Invasive Species Cost Assessment for New South Wales

CEBRA / CEER project

Final Project Report

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Executive summary

The NSW Premier has requested the Commission review the priority risks and impacts of invasive species in NSW. The Premier's request includes the requirement to: 1) quantify the current extent and impacts of invasive species on NSW industry, environment, and communities; and 2) identify future risks posed to NSW industry, environment, and communities by invasive species, including any which are driven by climate change impacts and natural disasters. The Commission has engaged the Centre for Excellence for Biosecurity Risk Analysis (CEBRA) who, in partnership with the Centre for Environmental and Economic Research (CEER), at the University of Melbourne have analysed the cumulative, current, and future financial impact (or costs) of invasive species on NSW.

The CEBRA/CEER team employed an approach consisting of two parts: a retrospective one to quantify the historic cumulative cost of invasive species on the NSW economy, environment, and society, and a prospective one that identifies, and when and where possible quantifies the costs that invasive species may have into the next decade.

The retrospective or 'looking back' approach involved a rapid review to aggregate and model costs of currently established invasive species in NSW and their cumulative cost between 1970 and 2022.This review has contributed significantly to the improvement of the existing Invacost database. CEBRA have reviewed the database records, identified and removed duplications and records of poor reliability, and contributed records to the database that where either missing or post-dated existing analyses.

The total cumulative costs reported between 1970 – 2022 associated with current invasive species in NSW amounts to $30.761 billion (excluding public expenditure based costs). The raw aggregated cost for 2022 is $0.424 billion, while the costs for 2020 and 2021 were considerably higher, i.e. $1.339 and $1.379 billion. These years were more consistent with the averaged annual costs during 2010s (i.e. $1.319 billion per year).

The modelled cost predictions (using historical data) amount to $1.780 billion in 2022, and $2.076 for 2023 $1.339 billion for 2020 and $1.379 billion for 2021.

Terrestrial plants and vertebrates account for the majority of costs, with plants accounting for 82.9%, and vertebrates accounting for 15.5%. For terrestrial plants, the most costly taxa were serrated tussock ($322 million total reported costs up to 2022), blackberry ($305 million), ryegrass ($153 million), fleabane ($130 million), and barnyard grass ($119 million). The most costly terrestrial vertebrates were cats ($2.291 billion), European rabbits ($443 million), wild dog ($441 million), feral pigs ($420 million), and red foxes ($393 million). The most costly terrestrial invertebrates were identified as the oat aphids ($47 million), blue oat mites ($42 million), lucerne fleas ($38 million), redlegged earth mites ($33 million), and cereal cyst nematodes ($31 million), while common carp ($30 million) was the only aquatic species for which species and/or genus specific cost estimates were found.

When grouping the impacted sectors we used: (1) Industry/agricultural losses to be those losses predominately attributed to production losses and control costs; (2) Research costs are research and innovation expenditure by industry representative bodies; (3) Health and public welfare costs are given by medical costs, as well as cost to community-based assets (e.g. indigenous communities/infrastructure, road crashes); (4) Environmental costs are estimates of the monetary value of damages to environmental assets/services, and the value of community/volunteer work on environmental programs; and (5) Mixed/Other. The most impacted sector on available data is the first (industry/agricultural losses) incurring 92.2% of all reported losses.

The allocation of costs by sector is heavily focused on the private costs of invasive species in agricultural industries, e.g. ABARES data on land manager expenditure. This may be driven partially by publication and reporting biases. Environmental and ecosystem services impacts are one area where costs are clearly under-reported, and we postulate a $7.133 billion monetary value of impact of invasive species on the environment between 1970 – 2022 and $0.322 billion in the 2022/2023 financial year.

Public expenditures are another area of costs missing from these estimates. These were specifically excluded from the rapid review, and instead estimated based on expenditure estimate obtained directly from relevant departments. The expenditure on management of invasive species from NSW government amounts to a total of $200.58 million in the 2022/2023 financial year.

When 'looking forward', in the prospective part of this report, we used the historical data to inform the future costs of established invasive species as well as trying to anticipate potential costs of species not yet in NSW. We used the CEBRA Value model to predict the costs of invasive species that are not yet in NSW.

Modelled projected costs from the reported costs (excluding the conjectures about the environmental damages and public expenditure) suggest costs reaching up to a mean of $2.42 billion for 2024, and up to $6.10 billion for 2030.

The 2030 prediction (7 year simulation) for future invasives, when considering the worst case scenario of all 24 representative species of their corresponding functional groups established in and spread through NSW is $29.73 billion, which is five times the (non-public) amount predicted for 2030 for the current invasive species ($6.10 billion).

In addition, we used the CEBRA Value model to predict the damage of red imported fire ants (RIFA) as one of the incomplete incursion examples. Results show that the damage caused by RIFA could be more than $60 billion over 30 years to Australia, or roughly $2.2 billion per year with the damage mostly in QLD and NSW. The cumulative and combined damage to agriculture, recreation, and tourism will exceed 1.5% of Australia's GDP and the 'unreported damage' to the environment will be 1.3% of GDP.

Combined, this is a cumulative damage of 2.8% of GDP measured in 2054, which is approximately half of a the COVID shock in 2020-2021.

Human activities accelerate the spread of invasive pests through trade and travel, urbanisation, and increasing demand for agricultural products with an increasing population. Advances in technology, in turn, could assist us in pest management such as through improved detection, genetic bio-control or tracing invasion pathways.

Climate change is expected to influence biological invasions by modifying their establishment and spread rates, as well as their impacts. The greatest economic and environmental impacts associated with biological invasions in NSW over the next decades are likely to come from exotic threats, yet to establish within the country, but whose probability of being introduced into climatically suitable areas is increasing under climate change. Pathogens, viruses, and invertebrate plant pests can potentially have very high economic impacts, causing a large economic loss even after a single outbreak in agricultural land. For example, recent work by CEBRA indicates that an outbreak of oriental fruit fly along the east coast of Australia (covering QLD and NSW) could result in $5.25 billion in average annual damages.

Part I.

Background and overview

I.1. Introduction

Invasive species generate significant negative impacts on the New South Wales (NSW) economy, environment, and society. Managing the risks they pose demands considerable expense both public and private. In only 60 years time, the impact of invasive species have cost Australia at least $390 billion (Bradshaw *et al.*, 2021). What part of these impact costs, those that can be considered a direct measure of impacts, was incurred by NSW is the focus of this research.

The review

The NSW Premier has requested the NSW Natural Resources Commission (Commission) review the priority risks and impacts of invasive species in NSW, including the effectiveness of current management strategies. The review follows the Commission's 2014 review of the effectiveness and efficiency of NSW weed management arrangements and 2016 review of NSW pest animal management.

The requirements of the review include:

- Quantifying the current extent and impacts of invasive species on NSW industry, environment, and communities, and
- Identifying future risks posed to NSW industry, environment, and communities by invasive species, including any which are driven by climate change impacts and impacts from natural disasters.

The Commission engaged researchers from the Centre of Excellence for Biosecurity Risk Analysis (CEBRA) and the Centre for Environmental and Economic Research (CEER) to conduct an assessment of the NSW invasive species costs and the potential costs of future invasions into NSW.

While both public and private impact costs are discussed in this report, CEBRA/CEER is responsible for impact analysis (as measured by costs), excluding the public expenditure. The Commission's team summarised the public expenditure (briefly mentioned in Section II.2.2, and detailed in Appendix C).

The review will help to inform the NSW Government of key opportunities to better manage invasive species, supported by the best available evidence.

Background

Despite the geographic advantage of an island continent and a comparatively advanced biosecurity system, the legacy of deliberate and accidental introductions of invasive alien species has had a hefty toll on the NSW economy and environment. These introductions by humans go back beyond the arrival of the first fleet in 1788, and today, many different alien species occupy almost every terrestrial, freshwater and marine habitat in NSW.

Many invasive species incursions have not yet run their course. For example feral deer have the capacity to occupy the entire state; and the estimated 30 years damages in NSW for red imported fire ant range from $20.8 billion to $77.7 billion.

With increasing trade and travel, rapid urbanisation, and growing demand for agricultural products, the spread rates of alien species have reached a new peak. The potential impacted range is expected to expand due to the warming climate.

Currently active incursions contribute to the growing cumulative burden on the NSW economy and environment created by long established invasive species such as rabbits, carp and serrated tussock. While there have been some successes in controlling populations, (e.g. biological control of rabbits, prickly pear cactus, and Paterson's curse) the impacts of invasive species represent a major, ongoing, and increasing management issue for NSW.

What to expect from this report

It is worth reiterating that invasive species impacts encompass negative consequences for the environment, human health, cultural values, industry, agriculture, etc. However, protecting valuable environmental or cultural assets comes with certain costs, but weighing up such trade-offs (between costs and benefits) is challenging, especially when the benefits are difficult to value, i.e. when they are not reflected in market prices. This report summarises all available impacts of invasive species as measured by reported costs, whenever cost is an appropriate measure of impact and the extent of impact.

The extent and impact of invasive species are intimately related, yet distinct aspects of invasions. While the extent may refer to the geographical spread or distribution and can be evaluated in terms of the number of locations where the species is present, or the percentage of the total area affected by the invasive species, its impact refers to the (negative) effects the invasive species have on those particular locations (in terms of harm to e.g. native ecosystems, pastoral land).

The extent of an invasion may also refer to the severity of the impacts as measured on a certain scale (often monetary). In this report, the impacts themselves, which are the consequences of the invasive species' establishment and spread are expressed and measured as costs in dollar terms.

This report is organised in four parts, as follows: Part I summarises the background and scope of the project, its need and importance, but also the potential challenges of accurately and reliably evaluating the costs of invasive species; Part II offers a retrospective view in terms of reported costs, while Part III paints a prospective situation of projected and predicted future costs. The report concludes with Part IV which summarises costs and recommendations. The organisation of the material pertinent to the approaches we used for this project is further discussed in Section I.4.

I.2. Importance of cost quantification

Quantifying the costs of invasive species is required for informed decision-making and effective management. Decision-makers can gain valuable insights into the magnitude of the problem, prioritise management efforts, allocate resources efficiently, and evaluate the effectiveness of management interventions.

A clear understanding of the current and projected costs of invasive species can inform the development of a strategy to manage these risks. For example, proactive investment in the capacity of the NSW biosecurity system may ameliorate projected future costs.

There will never be sufficient resources to manage all the risks that invasive species pose. The effective prioritisation of effort requires an understanding of the comparative costs of species and the effectiveness of management interventions.

The risks posed by invasive species are projected to increase as is the competition for government resources. Government's allocation of resources to invasive species management is likely to come under increasing scrutiny with greater returns on investment demanded.

I.3. Challenges of cost quantification

Quantifying the current costs of invasive species using reported costs is not trivial for various reasons. Maybe the most important reason is the tendency for quantification studies to report more easily observable and measurable costs. As cost estimates based on monetary values (e.g. management expenditure, production losses, control costs) are relatively easily to quantify, there may be biases towards reporting and counting those types of costs.

Invasive species, however, threaten biodiversity, disrupt ecosystems, cause environmental degradation and can negatively impact human health and community well-being, which can be much more difficult to estimate in monetary terms. Because of this difficulty, these costs are often under-reported, and as a consequence it leads to a gross underestimation of their reported costs.

Moreover, certain invasive species may be either over- or under-reported, and so are the costs for certain sectors (i.e. reporting biases). For example, serrated tussock has been the focus of numerous cost estimation studies in NSW since the 1970s and its costs have been relatively well quantified in the literature. This is likely due to its severe impacts on the pastoral industry, an industry of major economic importance to NSW. On the other hand, the costs of serrated tussock in other areas such as the environment, as well as the impacts of other species that primarily have non-market impacts may be subject to less reporting and their costs may therefore be relatively underestimated.

On the other hand, various invasive species may damage the same asset. Asset damage is influenced by the extent of previous damages. If damages are assumed to be additive (i.e. independent) total costs may be overestimated.

Extrapolating from the current available cost data to the future should be done with caution, given the data limitations discussed above and the various factors that may influence these costs in the future. We expect massive uncertainty to surround future cost values, and we conjecture that this uncertainty is generated by the unknown/missing or under-representative data.

I.4. Our approach

CEBRA/CEER assessed the current and future costs associated with invasive vertebrates, invertebrates and weeds in NSW through two separate lenses, a retrospective and a prospective one.

In the retrospective part (Part II), we use a rapid review approach to aggregate and model costs of currently established invasive species in NSW and their cumulative costs between 1970 and 2022. This provides a database of cost data that can be updated for future analyses and a robust foundation for future assessments of costs. The data sources are detailed in Section II.1.1, which includes published papers and grey literature such as InvaCost dataset and ABARES data on management costs. The data processing and modeling in Section II.1.2 and the limitations of the data are discussed in Section II.1.3. While creating this database (analysed in Section II.2.1) we identified gaps in the literature in terms of quantitative estimates of, for example, environmental and ecosystem services impacts. This is discussed in Section II.2.2, where it is also complemented by a review of the public expenditure.

When looking forward, in the prospective part (Part III) of this report, we use the historical data to inform the future cost of established invasive species (to the extent to which past data is representative of the future) as well as trying to anticipate potential costs of species not yet in NSW. The methodology for doing so and its limitations are detailed in Section III.1. Anticipated future invasives are modelled using the CEBRA Value model presented in Section III.1.2. The estimated costs of present species is presented in Section III.2.1, the potential costs of those yet to come is detailed in Section III.2.2, and potential costs of incursions that have not yet reached their full extent is exemplified in Section III.2.3. The effects of other trends (e.g. trade, travel) and of climate change on invasive species impacts are discussed in Section III.3 and Section III.4 respectively.

Part II.

Looking back

II.1. Methodology and limitations

This section details the approach used for gathering all the available (and appropriate) data on costs of currently established invasive species in NSW. The initial data sources (together with the reasons for using them as a starting point), and the additional sources identified by conducting independent literature searches are described in detail. This provides an updated (and updatable) database of cost data for the current and future analyses of impacts (as measured by costs).

The cost data processing is described in the second half of this section, and it covers partitioning national costs to costs specific to NSW, cost data aggregation and analysis, and identified limitations of the data.

II.1.1. Data sources for current invasive species costs

Cost estimates reported from published and grey literature were systematically compiled to estimate the current cost of invasive species' impacts to NSW. This specifically focused on costs associated with introduced animals and plants that are/or have previously established in NSW (i.e. excluding pathogens and native pests).

Reported cost data for NSW was compiled using a "rapid review" approach (also known as an "expedited systematic review" see Ganann *et al.*, 2010). This follows the general process of a formal systematic review, including standardised review guidelines/reporting practices for evidence synthesis studies (i.e. PRISMA/PRISMA-EcoEvo; O'Dea *et al.*, 2021; Moher *et al.*, 2009), while adopting strategies or excluding steps that allow the review to be completed within an accelerated time-frame.

The purpose of this review, as indicated, is to compile a comprehensive collection of reported invasive species costs for NSW, and to produce an updatable database of cost data for future analyses. An overview of the review strategy and data sources is shown in Figure II.1.1. This strategy combines existing review databases (i.e. InvaCost), data from additional systematic searches of research databases, and any additional cost data that could be identified by the authors.

InvaCost & CISS

To expedite the review, the InvaCost database was used as the starting point (Diagne *et al.*, 2020). This 'living' review has systematically collected cost data globally using structured search queries for online databases, i.e. Web of Science (WoS), Google Scholar and Google. This significant global database has been the foundation of numerous regional studies to estimate the current/cumulative costs of invasive species, including for the United States (Fantle-Lepczyk *et al.*, 2022), North America (Crystal-Ornelas *et al.*, 2021), Central and South America (Heringer *et al.*, 2021), Europe (Haubrock *et al.*, 2021), and Australia (Bradshaw *et al.*, 2021).

The current version includes 2,597 cost estimates specific to Australia from 282 original sources (v4.1, published 22/Jan/2022; Diagne *et al.*, 2022), and has incorporated a large body of additional estimates that were collected for a recent study focusing specifically on costs for Australia (i.e. Bradshaw *et al.*, 2021)[1].

There are several benefits of using this database as the basis for analysis. For example, cost estimates found in the systematic searches are traced to their original source, to remove duplicate estimates and avoid double counting of costs reported or re-analysed across different sources. The current version also includes expert reliability assessments for individual costs, to allow low quality/reliability estimates to be excluded. The database also includes a taxonomy of the cost data, including of the species, location, and cost type for which costs are attributed. Database-specific cost processing and aggregation tools are also available and have been utilised throughout this review ('invacost' R package, v 1.1.5, Leroy *et al.*, 2022).

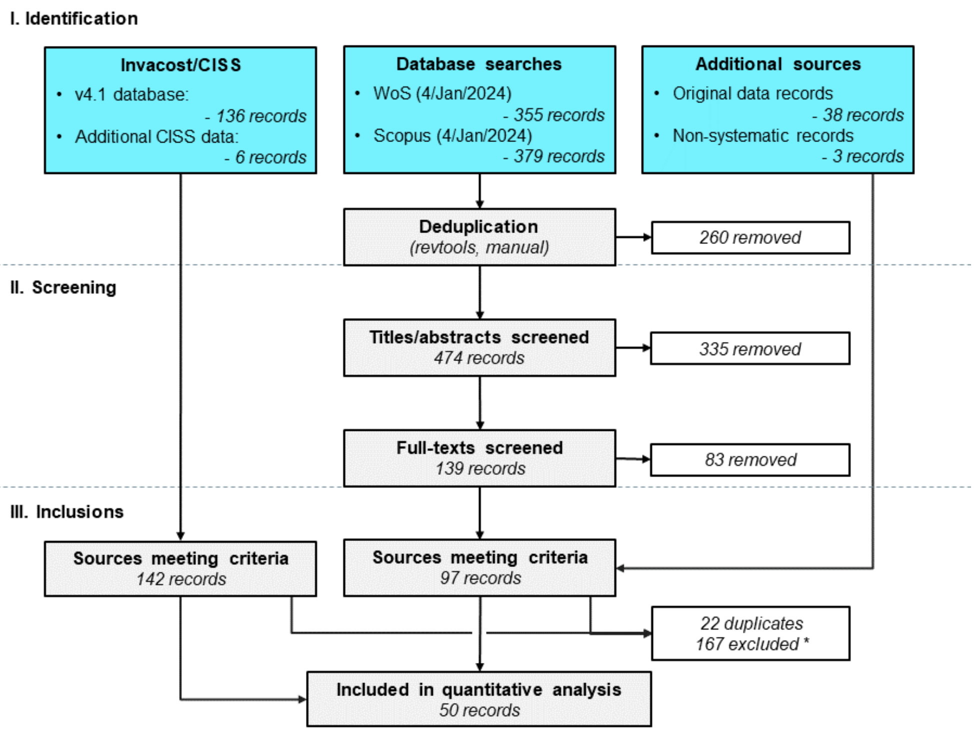

Figure II.1.1.: Rapid review PRISMA diagram, including data sources, processing and screening. (*Cost records identified through our review were excluded from quantitative analysis where they included only publicly funded costs, costs estimates that were rated as low reliability, duplicated/ non-original estimates, or potential/unrealised costs.)

[1]Note, data checks confirmed that all Bradshaw *et al.* (2021) data that is relevant to this project, i.e. cost data for areas within or including NSW, have been incorporated into the most current InvaCost database.

This database has also been expanded on by the Centre for Invasive Species Solutions (CISS, unpublished report), which incorporated cost estimates from several more recent reports that postdate the InvaCost/Bradshaw reviews. Data from each of these resources were compiled, and data outside of the scope of this project were removed (based on inclusion criteria described in Section II.1.1).

Database searches

In addition to the InvaCost/CISS data, we conducted our own independent literature searches to: (1) conduct a more targeted search to find cost estimates specific to NSW; (2) incorporate any recently published data not captured by previous reviews; and, (3) provide an independent source of cost data to assess the comprehensiveness of the InvaCost/CISS databases.

Searches were conducted in both WoS and Scopus on 4/Jan/2024 from the University of Melbourne. Advanced search functions were used with a standardised query (i.e. WoS query: *TS=(econom* OR cost OR monetary OR dollar OR *expens*) AND TS=(pest OR weed OR ((exotic OR invasi* OR invad* OR alien OR introduc* OR nonnative OR non-native OR non-indigenous) NEAR/5 (species OR animal OR plant))) AND TS=("New South Wales" OR "NSW" OR ((east* OR southeast*) NEAR/5 Australia))*).

This search query was designed to follow the structure used for InvaCost, but with some alterations and additional terms to specifically capture cost data for NSW. WoS searches were conducted with the Web of Science Core Collection (A&HCI , BKCI-SSH , BKCI-S , CCR-EXPANDED , ESCI , IC , CPCI-SSH, CPCI-S , SCI-EXPANDED , SSCI), based on titles, abstracts, author keywords and keywords plus. Searches in Scopus for titles, abstracts, author keywords and indexed keywords also followed the same query.

Records were extracted from both databases and processed in the R statistical environment (v4.2.3, R Core Team, 2013) via the 'revtools' package (v0.4.1, Westgate, 2019), to remove any duplicated references and prepare records for screening against predetermined criteria (see further details below).

Additional sources (e.g. ABARES land manager costs)

Additional cost data records were also included where they met the review's criteria. These included more recent grey literature/reports known to the authors that were not captured by previous reviews or database searches (i.e. "non-systematic records").

This includes, most notably, recent surveys and analyses from Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) such as the "*Pest Animal and Weed Management Survey 2016/2019/2022*" and "*Cost of established pest animals and weeds to Australian agricultural producers*" reports (Hafi *et al.*, 2023; Stenekes *et al.*, 2022).

In addition, if costs estimates from our own database searches were non-original (i.e. they referred to another reference as the source for their cost estimate), those additional records were located where possible and are accounted for here (i.e. "original data records").

Inclusion/exclusion screening

Inclusion/exclusion criteria were used to extract relevant data sources from the InvaCost/CISS data, and also to screen records from database searches. Inclusion/exclusion criteria were as follows:

Records were included for:

- Any introduced plant and animal species that have established in NSW.
- Studies with monetary estimates of their costs/damages. Impacts on any sector are included (e.g. health, community, industry, agriculture, etc.), provided they are estimated in monetary terms.
- Costs estimates that are for areas within or including NSW.

Records were excluded for:

- Introduced fungi, diseases or pathogens.
- Marine pests.
- Native Australian species that are considered pests for some areas or industries.

InvaCost/CISS data were processed within R to exclude records that do not meet the criteria. Specifically, cost data were filtered to include only estimates from Australia that apply to areas that are within or include New South Wales. Entries for fungi and viruses were also excluded (e.g. Wheat streak mosaic virus, Banana bunchy top virus, etc.). We also excluded data for taxa that are native to Australia [e.g. native bollworms (*Helicoverpa spp.*), windmill grass (*Chloris truncata*), koalas (*Phascolarctos cinereus*), etc.] or that are exotic to NSW [e.g. screw-worm fly (*Cochliomyia hominivorax*), mimosa (*Mimosa pigra*), banana skipper butterfly (*Erionota thrax*), etc.]. Similarly, CISS data was manually checked to confirm that the locations and species of costs met these criteria.

For our database searches, the titles and abstracts of records from Wos and Scopus were screened by LYW and NPM. Records were included for full-text screening where they met or appeared likely to meet each of the above criteria. Initially, 5% of records were double screened to assess inter-rater consistency/ reliability (17/14, 71% agreement, kappa = 0.417 suggesting moderate agreement; Cohen, 1960). To ensure that inclusion/exclusion decisions were consistent, a second 5% of records were double screened (21/24, 88% agreement, kappa = 0.75, suggesting strong agreement). Any conflicting decisions were discussed and resolved collaboratively. The remaining records were screened by a single screener.

Full-text records were then assessed against the inclusion criteria. If is was unclear whether a record met the criteria, both reviewers made a final decision collaboratively. Cost estimates from included records were identified, and where cost data referred to another record as the source of the cost data, that original source was also checked against our inclusion criteria and added into our database of included studies when relevant.

Current cost data summary

The following cost data records were identified from InvaCost/CISS and our review (see also Figure II.1.1):

- *InvaCost/CISS*: 142 cost data records were identified which appear to include cost estimates including NSW (i.e. 136 from InvaCost 4.1; 6 via CISS). Note, these include both public and private costs, observed and potential costs, and high and low reliability estimates. Bibliographic data for all records providing cost sources relevant to NSW is to be provided as supplementary materials for this report, although only a subset of these records were included in our quantitative analysis of current costs below (see further details under II.1.2).
- *Database searches and additional sources*: 97 cost data records were identified (i.e. 56 records from database searches, 38 original data records and 3 non-systematic records). Of these, approximately a quarter (i.e. 22) already have data extracted into InvaCost/CISS, and a similar proportion only reported secondary data that can be traced to other records.

Review records, including cost references bibliographic information, as well as raw and processed cost data is available via the Open Science Framework (also accessible via DOI: 10.17605/OSF.IO/TY7BF).

Our new database searches only found a relatively small proportion of the data in InvaCost. This further supports the use of InvaCost as the foundation for our analysis, as that database includes a substantial number of cost estimates that may not have been identified through traditional systematic literature searches. This is particularly the case for grey literature, that make up almost half of the relevant cost records in InvaCost. Nonetheless, our searches were also able to identify cost records from additional sources that were not found in the database, also highlighting the need to search for and include additional data to supplement InvaCost where possible.

Data was therefore extracted from an additional 10 records from our original database searches/additional sources, and added to the InvaCost/CISS database. These new cost records were extracted from studies reporting original private cost estimates (i.e. production losses, private control cost, etc.), and costs that have been observed (i.e. excluding potential or future costs not yet incurred). From these 10 records, an additional 50 individual cost estimates were added to the InvaCost/CISS database.

This combined dataset therefore included both InvaCost/CISS data filtered for NSW, and cost records identified though our own review, and was the basis of our analysis of current cost estimates (excluding public expenditure) of invasive species in NSW.

II.1.2. Cost data processing and modelling

Cost data identified through the review were each double checked to exclude costs that were outside of the scope of this analysis. The subset of costs included in this analysis were those incurred by private industry (e.g. agricultural production losses, and/or control costs), privately funded research expenditure, costs to human health and/or social wellbeing, as well as any quantifiable costs to the environment/environmental services[2]. The following data were considered outside of the scope of this analysis and were therefore excluded:

- Any costs based on public expenditure were excluded, as these costs are summarised elsewhere within this report (see Section II.2.2).
- Any non-observed/potential costs were excluded. For example, InvaCost includes a substantial number of entries for 'Potential' or 'Avoided costs'. These often refer to the costs of proposed management actions that have not yet been implemented, or for costs that would have been incurred but for certain management/control actions being implemented. These were excluded as these don't refer to invasive species cost that have actually been incurred.
- Low reliability costs were excluded. Each InvaCost data entry has been reviewed by an expert to identify any estimates that may be considered unreliable. For example, a cost estimate may be rated as unreliable if the source or methodology supporting the estimate is not reported or described in the record.
- Duplicated cost estimates were also identified and removed.
- A small number of potentially relevant cost estimates were excluded as there was no suitable method for extrapolating or partitioning those costs for NSW.

After exclusions, the final dataset included 374 individual cost estimates, from 50 records which were primarily technical reports and peer-reviewed research articles. This dataset includes the following key elements: taxonomic information for the invasive species and/or taxonomic group that the cost is attributed to; a total and per-year monetary cost for each estimate (including both the currency and year that the currency is valued in); the year or range of years that the cost was estimated to occur over; as well as any information about the location (e.g. within or including NSW), sector (e.g. agriculture, health, environment) and type of costs being incurred (e.g. control, production loss etc.). The list of invasive species concerned is available in Appendix A.

Partitioning cost estimates

For cost data that was not specific to NSW (i.e. 90 national or regional estimates), the fraction of costs that could be attributed to NSW were estimated. The appropriate fraction for each cost was estimated on a case-by-case basis. This fraction was primarily

[2]Note, data from InvaCost was checked against these criteria, where possible by locating and assessing the original source material. An obvious errors in the cost estimates entered into InvaCost were corrected where found. Any additional cost estimates found in those sources were extracted, and as well as any NSW-specific estimates that could be extracted in place of non-NSW-specific values. Nonetheless, for the majority of InvaCost estimates we have primarily relied on the data entered in InvaCost and only made limited corrections where obvious errors or more specific NSW data could be found.

estimated based on the relative area of a species' range and the impacted sector/industry that is in NSW.

The 90 data points involved 44 species and various impacted sectors, which were grouped into: agriculture, grazing, forestry, cropping, tree nuts and pine production. To assess the fraction of the NSW area impacted by a given species relative to the entire impacted area we used the Biosecurity Commons platform. Biosecurity Commons is a cloud-based decision-support platform for modelling and analysing biosecurity risk and response. It is a joint initiative between the Australian and Queensland governments, the National Collaborative Research Infrastructure Strategy (NCRIS) funded Australian Research Data Centre (ARDC) and four other partners.

The Biosecurity Commons platform allowed us to combine land use spatial data using the Australian Land Use and Management Classification with species distribution maps using the species occurrence records from the Atlas of Living Australia.

Cost data aggregation and analysis

After all (included) data was apportioned to NSW, we expressed all raw costs and costs per year in AUD using the appropriate conversion rates corresponding to the year of the cost estimation.

Data was further transformed using inflation adjustments to 2023 values. The inflation factor since the year of cost estimation was calculated using Consumer Price Index data (17th Series, accessed 14/02/2024) from the Australian Bureau of Statistics.

All costs were also converted to yearly estimates. Where a single total cost was reported for periods longer than one year, this cost was split evenly over the starting/ending year range. Similarly, costs that were reported as an average annual cost over a period of multiple years, were converted to individual annual costs applicable to each year within that period.

Using the inflation-adjusted yearly cost data, we calculated the observed cumulative and average costs over a specific period of time from the time interval (1970 – 2022). This period included all cost estimates found in the literature. Only a single cost estimate included cost impacts for years earlier than 1970 (in addition to post-1970 years), so costs for decades before 1970 were considered too sparse and under-reported to include in statistical analysis.

To estimate the long-term trend in annual costs we used statistical modelling to estimate average annual costs. Several (simple) models can be fit (using the invacost R package) and their fit quality checked. Most models are either simple regression models or variation of regression models accounting for heterogeneity of the variance and autocorrelation, and correcting for the influence of outliers. The Root Mean Square Error (RMSE) can be used as a measure of fit. Previous analysis of the InvaCost datasets showed very little differences in the performance of the various models (as measured by the RMSE).

For this project we chose the simplest (yet still appropriate) model that accounts for the heterogeneity of variance, while keeping the influence of outliers to the minimum, namely a form of robust regressions e.g. Croux *et al.*, 2003. Both linear and quadratic trends can be investigated and contrasted using linear robust regression, and quadratic robust regression respectively.

It is important to note that, even though this modelling approach is not designed for future predictions (due to the uncertainty in the underlying covariates that influence costs and their future trends), short term future predictions were still used to serve as an indication of trends, to be treated with caution.

II.1.3. Limitations of the data

In addition to the influences of reporting biases (as discussed in Part I, Section I.3), incomplete reporting is another limitation of the collected data that may lead to cost underestimations. Cost estimates from a study tend to only apply for a finite period, which often is only the year of the study. For example, costs linked to feral pigs were first reported starting from 1979, yet from 1979 up to 2022, costs that are attributable to feral pigs are only available within our database for 21 (<50%) of those years[3]. Therefore, incomplete reporting is likely to lead to significant underestimations of the total cumulative costs of invasive species.

Another limitation of using InvaCost data comes from its reliability. InvaCost data entries have been categorised as 'reliable' or 'unreliable' in a manner that may not reflect a systematic examination of the methodology, but rather reflects a subjective choice informed inpart by the transparency of the source studies. However, using unreliable data for the benefit of extra data points may introduce extra bias. Therefore, a conservative approach has been used here to exclude unreliable studies and produce a more robust and reliable cost estimate, at the expense of reducing the dataset size and therefore it's statistical power.

A similar situation involves non-observed costs which InvaCost data includes as 'Potential' or 'Avoided' costs, hence costs that have not yet been incurred. Again, a conservative approach has been used to exclude any of these costs that are considered potential costs.

Therefore, in general the annual and cumulative costs that are included in the analysis of current invasive species costs should best be interpreted as a highly conservative estimate of the reported costs in NSW, including only reliable costs that have actually been incurred, and incurred only during the periods for which were reported.

Finally, another limitation comes from the method used for costs which are not specific to NSW (see Section II.1.2), but apply to a larger region that includes (parts of) NSW. Several assumptions were made when estimating these proportional costs, for

[3]Including costs either specifically attributed to pigs or attributed to terrestrial vertebrate pests generally.

example that the impacts of a species on a particular sector/industry applies consistently across the area of overlap between the species' range and the impacted sector/industry. The appropriateness of these assumptions will influence the reliability of any specific cost estimate that has been partitioned to NSW, but this is not expected to introduce any systemic under- or overestimation of costs for NSW.

II.2. Estimated costs

In this section we estimate the costs of invasive species to the state using our comprehensive database of invasive species cost for NSW, produced via our NSW-focused rapid review combined with the global invasive species database InvaCost. This includes estimates of the cumulative total and current annuals costs to NSW, as well as analysis of trends in incurred costs over time.

In addition, we include an analysis of certain costs that may be underestimated using the above approach, focusing on the costs to the environment and ecosystem services, and costs incurred through public expenditure.

II.2.1. Cumulative and annual identified costs of current invasive species

Raw results

The total cumulative costs reported between 1970 – 2022 is $30.761 billion (excluding public expediture based costs). Average annual costs are clearly influenced by very high variation between years (see Figure II.2.1). This is likely to be linked to the incomplete reporting of costs as well as reporting biases, which would suggest that this value is likely to be an underestimate of the actual costs incurred over that period.

The raw aggregated cost for 2022 is $0.424 billion, while the costs for 2020 and 2021 were considerably higher (i.e. $1.339 and $1.379 billion). These years were more consistent with the averaged annual costs during 2010s (i.e. $1.319 billion per year).

The highest annual aggregate costs were also reported in the 2010s, with multiple years reporting a total cost over $3 billion dollars (e.g. peaking at $3.822 billion in 2019). The apparent drop in the average annual cost in the 2020s and specifically in 2022 is most likely caused by a time lag between the occurrence of a cost and its reporting, instead of any actual fall in costs over recent years (e.g. 255 distinct cost estimates are included from the 2010s, while only 25 are included from the 2020s).

From 1970, there has been a general increasing trend in the total value of reported costs for NSW each decade, from the 1970s – $25.51 million/year; 1980s – $299.21 million/year; 1990s – $456.22 million/year; and, 2000s – $661.22 million/year. While growth in costs does not appear to be linear (precluding us calculating a general rate of increase for any particular time period), reported costs have consistently increased over this period, and more than doubled between some decades (i.e. 1970 to the 1980s, and 2000s to 2010s). Furthermore, while this increase may partially be influenced by increased reporting over time, this is likely to reflect a rapid increase in the actual costs of invasive species to NSW from 1970 to 2022.

A graphical summary of the cost data identified through the review is shown in Appendix B, Figure B.1, as well as repository links to supporting materials for the review (e.g. cost data, reference lists/ bibliographic records, etc.).

Modelled trends

Due to the variability in the costs, the incompleteness of the data, and the lack of information about other predicting variables/covariates, we used an extremely cautious modelling approach and specifically avoided over-fitting. The two chosen models capture the general increasing trend since 1970, but do not over-fit to a tight pattern, as illustrated by the linear vs. quadratic robust regression models from Figure II.2.1. The linear trend suggests a steeper increase than the quadratic model and less uncertainty, as captured by the 95% confidence intervals.

Even though predicting future costs with these models is not advised, we can look over a very short time frame to have an indication of trends for a period of time for which the past data is still representative. The modelled cost prediction using a robust linear model amounts to $1.923 billion for FY 2022/23, which is consistent with the recent observed costs, however the robust quadratic model estimates an amount of $1.058 billion[1].

These estimates are relatively consistent with the recent Australia-wide review following similar methods (i.e. Bradshaw *et al.*, 2021), which estimated an US$5.25 billion annual cost for NSW using reliable and observed costs. While the Bradshaw estimate is somewhat higher, this is not unexpected due to the more limited scope of our review (e.g. excluding pathogens, public expenditure, native species, etc.), and our more conservative approach to modelling costs (e.g. not accounting for reporting lags/ incomplete reporting). Like Bradshaw, our results suggest that the annual costs of invasive species to NSW are in the scale of billions of dollars and continue to increase.

Costs by species

Looking at the distribution of the total costs with respect to taxonomic grouping (Figure II.2.2), we find that terrestrial plants account for the majority (82.9%) of costs and the terrestrial vertebrates account for almost a fifth of that.

Although the database includes a subset of reported costs that are aggregated over larger groups of species (e.g. introduced weeds, freshwater pests, etc.), most estimates could be attributed to a specific species or genus. The five species/species groups with the highest total costs for terrestrial plants, vertebrates and invertebrates are shown in Figure II.2.3. See Appendix A for a full list of species for which non-public costs estimates were found for NSW.

[1]Note that the quadratic model estimates a more conservative value that appears to under-estimate current costs based on raw values for recent years. For context and to further understand the uncertainty in modelled estimates, the predictions from both models and their 95% credible intervals are included in Section III.2.1.

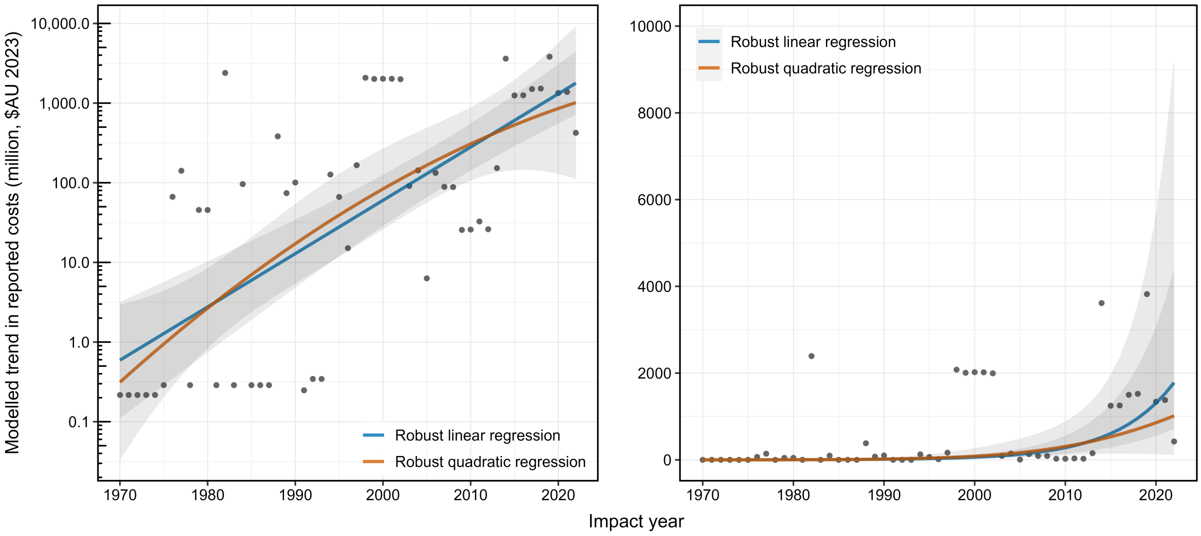

Figure II.2.1.: Modelled annual costs of established invasive species in NSW (1970 – 2022) for all non-public expenditure based costs, on a logarithmic (left) and a linear scale (right). Both are included to show the trend both in relation to the modelled unit (i.e. log-millions) and in relation to the actual dollar costs incurred. Shown are the annual total reported costs for each year (grey circles), the modelled trend via robust linear (blue line) and quadratic regression (orange line), and their 95% confidence intervals (grey bands).

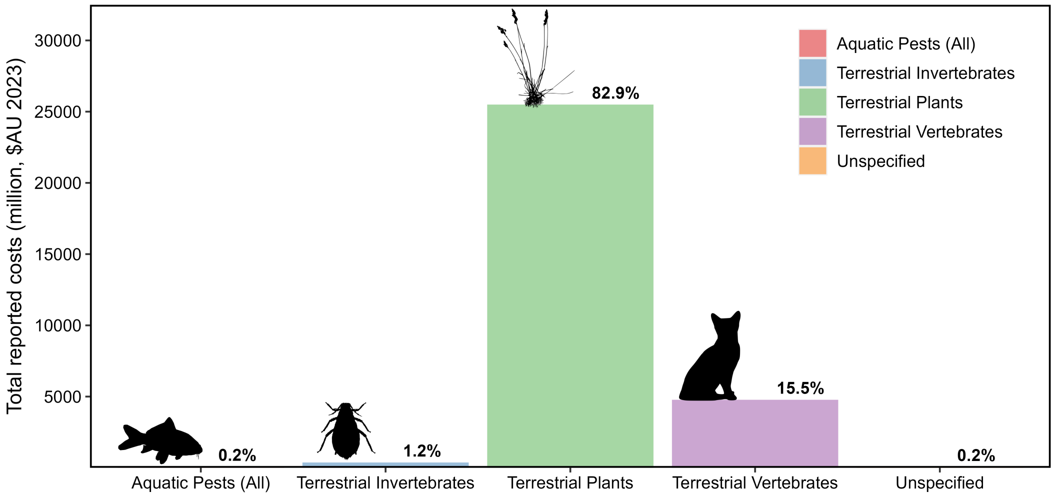

Figure II.2.2.: Sum of reported non-public costs (1970 – 2022) by environment and broad taxonomic groupings. Within the cost database the number of cost data entries per group are: Aquatic Pests (All) = 5; Terrestrial Invertebrates = 21; Terrestrial Plants = 252; Terrestrial Vertebrates = 95; and, Unspecified = 1.

From those costs that are specific to a species- or genus-level taxonomic grouping, the most costly species/genus from each of the four categories were identified. For terrestrial plants, the most costly taxa were serrated tussock (*Nassella trichotoma*; $322 million total reported costs up to 2022), blackberry (*Rubus fruticosus*; $305 million), ryegrass (*Lolium rigidum*; $153 million), fleabane (*Conyza* spp.; $130 million), and barnyard grass (*Echinochloa crus-galli*; $119 million).

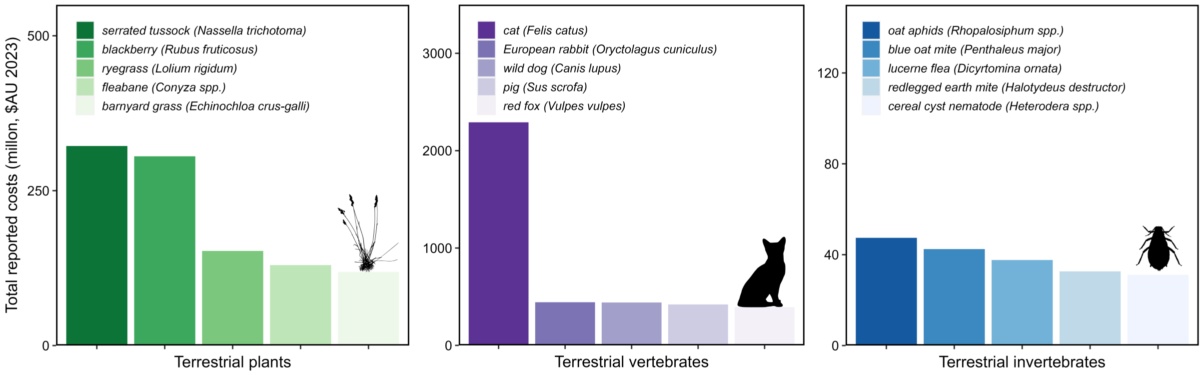

Figure II.2.3.: The five species with the highest reported costs for (left) terrestrial plants, (middle) terrestrial vertebrates, and (right) terrestrial invertebrates (1970 – 2022). Aquatic pests are not included as only common carp had species-specific cost estimates. Note, these cost totals are likely to be influenced by both reporting biases and actual differences in the costs associated with each species. Also note, y-axis scales differ between panels.

The most costly terrestrial vertebrates (over the period 1970 – 2022) were cats (*Felis catus*; $2.291 billion[2]), European rabbits (*Oryctolagus cuniculus*; $443 million), wild dog (*Canis lupus*; $441 million), feral pigs (*Sus scrofa*; $420 million), and red foxes (*Vulpes vulpes*; $393 million).

Oat aphids (*Rhopalosiphum spp.*; $47 million), blue oat mites (*Penthaleus major*; $42 million), lucerne fleas (*Dicyrtomina ornata*; $38 million), redlegged earth mites (*Halotydeus destructor*; $33 million), and cereal cyst nematodes (*Heterodera) spp.*; $31 million) were the most costly terrestrial invertebrates (over the period 1970 – 2022), while common carp (*Cyprinus carpio*; $30 million) was the only aquatic species for which species and/or genus specific cost estimates were found (between 1970 and 2022).

Costs by impacted sector

Looking at the distribution of the total costs with respect to the impacted sector, the industry/agricultural losses clearly dominate this dataset, accounting for 92.2.% (see Figure II.2.4). Heath, public and social welfare costs account for most of the remaining costs (7.4%), while other sectors accounted for <1% of reported costs (e.g. private expenditure on research, and environmental costs). We conjecture this is mainly due to the reporting bias and the ease to quantify such losses relative to the others (see further discussion below, Section II.2.2).

II.2.2. Missing costs of current invasive species

The allocation of costs by sector is heavily focused on the private costs of invasive species in agricultural industries (see Figure II.2.4). This may be driven partially by

[2]Note, the costs linked to cats also include a significant proportion of human health impacts by domestic cats (as estimated in Legge *et al.*, 2020).

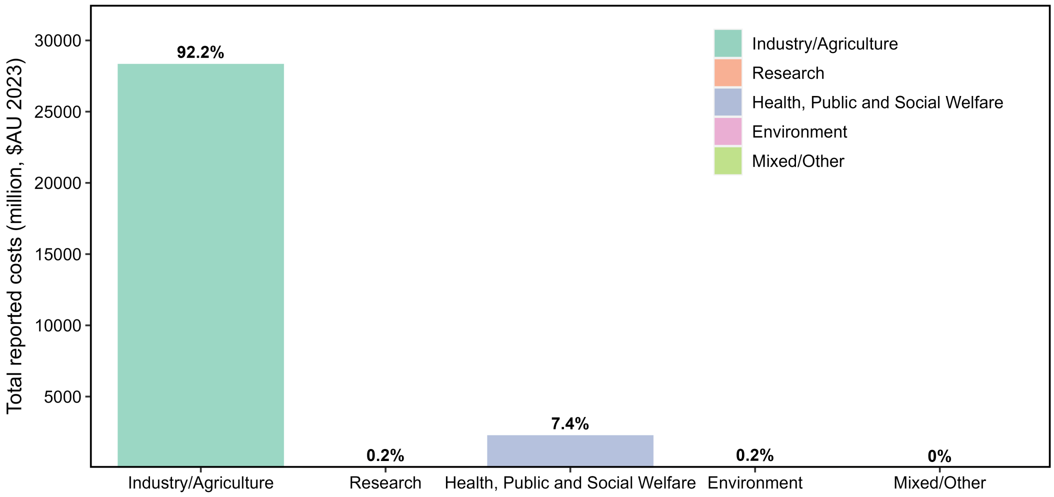

Figure II.2.4.: Sum of reported non-public costs by impacted sector/cost type (1970 – 2022). Industry/agricultural losses are predominately attributed to production losses and control costs. Research costs are research and innovation expenditure by industry representative bodies. Health and public welfare costs include medical costs, as well as cost to community-based assets (e.g. indigenous communities/infrastructure, road crashes, etc.). Environmental costs include estimates of monetary value of damage to environmental assets/services, and the value of community/volunteer work on environmental programs.

publication and reporting biases, which are likely to be more heavily focused on reporting economic impacts (see a more detailed discussion of publication biases and other data limitations in Sections I.3 and II.1.3).

Environmental and ecosystem services impacts are one area where costs are likely to be under-reported. Notably, a large number of ecological studies that were found through our systematic database searches focused on quantifying impacts of invasive species on the environment (e.g. impacts on endemic species abundances, ecosystem processes, etc.). Nonetheless, many of these are excluded from this type of review as they do not include costs estimated in terms of monetary value. Therefore other methods may be more appropriate for estimating this component (see further analysis in II.2.2).

Public expenditure is another area of costs missing from these estimates. This was specifically excluded from the rapid review, and instead estimated based on expenditure estimates obtained directly from relevant departments (see cost summary in II.2.2).

Environmental costs

Invasive species can affect the richness and abundance of native species, increase the risk of native species extinction, impact the genetic composition of native populations, change native animal behaviour, and modify trophic networks. Some invasive species can also change ecosystem functioning and the delivery of ecosystem services by altering nutrient and contaminant cycling, hydrology, habitat structure, and disturbance regimes. These biodiversity and ecosystem impacts are accelerating and will increase further in the future.

The results above illustrate the current bias in reporting the value of invasive species impact. This bias frustrates policy development and the appropriate allocation of resources for invasive species management. A commitment to the valuation and publication of the impact of invasive species on the stocks and flows of non-market ecosystem services, particularly biodiversity, is urgently required.

Such valuations will have benefits beyond the better allocation of resources for invasive species response and management. They will contribute to nature positive strategies recommended to the NSW Government by the Independent Review of the NSW Biodiversity Conservation Act (Henry *et al.*, 2023) and the Australian Government, i.e. DCCEEW (2022).

Recent research indicates that the methods for valuing invasive species impacts on non-market ecosystem service goods and services are well developed and their implementation feasible. However, the authors note that significant institutional capacity building is likely to be required before these methods can be widely applied at low cost (Greiner *et al.*, 2022).

In 2023, the value of the ecosystem services protected by the national biosecurity system were estimated (Stoeckl *et al.*, 2023). The research made estimates at the scale of Australia's 56 natural resource management regions and generated spatially explicit estimates of the current value of 16 different ecosystem services. This estimate relates to the impact of species not currently present but of high risk of incursion in the near future. There is, however, no corresponding valuation of the impact on ecosystem services of existing invasive species, or of the impact to the environment generally.

As discussed above, the impacts of environmental and ecosystem services are underestimated, resulting in a huge gap in reported costs between agriculture (92.2% of the total cost) and the environment (0.2% of the total cost). To account for the underestimation of the costs for environmental impacts, we formed a postulate by estimating the damage cost for the environment using the percentage of the agriculture (66.89%) and the environmental assets (16.73%) from results associated with the value model reported in Dodd *et al.* (2020) [3] — knowing that the environmental asset layers are underestimated even here — and the total cost from the rapid review in the current report ($30.761 billion). In our estimation, the cost of the environment increased from $0.615 billion between 1970 – 2022 to $7.113 billion (115 times higher). Using the same approach, we estimated the damage cost for environment assets to be $0.322 billion in the 2022/2023 financial year.

The large difference between the cost from our review in this report and the estimates derived from the Value Model ratios highlights the importance and need for

[3] The discounted proportional damages for NSW are sectioned from the Value Model for Australia and are derived from the median total damage caused by the 40 functional groups modeled. This model allows multiple (or zero) incursions at each time step, in contrast to the model in the current study, which allows only one single initial incursion and no re-incursions.

studies estimating the impact of invasive species on the environment and ecosystem in monetary terms.

Public expenditure

Given the public goods nature of ecosystem services and the inability of markets to efficiently allocate resources, governments national state and local play a crucial role in funding and coordinating efforts to manage the impacts of invasive species. The success of biosecurity systems is reliant on sustained levels of well-targeted investment over time, underpinned by strong funding principles and arrangements (NSW Auditor-General's Report to Parliament, 2019).

There are many competing demands on government budgets and there will never be sufficient resources to satisfy the expectations of many. In 2017 the report *Priorities for Australia's biosecurity system* (Craik *et al.*, 2017) stated that State and territory governments needed to increase biosecurity funding if they are to fulfil their biosecurity obligations.

The government funding mechanism to support invasive species management activities commonly include three categories: recurrent (e.g. public land management), programs, grants, and management. In this report, we use these categories as a framework for the analysis of expenditure. Although not a funding mechanism research is included separately in the analysis. There is considerable overlap between these categories. For example, research programs are funded by research grants and many programs and grants are funded by recurrent expenditure.

We have used publicly available data where available and made data requests to agencies where required. We have aimed to generate an estimation of annual expenditure for the 2022/2023 financial year as this data was most likely to be readily available.

Estimating the government expenditure on invasive species management is problematic for several reasons:

- Invasive species management is an activity that contributes to higher goals, biodiversity conservation, timber production, road safety rather than an outcome in its own right.
- There are no expenditure reporting standards at any level of government that enable the clear identification of invasive species management costs.
- There is no requirement for the NSW Government to publicly disclose their expenditure on invasive species management.
- The complexity of the institutional arrangements governing invasive species management makes attribution difficult and there are significant risks of double counting. [4]

[4] For example, the NSW Local Land Services receives funds from the Australian Government, State Government and through its rate base, Similarly Local Government receives resources from a variety of sources.

- Public invasive species management annual expenditure varies significantly based on the availability of and demand for financial resources. This supply and demand of resources are influenced by competing demands and climatic and political seasonality.
- There is inconsistent financial budgeting, data collection, analysis, monitoring and reporting for invasive species management across NSW government agencies.

Previous reviews of public expenditure have included the value of volunteer labour in the calculations. This value can be substantial for organisations such as National Parks and Wildlife Service (NPWS). Volunteer labour is not included in this review. Contributions from the Australian government are included in the estimation of public expenditure where it is delivered through NSW Government agencies. The expenditure of local government is not included except for their contribution to the Weeds Action Program. Resources provided by the NSW Biodiversity Conservation Trust to the management of invasive species on land under conservation agreements are not included. The analysis does not include the costs of administering grants programs such as those provided by the NSW Environmental Trust.

Table II.2.1 summarises the findings of the most current data collection. For details we refer to Appendix C. The expenditure on management of invasive species from NSW government amounts to a total of $200.58 million.

Funding category	Expenditure
Recurrent expenditure	$59.64 M
Programs	$119.13 M
Grants	$9.07 M
Research	$12.74 M
Total	$200.58 M

Table II.2.1.: Expenditure summary on management of invasive species from NSW government in 2022/2023 financial year.

Given the scale of the issue and the need for informed policy, data on expenditure on invasive species management in NSW is surprisingly difficult to obtain.

What is apparent is that the allocation of resources is extremely fragmented and predominately species focused. There is limited evidence that resource allocation is based on the objective analysis of risk, rates of return, or on how investment could contribute to an overall improvement of the functioning of the system. Some evidence also suggests that the funding mechanisms employed are not always suited to the management activities they resource, for example, the use of short-term grants to fund ongoing land management responsibilities. A review and reform of the process for allocating public resources to invasive species management may generate the efficiencies that could be reinvested.

Part III.

Looking forward

III.1. Methodology and limitations

To evaluate future costs of invasive species we will consider projections into the future of current invasive species, potential impacts from current species that have not reached their full extent, as well as new incursions. The models used, together with their assumptions and limitations are also discussed.

III.1.1. Existing invasives

To estimate the longer-term trend in annual costs we use the same statistical modelling we used in Part II to estimate current average annual costs. The chosen model is a robust regression model, chosen both for its simplicity, and its ability to account for the heterogeneity of variance and auto-correlation. Both linear and quadratic trends are again used.

Note that this should not be used as a predictive model, since no covariates are modeled explicitly. We only attempt short term future predictions merely to have an indication of trends. These predictions however, should be to be treated with caution, and this warning is reflected in the predictions intervals provided alongside estimates.

Additionally, we selected four invasive species for examples of incomplete incursion. In the example boxes, we reported the change in species distribution and their impacts on NSW and/or Australia, and the damage to the industries and the environment from published reports. In the RIFA case, we also projected its future damage for 30 years using the CEBRA's Value Model detailed below.

III.1.2. Future invasives

Tens of thousands of species have established "alien" populations outside their native range, globally (Seebens *et al.*, 2017a), so worrying about the impacts of them all is clearly impossible. Reducing the list of species to those which are likely to cause nationally significant impacts in Australia is one strategy to reduce the burden, however according to (Diez *et al.*, 2009) this still leaves us with thousands of species. A further simplification is to use groups of species, rather than individual species. Several studies (Epanchin-Niell *et al.*, 2014, e.g.) have classified species into "functional groups" based on their mode of action. For example generic groups of fruit flies, tramp ants, etc. may be used simply because their impacts and their management controls are highly similar.

CEBRA Value Model

CEBRA has previously developed a spatially explicit, bio-economic model (the Value Model) that simulates the arrival and spread of 40 functional groups of species, not yet present in Australia, and their combined impact over time on 16 assets (Dodd *et al.*, 2020). The model incorporates best available data describing the distribution and value (market and non-market) of assets vulnerable to these potential hazards, as well as hazard-specific national arrival/establishment rates, post-establishment spread rates (local and long-distance), and impacts (percentage yield reduction) on each affected asset. Management costs here are only considered as an aggregate expenditure at the appropriate government level.

Future invasives within the scope of this project will be based on 24 out of the 40 exemplar species from the Value Model, which were selected to represent 24 functional groups of invasive animals and weeds e.g. red witchweed, *Striga asiatica*, to represent broadacre weeds.

The Value Model involves running a large number of replicate simulations for each hazard, with each iteration entailing: (1) randomly selecting an establishment location (weighted by relevant factors such as human population density) for the initial incursion, from amongst the cells susceptible to the hazard; (2) spreading annually from infected cells to all susceptible cells within the hazard's annual dispersal distance; and (3) spreading the infection to potentially-distant locations when certain criteria are met, representing long-distance movement events. For each iteration, the time series of infection is recorded, and the corresponding damages on affected assets are computed.

Two additional points are worth noting. First, the asset layers in the CEBRA Value model across 16 aggregated layers are disaggregated from basic natural and physical categories and include everything from agriculture (which can be further disaggregated) to residential use and non-use, recreation, existence and bequest motives, tourism, water, flood control and infrastructure.

The Value Model for NSW

Initially designed to estimate the value of Australian biosecurity at the national scale, the Value Model can be applied to determine the expected costs at state and regional scales. While the absence of regionalised arrival rates hinders complete risk calculations at such scales, consequences can be effectively examined by imposing a deterministic initial incursion of a hazard, and simulating the resulting spread and damage. The transition from a national scale to a regional one is otherwise uncomplicated, since asset values are expressed as a function of cell attributes, and damages are expressed in terms of proportional yield reduction (rather than, for example, being derived from an aggregated national estimate). These are, therefore, readily calculated at any subnational scale.

With its national focus, the CEBRA Value Model as originally developed does not simulate post-border management actions. However, these were further developed in a sub-national version for NSW that has been developed for NSW DPI and employed as an Excel 'Cost-Benefit' Tool used to assess potential damages and response measures across the 40 different pests. These response measures are, however, user defined, so for the purposes of this project we will use the default setting of no post-border management actions. Moreover we assume that the likelihood of an incursion (of any of the species) to be one.

Using these assumptions, we estimated the damage cost of 24 functional groups (animals and plants) for each of the 11 natural resource management (NRM) regions and the cost for 7 after the initial (and only) incursion with a 5% discount rate for financial assets and a 3% discount rate for environmental assets.

Limitations of the Value Model

The Value Model quantification of impacts used as much data as was available, however, the authors acknowledge that impacts on assets other than agriculture are sparse and often unreliable. Moreover, the asset values are based on data from 2015-2017 (depending on asset), so careful interpretation of what year "7 years in the future" represents is necessary.

In the NSW version of the model, establishment likelihood maps were not used. Instead the damages were estimated given establishment and spread. Moreover the NSW model only looks at the costs associated with a *single* incursion over a number of years, whereas the Australian model permits multiple incursions per year (depending on the species).

Keep in mind too that species are considered in isolation so summing the damages of two species that interact here (through spatial overlap and impact on the same assets) will result in double-counting of some of the coincident damages.

Finally, it is well acknowledged by the authors that the Value Model underestimates environmental asset layers and damages to the environment generally.

III.2. Estimated costs into the future

Using the models described in Section III.1 we estimate future impacts of both current and future new invasive species and discuss a few case studies of incomplete incursions (i.e. incursions that have not reached their full extent).

III.2.1. Future costs of current invasives

Predicting future costs modeled based on the data presented in Section II.1.1 is not advisable for a number of reasons mentioned previously. However, very short time frame predictions may be useful as an indication of trends for a period of time, for which the last 10 years may be considered still representative.

In this case we have estimated for FY 2022/23, to complement the data available for current public expenditure and cost summaries in Section II.2.2. In addition, we have estimated the future cost estimate for calendar year 2030, to indicate possible future trends in costs and their uncertainty. 2030 was chosen for future predictions to align with the 7-year future cost estimates from the Value Model.

The robust regression estimates in billions are shown in Table III.2.1 together with 95% credible intervals. The width of these intervals reflects the size of the dataset, its inherit variability, and the inappropriateness of the models for future prediction.

Model	FY 2022/23	2030
Robust linear regression	1.923 [0.008, 457.766]	6.103 [0.025, 1518.008]
Robust quadratic regression	1.058 [0.006, 219.357]	1.799 [0.004, 868.669]

Table III.2.1.: Robust regression predictions of total costs in billion $ for the years FY 2022/23, and 2030. Estimates are accompanied by credible/prediction intervals in square brackets.

III.2.2. Future invasive species costs

Potential damages associated with future invasions were simulated using the NSW version of the Value Model for the 24 functional groups chosen for the purposes of this project, for 7 years after the incursion. These are summarised in Table III.2.2. We reiterate that the default setting of the model is no post-border management actions and certainty of (only one) incursion.

	Functional groups	7 years
1	AGM	0.91
2	Broadacre beetle	2.27
3	Broadacre bug thrips mite	6.50
4	Broadacre mollusc	0.00
5	Broadacre weed	0.00
6	Forestry beetle	0.21
7	Forestry nematode	0.09
8	Forestry termite	1.25
9	Forestry weed	0.00
10	Fruit fly	2.02
11	GAS	0.40
12	Horticulture beetle	0.00
13	Horticulture bug thrips mite	0.00
14	Horticulture fly moth	0.00
15	Horticulture nematode	0.00
16	Horticulture weed	0.00
17	Khapra beetle	11.19
18	Livestock bug thrips mite	0.86
19	Livestock fly moth	0.53
20	Non-agricultural bee wasp	0.00
21	Non-agricultural fly moth	0.16
22	Non-agricultural vertebrate	0.01
23	Non-agricultural weed	0.00
24	Tramp ant	3.33

Table III.2.2.: Estimated damage cost (billions $) for each functional group in NSW, 7 years after invasion.

The simulations performed using the Value Model consider species to be damaging assets in isolation. As a consequence, when summing the damages of more species we may multiple-count coincident damages, leading to overestimation of costs. On the other hand, due to the limitations described in Section III.1.2 we conjecture that the Value Model underestimates the damages in general. These two issues may counter-balance the estimation of costs enough for us to scrutinise the the 2030 prediction (7 years simulation) of the worst case scenario when all 24 representative species of their corresponding functional groups establish in and spread through NSW. The total damages amount to $29.73 billion, which is almost 5 times the amount predicted for 2030, for the current invasive species ($6.1 billion).

To better understand the costs in relation to the assets they damage, we can also look at the spatial spread of these damages per species, across the NSW NRM regions. Figure III.2.1 shows the predictions for 7 years after incursion (which can be considered a good approximation for 2030). Note that these are the median values (i.e. the 50th percentile) of the replicate simulations, and may be very different than the mean damages (for non-symmetric distributions of damages). The 2.5th, and the 97.5th percentiles which are often used to represent the 95% credible interval around the median are shown in Figures D.1 and D.2, in Appendix D. For the exact values used to produce the maps in Figure III.2.1 we refer to Table D.1 in Appendix D.

It is worth mentioning that the distributions of damages (per pest) are heavy right tailed (i.e. with a large positive skew), so the mean damages will be much larger than the median damages. This behaviour can also be shown by looking at the extreme cases (the 2.5th, and the 97.5th percentiles of such distributions) in relation to the median. The 97.5th percentile would then represent the worst case scenario for the potential impacts. Figure III.2.2 shows the low (2.5th percentile), median (50th percentile), and high (97.5th percentile) estimates of damage cost (billions $) of the Khapra beetle (*Trogoderma granarium*) 7 years after invasion.

III.2.3. Costs of incomplete incursions

Many invasive species have been present in the country for a long time and despite management they have expanded to occupy their potential range. These ranges fluctuate through climatic seasonality and the effectiveness of control programs. However there are many incursions that have not achieved their potential range. Any estimation of the future impact of invasive species needs to consider these incursions, their rate and range of expansion, and their potential impact on the land they do not currently occupy.

Once an invasive species is in a new suitable environment, it increases in density and area. The rate of their population growth and range expansion vary between species and locations, depending on their life histories, the suitability of the habitats, and the effectiveness of control activities. If not eradicated, the pest would establish locally meanwhile expand to other areas from the initial sites. Before the pest occupies all the available suitable habitats, this type of invasion can be classified as incomplete incursion.

There are several reasons why a pest has not reached its potential range. It could be simply because it needs more time to propagate. It could also be due to the surveillance and management measures that slow down its expansion. Nevertheless, it is difficult to contain incursions as it may be quite expensive and harder once expansion has started. Most importantly, containment is essentially slowing down the speed of invasive species reaching their maximum carrying capacity (Grice *et al.*, 2013). The pest does not recognize administrative boundaries; hence it may require teamwork between different regional bodies and land managers from different tenures such as national parks, state forests.

There are many incomplete incursions that will contribute to the future impacts of invasive species. Cane toads (*Rhinella marina*), for example, are a commonly known invasive species in NSW. They were first introduced to Australia in 1935 as a biological control agent to manage scarab beetles in sugar cane fields, but now have invaded most of northeastern Australia, including NSW. In NSW, they are now found in the northeast

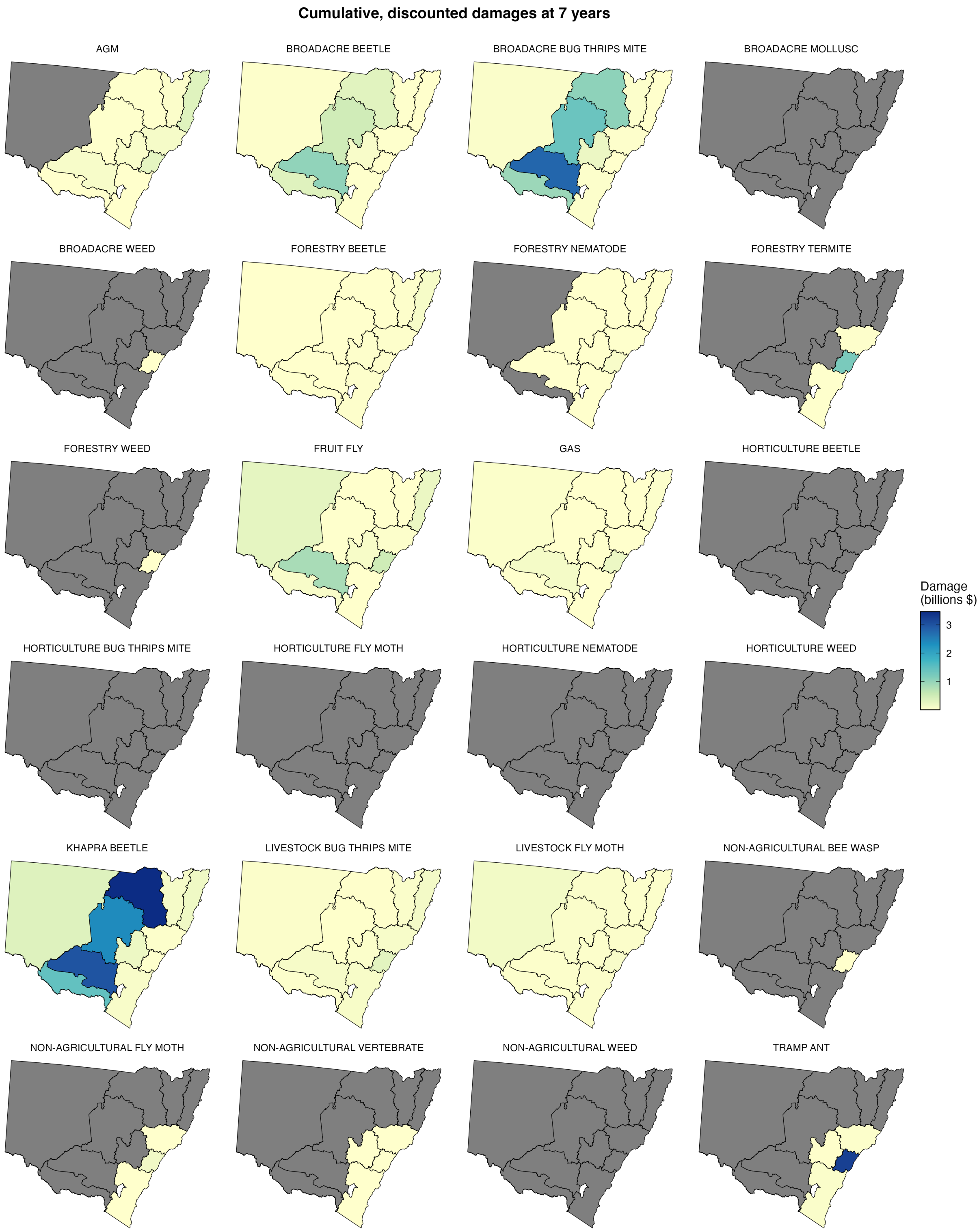

Figure III.2.1.: Estimate of damage cost (billions $) of the 24 functional groups, in each of the 11 National Regional Management (NRM) regions in NSW, 7 years after invasion. Grey areas correspond to zero values.

part of the state with a high potential to expand into the west with an estimated speed

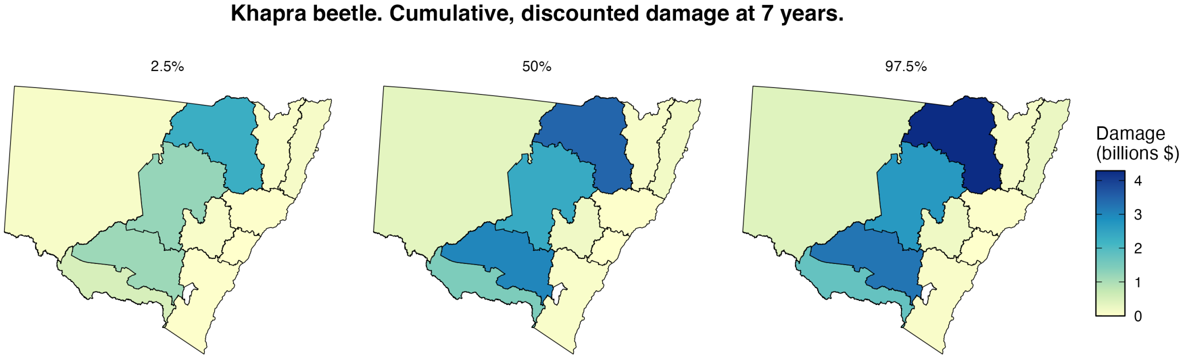

Figure III.2.2.: Estimate of the low (2.5th percentile - left), median (50th percentile - middle), and high (97.5th percentile - right) estimates of damage cost (billions $) of the Khapra beetle in each of the 11 National Regional Management (NRM) regions in NSW, 7 years after invasion.

of 40-60 km per year (NSW DPI, 2024a). The NSW government currently divide the state into three biosecurity zones based on the population of the cane toad (Figure III.2.3). Currently, there are no active measures such as surveillance in NSW to manage cane toads. In the green zone, cane toads are established, and no control measures are in place. There are two biosecurity zones, i.e. the amber buffer area and the red cane toad-free area. Spotted cane toads in the biosecurity zones are expected to be contained and reported to the authorities for further removal. There is no eradication program for cane toads in NSW and cane toads will inevitably expand their range and invade suitable habitats in NSW in the future.

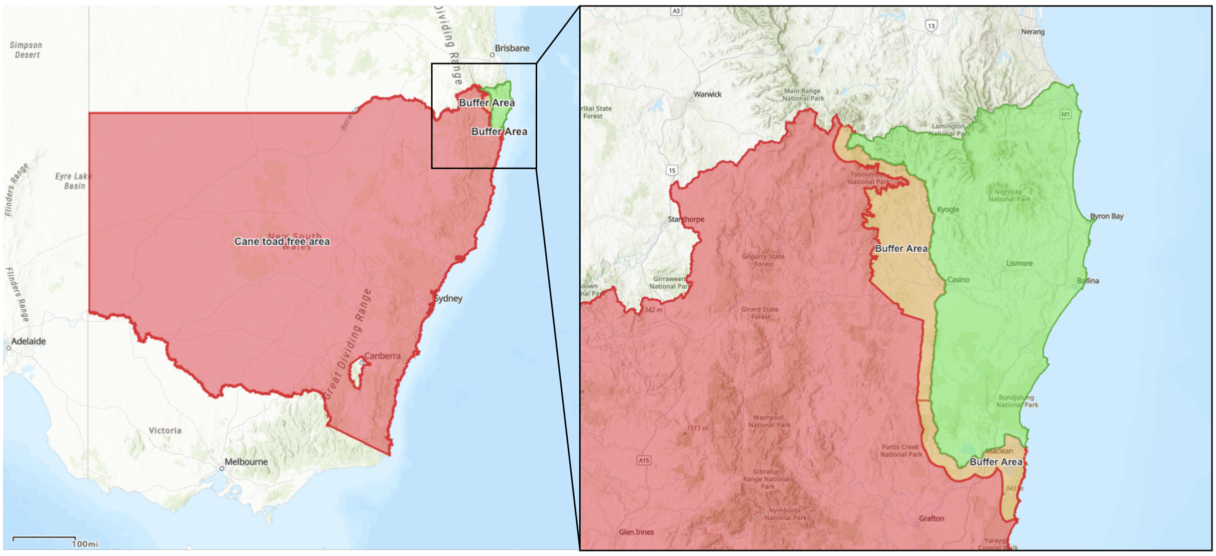

Figure III.2.3.: Biosecurity zones in NSW. The green region shows the area with an established population and the amber and red areas are biosecurity zones. The amber region shows the buffer area, and the red region shows the cane toad-free area. Source: NSW DPI (2024a)

Here we additionally demonstrate the significant risk to NSW of four selected invasive species (i.e. red imported fire ant, Tilapia, feral deer, hawkweeds) in the boxes, detailing their current status in NSW and their impact on the NSW economy, environment, and society.

Impact and the extent of the invasion of red imported fire ants

Red imported fire ants (RIFA) are one of the most notorious invasive pests in the world. In Australia, they were first detected in Southeast Queensland in 2001 and the eradication program has been ongoing since then for nearly 20 years. RIFA were also found in other states including NSW and has been successfully eradicated. However, recently, RIFA has been found in NSW again in early 2024. Currently, NSW DPI, the National Fire Ant Eradication Program, and the local councils are working together to conduct surveillance and treatment in Wardell and South Murwillumbah to restrict the spread and to eventually eradicate them.

RIFA will have a huge and expensive impact in Australia once established. They are a huge threat to public health. Their bites, as the name refers to, cause burning pain, itchiness, blisters, and fatal allergic reactions in more serious cases. When they sting, they release hormones to recruit more ants and attack in groups, which causes massive damage. RIFA has caused more than 85 deaths in the US. If not controlled, it is estimated to cause 140,000 medical consultations and 3000 allergy reactions per year (ref; 13 Invasive Species Council). They feed on animals that nest or feed on the ground such as birds, insects, and lizards, which is a big threat to Australian fauna and even flora as they also feed on native pollinators. RIFA not only cause long-term changes in ecosystems and landscapes but also our lifestyles due to their invasion of outdoor spaces and facilities such as lawns and playgrounds. They can also damage electrical facilities and cause short circuits to, for example, traffic lights. RIFA can take a hefty toll on several industries including tourism and agricultural industries. They can damage crops and farming machines, turn the turf into their inhabit sites, and decrease production. RIFA also attack livestock, causing injuries such as blindness or suffocation, and sometimes this lead to starvation and dehydration of the animals.

Using CEBRA's Value Model, which calculates damages of invasive species if they are allowed to establish and spread throughout Australia, potential damages due to the impact of RIFA were estimated to be more than $60 billion over 30 years, or roughly $2.2 billion per year (mostly in QLD and NSW initially). Overall, the model combines predictions of the spatial spread of RIFA originating from Queensland and New South Wales with damages to 16 different asset categories, which include agriculture, recreation, and infrastructure. These damages can escalate rapidly with large numbers of uncontrolled outbreaks and over a longer time period. CEBRA projects that the cumulative and combined damage to agriculture, recreation, and tourism will exceed 1.5% of Australia's GDP and that the 'silent cost' (i.e. largely unreported) to the environment will be 1.3% of GDP. Jointly, this is a cumulative damage of 2.8% of GDP measured in 2054, which is approximately half of the COVID shock in 2020-2021.

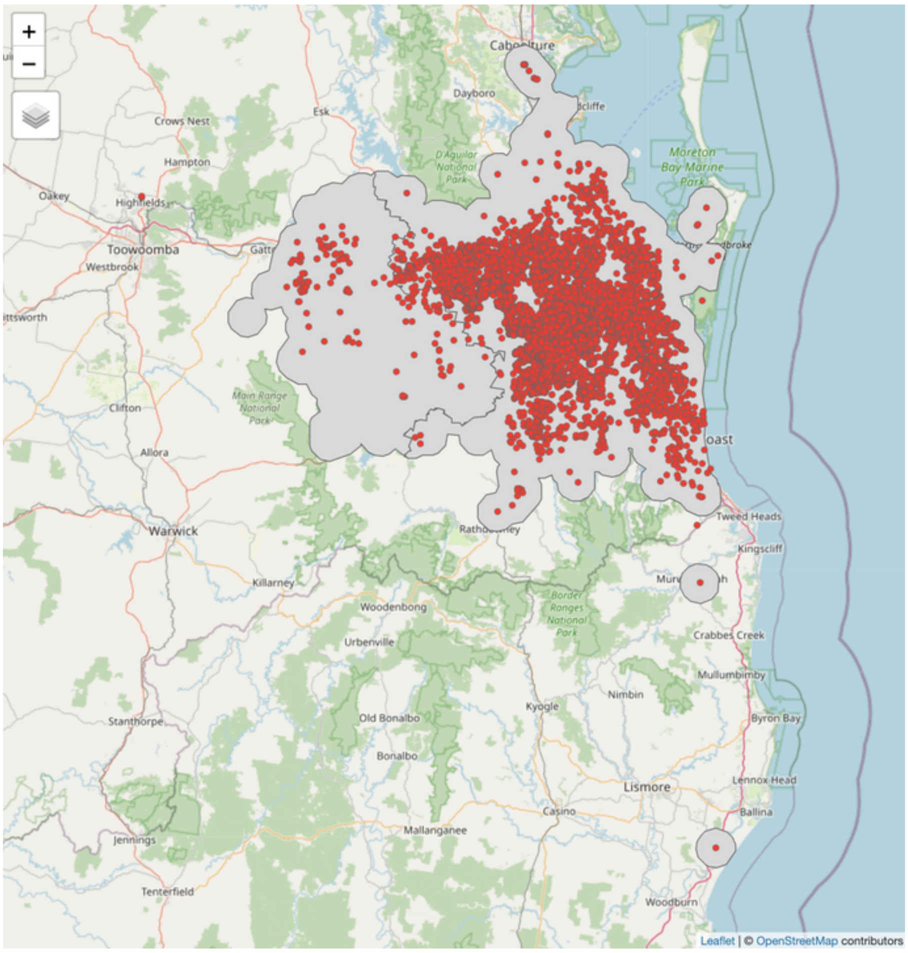

Figure III.2.4.: Predicted initial spatial distribution of red imported fire ants using CEBRA's Value Model.

	Asset	30 years	50 years
1	Agriculture	16.7	58.8
2	Domestic Animals	13.4	30.7
3	Recreation	11.0	25.8
4	Tourism	8.04	17.8
5	Rec. Horses	4.27	9.54
6	Infrastructure	3.90	8.54
7	C Sequestration	2.19	7.40
8	Erosion	1.29	6.51
9	Gene Pool	1.42	5.12
10	Water	1.30	4.52
11	Existence	1.35	4.03
12	Flood Mitigation	0.753	2.84
13	Forestry	0.808	2.25
14	Toxin Mediation	0.752	2.18
15	Indigenous	0.428	1.61
16	Subsistence	0.0126	0.0350

Table III.2.3.: Estimated damage of RIFA to 16 different asset categories in Australia (mostly Queensland and New South Wales) over 30 and 50 years.

Impact and extent of the invasion of Tilapia

Tilapia is an invasive aquatic fish in Australia. Three species of tilapia have established in Australian waterways, including Mozambique tilapia (*Oreochromis mossambicus*), spotted tilapia (*Pelmatolapia mariae*), and redbelly tilapia (*Coptodon zillii*). Mozambique tilapia is listed in the top 100 invaders by the International Union for Conservation of Nature (IUCN). So far, there is only one established tilapia population (Mozambique tilapia) found in NSW, which is first detected in 2014 in Cudgen Lake near Cabarita Beach on the NSW far north coast (Figure III.2.5).

Figure III.2.5.: Current invaded location in NSW. The red dot is the established population of Mozambique tilapia in Cudgen Lake. Pink shaded area is the distribution range of Mozambique tilapia in Queensland and the blue line is the Murray-Darling Basin range. Source: NSW Tilapia control plan. Source: State of New South Wales (2023).

Tilapia were first illegally introduced in Australia in the 1970s and quickly established since their introduction due to their biological characteristics. They are hardy and flexible in habitat preferences. They withstand low dissolved oxygen and a wide range of water temperatures (8 to 42°C for Mozambique tilapia). They mostly inhabit freshwater environments such as slow-flowing rivers and streams and still-water habitats, but can also survive in high salinity. They are omnivores, feeding on a wide variety of plant and animal matter. They have an efficient breeding strategy. They are mouth brooders where females protect the eggs and young from predators by holding them in their mouths while males build circular breeding nests on muddy substrate. Because of their simple requirements for environment and their aggressiveness, they out-compete many native species in terms of food and space. Nest buildings may also change natural habitats by damaging vegetation and increasing turbidity. Economically, they might decrease water quality in warm-water lakes and reservoirs and with extreme and damaging weather events, dead fish may foul domestic water supplies and lead to expensive re-sourcing of alternative water. They might also affect the tourism industry at places where recreational fisheries are the primary source of income for the local economy.

In 2023, the NSW government developed a Tilapia Control Plan (State of New South Wales, 2023) with three major goals. The first goal is to contain the current established population in Cudgen Lake and prevent the spread of the existing tilapia population in NSW. The second goal is to prevent new incursions of tilapia in NSW from other states. The third goal is to build up the capacity and capability to ensure the NSW government has the ability to control and manage tilapia. Achieving these requires government agencies at different levels (e.g. NSW DPI, Local Land Services) and other stakeholders (e.g. local councils, Murray-Darling Basin Authority) to work together.

Impact and extent of the invasion of feral deer

There are currently 6 feral deer species in NSW and 5 of them are widespread, namely fallow (*Dama dama*), red (*Cervus elaphus*), sambar (*Cervus unicolor*), chital (*Axis axis*) and rusa (*Cervus timorensis*) deer. Though the dispersion rate has been slowed, dropping from 35% in the 2016-2020 survey to 4.6% in the 2020-2023 survey period, the total abundance and distribution area are still expanding since 2016. For example, the most widespread species, fallow deer, have increased their distribution by 60% in the 2016-2020 period and to a total of 149,426 km2 (18.65% of NSW) in 2023.

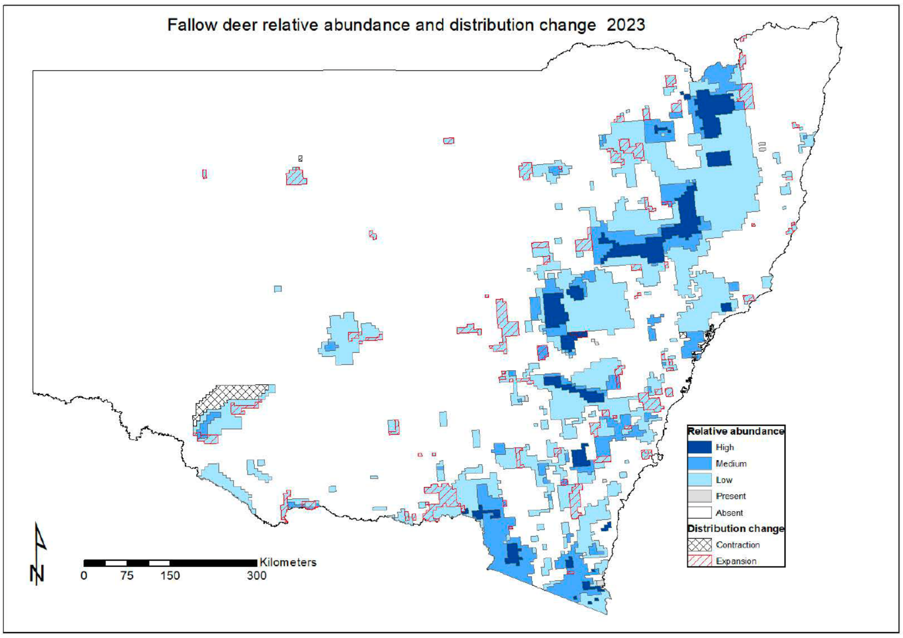

Figure III.2.6.: The change in the distribution of fallow deer from 2020 to 2023. Figure retrieved from NSW DPI (2024b). Blue regions indicate the expanded areas to previously absent areas.

Feral deer have significant impacts in diverse ways. They affect the environment through grazing and browsing, which affect plant growth and seeding recruitment, and pose threats to native plants by spreading weed seeds. They have an economic impact on agriculture including damaging crops and young trees, disturbing resting pasture, and completing for grazing resources with livestock. The lost production is estimated to be nearly $100,000 per year from pasture competition with cattle alone as reported by a farmer in the Snowy Mountains in NSW (McLeod, 2023). Feral deer are also a threat to livestock health. They have been reported to carry Bovine Johne's disease and are potential hosts for foot-and-mouth disease (FMD), which is estimated to cost Australia up to $50 billion over a decade from a potential outbreak. In urban areas, they also impact human health by causing vehicle accidents with cars and damages to trains.

Fencing and trapping is one way to reduce the impact but it is very expensive. The NSW government (National Parks and Wildlife Service) has spent more than $200,000 funding fences and electrical skirting on just one property alone. NSW local governments also fund feral deer control. For example, the Wollongong City Council was estimated to fund $400,000 per year for feral deer control in 2018. Combined, the public expenditure on feral deer control is estimated to be $5.7 billion per year in NSW (Local Land Services, NSW Department of Primary Industries, NSW National Parks and Wildlife Service).

Impact and extent of the invasion of hawkweeds

All hawkweeds are invasive to Australia. They are long-lived plants, grow slowly but mature quickly, and spread both by runners and seed. They are a threat to Australian native plants because they out-compete Australian native plants by growing dense mats that smother the ground, depleting the nutrition and lowering the pH of the surrounding soil which discourages other plants from growing nearby, along with reducing natural habitats and food for native animals. They also generate economic and agricultural impacts on livestock by destroying healthier pastures and on the public by damaging gardens and roadsides.

In NSW, hawkweeds were found in Kosciuszko National Park and neighbouring farms, Katoomba and Mount Irvine. There is potential re-invasion from other states as hawkweeds are found in VIC, TAS, and WA as well. It is estimated that a hawkweed invasion in Australia will put 14.3 million hectares of land at high risk with a $1.25 billion production loss (Brinkley & Bomford, 2002). Kompas *et al.* (2016) proposed a practical analytical framework to assist the government in making optimal surveillance strategies for weeds using hawkweed as an example. The model predicts that the annual surveillance budget for hawkweed should be roughly $3,000 per 10,000 ha at risk. With global warming, much of the alpine regions will be climatically suitable for hawkweeds by 2070 (Beaumont *et al.*, 2009), which is a significant threat to the unique Australian biodiversity. Currently, there is one location in the south of Sydney categorised as present-occurrence unknown in NSW, yet a potential re-invasion is foreseeable.

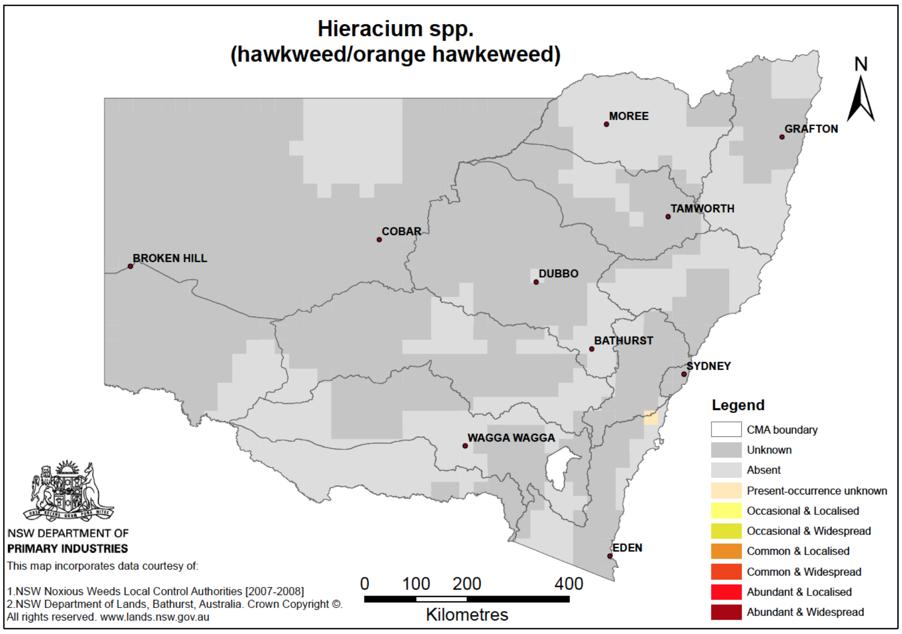

Figure III.2.7.: Current distribution of hawkweeds in New South Wales but the present-occurrence is unclear. Source: NSW Weed maps (2024).

III.3. Effect of trends on invasive species impact

In this section, we discuss how human activities affect invasive species. We breakdown the discussion into four parts: trade and travel, urbanisation, agricultural intensification, and technology.

III.3.1. Trade and travel

Greater levels and speed of global trade, travel and interstate freight are creating new opportunities for pests and diseases to enter and spread across Australia. In the last 50 years, the number of people in the world has more than doubled, consumption has tripled, and global trade has grown nearly tenfold, with shifting patterns of trade across regions (IPBES, 2023). There is a strong link between the volume of commodity imports and the number of invasive alien species in a region, and patterns in the global spread of species mirror shipping and air traffic networks (IPBES, 2023). Between 2016 and 2030 international and domestic passenger movements through Australia's capital cities is expected to double (Department of Infrastructure and Regional Development, 2016). In addition, the volume of freight flown into and out of Australia is projected to increase by 120 per cent from 2014 to 2030 (Department of Infrastructure and Regional Development, 2016). The growth of ecommerce also presents greater opportunity for pest and disease introduction through illegal flora and fauna trade (CSIRO, 2020).

Biosecurity measures at international borders have not kept pace with this growing volume, diversity and origins of global trade. Projected growth in international trade and the movement of people, including tourism, will lead to further pressure on border inspection regimes and could soon overwhelm the biosecurity capability of most countries (IPBES, 2023). A recent audit (The Auditor-General, 2021) of the Australian Government's capacity to respond to non-compliance with biosecurity requirements found that the current arrangements were largely inappropriate. That there is no framework to assess risk across the entire biosecurity system and that undetected non-compliance is increasing.

III.3.2. Urbanisation

Population increases will require more and increasingly denser urban areas. The total population in NSW in 2020 was 8.2 million. This is projected to increase to 9.9 million people over the next 20 years driven by migration and the balance between births and deaths (NSW Treasury, 2024). The ongoing expansion of cities is changing interactions between people, wildlife and agriculture potentially increasing risk of spreading pests and diseases across these boundaries (IPBES, 2023). Peri-urban regions on the fringes of cities are a source of new pest and disease risk as they are often under the stewardship of inexperienced or under-engaged owners (CSIRO, 2020).

III.3.3. Agricultural intensification

To meet the increasing global demand for food and to ensure food security the intensification of agricultural production is projected to increase (Linehan *et al.*, 2012). This agricultural intensification will include both vertical integration, and expansion into new areas. These changes can impact the resilience of ecosystems and render them more vulnerable to damage from both invasive species not yet in Australia and those that are already established (CSIRO, 2020).

III.3.4. Technology

Although the current invasive species management toolbox is often inadequate, recent advances in technology are demonstrating substantial returns on investment (Hulme *et al.*, 2023). These advances suggest that some invasive species challenges thought insurmountable may be overcome. There have been advances in existing technologies such as biological control. These advances are being assisted by both new technologies e.g. genetics and cross-over applications for other existing technologies e.g. unmanned aerial vehicles (Martinez *et al.*, 2020).

In particular, advances in genetic technologies are equally promising and challenging. Gene editing techniques such as CRISPR-Cas9 allow for precise modification of invasive species' genomes, potentially rendering them less harmful or even eradicating them altogether. Genetic markers enable the identification of invasive individuals and tracing their origins, aiding in tracing invasion pathways and implementing targeted control measures (McGaughran *et al.*, 2024). Additionally, genetic biocontrol methods, such as sterile insect techniques and gene drives, offer innovative approaches to suppress invasive populations (Teem *et al.*, 2020).

The speed of development and impact of all these technologies are being amplified by advances in artificial intelligence. While these advances in technology hold great promise they are not without risk and likely to be resisted (Kirk *et al.*, 2019). In partnership with other jurisdictions an education and communication strategy should be developed to help establish social licence for the application of potentially controversial invasive species management technologies.

III.4. Effect of climate change on invasive species impact

This section discusses the expected impact of climate change on the arrival and distribution of pests across Australia in general, and NSW in particular.

The impacts of climate change are becoming increasingly evident worldwide. According to the latest State of the Climate report (CSIRO & of Meteorology, 2022), Australia is expected to continue experiencing elevated temperatures and increases in the frequency and intensity of both heatwaves and fire. Rainfall is becoming more unreliable, especially in southern Australia, with snow cover expected to decrease across alpine regions and extreme meteorological events (e.g. intense heavy rains) likely to intensify across the country.

Climate change is expected to influence biological invasions by modifying their establishment and spread rates, as well as their impacts (Hulme, 2017). The next few decades will see an acceleration in the introduction and detection rates of new exotic species across every region of the world (Seebens *et al.*, 2021), including Australia. This is the result of several processes that act simultaneously, and often synergistically. While many species that will be detected in the near future have already, but just recently, been introduced to Australia (Essl *et al.*, 2011), the rate of arrival of new and existing threats to the country is expected to increase with climate change. International socio-economic relationships (e.g. international trade) and species' global distributions (Chapman *et al.*, 2017; Lenzner *et al.*, 2020) are both linked to climate and global warming. This combination of potential climate-induced changes in global trade patterns and species distributions is likely to have short-, medium- and long-term implications on biosecurity risk globally. What is more, the distribution and spread rate of endemic pests (i.e. pests that have established and spread) within Australia are also expected to respond to climate change and global warming. This is particularly true for New South Wales, with endemic threats established in Queensland such as cane toads and red imported fire ants, expected to spread further south because of climate-induced changing species distributions, extreme weather events (e.g. flooding), and geographic changes in human movement.

Climate change will increase biosecurity risk

Impacts of climate change on global species' distributions

Climate is arguably the main driver of species distributions; local climatic conditions must be suitable for any given species to survive and reproduce. Thus, new conditions driven by changing climate will undoubtedly lead to changes in species' geographic ranges worldwide (Gallardo & Aldridge, 2013; Bellard *et al.*, 2013; Dullinger *et al.*, 2017; Essl *et al.*, 2020). For example, two species of exotic ants (Argentine ants, and Yellow crazy ants) are expected to overcome climatic barriers that had so far prevented their establishment in many high latitude temperate and subtropical regions around the world (Figure III.4.1; Chen (2008); Roura-Pascual *et al.* (2004)). This change in climate suitability is particularly relevant to NSW and Victoria, which are expected to become more suitable for the Argentine ant in the next few decades.

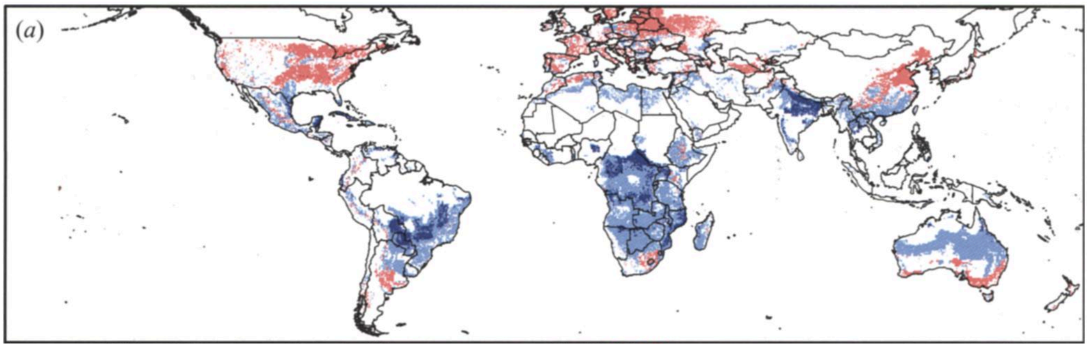

Figure III.4.1.: Predicted changes in the potential distribution of the Argentine ant between the years 2000 and 2050. Red indicates areas where climatic suitability is predicted to improve, while blue indicates areas where it is predicted to worsen. Source: Roura-Pascual *et al.* (2004)

It has been long hypothesised (and more recently demonstrated for some groups like butterflies; (e.g. Rodder *et al.*, 2021)) that species' distributions are likely to shift towards higher latitudes and altitudes, as increases in temperature result in milder climates. A biosecurity threat that will very likely take advantage of increased climatic suitability in Queensland and New South Wales is the tropical oriental fruit fly. Following changes in climatic conditions, the distribution of fruit fly species is expected to expand towards higher altitudes in both northern and southern hemispheres (Szyniszewska *et al.*, 2024) and potentially causes significant impacts across major horticultural areas in Queensland, NSW and Victoria (Figure III.4.2; (Sultana *et al.*, 2020)).

Ecotherms and pathogens, are expected to benefit from a warmer climate. This is particularly the case with invertebrates (which are also a primary vector of many human and animal pathogens). In many invertebrates, higher temperatures are correlated with greater activity and reproduction. As such, elevated temperatures may increase both activity and population size in more temperate, higher latitude and altitude locations, while also reducing activity and reproduction rates in more tropical locations – depending on a species' tolerance to extreme temperatures. As a consequence, southern states such as NSW and Victoria are likely to be increasingly exposed to both established and exotic tropical threats. For example, cane toads and fruit fly are expected to move further south into NSW and Victoria due to warmer temperatures, with dire consequences to biodiversity as well as agricultural and social assets. Similarly, the tropical native *Culicoides brevitarsis* – a biting midge fly and potential vector of the animal disease lumpy skin disease – may also migrate further south, increasing the exposure of Victorian and New South Wales livestock industries to potential disease outbreaks.

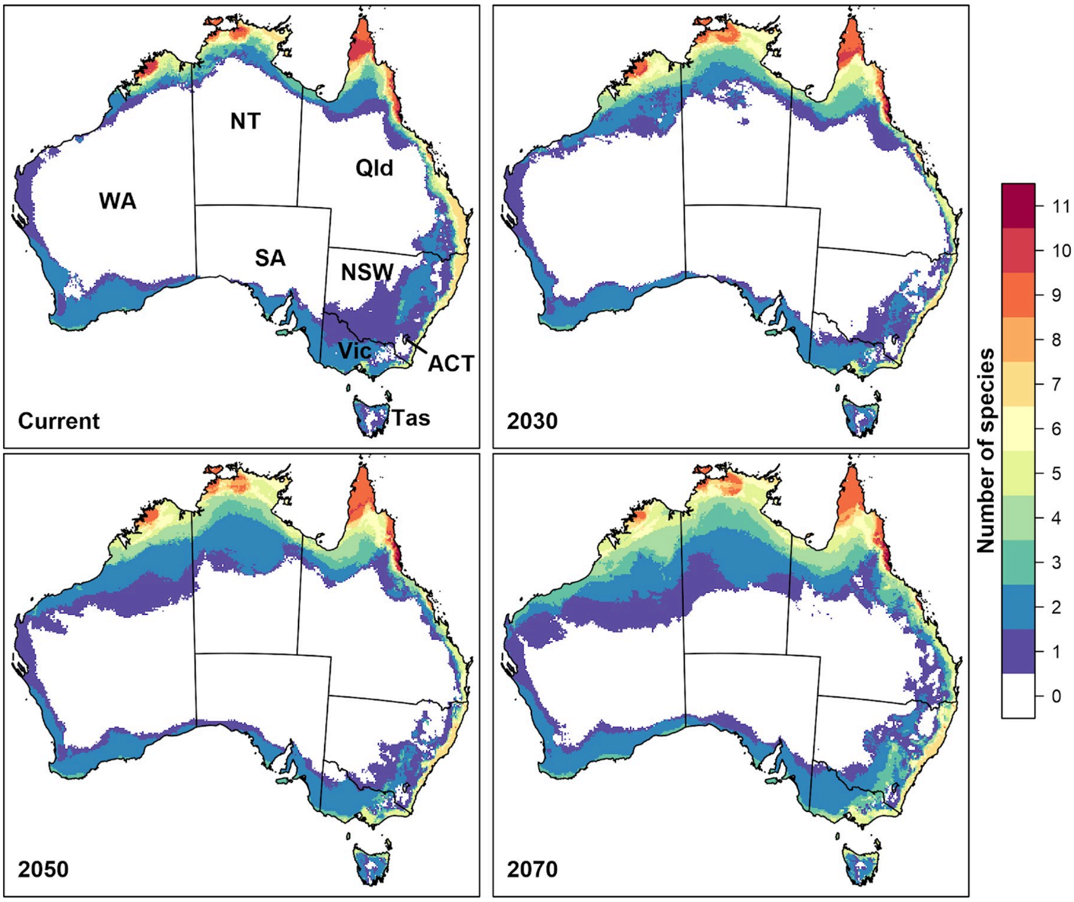

Figure III.4.2.: Number of fruit fly species for which habitat is projected to be suitable under future climate scenarios. Source: Sultana *et al.* (2020)

Changing global distributions are also likely to have significant impacts on the likelihood of exotic pests arriving and establishing within Australia. For example, two priority plant pests, the brown marmorated stink bug and spongy moth, are predicted to experience shifts in global ranges due to climate change (Figure III.4.3). These changes manifest in changes in trading partner risk and ultimately Australia's exposure in accidentally importing these pests into the country. Both pests are highly polyphagous and are expected to have significant impacts on agricultural, environmental and social assets across Australia, but especially southern states such as Victoria and NSW which are expected to remain highly suitable for both threats (Figure III.4.3).

Impacts of climate change on global trade

Global connectiveness and trade volume are increasing around the world in the form of new trade agreements, routes, and commodities. The volume of global trade and its connectiveness has, and will continue to have, a direct strong impact in the number of invasive species detected around the world, with a linear increase in detection across every group of species following temporal increases in global trade (Seebens *et al.*, 2017b). New trade patterns partially respond to the effects of climate change and global warming, and they can alter pest pathways into Australia and NSW. Climate and climate change can directly impact a country's productivity (e.g. labour produc-

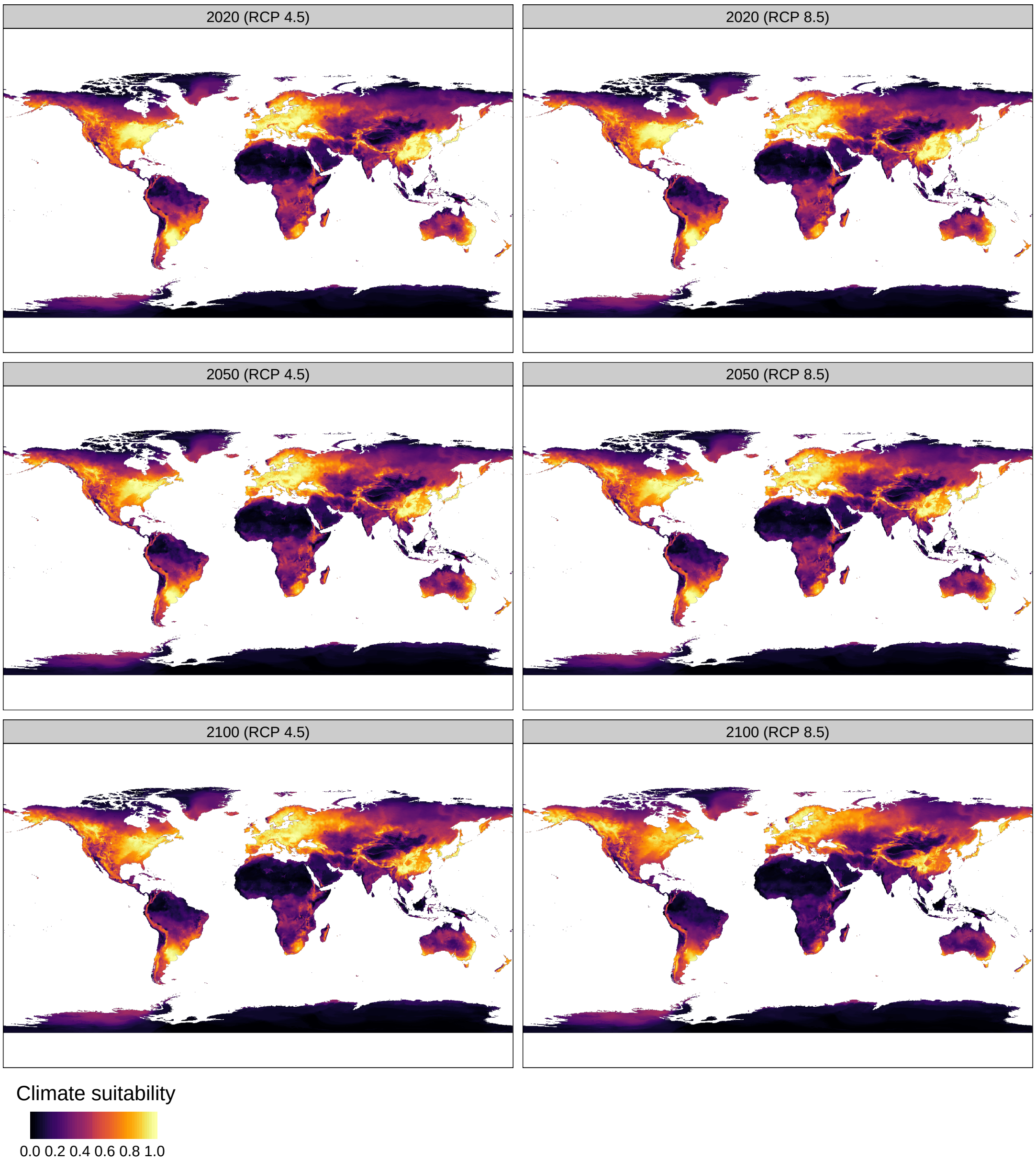

Figure III.4.3.: Estimated global climate suitability for the brown marmorated stink bug in 2023, 2050 and 2100 under two different climate change scenarios, with warmer colours indicating areas of higher climatic suitability. Source: Camac *et al.* (2024b)

tivity loss due to number of heat stress days), which in turn, influences international competition, and ultimately, global trade patterns. Climate change itself can lead to changes in the species (and genes) pools traded from exporting regions. By governing species global distributions, climate and global warming can impact international trade – such as where plant (e.g. crops) and animal (e.g. livestock) goods can be reliably produced, or where significant biosecurity threats (both known and unknown) may occur. More extreme climate can also create new market demands, such as plant products that are pre-adapted to the new climatic conditions (Hulme, 2017; Essl *et al.*, 2020). Generally, the creation of novel, and possibly quicker trade routes (e.g. through the Arctic region), will lead to changes not only in the origin, volume, and nature of imported commodities into Australia and NSW, but also in the likelihood that hitchhiking threats may survive the journey.

Previous work by CEBRA has extensively explored how imports into Australia will change over the next few decades under different climate scenarios (Camac *et al.*, 2024b). One of the outputs of this work - a visualisation tool that offers predictions of future trade patterns for different commodities and exporting countries – can be found here. This work indicates that, even with a conservative set of climate change damage functions, changing climate will have variable impacts on the types of goods Australia (and therefore NSW) imports, and where these imports come from.

Crop imports into Australia, for example, are expected to vary substantially, with exports from Brazil, India, part of Eastern Africa, and part of South America expected to decline under both RCP 4.5 and RCP 8.5 climate scenarios (Figure III.4.4 left). In this example, only China is expected to continue to increase crop exports to Australia – albeit at a lower rate under RCP 8.5. These changes in exports arise from climate-induced predicted changes in crop yields and labour productivity. Smaller climate change impacts are expected for other non-agricultural land-use sectors, such as livestock or forestry (Figure III.4.4 right). This is primarily due to the fact that many of the largest exporters are situated outside of the global zones that will experience the greatest damages from global warming, defined as heat stress impacts from losses in agricultural and labour productivity (Kompas *et al.*, 2018).

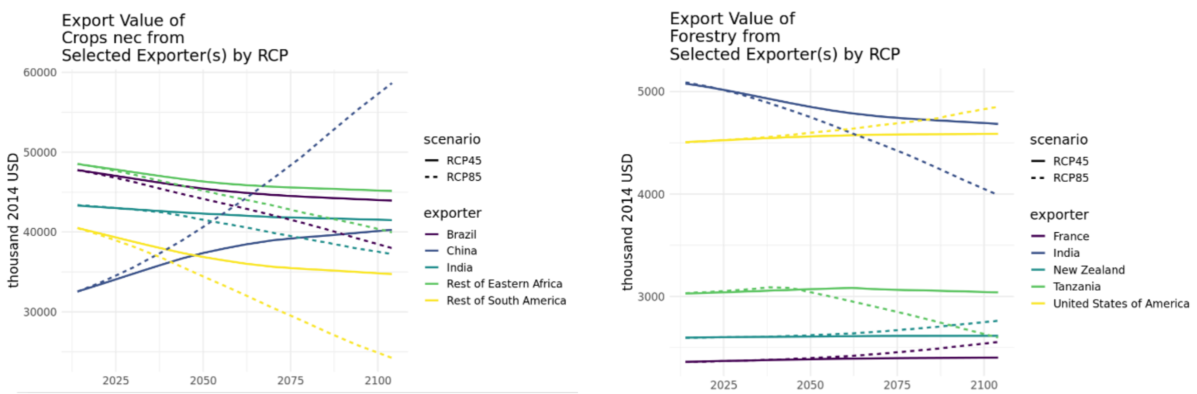

Figure III.4.4.: Predicted export value of crop (left) and forestry industries (right) for the main exporting partners into Australia under different climate change scenarios (RCP 4.5 vs RCP 8.5) for the 2020-2100 period.

If we dive into the manufacturing (Figure III.4.5 left) and the food- and agriculture-related sectors (Figure III.4.5 right), we see how exports into Australia from different regions (on the Y axes) and across several commodities (on the top) will change by 2100. Regions highly affected by climate change (East, South, and Southeast Asia; Kompas *et al.* (2018)) will overall bear the greatest drops in exports (represented by dark red in the figure), while several European regions will see net gains in their exports to Australia (represented by dark blue in the figure).

Climate change will, therefore, influence the risk of exotic species and diseases arriving and spreading within Australia, and to and within New South Wales; directly

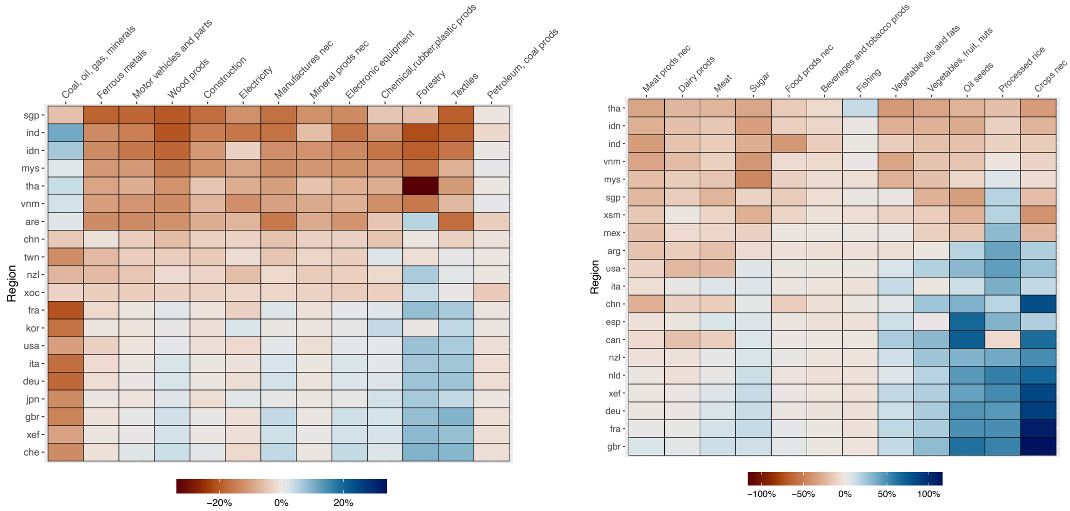

Figure III.4.5.: Relative change in import dynamic among the top 20 exporters of manufacturing products (left) and food and agricultural goods (right) to Australia under RCP 8.5 in 2104. Both panels are limited to the top sectors by imported value. Source: Camac *et al.* (2024b).

via its effects on species global distribution and indirectly via its effects on global trade patterns.

Countries such as Australia utilise a range of risk assessments (e.g. Import Risk Assessments as well as Weed and Pest Risk Assessments) to inform risk that may be associated with international trade and human movement. However, these methods are mostly based on information from regions where the threat is known to occur. Changing climate and global warming going forward is likely to make these forms of risk assessment less reliable, as new trade routes open up and potentially expose countries to new biosecurity risk (Seebens *et al.*, 2018; Hulme, 2017). Research to date points to invertebrates and pathogens as the groups posing the highest biosecurity risk moving forward, since they present the ability to increase their worldwide distribution due to the individual and combined effects of future changes in trade patterns and warmer temperatures (Bellard *et al.*, 2013; Seebens *et al.*, 2021). These organisms are usually introduced unintentionally through high-risk pathways, as contaminants of commodities (e.g. wood products, live plants) or stowaways in vessels. These organisms can easily capitalise on quicker trade routes and/or warmer climatic conditions to reduce their on-route mortality or increase their on-route population growth, both of which are expected to lead to improved arrival and establishment rates. These mechanisms are relevant for NSW risk assessment procedures, since to date Australia has likely benefited from arrivals of pests that have never established.

Another group for which biosecurity risk is expected to increase is plants. Increasingly warmer and drier conditions are expected to bring on demands for a wider variety of drought-resistant gardening plants (Bradley *et al.*, 2012; van Kleunen *et al.*, 2018). It is well-known that the horticultural industry is responsible for the consistent release of many established and invasive species around Australia over the last two centuries (Dodd *et al.*, 2015). These patterns can only continue, if not worsen, with a new wave of introduced ornamental plants that are pre-adapted to global warming. Equally, the introduction of new pasture species has the potential to cause environmental issues in the future. This is particularly true for annual C4 grasses, which are predisposed to thrive under warmer conditions, but in turn will eventually outcompete other species in arable lands (Hulme, 2017).

The risk of biosecurity material arriving within a country like Australia due to trade, will ultimately be governed by the amount of imports it receives from exporters containing a threat of interest, and how the geographic distribution of suitable climate will change within both exporting and importing countries. For example, in exporting countries where climate suitability is expected to increase, one can expect an increase in local pest distributions, and thus, an increase in goods potentially being contaminated. This ultimately manifests itself as higher propagule pressure (e.g. number of contaminated items) hitting an importer country's borders. However, whether this higher propagule pressure results in higher risk of establishment, also depends on whether the climate is also suitable at destinations where these goods are unpacked. Camac *et al.* (2023) encapsulated these complications and also incorporated predictions in climate-induced international trade patterns to approximate how both propagule pressure (termed pressure) and establishment exposure (termed exposure) of high priority plant pests, were expected to be altered under climate change and future international trade patterns. They found that for threats such as brown marmorated stink bug, propagule pressure (i.e. number of contaminated lines) hitting Australia's border is expected to marginally decline between 2023 and 2100 under RCP 8.5 (Figure III.4.6 left). This decline is largely attributable to two factors: (1) climate and climate change induced changes in trade patterns (i.e. volumes and origins) of goods the brown marmorated stink bug commonly hitchhikes on; and (2) changes in the climatic suitability of brown marmorated stink bug within trading partners that currently have established populations. The effects of these two factors ultimately manifest in changes in the relative contribution of risk attributable to different trading partners (Figure III.4.7); with higher propagule pressure contributions expected from Canada, China, Great Britain and the United States, and lower contributions from Italy.

Camac *et al.* (2023) also found that under RCP 8.5, establishment potential for brown marmorated stink bug within Australia is also expected to marginally decline (Figure III.4.6 right). This is because the predicted amount of suitable climate for the species within Australia is expected to decline – becoming more restricted to the coasts of NSW and Victoria – and therefore, fewer contaminated items are likely to be destined for climatically suitable locations. However, it is important to note, that the expected number of contaminated items arriving in climatically suitable locations is still very high ($>$ 4000) – meaning that both NSW and Victoria will be most exposed to potential establishment events of this species.

Climate change will impact rates of establishment and spread of exotic species

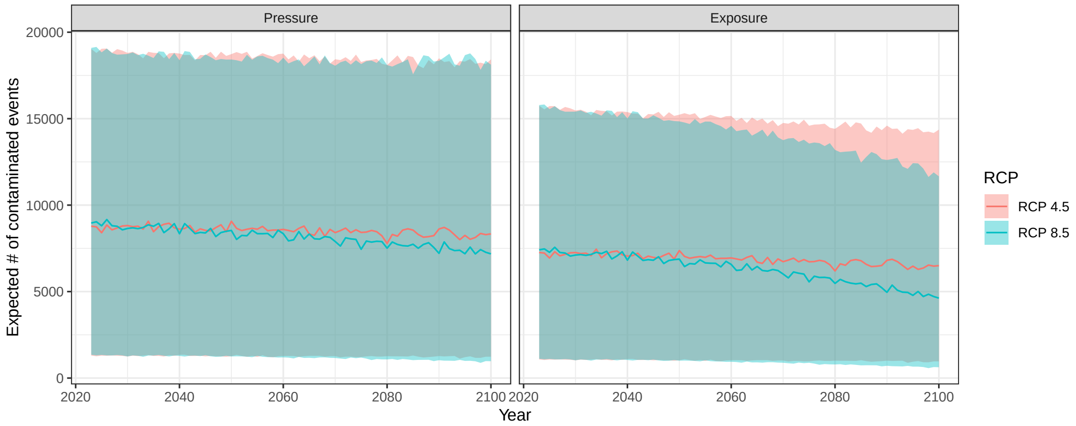

Figure III.4.6.: Annual mean (95% CI) brown marmorated stink bug propagule pressure (i.e. number of contaminated lines; left) and establishment exposure (i.e. number of contaminated lines arriving at climatically suitable locations; right) hitting Australia under RCP 4.5 and RCP 8.5. Source: Camac *et al.* (2023)

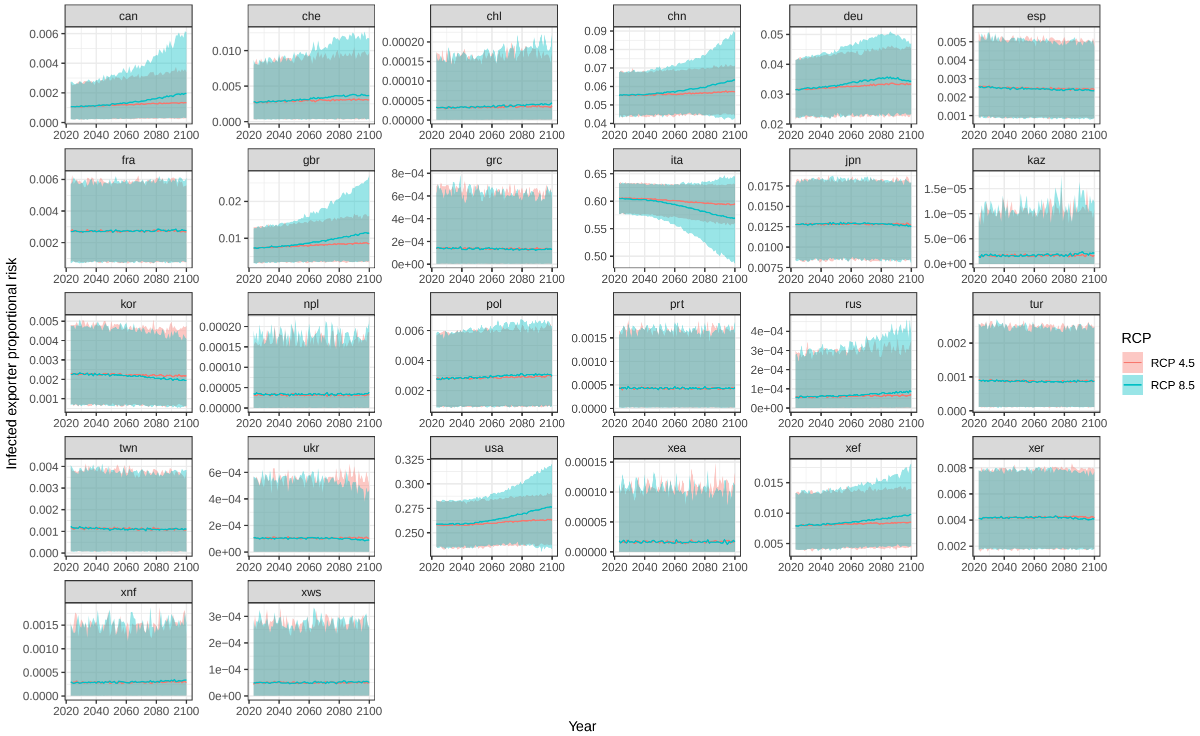

Figure III.4.7.: Annual mean (95% CI) exporter proportional contributions to Brown marmorated stink bug propagule pressure hitting Australia under RCP 4.5 and RCP 8.5. Country names as follows: can=Canada, che=Switzerland, chl=Chile, chn=China, deu=Germany, esp=Spain, fra=France, gbr=United kingdom, grc=Greece, ita=Italy, jpn=Japan, kaz=Kazakhstan, kor=Korea, npl=Nepal, pol=Poland, prt=Portugal, rus=Russian Federation, tur=Turkey, twn=Taiwan, ukr=Ukraine, usa=United States of America, xea=Rest of East Asia, xef=Rest of EFTA, xer=Rest of Europe, xnf=Rest of North Africa, xws=Rest of Western Asia. Source: Camac *et al.* (2023)

Exotic species establishment rates under climate change

How exotic species that are already present in Australia will respond to climate change is highly uncertain, and likely extremely context-dependent. Not all of them will overcome barriers to establishment and spread under novel climatic conditions; it has been shown that climate suitability for many Weeds of National Significance in Australia may decrease under climate change (Wilson *et al.*, 2011; O'Donnell *et al.*, 2012). However, it is expected that some will take full advantage of climate change. These winners will be capable to exploit increased temperatures to reach higher growth rates or longer lifespan, while still being able to deal with drier and less reliable rainfall patterns, and an increase in extreme events such as fires. Species that are currently limited to human environments (e.g. glasshouse plants, aquaculture farms, some plants pathogens) are expected to be the ones benefiting the most from warmer temperatures to increase their establishment potential (Hulme, 2017), since their closeness to human activity will very likely alleviate other constraints caused by climate change, such as drought.

CEBRA has recently developed a tool to inform geographic risk of establishment for one or multiple threats that explicitly accounts for climate suitability, pathways of arrival or spread, and biotic suitability (i.e. habitat or host availability; Camac *et al.* (2024a)). By creating maps for current and forecasted climatic conditions, as well as forecasted changes in introduction pathways, this tool has proven of excellent value to uncover areas of high invasion risk. For example, the current establishment risk for the oriental fruit fly for greater Sydney is shown in Figure III.4.8, with dark purple representing areas of low risk of establishment, and light orange areas of high risk. This map shows that high establishment risk arises in areas with high human activity (where the oriental fruit fly is more likely to be released) where climatic suitability for the species is also high. Invasion risk maps are the first step in translating establishment risk of particular threats into invasion impact for the economy, the environment and/or society.

Quicker spread of exotic species

In addition to weaker climatic barriers between northern Australia and neighbouring countries, climate change is expected to increase the frequency and intensity of extreme events such as fire, winds, and flooding events. Both changes in the local climatic suitability and extreme climatic events can exacerbate the spread of species both into northern Australia and amongst Australian states via unregulated pathways (e.g. pathways that cannot be regulated through trade). Extreme climatic events have been shown to increase the chance of dispersal of exotic species. Zebra mussel has been able to reach new catchments following river flooding events in North America (Diez *et al.*, 2012). The fall armyworm, a moth that can cause high damage in crops, is believed to be capable to rely on wind currents for rare long distance dispersal events (Phillips *et al.*, 2006). Its dispersal capabilities are expected to be enhanced under climate change with extreme wind episodes becoming more prevalent. Likely, strong winds were responsible for its recent arrival to New Zealand, where it was detected for the first time in 2022, from other exotic populations in Australia or Papua New Guinea.

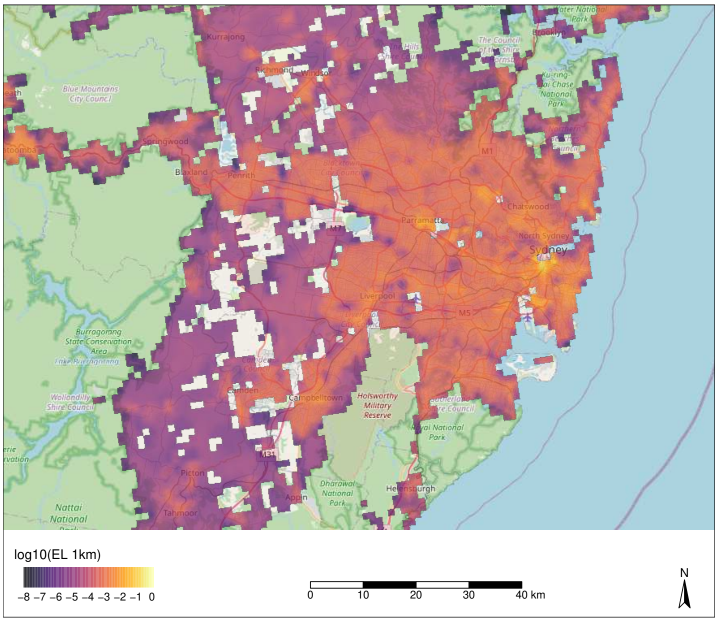

Figure III.4.8.: Oriental fruit fly establishment likelihood for greater Sydney, with lighter colours showing a higher risk of establishment. Source: Camac *et al.* (2020).

Natural spread of organisms that pose a threat to the Australian economy and environment, such as the oriental fruit fly, the Asian citrus psyllid or the red imported fire ant (RIFA), from southern Asian countries, Papua New Guinea and Indonesia will increase under climate change, allowing these organisms to arrive more often and/or in higher numbers via non-regulated pathways. This, along with softened climatic barriers in Australia (Sultana *et al.*, 2020), will cause outbreaks by these potential threats to occur more often and further south in the next decades.

Extreme climatic events can also influence the spread dynamics of exotic species that have already established within Australia, potentially increasing their distribution across state borders. Recent extreme rainfall and the following flooding events in Queensland have highlighted the potential of some invasive species, particularly the RIFA, to take advantage of unusual but extreme rainfall events by forming rafts to move across the landscape (Figure III.4.9), potentially reaching NSW.

Equally, an increase in the frequency and intensity of fire is expected to provide more opportunities for weed colonisation. Climate change, along with land use change, can lead to the formation of novel ecological conditions that open up colonisation opportunities for new species and promote shifts in the composition of plant and animal communities (Hoffmann *et al.*, 2019). It is also believed that some exotic plant species will be able to escape drought by venturing into higher elevations in Australia, i.e. the Alpine region (Petitpierre *et al.*, 2016).

Exotic threats can potentially have catastrophic

Figure III.4.9.: Raft of fire ants drifting on the Mississippi river (USA) after flooding events that occurred in May 2011. Credit: FIRE ANT RAFT by Maggie / CC-BY-2.0 via Flickr.com

economic impacts causing large economic loss even after *one single outbreak* in agricultural land

The greatest economic and environmental impacts associated with biological invasions in NSW and Australia for the next decades are likely to come from exotic threats, yet to establish within the country, but whose probability of being introduced into climatically suitable areas is increasing under climate change (Hulme, 2017). Pathogens, viruses, and invertebrate plant pests can potentially have very high if not catastrophic economic impacts (Hulme, 2017), causing a large economic loss even after a single outbreak in agricultural land. For example, recent work by CEBRA indicates that an outbreak of oriental fruit fly along the east coast of Australia (covering Queensland and NSW) could result in $5.25 billion in average annual damages. This estimate, based on an assumed establishment rate of 0.054 per annum and a 2.5 km spatial resolution, is a conservative one. Higher dimensional spatial mappings and longer time-frames would result in even more damage (Dodd *et al.*, 2020).

Species that are already present in the country, even if their climatic suitability increases with climate change, are not expected to cause impacts that are as strong or quick as the former group of threats. Changes in species distributions cause by climatic suitability alone are expected to occur relatively slowly, compared to changes in species distributions caused by global trade, which can happen relatively quickly. The exception would be those species capable of taking advantage of extreme climatic events to quickly spread into Australia, or among Australian states, unassisted.

Part IV.

Discussion

IV.1. Summary

A summary of all the estimates discussed in the previous sections will give an overview of the magnitude of impacts. It is, however, worth reiterating that the uncertainty around the modelled estimates spans many orders of magnitude and this is due to all the caveats indicated about the collected data, and the limitations and the assumptions of the models used.

The total cumulative costs reported between 1970 and 2022 is $30.761 billion (excluding public expenditure based costs). The raw aggregated cost for 2022 is $0.424 billion, while the costs for 2020 and 2021 were considerably higher, i.e. $1.339 and $1.379 billion. These years were more consistent with the averaged annual costs during 2010s (i.e. $1.319 billion per year).

The modelled cost predictions (using historical data) amounts to $1.923 billion in FY 2022/2023 based on the robust linear regression, and to $1.08 billion based on the robust quadratic regression. In addition, the levels of uncertainty in 2022/2023 (and 2030) estimates are extremely high, owing to the high level of variation in the dataset, among other limitations.

Terrestrial plants and vertebrates account for the majority of costs, with plants accounting for 82.9% , and vertebrates accounting for 15.5%.

For terrestrial plants, the most costly taxa were serrated tussock ($322 million total reported costs up to 2022), blackberry ($305 million), ryegrass ($153 million), fleabane ($130 million), and barnyard grass ($119 million). The most costly terrestrial vertebrates were cats[1] ($2.291 billion), European rabbits ($443 million), wild dog ($441 million), feral pigs ($420 million), and red foxes ($393 million). The most costly terrestrial invertebrates were identified as the oat aphids ($47 million), blue oat mites ($42 million), lucerne fleas ($38 million), redlegged earth mites ($33 million), and cereal cyst nematodes ($31 million), while common carp ($30 million) was the only aquatic species for which species and/or genus specific cost estimates were found.

When grouping the impacted sectors we used: (1) Industry/agricultural losses to be those losses predominately attributed to production losses and control costs, (2) Research costs are research and innovation expenditure by industry representative bodies; (3) Health and public welfare costs are given by medical costs, as well as cost to community-based assets (e.g. indigenous communities/infrastructure, road crashes, etc.); (4) Environmental costs are estimates of the monetary value of damages to environmental assets/services, and the value of community/volunteer work on environmental programs; and (5) Mixed/Other. The most impacted sector is the first (indus-

[1]Noting this is largely potential health costs associated with domestic cats.

try/agricultural losses) incurring 92.2% of all reported losses.

The allocation of costs by sector is heavily focused on the private costs of invasive species in agricultural industries. This may be driven partially by publication and reporting biases. Environmental and ecosystem services impacts are one area where costs are likely to be under-reported, and we postulate a $7.113 billion monetary value of impact of invasive species on the environment between 1970 - 2022 and $0.322 billion in the 2022/2023 financial year.

Public expenditure is another area of costs missing from these estimates. This was specifically excluded from the rapid review, and instead estimated based on expenditure estimates obtained directly from relevant departments. The expenditure on management of invasive species from NSW government amounts to a total of $200.58 million.

Modelled projected costs from the reported costs (excluding the conjectures about the environmental damages and public expenditure) suggest costs reaching up to a mean of $6.10 billion for 2030.

The 2030 prediction (7 year simulation) for future invasives, when considering the worst case scenario of all 24 representative species of their corresponding functional groups established in and spread through NSW is $29.73 billion, which is five times the (non-public) amount predicted for 2030, for the current invasive species.

From the additional CEBRA Value model, we show that the damage caused by RIFA could be more than $60 billion over 30 years to Australia, or roughly $2.2 billion per year with the damage mostly in QLD and NSW. The cumulative and combined damage to agriculture, recreation, and tourism will exceed 1.5% of Australia's GDP and the unreported damage to the environment will be 1.3% of GDP. Combined, this is a cumulative damage of 2.8% of GDP measured in 2054, which is approximately half of the COVID shock in 2020-2021.

Human activities accelerate the spread of invasive pests through trade and travel, urbanisation, and increasing demand for agricultural products along with the increasing population. Advances in technology could assist us in pest management such as through genetic biocontrol or tracing invasion pathways.

Climate change is expected to influence biological invasions by modifying their establishment and spread rates, as well as their impacts. The greatest economic and environmental impacts associated with biological invasions in NSW for the next decades are likely to come from exotic threats, yet to establish within the country, but whose probability of being introduced into climatically suitable areas is increasing under climate change. Pathogens, viruses, and invertebrate plant pests can potentially have very high economic impacts, causing a large economic loss even after a single outbreak in agricultural land. For example, recent work by CEBRA indicates that an outbreak of oriental fruit fly along the east coast of Australia (covering Queensland and NSW) could result in $5.25 billion in average annual damages.

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A. Appendix: Species lists

Current or previously established species in NSW

Analysis of the costs of species that are currently or have previously established in NSW included any species for which there were private/non-public expenditure cost estimates that could be attributable to NSW. This included the following species and/or genus of invasive species[1]:

- Terrestrial plants:
  - serrated tussock (*Nassella trichotoma*)
  - blackberry (*Rubus fruticosus*)
  - ryegrass (*Lolium rigidum*)
  - fleabane (*Conyza* spp.)
  - barnyard grass (*Echinochloa crus-galli*)
  - wild oats (*Avena* spp.)
  - barley grass (*Hordeum* spp.)
  - melons (*Curcumis* spp.)
  - common heliotrope (*Heliotropium europaeum*)
  - lantana (*Lantana camara*)
  - silver grass (*Vulpia* spp.)
  - panic grass (*Panicum maximum*)
  - lippia/frog fruit (*Phyla* spp.)
  - Brassica weeds (*Brassica* spp.)
  - St John's wort (*Hypericum perforatum*)
  - Paterson's curse / salvation Jane (*Echium* spp.)
  - feathertop Rhodes grass (*Chloris virgata*)
  - sweet summer grass (*Brachiaria eruciformis*)
  - common sowthistle (*Sonchus oleraceus*)
  - scotch, stemless and Illyrian thistles (*Onopordum* spp.)
  - brome grass (*Bromus* spp.)
  - wild radish (*Raphanus raphanistrum*)
  - brown-top bent grass (*Agrostis capillaris*)
  - skeleton weed (*Chondrilla juncea*)
  - saffron thistle (*Carthamus lanatus*)
  - black bindweed (*Fallopia convolvulus*)
  - fireweed (*Senecio madagascariensis*)
  - mint weed (*Salvia reflexa*)
  - caltrop (*Tribulus terrestris*)
  - wild mustard (*Sisymbrium officinale*)
  - wireweed (*Polygonum aviculare*)
  - capeweed (*Arctotheca calendula*)
  - Xanthium burrs (*Xanthium* spp.)
  - spiny emex/docks (*Rumex* spp.)

[1]Note, some cost estimates were attributed to broader aggregated groupings of species, which are not included in this list.

  - phalaris (*Phalaris aquatica*)
  - parthenium (*Parthenium hysterophorus*)
  - gorse (*Ulex europaeus*)
  - goosefoots (*Chenopodium spp.*)
  - horehound (*Marrubium vulgare*)
  - Mexican poppy (*Argemone mexicana*)
  - giant rat's tail grass (*Sporobolus pyramidalis*)
  - parkinsonia (*Parkinsonia aculeata*)
  - onion weed (*Asphodelus fistulosus*)
  - prickly lettuce (*Lactuca serriola*)
  - deadnettle (*Lamium* spp.)
  - buffel grass (*Cenchrus ciliaris*)
  - mesquite (*Prosopis* spp.)
- Terrestrial vertebrates:
  - cat (*Felis catus*)
  - European rabbit (*Oryctolagus cuniculus*)
  - wild dog (*Canis lupus*)
  - pig (*Sus scrofa*)
  - red fox (*Vulpes vulpes*)
  - deer (*Cervus* spp.)
  - mouse (*Mus musculus*)
  - rat (*Rattus* spp.)
  - goat (*Capra hircus*)
  - camel (*Camelus dromedarius*)
  - horse/donkey (*Equus spp.*)
- Terrestrial invertebrates:
  - oat aphids (*Rhopalosiphum* spp.)
  - blue oat mite (*Penthaleus major*)
  - lucerne flea (*Dicyrtomina ornata*)
  - redlegged earth mite (*Halotydeus destructor*)
  - cereal cyst nematode (*Heterodera* spp.)
  - root lesion nematodes (*Pratylenchus* spp.)
  - sirex wood wasp (*Sirex noctilio*)
  - spotted alfalfa aphid (*Therioaphis trifolii*)
  - yellow fever mosquito (*Aedes aegypti*)
  - grape phylloxera (*Daktulosphaira vitifoliae*)
- Aquatic pests:
  - common carp (*Cyprinus carpio*)

Potential future invasive species

For use in the Value Model, a species or taxonomic group were selected to represent 24 functional groups of invasive pests. Each of the functional groups included in analysis, and their representative species/taxa are as follows:

- AGM (Asian gypsy moth, *Lymantria dispar asiatica*)
- Broadacre beetle (large grain borer, *Prostephanus truncatus*)
- Broadacre bug thrips mite (Russian wheat aphid, *Diuraphis noxia*)

- Broadacre mollusc (golden apple snail, *Pomacea canaliculata*)
- Broadacre weed (red witchweed, *Striga asiatica*)
- Forestry beetle (Asian long-horned beetle, *Anoplophora glabripennis*)
- Forestry nematode (pine wilt nematode, *Bursaphelenchus xylophilus*)
- Forestry termite (termites, infraorder Isoptera)
- Forestry weed (false indigo-bush, *Amorpha fruticosa*)
- Fruit fly (papaya fruit fly, *Toxotrypana curvicauda*)
- GAS (giant African snail, *Achatina fulica*)
- Horticulture beetle (Colorado potato beetle, *Leptinotarsa decemlineata*)
- Horticulture bug thrips mite (thrips, order Thysanoptera)
- Horticulture fly moth (false codling moth, *Cryptophlebia leucotreta*)
- Horticulture nematode (potato cyst nematode, *Globodera* spp.)
- Horticulture weed (generic *Cyperus* spp.)
- Khapra beetle (khapra beetle, *Trogoderma granarium*)
- Livestock bug thrips mite (varroa mite, *Varroa* spp.)
- Livestock fly moth (screw worm fly, *Cochliomyia hominivorax*)
- Non-agricultural bee wasp (generic *Hymenoptera* spp.)
- Non-agricultural fly moth (generic *Diptera* spp.)
- Non-agricultural vertebrate (black spined toad, *Duttaphrynus melanostictus*)
- Non-agricultural weed (Mexican feather grass, *Nassella tenuissima*)
- Tramp ant (RIFA, *Solenopsis invicta*)

B. Appendix: Current invasive costs - review data summary

Review records, including cost references bibliographic information, as well as raw and processed cost data is available via the Open Science Framework (also accessible via DOI: 10.17605/OSF.IO/TY7BF).

The aggregated cost data for NSW identified in the rapid review is shown in Figure B.1. Individual data points are total annual costs for each year (i.e. the sum of all individual cost estimates for that year). Horizontal bars mark the average average annual cost for 10-year intervals.

The full range of cost data is from 1952 - 2022. Only a single cost estimate is applicable to dates prior to 1970, and there is a clear surge in reporting of cost estimates from the 1970s on. Therefore analysis of these costs was limited to the 1970s onwards.

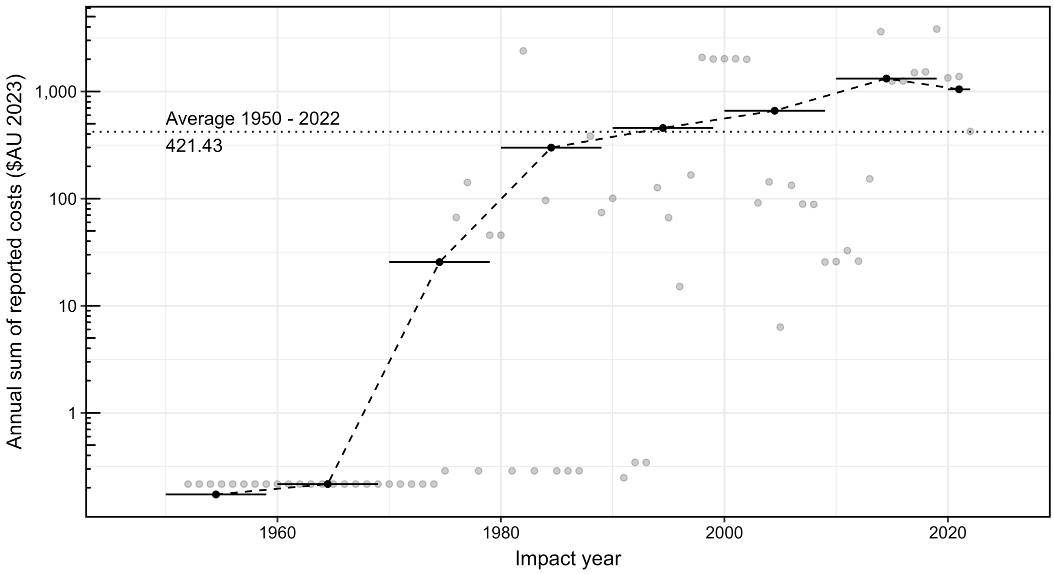

Figure B.1.: Aggregated total reported costs of established invasive species in NSW, for all non-public expenditure based costs (e.g. private control costs, production losses, health impacts and environmental costs). Shown are the annual total costs for each year (grey circles), the average annual cost per decade from 1950 to current (black circles with horizontal bars). The dashed line represents the average total cost per year over the full data period. Only costs that are reported in published or grey literature are included.

C. Appendix: Detailed public expenditure

The review of cost from NSW government is reported in four funding categories: Recurrent, programs, grants, and research.

C.1. Recurrent expenditure

Public land managers have a responsibility for the control of invasive species on the land they manage. For the purposes of this paper, public land management includes terrestrial protected areas, State forests, travelling stock reserves and other Crown land reserves. Together, it forms an estate of about 12.5 million hectares, or 15% of NSW.

There are also Western Land Leases, public land under long term lease which cover around 29 million hectares. These Western Land Leases are not included in this public land assessment as, their management is primarily funded by private expenditure consistent with the terms of the lease. All land is subject to invasive species risks. The extent to which these risks are managed on public land varies based on the responsible agency.

1. NSW National Parks and Wildlife Service (NPWS)

   A network of over 7 million hectares of protected land is managed by the NPWS. Management priority is the permanent conservation of natural and cultural values.

   Since 2018 NPWS feral animal and weed control activities have been guided by the relevant Regional Strategic Pest Animal and Weed Management Plans, the prioritisation framework in the 2012 NPWS Regional Pest Management Strategies, and the Zero Extinctions Threatened Species Framework.

   Under the Zero Extinctions Threatened Species Framework, feral animal and weed control actions in NSW national parks are prioritised to protect threatened species through the Saving Our Species program, the implementation of Conservation Action Plans for Assets of Intergenerational Significance, and the establishment of feral predator free areas. Therefore, there may be double counting between NPWS public land management, programs and grants.

   The 2022/2023 service delivery plan is reporting for NPWS feral animal and weed control programs across each of the eight NPWS operational branches, along with the Conservation Programs and Fire and Incident Operations branches, who provide significant support to feral animal control across NPWS.

   NPWS has annual state-wide service delivery commitments across each program area. State-wide feral animal and weed control metrics for NPWS in 2022/2023 include:

- 47,409 feral animals removed by aerial shooting, ground shooting, mustering, and trapping;
- 1,493 hours of aerial shooting;
- 30,484 km of aerial baiting;
- 18,403 ground baits laid;
- 304 mustering days;
- 199 ground shooting days;
- 57,436 hectares of weed control.

In response a request from the NRC, NPWS provided the following figures for the NPWS feral animal control and weed control programs for the financial year of 2022/2023.

Category	State Gov. funding	Aust. Gov. funding	Other sources	Total
Pest animal	$10,518,398	$1,440,351	$55,904	$12,014,652
Pest plant	$5,221,469	$1,892,409	$1,253,638	$8,367,516
Total	$15,739,867	$3,332,760	$1,309,542	$20,382,168

Table C.1.: NSW National Parks and Wildlife Service *operating* expenditure on feral animal and weed control programs in 2022/2023 financial year.

Importantly, only *operating* expenses are provided in Table C.1. The NPWS estimate 2022/2023 labour expenditure at $26.8 million. The estimate is calculated using the same proportions of labour and operating expenditure across all NPWS programs and is subject to the limitations and discussion outlined in this document.

The NRC understands a range of NPWS staff and contractors are involved in pest and weed management, including Rangers, Project Officers and Field Officers. Likewise, it is NRC understanding that Field Officers are engaged in a range of activities including – but not limited to - invasive species management. The figures are therefore likely to be an underestimate of actual effort.

NPWS also delivers training in invasive species management in partnership with the NSW DPI and LLS. For example, NPWS leads the NSW Feral Animal Shooting Aerial Team (FAAST) training program the annual expenditure has not been provided.

In summary, the estimation of the NPWS 2022/2023 annual expenditure totals $47.18 million comprised of $20.38 million operational and $26.80 million labour.

2. State Forests

   Over Forestry Corporation of NSW (FCNSW) manage 2 million hectares of State forests. The management objectives are the sustainable supply of timber products, protecting natural and cultural values and providing for sustainable recreational activities.

   FCNSW works with a range of partners and land managers to identify priority pests and weeds and conduct targeted control works at a coordinated landscape scale to maximise effectiveness.

Division & Activity	2018/19	2019/20	2020/21	2021/22	2022/23
Hardwood Forests Division					
Other weed treatment	$172,027	$293,888	$354,441	$456,006	$437,137
Wild dog and foxes control	$698,300	$816,455	$1,052,072	$873,061	$809,565
Softwood Plantations Division					
Noxious animal	$300,122	$240,440	$260,903	$99,782	$313,003
Noxious weed	$551,861	$510,357	$743,594	$595,317	$747,324
Post-establishment competition control	$730,685	$769,551	$2,688,479	$746,446	$1,557,844
Total	$2,452,995	$2,630,691	$5,099,489	$2,770,612	$3,864,873

Table C.2.: Expenditure from Hardwood Forests Division and Softwood Plantations Division on different types of management between 2018-2023 financial years.

In 2022/2023 FCNSW spent $1.25 million on invasive species management in the Hardwood Forests Division and $1.62 million in the Softwood Plantation Division amounting to a total of $3.87 million[1].

In addition to FCNSW expenditure, the DPI Forest Health Team manages two programs:

- Forest biosecurity surveillance: This focusses on points-of-entry for early detection of invading exotic pests and pathogens. Monitoring of traps and sentinel trees as well as stakeholder engagement of local councils etc. The program has been operating since 2014 and is part of national forest biosecurity surveillance strategy funded by Plant Health Australia (2018) through subscription income from the Commonwealth government, state and territory governments and plant-based industries totalling $120,000 annually.
- 2 Forest health surveillance & invasive species management: This involves an annual surveillance of the plantation estate mapping and monitoring pest spread and impact, pest and disease management advice and monitoring, training, and engagement in biosecurity. The program has been operating since 1996. It is funded $350,000 annually by FCNSW.

The expenditure on these programs total $470,000 which brings the state forest expenditure from $2.31 million to approximately $2.78 million.

3. Travelling Stock Reserves

There are currently more than 6,500 Travelling Stock Reserves (TSR) on Crown Land in NSW, covering an area of approximately 2 million hectares. Almost 1.5 million hectares, or 75% of the TSR network, is in the Western Division of NSW. Those TSRs that are covered under Western Lands Leases are excluded from this assessment as they are privately managed.

NSW Local Land Services cares, controls and manages about 500,000 hectares of TSR land, concentrated in the central and eastern divisions of the state. In 2022/23 the NSW Local Land Services spent $16.51 million on the management of TSRs up from $11.87 million the previous year (average $14.19 million). The

[1]Personal communication, FCNSW information, email from Chris Slade.

NSW LLS suggest that 30% of this average cost is spent on invasive species management which amounts to approximately $4.32 million annually[2].

4. Other Crown Land Reserves

   Crown reserves are public lands managed under the *Crown Land Management Act 2016* Management objectives are the public use and enjoyment of public land, as well as the protection of natural and cultural values.

   Over one million hectares of Crown reserves are either managed directly by the Department of Industry Planning, Housing, and Infrastructure – Crown Lands and Forestry, or indirectly by Crown land managers, including Community Boards, Trusts, Local Government, and others. When managed by other organisations (normally local governments), lease agreements require that Crown land managers are responsible for ensuring the reserves are managed appropriately, including invasive species control. This management of Crown reserves is supported by the Crown Reserves Improvement Fund (CRIF).

   The Crown Reserves Improvement Fund (CRIF) serves as the primary funding mechanism for the management of Crown Reserves, despite operating as a grant system. The CRIF is a self-sustaining program supported by income generated from loan repayments and interest, leases, and licences on Crown land, as well as levies from the operation of coastal Crown caravan parks. The CRIF covers all improvements to Crown Reserves. This may include invasive species management but also activities such as repairs to buildings, sporting facilities, etc.

   The CRIF funding process is competitive. The total funding of project applications normally exceeds available funding by four to five times. In the 2023-24 funding round, around $16 million is available to the highest priority projects in grants ($14 million) and loans ($2 million). If a crown reserve manager does not receive a CRIF grant, then invasive species management is either not undertaken or needs to be funded from other sources.

   In 2022-2023, $16.5 million was allocated to Crown Reserve improvements through CRIF. Of this, just over $2.8 million was allocated for invasive species management10. Additionally, just over $1 million was expended from the Crown Lands operational budget on invasive species projects on directly managed lands, totalling $3.8 million.

5. Summary

   The analysis found that public recurrent expenditure on invasive species management totalled $58.08 million. This expenditure varied across different public land categories as illustrated in Table C.3.

C.2. Programs

1. DCCEEW Programs

   The *Saving our Species (SoS)* program strategically identifies the most important actions needed to ensure the survival of threatened species and ecological communities in the wild in NSW. In 2022/2023 SoS implemented projects to reduce

[2]Local Land Service expenditure data provided by Adam Hinkley

Land type	2022/23 Expenditure
NSW National Parks and Wildlife Service	$47.18 M
State Forest	$2.78 M
Travelling Stock	$4.32 M
Crown Reserves	$3.80 M
Total	$58.08 M

Table C.3.: Recurrent expenditure on invasive species management in different land types from NSW government in 2022/2023 financial year.

threats and monitor outcomes for more than 350 threatened species and ecological communities.

On 1 July 2021, SoS secured an additional $75 million to continue the program for the five years from 2021 to 2026 (Environment and Heritage, 2022) ($15 million annually). In 2022/2023 there were 1316 SoS actions planned to be undertaken involving Invasive Species management, of which over 90% (1193) were implemented. $3,809,638 of the SoS budget was allocated to implement those actions including both operational and labour costs.

2. Department of Primary Industry (DPI) Programs

    a) NSW Weeds Action Program The NSW Weeds Action Program is the primary weed management program in NSW. The NSW Government subsidises the weed management programs operated by local control authorities. Local control authorities are local governments or regional organisations of local governments. In 2022/23 the NSW Department of Primary Industry provided $12.8 million to the program. This investment is more than doubled by the matching contributions of Local Control Authorities and LLS as indicated in Figure C.1 [3] Their contribution totals an additional $22.2 million. Total annual WAP expenditure in 2022/23 was approximately $35 million.

       The program has a focus on early identification of incursions including the resourcing of property inspections. Following a review of those regions who have submitted their reports it can be shown that most of the program funding (over 75%) is being allocated to early detection and response outcomes.

    b) Invasive Species Biosecurity Policy and Programs The NSW DPI leads invasive species management. This leadership includes the development of policies and plans and the co-ordination of some statewide programs. Performing these functions in 2022/23 the NSW DPI expended $3,365,236 for pest plants and $227,350 for vertebrate pests with an approximate total of $3.59 million [4].

    c) Incursion Management DPI leads the management of incursions of new invasive species. The DPI indicated that their 2022/23 expenditure on incursion management was $152,134 for vertebrates and $323,667 for inver-

[3] NSW DPI Pete Turner personal communicatin.
[4] NSW DPI Quentin Hart personal communicatin.

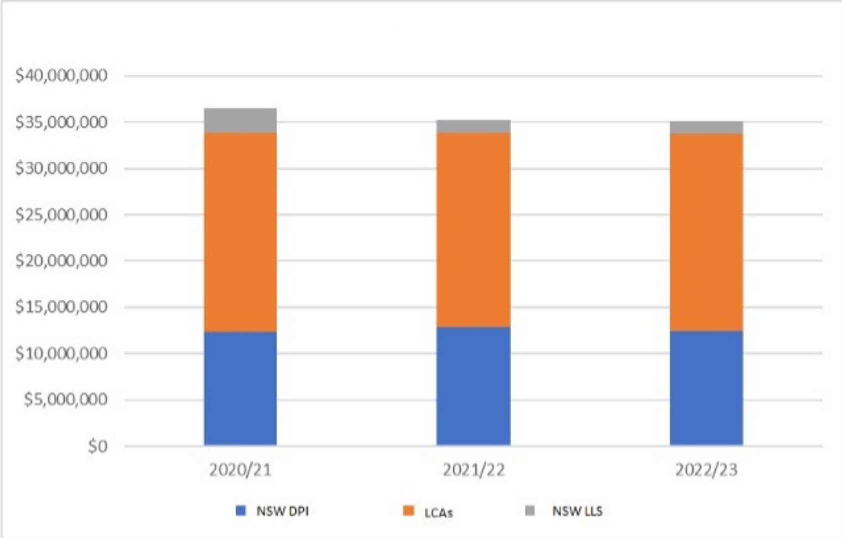

Figure C.1.: Contributions to the NSW Weeds Action Program

tebrates, totalling $480,000[5]. The Weeds Management Program funds the management of new incursions of pest plants and it is accounted for in that section.

d) Training The NSW DPI delivers training to land managers and authorised officers to facilitate the consistent implementation of policies and programs. This training is delivered for both pest plants and vertebrate pest animals. The pest plant training is incorporated into the Weeds Action Program and accounted for in that section. The expenditure on vertebrate pest animal management training in 2022-23 was $111,000[6].

e) Compliance The DPI plays a leading role in risk-based, outcome-focused audits, inspections, and investigations to improve industry behaviour with biosecurity, food safety and animal welfare requirements. These activities are performed by the Biosecurity and Food Safety Unit of DPI rather than the Invasive Species Unit. Compliance activities span a range of legislation and focuses primarily on primary production. In respect of invasive species their focus is on invertebrates, cattle tick, varroa mite and invasive ants. They also undertake investigation regarding the trade and keeping of illegally imported and potentially invasive pets.

   In 2022/23 Border Compliance Operations who are responsible for administering the Cattle Tick program, had 39.9 FTE with a labour cost of $3.1 million and an operating expenditure of $1.5 million making a total of $4.60 million.

   Compliance officers from other parts of Compliance & Integrity Systems supported both the Gypsy Moth (555 hours) with 6 staff and Varroa Mite (14,635 hours) investigations with 51 staff. These costs are accounted for in the DPI incursion management totals above. There was an additional non-indigenous animals' compliance investigations and administration (150

[5]NSW DPI Quentin Hart personal communicatin.
[6]NSW DPI Quentin Hart personal communicatin.

hours) with 4 staff at a cost of $20,000[7].

f) Parthenium Weed

NSW spends an average of $250,000 per year (2020/21-2022/23) to keep Parthenium weed from establishing in NSW. This investment funds inspections of machinery at the border and early response activities. $140K of this investment is provided by an NSW WAP project. However the $250,000 does not include program coordination nor the property inspections to detect incursions into NSW. Including these costs returns the estimate to $250,000.

g) NSW Local Land Services Programs

The NSW Local Land Services is the primary delivery agency for invasive species management. The NSW LLS manages a range of invasive species management programs for the NSW Government. The NSW LLS attracts funding from a range of sources including the Australian and NSW Governments, NSW Environmental Trust, from LLS rate payers and the Pest Animal Levy.

The NSW LLS has significantly improved its expenditure reporting data processes. Data is collected in alignment with its Strategic Plan and NSW State Outcomes. The total expenditure includes operating and labour expenditure, grants and subsidies, depreciation and amortisation and the allocation of the organisational inputs required to deliver programs[8].

Category	2022/2023
Pest animals	$48,565,767
Pest plants	$6,262,288*
Total	$54,828,055

Table C.4.: Expenditure from NSW Local Land Services (LLS) on pest animals and plants for the financial year of 2022/2023. *Note that the total LLS expenditure for pest plants is $19,062,288, which includes the $12.8 million DPI Weeds Action Program (WAP) funding accounted for in the WAP section. Therefore, the LLS contribution to pest plants is adjusted to $6.26M in the summary table here.

h) Wild Dog Fence

The NSW government has obligations under national agreements to contribute to the cost of eradicating invasive species of national significance. Red Imported Fire Ant is a nationally significant pest managed under the National Environmental Biosecurity Response Agreement (NEBRA). This ant is the target of a $596 million national cost-shared eradication program. The NSW annual contribution to the program was $16 million in 2022/2023 (The Border Fence Maintenance Board, 2022).

i) National Cost Shares

The NSW government has obligations under national agreements to contribute to the cost of eradicating invasive species of national significance.

[7] NSW DPI Manager Regulatory Business Programs, Adam King personal communicatin.

[8] Local Land Service expenditure expenditure Data

Red Imported Fire Ant is a nationally significant pest managed under the National Environmental Biosecurity Response Agreement (NEBRA). This ant is the target of a $596 million national cost-shared eradication program. The NSW annual contribution to the program was $16 million in 2022/2023[9].

NSW Government also contributes to two National Cost Shares for pest plants. In 2022/23 NSW contributed $226,173 for the four Tropical Weeds cost share and $41,995 for the Red Witchweed cost share. These payments are included in the DPI $12.80 million WAP funding so are not accounted for here.

3. Summary
   Invasive species management programs accounts for the largest proportion of public expenditure on invasive species management. Therefore, improvements in program design and management are likely to generate the greatest returns. Independent program evaluation consistent with NSW Treasury Evaluation Policy and Guidelines (NSW Treasury, 2022) is central to improving effectiveness.

   Programs expenditure amounts to a total of $119.13 million as shown in Table C.5.

Program	Expenditure
Saving our Species	$3.80 M
Weeds Action Program	$35.00 M
Invasive Species Policy/Programs	$3.60 M
Incursion Management	$0.48 M
Training	$0.11 M
DPI Compliance	$4.60 M
Parthenium Weed	$0.25 M
Local Land Services - Pest Animals	$48.60 M
Local Land Services - Pest Plants	$6.26 M
Wild Dog Fence	$0.43 M
National Cost Share	$16.00 M
Total	$119.13 M

Table C.5.: Summary of estimated public expenditure from the NSW government on invasive species management through different programs in the financial year 2022/2023.

C.3. Grants

Grants are a funding mechanism where resources are provided to a person or organisation to support a specific, connected set of activities, with a beginning and an end, explicit objectives, and a predetermined cost. They are generally competitive therefore more suitable to the resourcing of discrete projects rather than ongoing management obligations.

[9]NSW DPI Quentin Hart, personal communication.

The NSW Government operates several grant programs that support invasive species management. The Crown Reserves Improvement Program is an example already discussed. The NSW Environmental Trust deliver the largest grant programs including invasive species management. Grants fund projects that operate over several years.

There is considerable inter annual variability in grant funded project expenditure over the duration of the project. It is beyond the scope of this rapid analysis to interrogate the annual expenditure of every grant funded project to ascertain the actual expenditure in the 2022/2023 financial year. The analysis has relied predominately on publicly available information, normally grant amount and duration. Therefore to determine an average annual expenditure the analysis has divided the grant amount by the scheduled duration. The analysis has used the average annual expenditure as the 2022/2023 expenditure.

1. Major projects program

   The greatest Environmental Trust investment in invasive species management comes through the Major Projects Program. Projects funded under this program are not contestable and designed to tackle large-scale and/or complex issues. The Trust identifies and designs these projects through consultation with key stakeholders.

   The costs for six major projects on different invasive species are listed below.

   a) Hawkweed eradication project
   The NSW Environmental Trust allocated $7.2 million over eight years, approximately $0.91 million annually. This investment is matched by a $5.2 million contributions from other agencies including $3.7 million from NSW National Parks and Wildlife Service. Total project funding is approximately $2.2 million annually. The funding for this project is included in the NPWS and WAP expenditure and therefore is not accounted for here.

   b) Cross tenure feral deer project
   The NSW Environmental Trust allocated $9.2 million over eight years, approximately $1.15 million annually. This investment is complimented by a further $7.4 million from other sources over the eight years ($0.93 million annually). As above the funding for this project is included in the NPWS expenditure and therefore not accounted for here.

   c) NPWS feral predator free area program
   Otherwise known as the Rewilding Initiative. In 2020 the NSW Environmental Trust invested $20.3 million over 10 years from 2021-31 ($2 million annually).

      Establishing four new feral predator-free areas paves the way to return wildlife lost from national parks due to feral cats and foxes. This commitment is matched by an in-kind contribution by NPWS to establish and manage the predator free areas. NPWS estimates this expenditure at $25 million expenditure over 20 years. This annual expenditure is accounted for previously and not included here.

   d) Beyond Fencing Project
   The NSW Environmental Trust allocated UNSW a grant of $516,223 for 10 years 2020 – 2030 (≈ $50,000 annually). This project is conducted in Sturt

National Park in partnership with the NPWS. This project aims to use an innovative two-pronged approach through improving control of feral predators and increasing prey awareness to these predators to enable these species to live beyond fences and co-exist with feral predators.

e) Keeping Cats Safe at Home (RSPCA)
The NSW Environmental Trust allocated RSPCA a grant of $2,547,393 for 2020 –2024 ($0.64 million annually). This Project will develop and implement a behaviour change strategy in 11 local government areas to reduce domestic cat predation on wildlife by encouraging responsible cat ownership, especially increased containment of owned pet cats.

f) Saving Our Species Partnership Grants Program
This program includes pest plant and animal management as well as revegetation. It amounts to $10 million over 10 years ($1 million annually). Assuming 50% is spent on invasive species management, we could count $0.5 million annually (NSW Environmental Trust, 2023).

g) Developing Strategies for Effective Feral Cat Management
The NSW Environmental Trust allocated University of New England a grant of $14,683,125 over 6 years (≈ $2.48 million annually)to address the widespread, recognised need for feral cat control by developing effective, integrated management strategies for feral cats in NSW environments.

2. NSW Environmental Trust - Contestable Grants Program
The Trust provides funding through a range of contestable grant programs and administers both long-standing annual programs and one-off, issue-specific programs.

a) Saving Our Species Partnership Grants Program
The NSW Environmental Trust allocated $10 million over 10 years ($1 million annually) to Savings our Species Partnerships. The program includes pest plant and animal management as well as revegetation projects. The contribution of projects to invasive species management varies. Some such as Turtles Forever: Securing the NSW population of Bell's Turtle focusses on egg predation by invasive species. Others focus on data collection and make no contribution. A review of project summaries (Environment and Heritage, 2024c) suggest approximately 50% of the funds are expended on invasive species management totalling approximately $0.5 million annually (NSW Environmental Trust, 2023).

b) Saving our Species Contestable Grants Program
Aligned with the NSW Saving our Species program the NSW Environmental Trust allocated $8.2 million running over 7.5 years until 2025. Project activities includes education training and revegetation as well as invasive species management. A review of project summaries (Environment and Heritage, 2024c) suggest that approximately 50% of the funds are expended on invasive species management, totalling $1 million annually.

c) Bush Connect Program
This program delivers on-ground and community capacity-building activities within the Great Eastern Ranges corridor. The NSW Environmental

Trust allocated $8 million running over 10 years ($0.8 million annually). A review of project summaries (Environment and Heritage, 2024a) suggest that approximately 50% of the funds are expended on invasive species management, so it is estimated the approximate expenditure on invasive species management is $0.4 million annually.

d) Restoration and Rehabilitation Grant Program
Restoration and Rehabilitation Grant Program Projects extend from two to four years. Eligible activities include bush regeneration and other pest plant and animal management practices. However, eligible activities also include community development, signage, fire, etc. So, it is difficult to ascertain the proportion of the $4 million annually that is spent on invasive species management. A review of a sample of successful projects (Environment and Heritage, 2024b) suggests that 50% of the funds are expended on invasive species management, so it is estimated that approximately $2 million annually is spent.

3. Summary
Grants are a considerable proportion of the total public expenditure on invasive species management. The extent to which grants are incorporated into the operation expenditure of agencies indicates both that the estimate may be low and the importance of grants to operational effectiveness. The NSW Government is strengthening the effectiveness of grants through the passing of the Government Sector Finance Amendment (Grants) Bill 2023. The changes the bill introduces may influence the current invasive species management resource allocation processes and provide an opportunity for reform. The grant expenditure amounts to a total of $9.07 million as shown in Table C.6.

Grant scheme	Expenditure
Hawkweed eradication project	–
Cross tenure feral deer project	–
NPWS feral predator free area program	$2.00 M
Beyond Fencing Project	$0.05 M
Keeping Cats Safe at Home (RSPCA)	$0.64 M
Developing Strategies for Effective Feral Cat Management	$2.48 M
Saving Our Species Partnership Grants Program	$0.50 M
Saving our Species Contestable Grants Program	$1.00 M
Bush Connect Program	$0.40 M
Restoration and Rehabilitation Grant Program	$2.0 M
Total	$9.07 M

Table C.6.: Expenditure summary of grants from NSW government on invasive species management in the financial year 2022/2023. Expenditure of Hawkweed eradication project and Cross tenure feral deer project are already accounted for in NPWS program expenditure, so not included in the total expenditure here.

C.4. Research

Improving the knowledge base supporting invasive species management increases effectiveness and it is an important investment. Advances in sensor technology and information management are revolutionising invasive species management research by providing timely information to support evidence-based decision-making. Robust research is indispensable for developing and adopting policies and practices that ensure the long-term effectiveness of invasive species management investment.

NSW invasive species research is primarily funded by the NSW Departments of Primary Industry and Climate Change, Energy, Environment and Water. Research funding is also provided through the NSW Environmental Trust to NSW Government agencies and to other research institutions.

1. The NSW Department of Primary Industry

   Total expenditure by the NSW DPI Vertebrate Pest Research Unit for 2022/2023 was $9,453,952[10] including contributions from research collaborators including the NSW Environmental Trust; Centre for Invasive Species Solutions; Commonwealth Department of Agriculture; NSW Local Land Services; the Game Licensing Unit; Saving our Species and National Parks and Wildlife Service and Commonwealth Scientific and Industrial Research Organisation.

   Total expenditure by the NSW DPI Weeds Research Unit for 2022/2023 was $3,312,242[11], including contributions from collaborators including NSW Environmental Trust, Centre for Invasive Species Solutions, Australian Research Council (ARC), Australian Wool Innovation (AWI), Australian Centre for International Agricultural Research, Cotton Research and Development Corporation, CSIRO Australia, Department of Agriculture and Water Resources, Environmental Trust, Grains Research and Development Corporation, Local Land Services, Meat and Livestock Australia, National Heritage Fund, Australian Greenhouse Office, Rural Industries Research and Development Corporation.

2. DCCEEW Saving our Species (SOS)

   The SOS program also funds research projects including those to inform better management of feral cats and deer as well as exotic vines and scramblers. Other projects address priority knowledge gaps to inform improved management and conservation of threatened species. This research is identified as actions under the SOS programs and is accounted for in the Grant section 2b.

3. NSW Environmental Trust – Research Program

   The Environmental Research program provides funding for applied research in priority environmental themes to help address contemporary environmental problems in New South Wales. Eligible applicants include Universities, NSW government agencies, Local Government, community, and Aboriginal groups. Research programs operate over several years.

4. Summary

[10] NSW DPI Quentin Hart personal communication.
[11] NSW DPI Quentin Hart personal communication.

Invasive species management research is critical to ensuring effectiveness. This is particularly so as new technologies provide opportunities to maximise the returns on investment. Ensuring that research is targeted, and that the knowledge generated is translated into policy and practice is critical.

Reseach	Expenditure
DPI Vertebrate Pest Research	$9.43 M
DPI Weeds Research	$3.31 M
DECCWW SOS Research	(Accounted for in program section)
Total	$12.74 M

Table C.7.: Expenditure summary on research from NSW government on invasive species management in the financial year 2022/2023.

C.5. Summary

The expenditure on management of invasive species from NSW government amounts to a total of $199.02 million. The breakdown of this expenditure is provided in Table C.8. This investment is delivered through complex arrangements with a variety of sources and recipients. The processes for allocating resources and measuring the return on investment are similarly complex. A review of the process for allocating public resources to invasive species management may generate the efficiencies required to address the projected increase in invasive species risks.

Funding category	Expenditure
Recurrent expenditure	$59.64 M
Programs	$119.13 M
Grants	$9.07 M
Research	$12.74 M
Total	$200.58 M

Table C.8.: Expenditure summary on management of invasive species from NSW government in 2022/2023 financial year.

Given the scale of the issue and the need for informed policy, data on expenditure on invasive species management in NSW is surprisingly difficult to obtain. Even though the total annual expenditure is significant, a question remains: is this expenditure proportionate to the scale of current and future risks?

What is apparent is that the allocation of resources is extremely fragmented. There is limited evidence that resource allocation is based on objective analysis of risk, rates of return, or on how investment could contribute to an overall improvement of the functioning of the system.

Some evidence also suggests that the funding mechanisms employed are not always suited to the management activities they resource, for example, the use of short-term grants to fund ongoing land management responsibilities.

D. Appendix: 2030 future invasive species – detailed damages

The value model uses repeated simulations to estimate, mean, median, and best/worst case scenarios for impacts/damages. The best case scenario may be represented by a very low percentile of the distribution of damages, and the worst case scenario, by a very large percentile of the damages distribution. The 2.5th, and the 97.5th percentiles are often used to represent the 95% credible/prediction interval around a median (i.e. the 50th percentile). Figures D.1 and D.2 show the best case and the worst case scenario, respectively.

The median estimates of damage cost (billions $) of the 24 functional groups, in each of the 11 National Regional Management (NRM) regions in NSW, 7 years after invasion are given in Table D.1

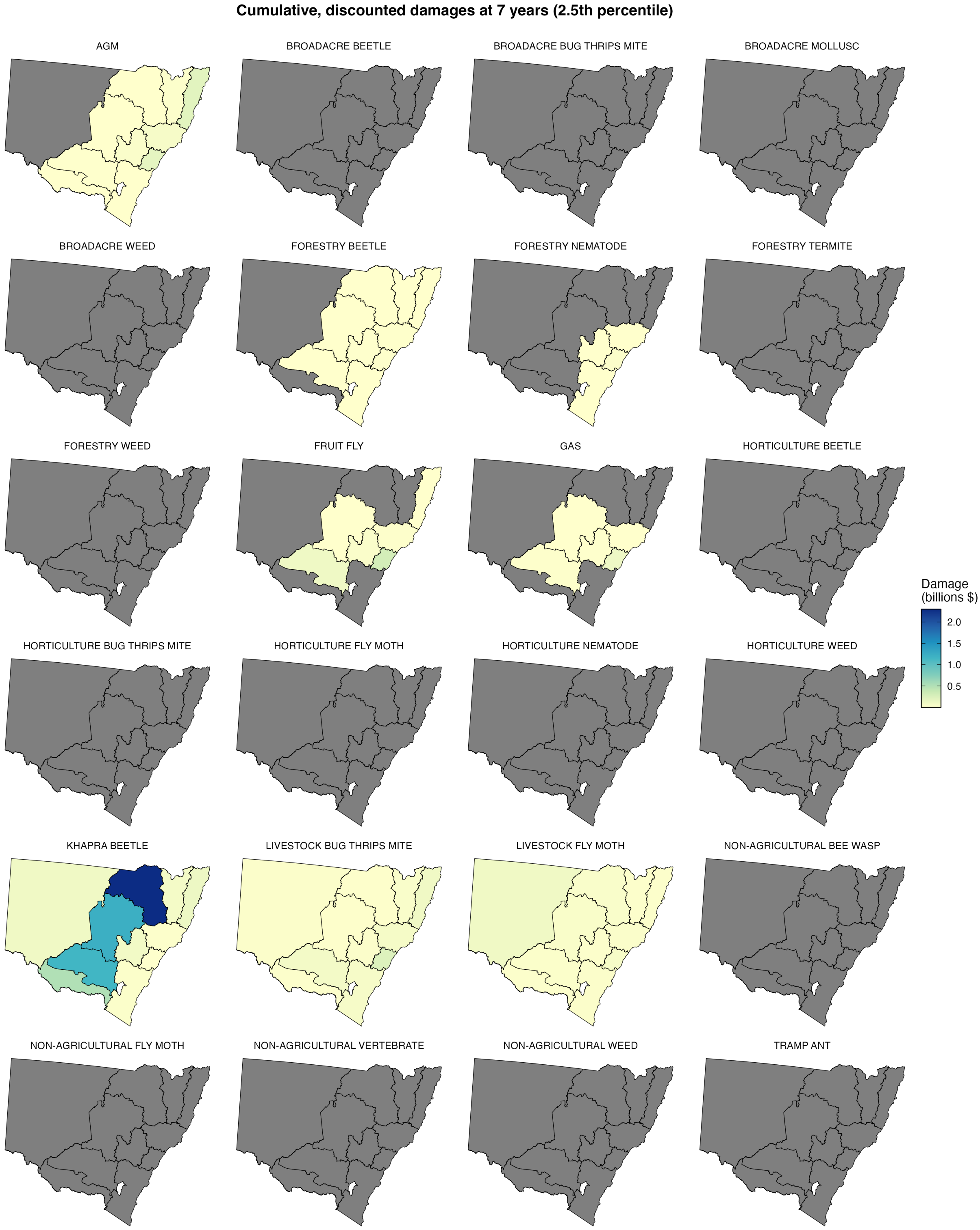

Figure D.1.: The 2.5th percentile the of damage cost distribution (billions $) of the 24 functional groups, in each of the 11 National Regional Management (NRM) regions in NSW, 7 years after invasion.

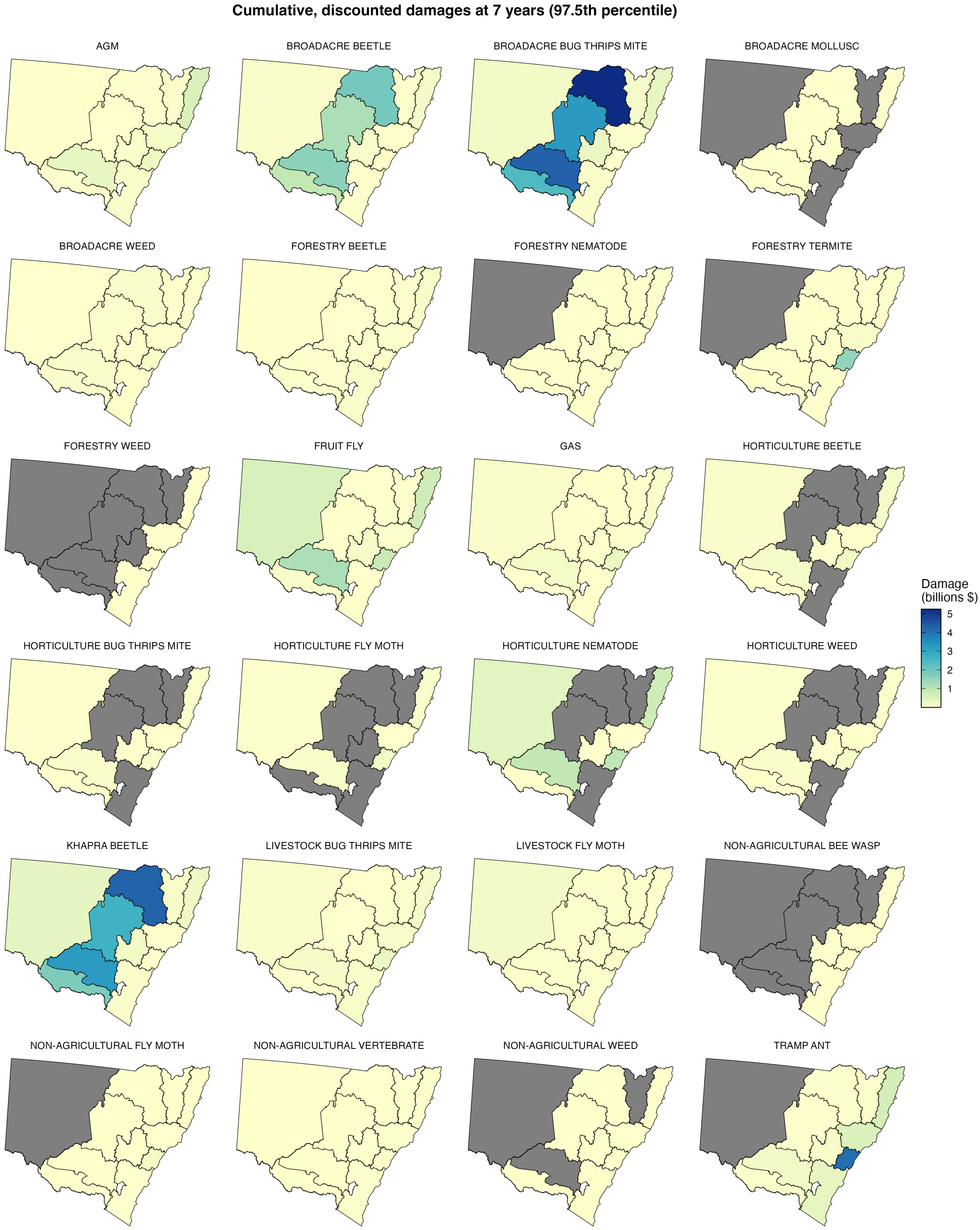

Figure D.2.: The 97.5th percentile the of damage cost distribution (billions $) of the 24 functional groups, in each of the 11 National Regional Management (NRM) regions in NSW, 7 years after invasion.

	Functional groups	1010	1020	1030	1040	1050	1060	1070	1080	1090	1100	1110
1	AGM	0.058	0.006	0.267	0.101	0.005	0.328	0.011	0.045	0.083	0.004	0.000
2	Broadacre beetle	0.076	0.488	0.000	0.008	0.330	0.001	0.309	0.009	1.023	0.011	0.017
3	Broadacre bug thrips mite	0.201	1.381	0.000	0.022	0.943	0.003	1.045	0.027	2.799	0.030	0.051
4	Broadacre mollusc	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	Broadacre weed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	Forestry beetle	0.019	0.003	0.020	0.023	0.008	0.090	0.004	0.022	0.005	0.016	0.000
7	Forestry nematode	0.002	0.000	0.074	0.008	0.000	0.000	0.000	0.000	0.000	0.002	0.000
8	Forestry termite	0.000	0.000	1.218	0.022	0.000	0.000	0.000	0.000	0.000	0.009	0.000
9	Forestry weed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	Fruit fly	0.088	0.010	0.499	0.034	0.073	0.206	0.001	0.002	0.836	0.002	0.266
11	GAS	0.012	0.001	0.192	0.005	0.010	0.028	0.000	0.000	0.114	0.000	0.037
12	Horticulture beetle	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	Horticulture bug thrips mite	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	Horticulture fly moth	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	Horticulture nematode	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	Horticulture weed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	Khapra beetle	0.188	2.372	0.011	0.031	1.453	0.162	3.465	0.099	2.999	0.073	0.341
18	Livestock bug thrips mite	0.037	0.013	0.294	0.083	0.027	0.126	0.014	0.048	0.096	0.086	0.041
19	Livestock fly moth	0.027	0.047	0.074	0.043	0.027	0.028	0.047	0.027	0.033	0.043	0.135
20	Non-agricultural bee wasp	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	Non-agricultural fly moth	0.000	0.000	0.150	0.003	0.000	0.000	0.000	0.000	0.000	0.003	0.000
22	Non-agricultural vertebrate	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	Non-agricultural weed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	Tramp ant	0.014	0.000	3.234	0.030	0.000	0.000	0.000	0.000	0.000	0.049	0.000

Table D.1.: Estimate of damage cost (billions $) of the 24 functional groups, in each of the 11 National Regional Management (NRM) regions in NSW, 7 years after invasion.