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Cost benefit analysis of a mission to discover and document Australia's species

Prepared for the Australian Academy of Science

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Deloitte Access Economics

Rapid cost benefit analysis of a mission
to discover and document all remaining species in Australia in a generation

Every **$1 spent** on Taxonomy Australia's mission *could result in* **benefits** ranging from **$4 to $35** to Australia

Biosecurity diagnostics

$465 million to $660 million

Genuine threats: *Cost of delay* x *Frequency of delay* **+** **Speculative threats**: *Cost of delay* x *Frequency of delay*

Reduced frequency of genuine threats to biosecurity from one in five years to one in 10 years results in benefits of **$435 million** in avoided costs to society. Reduced frequency to 15 years results in **$617 million** in avoided costs to producers and consumers.

Reduced frequency of proving the absence of a suspected threat from one in every five years to one in 10 years results in benefits of **$31 million** in avoided costs to society. Reduced frequency to 15 years results in **$43 million** in avoided costs to producers and consumers.

Agricultural research & development

$49 million to $287 million

Value of hybridising crops **X** **Acceleration rate**

Targeted taxonomic discovery could accelerate the R&D process to hybridise crops with wild crop relatives by between two and 10 years. Bringing forward benefits valued at $41 million per annum results in net benefits ranging from **$49 million** to **$287 million.**

Benefits

Total benefits range from **$3.7 billion** to **$28.9 billion**

Total costs are estimated at **$824 million**

25 years

Benefits

Biodiscovery for human health

$3 billion to $27 billion

Precommercial value: *Value of species samples* **+** **Market value**[a]: *Value of medicines derived from bioactive samples* **/** **Health benefits**: *Value of medicines derived from bioactive samples*

The research value of increased sampled species for biodiscovery is **$123 million.**

The value of health benefits enabled by more effective targeting of bioactive samples for biodiscovery ranges from **$3 billion** to **$27 billion.**

The market value of natural compound-based drugs and medicines enabled by more effective targeting of bioactive samples for biodiscovery ranges from **$300 million** to **2.9 billion.**

Biodiversity conservation

$74 million to $372 million

Number of unknown threatened species **X** **Rate of successful species conservation** **X** **Value of species conservation to Australians**

A 10% improvement in taxonomic knowledge could improve conservationists' ability to manage threats and focus effort, reducing the number of species considered threatened between 1% and 5%. Biodiversity conservation benefits, measured as the number of no longer threatened species valued by Australians' willingness to pay for conservation, ranges from **$74 million** to **$372 million.**

Costs

- **$33 million** Funding for national taxonomy innovation
- **$31 million** Funding for national taxonomic research infrastructure
- **$102 million** Increasing the National Taxonomy Research Grants Program (NTRGP)
- **$73 million** Doubling the national taxonomy workforce
- **$124 million** Funding for a national sequencing, bioinformatics and diagnostics facility
- **$441 million** Funding a national field campaign
- **$49 million** Enhanced management and delivery of taxonomy products and services

(a) Market value is excluded from the total benefit calculation to avoid double counting

Note: This CBA includes only selected benefits in the biosecurity, biodiscovery, agricultural R&D and conservation sectors and do not capture all benefits from increased taxonomic knowledge. These benefit streams are constructed as hypothetical scenarios based on assumptions and inputs obtained during stakeholder consultations. Costs were contributed by Taxonomy Australia. Present value estimates are calculated over a 25 year period and discounted at 4%.

Contents

Glossary

Acronym	Full name
AAS	Australian Academy of Science
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ACIAR	Australian Centre for International Agricultural Research
CBA	Cost benefit analysis
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DCF	Discounted Cash Flow
EPBC Act	Environmental Protection and Biodiversity Conservation Act
EPPRD	Emergency Plant Pest Response Deed
GRIDD	Griffith Institute for Drug Discovery
IPPC	International Plant Protection Convention
R&D	Research and Development
PV	Present Value
NEBRA	National Environmental Biosecurity Response Agreement
NPV	Net Present Value
STEM	Science, Technology, Engineering and Mathematics
WTO	World Trade Organisation

Part 1:
Summary Report

Executive summary

Australia is home to an estimated half a million species. The science of describing, documenting, naming and classifying each of these living species is the work of taxonomy. This work is vital to our understanding of biodiversity and life on earth. Taxonomists can be thought of as 'mapmakers' – they create the 'map' of biodiversity that other people use to navigate the tremendous complexity of nature. However, the vast majority of Australian species have not yet been discovered. An estimated 420,000 taxa, or 70% of species thought to exist on our megadiverse continent, remain unknown.

The taxonomy sector, through Taxonomy Australia, is planning a mission to discover and document all remaining species in Australia in a generation.

Achieving this ambitious goal could unlock invaluable benefits for society and the environment. As a foundational science, taxonomy enables and facilitates advances in many other scientific fields, including ecology, genetics, geology, earth and climate sciences, oceanography, medicine, ethnobiology, agriculture, and environmental and conservation sciences. A complete taxonomic understanding of Australia's species would lead to increased skills and jobs across a wide cross-section of Australia's STEM workforce. More fundamentally, protecting, maintaining and enhancing the ecological and biodiversity assets on which human economies and wellbeing depend is vital in a finite world. Taxonomic discovery over the next generation will therefore play an important role in securing Australia's future prosperity. This mission has in its sights the discovery and documentation of all remaining Australian species: as vertebrates and vascular plants are already well documented, the focus will largely be on invertebrates, fungi and microorganisms.

Deloitte Access Economics has been engaged by Taxonomy Australia to conduct a rapid cost-benefit analysis (CBA) of this mission. Four key benefit streams have been selected for quantification in this CBA, reflecting benefits enabled by greater taxonomic knowledge in the sectors of biosecurity, biodiscovery, agricultural R&D and biodiversity conservation. The benefit categories were selected from examples given in the Australian Academy of Science's Decadal Plan for taxonomy and biosystematics, and the modelling approach refined with input from end users of taxonomy in these four sectors. This does not capture all potential benefits or avoided costs from improved taxonomic knowledge; many environmental and economic areas beyond these four categories have not been addressed in this report and should be considered in a further stage of work. Further, this rapid CBA seeks to value only the potential marginal contribution of Taxonomy Australia's mission, calibrated to a static base case that does not represent dynamic uncertainties of the future.

This rapid CBA finds that the **returns to society from only four identified benefits could be four to 35 times greater than the investment.** As shown in Table 1.1, estimated benefits to these four sectors range from $3.7 billion to $28.9 billion over a 25 year period through to 2045 in present value (PV) terms. A more comprehensive CBA can refine these estimates and may be able to identify other benefit streams beyond these four, in tourism, human and animal health, biomimicry, environmental monitoring and other sectors. To implement the mission, identified funding needs include investing in early career researchers, innovation technologies, and a national facility for sequencing and diagnostics. Many of these upfront investments are intended to create long term operational efficiencies in a sector that engages in many disparate and dispersed activities, bringing about a step-change in the rate of species discovery. All cost estimates, including key input assumptions and the proposed investment mechanisms, have been provided by Taxonomy Australia. The estimated cost of investment across seven proposed funding mechanisms is estimated to be $824 million over 25 years.

Table 1.1: Costs and benefits of the discovery and documentation of all remaining Australian species in a generation

	PV
Costs	$824 million
Benefits	Ranging from $3.7 billion to $28.9 billion

Source: Deloitte Access Economics. Results are calculated using a 4% discount rate over a 25-year time horizon from 2020 to 2045.

For this preliminary analysis, the range of identified benefits covers potential impacts in the following four sectors:

- **Biosecurity:** the benefits of reduced frequency of costly delays in identifying genuine and non-genuine threats range from $465 million to $660 million. Genuine threats are exotic invasive species incursions that threaten Australia's biosecurity, native species and environment. Non-genuine threats are suspected detections that are later confirmed to pose no or low risk, for example native species lookalikes.
- **Biodiscovery:** the benefits of more cost-effective and strategic testing of samples for drug discovery amount to $123 million in the research phase of the pharmaceutical and medical biodiscovery process. Subsequent health benefits range from $3 billion to $27 billion.

- **Agricultural R&D:** the benefits of accelerated research into wild relatives of major commercial crops range from $49 million to $287 million.
- **Biodiversity conservation:** the benefits of improved conservation outcomes such as increased species resilience is estimated to be between $74 million and $372 million.

These benefits will likely continue to accrue beyond 2045, and exclude many types of unquantifiable benefits, including those that are enabled by taxonomic research in more indirect ways. This analysis indicates clear benefits from the discovery and documentation of all remaining Australian species, despite relatively high uncertainties on both the cost and benefits side. This suggests that investigation into the development of an implementation plan by Taxonomy Australia is warranted. To progress this mission, Taxonomy Australia should consider undertaking detailed further costings and a comprehensive evaluation of benefits beyond this rapid CBA.

How to interpret the estimated benefits

Like many other types of R&D investment, the benefits created by increased taxonomic research and discovery have the potential to be very large. In the Main, the nature of benefits considered here are linked to the proposed investments through indirect and intangible channels. Appropriate consideration of the definition of these channels, among other issues outlined below, is necessary to understand and interpret the results of this rapid CBA. Across all benefit streams, an estimated benefits range has been presented to partially account for these issues. All estimates should be interpreted with these considerations in mind.

Marginal benefits above a static baseline

This rapid CBA seeks to value the contribution of Taxonomy Australia's mission. It does not seek to value taxonomy and the services it already provides, that is, the existing base of knowledge. Benefits estimated in this report should hence be understood as **marginal** or **incremental** benefits above a base case in which taxonomic knowledge continues to accumulate at its current rate and in its current form – the 'business as usual' world.

However, this rapid CBA also has acknowledged limitations in the definition of the base case. Firstly, the base case does not fully capture the full value of taxonomy: it only explores four selected benefit categories aligned with the sectors of biosecurity, biodiscovery, agricultural R&D and conservation.

Secondly, but no less importantly, the base case is static, meaning it does not attempt to account for all environmental and sector-specific changes in the future. However uncertain, we know that the environment, as well as economic, social and scientific conditions, will continue to change, with bearing on the value of taxonomic knowledge. While theoretically a dynamic baseline could be constructed that calibrates the value of taxonomic knowledge to these changes, making this realistic and accurate is not a simple task and lies beyond the scope of this rapid CBA.

Uncertainty

Taxonomy is a foundational science that indirectly enables benefits in numerous other pure and applied disciplines and sectors. These include both tangible benefits, that is, those with an established market value or widely accepted method for estimating value, and intangible benefits. Any positive change in taxonomic outputs is hence expected to result in an increase in indirect, enabled benefits across these other sectors. For this rapid CBA, benefit streams have been defined and constructed using stylised representations of selected impact channels. However, there are complex interdependencies within each benefit stream, and impacts are highly contingent on the accessibility of taxonomic knowledge to end users, among other key assumptions. It is therefore important to emphasise the uncertainty that accompanies the realisation of any of the estimated benefits. On the other hand, we also should not discount the possibility that discoveries could be made that generate exponential benefits, depending on the spill-over effects of certain R&D outcomes.

Sectoral input

Benefit streams were identified and selected based on examples of impacts of taxonomy from the Australian Academy of Science's Decadal Plan for taxonomy and biosystematics. This narrow selection necessarily misses other benefit streams or impact channels that could be reasonably expected to flow from increased taxonomic discovery. The benefit streams were further developed with input from sectoral stakeholders in each of the sectors expected to benefit from the mission. The benefits framework hence reflects the focus areas of these stakeholders.

Social discount rates

Recognising the nature of benefits considered, this rapid CBA uses a social discount rate of 4% to calculate the primary results. This relatively low social discount rate appropriately reflects the intergenerational welfare implications and societal time preferences over discounting future environmental and social benefits, balanced against the greater expected prosperity of future economies and time preference of money. Sensitivities at discount rates of 1% and 7% are presented alongside the primary social discount rate.

How to interpret the estimated costs

Taxonomy Australia's mission calls for a coordinated step-change in species discovery within the taxonomy sector. Currently, taxonomic research efforts and outputs are relatively dispersed across academic, professional and industry sectors. Taxonomy Australia's mission requires 'levelling up' the sector's activities to create a world class taxonomic research and innovation ecosystem.

Taxonomy Australia will need to implement a program of works that includes a substantial and sustained increase in the numbers of professional taxonomists, significant research process and knowledge distribution efficiencies, adoption of innovative technologies, novel research methods, and in some cases the creation of new research infrastructure and assets. Importantly, improved accessibility to taxonomic knowledge outputs by end users in other sectors will be vital to realising end benefits. As well, there may be critical dependencies between certain investment actions. For example, a strong pipeline of students at the undergraduate and postgraduate level needs to be established before skilled workforce recruitment can begin.

Seven key investment actions have been identified in this rapid CBA to implement Taxonomy Australia's mission. These investment actions, mentioned in the program of works above, represent preliminary investment actions required to achieve Taxonomy Australia's mission (to be developed upon further assessment). To meet these funding needs, a diverse range of funding partners and funding models may be suitable.

Funding partners

Public, private, and joint funding partnerships each have advantages and disadvantages in meeting different funding needs, depending on the objectives of funding partners, extent of shared incentives, financial capacity and level of interest. For example, public funding may be the most appropriate source for infrastructure for which there is no private incentive or willingness to invest. On the other hand, research organisations and the pharmaceutical industry may benefit from co-funding to support expansion of the taxonomic workforce.

Funding models

Potential funding models could include a mix of options other than traditional funding instruments such as block funding and grants. A range of alternative government investment models could potentially be suitable, including green and sustainability-linked loans and bonds, recoupable grants, revolving funds, capital leases, and joint infrastructure funds. Taxonomy Australia and its funding partners could co-design funding models with greater or lesser consideration to outcomes and cost recovery. For example, the establishment of a fee-for-service national facility for taxonomic outputs could help off-set some costs, at least in out-years of the mission once suitable infrastructure has been established.

Going forward, it will be necessary to understand how best to align Taxonomy Australia's identified funding needs with the most appropriate funding partners and models. We recommend that Taxonomy Australia considers this in the next stage of work.

Future considerations

This rapid CBA provides a clear indication that the potential benefits merit further investigation into Taxonomy Australia's mission, including the development of a detailed implementation plan. At that stage, a comprehensive CBA of the implementation plan would be advised. The comprehensive CBA could consider:

- Broader scope of benefits, including benefits not included in this rapid CBA. This could include economic contribution analysis or economic impact assessment of the taxonomy industry to employment and revenue in downstream industries.
- Assessment and identification of appropriate funding partners and models to funding needs and investment pathways.

1

Cost benefit analysis

Taxonomy is the science of classifying living organisms and arranging them into groups to understand relationships between species. Taxonomists discover, discern, describe, name, classify, study, compare and identify the world's living and extinct species and other taxa.[1] Their core task is to document the living world.

The discipline provides the foundational 'map' of biodiversity: taxonomic names and classifications are the key framework around which global knowledge and understanding of biodiversity can be organised and accessed.

Over the centuries, the development of taxonomic knowledge in Western scientific exploration has enabled significant advances in many scientific fields.

However, currently only around 30% of all Australian species of terrestrial and marine organisms have been discovered and documented in more than 250 years of Western scientific exploration. At the current rate, it will take more than four centuries to complete a first-pass documentation of Australia's biodiversity.

To address this challenge, in 2018, the Australian and New Zealand taxonomy sector, working with the Australian Academy of Science (AAS) and New Zealand's Royal Society Te Apārangi, developed a ten-year strategy for the taxonomy and biosystematics sectors in Australia and New Zealand ('the Decadal Plan').

The Decadal Plan sets out at high level the value proposition of taxonomy, including the achievements, opportunities, and threats faced by the sector, and ends with 22 strategic actions which together form a vision for the sector across Australia and New Zealand in the next decade.

Since then, the Decadal Plan has served as a foundation document for Taxonomy Australia, which was established with a remit to take carriage of the Decadal Plan in an Australian context. In working through the strategic actions of the Decadal Plan, Taxonomy Australia has issued a mission statement as follows:

"Taxonomy Australia will prepare for launch a mission to discover and document all remaining Australian species in a generation."

To achieve this mission, which is based on Strategic Action 1.1 of the Decadal Plan, a 16-fold increase in the annual rate of discovery over the next 25 years is needed.

Deloitte Access Economics has been engaged to conduct a rapid Cost Benefit Analysis (CBA) of the investment and resources required to implement Taxonomy Australia's mission to describe all remaining Australian species in a generation. Key insights from this rapid CBA will inform whether there is scope for future assessment including a comprehensive and detailed CBA of Taxonomy Australia's implementation plan.

A stylised rapid CBA has been undertaken for this assessment of the Taxonomy Australia mission to determine an order-of-magnitude for the initiative's net economic worth. It aims to provide a reasonable, conservative approximation of net economic worth, to determine whether investment in a more detailed implementation plan and detailed CBA is warranted.

Five key steps have been taken to prepare this CBA:

1. **Definition of the base and scenario cases**
The base case represents a depiction of the world under which the development of taxonomic knowledge continues at the historical, business-as-usual rate of 0.6% of remaining species (or 1,000 species) discovered in Australia per year. The scenario case translates the potential process improvements made possible under the implementation of Taxonomy Australia's mission into a 16-fold acceleration in taxonomic discovery. Under the scenario case, it is assumed that 2.75% of all remaining species (or 16,800 species) will be discovered per year.

2. **Definition of the assessment period**
Costs and benefits are assessed over a 25-year period spanning 2020 to 2045. The 25-year period is chosen to represent the time frame set by the mission to achieve its goal to describe all species in a generation.

3. **Benefit specification and estimation**
Four key benefits were identified that are expected to be enabled or improved by the mission's aim to accelerate species discovery, resulting in improved taxonomic knowledge. To achieve a reasonable, conservative estimate of net economic worth, a relatively narrow lens has been applied to quantify the benefits. These are enabled benefits in biosecurity diagnostics, biodiscovery, agricultural R&D and biodiversity conservation.

4. **Cost specification and estimation**
Taxonomy Australia provided cost estimates of a high-level implementation plan developed during a national conference of taxonomists held in April and May 2020. The conference aimed to determine how a mission to discover and document all remaining Australian species in a generation could be achieved, including how to deploy new technologies and methods in genomics, machine learning and computing, and how to change current work practices to achieve the needed acceleration.

5. **Discounted cash flow modelling**
Discounted Cash Flow (DCF) modelling is undertaken to calculate the present value of benefits and costs expected to flow from 2020 to 2045. The discounting reflects the time-value of money, uncertainty of future flows and increased wealth in future economies. Present values for this rapid CBA are discounted at a social discount rate of 4% per annum, to reflect the nature of the social and environmental benefits quantified here. Sensitivity analysis on present values is conducted at discount rates of 1% and 7%.

Core steps of a CBA process

Specify the base case and framework of analysis	Specify the framework of analysis and select an appropriate base case. This determines the incremental costs and benefit included in the CBA.
Estimate Costs	Estimate the project costs for the mission (defined as 'economic' and 'financial' costs).
Estimate Benefits	Estimate the project benefits for the mission (also 'economic' and 'financial' in nature).
Apply discounted cash flow modelling	Apply discounted cash flow modelling techniques to costs and benefits to estimate the Net Present Value (NPV) of short listed option.

2 Results

Benefits and costs modelled in this rapid CBA indicate that the proposed Taxonomy Australia mission has strong potential to create significant economic and social benefits for Australia. The benefits for four selected streams known to be enabled or accelerated by taxonomic research could be four to 35 times greater than the costs of implementation.

Benefits in the sectors of biosecurity, biodiscovery, agricultural R&D and biodiversity conservation attributable to accelerated taxonomic discovery range from $3.7 billion to $28.9 billion over a 25-year period to 2045 in present value terms, depending on the low, medium or high scenario cases defined for each benefit stream. The costs of investment in seven key categories are estimated to total $824 million over the same period.

A summary of the core results is presented in Table 2.1 below. Low, medium and high scenario cases representing a partial range have been constructed for each specific benefit stream, and are defined in detail in Chapters 4 to 7 in Part 2: Technical Report.

Table 2.1: Estimated costs and benefits of a mission to discover and document all remaining species ($ million, present value)

	Low	Medium	High
Costs	**824**	**824**	**824**
Benefits	**3,761**	**13,238**	**28,891**
Biosecurity diagnostics	465	563	660
Biodiscovery for human health			
Research	123	123	123
Development	3,050	12,200	27,449
Agricultural R&D	49	129	287
Biodiversity conservation	74	223	372

Source: Deloitte Access Economics. Results are calculated using a 4% discount rate over a 25-year time horizon from 2020-2045. Note: low, medium and high scenarios are defined differently for each benefit stream, see chapters in technical report for further detail. *No medium scenario case has been calculated for biodiversity and biosecurity streams; this represents the average of the low and high scenarios.

A few key caveats to this rapid CBA are significant to the interpretation of these results.

- **Modelled relationships between taxonomy and applied benefits are stylised representations.** To model the net benefits of Taxonomy Australia's mission, we have employed the use of stylised hypothetical scenarios to construct base and scenario cases. These do not fully reflect the full scope of factors relevant to each benefit stream, and minor benefits have largely been excluded in these stylised hypothetical scenarios.
- **The realisation of benefits is not uniform or predictable across time.** Translation of taxonomic research into applied uses is inherently uncertain in both probability and return. At the same time, investments in research made today have the potential to generate cumulative benefits in perpetuity. In fact, while the present value of benefits and costs are bound by a 25-year assessment period for this CBA, the flow of benefits is expected to continue indefinitely as long as knowledge is preserved and continues to be accessible.
- **Many benefits have been excluded here, including those that are not yet knowable.** We have endeavoured to identify and quantify only four selected benefits that are known to be enabled or improved by taxonomic research.
- **Employment and revenue benefits are excluded.** This rapid CBA estimates the monetary value of social and environmental benefits. However, it does not estimate the direct or indirect jobs that may be generated by the implementation of Taxonomy Australia's mission.

Taxonomy Australia may wish to consider these factors in developing the next stage of the implementation plan for its mission.

The results of sensitivity analyses on the present values of benefits under the medium scenario case, at discount rates of 1% and 7% are presented in Table 2.2.

Table 2.2: Sensitivity analysis of medium scenario results at discount rates of 1% and 7% ($ million, present value)

	1%	4%	7%
Costs	**1,212**	**824**	**587**
Benefits	**25,463**	**13,238**	**7,190**
Biosecurity diagnostics	828	563	396
Biodiscovery for human health			
Research	189	123	83
Development	23,883	12,200	6,362
Agricultural R&D	184	129	213
Biodiversity conservation	380	223	136

Source: Deloitte Access Economics

2.1 Costs

In April 2020 the Australian taxonomy sector held a national meeting to consider the capability needs for such a mission and to develop an initial roadmap. Based on this roadmap, the estimated cost of building capability needed to discover and document all remaining Australian species in a generation is $824 million over 25 years.

Currently, taxonomic research in Australia is highly constrained. While there is an estimated taxonomic workforce of approximately 335 FTE and an estimated annual budget of $36.8 million, a relatively small proportion of the FTE works directly on species discovery and most of the budget is taken up in salaries and fixed institutional expenses. A single national research grant program, the $2 million per annum National Taxonomic Research Grant Program managed by the Australian Biological Resources Study, funds taxonomic research.

The national meeting of the taxonomy sector, facilitated by Taxonomy Australia in May 2020, identified a collection of programs and actions needed to build the capability to discover and document all remaining Australian species in a generation (Table 2.3).

Table 2.3: Estimated cost of a mission to discover and document all remaining Australian species in a generation ($ million, present value cost estimates)

Cost item	PV ($ million)
Funding for national taxonomy innovation	33
Funding for national taxonomic research infrastructure	31
Increasing the National Taxonomy Research Grants Program (NTRGP)	102
Funding for a national sequencing, bioinformatics and diagnostics facility	125
Doubling the national taxonomy workforce	73
Funding a national field campaign	411
Enhanced management and delivery of taxonomy products and services	49
Total	**824**

Source: Deloitte Access Economics

2.2 Benefits

2.2.1 Biosecurity diagnostics

The benefits to biosecurity of more complete taxonomic knowledge amount to a present value of between $465 million and $660 million over a 25-year period. Australian biosecurity practitioners at both federal and state levels expect that these benefits would occur through earlier detection of suspected biosecurity incursions and reduced delays in reaching taxonomic certainty in the diagnostic process. This would result in earlier intervention in cases of genuine threats and more rapid confirmation of evidence-of-absence in cases of non-genuine threats, reducing the costs of delay to agricultural producers.

Given that up to a quarter of incursions under national management at any given time experience delays, there is considerable capacity for taxonomic research to improve biosecurity processes and outcomes. While most of these delays are relatively minor (from a few days to a few months), consultees indicated that outliers, with extreme multi-year delays, currently occur once every five years at most.

We construct hypothetical scenarios to model potential benefits from reducing delays in cases of genuine threats and non-genuine threats:

- *Genuine threats:* this scenario models a reduction in the frequency of extreme delays in the detection and diagnostic process, from once every five years in the base case to once every 10 years (low change scenario) or 15 years (high change scenario). Given a specific example of delayed detection (an incursion of the globally serious bee pest varroa mite, devastating bee populations and costing $355 million over 30 years),[2] if this is assumed to occur once every five years, then the benefit of reduced frequency to once every 10 years would be $435 million, and reduced frequency to once every 15 years would be $617 million.
- *Non-genuine threats:* this scenario models a reduction in the frequency of delays in proving absence of a suspected threat, from once every five years in the base case to once every 10 or 15 years. Given a high profile example of delayed evidence of absence (of the globally serious wheat pest karnal bunt fungus in a wheat export trade shipment costing $25 million), if this is assumed to occur once every five years, then the benefit of this happening only once every 10 years would be $31 million, and reduced frequency to once every 15 years would be $43 million.

These hypothetical benefits are sensitive to key assumptions on:

- the representative cost of delay in detection of genuine threats and reaching diagnostic certainty on non-genuine threats
- the exclusion of more frequent, minor delays
- future expected frequency of such delays with and without accelerated taxonomic discovery. For example, improvements made to biosecurity regimes that are independent of Taxonomy Australia's mission would likely also lead to reduced frequency of extreme delays and associated costs – these are not included in the base or scenario cases.

We note that these scenarios do not represent fully the range of invasive species and native species dynamics. This would need to take into account the impacts of climate change and other biodiversity threats, in both marine (ports and harbours) and terrestrial (native forests, rangelands) environments. For a detailed explanation of the modelling methodology for biosecurity benefits, refer to Part 2: Technical Report, section 4.

2.2.2 Biodiscovery for human health

The benefits of more complete taxonomic knowledge to the research segment of the pharmaceutical and medical biodiscovery process could result in present values of at least $123 million over a 25-year period. The market value and health benefits from commercialising natural product-based drugs could be many factors higher, amounting to $1.3 billion and $12 billion respectively.

The research and development segments of the biodiscovery processes are considered and modelled separately for this stream, reflecting distinct parts of the value chain.

Research – pre-commercial value

- The research segment of the biodiscovery value chain creates pre-commercial value even before clinical testing and drug development. This value is realised in the market for species-based samples, generally through a form of transactional arrangement between biotechnology researchers and pharmaceutical companies. Stakeholder opinion suggests that the likely pool of species with high potential for biodiscovery is close to 500,000 species, and based on fees transacted historically, each sample is conservatively worth an average of $500.[3] Currently, approximately 20,000 species are sampled each year.
- In the scenario case, taxonomic discovery is expected to double the annual number of species for sampling, leading to present value of net benefits of $123 million.

Development - market value

- In the development segment of the biodiscovery value chain, benefits accrue to producers through the successful commercialisation and sale of over-the-counter and prescription organism-derived drugs and medicines. This value could be extrapolated from the pool of species for sampling, using estimated probabilities of bioactivity, clinical interest and drug commercialisation (the latter being a 0.0001% chance overall).[4] Some market value estimates of successfully commercialised drugs have been applied from a US context to Australia, giving a market value of over-the-counter and prescription organism-derived drugs and medicines per species of $1.8 billion to $6.2 billion respectively.
- In the scenario case, taxonomic discovery is expected to increase the probability of drug commercialisation through more strategic targeting of species for sampling (greater numbers of samples not considered). The pool of species for sampling would be chosen with higher probabilities of samples being potentially bioactive and ultimately viable for clinical testing and development. Under the scenario case, a fivefold increase in this probability could see present value of market benefits of $1.3 billion.[5] Sensitivity analysis around this key assumption indicates that a twofold increase in this probability would result in present value market benefits of $300 million, while a tenfold increase would result in benefits of $2.9 billion.

Development - health benefits

- Benefits accrue to patients through avoided deaths attributable to over-the-counter and prescription natural product-based drugs and medicines. Health benefits to Australia are calculated by extrapolating from estimates of 22,500 to 37,500 lives saved in the US per year.[6] Population adjustments are made to apply the benefit to an Australian context, however disease prevalence, market access and use of drugs is assumed to be identical between the US and Australia.
- In the scenario case, taxonomic discovery is expected to drive increased health benefits similar to the market value benefits. A fivefold increase in the probability of samples being potentially bioactive could see present value of health benefits of $12 billion. Sensitivity analysis around this key assumption shows that a twofold increase in this probability would result in present value health benefits of $3 billion, while a tenfold increase would see benefits of $27 billion.

These hypothetical benefits are sensitive to key assumptions on how the value of these drugs and medicines may vary as a function of likely substitute processes to developing drugs to treat the same set of medical conditions, and lead times in drug commercialisation.

It is noted that scientific discovery is an inherently uncertain process, as is pharmaceutical R&D. In many cases, disruptive technologies that may herald major advances in the field of drug discovery and medical intervention cannot be predicted in advance.

This uncertainty is relevant to the probability and magnitude of returns from biodiscovery – while this modelling approach necessarily takes an aggregate approach using average probabilities and values, the true commercialisation likelihood or value may be much lower, or much higher (for example, in the case of one very successful drug). The full spectrum of possibilities impacting on this rate have not been factored into the counterfactual base case. For a detailed explanation of the modelling methodology for biodiscovery for human health benefits, refer to Part 2: Technical Report, section 5.

2.2.3 Agricultural R&D

The benefits of more complete taxonomic knowledge to the agricultural R&D process amount to present values between $49 million and $287 million over the 25-year period.

There are many potential enhancements to agricultural R&D owing to accelerated taxonomic discovery, such as taxonomic study into soil bacteria species that enhance crop management, soil fertility, and harmful organisms such as nematodes, or use of non-agricultural species in the transition to non-farm production of protein and carbohydrates. Our framework here, however, focuses on one area: the benefits arising from R&D into hybridisation with crop wild relative species. The discovery of ancestral wild species related to commercial cultivars of major crops helps expand genetic diversity and breeding of beneficial traits, with benefits such as enhanced adaptation under climate change, increased yield productivity and resistance to disease.

The economic benefits from improvements to a single crop from hybridising with crop wild relatives is valued at $41 million annually based on work done for the Millennium Seed Bank. Absent quantitative estimates on the impact of greater taxonomic discovery on this process, three scenarios representing low, medium and high rates of acceleration are constructed. In the scenario case, targeted taxonomic discovery is expected to accelerate the R&D process. If the process is accelerated by two years, the present value of net benefits amount to $49 million. For acceleration by five or 10 years, net benefits could be as high as $129 million and $287 million respectively.

Unlike the other quantified benefits, this framework was not reviewed by or tested with end users of taxonomic research due to limitations in seeking industry stakeholders. Estimates for this stream were highly contingent on available data on the selected crop wild relative benefit category. This benefit stream should be developed further in a full CBA. For a detailed explanation of the modelling methodology for agricultural R&D, refer to Part 2: Technical Report, section 6.

2.2.4 Biodiversity conservation

The present value of biodiversity conservation to Australia due to increased taxonomic discovery is estimated to be between $74 million and $372 million.

Consultation with stakeholders outlined a number of pathways through which taxonomic knowledge informs more effective conservation decision-making. Central to all pathways, taxonomy provides the foundational 'map' of biodiversity to inform ecology and conservation disciplines. With these disciplines and others, scientists are better equipped to understand species and their role within a given ecosystem to promote species resilience - to defend and strengthen ecosystems against an increasing number of environmental stressors.

For this reason, conservation benefits are defined here as the marginal improvements in species resilience resulting from increased taxonomic knowledge. This is only one way of thinking about conservation outcomes.

The current statutory provisions for conservation rely on a much narrower definition of conservation: to reduce the number of threatened species in order to reduce the risk of species becoming extinct. Whilst this definition is a limited view of conservation (which also addresses more holistic conservation goals), a reduction in the number of threatened species is used as a proxy for species resilience for the following reasons:

- Reducing the number of threatened species to prevent extinction is a conservation goal broadly understood by the public.
- The number of threatened species is closely monitored and publicly available from the Environmental Protection and Biodiversity Conservation Act 1999 ('EPBC Act') database, and directly links taxonomic discovery to conservation outcomes.
- Reduced number of threatened species is a conservative proxy for conservation success, as it represents only a small component of the overall conservation goal.

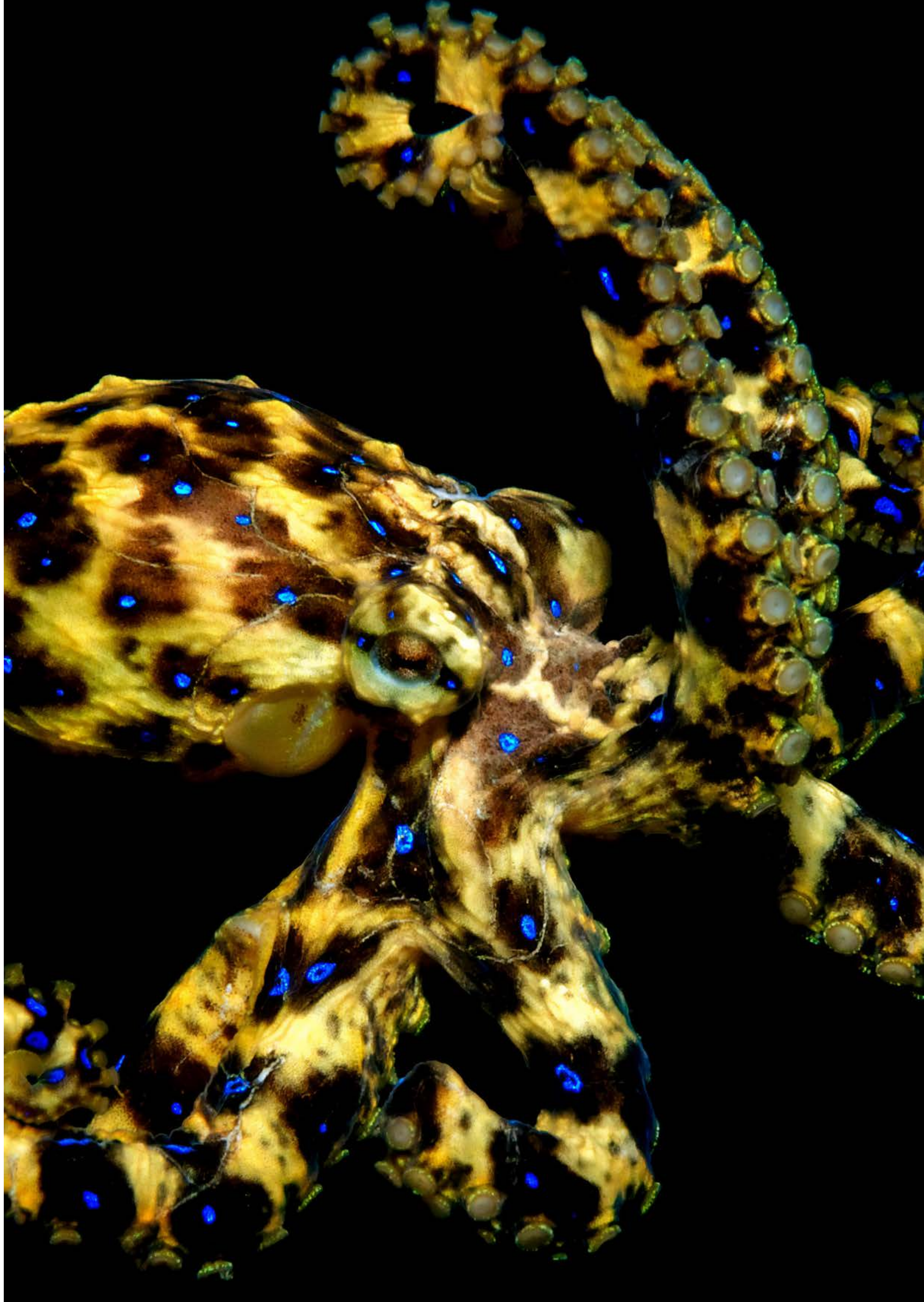
The approach estimates the number of species 'successfully conserved' using data from the EPBC database, projected to 2045. The Taxonomy Australia mission increases the rate of taxonomic discovery, so that the number of species described (classified as threatened, and then conserved) is greater over a 25-year period. Given limitations in funding and spill-over effects of existing conservation efforts, the number of species conserved is not expected to increase with each new threatened species discovered. Instead, consultation with stakeholders suggested that a 10% increase in taxonomic knowledge would lead to an improvement in conservation outcomes between 1% (lower bound) and 5% (upper bound) through improved ability to manage threats and focus effort.

This estimate of species conservation is then applied to a 'willingness to pay' measure of $11 (2020 dollars) per person per year to estimate the intrinsic non-use value of conservation success, based upon survey data collected by Jakobsson and Dragun (2001).

These hypothetical benefits are sensitive to key assumptions on:

- Recovery plans allocated by the EPBC Act as a proportion of total known threatened species remains constant at 38%, with a success rate of 50%.
- A consumer's 'willingness to pay' for the conservation of an additional species is linear, and the consumer's knowledge of the role of taxonomy remains constant.
- The total number of threatened species at baseline (known and unknown) remains constant over time.

For a detailed explanation of the modelling methodology for biodiversity conservation benefits, refer to Part 2: Technical Report, section 7.



3

Key insights

Taxonomic knowledge is foundational to our understanding of nature. As 'mapmakers' of life on earth in all its complexity and abundance, taxonomists enable discoveries to be made in many scientific disciplines and facilitate commercially valuable applications in a range of industries.

End users of taxonomic knowledge in the sectors of biosecurity, biodiscovery, biomonitoring and conservation can attest to its importance in their own fields. However, the value of taxonomy is hard to measure precisely because of its enabling nature. These difficulties can result in underfunding and underproduction of taxonomic knowledge relative to its full value.

This rapid CBA finds that Taxonomy Australia's mission to discover and document all remaining species in Australia in a single generation could create **significant benefits in the range of $3.7 billion to $28.9 billion** relative to an investment cost of $824 million over 25 years. These benefits result primarily by enhancing the effectiveness of applied sciences in four chosen sectors. **These benefits represent a return of four to 35 times greater than the likely cost of investment.**

The benefits from four selected benefits quantified in PV terms over a 25-year period to 2045 are as follows:

- **Biosecurity:** the benefits of reduced frequency of costly delays in biosecurity diagnostics of genuine and non-genuine threats range from $465 million to $660 million.
- **Biodiscovery:** the benefits of more cost-effective and strategic testing of species-based samples amount to $123 million in the research phase of the pharmaceutical and medical biodiscovery process and health benefits range from $3 billion to $27 billion.
- **Agricultural R&D:** the benefits of accelerated research into crop wild relative species of major commercial crops range from $49 million to $287 million.
- **Biodiversity conservation:** the benefits of improved conservation outcomes such as increased species resilience is estimated to total between $74 million and $372 million.

Many benefits have not been considered here or are entirely unknowable at present. These include the intrinsic benefits of greater scientific knowledge, enabled ecosystem benefits whose value cannot be fully captured by traditional valuation methodologies, industrial designs and processes inspired by nature, and commercialisation of research projects in sectors not included here.

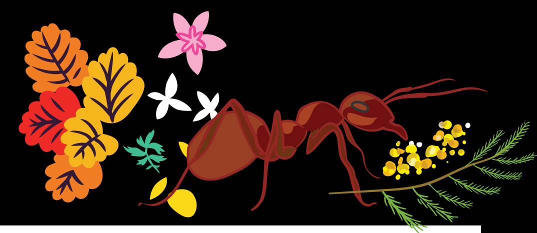
Like all research, the gains from taxonomic research are inherently uncertain – species found to be of enormous environmental or economic consequence are difficult to predict in advance. Further, benefits cannot be constrained to the 25-year period considered in this CBA. Rather, benefits are expected to accumulate in perpetuity, as researchers preserve and build upon the information stored in scientific papers, biological collections, and taxonomic and genomic sequence libraries, to name a few repositories of taxonomic knowledge.

Climate change, including rapid onset disasters such as the bushfires experienced in the summer of 2019-20, is accelerating the extinction of species from the planet. Many species will disappear without ever having been known to humankind. These and other imminent challenges stress the need for scientists to better understand the countless undiscovered species in Australia and elsewhere on Earth.

Taxonomy Australia's mission will help Australia face these challenges while bringing about social and economic benefits described in this report, and in doing so create significant opportunities to build skills and jobs for the nation's scientific workforce.

Part 2:
Technical Report

1



Taxonomy in Australia

1.1 What is taxonomy?

Taxonomy is the science of classifying living organisms and arranging them into groups to understand their evolution and the relationships between species. Taxonomists discover, discern, describe, name, classify, study, compare and identify the world's living and extinct species and other taxa.[7] Their core task is to document the living world to provide the foundational 'map' of biodiversity. Taxonomic names and classifications are the key framework on which global knowledge and understanding of biodiversity can be organised and accessed.

Through this documentation process, taxonomic discovery contributes to the cumulative collection of known and described species and other taxa. Taxonomic discovery can occur through:

- Reviewing existing collections of undescribed species collected in prior fieldwork, and resolving these with known species
- Undertaking fieldwork to systematically collect species samples
- Serendipitous discovery of previously unknown species, which prompts naming and classification.

> Taxonomy, together with the discipline of biosystematics – the study of evolutionary relationships among species - provides the framework that enables scientists to understand the living world.

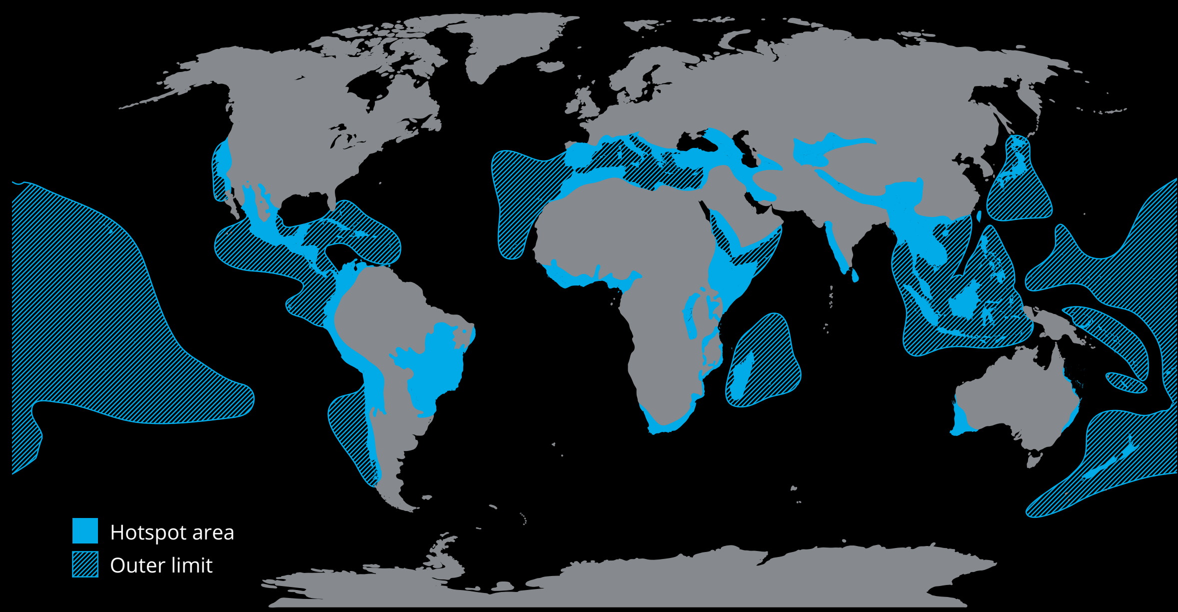
Decadal Plan

South-west Australia – one of the world's 25 megadiverse hotspots

Australia's long geographic isolation has created a rich diversity of unique endemic species the likes of which cannot be found anywhere else in the world. Specifically, the south west of Australia has been identified as a biodiversity hotspot.

It is estimated that south-west Australia is home to 5,500 plant species and at least 4,300 endemic species that occur naturally only in that region. Areas with high endemism are expected to yield many varied and unusual natural compounds, with implications for activities such as pharmaceutical biodiscovery

Figure 1.1: Global diversity hotspots



Source: Mittermeier et al (2011) in Taxonomy Decadal Plan (2018)[8], Harvey and Gericke (2011)[9]

1.2 Why taxonomy matters

Taxonomic knowledge is deeply embedded in the way individuals, societies and scientists observe the world around us. Over the centuries, the development of taxonomic knowledge in Western scientific exploration has enabled significant advances such as:

- **Biodiscovery –** for example, many biologically active natural products have shown a wide range of pharmacological activities such as anticancer, antifungal, antiviral, anthelmintic, antiprotozoal, anti-inflammatory, immunosuppressive and neurosuppressive activities. The therapeutic potential of these compounds in the treatment of human diseases is the subject of research by many scientists. There are also other important ways in which lack of taxonomic study can have enormous putative costs on human health, including the transmission of disease from arthropods that are vectors of human diseases and the emergence of zoonotic diseases from wild animals, such as the SARS-CoV-2 virus responsible for COVID-19. Other imminent challenges, including growing antibiotic resistance, stress the need for scientists to better understand the countless undiscovered species of bacteria and viruses.
- **Conservation -** taxonomists have described an estimated 242,000 terrestrial, freshwater and marine species in Australia and New Zealand, many of which are important for understanding ecological function. For example, recent efforts to better understand soil microbes have revealed a previously undocumented richness in genetic, functional and taxonomic diversity in this crucial community, which is critical to ensuring agricultural and environmental sustainability. Another example is the discovery of hydrocarbon-eating microbes such as Alcanivorax borkumensis, that can aid the clean-up of oil spills.[10]
- **Biosecurity –** species such as bee mites of the genus Varroa are major pests in Western honeybees, causing millions of dollars of damage to apiary industries and pollination services worldwide. Only some species of Varroa are damaging to commercial apiaries. Without taxonomic clarity of the species of Varroa (and related genera), taxonomists would not be able to provide morphological and genetic descriptions of the species; without these, in turn, Australian biosecurity officers would be hampered in carrying out biosecurity inspections and incursion management strategies.
- **Research and development -** biodiversity in our region holds globally significant potential in biomimetics or 'biomimicry', the application of natural design features to industrial materials and processes.

The full development of these benefits depends not only on taxonomic knowledge, but also on its accessibility and application in other disciplines and sectors.[11] However, one thing is clear - without taxonomic exploration and research, these benefits would be realised only partially or not at all.

The remainder of this section describes some qualitative benefits of taxonomic discovery: STEM skills across Australia, avoided delays from misidentification, and improvements to biomonitoring.

Building STEM skills

Benefits from training Australia's future scientific workforce with increased taxonomic skills and capabilities will likely arise from interventions such as increased resources and investment into the sector. Chapter 2 sets out Taxonomy Australia's mission to realise strategic actions identified in the Decadal Plan developed for the taxonomy and biosystematics sectors in Australia and New Zealand.

To ensure there are enough people with the skills required to advance the mission, Taxonomy Australia and the Australian Academy of Science plan to develop integrated teaching resources for taxonomy (Key Initiative 5 of the Decadal Plan). These education programs would be aligned with the national STEM curricula from primary schools to postgraduate studies, and teach important skills in biological diversity, evolution, and modern methods in taxonomy and biosystematics.

The taxonomy and biosystematics sectors are already undergoing a significant technological revolution, triggered by innovations in genomics, three-dimensional imaging, big data computation and machine learning.[12] Advancing these technologies will continue to require STEM, technological innovation, and analytical skills.

More broadly, a flourishing taxonomy sector can support jobs in scientific disciplines and demand for science, technology, engineering and mathematics (STEM) skills. STEM skills are critical to adapting to a changing working world driven by rapid technological change.[13] The importance of STEM to the economy is highlighted in a PwC report, which indicated that changing just 1% of the workforce into STEM roles would add $57.4 billion to Australia's gross domestic product (GDP).[14]

Avoided delays from misidentification

Taxonomic uncertainty in species identifications can cause costly delays and errors in disciplines and sectors dependent on this knowledge, such as biosecurity and environmental regulatory approval.

For example, evidence suggests that a one-year delay to a mining project, for instance by the identification of an environmental risk to a significant species, can reduce its present value by between 10 and 13 per cent per year.[15] These delay costs could be considered necessary to ensure a rigorous check on the project's costs and benefits from a public benefit perspective.[16] However, if the environmental risks associated with operations are realised only very late into the planning stage of the process (such as by the late-stage discovery of a threatened or other significant species), this represents a significant misallocation of resources that could be spent elsewhere in the economy if decisionmakers had a better understanding of the project's biodiversity in the first place. This significance is recognised by the WA Government's decision to establish a Biodiversity Information Office (BIO), with a funding commitment of $7.7 million combined with a $1.5m commitment from the Commonwealth Government. This will provide a cost-effective system to capture, store, curate, publish and analyse biodiversity data throughout WA, ultimately reducing project delays. The WA Government estimates that this could save up to $72 million per year for industry-led projects and $100 million per year for State Government infrastructure projects.[17]

Improvements to biomonitoring

Taxonomy is a critical component of biomonitoring services, which measures changes in the distribution and density of organisms. This is used to assess, for example, the levels and impacts of environmental contamination such as biological run off, changes in water quality in streams, lakes and estuaries, and to assist with natural resource management.

As part of environmental regulatory activities, environmental assets generally undergo routine biomonitoring to ensure that the health of the environment – our 'public property' – is maintained. Ongoing biomonitoring is also a significant operation for resource extraction projects to ensure their operations adhere to environmental protection laws, such as LNG processing operations at the A Class Nature Reserve, Barrow Island.[18]

Biomonitoring relies on an extensive database of accurately named species to compare samples and understand environmental conditions over time. For this reason, improving taxonomic discovery indirectly enables improvements in the accuracy of detecting environmental impacts, thereby improving efficiency and efficacy of biomonitoring processes.[19] Improving the efficiency of these processes may enable cost savings to environmental regulation agencies, industries and society.

Stakeholders who work in biomonitoring services have indicated that accessibility of taxonomic information to end users is critical - only in combination with the right tools and the dissemination of knowledge and genomic sequences will biomonitoring become faster, cheaper and more accurate.

Moreover, biomonitoring in many cases is currently only undertaken at a high taxonomic level (e.g. family level).[20] Greater taxonomic discovery and better biosystematics processes could enable biomonitoring processes to identify organisms at the species level. This would result in significantly greater accuracy in the monitoring and management of biological impacts.

A complete taxonomic 'map' will bring about even greater benefits

The benefits discussed so far in this chapter have been realised with a largely incomplete taxonomic 'map'. Only an estimated 15% of species have been discovered and documented worldwide, including an estimated 30% of Australian species. While most vertebrate animals and vascular plants are relatively well-known, many more taxa, including non-vascular plants, fungi, and invertebrates, remain poorly studied. These limits to our understanding of the natural world highlight the potential to gain significantly from a more complete taxonomic understanding of biodiversity. There is also intrinsic value in understanding the world around us more completely.

Moreover, environmental stressors to Australia's biodiversity are significant and increasing. These directly impact on threatened ecological communities, species extinction and co-extinction risk. Gradual climate change has already begun to affect species distributions and migration at regional scales due to diminishing habitat and food availability, and inability to withstand changing temperatures.[24] The Threatened Species Commission has allocated $50 million to wildlife impacts[25] and putative loss of ecosystem services. This is particularly important for invertebrates, where losses could be catastrophic but underestimated. Highly uncertain possibilities of insect collapse, of which not much is currently known beyond case studies in the Northern Hemisphere, point towards significant loss of ecological functioning and services.

The increasing number of extreme weather events as a consequence of climate change presents an urgent need to better understand our biodiversity. Taxonomy plays an important role in understanding the extent of biodiversity adaptation to climate change.

> We cannot properly grasp or understand the natural world without this taxonomic system".
>
> **Sir David Attenborough.[26]**

1.3 Taxonomic knowledge is currently undervalued as a public good

Like all R&D, core taxonomic research can be thought of as a public good. Research and knowledge outputs created by taxonomic research are available to all, and add to the body of knowledge about living species. However, as a public good, it is also subject to the 'free rider' problem, in which many users of taxonomy do not pay for the benefits they receive.

Another dimension that leads to taxonomy often being undervalued is the uniquely indirect nature of its contribution to social and environmental benefits. As a discipline, taxonomy is the fundamental building block on which many applied natural and life sciences stand. This can make it difficult for the sector to demonstrate its full value, and creates challenges in attracting funding and investment commensurate to the value directly and indirectly created. Failing to appropriately value the foundational research base of taxonomy creates the risk of underinvesting in a sector that provides such widely used foundational knowledge. This could have real flow-on implications to numerous scientific, industrial and environmental systems. For-profit cost recovery models could help partially capture this value, and Chapter 5 will highlight some proposed and established approaches.

Australia's black summer

The summer of 2019-20 brought about the worst bushfire season Australia has seen yet. The bushfire season started in winter due to dry conditions and average temperatures reaching 1.5 °C above the yearly average. More than 11 million hectares of land was burnt nationwide – an area the size of England. Many rainforests in southern Queensland and northern New South Wales burnt for the first time ever.

It is estimated that nearly three billion animals were killed or displaced during Australia's black summer.[21] Preliminary results indicated that of the 84 nationally listed threatened ecological communities (TECs), 37 have been affected by fire. Seven of these had more than 30 percent of their habitat destroyed. However, it is too early to confirm which species may have become extinct.[22] In February 2020, a scientific panel convened by Environment Minister Sussan Ley listed 113 animal species requiring the most urgent action, including the Kangaroo Island dunnart, northern corroboree frog, Blue Mountains water skink, Kangaroo Island glossy black cockatoo, superb lyrebird, parma wallaby, mountain pygmy possum and brush-tailed rock wallaby.[23]

A key concern is the impact these bushfires had on species we know nothing about – and may never know about. Beyond the prevention of species loss, the spatial distribution of species, their functions and how they interact with other species and their ecosystems hold critical information that informs recovery efforts to restore ecosystem communities. With full taxonomic knowledge – describing all species – we could better understand the impact adverse events, such as the black summer fires, have on our ecosystems to promote species resilience and better manage recovery.

Without this knowledge, it will be difficult to restore full functionality of many ecosystems damaged by Australia's black summer.

2

Cost benefit analysis

Deloitte Access Economics has been engaged to conduct a rapid Cost Benefit Analysis (CBA) of the investment and resources required to implement Taxonomy Australia's mission to describe all remaining Australian species in a generation. Key insights from this rapid CBA will inform whether there is scope for future assessment including a comprehensive and detailed CBA of Taxonomy Australia's implementation plan.

2.1 Taxonomy Australia's mission

In 2018, the Australian Academy of Science (AAS) convened the Taxonomy Decadal Plan Working Group to envision a 2018-2027 strategy for the taxonomy and biosystematics sectors in Australia and New Zealand ('the Decadal Plan').

The Decadal Plan sets out at high level the value proposition of taxonomy, including the achievements, opportunities, and threats faced by the sector, and ends with 22 strategic actions which together form a vision for the sector across Australia and New Zealand in the next decade.

Since then, the Decadal Plan has served as a foundation document for Taxonomy Australia, which was established within the AAS with a remit to take carriage of the Decadal Plan in an Australian context. Taxonomy Australia's role is to develop a detailed roadmap for achieving the vision set out in the Decadal Plan, including developing a series of implementation plans for each of the strategic actions. In working through the strategic actions of the Decadal Plan, the taxonomy sector, facilitated by Taxonomy Australia, has refined Strategic Action 1.1 and issued a mission statement which serves as the project scenario considered in the rapid CBA, as follows:

> "Taxonomy Australia will prepare for launch a mission to discover and document all remaining Australian species in a generation."

Currently, only around 30% of all Australian species of terrestrial and marine organisms have been discovered and documented in more than 250 years of Western scientific exploration. At the current rate, it will take more than four centuries to complete a first-pass documentation of Australia's biodiversity. The aim of the mission is to bring that timeline to a scale that is commensurate with need, particularly in the face of challenges such as accelerating biodiversity extinctions.

2.2 Expected acceleration of discovery

This mission sets a key objective to accelerate the discovery of species in Australia. Under the base case, at the current discovery rate, the discovery and documentation of all Australian species would likely take four centuries, at the very least. However, in that time many of Australia's native species may be gravely threatened and their value lost without ever being recorded. To achieve the mission, a 16-fold increase in the annual rate of discovery over the next 25 years is needed.

In straightforward mathematical terms, the taxonomy sector proposes to increase the rate of species discovery from:

- *Current discovery rate* – 1,000 species, or around 0.16% of all Australian species, discovered per year
- *Scenario discovery rate* – 16,800 species, or 2.75% of all Australian species, discovered per year.

While the discovery and description of species has inherent knowledge value, their discovery also enables broader benefits for society and the environment.

In order to achieve this acceleration and unlock these benefits, the prioritisation of strategic actions and investment in the taxonomy sector is required. This prioritisation can be thought of as engendering a 'step change' in the taxonomy sector, that include improvements to processes and practices to foster:

- Increased collaboration between taxonomists and users of taxonomic knowledge
- Increased knowledge sharing between taxonomists and other scientists
- Broader and more open access to taxonomic resources such as reference collections, libraries and facilities
- Increased development and use of technologies for collecting, imaging and sequencing species traits (both morphological and genetic)
- Greater education and awareness in students and the public
- Greater prioritisation of species for taxonomic research.

2.3 Methodology

In order to estimate the economic benefits enabled by the mission, Deloitte Access Economics has identified four benefit streams with 'knowable' applications of taxonomy. These were tested with stakeholders identified by Taxonomy Australia as intended beneficiaries of accelerated taxonomic discovery.

Separately, Taxonomy Australia has developed plausible cost estimates required to achieve the mission and carry out the step change in processes and practices to deliver an accelerated discovery of species in Australia.

2.3.1 About cost benefit analysis

The purpose of a CBA is to compare the total costs of implementing a policy, program and/or investment with the total benefits generated to the community. As such, a CBA determines whether the benefits outweigh the costs, and by how much.

When to undertake a CBA
CBAs are often undertaken to support government and commercial decisions regarding investment. For example, CBAs are the preferred quantitative assessment tool under the Infrastructure Australia Business Case Assessment Framework and the Building Better Regions Fund Assessment Framework.

The rationale for using a CBA as a decision-making tool is strong given that public and private funds come at a significant cost to the economy (through taxes collected by local, State, and Commonwealth governments). Therefore, understanding the benefits generated from those outlays is of significant value.

The logic of a CBA
A CBA compares the total costs of a policy, program and/or investment with the total benefits in a discounted cash flow (DCF) framework. This determines whether the net return from investment is positive in present value (PV) terms.

A positive net present value (NPV) indicates that the discounted benefits related to a policy, program and/or investment are greater than the discounted costs required to generate those benefits. This suggests value in further supporting and investing in those efforts.

Not all benefits and costs may be quantifiable under a CBA framework. In many cases, significant non-quantifiable costs and benefits are relevant and must be taken into account in decision-making. In such circumstances a CBA should not be the sole tool used to support decision-making.

Nonetheless, a CBA provides a robust framework for analysing information in a logical and consistent manner. It can assist governments and stakeholders to determine if a policy, program and/or investment efficiently achieves a stated objective. This can assist decision-makers to optimise the level of funding allocated to an initiative, or to adjust the scope of the initiative to help deliver the greatest benefit.

Rapid CBA
A rapid CBA is an approach that identifies the major components of costs and benefits and provides insightful order-of-magnitude results which can materially assist in informing whether an initiative is likely to pass a detailed appraisal.

Rapid CBAs are often undertaken to support government and commercial decisions regarding investment in early stages of an initiative's development. For example, rapid CBAs are the preferred quantitative assessment tool to assess a short list of options under Infrastructure Australia guidelines to determine the best performing options of an initiative. This process is followed by a detailed CBA for the identified best options. The resources required for a detailed CBA can then be expended only on initiatives that are likely to be an economically efficient use of resources.

A stylised rapid CBA has been undertaken for this assessment of the Taxonomy Australia mission to determine an order of magnitude for the initiative's net economic worth. The purpose of this study is therefore not to provide a precise representation of the benefits and costs of the initiative, rather, to provide a reasonable, conservative approximation of the net economic worth to determine whether investment in a more detailed implementation plan and detailed CBA is warranted.

2.3.2 Approach to undertaking this rapid cost benefit analysis

This CBA compares the incremental costs and benefits under the base case and scenario case associated with the implementation of Taxonomy Australia's mission. These are assessed over a 25-year period, from 2020 to 2045. Five key steps have been taken to prepare this CBA:

1. Definition of the base case and investment scenarios
2. Definition of the assessment period
3. Benefit specification and estimation
4. Cost specification and estimation
5. Discounted cash flow modelling.

These steps are described in more detail below.

Definition of the base case and scenario case

Defining a counterfactual scenario, or base case, is a critical component of a CBA. The net benefits of the investment are measured as an incremental change from the specified base case. This ensures that only the benefits that can be reasonably attributed to an investment are included in the analysis.

The base case is characterised by a status quo scenario where the current rate of taxonomic discovery remains at the current rate, approximately 0.16% per year (or 1,000 species per year).

The scenario case is considered in comparison to the base case in the CBA, in which approximately 2.75% of species (or 16,800 species) are discovered per year. The scenario case refers to the mission: by 2045, all species in Australia are discovered and described. The mechanisms through which benefits occur from taxonomic discovery under the base and scenario cases are defined specifically for each benefit stream in Chapters 4 to 7.

Definition of the assessment period

The net benefit is measured over a 25-year assessment period, from 2020 to 2045. This period has been selected as it contains the 25-year implementation plan and accounts for five years' worth of benefits that are expected to continue beyond the mission's implementation. In reality, benefits from knowledge outputs are expected to accumulate in perpetuity.

Benefit specification and estimation

Four key benefits are expected to be enabled or improved by the mission's aim to accelerate species discovery resulting in improve taxonomic knowledge. To achieve a reasonable though conservative estimate of net economic worth, a relatively narrow lens has been applied to quantify the benefits. These are enabled benefits in biosecurity diagnostics, biodiscovery, agricultural R&D and biodiversity conservation.

The logic flow of each benefit is outlined in Table 2.1. Each of the expected benefits is made up of a number of components, described in detail in Chapters 4 to 7.

Table 2.1: Benefit streams assessed for this CBA

Application	Expected mission impact	Expected outcomes	Quantified benefit	Unquantified benefits
Biosecurity diagnostics	Reduction in diagnostic uncertainty	Reduction in diagnostic delays	Reduction in trade losses and biosecurity management costs from severe delays	Reduction in trade losses and biosecurity management costs from less severe delays Reduction in eradication costs for biosecurity managers
Biodiscovery for human health	Increased ability to target discovery of novel and medically useful compounds	Faster and more effective drug discovery	Increase in the market value of pharmaceuticals or, decrease in health care costs through marginal improvement in pharmaceuticals	Possibility of major breakthroughs in pharmaceutical development
Agricultural R&D	Increased speed of research	Faster R&D through quicker identification of useful crop wild species for hybridisation	Faster development of resilient crop species	Benefits from other R&D streams
Biodiversity conservation	More effective targeting of conservation efforts	Increased species resilience	Improvement in conservation outcomes (proxied by Willingness to Pay for species conservation)	Shift in understanding of biodiversity Improvements to other types of conservation outcomes

Source: Deloitte Access Economics

Cost specification and estimation
Taxonomy Australia provided cost estimates of a high-level implementation plan developed during a national conference of taxonomists based on Strategic Action 1.1 of the Decadal Plan. Investments included in the cost estimates are required to:

- Establish a national taxonomy innovation grants program
- Establish a national taxonomic institution infrastructure grants scheme
- Increase the National Taxonomy Research Grants Program
- Establish and operate a national sequencing, bioinformatics and diagnostics facility
- Double the current national taxonomy workforce
- Fund a national field campaign
- Enhance the management and delivery of taxonomy products and services for end-users.

Discounted cash flow modelling
DCF modelling is undertaken to calculate the present value of benefits and costs expected to flow from 2020 to 2045. The discounting reflects the time-value of money, uncertainty of future flows and increased wealth in future economies. Present values for this rapid CBA are discounted at a social discount rate of 4% per annum, to reflect the nature of the social and environmental benefits quantified here. Sensitivity analysis on present values is conducted at discount rates of 1% and 7%. A detailed discussion of social discount rates can be found in Appendix B.

2.3.3 Stakeholder engagement process

The rapid CBA approach used a literature review process to define key assumptions of benefit streams, supplemented with a stakeholder engagement process. In total, this process engaged 19 end-users of taxonomy in the sectors of biosecurity, conservation, pharmaceutical biodiscovery and biomonitoring. These end-users represent some of the intended beneficiaries of Taxonomy Australia's mission to discover all remaining species and produce more taxonomic knowledge.

The purpose of stakeholder engagement was to:

- **Confirm the general modelling framework.** Stakeholders were invited to provide feedback on the conceptual relationship between taxonomic discovery and the identified benefit in their area of expertise. These views were reflected in the modelling framework, key modelling choices and the narrative of this report.
- **Test key assumptions of each benefit stream.** Stakeholders were asked to provide feedback on key assumptions of the model. Where gaps existed in the literature, stakeholders were asked to provide an indicative range of values that reflected the taxonomic links.

Consultees were also provided with the opportunity to comment on the final outputs of Chapters 4 to 7. The stakeholder engagement process is detailed in Appendix A.

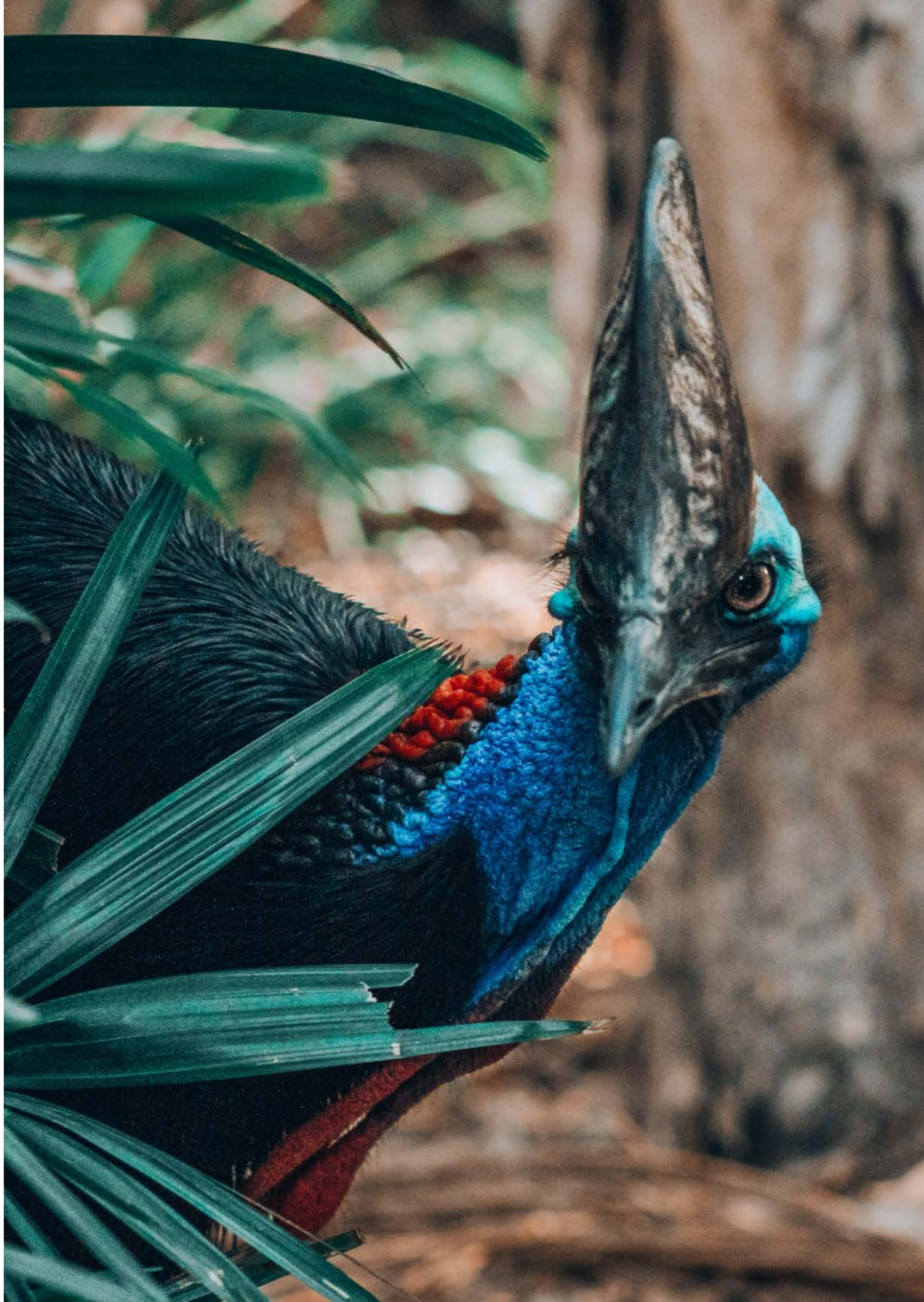
2.3.4 Future considerations

As noted at the beginning of this section, the objective of this rapid CBA is to inform whether investment in a more detailed implementation plan is warranted. This rapid CBA brought various stakeholders and end-users of taxonomy together, to quantify the relationships between core taxonomic research and industry applications.

The resulting benefits and costs can thus be considered a starting point for estimating the full value of increased taxonomic research. A number of caveats remain on this work. Primarily, the methodology employed in this CBA applies a relatively narrow lens by selecting only four types of benefits that are known to be directly or indirectly enabled by taxonomic research. This method does not seek to quantify other benefits that may occur through applications of taxonomic knowledge, nor does it value the intrinsic value of taxonomic knowledge or economic benefits pertaining to jobs and skills.

This rapid CBA has provided an indication that the potential benefits do merit further investigation of Taxonomy Australia's mission, including the development of a detailed implementation plan. At that stage, a comprehensive CBA of the implementation plan would be advised. The comprehensive CBA should consider:

- Broader scope of benefits, including benefits not included in this rapid CBA
- In-depth exploration of the benefits arising from proposed investments, including a greater focus on the direct attribution of taxonomic research to benefits. This could include economic contribution analysis or economic impact assessment of the taxonomy industry to employment and revenue in downstream industries
- Assessment and identification of appropriate funding partners and models of funding needs and investment pathways.



3 Cost of investment

Taxonomy Australia's mission calls for a coordinated step-change in species discovery within the taxonomy sector. Currently, taxonomic research efforts and outputs are relatively dispersed across academic, professional and industry sectors. Taxonomy Australia's mission therefore requires 'levelling up' the sector's activities to create a world class taxonomic research and innovation ecosystem.

Taxonomy Australia will need to implement a program of works that includes a substantial and sustained increase in taxonomist positions, significant research process and knowledge distribution efficiencies, adoption of innovative technologies, development of novel research methods and practices, and in some cases the creation of new research infrastructure and assets. Importantly, improved accessibility to taxonomic knowledge outputs by end-users in other sectors will be vital to realising end benefits. As well, there may be critical dependencies between certain investment actions. For example, a strong pipeline of students at the undergraduate and postgraduate level needs to be established before skilled workforce recruitment can begin.

The costs of seven key investment actions in this rapid CBA represent some proposed mechanisms for addressing the funding needs for implementation of Taxonomy Australia's mission. To meet these funding needs, a diverse range of funding partners and funding models may be suitable.

- *Funding partners* – public, private, and joint funding partnerships each have advantages and disadvantages in meeting different funding needs, depending on the objectives of funding partners, extent of shared incentives, financial capacity and level of interest. For example, public funding may be the most appropriate source for infrastructure for which there is no private incentive or willingness to invest. On the other hand, research organisations and the pharmaceutical industry may benefit from co-funding to support expansion of the taxonomic workforce.
- *Funding models* – potential funding models could include a mix of options other than traditional funding instruments such as block funding and grants. There are a range of alternative government investment models that could potentially be suitable, including green and sustainability-linked loans and bonds, recoupable grants, revolving funds, capital leases, and joint infrastructure funds. Taxonomy Australia and its funding partners could co-design funding models with greater or lesser consideration to outcomes and cost recovery. For example, the establishment of a fee-for-service national facility for taxonomic outputs may be able to offset investments, at least in the out-years of the mission once saleable value has been created.

Going forward, it will be necessary to understand how best to align Taxonomy Australia's identified funding needs with the most appropriate funding partners and models. We recommend that Taxonomy Australia considers this in the next stage of work.

3.1 Summary of costs

In April 2020 the Australian taxonomy community held a national meeting to consider the capability needs for such a mission and to develop an initial roadmap. The cost estimates below are based on this roadmap. All cost estimates, including key input assumptions and the proposed investment mechanisms, have been provided by Taxonomy Australia for this rapid CBA. The cost estimates and modelling have not been verified by Deloitte Access Economics.

Currently, taxonomic research in Australia is highly constrained. While there is an estimated taxonomic workforce of approximately 335 FTE and an estimated annual budget of $36.8 million, a relatively small proportion of the FTE works directly on species discovery and most of the budget is taken up in salaries and fixed institutional expenses. A single national research grant program, the $2 million per annum National Taxonomic Research Grant Program managed by the Australian Biological Resources Study, funds taxonomic research.

The national meeting identified a series of programs and actions that will together build the capability to discover and document all remaining Australian species in a generation.

The estimated costs of these programs and actions are given in Table 3.1. **The present value of total costs, discounted at a rate of 4% over 25 years is $824 million, outlined in Table 3.1 below.**

Table 3.1 Estimated costs of building the capability needed to discover and document all remaining Australian species in a generation (PV $million, 4% discount rate)

Cost item	PV ($ million)
Funding for national taxonomy innovation	$33
Funding for national taxonomic research infrastructure	$31
Increasing the National Taxonomy Research Grants Program (NTRGP)	$125
Funding for a national sequencing, bioinformatics and diagnostics facility	$73
Doubling the national taxonomy workforce	$411
Funding a national field campaign	$102
Enhanced management and delivery of taxonomy products and services	$49
Total	**$824**

The undiscounted total estimated cost over 25 years is $1.66 billion, outlined in Table 3.2 below. The estimated time profile of investment across the time period is also set out.

Table 3.2: Undiscounted cost estimates for 5-year intervals to 2045 ($ million per annum)

	Years 1-5	Years 6-10	Years 11-15	Years 16-20	Years 21-25	Total
Funding for national taxonomy innovation	4	2	1	1	1	45
Funding for national taxonomic research infrastructure	2	2	2	2	2	50
Increasing the National Taxonomy Research Grants Program (NTRGP)	8	8	8	8	8	200
Funding for a national sequencing, bioinformatics and diagnostics facility	8	6	2	2	2	100
Doubling the national taxonomy workforce	-	37	37	37	37	736
Funding a national field campaign	2	5	10	10	10	185
Enhancing the management and delivery of taxonomy products and services for end-users	3.2	3.2	3.2	3.2	3.2	78.8
Total	**27**	**63**	**63**	**63**	**63**	**1,395**

Source: Taxonomy Australia

3.2 Funding needs

Key estimated numbers on which the costs below are based on the following assumptions in Table 3.3.

Table 3.3: Cost assumptions

Category	Assumption
Estimated number of documented species in Australia	192,000
Estimated number of undocumented species in Australia	420,000
Estimated number of taxonomy positions (FTE) in 2017	335
Estimated annual spend (Commonwealth and state governments) in 2017	$43.6 million

Source: Taxonomy Australia

3.2.1 Funding for national taxonomy innovation

Taxonomic research and the documentation of new species is ripe for, and requires, innovation. Existing and emerging technologies such as machine learning, super-computing, continually improving methods for rapid genome sequencing and high-resolution 3D digital imaging provide the means to substantially enhance species discovery and documentation. Taxonomists have historically been early adopters of new technologies whenever resourcing allows. However, rapid and widespread adoption of new technologies is limited by the lack of a defined framework to ensure that the best innovations are made widely available. For example, while machine learning is being used to build tools to help identify known species, resources are currently lacking to explore its scope in discovering new ones. Likewise, while some taxonomists are exploring 3D digital imaging as a powerful tool for species documentation, its widespread use is limited by the lack of a suitably powerful national computing framework to store, analyse and share images.

Innovation could be funded through a grants program or through an alternative funding model. A National Taxonomy Innovation grants scheme could provide competitive grants to institutions and individuals to fund the development and roll-out of new taxonomic tools, work practices and processes that will provide significant efficiency and acceleration for species discovery and documentation.

Expected outcomes are innovative and creative research targeted at specific parts of the taxonomy pipeline that limit the rate of discovery and documentation of new species. Funding will be available to researchers at all career stages but will be weighted to early and mid-career researchers. The proposed grants scheme is weighted towards years 1-10, continuing at reduced rate for the life of the mission given that opportunities for innovation will be ongoing.

The quantum of funding of $45 million over 25 years in undiscounted terms has been tested within the community. Comparable innovation grants schemes include the Advanced Manufacturing Early Stage Research Fund[27] (AMESRF) and National Health and Medical Research Council (NHMRC) 2020 Ideas Grants.[28]

3.2.2 Funding for national taxonomic research infrastructure

The collections of preserved scientific specimens in museums and herbaria comprise a $7 billion[29] national research asset for taxonomic research and species discovery and provide the key point-of-truth for much of our knowledge of Australia's biodiversity. However, the physical infrastructure to protect and manage, and the workforce to curate and maintain, biodiversity collections is barely adequate or inadequate, resulting in substantial risks to a priceless national asset. A substantial acceleration in taxonomic research needed for a mission to discover and document all remaining Australian species in a generation will place substantial demand on physical, IT and human resource capacity in all Australian biodiversity institutions.

As with national taxonomic innovation, this infrastructure could be funded through a grants program or through an alternative funding model. A National Taxonomic Institution Infrastructure Grants Scheme could be used to provide competitive grants to institutions to address infrastructural limits to accelerated species discovery and documentation.

Expected outcomes are ongoing reductions in institutional limits to supporting a mission to discover and document all remaining Australian species. The grants scheme will need to be ongoing for the life of the mission, to accommodate ongoing institutional needs and challenges during the life of the mission. Applications for grants will be competitive, to ensure resources are directed to greatest need. Infrastructure grants will be for new infrastructure and enhancement, replacement and turnover of critical infrastructure directly related to the mission, not for ongoing running costs of institutions.

The quantum of funding of $50 million over 25 years in undiscounted terms has been tested within the taxonomy sector.

3.2.4 Increasing the National Taxonomy Research Grants Program (NTRGP)

Currently, the $2 million per annum National Taxonomy Research Grants Program (NTRGP) managed by the Australian Biological Resources Study (ABRS) is the only nationally funded competitive grants scheme supporting taxonomy and species discovery and documentation in Australia.[30] It funds a mix of PhD and postdoctoral programs, and research grants throughout the sector.

Funding through this scheme has a demonstrable effect on the rate of species discovery in Australia. The establishment of ABRS and its grants program in 1973 led to an immediate increase in the rate of species discovery in Australia. This was sustained until the early 1990s, when the rate of species discovery plateaued then declined, largely due to funding for the scheme remaining static in dollar terms and hence declining substantially in real value. A sustained five-fold increase in the annual value of the NTRGP, from its current $2 million to $10 million per annum, will be needed to fund core species discovery and documentation for this mission, or an incremental cost of $200 million over 25 years in undiscounted terms ($8 million per annum).

An enhanced NTRGP will need to support both existing researchers in a renewed effort to discover and document species, and PhD and post-doctoral positions to train the workforce needed for outyears of the mission. The component of the NTRGP that funds PhD and postdoctoral positions will need to be shaped so that in the early years (Years 1-10) it is weighted towards funding PhD and other training programs while in later years it will be weighted towards postdoctoral and other research grants.

Costs are comparable with the National Science Foundation's Dimensions of Biodiversity grants program (US$8–12 million per annum), one of several NSF grants programs directly targeted at taxonomy and species discovery.

3.2.5 Funding a national genomics and biodiversity diagnostics service

Biodiversity diagnostics – the identification of organisms – is one of the most important services supported by taxonomic research. Many stakeholders need accurate, efficient and timely identification of species, including biosecurity officers, conservation agencies, researchers, environmental consultants, and members of the public. The ability to identify specimens rapidly and accurately is also crucial to accelerate the discovery of new species, as new species can only be recognised by comparing them against existing species, which requires effective identification methods.

A key need for identification and biosecurity diagnostics is a comprehensive reference library of DNA sequences of all known Australian species. While the promise of DNA sequencing for identification is often discussed and researched, it is rarely operationalised, and sequences are currently under-utilised for biodiversity diagnostics. DNA sequencing and genomics will also play a critical direct role in the discovery and documentation of new species at the rate needed for this mission.

The National Genomics and Biodiversity Diagnostics Service is planned as a virtual, distributed facility created by investing in and coordinating existing institutional sequencing labs, rather than as a new facility. This is because many small to medium sequencing labs in Australian biodiversity institutions (museums, herbaria and universities) are currently used at only a fraction of capacity, providing an opportunity for efficiency gains by ensuring that they operate at close to capacity.

The service will comprise an efficient pipeline for DNA extraction, preparation and sequencing, bioinformatic processing of sequences, and the provision of diagnostics services based on a growing sequence library. The initial (capability enhancement and library building) phase will require investment, but once the library of sequences is comprehensive the diagnostic services provided are likely to be highly attractive to a wide range of end-users, by providing rapid, cost-effective and accurate identification of any sample of any Australian organism. Income generated from this service will be able to offset the costs of using the service for species discovery, and for continuing to build the library as more species are discovered and documented.

An important capability of a National Genomics and Biodiversity Diagnostics Service will be the provision of dedicated bioinformatics services for taxonomic research. Currently, taxonomists using DNA sequencing and genomics for taxonomy need to master a wide range of technical skills, from laboratory-bench DNA extraction and preparation methods and the bioinformatic processing of raw sequence data to the analysis of the processed data using complex software. Of these skills, the bioinformatic processing of raw sequence data is particularly time-consuming and constitutes a significant bottleneck for taxonomic research. Given that these same services are needed for diagnostics, the up-stream skills in this pipeline would be best handled by dedicated specialists in each of these methods, leaving the taxonomists to deal with the taxonomic analysis of the processed data.

Estimated costs for the facility of $100 million over 25 years in undiscounted terms are based on current (2020) sequencing costs for high-throughput next-generation genome sequencing, assuming one specimen per species for the library-building phase over ten years (20,000 samples per year at $330 per sample) and with a 10% p.a. reduction in non-fixed costs. Once the library building phase is complete (10 years) annual operating costs are substantially reduced on the assumption of significant off-setting income through the provision of biodiversity diagnostics services for commercial clients.

3.2.6 Doubling the national taxonomy workforce

The current national taxonomy workforce comprises approximately 335 FTE. The current workforce does not have sufficient capacity to achieve the approximately 16-fold increase in the rate of species discovery and documentation needed to achieve the mission. However, a 16-fold increase in the workforce is not required, given the efficiencies that can be achieved through innovation, the deployment of new technologies, and the centralisation of some services such as DNA processing and bioinformatics. A doubling of the workforce is estimated to be sufficient when these efficiencies are taken into account.

Current funding for taxonomic research (mainly salaries) is split between the states and Commonwealth, with approximately 70% from state governments (operating and staffing costs for state museums, herbaria and other taxonomic research institutions) and approximately 30% from the Commonwealth (largely through funding for the CSIRO biodiversity collections, the Atlas of Living Australia, and the Australian Biological Resources Study). This split funding model should continue, as the discovery and documentation of Australia's biodiversity will be of equal benefit to states and the Commonwealth.

Note that expansion of the workforce will need to be carefully shaped, as there are currently insufficient graduates from PhD and other training programs in taxonomy to allow for rapid expansion. Provision of adequate PhD places and other training programs, particularly in the first decade of the mission, will be a critical constraint. For this reason, the incremental cost of expanding the national taxonomy workforce commences five years into the mission (from 2026).

Based on a 50/50 split between research and technical positions, with the following indicative annual salaries, the nominal wage costs over 20 years are estimated to be $736 million in undiscounted terms.

- Research staff have an annual salary of $96,971 plus 30% on-costs[31]
- Technical staff have an annual salary of $72,000 plus 30% on-costs.

3.2.7 Funding a national field campaign

Initially, most species discovery for the mission will happen within biodiversity collections institutions, as many new species are already represented in collections but have not yet been resolved into new species or taxonomically documented. A milestone in the first half of the mission will be the documentation of all species that can be resolved using existing collections.

However, many species have not yet been collected, or cannot be adequately resolved and delimited using available material. Once species discovery transitions from discovery within collections to discovery of entirely new, never-before-collected species, a targeted field campaign will be needed to complete the mission.

There are opportunities for significant involvement of citizen scientists in such a field campaign, which is likely to comprise a mix of targeted field campaigns by taxonomists and intensive, guided collecting across Australia by local residents, schools, enthusiast societies and others.

The estimated cost of $185 million over 25 years in undiscounted terms is based on a sustained 5-fold expansion of the Bush Blitz program,[32] jointly funded by the Commonwealth Government and BHP-Billiton at $11 million over 5 years.

3.2.8 Enhancing the management and delivery of taxonomy products and services for end-users

While discovering and documenting Australia's remaining species is a core goal of this mission, species discovery is useful and effective only if knowledge of all known species can be delivered to end-users and other stakeholders efficiently and effectively. Currently, taxonomic research results in widely dispersed products, many of which (e.g. scientific papers) are inaccessible for many users. A key goal of the mission is to deploy all available knowledge of all Australian species in universally accessible products and services using new and innovative technologies to manage the vast array of information and data that will both underpin and result from this mission.

The Commonwealth-funded Australian Biological Resources Study (ABRS), part of the Department of Agriculture, Water and the Environment, is tasked with both coordinating and managing taxonomic knowledge of Australia's biodiversity. It does this by managing and maintaining core databases of Australian species, producing products such as the Flora of Australia, and helping manage taxonomic research in Australia.
Since its establishment in 1973, however, annual investment in ABRS has declined in real dollar terms in recent decades, and it is no longer capable of providing the key services to manage the increased information and data derived that would result from a mission to discover and document all remaining Australian species in a generation. The Australian Academy of Science estimates a four-fold increase in ABRS budget is required to rebuild this capability.

The role of ABRS in the mission will be to provide a step-change in the efficient management and effective delivery of biodiversity knowledge to stakeholders, end-users and the taxonomic research community.

The estimated cost of $79 million over 25 years in undiscounted terms is the incremental cost estimate from the base case, based on a four-fold increase in ABRS staff and operating costs. This will restore ABRS staffing to levels reached in the 1980s, when it achieved a very high increase in annual rates of species discovery.

How to interpret estimated benefits

Like many other types of R&D investment, the benefits created by increased taxonomic research and discovery have the potential to be very large. In the main, the nature of benefits considered here are linked to the proposed investments through indirect and intangible channels. Appropriate consideration to the definition of these channels, among other issues outlined below, is necessary to understand and interpret the results of this rapid CBA. Across all benefit streams, an estimated benefits range has been presented to partially account for these issues. All estimates should be interpreted with these considerations in mind.

Marginal benefits above a static baseline

This rapid CBA seeks to value the contribution of Taxonomy Australia's mission. It does not seek to value taxonomy and the services it already provides, that is, the existing base of knowledge. Benefits estimated in this report should hence be understood as marginal or incremental benefits above a base case in which taxonomic knowledge continues to accumulate at its current rate and in its current form – the 'business as usual' world. However, this rapid CBA also has acknowledged limitations in the definition of the base case. Firstly, the base case does not fully capture the full value of taxonomy: it only explores four selected benefit categories aligned with the sectors of biosecurity, biodiscovery, agricultural R&D and conservation, and even so does not capture the full scope of benefits and dynamics in each sector. Secondly, but no less importantly, the base case is static, meaning it does not attempt to account for all environmental and sector-specific changes in the future. However uncertain, we know that the environment, as well as economic, social and scientific conditions will continue to change with bearing on the value of taxonomic knowledge. While theoretically a dynamic baseline could be constructed that calibrates the value of taxonomic knowledge to these changes, making this realistic and accurate is not a simple task and lies beyond the scope of this rapid CBA.

Uncertainty

Taxonomy is a foundational science that indirectly enables benefits in numerous other pure and applied disciplines and sectors. These include both tangible benefits, that is, those with an established market value or widely accepted method for estimating value, and intangible benefits. Any positive change in taxonomic outputs is hence expected to result in an increase in indirect, enabled benefits across these other sectors. For this rapid CBA, benefit streams have been defined and constructed using stylised representations of selected impact channels under Taxonomy Australia's mission. However, these do not reflect the full range of impacts that could be possible under the mission. Equally, there are complex interdependencies within each benefit stream, and impacts are highly contingent on the accessibility of taxonomic knowledge to end-users, among other key assumptions. It is therefore important to emphasise the uncertainty that accompanies the realisation of any of the estimated benefits. On the other hand, we also should not discount the possibility that discoveries could be made that generate exponential benefits, depending on the spill-over effects of certain R&D outcomes.

Sectoral input

Benefit streams have been identified and selected using examples from the Australian Academy of Science Decadal Plan for taxonomy and biosystematics. This narrow selection necessarily misses other benefit streams or impact channels that could be reasonably imagined to flow from increased taxonomic discovery. Benefit streams were further developed with input from sectoral stakeholders in each of the sectors expected to benefit from the mission. The benefits framework hence reflects the focus areas of these stakeholders.

Social discount rates

Recognising the nature of benefits considered, this rapid CBA uses a social discount rate of 4% to calculate the primary results. This lower social discount rate more appropriately reflects the intergenerational welfare implications and societal time preferences over discounting future environmental and social benefits, balanced against the greater expected prosperity of future economies and time preference of money. Sensitivities at discount rates of 1% and 7% are presented alongside the primary social discount rate.








4

Benefit stream 1: Biosecurity diagnostics

Taxonomic knowledge underpins Australian biosecurity systems and international obligations under the World Trade Organisation Agreement (WTO) on the Application of Sanitary and Phytosanitary Measures, International Plant Protection Convention (IPCC), World Organisation for Animal Health, and the World Health Organisation.[33]

Invasive species can have distinct consequences for Australia's environment and agricultural sectors and are typically treated separately under the National Environmental Biosecurity Response Agreement (NEBRA) and Emergency Plant Pest Response Deed (EPPRD). In 2017, taxonomists and biosecurity diagnostics staff in Australia identified over 30,000 specimens in biosecurity incidents and checks of shipments of goods and agricultural products.[34]

The Senate Inquiry of Australia's biosecurity system (2015) found that:

"For plant pests, on average there are two new pests reported to the Department of Agriculture by the state or territory governments each week, many relating to extensions of geographical or host range or new variants detected through improved diagnostic techniques. Exotic plant pests and other invertebrates are considered in accordance with the EPPRD or NEBRA, and following initial investigations, are often found to be widespread or found to be a previously undescribed native or introduced species. It is estimated that only 30 per cent of Australia's and 20 per cent of the world's insects have been described; and only 5 per cent of the world's viruses. Given the large number of species associated with plants, there is also often a lack of available scientific information available to inform a decision on potential impact to the environment or production.[35]"

In its submission to the Senate Inquiry, CSIRO estimates of current rates of incursion range from 20 to 40 per year in total across plant naturalisations, vertebrate and invertebrate pests, plant pathogens, and animal diseases.[36]

Accidental and deliberate introductions of invasive species are a major threat to Australian and global ecosystems. Introduced pests to crops, pastures, and forests in Australia cost an estimated $13.5 billion annually (Table 4.1), and environmental losses are estimated to be even greater at $14.9 billion annually.[37]

Table 4.1: Economic losses from introduced pests to crops, pastures and forests in Australia ($ billion)

Introduced pest	Damage	Annual economic impacts ($bn)
Weeds	Crops and pastures	5.2
Vertebrates	Crops	0.43
Arthropods	Crops and forests	2.04
Plant pathogens	Crops and forests	5.85
Total		**13.52**

Source: Pimentel et al (2001). All figures are expressed in Australian 2019 dollars.
Note: We are not aware of more recent estimates of the cost of biosecurity incursions Australia-wide. This cost is therefore likely an underestimate of contemporary economic losses attributable to biosecurity threats, given greater trade flows and movement of people.

4.1 Taxonomic knowledge driving biosecurity outcomes

More comprehensive, updated and accessible biological reference collections will drive positive biosecurity outcomes, both directly, in their use for biosecurity and emergency response, and indirectly, as an essential tool in scientific research into the occurrence and distribution of pest organisms.

The significance of any species discovered over the course of normal taxonomic research is difficult to predict and may only become clear when an exotic species that is potentially invasive has been discovered, or a native species that could be misidentified as invasive is discovered. This information is critical when new specimens are detected during biosecurity incidents and checks. When this happens, biosecurity managers and diagnosticians are required, under NEBRA and the EPPRD, to achieve taxonomic certainty on the identity of specimens as a prerequisite to forming a biosecurity response. Consultees indicated that in many instances, border specimens are not diagnosed to the species level, but to a level that is sufficient to know whether biosecurity action is required.

In some cases, for example in species diagnostics during biosecurity surveillance, the work of taxonomists and diagnosticians can be distinct – professional taxonomists classify and describe the species, then others do the identification. In many other cases, taxonomists are the best and most appropriate diagnosticians because they have the deepest, broadest and most complete knowledge. And in yet other cases, where the species identity is taxonomically unclear, having taxonomists involved in diagnostics takes biosecurity forward in the understanding of both the taxa and their diagnoses, which would not be the case otherwise.

The Global Invasive Species Programme (2008) notes that:[38]

"Even where there is no direct link with taxonomists, action throughout the management system is predicated on taxonomic information – basic information on the identity, name and occurrence of both alien and native species."

4.1.1 Facilitating market access and trade

The expansion of biological reference collections and improved understanding of contained specimens can facilitate improved inbound and outbound agricultural trade. Taxonomists and biosecurity regulators often work side by side examining collections to identify priority pests and ensure they are represented in important trade and biosecurity-related protocols, such as Australia's national priority lists and those held by trading partners. Accessibility to this information by trading partners, especially as taxonomic identities are updated, is paramount to maintaining market access and ensuring that shipments are not unnecessarily delayed or rejected based on outdated information.[39]

Conversely, the costs of incomplete taxonomic information are high. Taxonomic uncertainty can stymie inbound and outbound trade deals until a satisfactory level of confidence in the classification and treatment of invasive species is reached. For example, myrtle rust and guava rust are pathogens that have the potential to infect and cause serious disease in many species of *Myrtaceae*, a family of significant Australian native plant species.[40] However, there is still no consensus over whether these two pathogens are the same or different species, and how many species there are in the guava rust complex. The resolution of these questions is critical and has multiple implications for international quarantine and market access measures imposed to restrict spread from Australia. The box that follows presents some other examples.

Biological reference collections are critical for trade outcomes

Reference collections are paramount to trade outcomes for Australian producers and consumers. Presented are some select examples identified by Plant Health Australia.

Outbound trade

Exporting to trading partners often requires verification that growing areas are free from certain known pests. Under these circumstances, well maintained specimen collections can be compared against field survey samples to determine evidence of absence. Separately, when specimens detected in Australian shipments are suspected pests, the process to identify and determine whether they are invasive or a closely related non-invasive species often requires examining samples of the species held in Australian biological collections.

- *Dwarf bunt of wheat* – in 2005 reference collections were used to prove that this pathogen did not exist in Australia. Prior to this, considerable resources had to be expended to prove freedom from this pest to export to each country.
- *Walnut anthracnose* – a specimen that was kept in a biodiversity collection was examined to provide evidence of absence of this fungal disease and allow export market access for the walnut industry.

Inbound trade

Incursions through trade pathways require evidence to differentiate suspected invasive species from similar native species. This process often draws on native species samples in reference collections, as in the cases of:

- *Blueberry and Rhododendron rust* – in 2014 samples of both species in a collection were used to differentiate the species and resume interstate trade when Blueberry rust was found in a nursery in Victoria.
- *Pine wood nematodes* – determination of whether this exotic species posed a threat to Australia's forestry industry required checking confirmed samples of this species from previous incursions. This led to a diagnosis that precluded the need for an eradication campaign, saving resources and facilitating trade.

Source: Plant Health Australia (2018), National Plant Pest Reference Collections Strategy 2018: Ensuring biological collections support trade and biosecurity

4.1.2 Faster detection and diagnostic certainty

A direct benefit of a complete taxonomic understanding of all Australian native species relates to the enhancement of biosecurity surveillance processes – the timely interception and diagnosis of potential pests in regulated pathways such as international trade. Other than regulated pathways, invasive species can also enter Australia through natural pathways, for example from the north through the Torres Strait Islands.[41]

The ability of diagnosticians and taxonomists to achieve certainty in the identification of species, given available information and biological collections to date, is critical to reducing or avoiding the costs of uncertainty.

Biological collections in Australia may include common native relatives and lookalikes of exotic pests, which is essential for the development of effective diagnostic methods.[42] Reference collections serve the purpose of defining and validating a diagnostic test, for example in the choice of a control species to use in testing. The speed and accuracy with which diagnosticians can distinguish between invasive and native species is also directly related to their ability to refer to these collections or access taxonomic expertise.

According to views heard during consultations, approximately 20-25% of 60-80 incursions under national management at any given time experience minor to significant delays to reach taxonomic certainty. The length of delay can range from days to months, with the most extreme cases stretching into a few years (though this is unlikely to happen more frequently than once every 5 years at most). More complete taxonomic knowledge is predicted to speed up the identification process to reach an acceptable level of taxonomic certainty, thus reducing the cost of delay for producers.

In terms of detection through regulated pathways, misidentification errors due to confusion between exotic and native lookalikes or incorrect delimitation of species can result in:

- **late detection of genuine threats –** risks are not detected early, leading to delayed biosecurity responses, and subsequently greater agricultural and environmental damage as well as higher eradication costs.
- **delayed evidence of absence for non-genuine threats –** a potential risk is identified that is subsequently confirmed to be a non-threat, however until that time producer losses are incurred from quarantine, product recall, or rejection from buyers.

We discuss the potential for greater taxonomic knowledge to reduce the costs of uncertainty in both cases in the remainder of this chapter. We note that this is a necessary simplification of the relationships between taxonomic knowledge and biosecurity outcomes, and complex conditional probability modelling is routinely used by ACIAR and ABARES to estimate the benefits of the biosecurity system or specific biosecurity management policies. The purpose of this exercise is to construct stylised hypothetical scenarios to illustrate the marginal contribution of improved taxonomic knowledge to biosecurity outcomes.

We note that these scenarios do not fully represent the range of invasive species and native species dynamics. This would need to take into account the impacts of climate change and other biodiversity threats, in both marine (ports and harbours) and terrestrial (native forests, rangelands) environments.

4.2 Value of taxonomy in biosecurity

Based upon the regulated pathways through which misidentification errors can occur (section 4.1.2), the benefits of improving taxonomic knowledge for biosecurity are realised according to the avoided damages from late detection of biosecurity threats and the avoided trade losses from biosecurity threats that are a false alarm.

4.2.1 Avoided damages from late detection of biosecurity threats

Late detection of invasive species can result in catastrophic losses to agricultural producers, as failure to correctly identify genuine disease, pests and weeds means outbreaks are not prevented. This can impact production of crops, horticulture and livestock, and result in long-term reputational impacts, loss of production capacity and trade e.g. resulting from export bans (as modelled by ABARES in the case of a scrapie outbreak in sheep).[43]

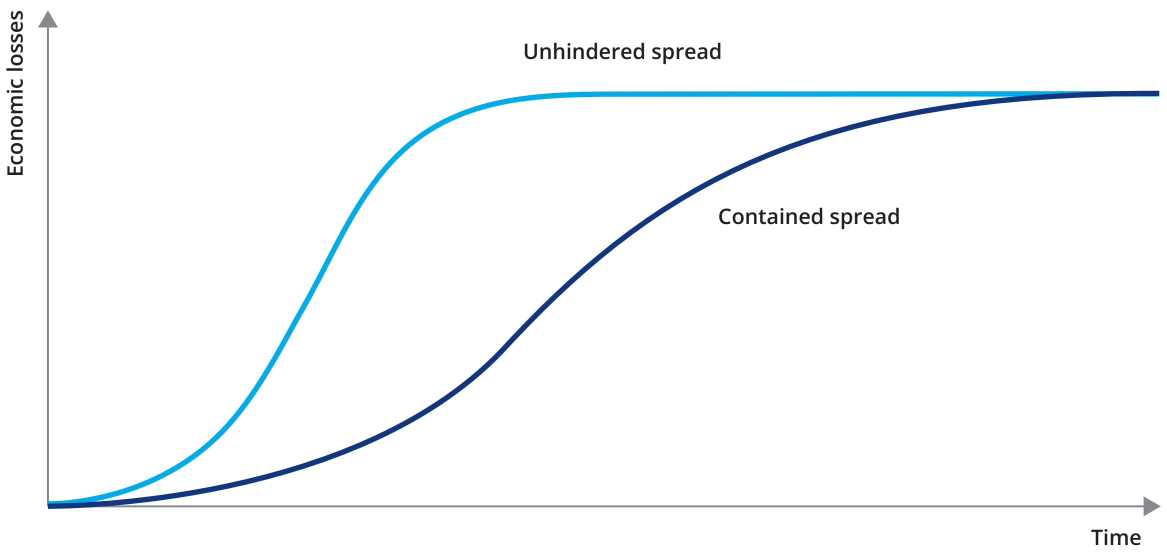
Instances of late detection can occur when taxonomic uncertainty leads to inadequate biosecurity action or a suspicious specimen not being escalated to a biosecurity specialist.

Consultations with biosecurity stakeholders revealed that this often happens in a variety of circumstances, for example:

- The target invasive species is unknown, meaning biosecurity staff either may not be aware of a risk until it surfaces, hence cannot look for it beyond regulated pathways e.g. at border inspections.
- Diagnoses of taxa that traditionally rely on visual inspection, for example ants. This can be misleading as different species can look morphologically identical. An invasive species may not be differentiated from native species until revealed by molecular diagnosis.

A slower response to managing a potential threat may result in cascading agricultural damages - for every day that there is taxonomic uncertainty over the detected species, the biosecurity response is delayed and the invasive species continues to spread. This may mean that eradication becomes less likely and the size of the damage is far larger than under early detection (Chart 4.1). In these cases, the final cost of damage depends on multiple factors, such as the spread rate, likelihood of eradication, efficacy of control measures, and value of the damaged crop or product. In other cases, early detection is necessary for successful eradication (i.e. loss reduction function is not continuous in time but discrete). For these types of incursions the economic losses of late detection are equivalent to the full amount of losses incurred under unhindered spread.[44]

Chart 4.1: Economic losses over time from different spread rates

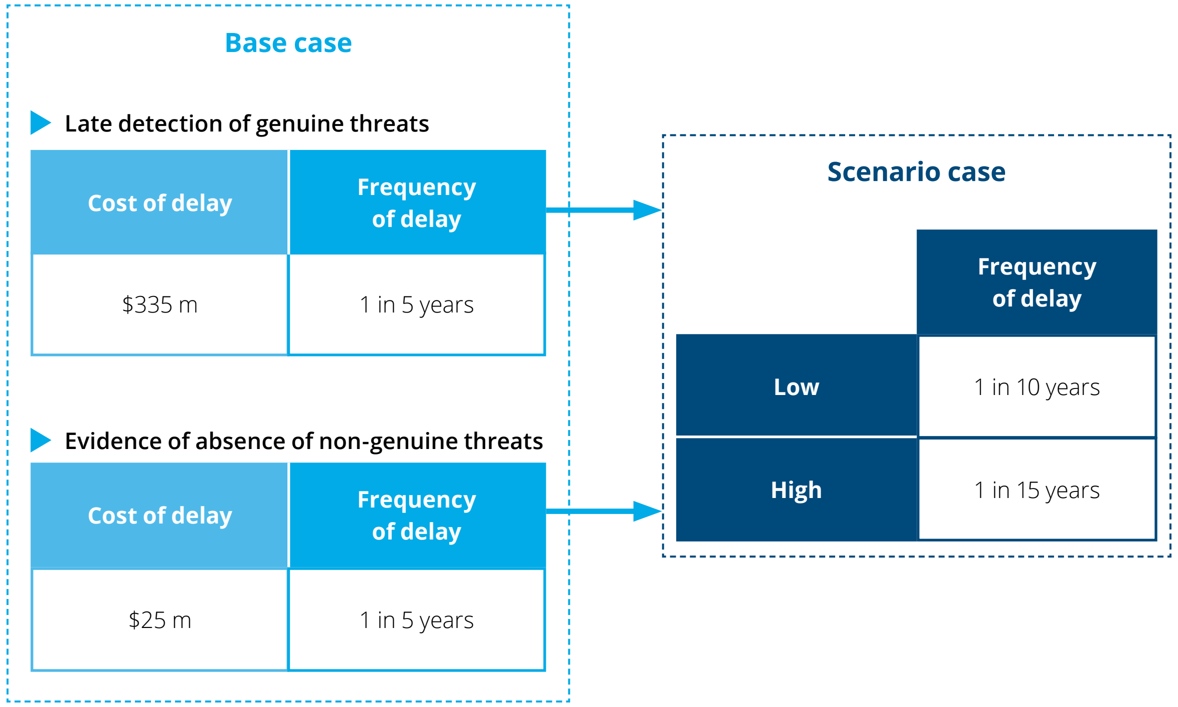


Increased taxonomic knowledge drives reduced economic losses from incursions by reducing delays in detection and taxonomic certainty over species identity. In order to infer the reduction in cost of delay, one could:

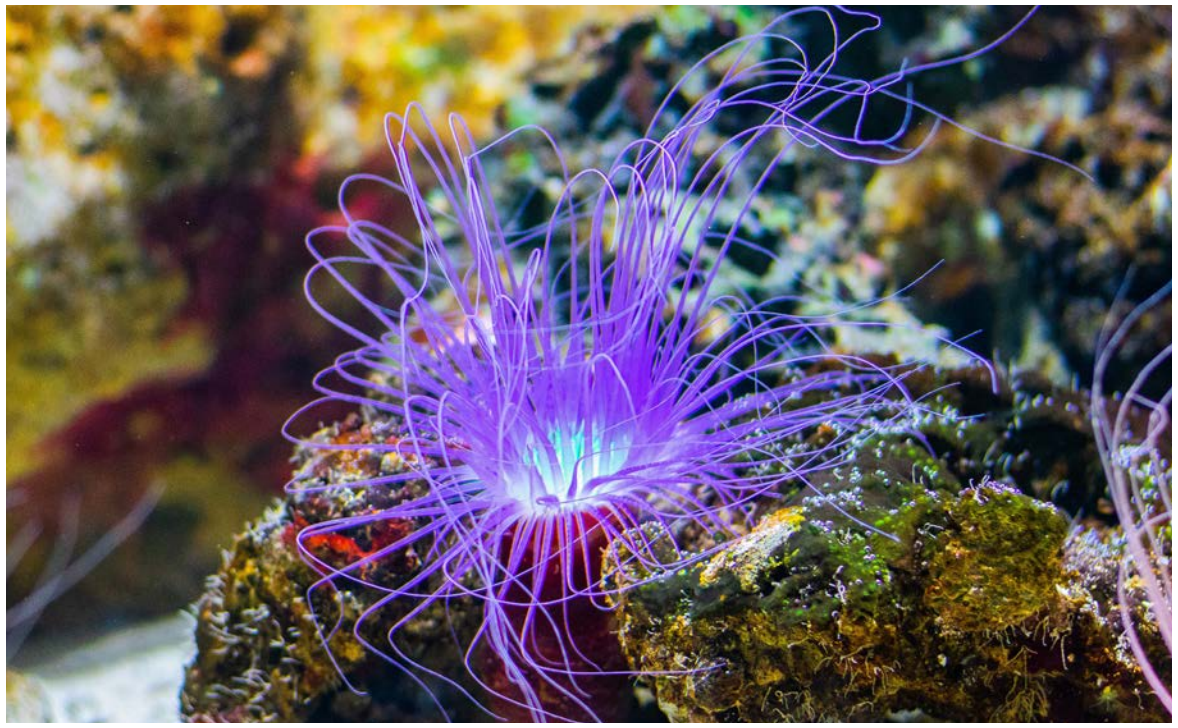
- Estimate total costs of damages attributable to late detection for all incursions, that is, formulation of a damage function that relates economic losses to detection time.
- Estimate the reduction in delay enabled by taxonomic knowledge, that is, the formulation of a function that relates detection time to taxonomic discovery.
- Bring these two functions together to estimate the reduction in economic losses enabled by taxonomic discovery.

Noting resource and data limitations that prevent the above estimation process from being undertaken here, we present a simplistic, stylised estimation of the benefits resulting from a reduced frequency in extreme delays. Historically speaking, it is these outliers that tend to account for the significant majority of economic losses. According to consultation, extreme delays in detection of incursion take place approximately once every five years. Consultees said that with more complete taxonomic knowledge, delays of this nature could be significantly reduced. These statements were strongly qualified by the need for this knowledge to be well documented and accessible.

Figure 4.1: Biosecurity value from increased taxonomy



Source: Deloitte Access Economics



Base case

We note that a range of economic losses are possible from late detection of incursions, depending on the spread rates and the value of crops damaged. The benefits of early detection and biosecurity management strategies have been estimated for a variety of hypothetical invasive species scenarios by ABARES. For example, losses from a Mexican feathergrass incursion to producers' gross profits could be $255 million per year after taking into account the annual probability of incursion.[45] The loss reduction from early detection of Mexican feather grass could be 25% to beef systems and 14% to sheep systems.[46]

We use one example of the economic losses from late detection of varroa mite through the port of Cairns. The cost of late detection, and hence the benefit from avoiding this, is equivalent to the losses from a contained spread. This is because losses cannot be fully averted – late detection restricts the best possible outcome to containment, as eradication will no longer be possible. In the case of varroa mite, this cost is estimated to be $355m.[47] The benefits of early detection, in which eradication is possible, is equivalent to avoiding the loss of unhindered spread, which is $627 million.

Under the base case, an extreme case with late detection costs of $355 million occurring with a frequency of once every five years amounts to economic losses of $1.1 billion in present value terms over 25 years.

Scenario case

We hypothesise that under the scenario case, more complete taxonomic knowledge could reduce the frequency of extreme delays to once every ten years or once every 15 years. The expectation that there will be an early and significant reduction in late detection of biosecurity threats is based on an assumption that taxonomic research prioritised by the implementation plan of the mission will focus on species which are a greater threat to biosecurity (e.g. insects, mites and bacteria). However, this is unlikely to eliminate instances of late detection, given known resource constraints in border detection and the vast scale of trade and international travel.

Under a 'low change' scenario case, in which the frequency is reduced to once every ten years, economic losses amount to $673 million in present value terms. Under a 'high change' scenario case, in which the frequency is reduced to once every 15 years, economic losses amount to $491 million in present value terms.

The net benefit of taxonomic knowledge is calculated as the difference in economic losses under the scenario and base cases, which can also be interpreted as the reduced or avoided loss attributable to a lower frequency in extreme delay**. In the 'low change' case, the present value of net benefits is equal to $435 million. In the 'high change' case, the present value of net benefits is equal to $617 million.**

Table 4.2: Net benefits from reduced biosecurity losses (present value $ million)

	4%	1%	7%
Base case	1,107	1,563	824
Scenario case – low change	673	939	512
Scenario case – high change	491	641	395
Net benefits – low change	**435**	**625**	**312**
Net benefits – high change	**617**	**922**	**429**

Source: Deloitte Access Economics, based on ABARES and stakeholder consultation

4.2.2 Avoided trade losses from false alarms

False alarms occur when taxonomic uncertainty leads to overly conservative biosecurity action, such as quarantining and recalling products suspected to contain invasive species when their taxonomic identity is uncertain. This generates costs to producers in the form of trade losses, unsaleable product and foregone production, and to biosecurity regulators in the form of labour cost and time. However, from the perspective of biosecurity regulators, a higher incidence of this may be preferable to a higher incidence of missed or late detections of threats – as these costs are smaller than those associated with an undetected genuine threat.

Consultees indicated that this kind of uncertainty can also be characterised by delays – often the true identity of a specimen isn't stated until the diagnostician is sure that it is a case of 'false alarm', which can result in costly losses and trade delays for producers.

False positive errors relating to non-genuine threats can result in economic damages to agricultural producers from one-time export losses if shipments thought to contain falsely identified biosecurity risks are rejected or consigned. For example, in 2013 a relatively harmless bacterium was misidentified as the potentially fatal C. botulinum, resulting in a recall of New Zealand export milk products worth NZ$100 million.[48]

Karnal bunt?

A prominent example of a case where a successful taxonomic and biosecurity response to a 'false alarm' enabled positive outcomes.

In 2004, Pakistan rejected a 150,000 tonne shipment of wheat from Australia worth A$25 million (in 2019 dollars) due to suspected presence of a fungal pathogen, karnal bunt, *Tilletia indica.*[49] This led to 495 consignments at sea being halted and placed at risk of rejection by their export destinations, including Egypt, Saudi Arabia, and South Korea.

During this crisis, 40 pathologists from all wheat growing states surveyed samples from every port wheat store in Australia using the National Diagnostic Protocol for *T. indica. T. indica*-like spores were detected in 60% of samples, but were subsequently confirmed as a harmless relative, *T. ehrhartae* using herbarium specimens from the Victorian Plant Pathology Herbarium. The identification of *T. ehrhartae* utilising reference collections and good taxonomic observation facilitated the following outcomes:

- proof that *T. indica* does not occur in Australia (evidence of absence)
- reassurance to trading partners that Australian trade is science-based
- resumption of the multi-billion dollar wheat export trade.

Source: Information provided by consultees

Taxonomic discovery can help reduce 'false positive' diagnoses of non-genuine threats. Making accessible information about native lookalikes helps to establish evidence of absence that enables biosecurity regulators to clear shipments for trade.

For example, the Plant Biosecurity CRC based at Agriculture Victoria's AgriBio, Centre for AgriBiosciences, recently discovered a new type of native eggplant psyllid, which can help ensure diagnostic tests do not give false results for destructive diseases associated with other types of psyllids, such as the tomato potato psyllid.[50] The tomato potato psyllid (TPP), *Bactericera cockerelli,* is known to spread zebra chip disease and has recently been detected in Western Australia. TPP and the eggplant psyllid both feed on eggplants, making this research highly relevant to the large-scale surveillance for TPP currently taking place across Australia. Both zebra chip and citrus greening diseases pose severe threats to Australia's potato and citrus industries. Therefore, a misdiagnosis could result in substantial foregone trade revenue.

As with the late detection of biosecurity threats in section 4.2.1, we hypothesise that more complete taxonomic knowledge could reduce the losses from delayed evidence of absence in cases of non-genuine threats.

We hypothesise that under the scenario case, more complete taxonomic knowledge could reduce the frequency of these delays to once every ten years or once every 15 years.

We use one example of the economic losses from the case of suspected karnal bunt in the Pakistan shipment from 2004, valued at $25m in 2019 dollars. We note that this is not intended to be a fully representative cost, given the highly variable and infrequent nature of these incidents. For example, another prominent case of this type of 'false alarm' incident cost NZ$100 million in 2013.

Base case

Under the base case, an extreme case with delayed evidence of absence of $25 million occurring with a frequency of once every five years amounts to economic losses of $78 million over 25 years in present value terms.

Scenario case

Under a 'low change' scenario case, in which the frequency is reduced to once every ten years, economic losses amount to $47 million in present value terms. Under a 'high change' scenario case, in which the frequency is reduced to once every 15 years, economic losses amount to $35 million in present value terms.

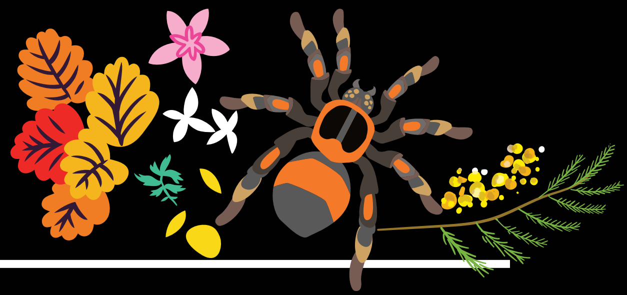
The net benefits of taxonomic knowledge is calculated as the difference in economic losses under the scenario and base cases, which can also be interpreted as the reduced or avoided loss attributable to a lower frequency in extreme delay. **In the 'low change' case, the present value of net benefits is equal to $31 million. In the 'high change' case, the present value of net benefits is equal to $43 million.**

Table 4.3: Net benefits from reduced biosecurity losses (present value $ million)

	4%	1%	7%
Base case	78	110	58
Scenario case – low change	47	66	36
Scenario case – high case	35	45	28
Net benefits – low change	**31**	**44**	**22**
Net benefits – high change	**43**	**65**	**30**

Source: Deloitte Access Economics, based on ABARES and stakeholder consultation

5



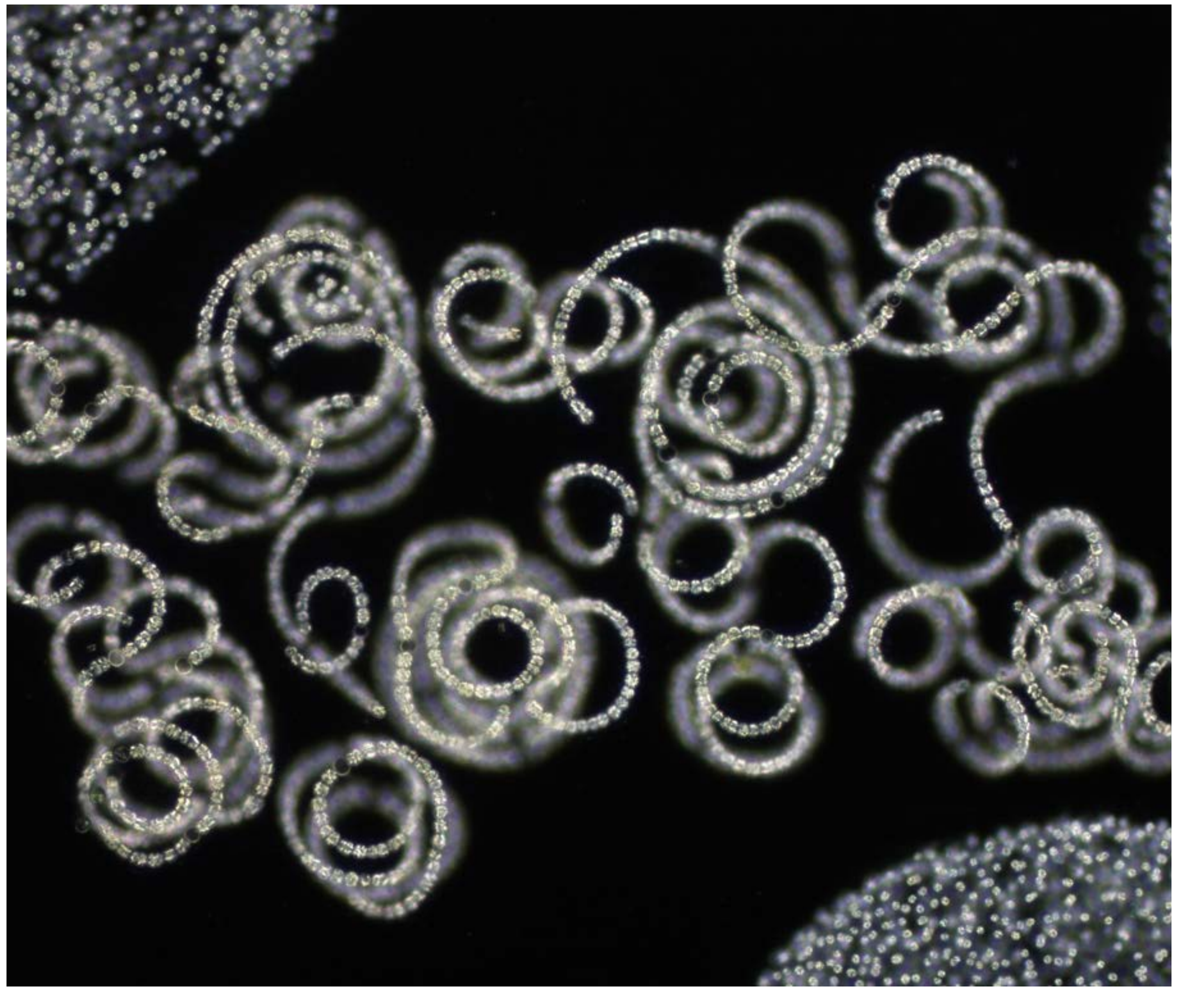
Benefit stream 2: Biodiscovery for human health

Biodiscovery is the process of sourcing natural compounds from species with applications in agriculture, medical and pharmaceuticals products, and cosmetics. Biodiscovery has significant potential to create value in the form of health benefits for patients and commercial benefits for the pharmaceutical research and development industry.

Over the last three decades, pharmaceutical companies' investment in natural product-based biodiscovery has declined significantly, not only in Australia but worldwide.[51] Consultations revealed that this is partially explained by growing cost pressures in the pharmaceutical industry, coupled with the reduced willingness of companies to invest in certain types of pre-clinical research bearing highly uncertain returns. The withdrawal of these resources for exploratory research has meant that governments have increasingly taken on the cost burden. Even so, declining funding has led to the underproduction of taxonomic biodiscovery research relative to the full value of potential benefits. As noted in section 1.3, taxonomic research is a classic public good that benefits many users who do not contribute towards full cost recovery.

There are strong benefits to developing collaborative and sustainable funding approaches for taxonomic biodiscovery research. Without the foundational study of natural resources, there can be no natural resources to develop and commercialise. Long lead times from research to application can also mean that long-term returns from investment are not considered within the constraints of short-term funding cycles.

Views from stakeholders in the taxonomy and biodiscovery sectors have included ideas such as the establishment of for-profit national facilities to collect, store, curate and sell samples for biodiscovery screening. These would be central points to deposit extracts potentially containing new compounds made available to medical research institutes, and would serve as a starting point for molecular research.[52] This, and other innovative funding models, could help meet the funding and investment needs necessary to achieve Taxonomy Australia's mission.



Sharing the benefits of biodiscovery in Queensland

In 2018, the Queensland Government entered into a Benefit Sharing Agreement with Griffith University to give the Griffith Institute for Drug Discovery (GRIDD) the right to use native biological material from Queensland State land and waters for biodiscovery. GRIDD brings together research partners from Griffith University, NatureBank and Compounds Australia to find natural solutions to challenges in health, agriculture, food and cosmetics through biodiscovery.

Biodiscovery encompasses a stage of the R&D value chain that involves locating potentially valuable bioactive compounds in nature, collecting samples of native biological materials (such as plants, marine sponges and microorganisms) and testing for chemical compounds, in some cases those that have commercial applications, for example in pharmaceuticals and agricultural biocides. According to GRIDD Principal research leader Professor Ron Quinn, the Benefit Sharing Agreement "provides a path to sustainably use naturally produced compounds by decoding nature's language, something that the original inhabitants of this land valued over thousands of years."

GRIDD's work includes screening plants, fungi and marine invertebrates in Queensland to identify new medical drugs. NatureBank is a drug discovery platform with over 100,000 natural product samples for high-throughput screening.

Rather than relying on chance discoveries or isolating active ingredients in traditional medicines, modern natural product-based drug discovery has become increasingly targeted, by better understanding the molecular and physiological levels of diseases and infections, to target specific therapeutic responses, or drug targets. This is also providing fertile opportunity for international research collaboration, for example with the University of Luxembourg in the area of anti-Parkinson drug discovery, and nutraceutical companies in the area of health food supplements.

Source: Queensland Government (2018)[53]

5.1 Taxonomic knowledge driving biodiscovery

Historically, until two to three decades ago, the pharmaceutical drug discovery process was dominated by the biodiscovery process. This process is essentially the study of plant, animal, fungal and microbial species to find pharmacologically active compounds for testing and development (at which stage the synthesis of natural product derivatives can be undertaken).

Some 25-60% of all drugs today are derived from natural compounds, depending on the extent of derivation from natural products considered.[54,55,56] Of all new approved drugs for cancer from 1981-2010, 49% were derived directly from natural sources, and an average of 34% for all clinical targets over 30 years.[57]

Many natural product-based drugs originate from microbial species, particularly in the anti-infective area. Plant-derived drugs have also made significant contributions, notably natural plant-derived drugs such as morphine, artemisinins, and quinine. Drugs from marine organisms are also making an increasing contribution. For example, a new protein derived from cone snail venom, conotoxin, is 1,000 times more potent than morphine but without the side effects of addiction.[58]

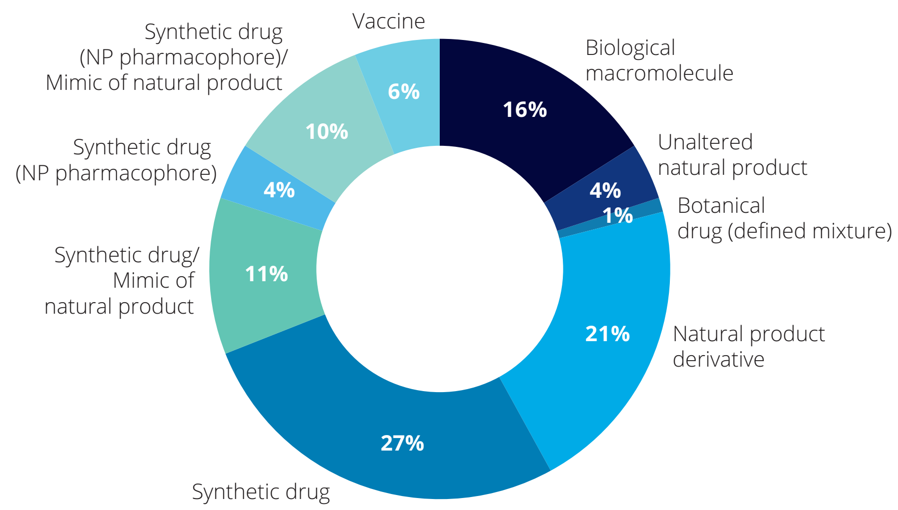
According to stakeholders consulted who are engaged in different parts of the biodiscovery and natural product-based drug development value chain, at least 25% of drugs used today could not have been developed without the knowledge of natural products. These are generally drugs that are:

- Unaltered natural products
- Botanical drugs (defined mixture)
- Natural product derivatives.

These were historically used to develop:

- antibiotics for infectious diseases – these molecules are difficult to originate or replicate using synthetic, computational chemistry
- immuno-modulators for transplant procedures – these molecules cannot be designed synthetically.

Chart 5.1: All new approved drugs 1981-2014



Source: Newman and Cragg (2016),[59] n = 1,562

The last 40 years has seen the emergence of rational drug design, that is, the design and synthesis of small molecules intended to interact with target biological proteins and antibodies in the human body. This has been successfully applied to develop cytostatic drugs to treat cancer, antiviral drugs to treat flu and statins used to lower cholesterol.[60] Drugs developed using these processes can be categorised as:

- Synthetic drugs
- Synthetic drugs with natural product pharmacophore.

In addition, 'biopharmaceuticals' research (vaccines, blood, blood components, allergenics, somatic cells, gene therapies, tissues, recombinant therapeutic protein) has proved particularly promising in the fields of infectious diseases, immunotherapy and cancer treatments.[61]

Rather than being a substitute, rational drug design is considered complementary to biodiscovery, due to the types of diseases that are targeted by the two different molecular discovery pathways. Unlike rational drug design methods, natural compounds and natural product-based drugs tend to be developed when there is no starting point for the design of molecules, and generally starts with more complex molecules.

5.1.2 The future of biodiscovery

The overall volume of drugs developed is expected to expand as biopharmaceuticals research grows in the future. Within this growing 'pie', the relative volume of natural product-based drugs may shrink as a proportion of total drugs discovered. However, given that the value of natural product-based drugs cannot be entirely displaced by drugs developed using rational design methods, there are significant potential benefits from continued biodiscovery research. For example, bacterial resistance to antibiotics for many infectious diseases is on the rise, and novel natural product-based compounds will play a role in countering this threat to public health.

Other trends impacting the biodiscovery value chain over the previous decade include technological developments that have enabled bioassay testing to become more cost-effective and efficient, for example, technologies that minimise the amount of material needed for sampling. This has also given biotechnology researchers access to organisms that were previously inaccessible and may open new spaces for drug discovery. The principle of diminishing marginal returns suggest that returns to biodiscovery may be greatest in the discovery of species that are most different to already known species, as these are likely to yield new products in a way that other, more distantly related, organisms do not (see Box below).[62] That is, the marginal contribution of new species discovery to biodiscovery must consider the probability that other species available for testing would not have yielded the same outcome.

Greater taxonomic understanding has the potential to drive significant improvements in the effectiveness of biodiscovery. A more complete understanding of species relationships will allow a more focused exploration of the molecular potential of different species groups.[63] This in turn enables more strategic targeting of species discovery, which can lead to higher probability of drug discovery and more strategic targeting of known species for sampling – that is, it improves the choices in species to test for bioactive compounds against different and emerging diseases.

Valuing biological resources – principles and problems

Source: Reproduced from Lead and Beattie (2005) in New Products and Industries from Biodiversity

Several principles are important in considering the economic value of bioprospecting.

First, economic values are determined at the margin. This means that values must be placed in the context of particular magnitudes of change. If the great majority of Earth's biodiversity were to be lost, the value of the lost opportunities for inventing and improving products would be astronomical. Less value would be foregone if fewer components of biodiversity were at risk.

Second, research and development is an inherently random process, and the outcomes are uncertain. The value to be assigned to a change in the biodiversity available for conducting research is related to the increase in the expectation of the outcome it affords.

Third, value is determined by scarcity. If there is a lot of something, a little more or less of it does not make much difference. Conversely, unique resources command large values because there are no substitutes for them. These are illustrated by a thought experiment. Suppose there are many species that might provide the source of a particular new product. Many analyses of the value of bioprospecting have focused on the expected reward to success: the probability of making a "hit" times the payoff from developing a successful product. However, the value of biodiversity at the margin—what we might label the value of the "marginal species"—is the incremental increase in the expected reward to success. It is the probability of making a "hit" times the payoff times the probability that none of the other species available for testing would have yielded the same success.

While commentators often emphasize the rewards accruing to success, other considerations may be more salient. As the number of species researched increases, the value of having more necessarily declines and, in the limit, vanishes. This can be explained as follows. If the probability that any one species chosen at random will yield a success is relatively high, it is unlikely that it will be necessary to test a large number of species in order to achieve a success. Conversely, if the probability of success in testing any one species is low, it is unlikely that two or more will prove redundant, but also unlikely that any will prove successful. Regardless of the likelihood of success in any given test, the value of the "marginal species" will be small when the number of species is large.

The same species may, of course, be tested for any of a number of different applications. Thus, in order to calculate the overall value of the "marginal species," one would have to sum the values in all potential applications, both current and anticipated. If there are relatively large numbers of species available for testing, comparably large numbers of potential applications would need to be identified for the value of the "marginal species" to be appreciable. Moreover, not all species are equally attractive as potential research leads. Other things being equal, organisms that are "most different" from others will be more valuable. This is not because they are necessarily more likely to yield new products, but rather because they are more likely to yield new products in the event that other, more distantly related, organisms do not.

Knowledge is also valuable. Researchers will test first those organisms most likely to yield a success and will be willing to pay more to do so. The fact that some organisms are known to promise more leads means, necessarily, that others are considered less promising and less valuable. If promising prior information is available on the properties of species from better-known regions, the bioprospecting value assigned to the as-yet undescribed species of the world's remaining pristine ecosystems will be commensurately lower.

The pool of species with high pharmaceutical potential could be very large, based on various considerations in the literature outlined above, and stakeholder perspectives provided in stakeholder consultations. Some of these include:

- Scientists have identified 25 mega-diverse hotspots in the world with a wide range of genetic sources that pose potential for new drugs. Because these places have not been systematically sampled, the species that live there could be promising "most different" candidates for biodiscovery.[64] Two of these hotspots are South West Australia and New Zealand, which collectively host 7,800 vascular plant species of which 6,165 are thought to be endemic.
- Marine species have been identified as a high potential taxon group during stakeholder consultations, with 10,000 marine natural products (MNPs) discovered from marine invertebrates between 1990 and 2009.[65] Of these, brown algae and sponges are the most prolific producers (56% of MNPs). Cytotoxicity has been shown to be highly valuable and the most widespread activity class amongst compounds identified in nature.[66] Estimates of total marine species range from 700,000 to 1 million, of which only around 200,000 species are currently known (24-33%) and of which an estimated 366,000 species are potentially bioactive (36-52%).[67]
- Other studies have estimated that the current success rate of discovery from the marine world, namely seven clinically useful and approved drugs from 28,175 discovered molecular entities (e.g. one drug per 4,025 natural products described) is approximately 1.2- to 2.5-fold better than the industry average (1 in 5000–10,000 tested compounds).[68]
- Microorganisms also represent diverse potential for biodiscovery; however, exact estimates have not been included in the sampling pool estimates as there are current technological limits to the testing of compounds from micro-organisms, many of which cannot be cultured. If this limitation were to change, using new technologies, this could open up hundreds of thousands of diverse species for further taxonomic study and biodiscovery.

Based on the high potential represented by marine species, we estimate that a pool of 500,000 unknown species could be a reasonable size of species for priority biodiscovery sampling.

5.2 Value of taxonomy in biodiscovery

Generally, biodiscovery is a multi-staged, collaborative process in which biotechnology researchers at academic institutions or small companies and pharmaceutical companies play distinct roles at different stages. In most cases, biotechnology researchers prepare species for sampling and sell these samples to pharmaceutical companies under commercial knowledge-sharing arrangements.

Some biodiscovery benefits are outlined by the Nagoya Protocol under the UN Convention on Biological Diversity (CBD) in both monetary and non-monetary terms. These include:[69]

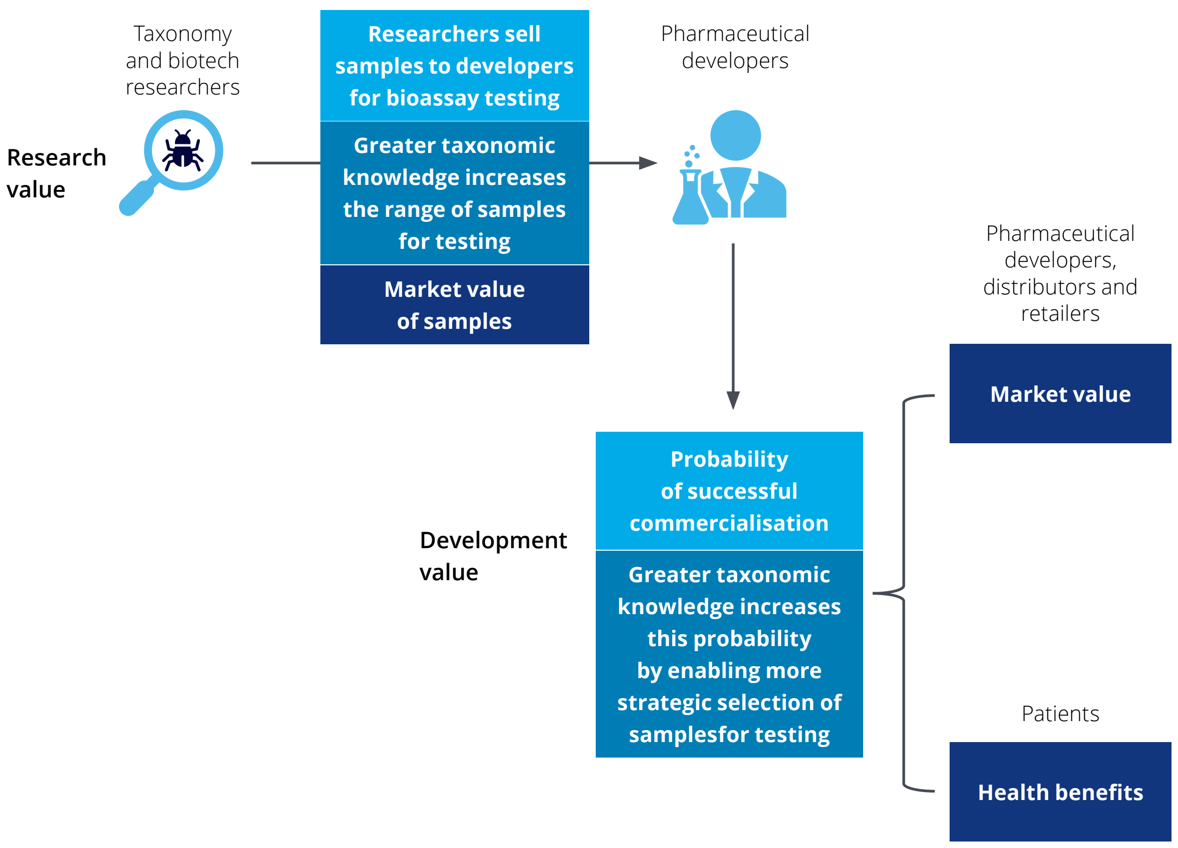
- access fees/fees per sample collected
- royalty payments
- milestone payments
- participation in product development
- sharing of research and development results
- collaboration, cooperation and contribution in scientific R&D programmes including biotechnical research activities
- institutional capacity-building
- human and material resource sharing and training.

Other than transaction value, we can also consider the health benefits to end-users of natural product-based drugs and medicines, such as avoided deaths or disease years attributable to these drugs.

Importantly, we recognise that the monetary valuation of biodiscovery benefits does not address adverse impacts, including the unsustainable harvesting of species for commercial interest. It also does not take into account value that is withheld from traditional owners of ecological knowledge (for example, Indigenous knowledge of medicinal plants), as well as other impacts of commercially driven bioprospecting on the rights of the Native Title owners. These issues are discussed at length in various reports for IP Australia on the value of Indigenous knowledge and in an international context.[70,71,72] It is also paramount to recognise that commercialisation may introduce priorities into the biodiscovery research agenda that disadvantage species that are of environmental or other importance. It is vital that not only species deemed economically important are considered for taxonomic research, but also species that are important to ecosystems whose value cannot be conventionally measured.

We present two separate estimates of the research (pre-commercialisation) value and development (post-commercialisation) market value and health benefits of biodiscovery.

Figure 5.1: Biodiscovery value chain



Source: Deloitte Access Economics

5.2.2 Research value

In the research stage of the biodiscovery value chain, the pre-commercialisation value of species samples represents the transaction value between biotechnology researchers and pharmaceutical developers. It is important to note that this does not represent the commercialised value of the species sample, since this value occurs post-commercialisation and transaction prices only partially reflect the probabilities of species samples being of pharmaceutical significance. Regardless of whether the samples are found to be pharmacologically bioactive, useful, or able to be commercialised, there is a significant amount of real economic value that is generated in the research stage.

In order to estimate the pre-commercial value transferred from biotechnology researchers to pharmaceutical developers, we multiply the number of potential species for targeting by the monetary benefit associated with each species. One measure of monetary benefit is the fee per sample paid by developers to researchers (a necessarily simplistic measure of value that does not capture other value generated in knowledge-sharing agreements such as milestone payments to cover overhead costs at various stages of the research and development process).

A review of five major transactions by pharmaceutical companies Novartis, GlaxoSmithKline and Merck and Co indicates that the prices paid to biotechnology researchers for bulk samples have historically ranged from $100 to $1,000 per sample.[73] Another transaction identified in the literature records the present value of each extract in a pharmaceutical screening program at $500. In our approach, we take $500 as a benchmark fee per sample.

According to stakeholders, approximately 20,000 species samples are tested every year in Australia. For 20,000 samples at $500 per sample, such a transaction between biotechnology researchers and pharmaceutical developers would generate value of $11 million. Assuming this type of R&D transaction occurs every year, the present value of benefits to 2045 under the base case would amount to approximately $172 million. Under the scenario case, in which the number of samples tested for biodiscovery doubles to 40,000 samples relative to the base case after a delay of 5 years, the present value of benefits would reach $295million. **Benefits achieved under the scenario case above the base case would therefore amount to $123 million (see Table 5.1).**

5.2.3 Development value

For the development stage of the biodiscovery value chain, we estimate both the market value and health benefits realised through the commercialisation of natural product-based drugs. We recognise two important components in this process. Firstly, the selection of bioactive samples of pharmaceutical interest is a key outcome of the pre-clinical and clinical testing and development process. Secondly, these samples must also be successfully commercialised and gain market access in order to generate health benefits to patients and market value to producers. It is important to note that health benefits and market value cannot be added as they represent value flowing from the same transaction between patients and pharmaceutical companies.

Stakeholder consultation provided the estimates of the proportion of samples selected in each stage in Figure 5.2. These can be multiplied to yield the compound probability of drug commercialisation from any species tested.

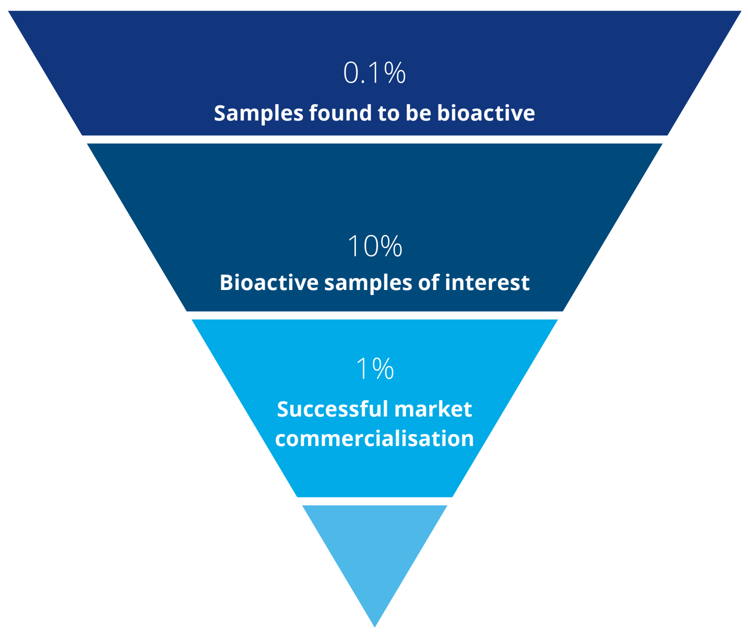
Table 5.1: Research value of bioprospecting samples (present value $million)

	4%	1%	7%
Base case	172	242	128
Scenario case	295	431	211
Net benefits	**123**	**189**	**83**

Source: Deloitte Access Economics analysis

Total prospective samples

Figure 5.2: Probability of market commercialisation in biodiscovery sampling



Source: Deloitte Access Economics based on stakeholder consultation

Overall, the probability of any species-derived sample being successfully commercialised for a disease in one year is as low as 0.0001% - that is, a **1 in 10,000 chance.** This is a conservative lower bound on the probability of commercially developed drugs that could be derived from natural products in the future. It is close to the industry average of one drug in 5,000 to 10,000 tested compounds, which is purportedly lower than the rate specific to natural product-derived drugs.[74] The range of estimates identified include:

- Approximately one clinically useful and approved drug derived per 4,025 marine natural products described, or 0.025% of samples.[75] Approximately 36-52% of marine species are thought to be bioactive, in contrast to 10% of all species that is built into the overall probability assumption.[76]
- Between 10,000-23,000 plant species have been identified in patents on pharmaceutical preparations in the World Patents Database, representing at least 0.5% of total described species. However, since this does not take into account the proportion of patents that are successfully commercialised, the proportion of drugs to plant species is likely to be lower than 0.5%.[77]

To derive total market value and health benefits arising from testing of natural compounds in species, it is possible to apply this conservative lower bound probability to measures of commercial value and economic benefits of these drugs and medicines found in the literature (Table 5.2):[78]

- Health benefits range from $38-75 billion per species, based on estimates of 22,500 to 37,500 lives saved in the US per year.
- Market value ranges from $1.8-6.2 billion per species.

Table 5.2: Selected values for plant-based pharmaceuticals ($ billion)

	Annual value per species
Market value of trade in medicinal plants	1.8
Market value of plant-based drugs	6.2
Value of plant-based drugs based on avoided deaths (anti-cancer only)	38
Value of plant-based drugs based on avoided deaths (anti-cancer and non-cancers)	75

Source: Deloitte Access Economics estimates based on Lead and Beattie (2005) and Principe (1989), adjusted for population and inflation. All values expressed in Australian 2019 dollars.

Taking the probabilities of commercialisation into account, the market value from sampling 500,000 species each year could reach $4.0 billion annually. The health benefits of plant-based drugs based on avoided deaths could be almost ten times as large, $37.5 billion.

Base case

In a 'business as usual' world, as outlined above, the probability of any species-derived sample being successfully commercialised for a disease in one year is as low as 0.0001% - that is, a 1 in 10,000 chance.

Based on stakeholder consultations, the continued development of drugs under rational drug design research methods is not expected to substitute or otherwise impact on the value of biodiscovery over time.

Taking the probabilities of commercialisation into account, the market value from sampling 20,000 species each year could reach $160m annually. The health benefits of plant-based drugs based on avoided deaths could be almost five times as large, $1.5 billion.

Under the base case, the present value of benefits could be $2.5 billion in market value and $23.5 billion in health benefit value.

Scenario case

Taxonomy Australia's mission will enable greater taxonomic discovery in high potential species and increase the development of pharmacological discovery. Stakeholder consultations revealed that the most likely benefit from increased taxonomic knowledge would be to enable more strategic targeting of species to be tested. The mechanism through which greater strategic targeting of species sampling is assumed to occur is the selection of species or compounds with higher potential for bioactivity.

This may not be the only benefit. For example, greater taxonomic knowledge could eventually lead to a greater number of species being tested than is currently possible. Setting these other possibilities aside, we model the benefit of greater strategic testing through an increase in probability of samples being bioactive (0.1% in the base case), and ultimately an increase in the probability of any species-derived sample being successfully commercialised (0.0001% in the base case).

Currently, the number of samples that are potentially bioactive is unknown, and in fact many samples that are tested may have zero bioactive potential. More strategic testing would enable only samples with potential for bioactivity to be tested. This in turn results in a higher end likelihood of any single assay or test of a sample against a disease being bioactive.

An example for illustrative purposes follows.

- 0.1% of samples test positively for bioactivity. This means 1 in 1,000 samples – however of this 1,000, a significant unknown number of total samples have no potential for bioactivity. The true probability of bioactivity in a pool of all potentially bioactive samples is unknown. Hypothetically, if this probability is 10%, meaning 100 samples are potentially bioactive, then this would make the probability of successfully testing for bioactivity, given all samples are potentially bioactive, 1 in 100, or 1%.
- Taxonomic discovery makes the sample selection more strategic such that a higher proportion of total samples are potentially bioactive. If this proportion were to increase by tenfold, i.e. from 10% to 100%, then all 1,000 samples would be potentially bioactive. However, the probability of successfully testing for bioactivity remains unchanged (1%) or 10 out of 1,000 samples.

Based on stakeholder consultation, we hypothesise that an initial 10% of samples are potentially bioactive, and that under the scenario case, this proportion increases fivefold to 50%. This results in a fivefold increase in the overall probability of successful drug commercialisation to 0.0005% under the scenario case. We conduct sensitivity analysis around this key assumption using a lower bound estimate of a twofold increase in probability and an upper bound estimate of a tenfold increase.

The scenario case also builds in a 20-year delay before the benefits begin to be realised. The first five years of this delay relate to lagged benefits from Taxonomy Australia's mission beginning to impact the biodiscovery sector, and the last 15 years of this delay represent the length of the drug discovery lifecycle from successful discovery to commercialisation.

This results in a higher amount of market value and health benefits that are possible. Under the scenario case, the present value of these activities could be $8.2 billion in market value and $38.4 billion in health benefit value.

The net benefits are equivalent to the difference between scenario case and base case benefits. **Net benefits are equivalent to $1.3 billion in market value and $12 billion in health benefits in present value terms over a 25-year period.**

This is at least as large as the annual gross value added for the pharmaceutical and medicinal product manufacturing industry in Australia, which in 2018-19 was approximately $3.4 billion.[79]

Table 5.3: Core results – market value and health benefits (present value $ billion)

	Market value	Health benefits
Base case	2.5	23
Scenario case	3.8	36
Net benefits	**1.3**	**12**

Source: Deloitte Access Economics. The core 'medium' scenario represents a fivefold increase in probability of drug commercialisation, 4% discount rate.

Sensitivity analysis

It is important to note that this scenario represents a midpoint in a range of possibilities that may occur, depending on the extent of cost-effective strategic targeting of samples enabled by the mission. The lower end of this range of benefits, assuming only a twofold increase in the probability of drug commercialisation of any tested sample, is $600 million in market value and $3 billion in health benefits value. The upper end of this range, assuming a tenfold increase in the probability of commercialisation, is $5.8 billion in market value and $27 billion in health benefit value. Tables 5.4 and 5.5 present the results of sensitivity analyses around the key probability assumption and discount rates.

Table 5.4: Sensitivity results - market value (present value $ billion)

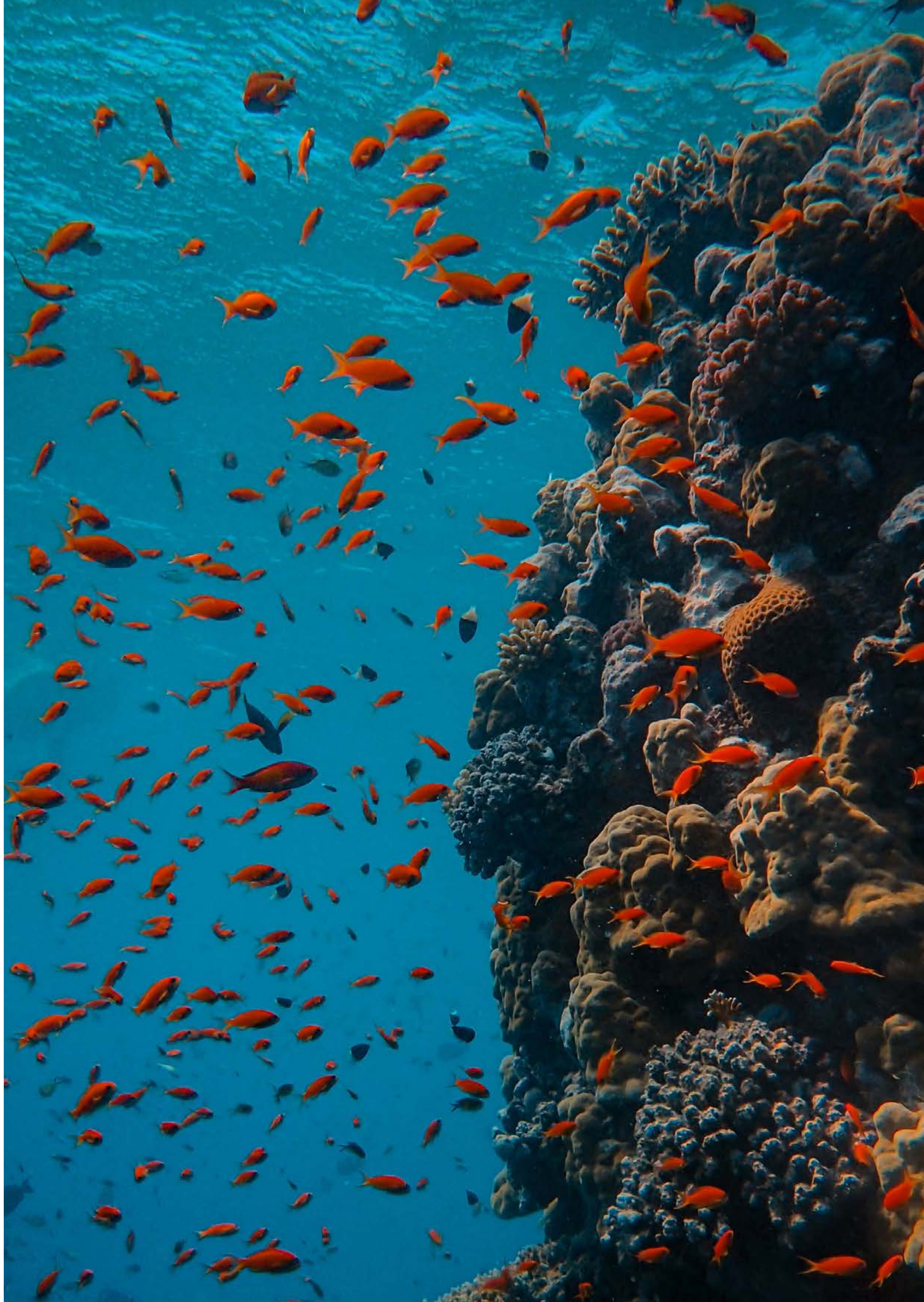
	4%	1%	7%
Base case	**2.5**	**3.5**	**1.9**
Scenario case			
Twofold probability increase	2.8	4.1	2.0
Fivefold probability increase	3.8	6.1	2.5
Tenfold probability increase	5.4	9.2	3.4
Net benefits			
Twofold probability increase	0.3	0.6	0.2
Fivefold probability increase	1.3	2.5	0.7
Tenfold probability increase	2.9	5.7	1.5

Source: Deloitte Access Economics

Table 5.5: Sensitivity results – health benefits (present value $ billion)

	4%	1%	7%
Base case	**23**	**33**	**17**
Scenario case			
Twofold probability increase	27	39	19
Fivefold probability increase	36	57	24
Tenfold probability increase	51	87	32
Net benefits			
Twofold probability increase	3	6	2
Fivefold probability increase	12	24	6
Tenfold probability increase	27	54	14

Source: Deloitte Access Economics



6

Benefit stream 3: Agricultural R&D

As outlined in the Decadal Plan, more complete taxonomic knowledge and biosystematics processes will provide significant opportunities for industry and agriculture. A multitude of micro-organisms impact Australia's agricultural and aquacultural systems in ways that are both known and unknown. There is also a multiplicity of ways in which greater taxonomic knowledge of native species can support and enhance R&D in Australia and New Zealand's agricultural industries.

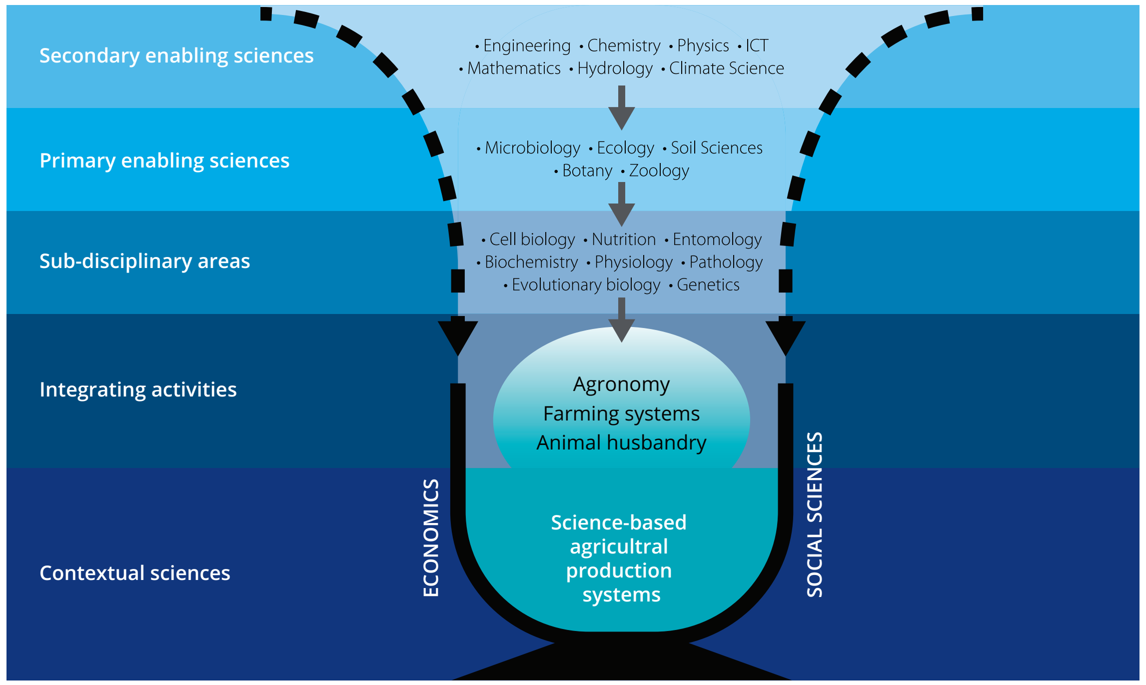
In general terms, improvements to agricultural production systems may take place with multiple intersecting disciplines and integrated research pathways, for which taxonomic knowledge serves as the foundation (Figure 6.1).

A few of the pathways in which taxonomic research enables increased benefits, which are not fully elaborated on in this report, include:[80]

- Discovery of species and genes that contribute to the transition to biomanufactured foods
- Greater understanding of soil and aquatic microbes enhancing yield productivity
- Greater understanding of the taxonomy of pests and pathogens
- Discovery of new and more effective biological control agents
- Discovery of native crop plants and animals with genetic traits that enhance breeding for e.g. disease resistance, yield productivity.

Of these pathways and more, only the benefits of taxonomic study on native crop plant species have been quantified for this rapid CBA.

Figure 6.1: Discipline inputs into agricultural sciences



Source: Reproduced from National Committee for Agriculture, Fisheries and Food (2017)[81]

Biomanufacturing the foods of the future

Global megatrends shaping Australia's agricultural industry will increasingly need to draw on the resources and knowledge embodied and enabled by taxonomy. For example, ecological constraints and changing consumer preferences are driving the need to find innovative and environmentally sustainable ways of feeding the world. Biomanufacturing of alternative proteins such as lab-grown meat and insect- or fungal-based protein and carbohydrates is one emerging solution.

While biodiversity has always been the source of the human food chain, biomanufacturing will require the development of new food technologies and an increased understanding of plant, animal, fungal and bacterial species. This is supported by an expanding role for taxonomic and biosystematics research.

Previous work conducted by Food Frontier and Deloitte Access Economics to quantify the economic contribution of Australia's plant-based meat sector show strong growth prospects for these products. By 2030, the Australian plant-based meat sector is projected to grow from $150 million in consumer expenditure in 2018-19 to between $1.4 billion to $4.6 billion, including economic contributions from employment, exports and value-added potential.[82]

Australia and New Zealand are well-placed to advance and commercialise the R&D that is produced in this area, with long-standing and extensive industry expertise and experience in food production chains and well-established reputations for quality in export markets. Australian start-ups, such as Wodonga-based v2Food, lab-based meat start-ups in Brisbane and Sydney, and agtech accelerators such as Sydney-based Cicada GrowLabs and Melbourne-based Rocket Seeder, are also driving domestic innovation in agricultural R&D.[83]

Soil and microbiomes

Increased taxonomic knowledge of soil bacteria can lead to improved soil fertility and crop management practices with economic benefits for agricultural producers and consumers.

As the Decadal Plan for Australian Agricultural Sciences puts it:[84]

"The interface between plant roots and the soil microbiome is still largely a 'black box' with regard to a true understanding of the functional diversity of the soil microbiome, the role of redundancy and the reciprocal ways in which plants and the microbiome influence each other…. Being able to consciously select the soil microbiome has the potential to significantly influence productivity and sustainability."

A few examples of public research projects include the Biomes of Australian Soil Environments (BASE) soil microbial diversity database and the Australian Centre for International Agricultural Research (ACIAR) research programmes.[85]

In the research value chain, taxonomic research comprises 'upstream' knowledge that directly or indirectly feeds into research in various independent and integrated sub-disciplines necessary for agricultural R&D to improve soil and crop management. This 'downstream' research and development has demonstrated substantial economic and social value. For example, a review of economic impact assessments of benefits of agricultural R&D indicate that the present value of benefits from ACIAR research project streams is estimated at around $22 billion to $30 billion.[86]

6.1 Taxonomic knowledge driving crop wild relatives research

For this rapid CBA, crop wild relatives R&D has been chosen for quantification, representing merely one of many possible applied agricultural benefits from increased taxonomic research.

Taxonomic knowledge of wild relative species for major crops can enhance the breeding and commercial development of varieties with beneficial traits such as insect and herbicide resistance, creating economic value for agricultural producers and consumers. As outlined in the Decadal Plan, Queensland taxonomic researchers recently discovered a species of native Australian rice, Oryza meridionalis, that can be readily hybridised with crop rice and transfer important properties such as enhanced drought tolerance.

Ancestral crop wild relatives can contribute valuable genetic diversity to the main crops that feed the world today. Generations of crop domestication and improvement to successively select for desirable crop characteristics have improved attributes such as uniformity and yields, allowing for dramatic increases in crop productivity. However, a significant cost of continuous domestication is the reduction in crop genetic diversity over time.[87] Against this background, agricultural scientists have turned to crop wild relatives for sources of genetic diversity. It is expected that these wild crops can act as 'gene donors' for beneficial traits to better deal with a variable farming environment and changing agronomic practices.[88]

Climate change impacts present a compelling need for the improved preservation and understanding of crop wild relatives. Impacts on agriculture will continue to intensify over the coming decades, primarily through reduced crop yields from heat stress and reduced irrigation water availability, increased harvest losses due more frequent pests and diseases, and degradation and loss of coastal farmland.[89] In the area of agricultural adaptation, crop wild species will become increasingly important, including the adoption of traits such as in Figure 6.2.

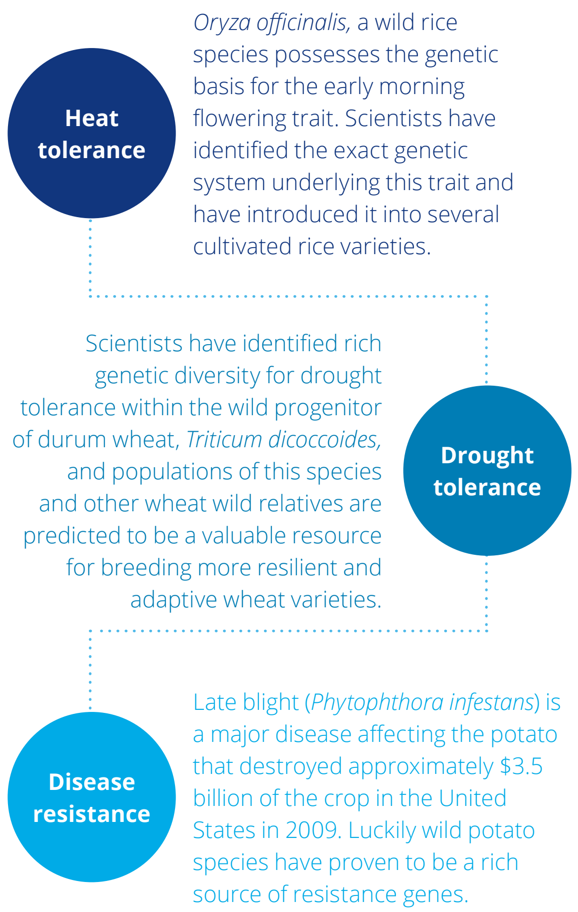
Hybridisation of wild and cultivated species tends to be the primary way that novel genes are introduced into established crops varieties.[90] Wild taxa are readily cross-compatible for most crops, however successful hybrid crossing can be challenging and resource intensive. The international Crop Wild Relatives project, carried out by the Global Crop Diversity Trust, focuses on the wild relatives of 29 priority crops based on their importance and occurrence on Annex 1 of the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) compiled by the Food and Agriculture Organization (FAO) of the United Nations (UN).[91] These are crop species including but not limited to: alfalfa, apple, Asian rice/African rice, banana, barley, bean, carrot, chickpea, cowpea, durum wheat/bread wheat, finger millet, potato, rye and sorghum.

As of 2009, for the 29 major crop species, there are 183 crop wild relative taxa for which the following useful traits have been identified:[92,93]

- 39% pest resistance
- 17% abiotic stress performance
- 13% yield increase.

Currently, Australian research agencies are partners in international research collaborations to advance hybridisation research on wild crop relatives for two of the 29 priority crops identified by the FAO of the UN in the ITPGRFA: alfalfa and sorghum.[94] These research projects are being led respectively by the South Australian Research & Development Institute and the Queensland Alliance for Agriculture and Food Innovation.

Figure 6.2: Crop wild relatives and climate change adaptation



Source: Crop Wild Relatives Project, Global Crop Diversity Trust (2020)

6.2 Value of taxonomy in crop wild relatives

Previous research commissioned by the Millennium Seed Bank has estimated the value of economic benefits from future improvements for these 29 crops in both current terms (over the useful economic life of traits in these crops) and in perpetuity (given the crop collection will be preserved for hundreds of years), relative to their collective gross production value in 2010. Drawing on stakeholder judgment on the type and magnitude of improvements expected for four specific crops, the study found that the potential economic benefits in perpetuity of crop improvements attributable to wild relatives for all 29 crops could amount to $120 billion.[95]

These findings are much smaller than other estimates, with significant caveats around comparability. Pimentel et al (1997) estimate that the contribution of genetic resources is responsible for 30% of the increase in global crop yields since 1945, worth $60 billion annually.[96] Pimentel et al estimate that the introduction of new genes and genetic modifications through crossing with wild relatives contributes approximately $20 billion per year in increased crop yields to the United States and an estimated $115 billion per year worldwide. We note that taken in perpetuity, these benefits are many factors greater than the estimates found for the Millennium Seed Bank.

In order to value the potential benefits that could be realised from increased taxonomic knowledge (and commercialisation) of wild crop relatives for alfalfa, sorghum and other crops in an Australian setting, a starting point would need to understand quantitatively:

- The gross production value of commercial cultivated crops across the Australian production value chain, including pre-breeding research, seed breeding of new crop varieties, commercial production and multiplication of crop seeds, and the agricultural production of crops
- The expected marginal change in crop attributes such as yield improvement, disease resistance and stress tolerance in percentage terms or monetary terms given gross production value
- The extent to which the above factors evolve dynamically over time with taxonomic discovery (i.e. specify a function that relates the rate of species discovery to the expected marginal change in gross production value).

Noting resource and data limitations that prevent the above estimation process from being undertaken here, we present a simplistic, stylised estimation of the hypothetical benefits resulting from an accelerated improvement of crop species through taxonomic research into wild crop relatives. This means accelerating the breeding, commercialisation and agricultural production of improvements to any crop species.

Base case

The base case (a world with taxonomic discovery and documentation occurring at the current rate) would see crop improvements continue to occur at the current rate. These benefits could be multiplied across all crop species that are being improved using hybridisation with wild crop relatives.

For any one crop, improvements due to crossing with crop wild relatives could generate a lower bound of economic benefits in perpetuity of $4 billion, derived by dividing $120 billion by the total number of crops (29). Assuming that perpetuity indicates 100 years in the original calculations, this might indicate average annual benefits of $41 million from one improved crop.

Hypothetically, we could assume that under the base case, a crop currently under improvement through research into crop wild relatives has a 10-year commercialisation lead time, such that annual benefits of $41 million will start occurring in 2035. **Under the base case, the present value of economic benefits would be $209m using a 4% discount rate.**

Scenario case

Under the Taxonomy Australia mission, the scenario case would see improvements across the entire value chain accelerated such that the realisation of these benefits would commence earlier. We construct three low, medium and high change scenarios and hypothesise that the taxonomic R&D on priority crop wild relatives is accelerated by 2, 5 and 10 years. However, to account for the lag in Taxonomy Australia's mission impacting the sector, the earliest that benefits could start occurring, under the 'high change' scenario case, is 2025. **Under the medium scenario case where R&D is accelerated by 5 years, the present value of economic benefits would be $339 million.** Under the low scenario case in which R&D is accelerated by only 2 years, the present value of economic benefits would be lower at $258 million. Under the high scenario case in which R&D is accelerated by 10 years, the present value of economic benefits would be higher at $496m.

In this context, net benefits are given by the difference in scenario and base case benefits, representing the marginal value generated by an acceleration in taxonomy. **The present value of net benefits in the medium scenario case is $129 million.** Under the low scenario case, the present value of economic benefits would be roughly half the medium case benefits ($49 million). Under the high scenario case, the present value of economic benefits would be more than double the medium scenario case benefits ($287 million).

As demonstrated by this exercise, these estimates are clearly highly sensitive to assumptions and value inputs and are a function of the extent to which taxonomic research can accelerate the actual realisation of benefits from crops improved by crop wild relatives. Table 6.1 presents the range of estimates for the low, medium and high scenario cases and with sensitivity analysis around the discount rate.

Table 6.1: Economic benefits from taxonomic research in crop wild relatives (present value $ million)

	4%	1%	7%
Base case	**209**	**373**	**120**
Scenario case			
Low (2 years)	258	446	154
Medium (5 years)	339	557	213
High (10 years)	496	750	342
Net benefits			
Low (2 years)	49	72	33
Medium (5 years)	129	184	213
High (10 years)	287	377	342

Source: Deloitte Access Economics

7

Benefit stream 4: Biodiversity conservation

Taxonomic knowledge underpins our understanding of biodiversity and is integrally linked with conservation efforts. Understanding species and their abundance and distribution informs understanding of which species are endangered (species-level conservation) and the make-up of ecosystems (ecosystem-level conservation), both of which are important factors in conservation decisions. In the long term, improved taxonomic knowledge may help to enhance shifting approaches to valuing biodiversity.

7.1 Taxonomic knowledge impacting conservation outcomes

Taxonomic knowledge is important for conservation decision-making under constrained resources. Understanding species, where they live, what their traits are and how they interact with their ecosystems informs conservation management to improve species resilience to changing environmental conditions. Given constrained resources, information about species and ecosystems informs where conservation efforts should be prioritised and what the most effective actions are.[97] As with all applied research, the effectiveness of increased taxonomic knowledge is contingent on how well it can be integrated with ecology, conservation and other scientific disciplines.

7.1.1 Taxonomic knowledge is important for conservation

Taxonomy is important for conservation efforts because conservation efforts cannot be targeted at unknown species. Until conservationists become aware of unknown species, only known species can be targeted.

Taxonomic knowledge also helps inform which species are threatened. Threatened species status, as defined by the Environmental Protection and Biodiversity Act 1999 ('EPBC Act'), informs conservation decision-making under the current statutory regime. The identification of threatened species, classified according to the severity of their status, enables conservation efforts to be prioritised towards the most threatened species through statutory protection.

In addition to threatened species status, taxonomic knowledge helps inform ecological and conservation disciplines that seek to understand how species interact with their environment. All three disciplines - conservation, ecology and taxonomy - are required to understand species and their ability to adapt to changing environments.[98] Taxonomic knowledge contributes to the understanding of a species' natural distribution, behaviour, habitat requirements, feeding, breeding and migration habits, all of which can affect conservation management decisions.

7.1.2 Defining and valuing conservation is complex

Conservation outcomes are difficult to define, in part because there are multiple objectives which are important for conservation. Even a seemingly straightforward objective, for example, to maximise biodiversity conservation, can have multiple dimensions and meanings.[99] Conservation efforts can suffer from ambiguity regarding biological features that scientists and policymakers refer to when they say an ecosystem has high biodiversity.[100] This ambiguity in turn leads to ambiguity in the understanding of conservation success. However, the importance of preserving biodiversity is an increasingly critical part of ensuring long term social and economic success.[101]

A common measure of biodiversity conservation outcomes is the change in the number of threatened species. This is readily understood by the general public and is reflected in many components of regulation (for example, the EPBC Act). The box on the next page emphasises the limitations of the EPBC Act in addressing conservation concerns and highlights the risks of overemphasising protection of threatened species as a measure of conservation.

EPBC Act

The EPBC Act provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places – defined in the EPBC Act as matters of national environmental significance, including nationally threatened species and ecological communities. However, species are required to have 'threatened species' status to be protected under the Act. This means that non-threatened species that are critical to ecosystem function are not protected under the Act.

A fundamental flaw in this system, outlined in a recent inquiry into Australia's faunal extinction crisis, highlights that by focusing on individual species rather than whole ecosystems, the EPBC Act fails to address cumulative environmental stressors:

"The EPBC Act is incapable of addressing many of the principal drivers of faunal population decline… [and] has no compulsory mechanism to address cumulative impacts.[102]"

While the critiques of current legislation are not the focus of this analysis, they are raised here to acknowledge that improving taxonomic knowledge will not solve all problems facing conservation. Despite these complexities in conservation governance, it is broadly agreed that improving taxonomic knowledge will improve long term conservation outcomes.

For the purposes of this analysis, we focus on increasing species resilience as a key conservation outcome. The concept of species resilience refers to the ability of species to withstand disturbance or perturbation and recover quickly. This concept of species resilience can be readily linked to taxonomic knowledge through the mechanisms described above. Available data from the EPBC Act on the protection of threatened species also provides a useful proxy for measures to increase species resilience. The concept is also useful for our analysis, as there is significant literature on society's willingness to pay ('WTP') for species protection.

At a minimum, a comprehensive understanding of species and their functional importance to ecosystem services will better inform trade-offs to allow more effective allocation of constrained resources and conservation management. While a better understanding of taxonomy may strengthen the business case for conservation funding, historically the discovery of new species has not increased the availability of conservation resources.[103] In the long term a comprehensive taxonomic 'map' will facilitate deeper understanding of our natural capital stock and ecosystem services to aid a more effective conservation approach, given the statutory provisions in place. It is difficult to manage what cannot be readily measured.[104]

Acknowledging the complexity of conservation goals and outcomes beyond the protection of threatened species, a stylised, conservative approach is used to quantify the increase in species resilience as a result of an increase in taxonomic knowledge relevant to the conservation of threatened species. This section outlines the rationale for our approach, followed by outlining the methodology and results.

Conservation of threatened species is only one objective of biodiversity conservation. For this reason, the purpose of measuring changes in conservation in terms of threatened species is to provide a conservative estimate of the potential benefits to conservation from increased taxonomic knowledge.

Conservation benefits can be thought of as marginal improvements in *species resilience* resulting from increased taxonomic knowledge.

Alternative measures of conservation outcomes include phylogenetic diversity, natural capital and ecosystem services. Ecosystems with high phylogenetic diversity are considered more stable, and therefore more resilient to environmental stressors and requiring less intervention.[105] Natural capital provides another possible measure of environmental assets, while ecosystem services comprises the array of benefits provided by species and ecosystems to the environment and societies.[106] Concepts of natural capital and ecosystem services have grown increasingly important to how we value conservation outcomes. These concepts are likely to become more important as society strengthens its understanding of the hidden value of our natural assets.

7.1.3 Benefits can only be realised under certain conditions

The interconnectedness of nature and the array of complexities associated with biodiversity resilience mean the effectiveness of taxonomic knowledge on conservation outcomes is not only contingent on how it is used to inform trade-offs, but also on how knowledge interacts with other scientific disciplines (section 7.1.1). To influence successful conservation outcomes, the discovery of new taxonomic knowledge must:[107]

- link taxonomic and geospatial data to understand geographic patterns of species habitat
- rapidly provide insights about the relationships between species and their ecosystems
- acknowledge that many common species – rather than undiscovered or threatened species – are central to ecosystems
- refrain from drawing resources away from conservation programs.

Given the complexities of defining, valuing and realising the benefits mentioned above, a conservative, stylised approach is adopted to quantify the benefits of taxonomic discovery to biodiversity conservation.

7.2 Value of taxonomy in biodiversity conservation

Lack of taxonomic knowledge presents a real challenge to the goal of species and ecosystem conservation. Taxonomists estimate there are 192,000 known species in Australia and more than half a million unknown species in Australia.[108] Assuming that rates of endangered unknown species are the same as the rates of threatened known species, we estimate that more than 4,000 unknown endangered species exist in Australia (Table 7.1).[109,110] Without a deeper taxonomic knowledge, it will not be possible to protect these species.

Table 7.1: Estimated total number of known and unknown species

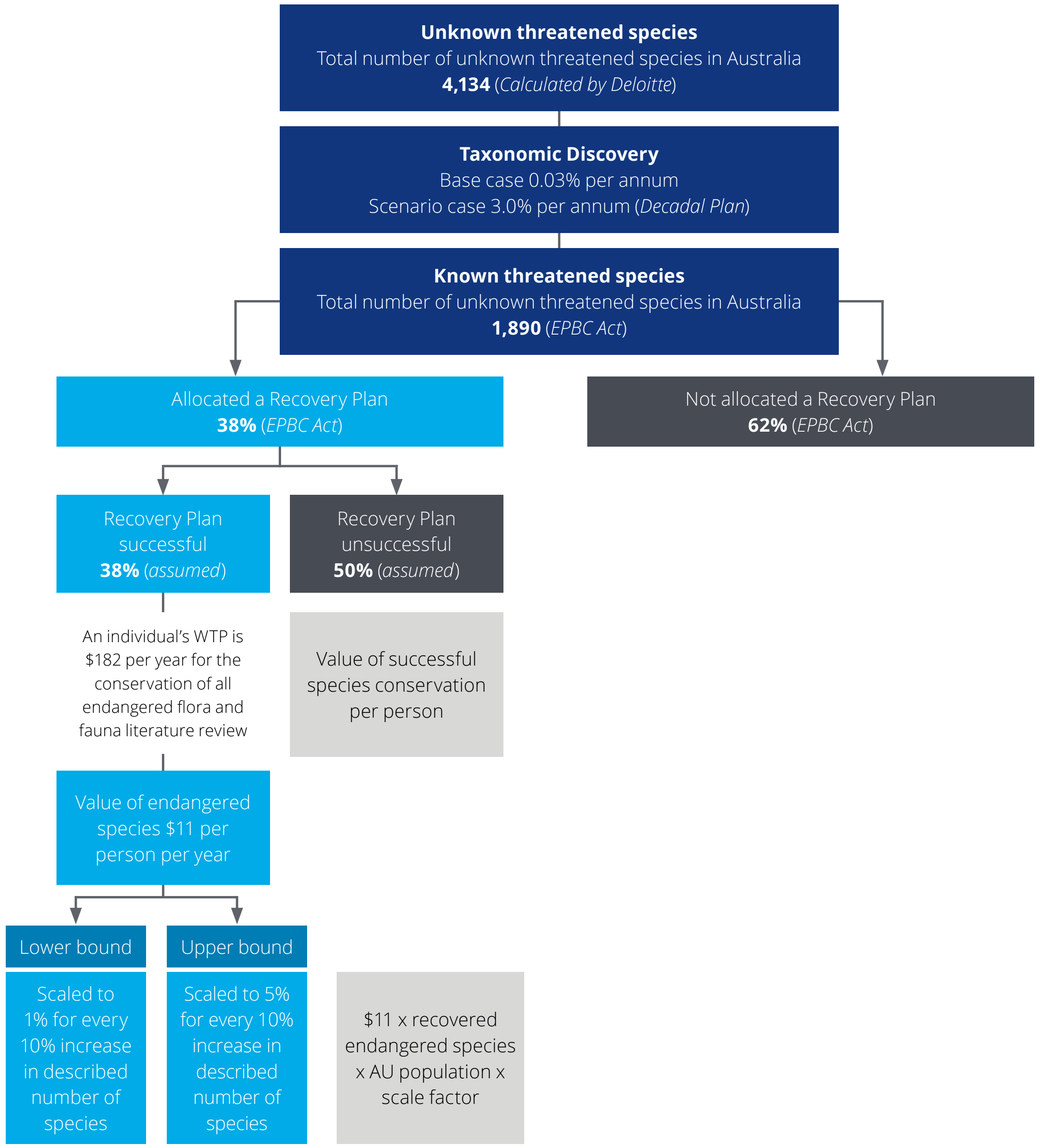
	Known species	Unknown species	Total
Threatened	1,890	4,134	6,024
Total	192,000	420,000	612,000

Source: Deloitte Access Economics analysis based on data from Taxonomy Australia data and the EPBC Act

Using these estimates of known and unknown species, the net benefit of species preservation enabled by increasing taxonomic knowledge is quantified as follows.

Taxonomic knowledge is required to identify a known threatened species. When a species becomes threatened or endangered, resources are allocated to conserve species and their habitat (see section 7.1.1). Over time this improves the status of threatened species by improving their resilience to changing environmental conditions. We use the number of known and estimated unknown species as a proxy for taxonomic knowledge. The approach to quantify the benefits of biodiversity conservation from taxonomic discovery is outlined in Figure 7.1.

Figure 7.1: Logic flow for biodiversity conservation benefit stream



Source: Deloitte Access Economics

Of the 1,890 known threatened species identified, 726 (38%) of these have been allocated recovery plans – strategic documents that outline the steps required to improve the threatened species status so that species become more resilient to environmental stressors. The success rate of these recovery plans is assumed to be 50%.[111] This means for every 100 known threatened species, 38 will receive a recovery plan, 19 of which are expected to recover so that the population are sufficiently resilient to environmental stressors and hence are no longer at risk of species decline.

A view that was raised in consultation held that the proportion of species allocated recovery plans might decrease in coming years. We have not reflected this in the modelling framework as its intention is to provide an estimate of the value of current conservation outcomes, against which potential improvements from taxonomic knowledge can be measured. Given the limitations of the EPBC Act outlined in section 7.1.2 recovery plans represent only a small part of conservation in Australia; we therefore are using a conservative assumption of conservation outcomes.

Conservation efforts can only be directed to species once they become known. Therefore, the rate of taxonomic discovery directly influences where effort in conservation can be directed. This increase is likely to be significantly less than a one-for-one improvement, as biodiversity conservation is challenged by many factors aside from lack of taxonomic knowledge. Consultation with stakeholders suggested that a 10% increase in taxonomic knowledge would lead to an improvement in conservation outcomes between 1% (lower bound) and 5% (upper bound) through improved ability to manage threats and focus effort.[112] These lower and upper bounds form the low and high estimates of conservation benefits to an increase in taxonomic knowledge.

To quantify the value of species conservation, a study by Jakobsson and Dragun (2001) determined the willingness to pay for conservation of all endangered flora and fauna in Victoria.[113]

The average willingness to pay for the conservation of flora and fauna was conservatively estimated at $118 per year per individual. This value is converted to 2020 Australian dollars and used as a proxy for the value individuals place on the successful conservation of species.

To determine the value of successful species recovery to an individual, the number of species discovered in one year is divided by the total estimated species, multiplied by the inflated value $182. It is assumed the willingness to pay for the preservation of each *additional* species is constant – at a rate of $11 per person for recovered threatened species. Despite the fact that studies have demonstrated the incremental willingness to pay diminishes for every additional species conserved,[114] a literature scan of Australian contingent valuation studies shows that this per-species WTP remains highly conservative (Appendix C).

Table 7.2: List of assumptions to measure biodiversity conservation benefits

	Assumption	Value	Description
A	Number of known threatened species	1,890 at baseline	The number of known threatened species are species classified as 'conservation dependent' 'critically endangered', 'endangered', 'vulnerable', 'extinct' and 'extinct in the wild' according to the EBPC List of endangered species in Australia from the Department of Agriculture, Water and the Environment (2020).
B	Number of recovery plans	38% of known species	The proportion of recovery plans for known threatened species (EPBC, 2020).
C	Recovery plan success rate	50%	The expected success rate of recovery plans to reduce the threatened species status to 'no longer threatened'.
D	Value of conservation of endangered flora and fauna **per person per year**	$11	The willingness to pay for the conservation of endangered flora and fauna is $118 (Jakobsson and Dragun 2001), adjusted to 2020 Australian dollars. Number of recovered species divided by the total estimated number of threatened species multiplied by $182. This equates to $11.00 per person per year.
E	Australian population	25.9 million in 2020	Australian Bureau of Statistics, Series B Population forecasts.
F	Increased conservation limitation factor	Lower bound, 1% Upper bound, 5%	To account for both the limitations in funding and the fact that some unknown species are likely to be inadvertently protected by existing conservation efforts we scale this by a factor 1% and 5% for a 10% increase in taxonomic discovery.

Source: Deloitte Access Economics, ABS, EPBC Act

The value of conservation outcomes is estimated by multiplying factors A-F in Table 7.2. It is assumed that over time as taxonomic discovery increases, these efforts will become more efficient leading to greater outcomes. Under the base case the estimated rate of increase in taxonomic knowledge is 0.16% per annum and under the scenario it is 2.75% per annum.

We use the EPBC data, and the willingness to pay studies to provide a stylised estimate of the current value to the Australian public of the impact of conservation benefits. We then apply the expected increase in taxonomic knowledge and the associated improvement in benefits to estimate the marginal increase in taxonomic knowledge over time. Benefits commence in 2026, five years after the mission is first implemented, based on the average timeframe of an interim recovery plan.[115]

Net benefits are calculated as the difference between base case benefits from species preservation and scenario case benefits from increased preservation as enabled by increasing taxonomic knowledge.

Base case

The base case rate of taxonomic discovery is a 0.16% increase in described species per year – or around 10 threatened species per year. The base case taxonomic discovery rate is based upon the 10-year average number of species described per year (1,000), divided by the total estimated number of species, including unknown species (612,000). The value of species conservation is extrapolated by this rate.

Table 7.3: Conservation scenarios

Scenario	Description
Low scenario	A 10% increase in taxonomic knowledge results in a 1% improvement in conservation outcomes
High scenario	A 10% increase in taxonomic knowledge results in a 5% improvement in conservation outcomes

Source: Deloitte Access Economics analysis based on data from Taxonomy Australia data and the EPBC Act

The low scenario case, in which a 10% increase in taxonomic knowledge results in a 1% increase improvement in conservation outcomes, gives a present value of species conservation to Australians of $5,545 million.

The high scenario case, in which a 10% increase in taxonomic knowledge results in a 5% increase improvement in conservation outcomes, gives a present value of species conservation to Australians of $5,579 million.

Scenario case

As previously mentioned in Chapter 1, the mission outlines the aim to describe all species, an estimated additional 420,000 species, by 2045. To achieve this goal, the rate of taxonomic discovery occurs at 2.75% per year – or 165 threatened species per year.

The low scenario case gives a present value of species conservation to Australians of $5,686 million.

The high scenario case gives a present value of species conservation to Australians of $6,402 million.

The net present value of net benefits from increased taxonomic discovery is estimated to be $73 million in the low scenario case and $372 million in the high scenario case.

Table 7.4: Present value of benefits of taxonomic discovery to conservation (present value $ million)

	4%	1%	7%
Base case			
Low	$4,505	$6,352	$3,360
High	$4,534	$6,400	$3,379
Scenario case			
Low	$4,579	$6,479	$3,405
High	$4,906	$7,033	$3,605
Net benefits			
Low	$74	$127	$45
High	$372	$633	$226

Notes: Sensitivity analysis for a discount rate of 1% and 7% have been included for comparison.
Source: Deloitte Access Economics

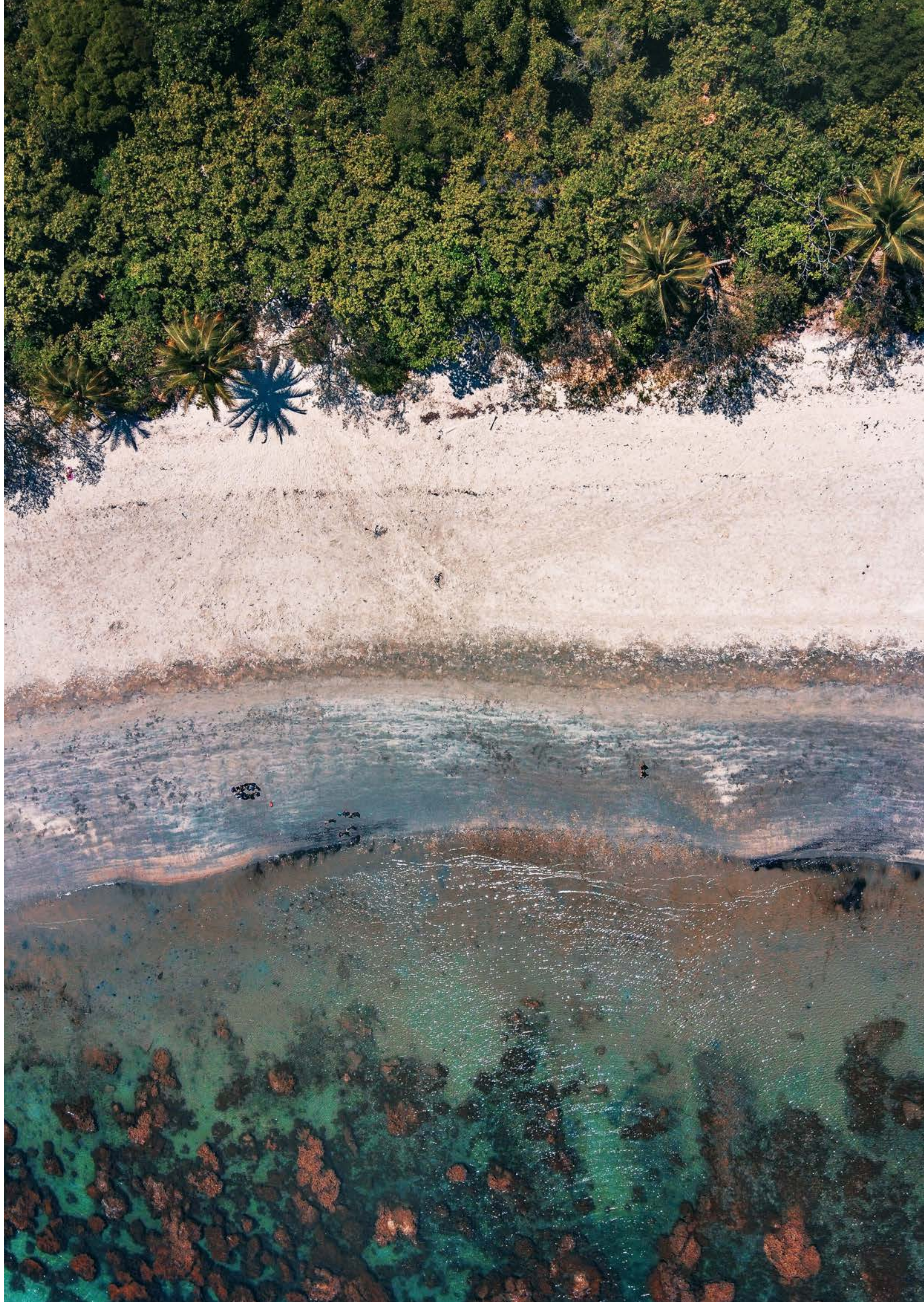
Sensitivity analysis
The present value of $74 million to $372 million is sensitive to the following key assumptions.

Conservation funding is constrained to current levels. As discussed in section 7.1.3, an increase in taxonomic knowledge historically has not led to an increase in funding. When stakeholders were asked to estimate expected increases in conservation outcomes based on gains in taxonomic knowledge, the question was posed with the constraint 'holding current levels of funding constant'. If this constraint were to shift, then the impact could increase markedly as improving taxonomic knowledge may enable best practice conservation outcomes rather than simply a reallocation of constrained resources. A hypothetical shift in this assumption such that all threatened species can be effectively managed, could potentially create a significant increase in the impact of conservation benefits (holding constant the relationship between taxonomy and conservation).

The WTP for species conservation. The WTP estimate used for species protection is highly conservative within a broad range of available estimates. Values for WTP for individual species can range from a few dollars to close to a hundred dollars depending on the species.[117] Because we anticipate that increases in taxonomic knowledge will be in large part used to protect less prominent or 'charismatic' species, we have taken the conservative approach of using a proportion.

The public awareness of conservation benefits remains constant. A component of the mission is to increase community engagement to educate the public about our biodiversity. By better understanding the make-up of our environment and how it is important for society, an opportunity presents itself for people to better appreciate – and therefore place a higher value on – conservation efforts of the total willingness to protect the collective group of known threatened species. Different willingness to pay measures could substantially raise the value by an order of magnitude.

The total economic value of ecosystems is undefined. Nature is difficult to value using conventional valuation methodologies, because many of the benefits we receive from nature aren't realised in conventional market settings. While established methodologies exist to determine the value of individual ecosystems, no such study has yet measured the complete and total value of Australia's ecosystems. To achieve this would be a monumental task, since benefits cannot be transferred easily due to the significant variation of Australia's environment – highly varied ecosystems contain different characteristics and benefits to users. A previous study by Deloitte Access Economics estimated the total economic value of the Great Barrier Reef as $56 billion.[116] Considering the number of other reef systems, river systems, rainforests, temperate forests and deserts that exist in Australia, the value of our ecosystems, and hence the value of conserving them is likely to be in the thousands of billions of dollars. Given the importance of taxonomic knowledge in understanding our biodiversity (section 7.1.1), it is likely that taxonomic knowledge will play a supporting role in conserving important ecosystems. If the benefits of conserving all ecosystems (rather than all species) were able to be defined, then the present value could increase by several orders of magnitude.



Conclusion

Taxonomic knowledge is foundational to our understanding of the natural world. As 'mapmakers' of life on earth in all its complexity and abundance, taxonomists enable discoveries to be made in many scientific disciplines and facilitate commercially valuable applications in a range of industries.

End-users of taxonomic knowledge in the sectors of biosecurity, biodiscovery, biomonitoring and conservation can attest to its importance in their own fields. However, the value of taxonomy is hard to measure precisely because of its enabling nature. These difficulties can result in underfunding and underproduction of taxonomic knowledge relative to its full value.

This rapid CBA finds that Taxonomy Australia's mission to discover and document all remaining species in Australia in a single generation could create **significant benefits in the range of $3.7 billion to $28.9 billion** relative to a NPV investment cost of $824 million over 25 years. These benefits result primarily by enhancing the effectiveness of applied sciences in our four chosen sectors. **These benefits represent a return of four to 35 times greater than the likely cost of investment.**

For this preliminary analysis, the range of identified benefits covers potential impacts in the following four sectors:

- **Biosecurity:** the benefits of reduced frequency of costly delays in identifying genuine and non-genuine threats range from $465 million to $660 million.
- **Biodiscovery:** the benefits of more cost-effective and strategic testing of samples for drug discovery amount to $123 million in the research phase of the pharmaceutical and medical biodiscovery process and health benefits range from $3 billion to $27 billion.
- **Agricultural R&D:** the benefits of accelerated research into crop wild relatives of major commercial crops range from $49 million to $287 million.
- **Biodiversity conservation:** the benefits of improved conservation outcomes such as increased species resilience is estimated to be between $74 million and $372 million.

Many benefits have not been considered here or are entirely unknowable at present. These include the intrinsic benefits of greater scientific knowledge, enabled ecosystem benefits whose value cannot be fully captured by traditional valuation methodologies, industrial designs and processes inspired by nature, and commercialisation of research projects in sectors not included here.

Like all research, the gains from taxonomic research are inherently uncertain – species found to be of enormous environmental or economic consequence are difficult to predict in advance. Further, benefits cannot be constrained to the 25-year period considered in this CBA. Rather, benefits are expected to accumulate in perpetuity.

Climate change, including rapid onset disasters such as the bushfires experienced in the summer of 2019-20, is accelerating the extinction of species from the planet. Many species will become extinct without ever having been known to humankind. These and other imminent challenges stress the need for scientists to better understand the countless undiscovered species in Australia and elsewhere on Earth.

Taxonomy Australia's mission will help Australia face these challenges while bringing about social and economic benefits described in this report, and in doing so create significant opportunities to build skills and jobs for the nation's scientific workforce.

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Appendix A: Stakeholder consultation

To ensure the cost benefit analysis approach was reasonable, 19 scientific experts were consulted in four consultation sessions to test the analysis framework for each benefit stream. The purpose of the stakeholder consultations for biosecurity diagnostics, biodiscovery for human health and biodiversity conservation was to:

- **Test the quantified benefit framework with industry experts –** Stakeholders were invited to confirm and / or critique the hypothesised link between taxonomic knowledge and each benefit stream, and the logical flow of assumptions.
- **Test key assumptions where gaps remained in the literature –** Stakeholders were invited to confirm and / or critique key assumptions. Where gaps in the literature remained, stakeholders provided additional data sources.

As biomonitoring benefits realised by improving the rate of taxonomic discovery is less well-known in the literature, the stakeholder consultation was exploratory in nature.

A1. Stakeholder consultation: Biosecurity diagnostics

A stakeholder consultation with experts in biosecurity diagnostics was undertaken on the 19 May 2020 with four scientific experts, listed in Table A1.

Table A1. Stakeholders who attended the biosecurity diagnostics consultation

Stakeholder	Title
Rod Turner	General Manager, Plant Health Australia
Susie Collins	Director, National Plant Health Policy, Australian Government Department of Agriculture, Fisheries and Forestry
Ian Thompson	Chief Environmental Biosecurity Officer (CEBO)
Prof. Brendan Rodoni	Professor in BRC, Department of Applied System Biology, La Trobe University

A2. Stakeholder consultation: Biodiscovery for human health

A stakeholder consultation with experts in biosecurity diagnostics was undertaken on the 20 May and 2 June 2020 with two scientific experts, listed in Table A2.

Table A1. Stakeholders who attended the biosecurity diagnostics consultation

Stakeholder	Title
Prof. Anthony Carroll	Professor at the Environmental Futures Research Institute, Griffith Institute for Drug Discovery.
Dr John Hooper	Honorary Associate, Queensland Museum Network

A3. Stakeholder consultation: Biodiversity conservation

A stakeholder consultation with experts in biosecurity diagnostics was undertaken on the 22 May 2020 with eight scientific experts, listed in Table A3.

Table A3. Stakeholders who attended the biosecurity diagnostics consultation

Stakeholder	Title
John Kanowski	Chief Science Officer, Australian Wildlife Conservancy
Dr Margaret Byrne	Senior Principal Research Scientist and Director of the Science Division, WA Department of Parks and Wildlife
Member of the Board of Terrestrial Ecosystem Research Network (TERN)	Chief Environmental Biosecurity Officer (CEBO)
Sally Box	Threatened Species Commissioner, Department of Agriculture, Water and the Environment
Prof. Glenda Wardle	Professor of Ecology and Evolution, University of Sydney
Prof. Craig Moritz	Director of the ANU-CSIRO-UC Centre for Biodiversity Analysis
Prof. Stephen Garnett	Fellow of BirdLife Australia and is elected co-counsellor for birds with the Convention on Migratory Species.
Helene Marsh	Professor of Environmental Sciences, James Cook University
Dr Judy West	Executive Director, Australian National Botanic Gardens

A4. Stakeholder consultation: Biomonitoring

A stakeholder consultation with experts in biosecurity diagnostics was undertaken on the 26 May 2020 with five scientific experts, listed in Table A4.

Table A4. Stakeholders who attended the biosecurity diagnostics consultation

Stakeholder	Title
Donald Hobern	Executive Secretary, International Barcode of Life
Michael Shackleton	Macro-invertebrate Biologist, Ctr Freshwater Ecosystems, La Trobe University
Prof Stephen van Leeuwin	Indigenous Chair for Biodiversity and Environmental Science, Curtin University
Industry stakeholder	
Dr Sue Nichols	Senior Research Fellow, Centre for Applied Water Science, University of Canberra

Appendix B: Social discount rates

The social discount rates used in this analysis were derived from a previous Deloitte Access Economics report that evaluated the total economic value of the Great Barrier Reef.[117]

Some people find it impossible or simply wrong to 'discount' the future of something as important as environmental benefits to taxonomic discovery. But it is important to recognise intergenerational benefits and welfare in determining the total social and economic asset value of any program. This raises the question of how future generations are valued relative to the present when it comes to the environment. How much value is attributed to those who are not yet born? In comparing welfare, utility and benefits across generations, a discount rate needs to be determined.

The Ramsey equation is used to calculate the discount rate applied to determine the PV of social and economic asset values of environmental benefits to taxonomic discovery. The Ramsey equation is as follows:
$r = \delta + \eta g$

The first term is the rate of time preference (δ), or the rate that utility is discounted for future generations. If this term is positive, present benefit realisation is given a higher utility weighting than benefits realised by future generations. If the time preference is zero, or close to zero, there is no discount placed on future generations and intergenerational utility is equally weighted. In the context of assessing the social and economic value of the GBR, it is ethically appropriate to distribute welfare equally across generations. As such, a near-zero pure rate of time preference is appropriate, and we have adopted a rate of 0.05 per cent. This is the same rate as was used in the Garnaut Climate Change Review 2008, and is similar to that used in the Stern Review 2007 (Table B.1).

Table B.1: Social discount rates

Study	Valuation	Activity/asset measured	Discount rate	Logic
Costanza et al. (2008)	Non-use	Ecosystem service – Hurricane protection	3%	No explicit reasoning standard social rate
United states environmental protection agency	Environmental costs and benefits	General environment	2–3%	General guidance for natural capital future costs and benefi ts
Stern review (2007)	Climate change review	Climate change damages	1.4%	Based on the Ramsey equation
Garnaut Review (2008)	Climate change review	Climate change damages	1.35–2.65%	Based on literature and Stern Review parameters

Source: Deloitte Access Economics

The second component includes the elasticity of the marginal utility of consumption (η) and the growth rate of the economy (g). The marginal elasticity of utility of consumption measures society's concern for equity in income distribution. Again, turning to the Garnaut Climate Change Review 2008, an elasticity of 1 is a common choice in literature and while there are differing views, we have adopted an elasticity of 1. The growth rate of the economy is assumed as the average annual GDP chain volume measures percentage change from 1987 to 2017, 5204.0 Australian System of National Accounts. It is important to note that when considering the environment and potential depletions of natural capital from development, GDP growth is not necessarily a good measure of environmental or human wellbeing. However, in the absence of an Australian net national welfare measure, a long-term economic growth rate is appropriate.

Using the Ramsey equation and the assumed parameters, a social discount rate of 3.7% is produced. This discount rate applies to the total social and economic asset calculations over the selected time period. Based on this, a social discount rate of 4% has been chosen for this rapid CBA.

Appendix C: Willingness to pay for conservation

Five key Australian studies that estimated the willingness to pay for species conservation in Australia were identified in a literature review process. Values ranged from $11 per year for bird conservation to $118 per year for endangered flora and fauna (in nominal terms). Charismatic species such as the tree Kangaroo tend to have a higher willingness to pay than less species (Table C1).

Note that values in this table are also contingent on different survey questions asked and the level of information provided to respondents; hence, values are not directly comparable between studies.

Table C1: Literature scan estimating the willingness to pay for species conservation in Australia

Species conservation	WTP measure	Value	Source
Endangered flora and fauna	$ per household/year	$118.00	Jakobsson & Dragun (2001)
Leadbeater's possum	$ per household/year	$29.00	Jakobsson & Dragun (2001)
Bird conservation	$ per household/year	$11.00	Zander et al. (2014)
Endangered mahogany gliders	$ per household/once	$25.00 to $36.00	Tisdell, Wilson and Nantha (2005)
Hairy-nosed wombat	$ per household/week	$1.73 to $1.94	Tisdell and Nantha (2007)

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112. Stakeholder consultation, 22 May 2020 (Appendix A)
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