Threatened Species Recovery Hub

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Addressing issues relating to the conservation of data-poor species, and options for their resolution

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Front cover: *Grevillea minutiflora*. Photo: David Coates

Summary

This report provides background information on the many dimensions of bias, uncertainty and information shortcomings that affect the conservation of poorly known species in particular and hence biodiversity in general. It was prepared as an issues paper for a workshop in 2016, and the workshop led to the subsequent development of an options paper (Rumpff 2018) that evaluated the costs, benefits and relative efficacy of a range of mechanisms that could address the issues affecting poorly known but imperilled species, and deliver better conservation outcomes for them.

Eleven components of bias and knowledge shortfalls are described, where possible using Australian examples. These comprise:

- **taxonomic biases**. There is far more information available for some taxonomic groups (notably birds and mammals) than for others (notably invertebrates); and some taxonomic groups (notably birds and mammals) are accorded more public concern than others (notably invertebrates). As a consequence, there are marked taxonomic biases in lists of threatened species and in conservation management efforts, to the detriment of some groups.
- **environmental and geographic biases**. There is marked spatial unevenness in biodiversity information across Australia. As a consequence, conservation priorities and actions in some areas are likely to be based on far more evidence than for other regions.
- **undescribed species and unresolved taxonomy**. There are formidable challenges for the conservation of the large component of existing species that are not yet described; preventable extinctions may occur for species at least in part because they have not yet been described or because their taxonomy is not yet resolved.
- **lack of evolutionary and phylogenetic context**. Evolutionary distinctiveness may be an important factor shaping conservation priorities; however, phylogenies are poorly defined for some groups. There is a spatial component to this issue also, as centres of endemism may be critical over evolutionary and shorter time scales, for the conservation of many species with small ranges and/or specialised habitat requirements: however, for some groups such important conservation features are not yet well circumscribed.
- **lack of knowledge of the distribution of species**. Many animal species have distributions that shift in complex patterns. These patterns are well understood for some species, but are poorly known for others. Effective conservation of dispersive species may be jeopardised if the dispersal patterns are poorly known, and if conservation actions do not encompass the full range of sites used by dispersive species.
- **lack of knowledge of the population size of species and its variation in space and time**. Information on population size and its trends is critical for assessment of the conservation status of species, and for assessment of the efficacy of conservation actions. Without such information, poorly known but imperilled may not be recognised as threatened.
- **lack of knowledge of the extinction rate**. Because many species are undescribed and/or not monitored, it is challenging to estimate the actual rate of extinction and hence the effectiveness of conservation efforts.
- **lack of knowledge of the biology of species**. The biology of many species is poorly known, rendering it challenging to manage them effectively or to provide contextual information for assessment of their conservation status.
- **lack of knowledge of the fit of species into ecological connections**. Many species have critical linkages to other species or environmental factors. There will be challenges for managing such species if information about such linkages is poorly known.
- **lack of knowledge of the relative impacts of possible threats and management actions**. Effective conservation of imperilled species requires some knowledge of the factors threatening those species and of the manner in which such threats can be mitigated.
- **lack of knowledge transfer from science to the community and decision-makers, and from the community to science**.

Some existing policy settings at global and national levels attempt to address these biases and knowledge shortcomings, aiming to enhance the conservation outlook for poorly known but imperilled species. A notable example is the provision in Western Australian policy for measures that target sampling for, and the protection of, short range endemic invertebrates in environmental impact assessments.

Furthermore, a range of initiatives now aim to increase the information base for poorly known species. These include targeted surveys (or taxonomic reviews) for poorly known taxonomic groups or in regions with relatively sparse data; increased involvement of citizen science and compilation of records deriving from such sources; and increased attempts to recognise and document traditional ecological knowledge.

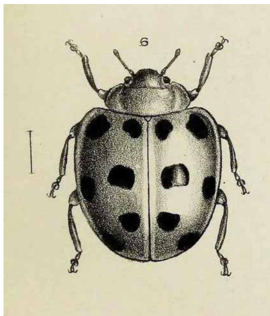
Conservation actions that can directly or indirectly benefit poorly known but imperilled species include expansion of the conservation reserve system, enhanced management of that system, further listings and enhanced management of threatened ecological communities, increased resourcing for threat abatement plans, and more protection and management of refuge areas and centres of endemism.

The *Environment Protection and Biodiversity Conservation Act 1999* provides little succour for poorly known species that may be imperilled. Unlike the global IUCN Red List, the Act does not include a Data Deficient category, and listing of species as threatened (with its consequent conservation protection) requires an evidence base that provides an impossible hurdle for many poorly known species. Reducing this burden of proof, in legislation or practice, to a more precautionary level would be likely to lead to better conservation outcomes for poorly known species and reduce the taxonomic bias in existing lists of threatened species. More use of inference (e.g., extrapolation of knowledge of threats and their impact from related species) and expert elicitation (to bolster a limited base of primary evidence) in assessments for eligibility for listing species as threatened would also be likely to contribute to the conservation of poorly known but imperilled species.

Context

This report was prepared in 2016 for a workshop led by the Threatened Species Recovery Hub of the National Environmental Science Program. It aims to provide a summary of issues relating to poorly known species, and hence to help explore options for enhancing their conservation. Where important, advances in knowledge or conservation actions since 2016 are indicated in footnotes.

Introduction



Three specimens of a previously unknown ladybird beetle were collected by Charles Andrews in 1898, soon after the first human settlement of Christmas Island, Indian Ocean, and named as a new species *Epilachna nativitatis* (Waterhouse et al. 1900). Its description included no information on its abundance or ecology. It has never been recorded again (Bielawski 1961). It is not listed as threatened, and has been afforded no specific conservation management response. It may now be extinct; it may now be extant but highly imperilled; or it may now be flourishing. It is one example of a pervasive and largely unresolved conservation management challenge: how do we deal with the conservation of poorly-known species? There are many variations on this theme. Indeed, the knowledge base for very many species is even poorer than for the Christmas Island ladybird – many species remain undiscovered or undescribed.

Here, we document different components of knowledge limitation, describe some mechanisms that are currently being used to provide some remedial responses, and indicate how such responses can be improved. Globally, there is increasing recognition that these shortcomings in knowledge or understanding are subverting, or at least biasing, the effectiveness of conservation efforts. Several recent studies have attempted a typology of this ignorance (Table 1) on the basis that this helps to better define the problem, its consequences and potential solutions (Cardoso et al. 2011b; Cottee-Jones et al. 2015; Hortal et al. 2015). Some of these categories have been 'tagged' as the domain of pioneer ecologists (e.g., the "Hutchinsonian shortfall"), and these tags are noted where relevant below.

The following sections largely follow this categorisation, and provide some examples or evidence about the magnitude of the problem. Most of these examples are from Australia, but many of the issues concern biodiversity conservation globally.

Some of the previous catalogues of ignorance relate to ecology in general, but here the focus is explicitly on conservation. Note that in some contexts here, we use the word 'imperilled' to imply a species that is actually of conservation concern or at risk of extinction, to differentiate from 'threatened' for which available evidence has been sufficient to assess and formally list the species: an unknown species may be as imperilled (i.e., have the same risk of extinction) as a listed threatened species, but the evidence base may be inadequate to currently demonstrate that.

The ability to understand the status of, to list and to protect poorly-known but imperilled species is limited by availability of resources. First, the available resources to recover the set of species currently listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) are inadequate (Wintle et al. 2019), and there may be understandable concern that adding many poorly known but imperilled species to the existing list of species that are demonstrably threatened may divert those limited management resources from the most pressing conservation needs. Second, the current process for adding (or removing) species from the threatened species list under the EPBC Act is subject to resource constraints (i.e., only a finite number can be assessed for eligibility per year), and poorly known species may take considerable time to assess against the established criteria relative to well-known species.

There are other flow-on effects in any consideration of changing legislation to embrace the protection of poorly known species. For example, it would be challenging to develop any targeted policy responses for species that are currently undiscovered and undescribed, or to develop guidance for impact assessments when it is difficult to predict or sample the extent to which an area may contain a significant proportion of a population of a poorly known species. Last, there may be concern that increased protection to, and regulatory burden around, poorly-known non-charismatic species may have unintended consequences, such as the erosion of social licence underpinning conservation policy and resourcing.

We follow the descriptions of the areas of bias or ignorance with an account of mechanisms that have been, or could be, adopted to redress the issue or its consequences. In many cases, these responses are relevant to more than one area of ignorance, so we do not organise this material to match exactly the area of ignorance. Our objective is primarily to consider research, management, policy and legislative options that identify and remedy the most critical knowledge gaps, and contribute most effectively and efficiently to the conservation of poorly-known species. These options are described and evaluated in more detail in a report based on a subsequent workshop (Rumpff 2018).

We include consideration of bias as well as of ignorance, recognising that the two issues are different but inter-related. As described below, bias may result in markedly variable levels of knowledge across different components of biodiversity.

Table 1. *Categorisation of knowledge shortfalls and their consequences (modified from Cottee-Jones et al. (2015)).*

Name	Definition	Source
Linnean shortfall	The disparity between the number of formally described species and the total number of species in existence	Lomolino *et al.* (2010)
Darwinian shortfall	Lack of knowledge of phylogenetic information	Diniz-Filho *et al.* (2013)
Wallacean shortfall	Lack of knowledge of the distribution of species	Lomolino (2004); Riddle *et al.* (2011)
Movement shortfall	Lack of knowledge of species' movements	Cottee-Jones *et al.* (2015)
Prestonian shortfall	Lack of knowledge about the abundance of species and its variation in time and space	Cardoso *et al.* (2011b)
Extinction deficit shortfall	Uncertainty surrounding extinction rates	Riddle *et al.* (2011)
Hutchinsonian shortfall	Lack of knowledge of species' ecology and sensitivities to habitat change	Mokany and Ferrier (2011)
Raunkiaeran shortfall	Lack of knowledge about species' traits and their ecological functions	Hortal *et al.* (2015)
Eltonian shortfall	Lack of knowledge of species' interactions	Peterson *et al.* (2011)
Poirot (or Caughley) shortfall	Lack of knowledge of the causes of decline and how to most effectively remedy it	
Public dilemma	Low profile species are little known or appreciated by the public	Cardoso *et al.* (2011b)
Political dilemma	Biodiversity (particularly, threatened species) is assumed by the public and politicians to have been protected	Cardoso *et al.* (2011b)
Scientific dilemma	Taxonomy and basic ecology are no longer priorities	Cardoso *et al.* (2011b)

Areas of bias or ignorance

1. Taxonomic biases

Knowledge is distributed unevenly across different components of the earth's biodiversity. Marked taxonomic biases pervade ecological research and knowledge, conservation planning and management, and public and political interest in biodiversity (Cardoso et al. 2011a; D'Amen et al. 2013a). This bias insinuates through most of the other areas of ignorance described here.

Taxonomic lacunae are notably non-random. For example, Chapman (2009) estimated that of the likely number of species in Australia, 99% of mammals, 92% of birds, 97% of reptiles, 87% of fish and 89% of vascular plants have been described, whereas this was the case for only 31% of invertebrates and 24% of fungi. All else being equal, undescribed species are more likely to be less common and have more restricted ranges than described species, and hence may be more likely to need conservation attention.

Vertebrates and, less so, plants are far more substantially documented than are invertebrates and fungi, and are far more likely to be the focus of conservation attention (Pressey et al. 2003; Mittermeier et al. 2004; D'Amen et al. 2013b). Such 'institutional vertebratism' (Leather 2013) results in far higher proportions of bird and mammal species listed as threatened than for most other groups (Cardoso et al. 2011a; Walsh et al. 2012). For example, notwithstanding that the number of Australian invertebrates far exceeds the number of Australian vertebrate species, there are 406 vertebrate species but only 55 invertebrate species listed as threatened under Australian legislation (as at May 2016[1]). This disparity is not necessarily because vertebrates are more threatened. Indeed, globally (and presumably in Australia) the actual number of imperilled invertebrates is estimated to be at least an order of magnitude greater than for vertebrates (Collen et al. 2012): in at least some regions, evidence demonstrates that some invertebrate groups are suffering much higher rates of loss than some vertebrate groups (Thomas et al. 2004; Régnier et al. 2015a; Régnier et al. 2015b). However, at global level, only an estimated 0.5% of invertebrate species have been assessed for conservation status through the IUCN's Red List process compared with 42% of vertebrates (Clausnitzer et al. 2009).

A component of the taxonomic bias relates to public affinity and perceived species' charisma. Relatively large and well-known birds and mammals are accorded more conservation value by the public and politicians than inconspicuous invertebrates, plants and fungi. For example, the first iteration of the Australian Threatened Species Strategy (Commonwealth of Australia 2015) explicitly gave priority for conservation effort to 20 threatened mammal and 20 threatened bird species, but no such attention to potentially more threatened invertebrate species or species in other vertebrate groups[2].

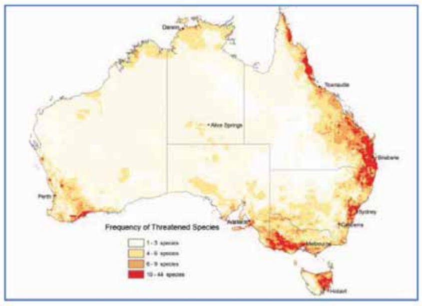
Even for particular vertebrate groups, there are marked and systematic disparities in knowledge. For example, far more research effort had been directed to Australian marsupial species than to Australian rodent and bat species, and to larger than smaller Australian mammals (Fleming and Bateman 2016).

In some applications, conservation triage or other approaches to prioritisation of conservation resources treats species inequitably, with selection variably for species with more public appeal, more phylogenetic distinctiveness, greater ecological leverage, or higher economic value (Bottrill et al. 2008; Bottrill et al. 2009; Faith 2009; Joseph et al. 2009; Wilson et al. 2009).

[1] At September 2021, these tallies have increased to 466 vertebrate taxa listed as threatened or Extinct and 67 invertebrate taxa.

[2] This taxonomic bias in prioritisation is being at least partly redressed in the subsequent (2021-2031) iteration of the strategy (https://www.environment.gov.au/biodiversity/threatened/publications/strategy-home).

2. Environmental and geographic biases



Knowledge about biodiversity and conservation needs is spatially uneven. The density of biodiversity records is typically far higher close to roads and to human population centres than in areas remote from human population centres (see adjacent map, which displays a random subset of Atlas of Living Australia records), because sampling in remote areas typically requires far more substantial expense, and because low human population density in such areas results in relatively few records from the public. For largely the same reasons, there are also notable environmental biases in biodiversity information, with relatively few records from remote and sparsely inhabited environments, such as oceanic depths, deserts and rugged areas.

This geographic bias is particularly evident in Australia, because it is so large and sparsely populated, its population dispersion is very uneven, and because remote fieldwork is relatively expensive. Hence, distribution records of Australian species are markedly uneven, and such disparity probably confounds our understanding of conservation needs and priorities.

To some extent, such biases can be addressed for some conservation purposes (such as systematic conservation planning) through the use of distributional modelling (Pressey 2004). However, areas subjected to more survey effort are far more likely to provide more comprehensive inventory of species that are present than are areas subject to less survey effort, and modelling will not discover new species. Furthermore, unusually in a global context, much of the biodiversity loss in Australia has occurred in areas remote from major human population centres (Woinarski et al. 2015). Because they are remote, there has been little monitoring effort in such areas, and hence little warning of past, current or future biodiversity loss.

Marked temporal variability in detection provides another dimension to sampling bias and adequacy. More so in Australia than in most other continents, many species may be extremely restricted and with low populations in most years, but far more widespread and apparent in the 'boom' times of high rainfall years. Sampling in normal or poor years may fail to detect these species, and sampling in good times may provide an unrepresentative estimate of their status (Silcock et al. 2015).

3. Undescribed species and unresolved taxonomy ("Linnean shortfall")

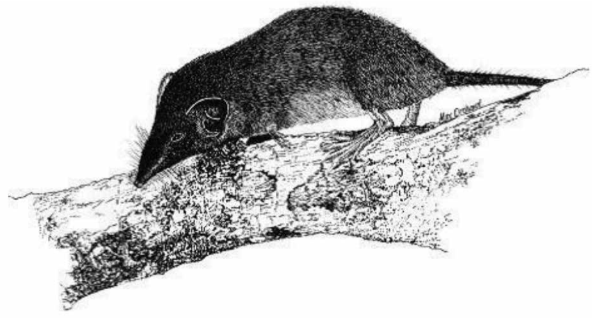
Most of the world's species are undescribed. For example, of an estimated 570,000 species (including fungi, plants and animals) in Australia, only about 150,000 have been described (Chapman 2009). Unknown and un-named species are – understandably – largely disregarded in conservation policy, management and legislation. Typically, they are not regarded as entities with formal status in legislation: so, for example, regulators need give them no heed when considering whether to approve a development application that may destroy their habitat, and conservation planners generally do not (indeed, cannot) explicitly include unknown species in considerations of the development of a conservation reserve system. One notable exception is for Western Australia, where flora survey guidelines for EIS work recognise that professionals conducting an EIS will attempt to discover new species and report them in the course of their work. In general, even after a species has been discovered, there may be a substantial lag time before it is formally described, and the duration of this period may also have substantial taxonomic biases (Fontaine et al. 2012).

There are many recent examples of modern species that have been recognised only after it is too late to render any conservation assistance. For example, only one helicinid land snail is known to now occur on the Gambier Islands, French Polynesia, but recent sampling of empty shells by taxonomists has resulted in the description of nine previously undocumented species, all rendered extinct in the nineteenth century (Richling and Bouchet 2013). Such 'post-mortem' recognition is not restricted to obscure and inconspicuous organisms. Many Pacific Island bird species have been described recently following their extinction over the course of multiple periods of human colonisation and introduction of rats and other predators, extending until at least the twentieth century (Steadman 1986, 2006). In Australia, at least 10 mammal species (the desert bettong *Bettongia anhydra*, Nullarbor dwarf bettong *B. anhydra*, central hare-wallaby *Lagorchestes asomatus*, Lord Howe long-eared bat *Nyctophilus howensis*, Capricorn rabbit-rat *Conilurus capricornensis*, short-tailed hopping-mouse *Notomys amplus*, large-eared hopping-mouse *N. macrotis*, Darling Downs hopping-mouse *N. mordax*, broad-cheeked hopping-mouse *N. robustus* and long-eared mouse *Pseudomys auritus*), all present at the time of European settlement in 1788, were not recognised and formally described until after their extinctions (Woinarski et al. 2014).

This list will continue to expand: a recent survey of mammal subfossils from the Kimberley, north-western Australia, reported three additional undescribed mammal species, never previously recognised, that probably became extinct some time after European settlement of Australia (Start et al. 2012). In many of these cases, the 'post mortem' recognition has relied on the serendipitous finding of sparse evidence: in probably far more cases, no trace has been left by recently extinct species and there is now no evidence that they ever lived: they existed, and then they didn't, without us ever being aware of them.

The taxonomic description of Australia's biodiversity is far from complete, even for some vertebrate groups (Meiri 2016). For example, more than 50 Australian endemic land mammal species have been described since 1970, with this rate showing no signs of diminishing: at least six new mammal species have been described since 2012 (Woinarski et al. 2015). The number of recognised Australian frog and reptile species is increasing at an even greater (and similarly undiminished) rate: the 664 species recognised in 1974 had grown to 1218 by 2013 (Cogger 2014), an average of more than 14 new species per year, and an 83% increase in fewer than 40 years.

Lack of taxonomic resolution also impedes the appropriate direction of conservation resources. For example, over the ca. 120 years since its discovery, the Christmas Island shrew *Crocidura trichura* was regarded as a subspecies of a species that was common and widespread elsewhere, and hence not afforded particular conservation significance. However, recent analysis (occurring >20 years after its last known sighting) of specimens collected many decades ago now confirms that it is (or was) specifically distinct (Eldridge et al. 2014). This belated resolution has probably come too late to provide any conservation benefit for what was Australia's endemic and only shrew species.



Christmas Island shrew. Illustrator Max Orchard

There are many similar examples of taxonomic study leading to re-assessment of the previously-assumed conservation status of species. In many cases, what was previously considered to be a widespread and secure species has been revealed to instead comprise many morphologically similar species each with much smaller range and less secure conservation status (Pepper et al. 2011; Oliver et al. 2012; Potter et al. 2012; Oliver and Parkin 2014; Oliver et al. 2014; Moritz et al. 2015).

Another complex recent example relates to the dingo, a canid introduced to Australia (with Asian origins) about 4000 years ago (Savolainen et al. 2004). A recent paper described the dingo as a distinct species *Canis dingo* (Crowther et al. 2014), and recognised that it has declined markedly due to persecution and hybridisation with domestic dogs, and hence may need to be considered as threatened and to merit considerable conservation attention. Conversely, a subsequent taxonomic assessment considered that this specific recognition is unwarranted, and that the dingo is simply an unexceptional part of the highly variable domestic dog *Canis familiaris* complex (Jackson and Groves 2015). In this case, limited genetic data and inconsistent interpretation of the available evidence has led to markedly divergent conservation implications.

4. Lack of evolutionary and phylogenetic context ("Darwinian shortfall")

Biodiversity has a deep temporal dimension relating to the evolutionary history of species (and other taxonomic units). Although phylogenetic relationships are increasingly understood for many groups (Cardillo et al. 2004), there are still major knowledge gaps (Diniz-Filho et al. 2013). The issue is relevant for conservation as many approaches seek to accord conservation priority to those species (or other taxonomic units) with the most substantial phylogenetic distinctiveness (Vane-Wright et al. 1991; Faith 1992, 2009). Knowledge of the evolutionary history of species (or other taxonomic units), and of biomes, also helps to characterise endemism, to describe the resilience of species and environments to change, to identify the location and strength of refugia, and to provide perspectives on conservation benchmarks (Byrne 2008; Byrne et al. 2008; Bowman et al. 2010; Marin et al. 2013). In one notable example, Oliver et al. (2018) analysed the evolutionary history of lizards endemic to Christmas Island, and concluded that the recent extinction of three species (two of which are Extinct in the Wild) caused the loss of 'millions of years of unique evolutionary history'.

One other component of this issue is the spatial co-occurrence of many species with small distributional extents (centres of endemism), that may have served to retain species and foster speciation over long evolutionary timeframes. The identification and conservation of such areas may now be critical for maintaining much phylogenetic legacy. Centres of endemism have been circumscribed for some components of Australian biodiversity (e.g., for plants: Crisp et al. 2001), but have not been detailed for most poorly known groups.

5. Lack of knowledge of the distributions of species ("Wallacean shortfall"; "movement shortfall")

Knowledge of the distribution of species is fundamental to conservation. Distributional information (and its change over time) is one of the pivotal parameters involved in the assessment of the conservation status of species. Distributional information (relating to species and environments) is critical for systematic planning for conservation reserve systems (Margules and Pressey 2000). Knowledge of the occurrence of species, particularly threatened species, is also critical for assessments of the impacts of proposed developments.

In Australia, knowledge of the distribution of most species is poor, with this ignorance relating particularly to four characteristics: (i) much of Australia is remote from human settlement and has been subject to little biological survey; (ii) many poorly-known species have idiosyncratic and highly restricted ranges (Harvey et al. 2011); (iii) an exceptionally large number of Australian species (but particularly birds) have highly inconstant distributions, with dispersal occurring regularly or irregularly over small or large scales (Woinarski et al. 1992; Gilmore et al. 2007; Runge et al. 2014; Runge et al. 2015); and (iv) the distributions of many Australian species (but particularly mammals) have changed (mostly shrunk) dramatically since European settlement (Woinarski and Catterall 2004; Johnson 2006; Hanna and Cardillo 2013; Woinarski et al. 2015), and many species continue to undergo rapid decline, such that distributional records from even one to two decades ago may now be unreliable evidence of ongoing occurrence. Furthermore, some species are undergoing directional shifts in distribution in response to climate change (Williams et al. 2003).

Limited knowledge about the distributions (particularly of refugial areas), movement patterns and the ecological factors underpinning dispersal is a problem particularly for the conservation of nomadic and irruptive species. For such species, it is difficult to design conservation reserves that span the extent of dispersal or to identify sites where conservation management may be most effectively applied (Woinarski et al. 1992; Runge et al. 2014; Cottee-Jones et al. 2015; Runge et al. 2015). Furthermore, many species may be relatively widespread generally, but at some stages occur only in a very small proportion of this range (e.g., for drought refuges, or breeding colonies for waterbirds, seabirds, seals, and some bats), with these sites then assuming particular significance for the conservation of the species because much of their total population is concentrated in a relatively limited area. Unless such aggregation sites are known and protected, much of the population of a species may be susceptible to loss through local actions or inaction.

Furthermore, there are marked taxonomic biases in distributional knowledge – in general, there is far more information available about the ranges of bird species than there is about invertebrates or fungi.[3]

6. Lack of knowledge of the population size of species, and its variation in space and time ("Prestonian shortfall")

Population size, and its variation over space and time, is a critical concern and parameter for conservation assessment, prioritisation of management, conservation planning, and impact assessment. However, even for relatively well known groups such as mammals, population size is known for only a very small proportion of described Australian species (Hone and Buckmaster 2014).

There are relatively few monitoring programs for Australian biodiversity, even for relatively high profile species (Lindenmayer and Gibbons 2012; Lindenmayer et al. 2014). Fewer than 10% of Australian threatened mammal species are the subject of robust monitoring programs (Woinarski et al. 2014), from which reliable population trend data can be derived; and the statistical power of monitoring programs may be particularly weak for rare species. The evidence base is likely to be better for Australian bird species, for which there are relatively many observers and continental-wide monitoring programs (Garnett et al. 2011), but is substantially weaker for most other groups, particularly reptiles, invertebrates, plants and fungi, and, partly because there is very little available information on population size and trends, only very small proportions of species in these groups are listed as threatened (Walsh et al. 2012).

The absence or limitations in monitoring programs for Australian biodiversity is of particular concern given that there are now many examples of very rapid decline (in some cases to extinction) of species that were previously considered relatively secure. A notable example is for a set of four endemic and one native lizard species on Christmas Island that were relatively abundant and widespread in the 1970s. Of the four endemic species, one became extinct and two extinct in the wild by 2015, and the non-endemic (but native) species was extirpated (Smith et al. 2012). Limited monitoring over the course if this decline precluded some conservation responses that may have prevented extinction. Elsewhere, some disappearances have been unnoticed: species had been considered secure until fruitless searches for them revealed that they were no longer extant (Fisher and Ineich 2012). Rapid decline is not a feature of island biota alone: many other taxa in mainland Australia have exhibited rapid decline to at least regional extinction over periods of one to two decades (Woinarski et al. 2001; Woinarski et al. 2010).

[3] For example, as at August 2021, the Atlas of Living Australia held an average of over 66,000 records per bird species, but an average of only 42 records per invertebrate species.

7. Lack of knowledge of the extinction rate ("Extinction deficit shortfall")

This aspect of ignorance relates closely to the previous component (lack of knowledge of species' population trends), being largely the terminus for that component: effectively, if we're not tracking the rate of decline in any given species, we will be unaware of the point at which that declining population reaches zero. It also relates closely to the component of taxonomic ignorance (undescribed species): for if we do not know that a species exists, we will also not know when it no longer exists.

There are two components to this problem: a mis-match between the number (or rate) of known extinctions and the number (or rate) of formally recognised extinctions, and a mis-match between the number (or rate) of known extinctions and the actual number of extinctions. Tallies of the number of extinct species provide a measure of the extent of failure in our conservation effort, for example in State of the Environment reporting. The Australian government nominally keeps a formal account of the number of recent extinctions. But this tally is extremely unreliable. For example, a recent review of the conservation fate of Australian mammals since European settlement recognised that 30 mammal species had become extinct (Woinarski et al. 2015), an increase of nine species beyond the then officially recognised list of Australia's extinct mammals.[4] The formal tally of extinct species is a marked under-estimate relative to the number of known extinctions. In part, this is simply administrative inefficiency, caution, or low prioritisation relative to perhaps more pressing needs. As an example, although it has been robustly documented that the last individual of the Christmas Island pipistrelle *Pipistrellus murrayi* died on 26 August 2009 (Lunney et al. 2011; Martin et al. 2012b), this extinction is not formally admitted by the Australian government, which instead hopefully keeps it listed as Critically Endangered.[5] In part, this disparity relates generally to burden of proof: with rare exceptions such as the pipistrelle, extinction may be difficult to prove. Where there may still be some doubt, it may be preferable to retain a threatened listing (hence providing some potential protection) for it rather than prematurely categorising it as extinct (a category that typically provides no protection) (Collar 1998). Several instances of 'Lazarus' plant species (those categorised as extinct but subsequently found to be extant) have been reported in Australia (Keith and Burgman 2004).

Because many species may have become extinct without any knowledge of their existence, the known extinction tally probably substantially under-records the actual number of extinctions. For example, Chisholm et al. (2016) developed an analytical approach for estimating the numbers of such unknown extinctions, and provided an example for the Singapore bird fauna, from which they concluded that whereas the number of known extirpations there over the previous 200 years was 58 species, a further 9.6 species were likely to have been extirpated, but were unrecorded. The proportion of unrecorded extinctions is likely to be substantially greater for less conspicuous plant and animal groups.

8. Lack of knowledge of the biology of species ("Hutchisonian shortfall", "Raunkiaeran shortfall")

Biological traits – including, for example, body size, fecundity, longevity, age at maturity, breeding system, dispersal, diet, habitat, physiology and responsiveness to disturbance – of individual species influence their conservation fate (Cardillo et al. 2005). Knowledge of some of these traits can help predict extinction risk (Luiz et al. 2016), and can guide conservation management (e.g., to match fire regimes to the demography of obligate seeder plants). Such knowledge is also integral for assessment of the conservation status of species: for example, knowledge of generation length is required to contextualise the rate of population decline in assessment of a species' conservation status (IUCN Standards and Petitions Subcommittee 2013).

The available knowledge of such traits varies markedly among species (Fleming and Bateman 2016). For some species-groups, there are well-established global databases that document many biological attributes – a notable example is for mammals (Jones et al. 2009). Modelling or inference also allows for estimation of some traits for poorly-known species from taxonomically or ecologically related species (Di Marco et al. 2012). However, for many other groups, and particularly for invertebrates, there is a marked shortfall in knowledge of basic life history and other biological attributes.

[4] This mis-match was subsequently remedied, with the EPBC Act listing in 2021 a further 12 Australian mammal species as Extinct.

[5] The pipistrelle's status under the EPBC Act was changed to Extinct in 2021, twelve years after its actual extinction.

9. Lack of knowledge of the fit of species into ecological connections ("Eltonian shortfall")

All species operate within ecological settings characterised by intricate inter-relationships with other species. As such, it may often be futile to attempt to manage individual species without knowledge of their fit into the ecological systems in which they are based and to which they contribute. Obligate dependency is one extreme example of these interactions: for example the Christmas Island flea *Xenopsylla nesiotes* was host-specific to two species of rats endemic to Christmas Island, and presumably became extinct with the rapid extinction of those species soon after the island's settlement (Green 2014). Other tight relationships may be more mutual: for example, many thynnine wasp species have narrow host-specificity as pollinators of individual orchid species, many of which are now threatened; and the local or regional loss of either the wasp or the orchid will likely result in the loss of the other species or stymie reintroduction attempts (Peakall et al. 2010).

Some species operate as keystone species or ecological engineers, structuring the environment around them. For example, many Australian mammal species played important roles in soil turnover and seed dispersal, and influenced plant recruitment, ecological productivity and possibly fire regimes (Fleming et al. 2014; Eldridge et al. 2015; Silvey et al. 2015; Hayward et al. 2016). Hence, these functions were disrupted when these mammal species suffered broad-scale declines, but can be restored with reintroduction of those mammal species. However, such ecological connections and roles are known for relatively few species, and this knowledge shortfall is likely to render it difficult to assess the ecological value of most species and to constrain the effectiveness of conservation efforts.

10. Lack of knowledge of the relative impacts of possible threats and management responses ("Caughleyan shortfall")

Surprisingly, this issue has not previously been included in published typologies of ignorance in biodiversity or conservation. In accord with the odd convention now established for tagging areas of ecological ignorance, we label it here as the "Poirot shortfall", in homage to the great detective who almost always unmasked the culprit in even the most baffling cases of murder, or the "Caughleyan shortfall", in homage to the ecologist Graeme Caughley, who recognised the need for, and pioneered much of the research approach to, resolving the relative impact of putative causal factors driving decline (Caughley 1994; Caughley and Gunn 1996).

For threatened species, conservation management may be largely futile if it is not directed at the primary threat(s) (Troyer and Gerber 2015), although, in some cases, adaptive management may allow for increasingly effective targeting of recovery effort for situations where the relative impacts of different candidate threats are initially unknown (Caughley and Gunn 1996). It is not always straightforward to identify the primary threat(s), for there may be many possible suspects, threat factors may operate interactively, and the relative significance of different threats may change spatially and temporally or their effects may vary depending upon the affected species' population size or for different age or sex components of the species (Woinarski et al. 2011). For example, notwithstanding, a reasonable amount of contemporary research, the factor(s) that were the main causes of the very recent extinctions of the Christmas Island pipistrelle and forest skink *Emoia nativitatis* remained uncertain over the period of their decline and loss (Smith et al. 2012; Woinarski et al. 2017; Woinarski 2018). The diagnosis of causality may be even harder for species that became extinct before they were subject to any research, and in such cases the apportionment of blame typically relies largely on weak correlative evidence (such as the degree of spatial and temporal synchrony in the timing of introduction of a threat and the onset of decline in a susceptible species) or extrapolation from the pattern and cause of decline from a set of better-known species (Burbidge and McKenzie 1989; Short and Smith 1994; Smith and Quin 1996; Johnson 2006).

For some threatened species, particularly highly localised species confronted with factors likely to lead to marked loss of their habitat, threats are generally well resolved. But for most threatened species, there may be a much more complex potpourri of threats, and there is little knowledge of the extent, severity, likelihood and consequences of the operation of individual threats, and hence which threats pose the most critical risks. This ignorance is likely to be compounded with climate change, which will introduce new threats directly (such as increased incidence of extreme weather events that may exceed the physiological tolerance of some species) (Watson 2016), and magnify the consequences of some existing threats. Nonetheless, experimentation designed to assess the influence of individual putative threats, and their interactions, may provide crisp evidence of the relative importance of those factors in driving species' decline (Frank et al. 2014).

Threats and their impacts are not necessarily static. For most threatened species, there is little knowledge of the species' capacity to respond behaviourally, morphologically or demographically to threats, and how effective such adaptive change may be in reducing the species' susceptibility to the threat.

Even once a pivotal threat is identified, sometimes the available information is insufficient to manage that threat effectively. This may be particularly so for novel threats, such as the Tasmanian devil facial tumour disease (McCallum et al. 2009), but it may apply also for well-established threats that are widespread and affect many species. For example, in Australia, the feral cat *Felis catus* is implicated in the decline and extinction of many mammal species (Woinarski et al. 2014), and occurs pervasively across the continent, but shortfalls in knowledge mean that there is currently no effective broad-scale control option available. Likewise, the ongoing spread of the cane toad *Rhinella marina* has caused major declines in many native vertebrate species (Shine 2010), but there is insufficient knowledge to deliver an effective broad-scale control.

11. Lack of knowledge transfer from science to the community and decision-makers, and from the community to science

As with any discipline, in ecological science, the practitioners will generally have a far more specialised and nuanced understanding of issues than the general community, including decision-makers. Scientists have not necessarily been effective communicators of the intricacies of biodiversity knowledge, the significance of such intricacy, and the consequences of knowledge imperfection. The community may also be relatively unconcerned about knowledge shortfalls in specialised fields. This "public dilemma" and "political dilemma" (see Table 1) (Cardoso et al. 2011b) may have the results that there is little appetite for supporting further research, especially for biodiversity groups whose values may be deemed low by the public or politicians, and that conservation efforts that provide at least short-term benefit for some high profile species may be considered to have solved the conservation problem.

But of course, there is also some reciprocity in this relative ignorance. The community may sometimes have far better information about some species than do scientists and it may not be straightforward for such information to be channelled into conservation assessment or management. A particular case is the intricate knowledge of the ecology and status of many plant and animal species held by Indigenous Australians. With some notable exceptions, relatively little of this knowledge is incorporated into conservation assessment (Ziembicki et al. 2013) or conservation management practice (Ens et al. 2015)

Dealing with ignorance: conservation in a data-poor world

Policy settings

There is some consideration in existing policy and legislation of major knowledge shortfalls, and the approaches that can be taken to remedy them.

At international level, three targets within the UN's Strategic Plan for Biodiversity 2011-2020 and the Aichi targets are relevant:

- **Target 12**: By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.
- **Target 18**: By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity … are respected … and fully integrated and reflected in the implementation of the Convention …
- **Target 19**: By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.

Similarly, the United Nation's Sustainable Development Goals include the targets to "take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species" (15.5) and "increase scientific knowledge, develop research capacity and transfer marine technology" (14.8) (https://sustainabledevelopment.un.org/?menu=1300).

Explicitly targeting knowledge shortfall (Miller et al. 2012), the Global Strategy for Plant Conservation includes the objective (Objective I) "plant diversity is well understood, documented and recognised", with two particularly relevant targets for the period 2011-2020: "an online flora of all known plants" (Target 1), and ''an assessment of the conservation status of all known plant species, as far as possible, to guide conservation action'' (Target 2). It also included (under Objective II), the target "at least 75% of known threatened plant species conserved in situ" (https://www.cbd.int/gspc/).

Australia's national biodiversity strategy (Natural Resource Management Ministerial Council 2010) includes short-term targets (to be achieved by 2015), including:

- "nationally agreed science and knowledge priorities for biodiversity conservation are guiding research activities" (target 8), and
- "establish a national long-term biodiversity monitoring and reporting system" (target 10).

It also proposed a series of outcomes, including:

- an increase in public awareness of biodiversity (1.1.1);
- an increase in the use of Indigenous knowledge in biodiversity conservation decision making (1.2.2);
- an improvement in the conservation status of listed threatened species and ecological communities (2.1.3);
- an increase in the accessibility of science and knowledge for biodiversity conservation (3.1.1);
- an improvement in the alignment of research with biodiversity conservation priorities (3.1.2);
- an increase in the application of knowledge of biodiversity conservation by all sectors and communities (3.1.3); and
- an increase in the use of information from both the private and public sector in the adaptive management of biodiversity conservation (3.3.3)

The Australian Threatened Species Strategy (Commonwealth of Australia 2015) commits to attempting to prevent any avoidable extinctions and includes the long-term goal "to halt the decline of Australia's threatened plants and animals and support their recovery".

Building and aggregating knowledge

There have been some remarkable advances over recent years in the aggregation and interpretation of previously widely scattered taxonomic, distributional and other biodiversity data, notably including the Global Biodiversity Information Facility and, in Australia, the Atlas of Living Australia (Faith et al. 2013), and the public-driven eBird aggregation of bird observations.

There has also been very substantial survey and taxonomic efforts that have aimed to move species from the large 'unknown' pile to the 'known' pile, and hence render their conservation somewhat more tractable. Much of this effort is strategic and cost-effective, involving well-designed surveys especially targeting previously poorly-sampled areas to fill major distributional and taxonomic knowledge gaps (Aranda et al. 2011), and/or to closely target surveys or other studies that may provide the pivotal information for poorly-known species that are likely to be threatened but for which the current information base is inadequate to satisfy qualification standards (Silcock et al. 2015).

Most evidence on which assessment of the eligibility for listing is currently based relates to published scientific studies. At least in Australia, traditional ecological knowledge is rarely considered in such assessments, notwithstanding the substantial experience and knowledge base of many Indigenous people. The lack of use of this knowledge source is probably because much of this knowledge is not documented, because the evidence may not fit readily into the often precise numerical criteria associated with listing, and/or because it may take considerable time to seek out unpublished Indigenous knowledge. Nonetheless, in an Australian context, Indigenous knowledge of the status of many species-groups may substantially exceed that reported in the scientific literature and provide a valuable perspective on distribution, abundance and the timing and extent of population declines (Burbidge et al. 1988; Ziembicki et al. 2013).

Knowledge-seeking will not always be a priority: some recent studies have evaluated the relative benefit of implementing conservation actions now based on imperfect knowledge against delay of conservation action in order to survey to find further information. These studies have concluded that in some but not all cases, actions taken now based on incomplete information resulted in better conservation outcomes (Grantham et al. 2008; Grantham et al. 2009; Grantham et al. 2010; Hermoso et al. 2013; Marignani et al. 2014). The relative benefit of obtaining more information is likely to depend upon the extent and representativeness of the current evidence base, the extent to which existing information acts as a surrogate for the distributions of poorly-known species, the costs of survey, and the urgency of implementing conservation actions.

Although the number of taxonomists dealing with Australian species is few, and probably diminishing (Braby and Williams 2016), an initiative ("Bush Blitz") based on partnership between governments and industry has sought to provide rapid taxonomic assessments for many species in many (including "obscure") groups in geographic areas (mostly previously little sampled conservation reserves) that are likely to have unusually high numbers of poorly-known species (Lambkin and Bartlett 2011). Over the period 2009-2015, more than 1100 new Australian species were described as a result of this survey and taxonomic effort (http://bushblitz.org.au/; Preece et al. (2015)). While this rate of description of new species (ca. 200 yr^{-1}) is probably a substantial improvement, even at this rate it may take another 2000+ years to fully document the Australian biota, given the currently estimated number of undescribed species (Chapman 2009).

Recognising the severe conservation challenge posed by unknown or undescribed species, especially for some taxonomic groups, a range of expeditious biosystematics approaches has been proposed, including the development of improved frameworks to systematically capture taxonomically unrecognised lineage diversity, increased use of metadata frameworks to allow better recording and dissemination of biodiversity information, emerging genomic and analytical techniques that will provide powerful new tools for the identification and understanding of evolutionary lineages, with a focus on priority groups likely to be tractable, representative and/or particularly imperilled (Oliver et al. 2015; Braby and Williams 2016). However, some taxonomic shortcuts may be problematic and bring substantial risks (Braby and Williams 2016).

In some situations, taxonomy may move more slowly than conservation need. The EPBC Act provides a limited opportunity to protect undescribed species, allowing the Environment Minister to function as a quasi-taxonomist:

> *'The Minister may, by instrument in writing, determine that a distinct population of biological entities is a species for the purposes of this Act.'* (s. 517(1))

In some limited situations, this provision may offer some protection for species that are known but not yet formally described. However, this provision has been very rarely used, at least in part because the legislative protection applies only after sufficient information has been compiled about the entity to demonstrate that it qualifies as threatened.

Another approach is to predict the location and numbers of currently unknown species (largely based on extrapolations from sites with known but contrasting survey effort and from species accumulation curves) and include such predicted unknown species in spatial conservation planning (Bini et al. 2006; Possingham et al. 2007). This approach has been little used to date, and is probably applicable only to reasonably well-known groups, and is likely to have very limited application for conservation policy.

Conservation management approaches

There are several conservation approaches that may provide a conservation 'shield' for some unknown and poorly-known species.

The cornerstone of biodiversity conservation globally, and in Australia, is the establishment of a conservation reserve system that is comprehensive, adequate and representative (Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee 1997; Australian and New Zealand Environment and Conservation Council 1999), alternatively defined as one based on redundancy, resilience and representation (Shaffer and Stein 2000; Groves et al. 2002; Tear et al. 2005; Scott and Tear 2007). The assumption is that if that reserve system includes samples of all ecosystems or habitats, with large enough areas of these, and multiple samples of each, then it should encompass (viable populations of) all species, even species not currently known. This assumption has some substantial shortcomings: (i) many unknown or poorly known species are likely to have restricted distributions and hence are unlikely to be present in those fragments of the land area that eventually make up a reserve system; (ii) many species may have distributions that are poorly linked to the vegetation types or other environmental classes that are typically used as the units for allocating areas to conservation reserves on the basis of comprehensiveness; (iii) even if unknown or poorly known species are represented in one or more reserves, those reserves may not be managed appropriately for them but rather (if they are managed at all) for high profile species. In Australia, although the tenet of comprehensiveness was initially defined explicitly to encompass the inclusion of all known 'elements of biodiversity' (i.e. including species) (Joint ANZECC/MCFFA National Forest Policy Statement Implementation Sub-committee 1997; Australian and New Zealand Environment and Conservation Council 1999), this objective has subsequently been diminished to relate only to the inclusion of all vegetation types or other landscape units and, to some extent, listed threatened species (Natural Resource Management Ministerial Council 2005; National Reserve System Task Group 2010). Furthermore, established global and national targets for the extent of the conservation reserve system, typically that they comprise at least 17% of any nation or terrestrial environment (e.g. Aichi Target 11), will be substantially insufficient to include representation of all species (Rodrigues and Gaston 2001; Brooks et al. 2004; Rodrigues et al. 2004): i.e., the entire distributions of many species, known and unknown, will lie outside reserve systems that comprise such a minority of the land extent.

Under Australian legislation, another measure that may offer some conservation benefit for some unknown or poorly-known species is the listing and subsequent protection of threatened ecological communities. These typically include a coherent set of co-occurring species that collectively have been much diminished in extent (or community health). Only some (typically dominant or indicator) species need to be named in the community for the listing process, but the community itself may be assumed to include some unknown or poorly-known species that share the ecological associations and degree of imperilment as the named species. While this mechanism may provide some benefit for some at risk unknown species, the total extent of listed threatened ecological communities is very small (<2% of the Australian land area), so, on the basis of current listing, this mechanism is likely to provide conservation benefit to only a very small proportion of Australia's unknown or poorly-known species.

Conservation actions taken for some listed threatened species ('umbrella' species) may also provide benefit for other co-occurring species, including some unknown or poorly-known species, but the extent of this conservation aureole is not well established.

The delineation and protection of 'biodiversity hot-spots', areas with exceptionally high diversity but a substantial degree of threat (Myers et al. 2000; Mittermeier et al. 2004), provides another mechanism to help conserve unknown or poorly-known species, given the presumption that protection of such areas is likely to stave off otherwise likely degradation, and that if any area has high diversity for some well-known groups it may also have high diversity for less well-known groups, although evidence for this latter presumption is mixed (D'Amen et al. 2013a; Leather 2013; Stork and Habel 2014). The Australian government has designated some biodiversity hotspots, and has episodically offered these some particular conservation priority.

Australian legislation also allows for the listing of key threatening processes, and the development and implementation of abatement plans for these threats. This listing and management may provide some conservation benefit for some unknown and poorly-known species detrimentally affected by these listed threats, but most threat abatement plans are little implemented. More generally, enhanced management of factors that are known to affect some components of biodiversity may also provide some benefits for species whose threats are not well documented: this may be especially the case if the better and less well known species are related or of comparable ecologies.

Threatened species listings

As noted in the policy settings above, global and national biodiversity strategies generally include some commitment to the protection and recovery of known listed threatened species. The listing of a species as threatened generally provides some level of conservation protection, or at least recognition of a conservation concern. For example, under Australian legislation, development proposals need more stringent evaluation if they are considered likely to have a significant impact on listed threatened species; some degree of management planning is compiled for listed species; and resourcing may be more likely to be available for their study and management. Hence, if two similar species have the same degree of imperilment, but one is formally listed as threatened and the other is not, then the listed species is more likely to be offered some protection and hence less likely to become extinct.

However, the 'known' and 'listed' qualifiers for threatened species in global and national strategies serve to exclude many unknown or unlisted species that similarly may be at high risk of extinction and in need of conservation response. There are two main components to this exclusion: (i) for some (known and unknown) species, the available evidence is inadequate to assess conservation status relative to the relevant criteria and their currently designated thresholds, and (ii) for some species, that evidence may be available, but the species have not yet been formally assessed, largely due to bureaucratic resource constraints (particularly if much effort is required to compile and assess a substantial evidence base). Given that most species are undescribed, and that knowledge about very many known species is rudimentary, it is highly likely that the number of currently listed threatened species represents a very small proportion of the actual number of species that are eligible for listing as threatened, or are at least as imperilled. The consequences of this are the high extinction risk of many species is not recognised and hence they are given little or no conservation protection (rendering their extinction more likely); and the magnitude of the conservation problem (as measured in the numbers of listed species) is seriously under-estimated.

There are several approaches, not necessarily mutually exclusive, that can be considered to address this problem of largely unrecognised biodiversity imperilment and loss: (i) the burden of proof required to qualify a species for listing as threatened can be modified from more evidentiary to more precautionary; (ii) a strategic program can be implemented to obtain more substantial evidence for species likely to be threatened but for which the current evidence is insufficiently compelling (see 'building and aggregating knowledge' section above); (iii) some form of conservation protection can be afforded to species that are recognised as data deficient; or (iv) all species can be considered threatened, and hence accorded conservation status, unless demonstrated to be not threatened. These approaches are described overleaf.

Under Australian legislation, assessment for listing a species as threatened is largely based on IUCN criteria (IUCN Standards and Petitions Subcommittee 2013). Generally, it requires relevant information relating to thresholds for population size or distributional extent, and trends (or future projections) over defined periods in these values (or, for population size, trends in relative abundance). Partly because of its legal consequences, the burden of proof required is typically higher than that for listing through the IUCN Red List process: for example, Australia's threatened species strategy notes: "nominations are subject to rigorous scientific assessment by the Threatened Species Scientific Committee and must be supported by a high level of evidence" (Commonwealth of Australia 2015). However, this high level of evidence is not available for many, and probably most, species.

The IUCN guidelines and Australian legislation provide some guidance relating to the assessment of conservation status 'in the absence of complete data' or where there may be 'considerable uncertainty' about data (IUCN Standards and Petitions Subcommittee 2013). This guidance includes the application of inference and projection in the interpretation of data directly (e.g., some monitoring information on the species) or indirectly (e.g., rates of habitat loss) pertaining to the species' status. The IUCN guidelines recommend that "assessors should adopt a precautionary but realistic attitude, and to resist an evidentiary attitude to uncertainty when applying the criteria (i.e., have low risk tolerance). This may be achieved by using plausible lower bounds, rather than best estimates … (but that) … 'worst case scenario' reasoning be avoided as this may lead to unrealistically precautionary listings."

Australian legislation provides less detailed guidelines, but the EPBC Act includes a premise that actions should be consistent with the principle of ecologically sustainable development: "if there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation" (s3A(b)). The EPBC Act also stipulates that the Minister "must consider (the) precautionary principle in making decisions": i.e., "lack of full scientific certainty should not be used as a reason for postponing a measure to prevent degradation of the environment where there are threats of serious or irreversible environmental damage" (s. 391(2)). The application of these principles to the listing process, and to actions taken to prevent extinction, has not been well defined or established.

Where evidence of a species' status relative to thresholds for listing as threatened may be sparse, contradictory or not compelling, interpretation is required, and that interpretation is likely to vary according to the extent to which the assessment is precautionary or evidentiary. This situation is akin to Type I (a 'false positive', the incorrect rejection of a true null hypothesis – i.e., incorrectly concluding an effect that is not present) and Type II (a 'false negative', the incorrect failure to reject a null hypothesis –i.e., failing to detect an effect that is present) errors in the interpretation of statistics. In this case, the detrimental consequences of one error type (assessment of species as not threatened, when in fact it is) are likely to be appreciably more substantial than the opposite error type (listing a species as threatened when it is not actually threatened).

Error type	Detrimental consequences of mis-assignment
The species is assessed as not meeting threatened listing criteria, when it is actually threatened	Opportunities may be lost to recover the species and prevent extinction; the tally of listed threatened species under-estimates the extent of the problem; the threatened species list loses credibility
The species is assessed and listed as threatened, when it is not actually threatened	A proportion of the limited resources for threatened species management may be 'wasted'; development proposals may be rejected for invalid reasons; the threatened species list loses credibility

Some measure of the extent to which the Australian listing process sits on the gradient between precautionary and evidentiary in its interpretation of data relevant to thresholds for listing can be gauged by the number of listed species that are subsequently de-listed on the basis that additional information collected after listing has revealed that the original listing was too precautionary and that the species should not have qualified as listed. Of about 470 species listed subsequent to the Act's inception, only three species have been de-listed (as at 2016), with two of those de-listings based on taxonomic revision, and not because new information has indicated that it did not originally meet listing criteria. Of 1359 species listed at the inception of the EPBC Act (July 2000) – most of which were transferred from previous listings (the *Endangered Species Protection Act*) that were not based on current IUCN status assessment criteria – as at 2016, 143 were subsequently de-listed (excluding species re-listed under new names). Of these, 111 were de-listed due to new information about distributional extent, population size or trends (in some cases with such improved information arising because the threatened listing catalysed additional survey effort and other research) and/or because it was recognised that, while the species may have met previous criteria for listing, they did not meet IUCN criteria. The remaining 32 de-listed species were removed because taxonomic review revealed that they were not valid species. Curiously, two additional taxa were de-listed after 2000, but subsequently re-listed: *Amytornis textilis* myall was de-listed in 2009, but re-listed in 2014, and *Macroderma gigas* was delisted in 2001 and re-listed in 2016. Overall, these tallies suggest that listing since the Act's inception has been robust and evidentiary, with little need for re-evaluation with accrual of subsequent information. It is more difficult to determine the number of cases of species that were not listed in initial assessment but were subsequently listed largely due to more robust evidence, at least partly because many species found not to be eligible (in some cases due to data insufficiency) have not been subsequently re-nominated.

Current IUCN assessments can indicate a span of potential conservation status categorisations for any given species based on consideration of uncertainty in the evidence base (Akçakaya et al. 2000; Mace et al. 2008), and explicit consideration of the assessors' risk tolerance (broadly a positioning on the evidentiary-precautionary spectrum) (Alonso-Redondo et al. 2013).

There is some scope for augmenting or better distilling and interpreting limited available data through the use of expert elicitation (Martin et al. 2012a; McBride et al. 2012). Modelling also offers a range of opportunities to extend and interpret limited available evidence. The likelihood of extinction can be predicted for poorly-known species from the relationship of life history and other parameters to extinction-proneness in related but better known species (Bland et al. 2012, 2015a; Bland et al. 2015b; Böhm et al. 2016), although such predicted values may not meet the evidentiary standards required for formal listing.

Because the EPBC Act includes both the precautionary principle and the principle of ecologically sustainable development as part of its foundations, it can be considered appropriate that the assessment of the conservation status of species should be more precautionary than evidentiary. This can be achieved with explicit consideration of risk tolerance in assessment, and amplification of limited existing evidence through expert elicitation and extrapolation of extinction-risk from other similar species.

However, a change to a more precautionary approach does not resolve another problem – the bottleneck in listing capability due to the legislated need for a substantial peer review and public consultation process for all considered species and to the limited capacity within the relevant department and the independent expert committee (the Threatened Species Scientific Committee) that recommends whether or not a species qualifies as threatened. There are several options for addressing this problem: (i) amending the Act to simplify and abbreviate the assessment process; (ii) reducing the amount and/or standard of documentation required for assessment; (iii) increasing the resources available to those involved in the assessment process; and (iv) synergising the assessment and listing process with international (IUCN) or other processes. To some extent, the latter component is being implemented by the Department of Environment[6] and the Threatened Species Scientific Committee through the Species Expert Assessment Plan (SEAP): to date, this has involved the adaptation and adoption of independent comprehensive assessments of the conservation status of Australian birds (Garnett et al. 2011) and mammals (Woinarski et al. 2014), the commissioning of a comprehensive assessment of the conservation status of Australian frogs, collaboration with the IUCN on a comprehensive assessment of the conservation status of Australian reptiles, and collaboration with the states and territories through the 2015 Common Assessment Method intergovernmental memorandum.

The IUCN guidelines include a Data Deficient category, effectively an "Orange List" of species (Victor 2006). This category is applied for known taxa for which "there is no direct or indirect information about … current status or possible threats" and in some cases where there is some relevant evidence but "where data are very uncertain". The guidelines note that "a data deficient listing does not imply that a taxon is not threatened", and that "taxa that are poorly known can often be assigned a threat category on the basis of background information concerning the deterioration of their habitat and/or other causal factors; therefore the liberal use of Data Deficient is discouraged". Notwithstanding such discouragement, the IUCN has assessed very many species as Data Deficient. Of IUCN assessed taxa, as at 2015, about the same number of animal species have been categorised as Data Deficient (11,398) as threatened (11,982), with rates varying widely among groups: for example, Data Deficient species comprise 14% of the world's mammals *that have been assessed,* 0.6% of birds, 18% of reptiles, 25% of amphibians, 20% of fish, and 29% of invertebrates (http://cmsdocs.s3.amazonaws.com/summarystats/2015-4_Summary_Stats_Page_Documents/2015_4_RL_Stats_Table_3a.pdf). The IUCN rates 7.8% of assessed plant species as Data Deficient (http://cmsdocs.s3.amazonaws.com/summarystats/2015-4_Summary_Stats_Page_Documents/2015_4_RL_Stats_Table_3b.pdf), and 20% of the very few assessed fungi and protists (http://cmsdocs.s3.amazonaws.com/summarystats/2015-4_Summary_Stats_Page_Documents/2015_4_RL_Stats_Table_3c.pdf). These are likely to be under-estimates because many species that have not been assessed formally for conservation status are likely to be data deficient. Although Data Deficient species are typically accorded less regulatory protection and fewer resources than listed threatened species, some recent studies have indicated that a high proportion of Data Deficient species are likely to be threatened (e.g., 64% of mammals recognised by the IUCN as Data Deficient are considered likely to be threatened: Bland et al. (2015a)), with this neglect labelled as "the silent extinction risk of data deficient species" (Howard and Bickford 2014).

Data deficiency covers a broad swathe of issues, and some authors have suggested annotating the category to include, for example tags for taxonomic uncertainty; for species likely to be threatened but with an assessment that is stymied by lack of information relating to the relevant population, range and trend parameters; and for species for which there is simply too little known information to consider the likelihood of being threatened (Victor 2006). To some extent, Western Australian practice has such a categorisation system (Priority I-IV) for species of concern that are not listed as threatened.

[6] now (2021) the Department of Agriculture, Water and the Environment

In contrast, the EPBC Act does not provide for a Data Deficient (or a Near Threatened) category, so provides no effective conservation protection for poorly-known (but potentially imperilled) species. However, some Australian jurisdictions (e.g., the Northern Territory) include a Data Deficient category (see Appendix A): as so used, this designation provides no particular conservation protection, but highlights these species as priorities for survey and research. In Western Australia, where many species (particularly plants and invertebrates) are known or presumed to have very small ranges ('short-range endemics'), existing policy provides some protection for poorly-known species that may be highly localised (Environmental Protection Authority 2009; Harvey et al. 2011). Where a proposed development may affect the location of such species, the onus lies with the development proponent to undertake additional information-gathering that may demonstrate that the species is more widespread, or that the proposed development will not have a significant impact on the species.

Such a burden of proof could be applied more widely in Australia. Australian legislation could be amended to include a category for species for which there is some reasonable grounds for assuming that they may be threatened but for which the evidence base is currently inadequate to meet the evidentiary standards for listing as threatened (essentially a "Data Deficient (but of concern)" category). Following the Western Australian policy for the protection of short-range endemics, a burden of proof could be demanded of development proponents to demonstrate that such species are not threatened, or that their proposals would not further threaten these poorly-known species.

Given the accelerating global rate of biodiversity decline (Loh et al. 2005), the slow deliberations involved in the compilation of threatened species' lists may mean that legislative protection is falling ever behind the conservation need (Parenteau 1998). A more extreme precautionary approach to this problem is to reverse the current process that lists a biased residue of comparatively well-known species as threatened and assumes all other species are not threatened. Instead, policy and legislation could list a set of species that are demonstrably secure, and assume – unless proven otherwise – that all other species, known and unknown, are threatened. Such a 'Green List' of species that are not of immediate conservation concern would allow further conservation studies and actions to focus more efficiently on the species that most need attention to ensure their future survival (Miller et al. 2012). Of course, there may be very formidable operational challenges in implementing any such approach, and a default listing of tens to hundreds of thousands of putative threatened species may not provide any manageable prioritisation for conservation protection.

Conclusions

In Australia, and the rest of the world, most species are unknown. Lack of knowledge results in amplified neglect in conservation responses: for example, because species are unknown or poorly known they are unlikely to be assessed as threatened and, because they are not listed as threatened, they are less likely to be included in the conservation reserve system, less likely to be afforded research funding for study, and therefore there will be little information available to identify their threats, and little priority accorded to their management (Fig. 2). Imperilled species that are unknown or poorly known are afforded little or no explicit protection under current conservation policy settings. To some extent, they are assumed to be provided with some protection by default through the establishment of a conservation reserve system, through conservation actions taken for 'surrogate' species, and through management actions taken for key threatening processes. However, as currently implemented, the conservation reserve system is inadequate to include all species, many species are not well represented by surrogates, and there is little resourcing for the implementation of most threat abatement plans. These actions are unlikely to provide adequate default or indirect conservation security for many, if not most, unknown and poorly-known species. Furthermore, it is more likely than not that a higher proportion of unknown than known species are at risk of extinction, given that a high proportion of unknown and poorly-known species will have small distributions and be relatively uncommon.

Australia's assessment and listing process for threatened species is unrepresentative (taxonomically biased), and unlikely to be keeping pace with the increasing rate of biodiversity loss. Legislative, policy and operational changes can make the process more inclusive and efficient, notably by more considered application of the precautionary principle. Furthermore, more substantial changes can be made to conservation policy, to add to the current listing of threatened species (effectively a 'Red List'), a listing of species that are data deficient but probably threatened (an 'Orange List'), to which some level of conservation protection can be provided.

This report describes major knowledge gaps that affect extinction risk especially for poorly known groups of species. Options that may help overcome these knowledge gaps and biases in order to enhance the conservation outlook of biodiversity are summarised in Table 2, along with the constraints associated with those options. A more detailed consideration of these options is presented elsewhere (Rumpff 2018).

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Table 2. Options to overcome knowledge shortfalls and biases to enhance the conservation of species.

Conservation action	Options for dealing with knowledge shortfalls	Benefits	Constraints
Threatened species listing	Reduce 'burden of proof' (e.g. by explicitly taking a more precautionary approach)	More species that are actually imperilled receive appropriate conservation attention; listing process may be streamlined and quicker	For formal listing, may require legislative change; may result in some invalid listings (i.e. of species that are not threatened) and more formal challenges to the listing process
	Amplify existing evidence base by expert elicitation or modelling of likely extinction-proneness from related better known species	More species that are actually imperilled receive appropriate conservation attention	Derived information may not be strong enough evidence to use formally; assessment process may take longer
	Undertake research to target key knowledge gaps; this may include use of sources not typically used (e.g. traditional ecological knowledge), as well as taxonomic studies, monitoring and surveys	More species that are actually imperilled receive appropriate conservation attention	Time and resource expenditure
	Include a 'Data Deficient (but likely to be of concern)' category. This could be coupled with (i) priority accorded to such species for additional research to better resolve status, and (ii) some protective mechanism (such as requiring proponents of developments to demonstrate that their impact will not have significant impact or that the species is not imperilled)	More species that may be actually imperilled receive some conservation attention	Such lists may be very long, and associated protective mechanisms may be costly or ineffective
	Reverse burden of proof by including a 'Secure' category and assuming all other species are of conservation concern, unless shown not to be	Poorly known and unknown species would be more likely to be protected	The listing of all species other than those known to be secure would be impractically long, and would be cumbersome for prioritising conservation response
	Increase the extent and number of listed threatened ecological communities	A higher proportion of imperilled but unknown or poorly known species would be accorded some protection through a reasonable surrogate mechanism	Assessments of conservation status of ecological communities may be time consuming; relies on surrogacy and many poorly known or unknown species may not be well represented by threatened ecological communities

Conservation action	Options for dealing with knowledge shortfalls	Benefits	Constraints
	Coordinate conservation status assessments at global, national and state levels. [Note that coordination at national and state/ territory levels is now being undertaken through the Common Assessment Method.]	Efficiency in assessment effort, and greater consistency in assessment outcomes and management responses	Assessment protocols have some differences, mostly associated with higher evidentiary standards for formal legal listing; groups of poorly known species may still be neglected if they are low priorities for any assessment process
	Undertake more frequent comprehensive assessments of the conservation status of taxonomic groups, particularly those currently under-represented in threatened species lists [i.e., where this reduces taxonomic bias]	Listing is likely to be more comprehensive and systematic and less biased	More resources required for assessment processes
Inclusion in conservation reserve system	Substantially increase the extent of the conservation reserve system to make it more likely that it includes adequate representation of a higher proportion of species	Conservation reserve system will encompass a higher proportion of species, will be more likely to harbour adequate populations of individual species to provide long-term viability, and will deliver more conservation security for biodiversity in general	Higher (acquisition and ongoing management) costs, and more conflict with other land uses
	Increase the comprehensiveness of the reserve system through use of more, and more disparate, selection criteria (particularly including a wide range of taxonomic groups). Test and refine surrogacy for biodiversity features included in reserve design	Conservation reserve system will encompass a higher proportion of biodiversity	Available data (particularly relating to distribution and abundance) for some taxonomic groups are limited, so more expenditure may be required to collect sufficient additional information
	Increase (e.g. distributional records) and amplify (by better collation, modelling etc.) the evidence base for biodiversity features included in reserve design	Enhanced knowledge will provide more confidence and flexibility in reserve design, and hence better outcomes for conservation	Time and resource expenditure
	Increase effectiveness of reservation system by better management of threats in reserves	Conservation reserve system will do better at maintaining or recovering the species it seeks to protect, including poorly known but imperilled species	Higher management costs

Conservation action	Options for dealing with knowledge shortfalls	Benefits	Constraints
Effective management of main threats	Undertake research to determine relative impacts of threats, and of management mechanisms to most effectively control threats. This may be encompassed within an adaptive management framework	Management most effectively targets primary threats, hence increases conservation outcomes, including for poorly known but imperilled species	Time and resource expenditure
	Develop more effective threat abatement plans for more threats that affect many species	More effective management of more threats will benefit more biodiversity, including poorly known and unknown species	More expenditure
	Enhance resourcing of threat management, and prioritise control of those threats affecting many species	Available resources optimally target those threats that most affect most species, hence allocated resources provide optimal conservation benefit	More expenditure

Figure 1. *Schematic diagram of the knowledge base for species, and its main shortfalls. Width of arrows corresponds to indicative proportion of species.*

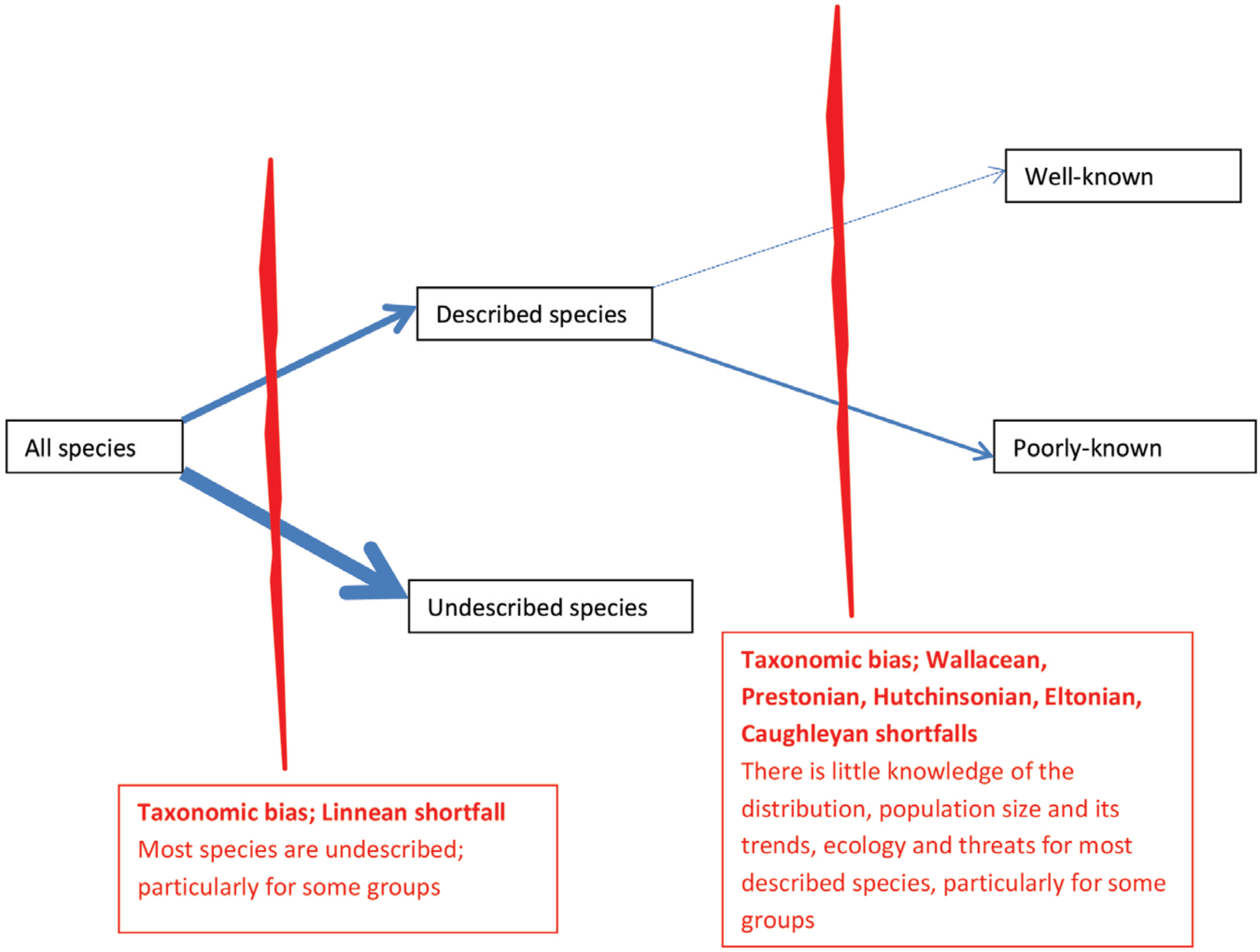

Figure 2. *Schematic diagram of the main conservation responses used for imperilled species that are well known, poorly known and unknown. Note that arrow thickness symbolises the relative likelihood of the outcome being realised. Further explanation in relation to numbered points is provided below.*

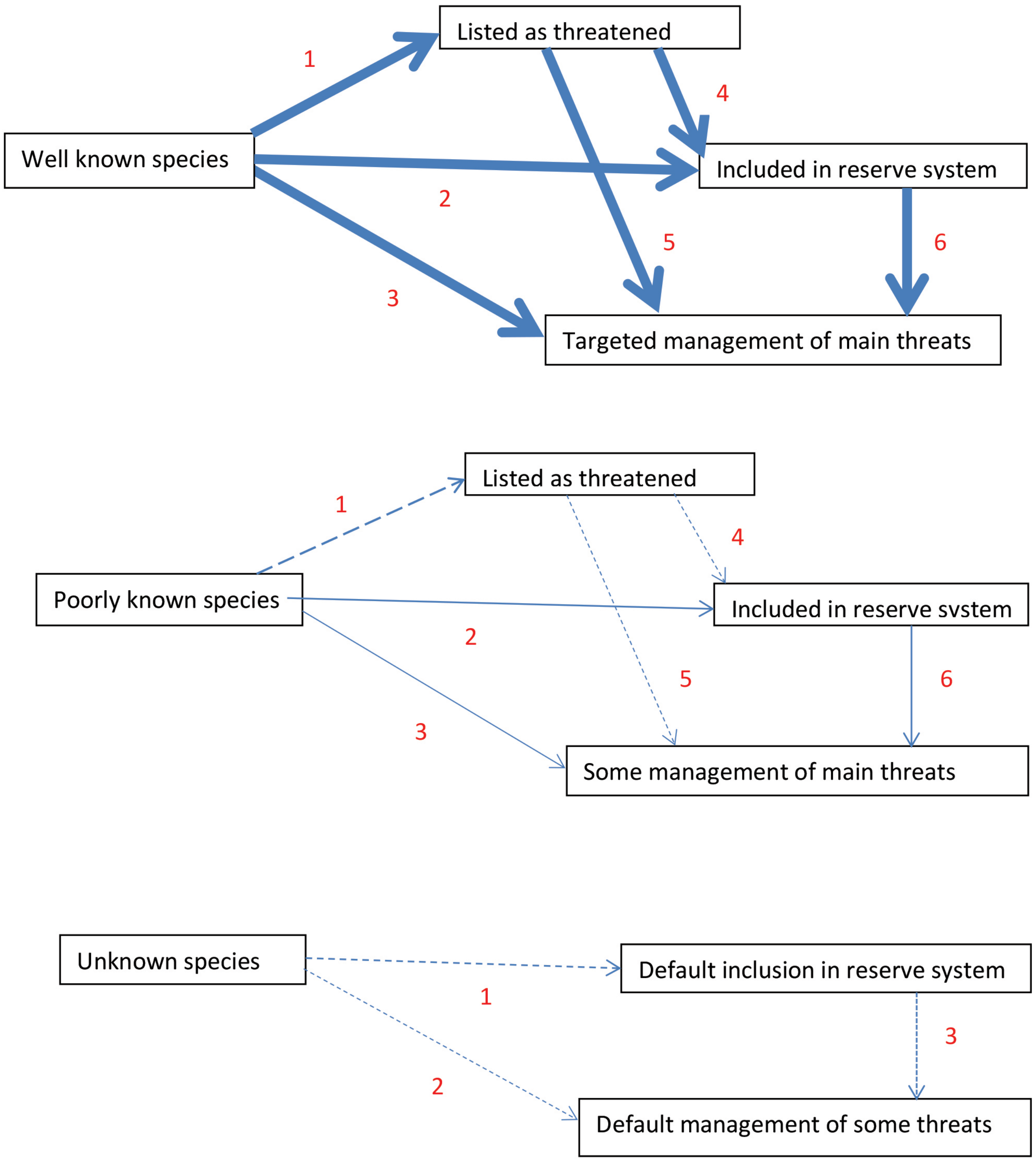

Figure 2 Explanation points:

Well known species 1. Because there is likely to be sufficient evidence about relevant conservation parameters, well known species are likely to be listed as threatened, although taxonomic biases may render some groups less likely to be nominated and assessed; 2. Because distributions are well known, such species are likely to be included in reserve planning, although taxonomic biases may render some groups less likely to be considered; 3. Because factors causing decline may be well known, targeted response is more likely to occur and be effective; 4. In many cases, reserve design includes representation of threatened species as a selection criterion; 5. Threats (particularly acute ones) to listed threatened species are more likely to be managed than for unlisted species; 6. Conservation management is more likely to occur in reserves than outside reserves.

Poorly known species. 1 In most cases, the evidence base will be inadequate to meet threshold standards for listing as threatened; 2. Some poorly known species will be included in conservation reserves by default, or because some taxonomic groups (notably birds and mammals) are often used as selection criteria, however limited information on distribution may render such representation suboptimal; 3. Some limited information on factors causing decline may allow for some, but probably suboptimal, management of some threats; 4. Because reserve design may include representation of threatened species as a selection criterion, the relatively small proportion of poorly known species that are listed as threatened may be included in reserves; 5. Threats (particularly acute ones) to listed threatened species are more likely to be managed than for unlisted species, but only a small proportion of imperilled poorly known species will be listed; 6. Conservation management is more likely to occur in reserves than outside reserves, but only a small proportion of poorly known species are likely to be included in reserves.

Unknown species. Imperilled unknown species will not be listed as threatened. However, 1 some may be included in the conservation reserve system by default, or because that reserve system may be designed for appropriate surrogates; 2. Management of some threats may happen to include those threats that affect some unknown species. 3. Conservation management is more likely to occur in reserves than outside reserves, but only a small proportion of unknown species are likely to be included in reserves.

APPENDIX A.

Collation of existing conservation mechanisms for poorly known and unknown species across Australian states and territories (as at 2016).

Jurisdiction	Recognised threat categories
Commonwealth	Critically Endangered, Endangered, Vulnerable, Conservation Dependent, Extinct in the wild, Extinct
NSW	Critically Endangered, Endangered, Vulnerable, Presumed Extinct
QLD	Extinct in the wild, Endangered, Vulnerable, Near threatened, Least Concern
WA	Critically Endangered, Endangered, Vulnerable and Presumed Extinct. PLUS: IA migratory birds protected under an international agreement; CD conservation dependent fauna and OS other specially protected fauna; and P Priority Species allocated to 4 categories; 3 of the 4 categories relate to species which are data deficient while the 4th category is for naturally rare and for near threatened spp.
SA	Endangered, Vulnerable and Rare.
Victoria	Threatened
Victoria (non-statutory)	Endangered, Vulnerable, Rare, Presumed Extinct, Poorly known
Tasmania	Endangered, Endangered-presumed extinct, Vulnerable and Rare
NT	Critically Endangered, Endangered, Vulnerable, Near threatened, Extinct, Extinct in the wild, Data Deficient, Least Concern, Not Evaluated
ACT	Endangered, Vulnerable, Rare, Insufficiently known

Treatment of data deficient, poorly known and insufficiently known taxa in jurisdictions for which such categories are available.

Western Australia

The *Wildlife Conservation Act* 1950 lists threatened native plants and animals where they are under identifiable threat of extinction, are rare, or otherwise in need of special protection. Ecological communities can also be listed as threatened by the Minister for Environment.

The Dept of Parks and Wildlife uses the IUCN criteria for assigning spp and communities to threat categories. CR critically endangered; EN endangered; VU vulnerable; EX presumed extinct; IA migratory birds protected under an international agreement; CD conservation dependent fauna and OS other specially protected fauna.

<u>P Priority Species:</u> Possibly threatened spp that do not meet survey criteria, or are otherwise data deficient. These species are added to one of three (four) categories, ranked in order of priority for survey and evaluation of conservation status.

Priority 1: Poorly-known species
Species that are known from one or a few locations (generally five or less) <u>*which are potentially at risk*</u>. All occurrences are either: very small; or on lands not managed for conservation, e.g. agricultural or pastoral lands, urban areas, road and rail reserves, gravel reserves and active mineral leases; or otherwise under threat of habitat destruction or degradation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under immediate threat from known threatening processes. Such species are in urgent need of further survey.

Priority 2: Poorly-known species
Species that are known from one or a few locations (generally five or less), some of which are *on lands managed primarily for nature conservation*, e.g. national parks, conservation parks, nature reserves and other lands with secure tenure being managed for conservation. Species may be included if they are comparatively well known from one or more locations but do not meet adequacy of survey requirements and appear to be under threat from known threatening processes. Such species are in urgent need of further survey.

Priority 3: Poorly-known species
Species that are known from several locations, and the species *does not appear to be under imminent threat*, or from few but widespread locations with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Species may be included if they are comparatively well known from several locations but do not meet adequacy of survey requirements and known threatening processes exist that could affect them. Such species are in need of further survey.

Priority 4: Rare, Near Threatened and other species in need of monitoring
(a) Rare. Species that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not currently threatened or in need of special protection, but could be if present circumstances change. These species are usually represented on conservation lands.

(b) Near Threatened. Species that are considered to have been adequately surveyed and that are close to qualifying for Vulnerable, but are not listed as Conservation Dependent.

(c) Species that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.

Victoria

http://www.depi.vic.gov.au/environment-and-wildlife/threatened-species-and-communities/flora-and-fauna-guarantee-act-1988/ffg-listed-taxa-communities-and-potentially-threatening-processes

The Threatened List contains taxa and communities of native flora and fauna which are threatened, and is established under the Victorian Flora and Fauna Guarantee Act 1988. There are no categories.

http://www.depi.vic.gov.au/__data/assets/pdf_file/0005/277565/Advisory-List-of-Rare-or-Threatened-Plants-in-Victoria-2014.pdf

Under the Advisory List process, poorly known (k) species are defined as those that are "poorly known and suspected, but not definitely known to belong to one of the [threatened] categories within Victoria. At present, accurate distribution information is inadequate". The advisory list categorises as poorly known in Victoria 232 vascular plants (cf. 1670 species as endangered, vulnerable or rare), 86 mosses and liverworts (cf. 66 species listed as endangered, vulnerable or rare) and 0 fungi and lichen (cf. 9 species listed as endangered, vulnerable or rare).

Tasmania

http://dpipwe.tas.gov.au/conservation/threatened-species/process-for-listing-threatened-species

http://dpipwe.tas.gov.au/Documents/Threatspeciesguidelines.pdf

The Threatened Species Protection Act 1995 recognises Rare species, defined as those species with a small population, that is not endangered or vulnerable but is at risk.

Northern Territory

The definition of Data Deficient species follows IUCN.

Currently, 23 mammal, 18 bird, 43 reptile, 5 amphibian, 93 fish, 48 invertebrate and about 860 plant taxa are classified as Data Deficient in the Northern Territory.

ACT

http://www.environment.act.gov.au/cpr/conservation_and_ecological_communities/threatenedspecieslist

The *Nature Conservation Act* 2014 establishes a formal process for the identification and protection of threatened species and ecological communities. There are two categories: Vulnerable or Endangered; plus two "working" categories (see http://www.environment.act.gov.au/__data/assets/pdf_file/0004/576301/Threatened_Species_and_Communities_in_the_ACT_-_Criteria_for_Assessment.pdf).

Rare species (and ecological communities) are defined as:

> "These are species or ecological communities with small distributions or small populations which, although not currently endangered or vulnerable, are at significant risk from events such as landuse changes, reduced protection measures or major disturbance."

Insufficiently known species (and ecological communities) are defined as:

> "These are species or ecological communities suspected to be endangered or vulnerable but for which there is inadequate information to make an assessment of risk of extinction based on distribution, population status or other attributes. The species or ecological communities may have poorly known distributions, the taxonomy of populations or species may be uncertain or populations may appear to be declining. Threatening processes may also be identified as insufficiently known. Items identified as Insufficiently Known are flagged for further survey and/or taxonomic research and kept under review."

Further information:

http://www.nespthreatenedspecies.edu.au/

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Threatened Species Recovery Hub

National Environmental Science Programme