Eucalypt Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions ecological community).

The initial list of assessable interactions was iteratively refined during the nomination phase of the expert elicitation protocol (see section 4.2). Experts were given the opportunity to comment on the initially selected interactions or suggest alternative interactions that they have knowledge about and that can be considered uniquely indicative of certain IAS impacts. These expert suggestions were then reviewed by the project team. In the process, pairwise interactions for two additional weeds were added to the list because they were indicating IAS impact in habitats and bioregions not well covered by other listed weeds. These included 9 interactions with threatened species or ecological communities for African lovegrass (*Eragrostis curvula*) and 2 interactions with threatened ecological communities for Hudson pear (*Cylindropuntia pallida* syn. *C. rosea*)

Additionally, any IAS that attracted fewer than three assessment nominations by experts was excluded from the assessment. This resulted in the removal of the two aquatic weeds alligator weed (*Alternanthera philoxeroides*) and sagittaria. Hudson pear was retained on the list despite being assessed by only two experts for only two interactions because it was considered uniquely indicative of IAS impacts on arid/semi-arid ecosystems. The final list of 'assessable interactions' comprised 227 interactions between 22 IAS (seven pest animals, 15 weeds; listed in Table 4) and 130 listed threatened species and ecological communities (25 threatened animals, 57 threatened plants and 48 threatened ecological communities).

Table 4 **IAS (weeds and pest animals) selected for the magnitude of impact assessment.**

In this first assessment, (a) 15 weeds and (b) seven pest animals were assessed for their magnitude of detrimental impacts on threatened species and ecological communities in New South Wales.

(a) Weeds		
Functional group	**Common name**	**Scientific name**
Aquatic plants	Alligator weed[1]	*Alternanthera philoxeroides*
	Sagittaria[1]	*Sagittaria platyphylla*
Herbs	Oxeye daisy	*Leucanthemum vulgare*
	St John's wort	*Hypericum perforatum*
Perennial grasses	African lovegrass[2]	*Eragrostis curvula*
	Coolatai grass	*Hyparrhenia hirta*
	Serrated tussock	*Nassella trichotoma*
Scramblers	Blackberry	*Rubus fruticosus* spp. agg.
	Ground asparagus	*Asparagus aethiopicus*
Succulents	Hudson pear[2]	*Cylindropuntia pallida* syn. *C. rosea*
	Mother-of-millions	*Bryophyllum delagoense*
Trees	African olive	*Olea europaea* ssp. *cuspidata*
Vines	Cat's claw creeper	*Dolichandra unguis-cati*
	Madeira vine	*Anredera cordifolia*

(a) Weeds		
Functional group	**Common name**	**Scientific name**
Woody shrubs	African boxthorn	*Lycium ferocissimum*
	Bitou bush	*Chrysanthemoides monilifera* ssp. *rotundata*
	Lantana	*Lantana camara*

(b) Pest animals	
Common name	**Scientific name**
Feral cat	*Felis catus*
Feral deer	(Family) Cervidae
Feral goat	*Capra hircus*
Feral horse	*Equus caballus*
Feral pig	*Sus scrofa*
Feral rabbit	*Oryctolagus cuniculus*
Red fox	*Vulpes vulpes*

1. Species that were initially selected but excluded due to lack of expert nominations.
2. Species that were not initially selected but added later in the elicitation process due to feedback.

4.2 Magnitude of impact assessment

4.2.1 Structured expert elicitation protocol

The structured expert elicitation protocol (McBride et al. 2012; Hemming et al. 2018) employed here can be divided into five phases: approval, identification, nomination, initial assessment and revision.

Approval

Ethics approval to conduct research with human participants was sought from the CSIRO Human Research Ethics Committee, and ethics clearance was provided on 29 May 2019 (project 075/19). Elicitation commenced in late August 2019 and was completed in early November 2019. Each of the steps detailed below took between two to three weeks.

Identification

The NSW *Saving our Species* database was queried to identify experts listed against the 227 entries on the final list of assessable interactions (see section 4.1). We searched for User Roles [Project coordinator, Threatened species expert, Site manager and Action implementer]. Expert names were returned for all 130 listed threatened species and ecological communities on that list. For the 22 IAS (15 weeds and seven pest animals) additional experts were suggested by IAS officers within the NSW Government. This process resulted in a pool of 260 experts with knowledge on at least one, but often several, of the IAS and threatened species or ecological communities included here. The pool of experts consisted mainly of expert practitioners (mostly NSW Government officers and selected consultants) and biodiversity or IAS coordinators, but relatively few scientific experts (NSW Government and universities).

Nomination

All 260 experts were invited via email to participate in the impact assessment by nominating one or several interactions that they felt able to assess based on their personal knowledge and experience, or their ability to synthesise secondary knowledge and data. For this purpose, a matrix of assessable interactions was compiled. This allowed species experts to easily identify all interactions of interest for a particular IAS or threatened species or ecological community. Experts were encouraged to recommend additional non-listed interactions if they had the knowledge to assess them. Experts were also invited to recommend others, resulting in six additions to our pool of experts.

A project information sheet and participant consent form were attached to the email, and experts asked to return a signed form. This was an important condition under which human research ethics clearance was provided. In total, 55 experts accepted the invitation to participate (response rate 20%). Many experts agreed to participate but subsequently did not nominate any specific interactions to assess or return a signed consent form. Other experts nominated to assess up to 50 interactions. Extensive follow-up to explain the assessment protocol and the time commitment required to complete an assessment was needed before proceeding to the next phase.

Initial assessment

For each of 50 experts, who consented to participate and nominated to assess at least one interaction, a personalised assessment workbook was created in Microsoft Excel software and sent via email. This workbook contained a separate worksheet for each nominated interaction on which to implement the assessment method. These worksheets were carefully designed to be as user-friendly as possible, including auto-fill and conditional formatting to minimise errors when completing the assessment and facilitate semi-automated analysis. Separate worksheets for assessments against threatened species versus ecological communities were created due to slight differences in the wording of assessment criteria. Where an expert nominated for many interactions, they were encouraged to firstly assess those interactions that they were most knowledgeable about, or keen to assess (rather than those where the magnitude of impact was perceived to be greatest). Experts were asked to complete their initial assessment on their own.

The workbook also contained seven other sheets with supporting information that could be referred to while completing the impact assessment. Their purpose was to facilitate a consistent implementation of the assessment method. These sheets included:

- A short introduction to the project, an overview of the contents of the workbook, the timelines of assessment, and a detailed description of each assessment step.
- A glossary containing definitions of key terms and concepts.
- A list of definitions of the impact categories for each of 12 impact mechanisms, separately for threatened species and ecological communities (Appendix D, Table 14).
- Definitions and considerations for assigning confidence scores.
- An updated matrix of all assessable interactions.
- A worked example of an assessment worksheet for the interaction ‘Lantana impacts on Illawarra subtropical rainforest in the Sydney Basin bioregion’.

Experts were given approximately three weeks to complete the initial assessment. In addition to the extensive guidance provided in the assessment workbook, experts were given ample opportunity to seek feedback and guidance from the project team. Thirty-six experts returned a fully or partially completed workbook, two withdrew from the assessment, and 14 experts either did not respond or were unavailable during the assessment period.

Revision

An opportunity for revising elicited judgements is an important step in structured expert elicitation protocols (McBride et al. 2012; Hemming et al. 2018). Once initial assessment workbooks were received from experts, we commenced developing workflows for automated data collation and analysis (see section 4.3). The revision process could not commence until all initial assessments were received, resulting in a limited period for expert revisions (1.5 weeks). All 36 experts who returned an initial assessment were then sent a follow-up email containing two attachments:

- The expert's own completed initial assessment workbook, which was cleaned to remove any worksheets that were not assessed and corrected for unintentional errors. Experts were asked to make any revisions directly to the worksheets in this workbook.
- A personalised spreadsheet containing the (de-identified) assessment results from other experts. Experts only received other's assessments relating to (a) the particular interaction(s) that they had assessed, and (b) other interactions for the same IAS they had assessed to allow a broader comparison.

During the revision phase, we drew experts' attention to important aspects of the assessment method that, upon review, emerged as the most easily misinterpreted. This included: asking experts to refer only to evidence of impacts caused by IAS 'under current contexts' at the time of the assessment; and clarifying the distinction between assessment as 'data deficient [DD]' and assessment as 'impact category + low confidence'. Experts were also asked to review their assessments for accidental errors. In some cases, potential errors flagged by the project team during preliminary analysis were highlighted. Only six of the 36 experts chose to make any changes to their assessments, and these were usually of a minor nature. These revised assessment workbooks, and the initial assessment workbooks of experts who made no changes, were used in subsequent analyses (see section 4.3).

4.2.2 Assessment method

The assessment method implemented by experts on each worksheet of their personalised assessment workbook consisted of four main assessment steps, each guided by the principles and standards outlined in the EICAT framework (IUCN 2019a, 2019b) that were modified to the needs of the Biodiversity Indicator Program (see section 2.2).

Step 1: Select impact mechanism

Experts were asked to select all applicable impact mechanisms by which the assessed IAS causes impacts on the assessed native species or ecological community. A list and generic definition for the 12 specific mechanisms was provided (see Table 5). All further steps only needed to be followed for the applicable impact mechanisms selected.

Table 5 The 12 impact mechanisms as defined here for a particular interaction between an IAS and a native species or ecological community.

Mechanism	Native species	Native ecological community
Competition	The invasive alien species competes with the native species for resources (e.g. food, water, space).	The invasive alien species competes with at least one characteristic native species of the ecological community for resources (e.g. food, water, space).
Predation	The invasive alien species predates on the native species.	The invasive alien species predates on at least one characteristic native species of the ecological community.
Hybridisation	The invasive alien species hybridises with the native species.	The invasive alien species hybridises with at least one characteristic native species of the ecological community.
Transmission of disease	The invasive alien species transmits diseases to the native species.	The invasive alien species transmits diseases to at least one characteristic native species of the ecological community.
Parasitism/ pathogens	The invasive alien species parasitises, or causes disease in, the native species.	The invasive alien species parasitises, or causes disease in, at least one characteristic native species of the ecological community.
Poisoning/ toxicity	The invasive alien species is toxic, or allergenic by ingestion, inhalation or contact to the native animal, or allelopathic to the native plant.	The invasive alien species is toxic, or allergenic by ingestion, inhalation or contact to at least one characteristic native animal, or allelopathic to at least one characteristic native plant, of the ecological community.
Bio-fouling	Individuals of the invasive alien species accumulate on the surface of the native species.	Individuals of the invasive alien species accumulate on the surface of at least one characteristic native species of the ecological community.
Grazing/ herbivory/ browsing	The invasive alien species impacts the native species by grazing, herbivory or browsing.	The invasive alien species impacts at least one characteristic native species of the ecological community by grazing, herbivory or browsing.
Chemical impact on ecosystem	The invasive alien species causes changes to the chemical properties of the native species' environment (e.g. pH, nutrient and/or water cycling).	The invasive alien species causes changes to the chemical properties of the ecological community's environment (e.g. pH, nutrient and/or water cycling), facilitating impacts on at least one characteristic native species.
Physical impact on ecosystem	The invasive alien species causes changes to the physical properties of the native species' environment (e.g. microclimate, fire or light regime).	The invasive alien species causes changes to the physical properties of the ecological community's environment (e.g. microclimate, fire or light regime), facilitating impacts on at least one characteristic native species.
Structural impact on ecosystem	The invasive alien species causes changes to the structural properties of the native species' environment (e.g. architecture or complexity).	The invasive alien species causes changes to the structural properties of the native species' environment (e.g. changes in architecture or complexity), facilitating impacts on at least one characteristic native species.
Indirect impact through interactions with other IAS	The invasive alien species interacts with other native or alien species (through any mechanism, e.g. pollination, seed dispersal, habitat modification, apparent competition, mesopredator release), facilitating indirect impacts on the native species.	The invasive alien species interacts with other native or alien species (through any mechanism, e.g. pollination, seed dispersal, habitat modification, apparent competition, mesopredator release), facilitating indirect impacts on at least one characteristic native species of the ecological community.

Note: Definitions specific to each impact category are provided in Appendix D, Table 14.

Step 2: Assign impact category

For each applicable impact mechanism selected, experts were asked to assign an impact category from a drop-down list and consider the accompanying definition that was automatically displayed upon selection. As with the standard EICAT method, the five impact categories were: minimal concern [MC], minor [MN], moderate [MO], major [MR] and massive [MV]. There was also a data deficient [DD] category which was defined as: There is insufficient information to classify the invasive alien species with respect to its magnitude of impact on the native species (or the characteristic native species that define the identity of the ecological community); or insufficient time has elapsed since introduction for impacts to have become apparent.

We modified the wording of the five impact category definitions to reflect our adapted assessment method (see Table 6 for generic definitions and Appendix D, Table 14 for definitions specific to each impact mechanism). These modifications were:

- Rather than referring to IAS impacts on an area's native biota in its entirety (IUCN 2019a), definitions reflected an interaction between an IAS and a particular native species or ecological community.
- In the EICAT method, the magnitude of impact scales with the level of biological organisation of a native species that is affected and the consequences of this impact. In order to maintain comparability between IAS interactions with species and those with ecological communities, we considered impacts on an ecological community only insofar as they affect the characteristic native species that define the identity of the ecological community. Accordingly, impact categories reflected the level of biological organisation of a characteristic native species that is impacted and the consequences of this impact to the community.
- In the EICAT method, the magnitude of impact should be assessed at typical spatial scales over which the local native population can be characterised (IUCN 2019a:23). We used the 'remnant patch' of a native ecological community as an analogous concept to the 'local population' of a native species. The appropriate spatial scale at which local populations or remnant patches can be characterised may vary, depending on species biology and the level of habitat fragmentation. Furthermore, the magnitude of impact caused by an IAS may vary between different local populations of a native species or remnant patches of a native ecological community across New South Wales due to contextual factors (e.g. IAS abundance, management effort, population size or connectivity). In line with the EICAT method, we asked experts to base their assessments on evidence of the highest impact observed in at least one local population, or at least one remnant patch.
- As in EICAT, the major [MR] and massive [MV] categories were distinguished by the lasting consequences, rather than the magnitude, of impact. Major [MR] impacts were considered reversible (i.e. '… if an invasive alien species were no longer present in an area where a local population of a native species, or a characteristic native species of an ecological community, has been extirpated, the impacted native species, or characteristic species of a native ecological community, would likely return to the area within 10 years or 3 generations'), while Massive [MV] impacts were considered irreversible ('… would not return to the area'). Reversibility was defined as a natural process '… without additional human assistance that was not already in place at the time the invasive alien species led to the local population extirpation'.
- Finally, we asked experts to only consider evidence of impacts caused by IAS 'under current contexts' at the time of the assessment. (i.e. '… the current distribution, abundance and demographics of both invasive alien and native populations, the current structure and composition of native ecological communities, and current management regimes and practices').

Table 6 The impact categories as defined here for a particular interaction between an IAS and a native species or ecological community.

Category	Native species	Native ecological community
Massive [MV]	Under current contexts, the invasive alien species causes extirpation of at least one local population of the native species, which is irreversible[1] even if the invasive alien species were no longer present.	Under current contexts, the invasive alien species causes extirpation of at least one characteristic native species (leading to changes in community composition) in at least one remnant patch of the ecological community, which is irreversible* even if the invasive alien species were no longer present.
Major [MR]	Under current contexts, the invasive alien species causes extirpation of at least one local population of the native species, which is reversible[2] if the invasive alien species were no longer present.	Under current contexts, the invasive alien species causes extirpation of at least one characteristic native species (leading to changes in community composition) in at least one remnant patch of the ecological community, which is reversible** if the invasive alien species were no longer present.
Moderate [MO]	Under current contexts, the invasive alien species causes a decline in population size in at least one local population of the native species, but no local population extirpations.	Under current contexts, the invasive alien species causes a decline in population size of at least one characteristic native species (leading to changes in community composition) in at least one remnant patch of the ecological community, but no local population extirpations.
Minor [MN]	Under current contexts, the invasive alien species causes a reduction in the performance of individuals in at least one local population of the native species, but no decline in population sizes.	Under current contexts, the invasive alien species causes a reduction in the performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes (and therefore no changes in community composition).
Minimal concern [MC]	Under current contexts, the invasive alien species causes negligible level of impacts, but no reduction in the performance of individuals of the native species.	Under current contexts, the invasive alien species causes negligible level of impacts, but no reduction in the performance of individuals of the characteristic native species that define the identity of the ecological community.
Data deficient [DD]	There is insufficient information to classify the invasive alien species with respect to its magnitude of impact on the native species, or insufficient time has elapsed since introduction for impacts to have become apparent.	There is insufficient information to classify the invasive alien species with respect to its magnitude of impact on the characteristic native species that define the identity of the ecological community, or insufficient time has elapsed since introduction for impacts to have become apparent.

Note: Definitions specific to each impact mechanism are provided in Appendix D, Table 14.

1. The native species, or characteristic species of a native ecological community, would not return to the area where it has been extirpated without additional human assistance that was not already in place at the time the IAS led to the local population extirpation.

2. The native species, or characteristic species of a native ecological community, would likely return to the area where it has been extirpated within 10 years or 3 generations without additional human assistance that was not already in place at the time the IAS led to the local population extirpation.

Step 3: Assign confidence score

Experts were asked, for each applicable impact mechanism selected in the first step, to select a degree of uncertainty attached to their assessment in the form of a confidence score (high, medium or low). These could be easily selected from a drop-down list and an accompanying definition was automatically displayed. The assessment workbook also contained further guidance on selecting an appropriate confidence score. Experts were encouraged to use the data deficient [DD] category only if they considered there was not enough evidence to assess the magnitude of impact for any of the applicable impact mechanisms. If they were able to make a judgement, albeit with high uncertainty, we suggested it was preferable to assign an impact category with a low confidence score.

Step 4: Provide evidence

Experts were asked to justify their assessment by providing evidence. Experts were encouraged to support their assessment with all available evidence, ranging from published documents and datasets to undocumented, in many cases anecdotal, field observations.

4.3 Data analysis

All analyses were conducted in *R* (v 3.4.3; R Core Team 2018) software. A documented script of all analysis steps is provided as part of the indicator data package (see section 6).

4.3.1 Data collation

First, we developed an automated script for importing the data provided in expert assessment workbooks. The data were arranged in a suitable format to perform further analyses, all fields without data were deleted and a de-identified unique expert ID was appended to each assessment result. Empty cells occurred when a specific impact mechanism was assessed as not relevant to an interaction between the IAS and the native species or ecological community. Assessment results were appended with two prepared data frames:

- The first data frame contained the list of all 227 assessable interactions with the following contextual information that was used in subsequent analyses: interaction code, IAS biological group, IAS type, native species/ecological community group, IAS name, native species/ecological community name.
- The second data frame specified a likelihood distribution that the 'true' impact is of a certain magnitude, given each combination between an impact category and a confidence score that could be assigned by experts (see Table 7). We used the specific values provided in the EICAT guidelines, which were based on a Beta distribution on the range [0, 1], discretised into five equal intervals (IUCN 2019b). For example, if an impact mechanism for a certain interaction was assessed as moderate [MO] impact with high confidence, we assumed a 90% likelihood that the true impact category is indeed moderate [MO], and a 5% likelihood each that the true category is actually major [MR] or minor [MN]. If the expert-assigned confidence score was medium, the likelihood that the true impact category is indeed moderate [MO] decreased to 70%, and the likelihood that it is actually major [MR] or minor [MN] increased to 15% each.

The resulting data frame contained one row for each assessment of an impact mechanism that was conducted by an expert (for many interactions, multiple relevant mechanisms were assessed). Data fields included the assessment result [expert ID, interaction code, impact mechanism, impact category, confidence score], the likelihood of impact distribution from Table 7 corresponding to the assessment result, and contextual information corresponding to the assessed interaction. Using the same process, we also generated personalised spreadsheets containing de-identified preliminary assessment results that were provided to the experts in the revision step of the structured expert elicitation protocol (see section 4.2).

Table 7 Likelihood distribution that the 'true' impact is of a certain magnitude.

Likelihoods were calculated for each combination between an impact category and a confidence score that could be assigned by experts. Ranks denoting increasing magnitudes of impact were used for data aggregation.

Expert assessment result		Likelihood distribution (%) of true impact category					Rank
Impact category	Confidence	MV	MR	MO	MN	MC	
Massive [MV]	High	90	10	0	0	0	16
	Med	75	23	2	0	0	15
	Low	36	34	21	9	0	14
Major [MR]	High	6	87	7	0	0	13
	Med	15	66	18	1	0	12
	Low	19	35	29	15	2	11
Moderate [MO]	High	0	5	90	5	0	10
	Med	0	15	70	15	0	9
	Low	6	26	36	26	6	8
Minor [MN]	High	0	0	7	87	6	7
	Med	0	1	18	66	15	6
	Low	2	15	29	35	19	5
Minimal [MC]	High	0	0	0	10	90	4
	Med	0	0	2	23	75	3
	Low	0	9	21	34	36	2
Data deficient [DD]	n/a	NA	NA	NA	NA	NA	1

4.3.2 Likelihood of impact

In the following analytical step, we used the ranks provided in Table 7 to select the likelihood distribution corresponding to the highest magnitude of impact across all impact mechanisms that were assessed by an expert. This resulted in a data frame containing one row per unique expert contribution (i.e. an individual expert's assessment of an interaction between an IAS and a threatened species or ecological community). A unique expert contribution was only considered as data deficient [DD] if the expert could not assign an impact category to any of the impact mechanisms.

Next, we averaged the likelihood of impact distribution across all unique expert contributions to a particular interaction. This resulted in a data frame containing one row per assessed interaction, and a likelihood distribution that each of the five impact categories is the true category given the impact categories and confidence scores assigned by each contributing expert. Information about the number of unique expert contributions per interaction was also appended. Interactions that were assessed as data deficient [DD] by all expert assessors were assigned with [NA] values in each impact category. For interactions that were assessed as data deficient [DD] only by some experts but with impact categories by others, the [DD] assessment did not affect the averaged likelihood distribution.

Finally, we generated the two metrics proposed for reporting on the IAS impact indicator dimension: likelihood of IAS impact and most harmful IAS (see section 2.2). The likelihood of IAS impact was calculated analogous to the interaction-level data frame, except that unique expert contributions were averaged across all interactions that were assessed for an IAS, and the two IAS biological dimensions: pest animals, weeds. This likelihood of IAS impact metric (averaged at the level of individual IAS) was then used to generate the most harmful IAS metric by summing the averaged likelihood values for the major [MR] and massive [MV] impact categories. Only IAS that exceeded a threshold value of 50% average likelihood were considered as the most harmful IAS. Interactions that were assessed as data deficient [DD] by all expert assessors, and hence assigned with [NA] values in each impact category, were excluded from the analysis.

4.3.3 Most likely magnitude of impact

The interaction-level data frame was used to determine the most likely magnitude of impact category for each assessed interaction between an IAS and a native species or ecological community. This deterministic impact measure was defined as the magnitude of impact that can be expected when considering all available information. An ‘expected value’ of a probability distribution is calculated by multiplying each value in a numerical series with its probability of occurrence and summing the resulting probability-weighted values. Here, the probabilities were given by the likelihoods that each impact category is the true category, averaged across all unique expert contributions to an interaction. In order to be able to assign a numerical value to each of the five impact categories, we converted categories into equal sized bins on the range [0, 100] and assigned each bin with its mid-point value (i.e. MC = 10, MN = 30, MO = 50, MR = 70, MV = 90). The expected value for each assessed interaction was then calculated as the probability-weighted sum of these bin values. Finally, the expected value was mapped back to one of the five impact categories by discretising the expected value range into five intervals [-Inf, 19.99, 39.99, 59.99, 79.99, Inf].

4.4 Results: magnitude of impact assessment

In total, 179 interactions between 22 widespread IAS (seven pest animals and 15 weeds) and 97 listed threatened species and ecological communities (16 threatened animals, 46 threatened plants and 35 threatened ecological communities) were assessed (see Table 9). This represents 79% of the 227 assessable interactions that were initially selected. Impacts on threatened ecological communities were much more often assessed for weeds (81, or 68% of 119 assessed interactions) than pest animals (13, or 21%, of 60 assessed interactions). Impacts on threatened animals were only assessed for pest animals (27 interactions). The proportion of assessed interactions with threatened plants was similar (32%) for both IAS biological dimensions (38 interactions for weeds and 27 interactions for pest animals).

On average, eight different interactions were assessed for each IAS, ranging between two (Hudson pear) and 12 (lantana). The number of experts contributing to the 179 assessed interactions also varied. Nearly half (49%) of interactions were assessed by only one expert, and 21% by three or more experts. Overall, there were 316 unique expert contributions to this first magnitude of impact assessment.

Experts could choose between 12 different impact mechanisms (as defined in Table 5) to assess each interaction. In many of the 316 unique expert contributions, experts assessed multiple mechanisms. Overall, 999 assessments (714 for weeds and 285 for pest animals) of an impact mechanism were conducted, ranging from 1 to 216 assessments per mechanism (see Figure 7). By far the most common impact mechanisms for weeds were competition (27% of weed assessments), physical (23% of assessments) and structural (22% of assessments) impact on ecosystems. For pest animals, impact was mostly attributed to grazing/herbivory/browsing (24% of pest animal assessments), predation (16% of assessments) and indirect impacts through interactions with other species (16% of assessments). Hybridisation, transmission of disease, parasitism/pathogens and bio-fouling were rarely considered relevant to the IAS evaluated in this first assessment (Figure 7).

The 999 impact categories thus assigned by experts to specific impact mechanisms were normally distributed along the ordinal assessment scale (see Table 8). Of these 999 assessments, 112 impact mechanisms were identified as relevant but assessed as data deficient [DD]. Expert confidence in their assessments was generally high, with a high confidence score attached to 37% of all assessments. Experts were most commonly moderately confident in their assessments (43% of cases). Only 9% of impact categories were assigned by experts with low confidence.

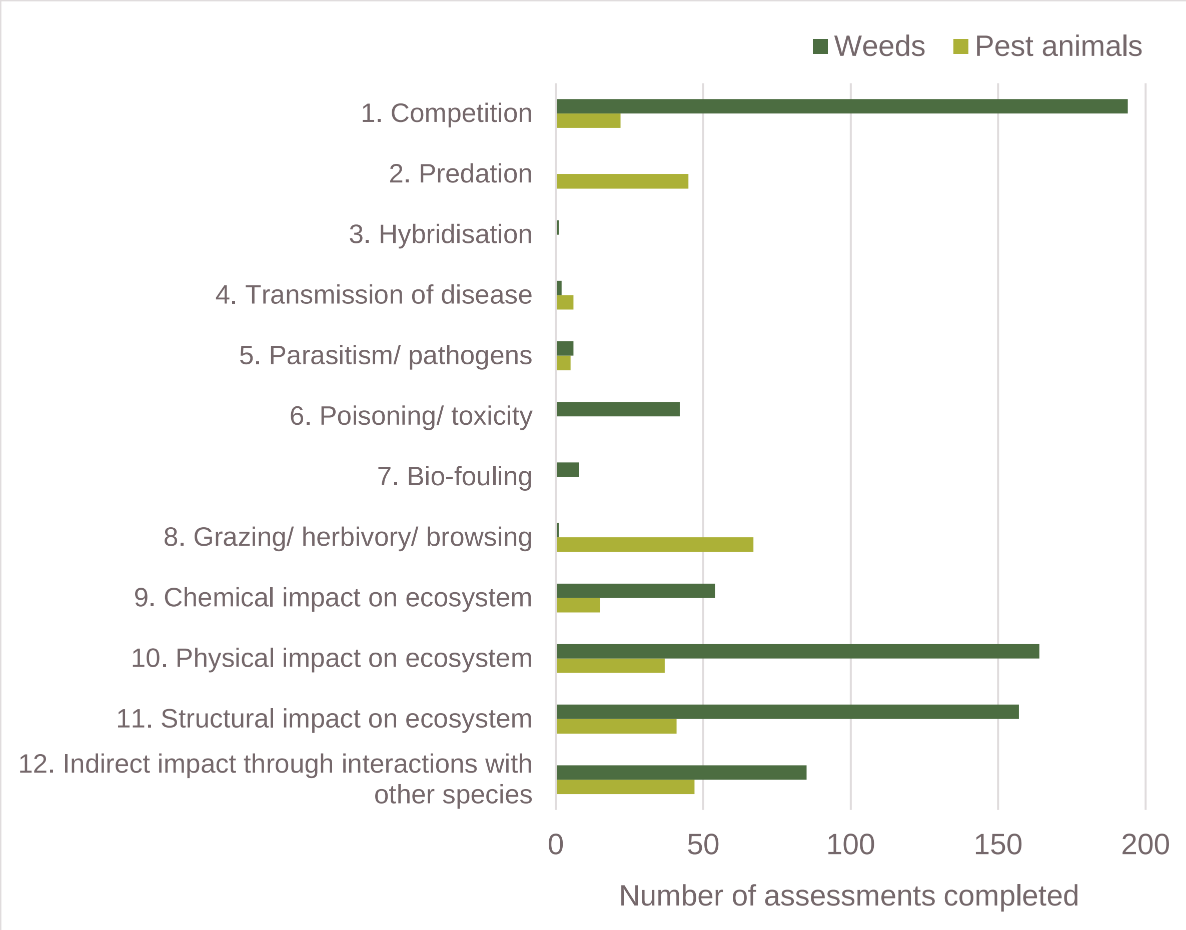


Figure 7 **Number of times that each impact mechanism was selected as relevant to an interaction across all assessments.**

Overall, 999 assessments (714 for weeds and 285 for pest animals) of an impact mechanism were conducted by experts. These were spread across 316 unique expert assessments of an interaction between an IAS and a listed threatened species or ecological community (for many interactions multiple mechanisms were assessed). Assessment frequencies are shown separately for pest animals and weeds.

Table 8 **Distribution of impact categories assigned by experts across all assessments.**

Minimal concern [MC]	Minor [MN]	Moderate [MO]	Major [MR]	Massive [MV]	Data deficient [DD]
36	164	371	251	65	112

4.5 Results: most likely magnitude of impact

After selecting the highest assigned magnitude of impact in each of the 316 unique expert contributions, and averaging results across all unique expert contributions in each of the 179 assessed interactions (119 for weeds and 60 for pest animals), we determined the most likely magnitude of impact category (see section 4.3). Results are presented in Table 9.

For most IAS the magnitude of impact varied considerably between assessed interactions, that is, the same IAS may have major [MR] impacts on one listed threatened species or ecological community and only minor [MN] impacts on another (see Table 9).

Overall, severe impacts were more often caused by weeds than pest animals. Weeds were assessed as most likely causing massive [MV] impacts (i.e. leading to irreversible local population extirpation) in nine (8% of all 119 assessed) interactions with threatened plants or ecological communities. There were many more weed interactions (52, or 44% of all assessed) where local population extirpations where thought to be most likely reversible without additional human assistance (i.e. major [MR] impact). Pest animals caused most likely irreversible massive [MV] or reversible major [MR] impacts in two (3%) and 21 (35%) of all 60 assessed interactions respectively. Severe impacts leading to local population extirpations were more often attributed to pest animal interactions with threatened animals (48% of 27 assessed interactions) than threatened plants (25% of 20 assessed interactions) or threatened ecological communities (38% of 13 assessed interactions).

The detrimental impacts caused by weeds and pest animals were assessed by experts as most likely moderate [MO] (i.e. causing declines in local population size) in 32 (27% of all 119 assessed) and 25 (42% of all 60 assessed) interactions respectively. Relatively few interactions were most likely leading to only minor [MN] impacts (11 for weeds and 9 for pest animals). Four weed interactions and one pest animal interaction were assessed as most likely of minimal concern [MC].

Thirteen out of 179 interactions (11 for weeds and 2 for pest animals) were not assigned with an impact category by any expert, and hence were reported as data deficient [DD]. The remaining 108 weed interactions and 59 pest animal interactions were used to calculate the likelihood of IAS impact and most harmful IAS metrics (see section 4.6).

Table 9 Most likely magnitude of impact category for each assessed interaction.

The 15 assessed weeds (119 interactions) are listed first in alphabetical order, followed by the seven assessed pest animals (60 interactions). Scientific IAS names are in Table 4. For each IAS, interactions are listed in order of decreasing magnitude of impact (impact categories are distinguished by colours and full category names corresponding to the codes displayed in this table are in Table 6). Interactions are distinguished by threatened entity group (animal, plant or threatened ecological community [TEC]). The number [n] of experts that contributed to assessing each interaction is also shown.

(a) Weeds			
Interaction name (including threatened entity group)		**Impact**	**n**
African boxthorn			
Carbeen open forest community in the Darling Riverine Plains and Brigalow Belt South bioregions	TEC	MR	2
Inland grey box woodland in the Riverina, NSW South Western Slopes, Cobar Peneplain, Nandewar and Brigalow Belt South bioregions	TEC	MR	2
Lepidium aschersonii	Plant	MO	1
Lowland grassy woodland in the South East Corner bioregion	TEC	MO	1
Myall woodland in the Darling Riverine Plains, Brigalow Belt South, Cobar Peneplain, Murray-Darling Depression, Riverina and NSW South Western Slopes bioregions	TEC	MO	3
White box yellow box Blakely's red gum woodland	TEC	MO	2
Cadellia pentastylis	Plant	MN	1
Cadellia pentastylis (Ooline) community in the Nandewar and Brigalow Belt South bioregions	TEC	MN	1
African lovegrass			
Lowland grassy woodland in the South East Corner bioregion	TEC	MV	1
Rutidosis leptorrhynchoides (Button wrinklewort)	Plant	MV	1
Cumberland plain woodland in the Sydney Basin bioregion	TEC	MR	1
Micromyrtus minutiflora	Plant	MR	1
Moist shale woodland in the Sydney Basin bioregion	TEC	MR	1
Natural temperate grassland of the South Eastern Highlands	TEC	MR	3
Shale gravel transition forest in the Sydney Basin bioregion	TEC	MR	1
White box yellow box Blakely's red gum woodland	TEC	MR	1
African olive			
Cumberland plain woodland in the Sydney Basin bioregion	TEC	MR	3
Moist shale woodland in the Sydney Basin bioregion	TEC	MR	1
Pimelea spictata	Plant	MR	3
River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	1
Shale gravel transition forest in the Sydney Basin bioregion	TEC	MR	1
Shale sandstone transition forest in the Sydney Basin bioregion	TEC	MR	1
Western Sydney dry rainforest in the Sydney Basin bioregion	TEC	MR	1
Bitou bush			
Bangalay sand forest of the Sydney Basin and South East Corner bioregions	TEC	MR	2
Euphorbia psammogeton	Plant	MR	2
Littoral rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	4
Sophora tomentosa	Plant	MR	1
Themeda grassland on seacliffs and coastal headlands in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	1
Pultenaea maritima	Plant	MO	1
Blackberry			
Eucalyptus canobolensis	Plant	MR	2

(a) Weeds			
Interaction name (including threatened entity group)		**Impact**	**n**
Ribbon gum, mountain gum, snow gum grassy forest/woodland	TEC	MR	3
Tablelands snow gum, black sallee, candlebark and ribbon gum grassy woodland in the South Eastern Highlands, Sydney Basin, South East Corner and NSW South Western Slopes bioregions	TEC	MR	3
River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MO	2
White box yellow box Blakely's red gum woodland	TEC	MO	2
Montane peatlands and swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions	TEC	MN	3
Brogo wet vine forest in the South East Corner bioregion	TEC	DD	1
Euphrasia ciliolata	Plant	DD	1
Grevillea beadleana	Plant	DD	1
Lowland grassy woodland in the South East Corner bioregion	TEC	DD	1
Shale sandstone transition forest in the Sydney Basin bioregion	TEC	DD	1
Southern highlands shale woodlands in the Sydney Basin bioregion	TEC	DD	1
Upland wetlands of the drainage divide of the New England Tableland bioregion	TEC	DD	1
Cat's claw creeper			
Lowland rainforest on floodplain in the NSW North Coast bioregion	TEC	MV	3
Floydia praealta (ball nut)	Plant	MR	1
Littoral rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	2
Lowland rainforest in the NSW North Coast and Sydney Basin bioregions	TEC	MR	2
Owenia cepiodora	Plant	MR	1
River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	2
Subtropical coastal floodplain forest of the NSW North Coast bioregion	TEC	MR	2
Syzygium hodkinsoniae	Plant	MR	1
Tinospora smilacina	Plant	MR	1
Tinospora tinosporoides	Plant	MR	1
Coolatai grass			
Bothriochloa biloba	Plant	MV	2
Dichanthium setosum	Plant	MV	2
Thesium australe	Plant	MV	2
Fuzzy box woodland on alluvial soils of the South Western Slopes, Darling Riverine Plains and Brigalow Belt South bioregions	TEC	MR	3
Howell shrublands in the New England Tableland and Nandewar bioregions	TEC	MR	2
Inland grey box woodland in the Riverina, NSW South Western Slopes, Cobar Peneplain, Nandewar and Brigalow Belt South bioregions	TEC	MR	3
White box yellow box Blakely's red gum woodland	TEC	MR	3
Goodenia macbarronii	Plant	DD	1
Homoranthus prolixus	Plant	DD	1
Indigofera baileyi	Plant	DD	1

(a) Weeds			
Interaction name (including threatened entity group)		**Impact**	**n**
Monotaxis macrophylla	Plant	DD	1
Ground asparagus			
Littoral rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	4
Cynanchum elegans	Plant	MO	2
Lowland rainforest in the NSW North Coast and Sydney Basin bioregions	TEC	MO	2
Syzygium paniculatum	Plant	MO	1
Swamp oak floodplain forest of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MN	2
Themeda grassland on seacliffs and coastal headlands in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MC	1
Hudson pear			
Brigalow within the Brigalow Belt South, Nandewar and Darling Riverine Plains bioregions	TEC	MO	2
Carbeen open forest community in the Darling Riverine Plains and Brigalow Belt South bioregions	TEC	MO	2
Lantana			
Illawarra lowlands grassy woodland in the Sydney Basin bioregion	TEC	MR	2
Littoral rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	3
Lowland rainforest in the NSW North Coast and Sydney Basin bioregions	TEC	MR	3
Lowland rainforest on floodplain in the NSW North Coast bioregion	TEC	MR	2
Senna acclinis	Plant	MR	1
Subtropical coastal floodplain forest of the NSW North Coast bioregion	TEC	MR	2
Irenepharsus trypherus	Plant	MO	1
River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MO	3
Swamp oak floodplain forest of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MO	3
Swamp sclerophyll forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MO	1
Syzygium paniculatum	Plant	MO	1
Zieria granulata	Plant	MO	1
Madeira vine			
Lowland rainforest in the NSW North Coast and Sydney Basin bioregions	TEC	MV	3
Lowland rainforest on floodplain in the NSW North Coast bioregion	TEC	MV	2
Littoral rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	3
River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	1
Subtropical coastal floodplain forest of the NSW North Coast bioregion	TEC	MR	2
Illawarra lowlands grassy woodland in the Sydney Basin bioregion	TEC	MO	1
Swamp oak floodplain forest of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MO	2
Illawarra lowlands grassy woodland in the Sydney Basin bioregion	TEC	MN	1

(a) Weeds			
Interaction name (including threatened entity group)		**Impact**	**n**
Mother-of-millions			
Brigalow within the Brigalow Belt South, Nandewar and Darling Riverine Plains bioregions	TEC	MO	2
Inland grey box woodland in the Riverina, NSW South Western Slopes, Cobar Peneplain, Nandewar and Brigalow Belt South bioregions	TEC	MO	1
Shale sandstone transition forest in the Sydney Basin bioregion	TEC	MO	2
Cumberland plain woodland in the Sydney Basin bioregion	TEC	MN	1
Themeda grassland on seacliffs and coastal headlands in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MN	1
Swamp oak floodplain forest of the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MC	2
Oxeye daisy			
Calotis pubescens (Max muellers burr daisy)	Plant	MR	1
Ribbon gum, mountain gum, snow gum grassy forest/woodland	TEC	MR	1
Tablelands snow gum, black sallee, candlebark and ribbon gum grassy woodland in the South Eastern Highlands, Sydney Basin, South East Corner and NSW South Western Slopes bioregions	TEC	MR	1
Carex raleighii	Plant	MO	1
Glycine latrobeana	Plant	MO	2
New England peppermint (Eucalyptus nova-anglica) woodland on basalts and sediments in the New England Tableland bioregion	TEC	MO	1
Rutidosis leiolepis	Plant	MO	1
Discaria nitida (Leafy anchor plant)	Plant	MN	1
Upland wetlands of the drainage divide of the New England Tableland bioregion	TEC	MC	1
Serrated tussock			
Natural temperate grassland of the South Eastern Highlands	TEC	MR	4
Themeda triandra (Kangaroo grass)	Plant	MR	1
White box yellow box Blakely's red gum woodland	TEC	MR	2
Calotis glandulosa (Mauve burr daisy)	Plant	MO	1
Tablelands snow gum, black sallee, candlebark and ribbon gum grassy woodland in the South Eastern Highlands, Sydney Basin, South East Corner and NSW South Western Slopes bioregions	TEC	MO	3
Rutidosis leiolepis	Plant	MN	1
St John's wort			
White box yellow box Blakely's red gum woodland	TEC	MV	1
Inland grey box woodland in the Riverina, NSW South Western Slopes, Cobar Peneplain, Nandewar and Brigalow Belt South bioregions	TEC	MO	1
Natural temperate grassland of the South Eastern Highlands	TEC	MO	1
Tablelands snow gum, black sallee, candlebark and ribbon gum grassy woodland in the South Eastern Highlands, Sydney Basin, South East Corner and NSW South Western Slopes bioregions	TEC	MO	1
Cumberland plain woodland in the Sydney Basin bioregion	TEC	MN	1
Rutidosis leiolepis	Plant	MN	1
Brigalow within the Brigalow Belt South, Nandewar and Darling Riverine Plains bioregions	TEC	MC	1

(b) Pest animals			
Interaction name (including threatened entity group)		**Impact**	**n**
Feral cat			
Isoodon obeseulus (Southern brown bandicoot)	Animal	MR	3
Mastacomys fuscus (Broad toothed rat)	Animal	MR	1
Potorous tridactylus (Long nosed potoroo)	Animal	MR	2
Pseudomys fumeus (Smoky mouse)	Animal	MR	1
Burramys parvus (Mountain pygmy possum)	Animal	MO	1
Dasyurus maculatus (Spotted tailed quoll)	Animal	MO	2
Petrogale penicillata (Brush tailed rock wallaby)	Animal	MO	2
Pseudomys oralis (Hastings River mouse)	Animal	MO	2
Pseudomys pilligaensis (Pilliga mouse)	Animal	MO	1
Leipoa ocellata (Malleefowl)	Animal	MN	2
Feral deer			
Discaria nitida (Leafy anchor plant)	Plant	MR	2
Littoral rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	2
Howell shrublands in the New England Tableland and Nandewar bioregions	TEC	MO	1
Illawarra lowlands grassy woodland in the Sydney Basin bioregion	TEC	MO	2
Montane peatlands and swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions	TEC	MO	3
Pomaderris pallida (Pale pomaderris)	Plant	MO	1
Eucalyptus saxatilis (Suggan buggan mallee)	Plant	MN	2
Petrogale penicillata (Brush tailed rock wallaby)	Animal	MN	2
Feral goat			
Petrogale penicillata (Brush tailed rock wallaby)	Animal	MV	1
Acacia carneorum (Purple wood wattle)	Plant	MR	2
Astrosticha roddii (Rodd's star hair)	Plant	MR	3
Howell shrublands in the New England Tableland and Nandewar bioregions	TEC	MR	2
Sandhill pine woodland in the Riverina, Murray-Darling Depression and NSW South Western Slopes bioregions	TEC	MR	1
Acacia curranii (Curly bark wattle)	Plant	MO	5
Acacia pubifolia (Velvet wattle)	Plant	MO	2
Bossiaea fragrans	Plant	MO	2
Grevillea iaspicula (Wee Jasper grevillea)	Plant	MO	1
Petrogale xanthopus (Yellow footed rock wallaby)	Animal	MO	4
Pomaderris cocoparrana	Plant	MO	3
Feral horse			
Mastacomys fuscus (Broad toothed rat)	Animal	MR	2
Montane peatlands and swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions	TEC	MO	4
Petrogale penicillata (Brush tailed rock wallaby)	Animal	MN	3
Euphrasia ciliolata	Plant	DD	1

(b) Pest animals			
Interaction name (including threatened entity group)		**Impact**	**n**
Pseudophryne corroboree (Southern corroboree frog)	Animal	DD	1
Feral pig			
Artesian springs ecological community in the Great Artesian Basin	TEC	MR	2
Howell shrublands in the New England Tableland and Nandewar bioregions	TEC	MO	1
Montane peatlands and swamps of the New England Tableland, NSW North Coast, Sydney Basin, South East Corner, South Eastern Highlands and Australian Alps bioregions	TEC	MO	3
Bossiaea fragrans	Plant	MN	1
Litoria booroolongensis (Boorolong frog)	Animal	MN	1
Feral rabbit			
Acacia carneorum (Purple wood wattle)	Plant	MV	1
Themeda grassland on seacliffs and coastal headlands in the NSW North Coast, Sydney Basin and South East Corner bioregions	TEC	MR	1
Acacia curranii (Curly bark wattle)	Plant	MO	4
Howell shrublands in the New England Tableland and Nandewar bioregions	TEC	MO	2
Sandhill pine woodland in the Riverina, Murray-Darling Depression and NSW South Western Slopes bioregions	TEC	MO	1
Zieria baeuerlenii	Plant	MO	2
Acacia terminalis (Sunshine wattle)	Plant	MN	1
Calotis pubescens (Max muellers burr daisy)	Plant	MN	2
Rutidosis leptorrhynchoides (Button wrinklwort)	Plant	MN	1
Discaria nitida (Leafy anchor plant)	Plant	MC	2
Red fox			
Dasyurus maculatus (Spotted tailed quoll)	Animal	MR	3
Haematopus longirostris (Pied oystercatcher)	Animal	MR	2
Isoodon obeseulus (Southern brown bandicoot)	Animal	MR	3
Leipoa ocellata (Malleefowl)	Animal	MR	1
Mastacomys fuscus (Broad toothed rat)	Animal	MR	1
Pedionomus torquatus (Plains wanderer)	Animal	MR	4
Petrogale xanthopus (Yellow footed rock wallaby)	Animal	MR	3
Sternula albifrons (Little tern)	Animal	MR	2
Burramys parvus (Mountain pygmy possum)	Animal	MO	1
Petrogale penicillata (Brush tailed rock wallaby)	Animal	MO	3
Potorous tridactylus (Long nosed potoroo)	Animal	MO	3

4.6 Results: likelihood of impact and most harmful invasive alien species

The likelihood of IAS impact metric integrated information on both the magnitude of impact category assigned by expert assessors and the uncertainty of the assessment (relating to both the confidence of each expert in making a judgement, and to diverging assessments between different experts). It was calculated by averaging expert assessments across all interactions with listed threatened species and ecological communities, thus masking variability between different interactions (see section 4.5, Table 9). Some of the seven assessed pest animals and 15 assessed weeds were, on average, more likely to have severe impacts on threatened species and ecological communities than others (Figure 8).

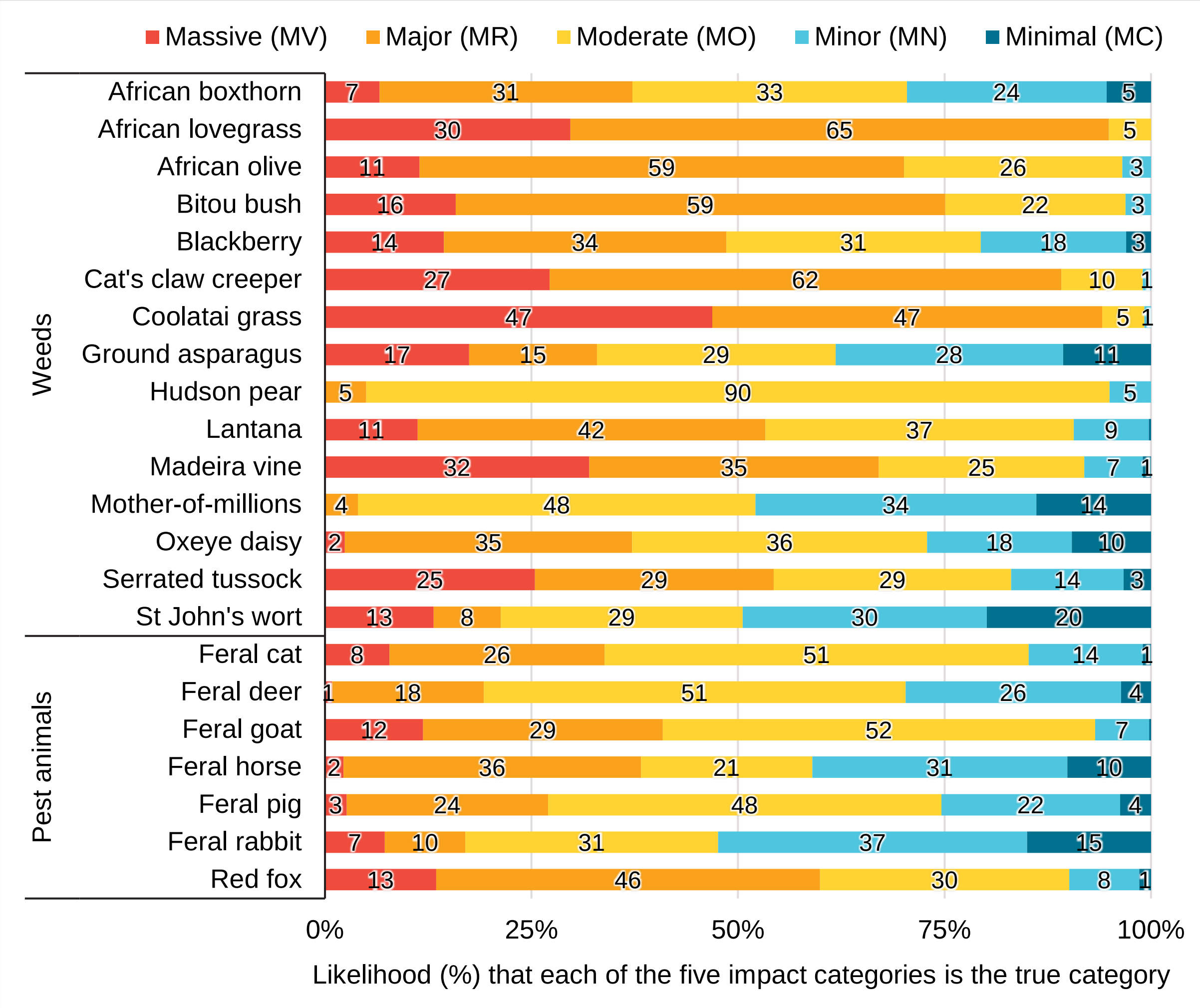


Figure 8 **Expert-elicited likelihood that the impact caused by IAS is of a certain magnitude (by individual IAS).**

The figure shows the likelihood (in percent of total) that each of the five impact categories is the true category, averaged across all interactions with threatened species and ecological communities that were assessed against an IAS. The 15 assessed weeds are listed first, followed by the seven assessed pest animals. Scientific IAS names are in Table 4. The data underlying this figure, including the number of assessed interactions and contributing expert assessors per IAS, are provided in Appendix D, Table 15.

Nine out of 22 (41%) IAS were assessed by experts as having a greater than 50% chance of causing local population extirpations (i.e. major [MR] reversible or massive [MV] irreversible impact) among the threatened species and ecological communities against which they were assessed. These ‘most harmful IAS’ included one pest animal (red fox) and eight weeds. Of these eight weeds, all assessed perennial grasses (African lovegrass, coolatai grass and serrated tussock) and vines (cat’s claw creeper and Madeira vine) as well as two woody shrubs (bitou bush and lantana) and one invasive tree (African olive) were among the most harmful IAS (see Figure 9).

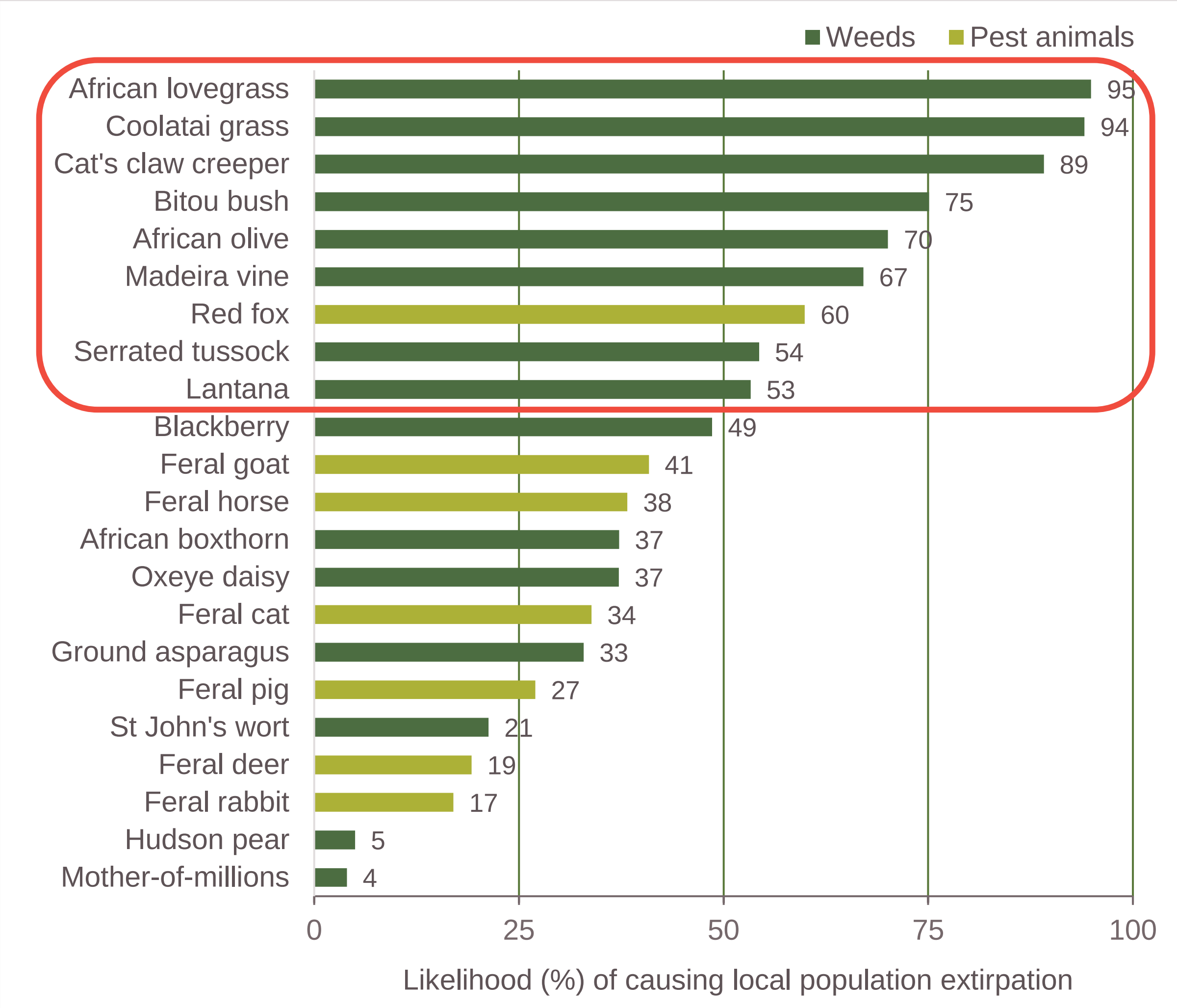


Figure 9 **Expert-elicited ‘most harmful IAS’ in this assessment.**

The most harmful IAS (circled in red) were defined as those IAS that were assessed by experts as having, on average, a greater than 50% chance of causing local population extirpations among the threatened species, or characteristic species of the threatened ecological communities against which they were assessed.

When averaging expert assessments for the two IAS biological dimensions (weeds, pest animals; see Appendix D, Table 16), there was an 85% chance that assessed threatened species are experiencing a decline in population size, and assessed threatened ecological communities are experiencing compositional changes due to a population decline in at least one characteristic species, as a result of weed impacts (impact likely moderate [MO] or higher). The average likelihood that weed impacts result in the extirpation of at least one local population of a threatened species, or at least one characteristic species in at least one remnant patch of a threatened ecological community, was 57% (impact likely major [MR] or massive [MV]). For pest animals, the average likelihood of causing population declines was similar (78% likelihood that impact is moderate [MO] or higher). However, pest animals were assessed by experts as much less likely to cause local population extirpations than weeds (36% average likelihood that impact is major [MR] or massive [MV]) (Table 16).

The magnitude of impact varied between the 16 threatened animals, 46 threatened plants and 35 threatened ecological communities that were assessed (see Appendix D, Table 16). Threatened ecological communities were assessed as more likely to be affected by extirpations than threatened plants and animals: threatened ecological communities had a 54% chance of extirpation of characteristic species in at least one remnant patch; threatened animals or plants had a 45% and 41% chance respectively of being affected by extirpations of at least one local population. IAS impacts on the population size (i.e. impact is moderate [MO] or higher) of threatened plants and animals, or characteristic species of threatened ecological communities, were assessed similarly (77%, 82% and 84% likelihood).

5. Discussion

5.1 Interpretation

5.1.1 Invasive alien species status list

The IAS status list generated in this first assessment (see Appendix B) represents alien species that had been identified as current or potential future threats to native biodiversity and ecosystem quality in New South Wales in at least one of several authoritative data sources accessed in November 2019 (see Table 1). This is a valuable novel data product that can be relatively easily maintained and updated in future assessments, pending a review by domain experts (see section 5.2). If the underlying data sources are updated (e.g. new threats identified in one of the data sources) during future assessments, the IAS status list would be updated following the workflows detailed in Table 1. If further data sources were added, for example, to achieve a better representation of biological groups other than (mostly vertebrate) pest animals and weeds, new workflows would need to be added (see section 5.2). The IAS richness and IAS spatial extent metrics of the IAS exposure dimension of the IAS pressure indicator would be retrospectively recalculated for this first assessment using the updated IAS status list to allow comparisons across time.

5.1.2 Invasive alien species exposure: richness metric

State-scale analysis

The statewide IAS richness metric signals the overall size of the IAS challenge faced by NSW land managers. In this first assessment we found that 344 IAS, or 83% of the 413 identified current or potential future IAS threats on the IAS status list, were recorded as naturalised in at least one location in New South Wales. Among those 344 IAS there were 305 weeds (85% of the 360 identified weed species on the IAS status list), 36 pest animals (73% of the 49 identified pest animal species on the IAS status list) and three diseases (75% of the four identified diseases on the IAS status list). These figures are comparable to previous estimates in *NSW State of the Environment 2018* (340 known weed threats and 64 naturalised terrestrial and freshwater pest animals; EPA 2018) and *NSW State of Biosecurity 2017* (266 weeds and 17 terrestrial vertebrate pest animals managed to reduce environmental impacts; DPI 2018). Differences may be explained by different measurement approaches, for example:

- Previous reports were based on knowledge about IAS status rather than on spatial information on IAS occurrence. We integrated spatial data across two major data repositories and a statewide survey of vertebrate pest animal occurrence (see section 3.2.2).
- Previous reports did not explicitly refer to a particular time period. We included all point occurrence records collected between 1980 and 2017, and pest animal survey data collected in 2016 (see section 3.2.2).
- Previous reports were informed by few data sources or references that were not always clearly specified. We attempted to compile a comprehensive IAS status list of identified current or potential future threats to native biodiversity and ecosystem quality in New South Wales. We drew on nine previous authoritative prioritisation processes conducted by IAS management agencies in New South Wales and nationally (see section 3.1), and used this IAS status list to collate spatial data on IAS occurrence.

By developing and documenting repeatable workflows to enable its consistent measurement, the IAS richness metric reported here adds value to previous reports. It may be used to track new introductions in future assessments (i.e. of alien species identified as potential future biodiversity threats on the IAS status list but not yet recorded in New South Wales at the time of this first assessment). It may also be used to summarise, at a glance, those identified future IAS threats that have not yet been recorded in New South Wales and whose introduction must be prevented.

Both intermediate data products used in the calculation of statewide IAS richness (i.e. the IAS status list and the integrated IAS occurrence dataset) are incomplete and not free of bias (see section 5.2). Hence, the results from this first assessment should be viewed as representing publicly accessible records for the most commonly identified IAS in the most well-documented biological groups: weeds and (mostly vertebrate) pest animals. However, these data products were designed to be updateable if new information or better spatial data become available, for example, if a new IAS is identified in one of data sources used to compile the IAS status list, or more systematic IAS surveys are conducted. If IAS richness was also retrospectively recalculated for this first assessment using these updated data products, change may still be rigorously evaluated.

Bioregion-scale analysis

This first assessment found considerable variability in weed richness between bioregions along a coastal–inland gradient, with much higher numbers of weeds recorded in the bioregions in eastern New South Wales. Pest animal richness was much more evenly distributed across bioregions. Results may have been influenced by reporting bias in the collated occurrence records, and because statewide gridded datasets were available only for vertebrate pest animals (see section 5.2). Nevertheless, we expect that patterns of weed and pest animal richness observed at this coarse spatial scale are indicative of ‘true’ invasion levels (Haque et al. 2017). The data on disease IAS status and occurrence collated in this first assessment were insufficient to enable a bioregion-scale analysis.

A range of factors may have contributed to the observed bioregion-scale patterns for pest animals and weeds:

- Biological traits: The characteristics of many pest animals such as large mammals or birds (high mobility, capacity for long-distance dispersal, tendency to be habitat generalists with broad ecological niches) may have allowed them to spread widely across all bioregions.
- Historical factors: Most vertebrate pest animals were first introduced during early European settlement, 200 years ago, providing sufficient time and opportunity to spread throughout the State. By contrast, new weeds continue to emerge and spread, mainly where introduction pathways are prevalent and propagule pressure is highest (i.e. near human population centres in coastal bioregions).
- Habitat heterogeneity: Higher weed richness in coastal bioregions may be due to a greater diversity in invaded ecosystems and habitat types (including coastal, rainforest, grassland, woodland, high altitude, wetland and other ecosystems). Observed patterns of IAS richness may simply reflect differences in native species richness (Peng et al. 2019). Measuring relative IAS richness (Catford et al. 2012) may help to elucidate this effect (see section 5.2).

The observed coarse-scale spatial patterns of IAS richness may be considered in future management planning. For example, bioregions with high IAS richness may be interpreted both as areas exposed to intense invasion pressures, and as sources of IAS that may threaten native biodiversity and ecosystem quality in adjacent bioregions with currently low IAS richness. Such ‘high-risk’ bioregions may be strategically prioritised for more comprehensive risk analyses to support tactical decisions on appropriate mitigation measures (aimed at minimising existing exposure to IAS pressures) or preventative measures (aimed at avoiding further IAS exposure by controlling pathways of introduction and spread).

Grid-scale analysis

The grid-scale analysis showed that there was also considerable local variability in weed richness within bioregions. Areas of very high local weed richness were concentrated around human population centres. These grid-scale patterns ultimately influenced the overall coastal–inland gradient observed at the bioregion scale. Local variability in pest animal richness was much less pronounced. Patterns of IAS richness observed at the grid scale were more strongly affected by data limitations than bioregion-scale or statewide results (Haque et al. 2017; see section 5.2), but also by the following contextual factors:

- Reporting bias and data gaps: Weed occurrence records were more likely collected near human population centres because there are more observers, monitoring resources and better access. For vertebrate pest animals, continuous statewide spatial data was available from the NSW Pest Animal Survey.
- Introduction rates and propagule pressure: New weeds were more likely to be introduced and spread near human population centres because there are more gardens, social and economic activities, imported goods and greater connectivity between sources of propagule pressure.
- Disturbance: New weeds were more likely to establish in disturbed habitats near human population centres.

The novel gridded IAS richness maps for weeds and pest animals developed here may be usefully integrated with other data products in a range of spatial analyses, including to inform future assessments of the Biodiversity Indicator Program indicator 3.1a: ecological condition (OEH & CSIRO 2019) or spatially explicit metrics of IAS impact (see section 5.2). Local IAS richness may be considered when determining priority areas for interventions (mitigation in areas with high IAS richness, and preventative measures in areas with low IAS richness that are adjacent to high richness areas). A more immediate application of grid-scale results may be to identify data deficient areas where additional data on IAS occurrence is needed for future assessments.

5.1.3 Invasive alien species pressure: spatial extent metric

The IAS spatial extent metric was designed to quantify the invasiveness of species and was calculated as the proportion of NSW grid cells with a resolution of approximately 5 kilometres where an IAS was recorded as naturalised in at least one location in New South Wales. The AOO maps for 344 IAS (305 weeds, 36 pest animals, three diseases) are a valuable novel data product. However, like the IAS richness metrics discussed above, these AOO maps and the derived spatial extent metric should be viewed as preliminary estimates representing publicly accessible occurrence records rather than the true spatial extent for each IAS (see section 5.2).

This first assessment showed that most IAS have a very limited spatial extent. There were only a few IAS that were widely recorded across the State, and these were all vertebrate pest animals. While these results were influenced by differences in data sources (only occurrence records for weeds and additional statewide gridded data for vertebrate pest animals were used), they are comparable to the results of South Australia’s IAS indicator (DEW 2018). If additional and improved spatial data can be integrated, and AOO accuracy verified, IAS spatial extent could be analysed by taxonomic or functional groups to gain deeper insights into common traits of widespread IAS (Catford et al. 2012; Wilson et al. 2018).

The spatial extent metric and its underlying AOO maps may also be used to inform future policy by indicating the area(s) where interventions to mitigate IAS exposure may be needed. Note that a restricted spatial extent does not necessarily indicate that species invasiveness and impact is low. For example, where the distribution ranges of a spatially restricted IAS and a sensitive native species overlap the impact may be high. Preventing potential future exposure of biodiversity to currently restricted IAS that may still be expanding their invaded range is an important goal of IAS management (UN 2015; CBD Secretariat 2019b). Comparisons between this first and future assessments may be used to demonstrate range expansions of IAS (Wilson et al. 2018; Hardisty et al. 2019). However, the metric in its current form is not well suited to demonstrating range contraction, for example as a result of local eradication, because absence records were not integrated into the AOO mapping methodology.

5.1.4 Invasive alien species impact

We developed a systematic, repeatable and comparable method for assessing IAS impact (i.e. the consequences of IAS pressures on native biodiversity and ecosystems) in the Biodiversity Indicator Program, drawing on the international EICAT standard. Our aim was to conduct a pilot study that demonstrates how the proposed method may be consistently implemented using a structured expert elicitation protocol. We took a pragmatic approach to data collection within the capacity and time constraints of this first assessment. Due to various limitations in the approach (see section 5.2), the results of this pilot study should be reported and interpreted with appropriate caution. Results refer only to those particular interactions between IAS and listed threatened species and ecological communities that were assessed. They are not representative of all IAS impacts on all native species and ecological communities sensitive to these impacts. While the proposed method can be consistently implemented in future assessments, allowing us in principle to detect change over time, we caution against directly comparing any future findings to the results of this first assessment, and make suggestions to enable better comparability in future (see section 5.2).

We proposed two probabilistic metrics for reporting on the impact dimension of the IAS pressure indicator: likelihood of IAS impact and most harmful IAS. We also determined the most likely magnitude of impact for each interaction between an IAS and a native species or ecological community. While the more complex probabilistic metrics were intended to integrate information on both the intensity of impact and the uncertainty in its assessment (Vilà et al. 2019), the deterministic metric may be better suited to (cautiously) highlighting any changes in future assessments of these same interactions.

This first assessment showed that the assessed IAS are likely causing significant impacts on those threatened species and ecological communities that were assessed. There were pronounced differences in the magnitude of impact between IAS, and also between the two assessed biological dimensions (pest animals and weeds), in general. Eight out of nine species that met the impact threshold for the most harmful IAS metric (i.e. 50% chance of causing extirpations among threatened species or ecological communities) were weeds. Red foxes were the only pest animal among these most significant biodiversity threats. In contrast, seven of the 15 assessed weeds and six of the seven assessed pest animals did not meet this impact threshold. These observed patterns may be due to intrinsic biological traits, contextual factors that modulate the magnitude of impact, or assessment bias.

Assessment bias may have contributed in at least two ways to the reported results:

- Bias in assessable interactions: Overall, the 999 impact categories assigned by experts were statistically normally distributed. This suggests that the entire set of assessable interactions was reasonably comprehensive, that is, not strongly biased towards very high or very low magnitudes of impact. However, there may have been differences between IAS. For example, IAS ‘X’ may have been assessed only against the most severely affected native species and ecological communities, while for IAS 'Y' the list of assessable interactions may have been more comprehensive. This does not necessarily mean that IAS 'Y' does not cause severe impacts on many other native species and ecological communities which were not assessed. This issue could only be addressed if a comprehensive, comparable and ideally representative set of interactions was assessed for each IAS (see section 5.2).

- Bias in expert assessments: Individual experts who assessed multiple interactions typically assigned a range of different impact categories to different interactions. This suggests that experts were discerning in their assessments and that differences in impact were not solely due to certain experts always assigning higher impact than others. However, experts' interpretation of impact may have varied between different IAS and the interactions against which they were assessed. For example, threatened ecological communities were often assessed as more severely affected by IAS than threatened animals or plants. This may be an artefact of the assessment method. It may be intrinsically more likely that 'at least one characteristic species in at least one remnant patch of a threatened ecological community' is extirpated than 'at least one local population of a threatened species'. The difference may also be due to expert perceptions of impact, with a displacement of a characteristic species in a threatened community's remnant patch being more easily perceived than the extirpation of a threatened species' local population. As the impacts on threatened ecological communities were much more often assessed for weeds than pest animals, this may have influenced the different results between the two biological groups.

A range of contextual factors may also have contributed to the surprising result that impacts currently caused by many weeds appear greater than impacts caused by pest animals:

- Differences in management: For example, investment in the NSW *Saving our Species* program has mostly prioritised threatened species management over the management of threatened ecological communities. While there are other management programs focusing on threatened ecological communities, the recent focus on managing impacts of pest animals on vulnerable threatened animals may have influenced the assessments of current magnitudes of impact reported here.
- Evidence base: Intensive monitoring of the threatened animals and high priority pest animals included in this assessment through the NSW *Saving our Species* program may have allowed experts to assess impacts more realistically than for some weeds. This implies that experts may have overestimated impact in the absence of data (Dueñas et al. 2019).
- Historical factors: Many local and statewide extinctions of native species (especially small mammals) attributed to pest animals may have already occurred during the history of their invasion (Woinarski et al. 2015); whereas the impacts of some of the most harmful weeds identified here (e.g. African lovegrass) may be more acutely happening under the 'current contexts' at the time of this first assessment.

Lastly, differences in the magnitude of impact may be due to biological traits of species. The presence of three perennial grasses and two vines among the most harmful IAS may point to underlying functional determinants of impact. However, a more representative set of IAS would need to be assessed to explore such questions with rigour.

The expert-informed impact assessment collected novel data on the likely magnitude of impact caused by IAS on a set of listed threatened species and ecological communities in New South Wales. We have emphasised that the results of this pilot study should be interpreted with appropriate caution. A more comprehensive and representative approach to data collection is needed. Expert-elicited assessments should also be validated against empirical data (see section 5.2).

Verified assessment results may then be used to inform the development of strategic and tactical approaches to management. For example, the identified most harmful IAS may need to be managed with more intensity so that impacts are reduced to acceptable levels. Management effectiveness could be measured by comparing the likelihood of impact for these IAS between future assessments. If verified by empirical data, management may also need to strategically respond to our finding that many weeds currently cause severe impacts on the persistence of threatened species and ecological communities. Our results suggest that in some instances current impacts may have already been effectively reduced for some high priority pest animals. Research and monitoring efforts may be most usefully focused on those IAS assessed with relatively high impact but low confidence. Finally, an encouraging finding was that there were very few interactions where the magnitude of IAS impact was assessed by experts as most likely leading to irreversible extirpations (i.e. massive [MV] impact). When recalling that only impacts on native species that are already threatened were assessed, this indicates that ongoing removal of IAS from localised areas could result in species and ecological communities recovering even where severely impacted.

5.2 Caveats and recommendations

5.2.1 Invasive alien species exposure

Invasive alien species status list

The IAS richness metric is clearly influenced by the number of IAS that are included in the analysis in the first place. Here, we compiled an IAS status list comprised of 413 species (360 weeds, 49 pest animals and four diseases) that had been identified as current or potential future threats to native biodiversity and ecosystem quality in New South Wales in at least one of several authoritative data sources (see section 3.1). There are several caveats to this approach:

- First, we could not confidently determine all IAS from the data sources. For example, the NSW *Biosecurity Act 2015* and Biosecurity Regulation 2017 did not distinguish between species that threaten NSW native biodiversity and those listed for socio-economic impacts. As a result, we did not list any ‘prohibited plant pests and diseases’ (mostly crop pests but potentially also threatening native flora), ‘animal pests and diseases’ (mostly livestock diseases but potentially also threatening wildlife) or ‘pest marine and freshwater finfish’ (no distinction between marine and terrestrial freshwater species).
- Second, the final IAS status list contained some taxonomic uncertainties that could not be resolved in this first assessment despite efforts to clean and harmonise the list. These include: listings at genus, subspecies or variety level rather than species level; possible taxonomic naming errors as indicated by missing values in the Australian Plant Name Index; and some remaining questions around synonymous taxon names. These issues affected the collation of occurrence records for some IAS, but were unlikely to have had a large effect on overall results.
- Third, the data sources themselves are incomplete collections of species lists based on previous published and unpublished information. They may be neither representative nor complete, especially with regards to the multitude of IAS that have not yet been introduced, or have only recently emerged, in New South Wales and may pose a potential future threat to native biodiversity and ecosystem quality.

Therefore, the final IAS status list (see Appendix B) should be viewed as a representation of commonly identified IAS rather than a comprehensive collection of all current or potential future IAS threats to native biodiversity and ecosystem quality in New South Wales. We are confident that the list is adequately complete for vertebrate pest animals and weeds (except for the KTP invasion of escaped garden plants, including aquatic plants, which comprises a complex of many species that would need to be explicitly listed to allow for identification on the IAS status list). Other biological groups of IAS such as invertebrate pest animals, freshwater aquatic pests and plant or wildlife diseases are inadequately represented. In particular, only four diseases (those listed as NSW KTPs at the time of this assessment) were included in the IAS status list, making any results for this IAS group in this first assessment unreliable. In order to generate an authoritative, updateable IAS status list for future use in the Biodiversity Indicator Program, we recommend that the current list be reviewed and extended in consultation with taxonomic domain experts. This work could also aim to comprehensively integrate potential future IAS threats, for example, drawing on the recent national priority list of exotic environmental pests and diseases (ABARES 2019).

Invasive alien species occurrence records

There are also several caveats associated with the spatial data that was collated to map the AOO of identified IAS on the status list. On the one hand, we adopted an integrative approach to collating fragmented and often incomplete datasets for all identified IAS across agencies and data repositories (Hardisty et al. 2019). This is a common issue particularly for IAS, where different biological groups and types of IAS are managed by various agencies at local, state and national levels, and monitoring is rarely coordinated. On the other hand, we relied on major data sources with statewide coverage to ensure that repeatable data collation and harmonisation workflows with limited manual processing could be implemented.

We drew on occurrence records from two large data repositories (ALA and BioNet Atlas) covering, in principle, all IAS biological groups and types of IAS. However, occurrence records are inconsistently accumulated across space and time (Haque et al. 2017). This may have led to data gaps where IAS are recorded only in parts of the ‘true’ invaded area. There may also be reporting bias, where some invaded areas are preferentially surveyed over other areas or some IAS are preferentially recorded than other IAS, for reasons unrelated to invasion levels (e.g. better accessibility, detectability or legislative status). As a result, the absence of an occurrence record may not indicate field absence, and the AOO maps generated here may have underestimated the ‘true’ spatial extent of some IAS. In this first assessment, we had limited capacity to address data gaps and bias or to verify data quality.

There are several caveats to our approach:

- We searched for any occurrence records from an extended period, 1 January 1980 to 25 August 2017 (i.e. the commencement date of the BC Act) to minimise the likelihood of missing valid records of naturalised populations. However, this meant that not all records may represent current naturalised occurrences at the time of this assessment, for example:
  - IAS was not present (e.g. misidentified or wrongly georeferenced)
  - IAS was present but not naturalised (e.g. garden specimen)
  - IAS was naturalised but has since been eradicated/disappeared naturally.
- For 16 vertebrate pest animals, we complemented occurrence records by data from the statewide gridded NSW Pest Animal Survey (Trotter pers. comm.). We were unable to source and access similar statewide occurrence data for other IAS biological groups (i.e. weeds, diseases and non-vertebrate pest animals). However, this dataset, based on largely unverified expert knowledge and some verified occurrence information collected in 2016 (but building on previous survey data dating back to 2002), is difficult to compare with the occurrence records sourced from ALA and BioNet Atlas and spanning a much longer time period (1980 to 2017).

As a result of these data caveats, the generated AOO maps and derived IAS spatial extent and IAS richness metrics of the IAS exposure dimension of the IAS pressure indicator may not readily allow comparisons across different IAS, biological dimensions and time periods. Further spatial data could be integrated in future assessments to enhance data completeness and comparability. For example, the NSW Biosecurity Information System (BIS) which has recently been mandated for local weed management agencies across the State (DPI 2017) may provide an opportunity for a comprehensive, standardised, statewide dataset of weed species in New South Wales. Unfortunately, the BIS was not publicly available at the time of this first assessment. Integrating more detailed datasets for particular biological groups or invaded areas that are collected by a range of IAS management agencies or research institutions would require significant additional effort into developing repeatable data harmonisation and integration workflows.

Area of occupancy mapping

In addition to the caveats associated with data sources, the AOO mapping methodology implemented in this first assessment had two important limitations affecting the accuracy and utility of results:

- To limit the effects of data gaps and reporting bias, we considered a spatial resolution of ~5 kilometres to be more appropriate than the ~2-kilometre resolution typically used in threatened species' Red Listing (IUCN 2017). If an IAS was not recorded throughout its 'true' invaded area, a fine-grained AOO map would severely underestimate its spatial extent. However, at coarser mapping resolutions it becomes increasingly difficult to discriminate between occupied and unoccupied areas, resulting in an AOO map that overestimates a species' spatial extent (Gaston & Fuller 2008). To avoid misrepresentation of the relatively coarse-grained results derived from our AOO maps, we reported spatial extent as a proportional metric (proportion of NSW grid cells occupied by an IAS) rather than in absolute square kilometre units. For an IAS with only one occurrence record, the reported spatial extent of the occupied grid cell would have been ~25 km^2 when it may in fact be orders of magnitude smaller.
- Comparisons between this first and future assessments may detect change, or growth in recorded knowledge, only in terms of range expansion (IAS spatial extent) or increases in invasion level (IAS richness). However, our methods are presently not suited to detecting any decrease in IAS spatial extent or IAS richness, for example, due to successful local, regional or statewide eradication, because spatial data on IAS absences was not integrated.

Both caveats could be addressed if more systematically collected, complete and verified field monitoring data was available that (i) labels IAS occurrence at a finer resolution, and (ii) reliably labels IAS absence, including disappearance from localities where it has previously been recorded as present. This would enable more accurate AOO mapping at a finer spatial resolution (e.g. 2 kilometres as used for Red Listing) and improve comparability between different IAS and biological dimensions as well as change detection across time. However, this would require additional investment into statewide data collection and integration, including setting data acquisition priorities.

Bioregion-scale analysis

In our bioregion-scale analysis of IAS richness, an IAS was counted towards a bioregion if it was recorded in at least one location in that bioregion between the period 1980 to 2017. The metric was therefore less affected by data gaps than grid-scale metrics (Haque et al. 2017). However, this meant that the size of the bioregion itself influenced results: larger bioregions had an increased likelihood of returning IAS occurrence records simply due to their larger size rather than a higher invasion level. In contrast, bioregions that extended beyond the NSW border into adjacent states may have reported lower IAS richness solely by virtue of their small size within New South Wales. Measuring relative IAS richness may be a better, scale-independent alternative (see below).

Alternative metrics of invasive alien species exposure

In this first assessment, we focused on developing and implementing metrics of biodiversity exposure to IAS pressures that can be derived from information about IAS status and occurrence, which are by far the most readily available and accessible types of data for IAS (Catford et al. 2012; Latombe et al. 2017; O'Loughlin et al. 2019). However, a range of alternative metrics may be developed that can address some of the shortcomings discussed above and give complementary insights into the invasiveness of species or the invasion level of invaded areas (Catford et al. 2012; Pearson et al. 2016; Wilson et al. 2018). These require additional data that are rarely available at the statewide scale for a large number of IAS and were therefore not implemented in this first assessment.

First, IAS richness is strongly influenced by both the scale at which it is measured and the diversity and richness of native communities within an invaded area (Catford et al. 2012; Peng et al. 2019). A relative IAS richness metric (measured as the proportion of all species, including native and alien, that are IAS) would be both scale-independent and give better insights into the degree of IAS pressure that the native biodiversity in an invaded area is exposed to (Catford et al. 2012; Wilson et al. 2018). For example, where low IAS richness coincides with low native species richness, native species and ecological communities may still be exposed to high levels of IAS pressure. The relative IAS richness metric could equally be applied at the statewide, bioregion and grid scales. However, additional efforts into collating spatial data on native species richness and developing data harmonisation and integration workflows would be required. In the first instance, occurrence records of native species in the same major data repositories used here (ALA and BioNet Atlas) may be used. Alternatively, it may be possible to derive a more robust measure of native species richness from existing spatial products developed as part of the Biodiversity Indicator Program (Nipperess et al. 2020) or from field-based monitoring programs.

Second, the presence and overall richness of IAS in an invaded area may not be a good indicator of invasion level, providing a simplistic view on biodiversity exposure to IAS pressures. IAS abundance (measured as the number of individuals, biomass, percent cover or density) has been found to be a more accurate indicator of invasiveness (when measured for a species) or invasion level (when measured across all IAS that are occurring in an invaded area) (Pearson et al. 2016; Fleming et al. 2017; O'Loughlin et al. 2019). Additionally, IAS are rarely eradicated, even locally, with a more common management outcome being a reduction in abundance. Measuring IAS abundance may better allow us to detect both increases and decreases in invasion level in future assessments. However, data on any of the potential measures of abundance are rarely available at the state scale and collecting data for a large number of IAS statewide may be cost-prohibitive (Catford et al. 2012). An alternative way forward may be to explore model-based approaches to inferring abundance from occurrence records (e.g. Croft, Chauvenet & Smith 2017; Jetz et al. 2019).

Third, each IAS that was (i) identified on the IAS status list as a current or potential future threat to native biodiversity and ecosystem quality and (ii) recorded as naturalised in at least one location in an invaded area contributed equally to IAS richness. This may not reflect the different degrees of threat posed by different IAS on native biodiversity and ecosystem quality. Data on the breadth of IAS impacts (i.e. occurrence of an IAS impacting a large number of sensitive species and ecological communities poses a greater threat than occurrence of an IAS impacting few species and ecological communities) may be usefully integrated in future assessments (see section 5.2.2).

Fourth, an alternative top-down, macro-ecological approach could be adopted in place of the bottom-up approach described in this report. We measured IAS occurrence and AOO at the level of species and derived aggregated metrics of IAS richness for three IAS biological dimensions: pest animals, weeds and diseases. In contrast, the exposure to collective IAS pressures in an invaded area could be measured without considering which species the IAS assemblage is made up of. For example, Early et al. (2016) recently mapped IAS threats at a global scale by analysing spatial data on a range of covariates representing both environmental and anthropogenic drivers of IAS introduction and establishment.

5.2.2 Invasive alien species impact

We have repeatedly stressed that the approach to data collection in this first assessment was pragmatic. Our intent was to conduct a pilot study that demonstrates how the proposed assessment method may be consistently implemented using a structured expert elicitation protocol, allowing us in principle to detect change over time. However, we caution against directly comparing any future findings to the results reported here.

Selection of assessable interactions

Firstly, we selected a limited set of known interactions between widespread IAS that are currently of significant concern (vertebrate pest animals and weeds only) and native species or ecological communities that are listed as threatened under the BC Act. These were considered most appropriate to assess in this pilot study due to a relatively broad evidence base and greater availability of experts. While efforts were made to capture a broad range of biodiversity impacts for each assessed IAS, including opportunities for expert feedback and revision, the list of assessable interactions is inherently not representative of all IAS impacts on native biodiversity in its entirety (OEH & CSIRO 2019).

Secondly, the list of assessable interactions may have been biased in different directions for each IAS. While some IAS may have been assessed only against the most severely affected native species and ecological communities, other IAS may have been assessed against species and ecological communities that are less affected by their impacts. Thus, it is possible that different results may be due to inherent differences in the assessed interactions, rather than differences in the magnitude of impacts caused by an IAS.

For better comparability between all IAS, and between future assessments (comparability to this first assessment would be limited), we recommend a systematic approach to selecting a set of assessable interactions be implemented in future. A comprehensive, comparable and representative set of interactions should capture indicative examples of the following:

- for each IAS that is assessed, detrimental impacts on both threatened and non-threatened species and ecological communities
- for each IAS that is assessed, detrimental impacts observed in all bioregions and habitat types occupied by that IAS
- for each IAS that is assessed, all mechanisms by which impacts are caused
- impacts caused by vertebrate pest animals and weeds that are more localised or of less significant concern than the ones assessed here
- impacts caused by biological groups and types of IAS that were not assessed here, for example, plant and wildlife diseases, invertebrate pest animals, or freshwater aquatic pests and plants.

However, developing such a representative set and implementing a more comprehensive assessment would require further investment and mainstreaming within agency work plans.

Assessment method

In this pilot study, considerable effort was put into developing a consistent assessment framework, customised to the needs of the Biodiversity Indicator Program, as well as repeatable methods for its implementation using expert elicitation. This included a structured approach to elicitation with opportunities for revision (McBride et al. 2012; Hemming et al. 2018), an assessment workbook containing comprehensive elicitation materials and guidance on key concepts and assessment steps, semi-automated assessment tasks to minimise error, and repeatable analysis scripts. We acknowledge that any data collection based on expert knowledge is subject to inherent bias. Within the constraints of this first assessment, we could only recruit relatively few participating experts (n = 36). This meant that 49% of interactions were assessed by only one expert. Hence, the results reported here may be particularly vulnerable to bias and should be viewed with appropriate caution.

There are several caveats to our approach:

- Individual experts may have interpreted impact differently. For example, this may relate to different perceptions of impact in native ecological communities compared to species or to a different understanding of the spatial and temporal scales to which the standardised impact categories were referenced. As a result, some experts may have incorrectly assessed historical or perceived future impacts rather than impacts 'under current contexts', or impacts at spatial scales other than the 'local population' of a native species or the 'remnant patch' of a native ecological community.
- In this pilot study, expert-assigned impact categories and confidence scores were 'trusted', that is, used in analyses without detailed verification. Experts were asked to provide evidence in support of their assessments. This served an important purpose in requiring experts to reflect on the defensibility of their judgement. However, we did not require experts to provide specific evidence, and were unable to use this evidence to verify assessment results because of the additional work that would be required to de-identify and process this qualitative data. Some experts provided little detail, while others' assessments were supported by extensive qualitative data that may prove to be equally as valuable as the synthesis of expert's quantitative results reported here.
- Experts were required to assign a confidence score to each assessment. This degree of uncertainty in expert knowledge was incorporated into the two probabilistic metrics likelihood of IAS impact and most harmful IAS. However, besides reporting the number of experts contributing to different interactions (see Table 9), we did not explicitly analyse assessment uncertainty, making it difficult to distinguish between assessment results that can be reported confidently and those that are highly uncertain (e.g. due to individual expert confidence or the level of agreement between multiple experts).

We recommend that future assessments invest more time and resources into recruiting and training a larger pool of expert assessors. A staged approach including expert calibration, training and elicitation activities has been shown to be the most effective way of reducing potential bias and increasing the robustness of findings (Hemming et al. 2018). The assessment method should also be amended to address issues encountered during elicitation and further reduce ambiguity. For example, we suggest that impact should be assessed for a specified time period rather than 'current contexts' at the time of the assessment (i.e. change definitions of impact categories from 'Under current contexts, the IAS causes …' to 'In the last five years, the IAS has caused …' or 'In the time period 2019–2024, the IAS has caused …').

Perhaps most importantly, additional effort should be expended on verifying the expert-elicited results of such an assessment. We suggest exploring several avenues:

- Experts could be required to back their assessments up with evidence. This evidence could then be used to verify or request clarification of expert judgements. However, this would require adequate resourcing to process and de-identify a potentially very large qualitative dataset, and to implement follow-up elicitation where insufficient evidence was provided. The qualitative data gathered in this first assessment may provide a test case for developing suitable methods. However, due to human ethics approval conditions further work would need to be conducted to remove personally identifiable information before it could be delivered as part of the indicator data package (see section 6).

- Additional analyses of assessment uncertainty should be considered in the future (Roy et al. 2018). For example, a consistent approach to evaluating uncertainty is used by the Intergovernmental Panel on Climate Change (Mastrandrea et al. 2010). It considers confidence as a function of both the quality of available evidence, and the agreement in that evidence. This framework could be applied here to integrate different sources of assessment uncertainty in a simple measure, with evidence measured as the number of contributing experts (i.e. the ‘sample size’), and agreement measured as the spread in the likelihood of impact distribution (due to both individual expert’s confidence and different expert’s assessments). Over time, it could be expected that this measure of confidence improves, providing the opportunity of detecting not only changes in the magnitude of impact, but also changes in accrued knowledge about such impacts.
- In this first assessment, we did not collect empirical data on IAS impacts. However, where time and resources permit, it is highly recommended to validate expert-elicited assessments against empirical evidence. This may include a systematic review of the published literature or, most importantly, field monitoring data that has been collected in New South Wales, perhaps as part of the *Saving Our Species* program.

Alternative metrics of invasive alien species impact

Finally, even if the proposed assessment method was improved to be fully repeatable, comparable and representative, it was designed to measure the current magnitude of IAS impacts on native species and ecological communities in New South Wales. It does not assess other important criteria of impact (Vilà et al. 2019; Bartz & Kowarik 2019).

For example, an additional assessment of the breadth of impact, that is, the number and diversity of species, communities and ecosystems detrimentally affected by a given IAS, may provide important complementary insights. This metric could be measured by counting the number of sensitive species and ecological communities affected by an IAS (Vilà et al. 2019). However, this may be difficult due to insufficient data for most IAS. An alternative indirect approach could involve (i) determining the bioregions, habitat types or ecological communities invaded by an IAS, (ii) determining the native species richness in those areas, and (iii) calculating the total number of species potentially affected across all invaded areas (Downey et al. 2010). The accuracy of this approach would increase at finer spatial resolutions (i.e. a bioregion-scale count would include many species that are not actually affected by an IAS present in that bioregion). A ‘breadth of IAS impact’ metric could also be integrated with the IAS richness metric to better report on biodiversity exposure to IAS pressures (see section 5.2.1).

Perhaps most importantly, the magnitude of IAS impact was assessed at the species level (i.e. What is the magnitude of impact caused by an IAS or aggregated across a biological group of IAS? Which IAS is likely to cause the highest magnitude of impact?). Variability in impact across invaded areas in New South Wales due to differences in IAS exposure, native species population size, community extent or population connectivity, was not captured. However, management decisions would highly benefit from a spatially explicit assessment of the ecosystem impacts caused by IAS across invaded areas (i.e. What is the magnitude of impact in an invaded area? Which areas are likely to be impacted worst by IAS?) (Wilson et al. 2018).

Developing such a spatially explicit bottom-up impact metric (i.e. one measured for individual interactions between IAS and sensitive native species or ecological communities, and then aggregated to all interactions occurring in an invaded area), would be an ambitious task. It would require synthesising and expanding on the methods for measuring IAS exposure and IAS impact developed in this first assessment. Data requirements include:

- The spatial distribution and local abundance of each IAS that is included in the analysis. Abundance could be expressed in discrete categories based on modelling or expert opinion due to lack of empirical data on many IAS.
- The spatial distribution of each native species and ecological community identified as affected by these IAS, so that the area of range overlap can be calculated, where IAS and native species and ecological communities interact and impacts are realised.
- The magnitude and density-dependence of IAS impacts (Fleming et al. 2017). The magnitude of impact may differ in each interaction with a native species or ecological community. Hence it would either need to be measured for each interaction included in the analysis (e.g. using the assessment method proposed here), or otherwise estimated as a generic value. Likewise, abundance-impact relationships could either be empirically quantified, or simply assumed to be in the form of a linear, uniform or logistic function.

Similar to the caveats of our assessment method discussed earlier, when implementing a spatially explicit impact analysis there would be a trade-off between representativeness and comparability (many interactions included in the analysis) and feasibility (few interactions included in the analysis). Future assessments may initially test an implementation method for a data-rich case study IAS, perhaps drawn from the IAS already identified in this report.

Alternatively, a top-down, macro-ecological approach could be taken (i.e. measuring the collective impact of all IAS in an invaded area without considering which species the IAS and native assemblages are made up of). For example, Wilson et al. (2018) suggest a relatively simple approach where the impact of IAS on selected ecosystem services is mapped by synthesising available evidence and translating it into discrete categories of impact. Mapping scales could range from broad regions to a fine resolution grid depending on the quality of information on the levels of ecosystem services and the impact of invasions on these services in the study area. Wilson et al. (2018) suggest that a similar approach could be taken to map the impacts of IAS on biodiversity.

If adequate quantitative data were available, either across the entire State or from a representative network of monitoring sites, an integrated modelling approach could be pursued; synthesising information on both biodiversity exposure to IAS pressures and the consequences of these pressures. For the purpose of the NSW Biodiversity Indicator Program such an analysis would require spatially explicit data on:

- IAS exposure: In the first instance, the gridded IAS richness map developed here could be used. In future, empirical data on IAS assemblages and relative IAS abundance (Wilson et al. 2018) from monitoring sites could be incorporated into a statewide predictive model.
- State of biodiversity: A range of data on native species richness, alpha diversity or community composition from the Biodiversity Indicator Program (e.g. data compiled for NSW native vascular plants by Nipperess et al. 2020) or field-based monitoring programs may be usefully integrated in such a modelling framework.
- Trends in biodiversity: Temporal information on the observed rate of biodiversity change is needed to indicate the biodiversity response to IAS pressures.
- Ideally, data on associated pressures would also be integrated in such a modelling framework in order to disentangle IAS impacts from other drivers of biodiversity loss.

However, macro-ecological models of IAS impact are a new area of research and would require considerable additional development before becoming operational.

6. Data products

The data used (where licences allow) and derived as a product of this analysis are publicly available through the CSIRO Data Access Portal (data.csiro.au). The following data packages are available for download:

> Froese JG, Gooden B, Hulthen AD, Ponce-Reyes R, Burley, AL, Cherry H, Hamilton M, Nipperess DA, Russell B, West P & Williams KJ 2021, Assessing invasive alien species pressures on biodiversity in New South Wales (exposure dimension): Data packages for the Biodiversity Indicator Program, first assessment, *SEED portal*, datasets.seed.nsw.gov.au/dataset/biodiversity-indicator-program-data-packages.

> Froese JG, Gooden B, Hulthen AD, Ponce-Reyes R, Burley, AL, Cherry H, Hamilton M, Nipperess DA, Russell B, West P & Williams KJ 2021, Assessing invasive alien species pressures on biodiversity in New South Wales (impact dimension): Data packages for the Biodiversity Indicator Program, first assessment, *SEED portal*, datasets.seed.nsw.gov.au/dataset/biodiversity-indicator-program-data-packages.

The data package forms part of a collection hosted on the Sharing and Enabling Environmental Data (SEED) Portal (seed.nsw.gov.au). The collection includes links to all available data packages for the first assessment of the Biodiversity Indicator Program:

> Department of Planning, Industry and Environment 2020, Data packages for the Biodiversity Indicator Program: First assessment, *SEED Portal*, Sydney, Australia, datasets.seed.nsw.gov.au/dataset/biodiversity-indicator-program-data-packages.

Appendix A. Indicator workflows

For each dimension of the IAS pressure indicator (IAS exposure and IAS impact), we provide a detailed workflow diagram and technical description of data inputs, analytical processes and derived outputs including indicator metrics. These are also included as supporting files with the associated data packages (see section 6). If the same workflows and metrics implemented in this first assessment (shown in blue) are repeated in future assessments (shown in orange), this will enable change detection over a five-year timescale.

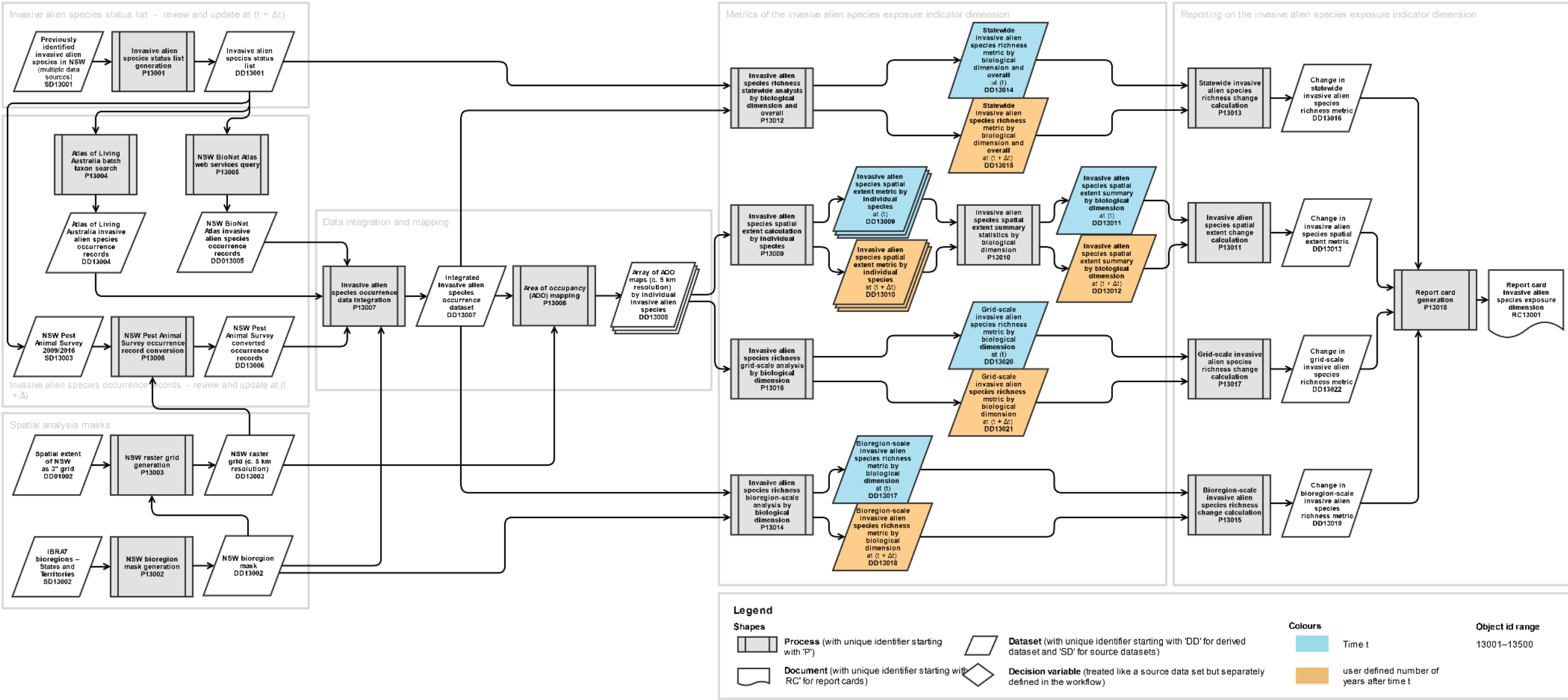


Figure 10 Indicator dimension invasive alien species exposure: workflow diagram.

A high resolution image file of this diagram is provided with the data package (datasets.seed.nsw.gov.au/dataset/biodiversity-indicator-program-data-packages).

Table 10 Indicator dimension invasive alien species exposure: technical object description.

Workflow objects include source data (SD), analytical processes (P), derived data outputs (DD) and reporting outputs (report card (RC)).

Workflow order	Object type	Object ID	Object label in workflow	Technical object description
1	Source data	SD13001	Previously identified invasive alien species in NSW (multiple data sources)	Multiple data sources that had previously identified IAS in NSW. In this first assessment, data sources included nine authoritative and sufficiently up-to-date prioritisation processes conducted by IAS management agencies in NSW and nationally, accessed in November 2019 (see Implementation report Table 1).
2	Process	P13001	Invasive alien species status list generation	Processing steps applied to data sources in order to prepare an IAS status list for automated downloads and queries of spatial data. These steps included: merging by taxon name, initial data cleaning, labelling with biological dimension and contextual information, harmonising taxonomic discrepancies, excluding alien species that are not IAS as defined here, final taxonomic checks (see Implementation report section 3.1 and DD13001, sheet “Process (P13001)”).
3	Derived data	DD13001	Invasive alien species status list (known impacts on sensitive biodiversity assets in NSW)	Merged and harmonised list of alien species that had been identified as current or potential future threats to native biodiversity and ecosystem quality in NSW in at least one of several authoritative data sources. All invasive alien species are grouped into one of three biological dimensions (biological groups: pest animals, weeds and diseases). Various sheets were added to the IAS status list, incl. “DD13001Append” for joining contextual information to IAS occurrence data (P13007); “Process (P13001)” containing workflow details; “Table12” for generating Appendix B, Table 12 of the Implementation report; and “APNI_Names”, “WeedTypeLookup”, “DD13007Lookup” (see DD13007) and “DD13009Lookup” (see DD13009) for appending ancillary information and analysis results to the IAS status list.
4	Source data	SD013002	IBRA7 bioregions – States and Territories	Department of the Environment (2012). Interim Biogeographic Regionalisation for Australia (Subregions) - States and Territories, v. 7 (IBRA) [ESRI shapefile].
5	Process	P13002	NSW bioregion mask generation	Processing steps applied to the IBRA7 source data, including extracting polygons for all areas in NSW, excluding polygons for the Australian Capital Territory (ACT) and Jervis Bay Territory (JBT) and dissolving to generate a single polygon for each of NSW’s 19 bioregions (see Implementation report section 3.2.1). A separate processing tool that does not exclude the ACT and JBT is also provided for lineage purposes.
6	Derived data	DD13002	NSW bioregion mask	Spatial analysis mask containing polygons for all 19 bioregions that are fully or partly contained in areas administered by the State of NSW. A separate mask that also includes the ACT and JBT is also provided for lineage purposes.
7	Derived data	DD01002	Spatial extent of NSW as 3" grid	A previously derived BIP spatial data product (filename: nsw_nact_nd), an output from the mask generation process P01001 (3" mask generator).
8	Process	P13003	NSW raster grid generation	Processing steps applied to the spatial extent of NSW mask, including expanding to cover the Lord Howe Island group, upscaling by a factor of 54 (resolution: ~ 4952.658 m) and extracting cells by the NSW bioregion mask (see Implementation report section 3.2.1). A separate processing tool that uses the NSW (incl. ACT and JBT) bioregion mask is also provided for lineage purposes.

9	Derived data	DD13003	NSW raster grid (c. 5 km resolution)	Spatial analysis mask containing 32,794 cells with a resolution of c. 5 kilometres (4,952.658 m) and a size of c. 25 km^2, a complete coverage of all areas administered by the State of NSW. A separate mask that also includes the ACT and JBT (containing 32,860 cells) is also provided for lineage purposes.
10	Process	P13004	Atlas of Living Australia batch taxon search	Batch taxon search of occurrence records from the Atlas of Living Australia (ALA) data repository for all taxa on the IAS status list, and subsequent processing steps including temporal filtering (1 January 1980 to 25 August 2017), data cleaning, resolving taxonomic naming variations and data labelling (see Implementation report section 3.2.2).
11	Derived data	DD13004	Atlas of Living Australia invasive alien species occurrence records	Pre-processed and labelled (Data_source [ALA], Occurrence [1]) point occurrence records for any taxa on the IAS status list during the period 1980 to 2017 from the ALA data repository.
12	Process	P13005	NSW BioNet Atlas web services query	Batch query of occurrence records from the BioNet Atlas data repository for all taxa on the IAS status list, and associated processing steps including temporal filtering (1 January 1980 to 25 August 2017), data cleaning, resolving taxonomic naming variations and data labelling (see Implementation report section 3.2.2).
13	Derived data	DD13005	NSW BioNet Atlas invasive alien species occurrence records	Pre-processed and labelled (Data_source [BioNet], Occurrence [1]) point occurrence records for any taxa on the IAS status list during the period 1980 to 2017 from the BioNet Atlas data repository.
14	Source data	SD013003	NSW Pest Animal Survey 2009/2016	For 16 vertebrate pest animals on the IAS status list, unpublished state-wide gridded dataset (c. 5-kilometre cell resolution) of species presence, relative abundance or absence; collated by the NSW Department of Primary Industries in 2009 and 2016 respectively by eliciting field knowledge from regional pest animal management practitioners, and provided by the data custodian in vector polygon format.
15	Process	P13006	NSW Pest Animal Survey occurrence record conversion	Processing steps applied to the NSW Pest Animal Survey source data, including extracting “presence” polygons, converting to raster format using the NSW raster grid, converting to point occurrence records and data labelling (see Implementation report section 3.2.2, processing tools in the data package are to be applied consecutively in alphabetical order).
16	Derived data	DD13006	NSW Pest Animal Survey converted occurrence records	Pre-processed and labelled (Data_source [DPI], Occurrence [1]) point occurrence records for 16 vertebrate pest animals on the IAS status list derived from the NSW Pest Animal Survey 2009/2016.
17	Process	P13007	Invasive alien species occurrence data integration	Integration steps applied to the IAS occurrence data from all sources, including merging of pre-processed point occurrence records, clipping by the NSW (incl. ACT and JBT) bioregion mask, joining contextual information from the IAS status list (DD13001, using the sheet “DD13001Append”) and the NSW (incl. ACT and JBT) bioregion mask (DD13002) to the attribute table, and a final manual data verification step (see Implementation report section 3.2.2).
18	Derived data	DD13007	Integrated invasive alien species occurrence dataset	Integrated dataset of harmonised and verified point occurrence records (1,214,429 records overall, of which 961,795 records fell into areas administered by NSW, including duplicates between data sources) for any taxa on the IAS status list from the Atlas of Living Australia, NSW BioNet Atlas and NSW Pest Animal Survey. Exported and appended to IAS status list (DD13001) as a lookup table (sheet “DD13007Lookup”).

19	Process	P13008	Area of occupancy (AOO) mapping	Process used to generate an area of occupancy (AOO) map for each individual taxon represented in the integrated IAS occurrence data set using the NSW raster grid (c. 5-kilometre resolution) (see Implementation report section 3.3.1).
20	Derived data	DD13008	Array of AOO maps (c. 5 km resolution) by individual invasive alien species	Array of AOO maps (c. 5-kilometre resolution) for each individual taxon represented in the integrated IAS occurrence data set (i.e. recorded as naturalised in at least one location in NSW in any of the data sources). Arrays split by biological dimension (pest animals, weeds, diseases) are also provided for analysis purposes (P13016). Separate arrays (by biological dimension and overall) that also include areas administered by the ACT and JBT are also provided for lineage purposes.
21	Process	P13009	Invasive alien species spatial extent calculation by individual species	Analysis steps applied to the array of AOO maps to calculate the IAS spatial extent metric by individual IAS (see Implementation report section 3.3.2).
22	Derived data	DD13009	Invasive alien species spatial extent metric by individual species at (t)	IAS spatial extent metric, reported by individual IAS as the proportion of NSW grid cells with a resolution of c. 5 kilometres where the IAS was recorded as naturalised in at least one location. Exported and appended to IAS status list (DD13001) as a lookup table with IAS name cleaned and biological group added (sheet “DD13009Lookup”).
23	Derived data	DD13010	Invasive alien species spatial extent metric by individual species at (t + Δt)	IAS spatial extent metric, reported at the time (t + Δt) in the same way as at the time (t); not calculated in the first assessment.
24	Process	P13010	Invasive alien species spatial extent summary statistics by biological dimension	Analysis steps applied to the species-level IAS spatial extent metric to calculate summary statistics (species count, mean, median, standard deviation, histogram) by biological dimension (pest animals, weeds, diseases) (see Implementation report section 3.3.2).
25	Derived data	DD13011	Invasive alien species spatial extent summary by biological dimension at (t)	Summary statistics of the IAS spatial extent metric (mean, median, standard deviation, histogram) by biological dimension (pest animals, weeds, diseases) (see Implementation report section 3.5).
26	Derived data	DD13012	Invasive alien species spatial extent summary by biological dimension at (t + Δt)	Summary statistics of the IAS spatial extent metric reported at the time (t + Δt) in the same way as at the time (t); not calculated in the first assessment.
27	Process	P13011	Invasive alien species spatial extent change calculation	Process used to calculate the change in the IAS spatial extent metric between two subsequent assessments; not applied in the first assessment.
28	Derived data	DD13013	Change in invasive alien species spatial extent metric	Change in the IAS spatial extent metric between two subsequent assessments at time (t) and (t + Δt); not calculated in the first assessment.
29	Process	P13012	Invasive alien species richness statewide analysis by biological dimension and overall	Analysis steps applied to the integrated IAS occurrence dataset, appended to the IAS status list, to calculate the statewide IAS richness metric by biological dimension (pest animals, weeds, diseases) and for all biological dimensions combined (see Implementation report section 3.3.3).

30	Derived data	DD13014	Statewide invasive alien species richness metric by biological dimension and overall at (t)	Statewide IAS richness metric, reported separately by biological dimension (pest animals, weeds, diseases) and for all biological dimensions combined, both as an absolute metric (number (count) of IAS that were recorded as naturalised in at least one location in NSW) and a proportional metric (the proportion (%) of all identified taxa on the IAS status list that were recorded in NSW).
31	Derived data	DD13015	Statewide invasive alien species richness metric by biological dimension and overall at (t + Δt)	Statewide IAS richness metric reported at the time (t + Δt) in the same way as at the time (t); not calculated in the first assessment.
32	Process	P13013	Statewide invasive alien species richness change calculation	Process used to calculate the change in the statewide IAS richness metric between two subsequent assessments; not applied in the first assessment.
33	Derived data	DD13016	Change in statewide invasive alien species richness metric	Change in the statewide IAS richness metric between two subsequent assessments at time (t) and (t + Δt); not calculated in the first assessment.
34	Process	P13014	Invasive alien species richness bioregion-scale analysis by biological dimension	Analysis steps applied to the integrated IAS occurrence dataset, joined to the NSW bioregion mask, to calculate the bioregion-scale IAS richness metric by biological dimension (pest animals, weeds, diseases) (see Implementation report section 3.3.3).
35	Derived data	DD13017	Bioregion-scale invasive alien species richness metric by biological dimension at (t)	Bioregion-scale IAS richness metric, reported separately by biological dimension (pest animals, weeds, diseases), both as an absolute metric (number (count) of IAS that were recorded as naturalised in at least one location in a bioregion) and a proportional metric (the proportion (%) of all IAS recorded in NSW that were recorded in a bioregion).
36	Derived data	DD13018	Bioregion-scale invasive alien species richness metric by biological dimension at (t + Δt)	Bioregion-scale IAS richness metric reported at the time (t + Δt) in the same way as at the time (t); not calculated in the first assessment.
37	Process	P13015	Bioregion-scale invasive alien species richness change calculation	Process used to calculate the change in the bioregion-scale IAS richness metric between two subsequent assessments; not applied in the first assessment.
38	Derived data	DD13019	Change in bioregion-scale invasive alien species richness metric	Change in the bioregion-scale IAS richness metric between two subsequent assessments at time (t) and (t + Δt); not calculated in the first assessment.
39	Process	P13016	Invasive alien species richness grid-scale analysis by biological dimension	Analysis steps applied to the array of AOO maps to calculate the grid-scale IAS richness metric by biological dimension (pest animals, weeds, diseases) (see Implementation report section 3.3.3).
40	Derived data	DD13020	Grid-scale invasive alien species richness metric by biological dimension at (t)	Grid-scale IAS richness metric, reported separately by biological dimension (pest animals, weeds, diseases), both as an absolute metric (number (count) of IAS that were recorded as naturalised in at least one location in a NSW grid cell with a resolution of c. 5 kilometres) and a proportional metric (the proportion (%) of all IAS recorded in NSW that were recorded in a grid cell).

41	Derived data	DD13021	Grid-scale invasive alien species richness metric by biological dimension at (t + Δt)	Grid-scale IAS richness metric reported at the time (t + Δt) in the same way as at the time (t); not calculated in the first assessment.
42	Process	P13017	Grid-scale invasive alien species richness change calculation	Process used to calculate the change in the grid-scale IAS richness metric between two subsequent assessments; not applied in the first assessment.
43	Derived data	DD13022	Change in grid-scale invasive alien species richness metric	Change in the grid-scale IAS richness metric between two subsequent assessments at time (t) and (t + Δt); not calculated in the first assessment.
44	Process	P13018	Report card generation	Process used to generate descriptive summaries, tables and figures reporting on the indicator dimension IAS exposure in a report card - ready format.
45	Report card	RC13001	Report card invasive alien species exposure dimension	Report card containing descriptive summaries, tables and figures reporting on the indicator dimension IAS exposure.

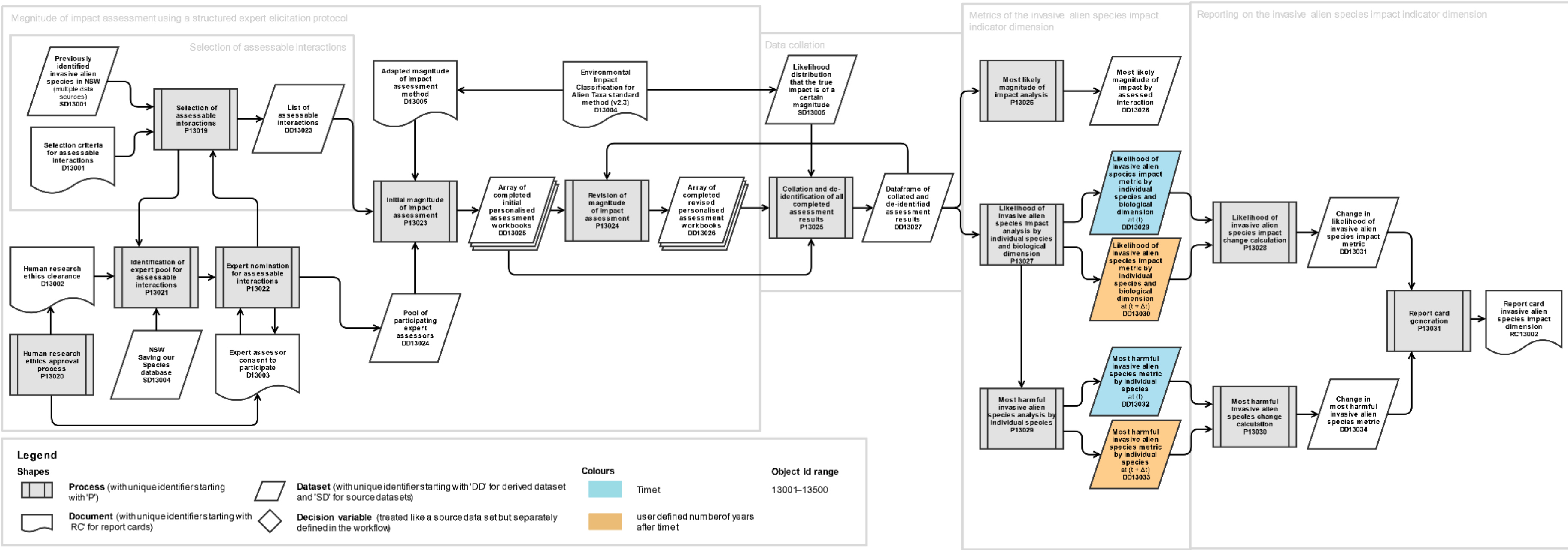


Figure 11 **Indicator dimension invasive alien species impact: workflow diagram.**

A high resolution image file of this diagram is provided with the data package (datasets.seed.nsw.gov.au/dataset/biodiversity-indicator-program-data-packages).

Table 11 Indicator dimension invasive alien species impact: technical object description.

Workflow objects include source data (SD), analytical processes (P), derived data outputs (DD), documents (D) and reporting outputs (report card (RC)).

Workflow order	Object type	Object ID	Object label in workflow	Object description
1	Source data	SD13001	Previously identified invasive alien species in NSW (multiple data sources)	Multiple data sources that had previously identified IAS in NSW. In this first assessment, data sources included nine authoritative and sufficiently up-to-date prioritisation processes conducted by IAS management agencies in NSW and nationally, accessed in November 2019 (see Implementation report Table 1).
2	Document	D13001	Selection criteria for assessable interactions	Agreed criteria for selecting a limited set of interactions between IAS and sensitive native species and ecological communities for inclusion in the magnitude of impact assessment. In this first assessment, these criteria included: known detrimental impact; indicative of a variety of impacts; assessment feasible (evidence and expert knowledge available), and sensitive to future change in impact (see Implementation report section 4.1).
3	Process	P13019	Selection of assessable interactions	Process used to select a limited set of interactions between IAS and sensitive native species and ecological communities for inclusion in the magnitude of impact assessment. In this first assessment, this iterative process involved: selected IAS experts (1) identified widespread IAS that are currently of significant concern and (2) priority interactions with native species or ecological communities that are listed as threatened under the BC Act; (3) a broader set of experts nominating to participate in the magnitude of impact assessment (process P13022) suggested amendments; (4) the project team made final decisions on amendments and removed all interactions for IAS that attracted fewer than three assessment nominations by experts (see Implementation report section 4.1).
4	Derived data	DD13023	List of assessable interactions	Final list of interactions between particular IAS and sensitive native species and ecological communities that were included in the initial magnitude of impact assessment. In this first assessment, this list comprised 227 interactions between 22 IAS (seven pest animals, 15 weeds) and 130 listed threatened species and ecological communities (25 threatened animals, 57 threatened plants and 48 threatened ecological communities).
5	Process	P13020	Human research ethics approval process	Process used to obtain human research ethics approval. In this first assessment, approval was sought from the CSIRO Human Research Ethics Committee.
6	Document	D13002	Human research ethics clearance	Human research ethics clearance and associated conditions. In this first assessment, these included: a project information sheet and participant consent form to be viewed and signed by experts (D13003) during nomination (process P13022) and de-identification of all personally identifiable information prior to public release.
7	Source data	SD13004	NSW Saving our Species database	NSW Saving our Species (SoS) database containing User Roles [e.g. Project coordinator, Threatened species expert, Site manager and Action implementer] for listed threatened species and ecological communities as well as listed threatening processes.

8	Process	P13021	Identification of expert pool for assessable interactions	Process used to identify a pool of experts with knowledge on at least one of the IAS, threatened species or threatened ecological communities included in the list of assessable interactions. In this first assessment, this process drew on the NSW SoS database and additional suggestions by the project team (see Implementation report section 4.2.1).
9	Process	P13022	Expert nomination for assessable interactions	Process used to invite experts to participate by self-nominating to assess at least one of the assessable interactions. In this first assessment, experts were also invited to recommend other experts, which were then invited to using the same self-nomination process. This expert nomination process also included extensive follow up to explain the magnitude of impact assessment protocol and required time commitment (see Implementation report section 4.1).
10	Document	D13003	Expert assessor consent to participate	Signed and returned participant consent forms; provided to experts together with a project information sheet. In line with the human research ethics clearance conditions (D13002), personally identifiable information cannot be publicly released. Only the unsigned form is provided. Signed forms are securely stored as per CSIRO’s Recordkeeping Procedure.
11	Derived data	DD13024	Pool of participating expert assessors	Pool of experts that had been identified, consented to participate and self-nominated to assess at least one of the assessable interactions for the magnitude of IAS impact. In this first assessment, this pool consisted mainly of expert practitioners and biodiversity or IAS coordinators, but relatively few scientific experts. In line with the human ethics clearance conditions (D13002), personally identifiable information cannot be publicly released. This data set is securely stored as per CSIRO’s Recordkeeping Procedure.
12	Document	D13004	Environmental Impact Classification for Alien Taxa standard method (v2.3)	Environmental Impact Classification for Alien Taxa (EICAT) standard method, version 2.3 (see Implementation report section 2.2.1); IUCN (2019a). Consultation document. Proposed IUCN standard classification of the impact of invasive alien taxa. Version 2.3 – July 2019. IUCN (2019b). Consultation document. Guidelines for using the proposed IUCN standard classification of the impact of invasive alien taxa. Version 2.3 – July 2019.
13	Document	D13005	Adapted magnitude of impact assessment method	Adapted assessment method used to collect data on the current magnitude of IAS impacts on native species and ecological communities in NSW for the purposes of the Biodiversity Indicator Program. The method was implemented by experts on a personalised assessment workbook and consisted of four main assessment steps (select impact mechanism, assign impact category and confidence score, provide evidence), each guided by the EICAT standard (see Implementation report Chapters 2.2.1 and 4.2.2).
14	Process	P13023	Initial magnitude of impact assessment	Process used to implement the initial magnitude of impact assessment. For each expert who consented to participate and nominated to assess at least one interaction, a personalised assessment workbook was generated that contained a separate worksheet for each nominated interaction on which to implement the assessment method and generic supporting information to facilitate a consistent implementation of the method; opportunities to seek feedback and guidance from the project team were also provided (see Implementation report section 4.2.1).

15	Derived data	DD13025	Array of completed initial personalised assessment workbooks	Array of fully or partially completed personalised assessment workbooks containing the initial results of the magnitude of impact assessment from all contributing experts. In line with the human ethics clearance conditions (D13002), personally identifiable information cannot be publicly released. This data set is securely stored as per CSIRO's Recordkeeping Procedure.
16	Process	P13024	Revision of magnitude of impact assessment	Process used to give expert assessors the opportunity to review, and where necessary revise, their initial assessments. In this process, experts were also provided with de-identified initial assessment results (impact mechanism, impact category, confidence score) from other experts relating to any interactions for the same IAS they had also assessed (see Implementation report section 4.2.1).
17	Derived data	DD13026	Array of completed revised personalised assessment workbooks	Array of fully or partially completed personalised assessment workbooks containing the revised results of the magnitude of impact assessment from all contributing experts. In line with the human ethics clearance conditions (D13002), personally identifiable information cannot be publicly released. This data set is securely stored as per CSIRO's Recordkeeping Procedure.
18	Source data	SD13005	Likelihood distribution that the true impact is of a certain magnitude	A likelihood distribution that the 'true' impact is of a certain magnitude, given each combination between an impact category and a confidence score that could be assigned by experts (using specific values suggested in the EICAT standard method, see Implementation report section 4.3.1).
19	Process	P13025	Collation and de-identification of all completed assessment results	Process used to collate and de-identify the revised, and where no revisions were made the initial, results of the magnitude of impact assessment. The same process was also used to collate and de-identify initial results prior to the expert revision process (P13024).
20	Derived data	DD13027	Data frame of collated and de-identified assessment results	Data frame containing one row for each assessment of an impact mechanism that was conducted by an expert. Data fields included the assessment result [expert ID, interaction code, impact mechanism, impact category, confidence score], the likelihood distribution (SD13005) corresponding to the assessment result, and contextual information corresponding to the assessed interaction. A preliminary data frame containing de-identified initial results [expert ID, interaction code, impact mechanism, impact category, confidence score] was used to generate personalised spreadsheets that were provided to experts in the revision process (P13024).
21	Process	P13026	Most likely magnitude of impact analysis	Analysis steps applied to the data frame of collated and de-identified assessment results to calculate the most likely magnitude of impact category for each assessed interaction between an IAS and a native species or ecological community across all contributing experts (see Implementation report section 4.3.3).
22	Derived data	DD13028	Most likely magnitude of impact by assessed interaction	Most likely magnitude of impact category for each assessed interaction between an IAS and a native species or ecological community, compiled in a colour coded table that visualises, at a glance, the expert-elicited magnitude of impact that can be expected when considering all available information.
23	Process	P13027	Likelihood of invasive alien species impact analysis by individual species and biological dimension	Analysis steps applied to the data frame of collated and de-identified assessment results to calculate the likelihood of IAS impact metric, averaged by individual IAS and by biological dimension (pest animals, weeds) (see Implementation report section 4.3.2).

24	Derived data	DD13029	Likelihood of invasive alien species impact metric by individual species and biological dimension at (t)	Likelihood of IAS impact metric, reported separately by individual IAS and by biological dimension (pest animals, weeds) as the average expert-elicited likelihood that impacts caused by assessed IAS on assessed native species and ecological communities are of a certain magnitude.
25	Derived data	DD13030	Likelihood of invasive alien species impact metric by individual species and biological dimension at (t + Δt)	Likelihood of IAS impact metric reported at the time (t + Δt) in the same way as at the time (t); not calculated in the first assessment.
26	Process	P13028	Likelihood of invasive alien species impact change calculation	Process used to calculate the change in the likelihood of IAS impact metric between two subsequent assessments; not applied in the first assessment.
27	Derived data	DD13031	Change in likelihood of invasive alien species impact metric	Change in the likelihood of IAS impact metric between two subsequent assessments at time (t) and (t + Δt); not calculated in the first assessment.
28	Process	P13029	Most harmful invasive alien species analysis by individual species	Analysis steps applied to likelihood of IAS impact metric (averaged by individual IAS) to calculate the most harmful IAS metric (see Implementation report section 4.3.2).
29	Derived data	DD13032	Most harmful invasive alien species metric by individual species (t)	Most harmful IAS metric, reported as the expert-elicited number, proportion and name of assessed IAS which are more likely than not (> 50% average likelihood) causing local population extirpation among assessed native species or ecological communities.
30	Derived data	DD13033	Most harmful invasive alien species metric by individual species at (t + Δt)	Most harmful IAS metric reported at the time (t + Δt) in the same way as at the time (t); not calculated in the first assessment.
31	Process	P13030	Most harmful invasive alien species change calculation	Process used to calculate the change in the most harmful IAS metric between two subsequent assessments; not applied in the first assessment.
32	Derived data	DD13034	Change in most harmful invasive alien species metric	Change in the most harmful IAS metric between two subsequent assessments at time (t) and (t + Δt); not calculated in the first assessment.
33	Process	P13031	Report card generation	The process used to generate descriptive summaries, tables and figures reporting on the indicator dimension IAS impact in a report card - ready format.
34	Report card	RC13002	Report card invasive alien impact dimension	A report card containing descriptive summaries, tables and figures reporting on the indicator dimension IAS impact.

Appendix B. Invasive alien species status list

Table 12 **IAS status list, containing 413 IAS (360 weeds, 49 pest animals, four diseases).**

These IAS have been identified as current or potential future threats to native biodiversity and ecosystem quality in New South Wales in at least one of several authoritative data sources. We separately list the three biological dimensions (a) weeds, (b) pest animals and (c) diseases, each ordered alphabetically by scientific name. Results for the IAS spatial extent metric of the IAS exposure indicator dimension are also shown (as % of the number of grid cells in NSW) for the 344 IAS (305 weeds, 36 pest animals, three diseases) that were recorded in New South Wales. The remaining 69 (not naturalised) species are shown as 'not recorded'.

(a) Weeds			**Spatial extent**
Type	Scientific name	Common name	(%)
Vine or scrambler	*Abrus precatorius*	Crabs-eye creeper	0.009
Tree-like	*Acacia saligna*	Golden wreath wattle	0.598
Tree-like	*Acer negundo*	Box elder	0.320
Tree-like	*Acer pseudoplatanus*	Sycamore maple	0.021
Vine or scrambler	*Acetosa sagittata*	Turkey rhubarb	0.832
Herb-like	*Achillea millefolium*	Yarrow	0.146
Herb-like	*Agapanthus praecox* subsp. *orientalis*	Agapanthus	0.592
Shrub-like	*Ageratina adenophora*	Crofton weed	2.260
Herb-like	*Ageratina riparia*	Mistflower	1.107
Grass-like	*Agrostis capillaris*	Brown-top bent	0.561
Tree-like	*Ailanthus altissima*	Tree-of-heaven	0.503
Aquatic plant	*Alternanthera philoxeroides*	Alligator weed	0.262
Herb-like	*Alternanthera pungens*	Khaki weed	1.086
Grass-like	*Amelichloa brachychaeta*	Espartillo, narrow kernel	0.012
Grass-like	*Amelichloa caudata*	Espartillo, broad kernel	0.012
Grass-like	*Andropogon gayanus*	Gamba grass	not recorded
Grass-like	*Andropogon virginicus*	Whisky grass	2.336
Tree-like	*Annona glabra*	Pond apple	not recorded
Vine or scrambler	*Anredera cordifolia*	Madeira vine	0.893
Grass-like	*Anthoxanthum odoratum*	Sweet vernal grass	2.241
Vine or scrambler	*Araujia sericifera*	Moth vine	1.641
Herb-like	*Arctotheca populifolia*	Beach daisy	0.088
Shrub-like	*Ardisia crenata*	Coral Berry	0.140
Shrub-like	*Ardisia elliptica*	Shoebutton ardisia	0.009
Herb-like	*Argemone ochroleuca*	Mexican poppy	0.698
Herb-like	*Aristea ecklonii*	Blue stars	0.088
Vine or scrambler	*Aristolochia littoralis*	Dutchman's pipe	0.027
Grass-like	*Arundinaria* spp.	Arundinaria reed	not recorded
Grass-like	*Arundo donax*	Giant reed	0.409

(a) Weeds			Spatial extent
Type	Scientific name	Common name	(%)
Vine or scrambler	*Asparagus aethiopicus*	Ground asparagus	1.494
Vine or scrambler	*Asparagus africanus*	Climbing asparagus	0.061
Vine or scrambler	*Asparagus asparagoides*	Bridal creeper	1.259
Vine or scrambler	*Asparagus declinatus*	Bridal veil creeper	not recorded
Vine or scrambler	*Asparagus falcatus*	Sicklethorn	0.024
Vine or scrambler	*Asparagus macowanii* var. *zuluensis*	Ming asparagus fern	not recorded
Vine or scrambler	*Asparagus plumosus*	Climbing asparagus fern	0.704
Vine or scrambler	*Asparagus scandens*	Snakefeather	0.146
Vine or scrambler	*Asparagus virgatus*	Asparagus fern	0.098
Herb-like	*Asphodelus fistulosus*	Onion weed	0.808
Herb-like	*Asystasia gangetica*	Chinese violet	0.030
Succulent	*Austrocylindropuntia cylindrica*	Cane cactus	0.006
Shrub-like	*Baccharis halimifolia*	Groundsel bush	0.509
Grass-like	*Bambusa* spp.	Bamboo	0.125
Shrub-like	*Barleria prionitis*	Barleria	not recorded
Shrub-like	*Bassia scoparia*	Kochia	not recorded
Shrub-like	*Berberis lomariifolia*	Mahonia	not recorded
Vine or scrambler	*Billardiera heterophylla*	Billardieria	0.064
Tree-like	*Broussonetia papyrifera*	Paper mulberry	not recorded
Succulent	*Bryophyllum delagoense*	Mother-of-millions	0.829
Succulent	*Bryophyllum x houghtonii*	Hybrid mother-of-millions	0.034
Aquatic plant	*Cabomba caroliniana*	Cabomba	0.052
Shrub-like	*Caesalpinia decapetala*	Mysore thorn	0.052
Herb-like	*Cakile edentula*	American sea rocket	0.186
Shrub-like	*Calluna vulgaris*	Heather	not recorded
Herb-like	*Canna indica*	Canna lily	0.363
Vine or scrambler	*Cardiospermum grandiflorum*	Balloon vine	0.564
Herb-like	*Carduus nutans* subsp. *nutans*	Nodding thistle	0.381
Herb-like	*Carrichtera annua*	Ward’s weed	0.948
Herb-like	*Carthamus lanatus*	Saffron thistle	5.004
Herb-like	*Carthamus leucocaulos*	Glaucous starthistle	not recorded
Aquatic plant	*Caulerpa taxifolia*	Caulerpa	0.040
Tree-like	*Cecropia peltata*	Mexican bean tree, Trumpet tree	0.003
Tree-like	*Celtis australis*	European hackberry	0.116
Tree-like	*Celtis sinensis*	Chinese celtis	0.186
Grass-like	*Cenchrus biflorus*	Gallon's curse	not recorded
Grass-like	*Cenchrus brownii*	Fine-bristled burr grass	not recorded
Grass-like	*Cenchrus ciliaris*	Buffel grass	0.293
Grass-like	*Cenchrus clandestinus*	Kikuyu	3.095

(a) Weeds			**Spatial extent**
Type	Scientific name	Common name	(%)
Grass-like	*Cenchrus echinatus*	Mossman River grass	0.082
Grass-like	*Cenchrus incertus*	Spiny burrgrass	0.165
Grass-like	*Cenchrus longisetus*	Long-style feather grass	0.149
Grass-like	*Cenchrus longispinus*	Spiny burrgrass, longispinus	0.079
Grass-like	*Cenchrus macrourus*	African feather grass	0.006
Grass-like	*Cenchrus setaceus*	Fountain grass	0.137
Herb-like	*Centaurea stoebe* subsp. *micranthos*	Spotted knapweed	not recorded
Shrub-like	*Cestrum nocturnum*	Lady-of-the-night	0.073
Shrub-like	*Cestrum parqui*	Green cestrum	0.875
Grass-like	*Chloris gayana*	Rhodes grass	2.183
Shrub-like	*Chromolaena odorata*	Siam weed	not recorded
Shrub-like	*Chrysanthemoides monilifera* subsp. *monilifera*	Boneseed	0.415
Shrub-like	*Chrysanthemoides monilifera* subsp. *rotundata*	Bitou bush	0.826
Herb-like	*Cineraria lyratiformis*	Cineraria	0.082
Tree-like	*Cinnamomum camphora*	Camphor laurel	2.071
Vine or scrambler	*Clematis vitalba*	Old man’s beard	not recorded
Shrub-like	*Clidemia hirta*	Koster’s curse	not recorded
Herb-like	*Collomia grandiflora*	Large-flowered mountain trumpet	0.030
Herb-like	*Conium maculatum*	Hemlock	0.488
Shrub-like	*Coprosma repens*	Mirror bush	0.152
Grass-like	*Cortaderia selloana*	Pampas grass	0.695
Shrub-like	*Cotoneaster glaucophyllus*	Cotoneaster	0.680
Shrub-like	*Crataegus monogyna*	Hawthorn	1.564
Herb-like	*Crocosmia x crocosmiiflora*	Montbretia	0.409
Vine or scrambler	*Cryptostegia grandiflora*	Rubber vine	not recorded
Succulent	*Cylindropuntia fulgida* var. *mamillata*	Boxing glove cactus	0.006
Succulent	*Cylindropuntia imbricata*	Rope pear	0.098
Succulent	*Cylindropuntia pallida*	Hudson pear	0.012
Succulent	*Cylindropuntia rosea*	Hudson pear	0.021
Herb-like	*Cynoglossum creticum*	Blue hound’s tongue	0.009
Grass-like	*Cyperus eragrostis*	Umbrella sedge	3.126
Grass-like	*Cyperus teneristolon*	Cyperus	0.009
Herb-like	*Cyrtomium falcatum*	Holly fern	0.055
Shrub-like	*Cytisus multiflorus*	White Spanish broom	0.003
Shrub-like	*Cytisus scoparius*	Scotch broom	0.570
Grass-like	*Dactylis glomerata*	Cocksfoot	3.010
Vine or scrambler	*Delairea odorata*	Cape ivy	0.704
Vine or scrambler	*Dioscorea bulbifera*	Aerial yam	not recorded

(a) Weeds			Spatial extent
Type	Scientific name	Common name	(%)
Herb-like	*Dipogon lignosus*	Dipogon	0.198
Herb-like	*Dittrichia viscosa*	False yellowhead	not recorded
Vine or scrambler	*Dolichandra unguis-cati*	Cat's claw creeper	0.238
Tree-like	*Dovyalis caffra*	Kei apple	0.021
Grass-like	*Echinochloa polystachya*	Aleman grass	not recorded
Herb-like	*Echium plantagineum*	Paterson's curse	8.523
Aquatic plant	*Egeria densa*	Leafy elodea	0.079
Grass-like	*Ehrharta erecta*	Panic veldgrass	1.860
Aquatic plant	*Eichhornia azurea*	Anchored water hyacinth	not recorded
Aquatic plant	*Eichhornia crassipes*	Water hyacinth	0.293
Herb-like	*Elephantopus mollis*	Tobacco weed	0.006
Aquatic plant	*Elodea canadensis*	Elodea	0.091
Herb-like	*Equisetum arvense*	Horsetails	0.015
Grass-like	*Eragrostis curvula*	African lovegrass	2.946
Shrub-like	*Erica lusitanica*	Spanish heath	0.076
Tree-like	*Erythrina crista-galli*	Cockspur coral tree	0.363
Herb-like	*Eschscholzia californica*	Californian poppy	0.107
Shrub-like	*Eugenia uniflora*	Brazilian cherry	0.040
Shrub-like	*Euphorbia cyathophora*	Wild poinsettia	0.043
Shrub-like	*Euphorbia paralias*	Sea spurge	0.076
Grass-like	*Festuca gautieri*	Bear-skin fescue	not recorded
Herb-like	*Galenia pubescens*	Galenia	0.442
Shrub-like	*Genista linifolia*	Flax-leaf broom	0.055
Shrub-like	*Genista monspessulana*	Cape broom	0.467
Tree-like	*Gleditsia triacanthos*	Honey locust	0.256
Herb-like	*Gloriosa superba*	Glory lily	0.119
Grass-like	*Glyceria maxima*	Reed sweetgrass	0.058
Aquatic plant	*Gymnocoronis spilanthoides*	Senegal tea plant	0.049
Succulent	*Harrisia martinii*	Harrisia cactus	0.021
Vine or scrambler	*Hedera helix*	English ivy	0.692
Herb-like	*Hedychium gardnerianum*	Ginger lily	0.482
Herb-like	*Heliotropium amplexicaule*	Blue heliotrope	0.698
Herb-like	*Heliotropium europaeum*	Common heliotrope	1.229
Herb-like	*Hemerocallis fulva*	Day-lily	0.006
Aquatic plant	*Heteranthera reniformis*	Kidney-leaf mud plantain	0.015
Aquatic plant	*Heteranthera zosterifolia*	Water star grass	0.003
Herb-like	*Heterotheca grandiflora*	Telegraph weed	0.049
Herb-like	*Hieracium aurantiacum*	Orange hawkweed	0.021
Grass-like	*Holcus lanatus*	Yorkshire fog	3.809

(a) Weeds			Spatial extent
Type	Scientific name	Common name	(%)
Aquatic plant	*Hydrocleys nymphoides*	Water poppy	0.012
Aquatic plant	*Hydrocotyle ranunculoides*	Hydrocotyl	not recorded
Aquatic plant	*Hygrophila costata*	Hygrophila	0.034
Aquatic plant	*Hygrophila polysperma*	East Indian hygrophila	0.009
Aquatic plant	*Hymenachne amplexicaulis*	Hymenachne	0.009
Grass-like	*Hyparrhenia hirta*	Coolatai grass	1.668
Shrub-like	*Hypericum androsaemum*	Tutsan	0.040
Shrub-like	*Hypericum calycinum*	Aaron’s beard	0.006
Shrub-like	*Hypericum kouytchense*	Goldflower	0.009
Herb-like	*Hypericum perforatum*	St. John’s wort	3.641
Herb-like	*Hypoestes phyllostachya*	Freckle face	0.079
Vine or scrambler	*Ipomoea alba*	Moonflower	0.030
Vine or scrambler	*Ipomoea cairica*	Morning glory, coastal	0.811
Vine or scrambler	*Ipomoea indica*	Morning glory, purple	0.744
Vine or scrambler	*Ipomoea purpurea*	Morning glory, common	0.168
Herb-like	*Iris foetidissima*	Stinking Iris	0.003
Vine or scrambler	*Jasminum polyanthum*	Jasmine	0.290
Shrub-like	*Jatropha gossypiifolia*	Bellyache bush	not recorded
Tree-like	*Juglans ailantifolia*	Japanese walnut	0.003
Grass-like	*Juncus acutus*	Sharp rush	0.851
Grass-like	*Juncus articulatus*	Rush	0.814
Grass-like	*Juncus effusus*	Rush	0.113
Tree-like	*Koelreuteria elegans* subsp. *formosana*	Chinese rain tree	0.003
Herb-like	*Lachenalia reflexa*	Yellow soldier	not recorded
Aquatic plant	*Lagarosiphon major*	Lagarosiphon	not recorded
Shrub-like	*Lantana camara*	Lantana	4.934
Shrub-like	*Lantana montevidensis*	Creeping lantana	0.146
Vine or scrambler	*Lathyrus tingitanus*	Lathyrus	0.009
Tree-like	*Leucaena leucocephala*	Leucaena	0.018
Herb-like	*Leucanthemum vulgare*	Ox-eye daisy	0.403
Shrub-like	*Leycesteria formosa*	Himilayan honeysuckle	0.030
Tree-like	*Ligustrum lucidum*	Privet, broad-leaf	1.714
Shrub-like	*Ligustrum sinense*	Privet, narrow-leaf	2.357
Tree-like	*Ligustrum vulgare*	Privet, European	0.098
Herb-like	*Lilium formosanum*	Taiwan lily	0.564
Aquatic plant	*Limnobium laevigatum*	Frogbit	0.006
Aquatic plant	*Limnobium spongia*	Spongeplant	not recorded
Aquatic plant	*Limnocharis flava*	Yellow burrhead	not recorded
Herb-like	*Limonium hyblaeum*	Sicilian sea lavender	0.006

(a) Weeds			**Spatial extent**
Type	Scientific name	Common name	(%)
Vine or scrambler	*Lonicera japonica*	Japanese honeysuckle	1.220
Grass-like	*Lophopyrum ponticum*	Tall wheat grass	not recorded
Aquatic plant	*Ludwigia longifolia*	Long-leaf willow primrose	0.070
Aquatic plant	*Ludwigia peruviana*	Ludwigia	0.198
Aquatic plant	*Ludwigia repens*	Red ludwigia	0.018
Shrub-like	*Lycium ferocissimum*	African boxthorn	3.775
Vine or scrambler	*Lygodium japonicum*	Japanese climbing fern	0.006
Tree-like	*Maclura pomifera*	Osage orange	0.107
Herb-like	*Macroptilium atropurpureum*	Siratro	0.195
Herb-like	*Marrubium vulgare*	Horehound	4.726
Herb-like	*Melilotus albus*	Bokhara	0.238
Grass-like	*Melinis minutiflora*	Molasses grass	0.189
Tree-like	*Miconia calvescens*	Miconia	0.003
Vine or scrambler	*Mikania micrantha*	Mikania vine	not recorded
Shrub-like	*Mimosa pigra*	Mimosa	not recorded
Herb-like	*Moraea flaccida*	Cape tulip, one leaf	0.024
Herb-like	*Moraea miniata*	Cape tulip, two-leaf	0.009
Shrub-like	*Murraya paniculata*	Murraya	0.335
Tree-like	*Musa ornata*	Seeded banana	not recorded
Tree-like	*Musa velutina*	Seeded banana	not recorded
Herb-like	*Myosotis laxa* subsp. *caespitosa*	Water forget-me-not	0.207
Aquatic plant	*Myriophyllum aquaticum*	Parrot's feather	0.296
Aquatic plant	*Myriophyllum spicatum*	Eurasian water milfoil	not recorded
Grass-like	*Nassella charruana*	Lobed needle grass	not recorded
Grass-like	*Nassella hyalina*	Cane needle grass	0.024
Grass-like	*Nassella neesiana*	Chilean needle grass	0.415
Grass-like	*Nassella tenuissima*	Mexican feather grass	0.009
Grass-like	*Nassella trichotoma*	Serrated tussock	1.680
Herb-like	*Navarretia squarrosa*	Californian stinkweed	0.015
Aquatic plant	*Neptunia oleracea*	Water mimosa	not recorded
Shrub-like	*Nerium oleander*	Oleander	0.534
Aquatic plant	*Nymphaea mexicana*	Mexican water lily	0.064
Shrub-like	*Ochna serrulata*	Ochna	1.363
Herb-like	*Oenothera curtiflora*	Clockweed	0.009
Tree-like	*Olea europaea* subsp. *cuspidata*	African olive	1.147
Tree-like	*Olea europaea* subsp. *europaea*	Feral olive	0.192
Succulent	*Opuntia ficus-indica*	Indian fig	0.061
Succulent	*Opuntia monacantha*	Smooth tree pear	0.125
Succulent	*Opuntia stricta*	Common pear	4.690

(a) Weeds			Spatial extent
Type	Scientific name	Common name	(%)
Succulent	*Opuntia tomentosa*	Velvety tree pear	0.314
Succulent	*Orbea variegata*	Carrion flower	0.012
Vine or scrambler	*Paederia foetida*	Skunk vine	0.003
Grass-like	*Panicum repens*	Torpedo grass	0.119
Herb-like	*Parietaria judaica*	Pellitory	0.244
Shrub-like	*Parkinsonia aculeata*	Parkinsonia	0.015
Herb-like	*Parthenium hysterophorus*	Parthenium weed	0.037
Grass-like	*Paspalum mandiocanum*	Broadleaf paspalum	0.820
Grass-like	*Paspalum quadrifarium*	Tussock paspalum	0.177
Grass-like	*Paspalum urvillei*	Vasey grass	1.619
Vine or scrambler	*Passiflora caerulea*	Blue passionflower	0.189
Vine or scrambler	*Passiflora suberosa*	Corky passionfruit	0.369
Vine or scrambler	*Passiflora subpeltata*	Passion flower	1.159
Vine or scrambler	*Passiflora tarminiana*	Banana passion flower	0.113
Tree-like	*Paulownia tomentosa*	Empress tree	0.037
Herb-like	*Peganum harmala*	African rue	not recorded
Herb-like	*Pelargonium alchemilloides*	Garden geranium	not recorded
Shrub-like	*Pereskia aculeata*	Leaf cactus	0.015
Herb-like	*Persicaria chinensis*	Chinese knotweed	0.012
Grass-like	*Phalaris aquatica*	Phalaris	3.461
Grass-like	*Phalaris arundinacea*	Reed canary grass	0.079
Tree-like	*Phoenix canariensis*	Phoenix palm	0.537
Grass-like	*Phormium tenax*	New Zealand flax	0.085
Herb-like	*Phyla canescens*	Lippia	0.726
Grass-like	*Phyllostachys aurea*	Fishpole bamboo	0.232
Grass-like	*Phyllostachys nigra*	Rhizomatous bamboo	0.037
Herb-like	*Physalis hederifolia*	Prairie ground cherry	0.021
Herb-like	*Physalis ixocarpa*	Wild gooseberry	0.229
Herb-like	*Physalis longifolia*	Perennial ground cherry	0.009
Tree-like	*Pinus contorta*	Lodgepole pine	0.009
Tree-like	*Pinus elliottii*	Slash pine	0.335
Tree-like	*Pinus halepensis*	Aleppo pine	0.043
Tree-like	*Pinus patula*	Mexican weeping pine	0.073
Tree-like	*Pinus ponderosa*	Ponderosa pine	0.003
Tree-like	*Pinus radiata*	Monterey pine	1.756
Grass-like	*Piptochaetium montevidense*	Uruguayan rice grass	not recorded
Aquatic plant	*Pistia stratiotes*	Water lettuce	0.015
Vine or scrambler	*Pithecoctenium crucigerum*	Monkey's comb	0.015
Vine or scrambler	*Podranea ricasoliana*	Pink trumpet vine	0.003

(a) Weeds			Spatial extent
Type	Scientific name	Common name	(%)
Herb-like	*Potentilla recta*	Sulphur cinquefoil	0.320
Herb-like	*Praxelis clematidea*	Praxelis	0.003
Shrub-like	*Prosopis* spp.	Mesquite	0.055
Tree-like	*Psidium cattleyanum*	Cherry guava	0.012
Vine or scrambler	*Pueraria lobata*	Kudzu	0.091
Shrub-like	*Pyracantha crenulata*	Firethorn	0.131
Shrub-like	*Retama raetam*	White weeping broom	not recorded
Shrub-like	*Rhamnus alaternus*	Buckthorn	0.046
Shrub-like	*Rhaphiolepis indica*	Indian hawthorn	0.210
Shrub-like	*Rhaphiolepis umbellata*	Japanese hawthorn	0.021
Shrub-like	*Rhododendron ponticum*	Rhododendron	0.006
Shrub-like	*Ricinus communis*	Castor oil plant	0.967
Herb-like	*Rivina humilis*	Pigeon berry	0.162
Tree-like	*Robinia pseudoacacia*	Black locust	0.274
Herb-like	*Romulea rosea*	Onion grass	2.839
Aquatic plant	*Rorippa nasturtium-aquaticum*	Watercress	0.354
Shrub-like	*Rosa rubiginosa*	Sweet briar	5.025
Shrub-like	*Rubus alceifolius*	Giant bramble	0.006
Shrub-like	*Rubus fruticosus*	Blackberry	4.178
Shrub-like	*Rubus niveus*	White blackberry	0.006
Shrub-like	*Rubus rugosus*	Keriberry	0.012
Aquatic plant	*Sagittaria calycina* var. *calycina*	Arrowhead	not recorded
Aquatic plant	*Sagittaria platyphylla*	Sagittaria	0.223
Tree-like	*Salix cinerea*	Grey sallow	0.101
Tree-like	*Salix fragilis*	Crack willow	0.348
Tree-like	*Salix nigra*	Black willow	0.082
Vine or scrambler	*Salpichroa origanifolia*	Pampas lily of the valley	0.052
Aquatic plant	*Salvinia molesta*	Salvinia	0.235
Tree-like	*Schinus areira*	Pepper tree	1.415
Tree-like	*Schinus terebinthifolius*	Broad-leaf pepper tree	0.098
Tree-like	*Searsia lancea*	Willow rhus	not recorded
Herb-like	*Sedum acre*	Bitter stonecrop	0.046
Vine or scrambler	*Senecio angulatus*		0.076
Herb-like	*Senecio glastifolius*	Holly leaved senecio	0.012
Herb-like	*Senecio jacobaea*	Ragwort	0.043
Vine or scrambler	*Senecio macroglossus*	Natal ivy	0.055
Herb-like	*Senecio madagascariensis*	Fireweed	4.409
Tree-like	*Senegalia catechu*	Cutch tree	not recorded
Shrub-like	*Senna pendula* var. *glabrata*	Cassia	1.644

(a) Weeds			Spatial extent
Type	Scientific name	Common name	(%)
Shrub-like	*Senna septemtrionalis*	Winter senna	0.988
Grass-like	*Setaria palmifolia*	Palm grass	0.274
Grass-like	*Setaria sphacelata*	South African pigeon grass	0.778
Herb-like	*Sisymbrium thellungii*	African turnip weed, eastern	0.006
Shrub-like	*Solanum chrysotrichum*	Giant devil's fig	0.055
Herb-like	*Solanum elaeagnifolium*	Silverleaf nightshade	0.168
Vine or scrambler	*Solanum laxum*	Potato vine	0.095
Shrub-like	*Solanum linnaeanum*	Apple of Sodom	0.217
Shrub-like	*Solanum mauritianum*	Tobacco bush	2.622
Shrub-like	*Solanum seaforthianum*	Brazilian nightshade	0.531
Shrub-like	*Solanum viarum*	Tropical soda apple	0.034
Herb-like	*Sonchus arvensis*	Corn sowthistle	not recorded
Tree-like	*Sophora japonica*	Japanese pagoda tree	not recorded
Grass-like	*Sorghum almum*	Columbus grass	0.006
Grass-like	*Sorghum halepense*	Johnson grass	0.457
Shrub-like	*Spartium junceum*	Spanish broom	0.015
Herb-like	*Sphagneticola trilobata*	Singapore daisy	0.113
Grass-like	*Sporobolus fertilis*	Giant Parramatta grass	0.488
Grass-like	*Sporobolus natalensis*	Giant rat's tail grass	0.009
Grass-like	*Sporobolus pyramidalis*	Giant rat's tail grass	0.079
Shrub-like	*Stachytarpheta cayennensis*	Cayenne snakeweed	0.003
Grass-like	*Stenotaphrum secundatum*	Buffalo grass	1.229
Aquatic plant	*Stratiotes aloides*	Water soldier	not recorded
Herb-like	*Stylosanthes guianensis*	Stylo	0.015
Herb-like	*Stylosanthes humilis*	Townsville stylo	0.003
Tree-like	*Syagrus romanzoffiana*	Cocos palm	0.552
Tree-like	*Tamarix aphylla*	Athel pine	0.043
Herb-like	*Tanacetum vulgare*	Common tansy	0.034
Shrub-like	*Tecoma capensis*	Cape honeysuckle	0.247
Shrub-like	*Tecoma stans*	Yellow bells	0.076
Shrub-like	*Tetrapanax papyrifer*	Rice paper plant	0.018
Vine or scrambler	*Thunbergia alata*	Black-eyed Susan	0.436
Vine or scrambler	*Thunbergia grandiflora*	Blue trumpet vine	not recorded
Vine or scrambler	*Thunbergia laurifolia*	Laurel clock vine	not recorded
Shrub-like	*Tibouchina urvilleana*	Glorybush	0.101
Herb-like	*Tillandsia usneoides*	Spanish moss	0.037
Tree-like	*Tipuana tipu*	Rosewood	0.012
Shrub-like	*Tithonia diversifolia*	Japanese sunflower	0.034
Herb-like	*Tradescantia cerinthoides*	Spiderwort	0.003

(a) Weeds			Spatial extent
Type	Scientific name	Common name	(%)
Herb-like	*Tradescantia fluminensis*	Trad	1.958
Aquatic plant	*Trapa* spp.	Water caltrop	not recorded
Tree-like	*Triadica sebifera*	Chinese tallow tree	0.156
Herb-like	*Trianoptiles solitaria*	Subterranean cape sedge	not recorded
Aquatic plant	*Typha latifolia*	Cumbungi	0.058
Shrub-like	*Ulex europaeus*	Gorse	0.201
Tree-like	*Ulmus parvifolia*	Chinese elm	0.192
Grass-like	*Urochloa mutica*	Para grass	0.052
Herb-like	*Urtica urens*	Stinging nettle	1.208
Tree-like	*Vachellia farnesiana*	Mimosa bush	0.951
Tree-like	*Vachellia karroo*	Karroo thorn	not recorded
Tree-like	*Vachellia nilotica*	Prickly acacia	not recorded
Herb-like	*Verbena rigida*	Veined verbena	2.241
Shrub-like	*Viburnum odoratissimum* var. *awabuki*	Awabuki sweet viburnum	not recorded
Herb-like	*Vinca major*	Blue periwinkle	0.512
Tree-like	*Washingtonia filifera*	California fan palm	0.034
Herb-like	*Watsonia meriana*	Watsonia	0.415
Herb-like	*Xanthium occidentale*	Noogoora burr	not recorded
Herb-like	*Xanthium spinosum*	Bathurst burr	3.058
Herb-like	*Zantedeschia aethiopica*	Arum lily	0.427

(b) Pest animals			Spatial extent
Type	Scientific name	Common name	(%)
Insect	*Anoplolepis gracilipes*	Yellow crazy ant	not recorded
Insect	*Apis cerana*	Asian honeybee	not recorded
Insect	*Apis dorsata*	Giant honeybee	not recorded
Insect	*Apis florae*	Dwarf honeybee	not recorded
Insect	*Apis mellifera*	Honeybee	0.857
Mammal	*Axis axis*	Chital deer	0.790
Mammal	*Axis porcinus*	Hog deer	0.268
Insect	*Bombus terrestis*	Large earth bumblebee	not recorded
Mammal	*Bos taurus*	Feral cattle	2.278
Mammal	*Camelus dromedarius*	Feral camels	0.778
Mammal	*Canis lupus*	Wild dog	45.877
Mammal	*Capra hircus*	Feral goat	47.344
Fish	*Carassius auratus*	Goldfish	1.122
Mammal	*Cervus elaphus*	Red deer	5.038
Mammal	*Cervus timorensis*	Rusa deer	0.683
Mammal	*Cervus unicolor*	Sambar deer	3.421

(b) Pest animals			Spatial extent
Type	Scientific name	Common name	(%)
Fish	*Cyprinus carpio*	Common carp	1.747
Mammal	*Dama dama*	Fallow deer	10.551
Mammal	*Equus asinus*	Feral donkey	0.354
Mammal	*Equus caballus*	Feral horse	3.796
Mammal	*Felis catus*	Feral cat	98.295
Fish	*Gambusia holbrooki*	Plague minnow	2.388
Insect	*Jamella australiae*	Pandanus planthopper	not recorded
Insect	*Lepisiota frauenfeldi*	Browsing ant	not recorded
Mammal	*Lepus capensis*	Cape hare	2.958
Mammal	*Mus musculus*	House mouse	5.303
Fish	*Oncorhynchus mykiss*	Rainbow trout	0.256
Fish	*Oreochromis mossambicus*	Tilapia	not recorded
Mammal	*Oryctolagus cuniculus*	European rabbit	82.442
Bird	*Passer domesticus*	Sparrow	10.435
Fish	*Perca fluviatilis*	Redfin perch	0.390
Insect	*Pheidole megacephala*	African big-headed ant	0.061
Mammal	*Rattus norvegicus*	Brown rat	0.598
Mammal	*Rattus rattus*	Black rat	3.007
Amphibian	*Rhinella marina*	Cane toad	1.022
Fish	*Salmo trutta*	Brown trout	0.268
Insect	*Solenopsis geminata*	Tropical fire ant	not recorded
Insect	*Solenopsis invicta*	Red important fire ant	not recorded
Insect	*Solenopsis richteri*	Black imported fire ant	not recorded
Bird	*Streptopelia chinensis*	Spotted dove	4.540
Bird	*Sturnus tristis*	Common (Indian) Myna	4.046
Bird	*Sturnus vulgaris*	Starling	17.933
Mammal	*Sus scrofa*	Feral pig	70.135
Reptile	*Trachemys scripta elegans*	Red-eared slider turtle	0.037
Bird	*Turdus merula*	European blackbird	5.815
Insect	*Vespula germanica*	European wasp	0.192
Mammal	*Vulpes vulpes*	Red fox	98.536
Insect	*Wasmannia auropunctata*	Electric ant/Little fire ant	not recorded
Fish	*Xiphophorus maculatus*	Platyfish	not recorded

(c) Diseases			Spatial extent
Type	Scientific name	Common name	(%)
Fungus	*Austropuccinia psidii*	Myrtle rust	0.290
Fungus	*Batrachochytrium dendrobatidis*	Chytrid fungus	0.113
Fungus	*Phytophthora cinnamomi*	Phytophthora	0.198
Virus	Psittacine circoviral disease	Beak and feather disease	not recorded

Appendix C. Invasive alien species richness

Table 13 **Bioregion-scale IAS richness (a metric of the exposure dimension of the IAS pressure indicator).**

For each of the three biological dimensions of IAS (biological groups: weeds, pest animals and diseases), we report both the number (count) of IAS that were recorded in the bioregion, and the proportion of all IAS recorded in New South Wales that were recorded in the bioregion.

Bioregion		Weeds (n=305)		Pest animals (n=36)		Diseases (n=3)	
Name	Code	Count	%	Count	%	Count	%
Australian Alps	AUA	36	11.8%	22	61.1%	1	33.3%
Brigalow Belt South	BBS	108	35.4%	26	72.2%	0	0.0%
Broken Hill Complex	BHC	29	9.5%	15	41.7%	0	0.0%
Channel Country	CHC	4	1.3%	11	30.6%	0	0.0%
Cobar Peneplain	COP	55	18.0%	24	66.7%	0	0.0%
Darling Riverine Plains	DRP	68	22.3%	28	77.8%	0	0.0%
Murray Darling Depression	MDD	26	8.5%	18	50.0%	0	0.0%
Mulga Lands	MUL	18	5.9%	20	55.6%	0	0.0%
Nandewar	NAN	129	42.3%	28	77.8%	0	0.0%
New England Tablelands	NET	112	36.7%	27	75.0%	1	33.3%
NSW North Coast	NNC	210	68.9%	30	83.3%	2	66.7%
NSW South Western Slopes	NSS	133	43.6%	29	80.6%	0	0.0%
Pacific Subtropical Islands (Lord Howe Island only)	PSI	50	16.4%	5	13.9%	0	0.0%
Riverina	RIV	83	27.2%	27	75.0%	0	0.0%
South East Corner	SEC	160	52.5%	30	83.3%	3	100.0%
South Eastern Highlands	SEH	139	45.6%	31	86.1%	2	66.7%
South Eastern Queensland	SEQ	180	59.0%	25	69.4%	3	100.0%
Simpson Strzelecki Dunefields	SSD	6	2.0%	10	27.8%	0	0.0%
Sydney Basin	SYB	264	86.6%	34	94.4%	3	100.0%
Average		**95.26**	**31.2%**	**23.16**	**64.3%**	**0.79**	**26.3%**
Standard deviation		**71.62**	**23.5%**	**7.78**	**21.6%**	**1.15**	**38.4%**

Appendix D. Invasive alien species impact

Table 14 The five impact categories used to assess the magnitude of impact on a native (a) species or (b) ecological community caused by an IAS (by impact mechanism).

Each impact category is defined for each of 12 mechanisms by which an impact may occur. Generic definitions for each of the five impact categories, and the data deficient category, are in Table 6. Generic definitions for each of the 12 impact mechanisms are in Table 5..

(a) Magnitude of impact on a native species					
Mechanism	**Massive [MV]**	**Major [MR]**	**Moderate [MO]**	**Minor [MN]**	**Minimal concern [MC]**
1. Competition	Competition causes replacement and extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	Competition causes replacement and extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	Competition causes decline in population size in at least one local population of the native species, but no local population extinctions	Competition reduces performance of individuals in at least one local population of the native species, but no decline in population sizes	Negligible level of competition with the native species; no reduction in performance of individuals
2. Predation	Predation causes extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	Predation causes extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	Predation causes decline in population size in at least one local population of the native species, but no local population extinctions	The invasive alien species preys on individuals of the native species in at least one local population, but no decline in population sizes	n/a; the lowest impact category for predation is MN
3. Hybridisation	Hybridisation between the invasive alien species and the native species causes extinction of at least one pure local population (genomic extinction), which is irreversible even if the invasive alien species and hybrids were no longer present	Hybridisation between the invasive alien species and the native species causes extinction of at least one pure local population (genomic extinction), which is reversible if the invasive alien species and hybrids were no longer present	Hybridisation between the invasive alien species and the native species regularly observed in the wild, causing decline in population size in at least one pure local population, but pure populations persist	Hybridisation between the invasive alien species and the native species rarely observed in the wild; no decline in size of pure native populations	No hybridisation between the invasive alien species and the native species observed in the wild (prezygotic barriers); hybridisation is possible in captivity
4. Transmission of disease	The invasive alien species is host or vector of disease that is also detected in the native species; disease causes extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	The invasive alien species is host or vector of disease that is also detected in the native species; disease causes extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	The invasive alien species is host or vector of disease that is also detected in the native species; disease causes mortality and decline in population size in at least one local population of the native species, but no local population extinctions	The invasive alien species is host or vector of disease that is also detected in the native species; disease reduces performance of individuals in at least one local population of the native species, but no mortality and decline in population sizes	The invasive alien species is host or vector of disease transmissible to, but not yet detected in, the native species; no reduction in performance of individuals

5. Parasitism/ pathogens	Parasitism or disease incidence (pathogens) directly causes extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	Parasitism or disease incidence (pathogens) directly causes extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	Parasitism or disease incidence (pathogens) directly causes decline in population size in at least one local population of the native species, but no local population extinctions	Parasitism or disease incidence (pathogens) reduces performance of individuals in at least one local population of the native species, but no decline in population sizes	Negligible level of parasitism on, or disease incidence (pathogens) in, the native species; no reduction in performance of individuals
6. Poisoning/ toxicity	The invasive alien species is toxic, allergenic or allelopathic to the native species, causing extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	The invasive alien species is toxic, allergenic or allelopathic to the native species, causing extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	The invasive alien species is toxic, allergenic or allelopathic to the native species, causing decline in population size in at least one local population of the native species, but no local population extinctions	The invasive alien species is toxic, allergenic or allelopathic to the native species, causing reduction in performance of individuals in at least one local population of the native species, but no decline in population sizes	The invasive alien species is toxic, allergenic or allelopathic to the native species, but level is very low; no reduction in performance of individuals
7. Bio-fouling	Bio-fouling causes extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	Bio-fouling causes extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	Bio-fouling causes decline in population size in at least one local population of the native species, but no local population extinctions	Bio-fouling reduces performance of individuals in at least one local population of the native species, but no decline in population sizes	Negligible level of bio-fouling on the native species; no reduction in performance of individuals
8. Grazing/ herbivory/ browsing	Herbivory, grazing or browsing causes extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	Herbivory, grazing or browsing causes extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	Herbivory, grazing or browsing causes decline in population size in at least one local population of the native species, but no local population extinctions	Herbivory, grazing or browsing reduces performance of individuals in at least one local population of the native species, but no decline in population sizes	Negligible level of herbivory, grazing or browsing on the native species; no reduction in performance of individuals
9. Chemical impact on ecosystem	Changes in chemical properties of the native species' environment cause extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	Changes in chemical properties of the native species' environment cause extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	Changes in chemical properties of the native species' environment cause decline in population size in at least one local population of the native species, but no local population extinctions	Changes in chemical properties of the native species' environment reduce performance of individuals in at least one local population of the native species, but no decline in population sizes	Small changes in chemical properties of the native species' environment; no reduction in performance of individuals
10. Physical impact on ecosystem	Changes in physical properties of the native species' environment cause extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	Changes in physical properties of the native species' environment cause extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	Changes in physical properties of the native species' environment cause decline in population size in at least one local population of the native species, but no local population extinctions	Changes in physical properties of the native species' environment reduce performance of individuals in at least one local population of the native species, but no decline in population sizes	Small changes in physical properties of the native species' environment; no reduction in performance of individuals

11. Structural impact on ecosystem	Changes in structural properties of the native species' environment cause extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present	Changes in structural properties of the native species' environment cause extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present	Changes in structural properties of the native species' environment cause decline in population size in at least one local population of the native species, but no local population extinctions	Changes in structural properties of the native species' environment reduce performance of individuals in at least one local population of the native species, but no decline in population sizes	Small changes in structural properties of the native species' environment; no reduction in performance of individuals
12. Indirect impact through interactions with other species	Interaction with other native or alien species causes extinction of at least one local population of the native species, which is irreversible even if the invasive alien species were no longer present; impacts would not have occurred in the absence of the invasive alien species	Interaction with other native or alien species causes extinction of at least one local population of the native species, which is reversible if the invasive alien species were no longer present; impacts would not have occurred in the absence of the invasive alien species	Interaction with other native or alien species causes decline in population size in at least one local population of the native species, but no local population extinctions; impacts would not have occurred in the absence of the invasive alien species	Interaction with other native or alien species reduces performance of individuals in at least one local population of the native species, but no decline in population sizes; impacts would not have occurred in the absence of the invasive alien species	Negligible level of interaction with other native or alien species facilitating indirect impacts on the native species; no reduction in performance of individuals

(b) Magnitude of impact on a native ecological community					
Mechanism	**Massive [MV]**	**Major [MR]**	**Moderate [MO]**	**Minor [MN]**	**Minimal concern [MC]**
1. Competition	Competition causes replacement and extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	Competition causes replacement and extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	Competition causes decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions	Competition reduces performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes	Negligible level of competition with characteristic native species of the ecological community; no reduction in performance of individuals
2. Predation	Predation causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	Predation causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	Predation causes decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions	The invasive alien species preys on individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes	n/a; the lowest impact category for predation is MN
3. Hybridisation	Hybridisation between the invasive alien species and at least one characteristic native of the ecological community causes extinction of pure population in at least one remnant patch of the ecological community, which is irreversible even if the invasive	Hybridisation between the invasive alien species and at least one characteristic native of the ecological community causes extinction of pure population in at least one remnant patch of the ecological community, which is reversible if the invasive alien	Hybridisation between the invasive alien species and at least one characteristic native of the ecological community regularly observed in the wild, causing decline in pure population size in at least one remnant patch of the ecological community, but pure population persist	Hybridisation between the invasive alien species and at least one characteristic native of the ecological community rarely observed in the wild; no decline in size of pure native populations	No hybridisation between the invasive alien species and characteristic native species of the ecological community observed in the wild (prezygotic barriers); hybridisation is possible in captivity

	alien species and hybrids were no longer present	species and hybrids were no longer present			
4. Transmission of disease	The invasive alien species is host or vector of disease that is also detected in at least one characteristic native species of the ecological community; disease causes extinction in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	The invasive alien species is host or vector of disease that is also detected in at least one characteristic native species of the ecological community; disease causes extinction in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	The invasive alien species is host or vector of disease that is also detected in at least one characteristic native species of the ecological community; disease causes mortality and decline in population size in at least one remnant patch of the ecological community, but no local population extinctions	The invasive alien species is host or vector of disease that is also detected in at least one characteristic native species of the ecological community; disease reduces performance of individuals in at least one remnant patch of the ecological community, but no mortality and decline in population sizes	The invasive alien species is host or vector of disease transmissible to, but not yet detected in, characteristic native species of the ecological community; no reduction in performance of individuals
5. Parasitism/ pathogens	Parasitism or disease incidence (pathogens) directly causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	Parasitism or disease incidence (pathogens) directly causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	Parasitism or disease incidence (pathogens) directly causes decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions	Parasitism or disease incidence (pathogens) reduces performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes	Negligible level of parasitism on, or disease incidence (pathogens) in, characteristic native species of the ecological community; no reduction in performance of individuals
6. Poisoning/ toxicity	The invasive alien species is toxic, allergenic or allelopathic to the native species, causing extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	The invasive alien species is toxic, allergenic or allelopathic to the native species, causing extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	The invasive alien species is toxic, allergenic or allelopathic to the native species, causing decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions	The invasive alien species is toxic, allergenic or allelopathic to the native species, causing reduction in performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes	The invasive alien species is toxic, allergenic or allelopathic to characteristic native species of the ecological community, but level is very low; no reduction in performance of individuals
7. Bio-fouling	Bio-fouling causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	Bio-fouling causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	Bio-fouling causes decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions	Bio-fouling reduces performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes	Negligible level of bio-fouling on characteristic native species of the ecological community; no reduction in performance of individuals
8. Grazing/ herbivory/ browsing	Herbivory, grazing or browsing causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	Herbivory, grazing or browsing causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	Herbivory, grazing or browsing causes decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions	Herbivory, grazing or browsing reduces performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes	Negligible level of herbivory, grazing or browsing on characteristic native species of the ecological community; no reduction in performance of individuals

9. Chemical impact on ecosystem	Changes in chemical properties of the native species' environment cause extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	Changes in chemical properties of the native species' environment cause extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	Changes in chemical properties of the native species' environment cause decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions	Changes in chemical properties of the native species' environment reduce performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes	Small changes in chemical properties of the ecological community's environment; no reduction in performance of individuals of characteristic native species
10. Physical impact on ecosystem	Changes in physical properties of the native species' environment cause extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	Changes in physical properties of the native species' environment cause extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	Changes in physical properties of the native species' environment cause decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions	Changes in physical properties of the native species' environment reduce performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes	Small changes in physical properties of the ecological community's environment; no reduction in performance of individuals of characteristic native species
11. Structural impact on ecosystem	Changes in structural properties of the native species' environment cause extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present	Changes in structural properties of the native species' environment cause extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present	Changes in structural properties of the native species' environment cause decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions	Changes in structural properties of the native species' environment reduce performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes	Small changes in structural properties of the ecological community's environment; no reduction in performance of individuals of characteristic native species
12. Indirect impact through interactions with other species	Interaction with other native or alien species causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is irreversible even if the invasive alien species were no longer present; impacts would not have occurred in the absence of the invasive alien species	Interaction with other native or alien species causes extinction of at least one characteristic native species in at least one remnant patch of the ecological community, which is reversible if the invasive alien species were no longer present; impacts would not have occurred in the absence of the invasive alien species	Interaction with other native or alien species causes decline in population size of at least one characteristic native species in at least one remnant patch of the ecological community, but no local population extinctions; impacts would not have occurred in the absence of the invasive alien species	Interaction with other native or alien species reduces performance of individuals of at least one characteristic native species in at least one remnant patch of the ecological community, but no decline in population sizes; impacts would not have occurred in the absence of the invasive alien species	Negligible level of interaction with other native or alien species facilitating indirect impacts on characteristic native species of the ecological community; no reduction in performance of individuals

Table 15 Expert-elicited likelihood that the impact caused by IAS is of a certain magnitude (by individual IAS).

The table shows the likelihood (in percent of total) that each of the five impact categories is the true category, averaged across all interactions with threatened species and ecological communities that were assessed against an IAS. Results are shown for (a) seven assessed pest animals and (b) 15 assessed weeds. The number of assessed interactions per IAS (excluding those that were assessed as data deficient [DD] by all experts) and the number of contributing expert assessors are also shown.

Invasive alien species name	Massive [MV]	Major [MR]	Moderate [MO]	Minor [MN]	Minimal [MC]	Inter-actions	Experts
(a) Pest animals						**(n)**	**(n)**
Feral cat	7.8%	26.1%	51.3%	13.8%	1.0%	10	6
Feral deer	0.9%	18.4%	51.1%	26.1%	3.6%	8	7
Feral goat	11.9%	29.0%	52.4%	6.5%	0.2%	11	11
Feral horse	2.3%	36.0%	20.8%	30.9%	10.1%	3	5
Feral pig	2.6%	24.4%	47.6%	21.6%	3.8%	5	5
Feral rabbit	7.2%	9.8%	30.6%	37.4%	15.0%	10	6
Red fox	13.5%	46.5%	30.2%	8.5%	1.4%	11	15
(b) Weeds						**(n)**	**(n)**
African boxthorn	6.6%	30.6%	33.2%	24.2%	5.4%	8	4
African lovegrass	29.7%	65.2%	5.1%	0.0%	0.0%	8	4
African olive	11.5%	58.6%	26.5%	3.5%	0.0%	7	4
Bitou bush	15.8%	59.3%	21.8%	3.1%	0.0%	6	6
Blackberry	14.4%	34.2%	30.8%	17.6%	3.0%	6	6
Cat's claw creeper	27.2%	61.9%	9.9%	1.0%	0.0%	10	4
Coolatai grass	46.9%	47.2%	5.1%	0.8%	0.0%	7	3
Ground asparagus	17.5%	15.5%	28.9%	27.5%	10.6%	6	6
Hudson pear	0.0%	5.0%	90.0%	5.0%	0.0%	2	2
Lantana	11.2%	42.1%	37.3%	9.1%	0.3%	12	7
Madeira vine	32.0%	35.1%	24.9%	7.1%	1.0%	8	4
Mother-of-millions	0.0%	4.0%	48.1%	34.0%	13.9%	6	4
Oxeye daisy	2.4%	34.8%	35.7%	17.5%	9.6%	9	3
Serrated tussock	25.4%	28.9%	28.8%	13.6%	3.3%	6	5
St John's wort	13.1%	8.1%	29.3%	29.6%	19.9%	7	3

Table 16 Expert-elicited likelihood that the impact caused by IAS is of a certain magnitude (by IAS biological dimension and threatened entity biological group).

The table shows the likelihood (in percent of total) that each of the five impact categories is the true category, averaged across all interactions that were assessed against (a) an IAS biological dimension (pest animals, weeds) and (b) a threatened entity group (threatened animals, threatened plants, threatened ecological communities). The number of assessed interactions per IAS (excluding those that were assessed as data Deficient [DD] by all experts) and the number of contributing expert assessors are also shown.

	Massive [MV]	Major [MR]	Moderate [MO]	Minor [MN]	Minimal [MC]	Inter-actions	Experts
(a) IAS biological groups						**(n)**	**(n)**
Pest animals	8.2%	28.3%	41.3%	18.0%	4.3%	58	25
Weeds	18.2%	38.8%	27.5%	11.9%	3.6%	108	21
(b) Threatened entity biological groups						**(n)**	**(n)**
Threatened animals	11.6%	33.0%	37.8%	14.7%	2.9%	26	14
Threatened plants	11.1%	29.4%	36.0%	18.7%	4.7%	51	23
Threatened ecological communities	16.6%	37.6%	30.0%	12.0%	3.8%	89	23

Glossary

Alien: not naturally occurring in any location in New South Wales.

Area of occupancy: the area within the total range area of a species (i.e. its extent of occurrence) which is currently occupied, excluding unsuitable and unoccupied areas.

Biodiversity, biological diversity: variability among living organisms from all sources (including terrestrial, freshwater, coastal, marine and other ecosystems and ecological complexes of which they are part), which includes genetic diversity, species diversity and ecosystem diversity.

Biological group: a grouping of biological entities (such as species) sharing common characteristics and treated as a unit for analyses and reporting. Grouping could be based on common ancestry, shared habitat requirements, shared functional characteristics or other criteria.

Bioregion: a relatively large land area characterised by broad, landscape-scale natural features and environmental processes that influence the functions of entire ecosystems and capture large-scale biophysical patterns. These patterns in the landscape are linked to fauna and flora assemblages and processes at the ecosystem scale. There are 19 bioregions represented in New South Wales.

Characteristic species: a native species that, together with other native species and biological features, defines the identity of an ecological community.

Dimension (of indicator): see ‘indicator dimension’.

Disease: any disease of a native species that is caused by a pathogen that is an invasive alien species.

Ecological community: an assemblage of native species occupying a particular area at a particular time.

Ecosystem: a dynamic complex of plant, animal and microorganism communities and their nonliving environment that interact as a functional unit. Ecosystems may be small and simple, like an isolated pond, or large and complex, like a tropical rainforest or a coral reef.

Essential variable: the minimum information needed to quantify environmental change at a range of geographic scales, from local to global. Essential variables enable comparisons between environmental conditions at different locations and times and can be integrated into indicators to fulfil a specific reporting requirement.

Extent of occurrence: the total range area of a species as delimited by its outermost occurrence records.

Extirpation, local extinction: the elimination of all individuals of a local population of a native species, or the elimination of all individuals of a characteristic native species from a remnant patch of an ecological community.

Grid: a georeferenced spatial raster dataset consisting of a two-dimensional array of pixels (grid cells) containing categorical or continuous numerical values representing some measure or characteristic of each location with additional attributes optionally stored in an associated raster attribute table.

Indicator dimension: a component of the indicator that can be reported and tracked separately or aggregated to provide an overall measure of the indicator (if appropriate). For example, the invasive alien species indicator has three biological dimensions (the biological groups of weeds, pest animals and diseases) and, to date, has two pressure dimensions (exposure and impact).

Interaction: the impact that an invasive alien species has on a co-occurring native species or ecological community.

Invasive alien species (IAS): a species whose introduction or spread outside their natural distribution threatens biodiversity. More precisely, a species, subspecies or variety or cultivar moved intentionally or unintentionally by human activities beyond the limits of its native geographic range, or resulting from breeding or hybridisation and being released into an area in which it does not naturally occur, and whose introduction or spread threatens native biodiversity and ecosystem quality.

Invasive alien species impact: the consequences of invasive alien species pressures, i.e. the changes to the properties of ecosystems caused by invasive alien species to the detriment of native species and ecological communities.

Invasive alien species impact (likelihood of IAS impact metric): the average expert-elicited likelihood that impacts caused by assessed invasive alien species on assessed native species and ecological communities are of a certain magnitude.

Invasive alien species impact (most harmful IAS metric): the expert-elicited number, proportion and name of assessed invasive alien species which are more likely than not (>50% average likelihood) of causing local population extirpation among assessed native species or ecological communities.

Invasive alien species exposure: the exposure to invasive alien species pressures, i.e. the presence, size and extent of these pressures on native biodiversity and ecosystem quality.

Invasive alien species pressure: the threat posed by invasive alien species to native biodiversity and ecosystem quality.

Invasive alien species richness (absolute metric): the number (count) of invasive alien species that were recorded as naturalised in at least one location in an invaded area.

Invasive alien species richness (proportional metric): the proportion of all identified invasive alien species that were recorded in New South Wales; the proportion of all invasive alien species recorded in New South Wales that were recorded in a bioregion, or a grid cell with a resolution of c. 5 kilometres, respectively.

Invasive alien species spatial extent (proportional metric): the proportion of New South Wales grid cells with a resolution of c. 5 kilometres where an invasive alien species was recorded as naturalised in at least one location.

Invasive alien species status: classified as an invasive alien species. Here referring to alien species that had been identified as current or potential future threats to native biodiversity and ecosystem quality in New South Wales in at least one of several authoritative data sources.

Invasiveness: a property of an invasive alien species; referring to its ability to invade geographically defined areas, habitats and ecosystems over both local and broad scales.

Invasion level: a property of a geographically defined invaded area, habitat or ecosystem; referring to the severity of the observed invasion.

Key threatening process: a process that has been defined by the New South Wales Threatened Species Scientific Committee as adversely affecting threatened species or ecological communities, or with the potential to cause species or ecological communities that are not threatened to become threatened, and is listed in Schedule 4 of the BC Act.

Local population: a geographically or otherwise distinct group of individuals of a native species, which may be connected to other groups of individuals by frequent immigration to form a subpopulation. In situations where a single group of individuals of a native species is isolated from other groups of individuals, local population and subpopulation are the same.

Magnitude of impact: the intensity of detrimental impacts caused by invasive alien species. Here referring to five categories that differentiate impact depending on the level of biological organisation of a native species, or a characteristic species of a native ecological community, that is impacted and the lasting consequences of this impact.

Metric: a quantifiable measure that is used to track and assess the status of a specific process. Here we refer to metric as a measure of a particular dimension of the indicator.

NARCliM: New South Wales and Australian Capital Territory Regional Climate Modelling project.

Native: naturally occurring in at least one location in New South Wales.

Naturalised: having established in at least one location in the wild, unaided by active human husbandry – i.e. cultivation (of alien plants) or keeping (of alien animals).

Occurrence record: information about the presence of a species in a given location (usually a point with geographic coordinates, but may also refer to other geographic units, e.g. a polygon area or a pixel in a regular grid). Occurrence records do not contain any information about the absence of a species from a given location. Absence of a species is instead inferred from the absence of information about its presence. Species occurrence records are also commonly referred to as presence-only records, detection records, locality records, distribution data or observations.

Pest animal, pest: any animal, whether vertebrate or invertebrate and in any stage of biological development, that is an invasive alien species.

Population decline, decline in population size: a reduction in the number of mature individuals of a native species.

Pressure: a threat in the landscape that causes biodiversity loss or threatens the quality of ecosystems.

Remnant patch: a remaining geographic location in which groups of individuals of the characteristic native species that define the identity of an ecological community co-occur.

Reversibility, reversible: Here referring to evidence (in a hypothetical scenario) that if an invasive alien species were no longer present in an area where a local population of a native species, or a characteristic native species of an ecological community, has been extirpated, the impacted native species, or characteristic species of a native ecological community, would likely return to the area within 10 years or three generations, whichever is longer, without additional human assistance that was not already in place at the time the invasive alien species led to the local population extirpation.

Reversibility, irreversible: Here referring to evidence (in a hypothetical scenario) that if an invasive alien species were no longer present in an area where a local population of a native species, or a characteristic native species of an ecological community, has been extirpated, the impacted native species, or characteristic species of a native ecological community, would not return to the area within 10 years or three generations, whichever is longer, without additional human assistance that was not already in place at the time the invasive alien species led to the local population extirpation.

Sensitive status (biodiversity, ecosystems): known to be detrimentally affected by the impacts caused by invasive alien species.

Species: a taxon comprising one or more populations of individuals capable of interbreeding to produce fertile offspring.

Surrogate: a variable that can be measured more easily than another ‘target’ variable of interest for which direct measurement is difficult. The usual approach is to measure the surrogate and use the measurement(s) to infer something about the target based on a known relationship between the surrogate and the target.

Threatened species: a native species (or subspecies, variety) that has been defined as threatened by the New South Wales Threatened Species Scientific Committee because (i) there is a reduction in its population size, (ii) it has a restricted geographic distribution, or (iii) there are few mature individuals, and is listed in Schedule 1 of the BC Act.

Threatened ecological community: a native ecological community that has been defined as threatened by the New South Wales Threatened Species Scientific Committee based on (i) characteristic native biota: biological features that define the identity of a community, (ii) environmental features such as geology, terrain or typical climate, and (iii) occurrence in a particular geographic location, and is listed in Schedule 2 of the BC Act.

Weed: any plant, whether vascular or non-vascular and in any stage of biological development in the taxonomic kingdom of Plantae, that is an invasive alien species.

Workflow: the sequence of processes through which a piece of work passes from initiation to completion.

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